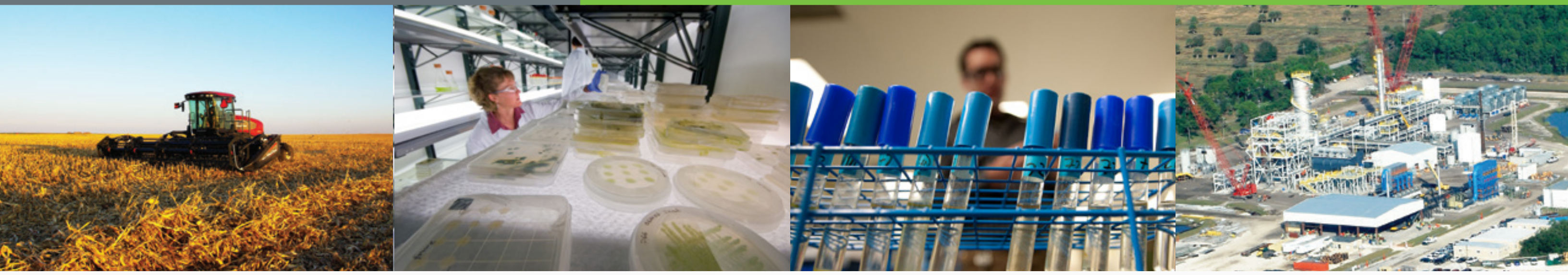
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BIOENERGY TECHNOLOGIES OFFICE



2013 PEER REVIEW REPORT

REVIEW PANEL SUMMARY REPORT AND PROJECT RESULTS

February 2014

2013 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BIOENERGY TECHNOLOGIES OFFICE

May 20–24, Alexandria, VA

2013 PROGRAM MANAGEMENT REVIEW

U.S. DEPARTMENT OF ENERGY • BIOENERGY TECHNOLOGIES OFFICE

July 30, Washington, D.C.

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Dear colleagues,

In the spring and summer of 2013, the Office of Energy Efficiency and Renewable Energy's (EERE's) Bioenergy Technologies Office (BETO or the Office) implemented a comprehensive external review of its research, development, demonstration, and deployment portfolio. The BETO Project Peer Review was held May 20–24, 2013, at the Hilton Mark Center, in Alexandria, Virginia, and was followed by a higher-level, Program Management Review on July 30, 2013, at the Renaissance Hotel, in downtown Washington, D.C. The review was conducted in accordance with the EERE peer review guidelines, and it was designed to provide an external assessment of the projects in BETO's portfolio and collect external stakeholder recommendations on the overall scope, focus, and strategic direction of the Office. Results from the peer review process are used to inform programmatic decision making; to enhance active project management; and to modify, expand, or discontinue existing projects.

In total, 219 projects across nine key technology areas—representing a total BETO investment of approximately $1.6 billion—were reviewed by 42 external experts from industry, academia, and government. The key technology areas reviewed during the 2013 review were as follows:

- Algae
- Analysis and Sustainability
- Biochemical Conversion
- Biodiesel
- Bio-Oil
- Feedstock Production and Logistics
- Gasification
- Heat and Power
- Integrated Biorefinery.

The 2013 Peer Review comprised three levels of review: (1) individual projects were scored on the basis of accomplishment, relevance, approach, future plans, and critical success factors; (2) each technology area portfolio was evaluated for overall potential impact, synergies, and effective project management; and (3) the structure and overall strategic direction of the Office was reviewed by an external Steering Committee. This report contains the results of each level of review, and represents the culmination of a 14-month peer review process. This report is inclusive of the inputs of approximately 300 participants in the peer review process, including principal investigators, reviewers, Steering Committee members, BETO staff, and contractors from BCS, Incorporated.

The Office would like to thank all of the reviewers and members of the Steering Committee who participated in this review. BETO is appreciative of the valuable insights and contributions that have been provided throughout the peer review process. Achieving the objectives of the Office is dependent on the effective management of all the projects in BETO's existing portfolio and on the appropriate focus and structure of future initiatives. BETO values the input of all the stakeholders in the bioenergy sector and looks forward to working with them in the years ahead to continue progress on the path toward building a successful advanced bioenergy industry.

Sincerely,

Jonathan L. Male

Dr. Jonathan Male
Director, Bioenergy Technologies Office

EXECUTIVE SUMMARY

The 2013 peer review process yielded a number of important results for the Bioenergy Technologies Office (BETO or the Office). External reviewers and Steering Committee members delivered a positive overall assessment of the Office and validated much of BETO's current research approach and technical strategy. The shift in focus from research and development in ethanol to hydrocarbon fuels was broadly supported as an appropriately timed transition in technical emphasis, and the Steering Committee commended the diverse mix of feedstocks, conversion pathways, targeted end products, and technology scales on which the Office portfolio is built.

Project portfolios were found to be actively managed and appropriately oriented toward those projects that exhibited high degrees of innovation and held the potential for significant industrial impact. Many of the integrated biorefinery projects were seen to be nearing completion and on the verge of adding significant production volumes to industry capacity. BETO's high-tonnage feedstock logistics projects were identified as a key asset, and several of the consortia projects, including the National Advanced Biofuels Consortium, were expected to yield significant technological dividends. In general, projects from the national laboratories and those that were the result of competitive selection scored well, and a number of the public-private partnerships that leveraged the resources of both sectors stood out as exemplary projects. In contrast, generally most, but not all, of the Congressionally directed projects scored on the lower end of the project spectrum.

Key recommendations included an expanded focus on understanding insertion points for hydrocarbon intermediates and increased coordination with the petroleum industry. The Steering Committee recommended steps to develop a better understanding of compatibility and blending requirements for hydrocarbon fuels and the fuel registration process. Reviewers recommended that the Office standardize assumptions and methodology for techno-economic analysis and life-cycle assessments, which should be used for cross-portfolio analysis and funding opportunity announcements (FOAs). Of the new potential areas of interest presented to the Steering Committee (natural gas-biomass to liquids, waste-to-energy conversion, carbon fiber, and an incubator program), the strongest, near-unanimous support was voiced for an incubator program that would allow BETO to develop potentially disruptive accelerator technologies. The Steering Committee also recognized the potential for low-cost natural gas to either enhance or inhibit the development of an advanced biofuels industry, and they urged the Office to continue to explore BETO's role in the emerging natural gas-biomass to liquids sector. Finally, reviewers expressed concern over the future budget profile of the Office and the continuing need for cost-share support for the construction of first-of-a-kind demonstration and commercial projects.

As a result of the 2013 Peer Review, BETO is moving forward with many of the recommendations provided by the Steering Committee and individual review panels. The Office is planning to establish a petroleum industry coordinating group and explore additional ways to interface with the petroleum and refining industry. Pending available funding, BETO is planning to issue a FOA in fiscal year 2014 for proposals outside of the Office's current portfolio to be included in an incubator program. In September 2013, BETO organized a Natural Gas-Biomass to Liquids Workshop to collect stakeholder inputs on an appropriate role for BETO, and the Office plans to continue work with the Office of Fossil Energy and the Advanced Research Projects Agency-Energy on research in this emerging area. At the portfolio level, the peer review provided a number of invaluable insights and specific recommendations that will continue to be utilized in managing specific projects and ongoing improvements in portfolio planning and oversight.

ACRONYM GUIDE

\$/MT	Dollars per metric ton
ABPDU	Advanced Biofuels Process Demonstration Unit
AD	Anaerobic digestion
AFDW	Ash-free dry weight
AFEX	Ammonia fiber expansion
ALD	Atomic-layer deposition
ALM	Algae Logistics Model
ALU	Algal lipid upgrading
ANL	Argonne National Laboratory
AOP	Annual operating plan
ARRA	American Recovery and Reinvestment Act of 2009
ARPA-E	Advanced Research Projects Agency-Energy
ASTM	American Society for Testing and Materials
ATP3	Algae Testbed Public–Private Partnership
BAT	Biomass Assessment Tool
BDO	Butanediol
BETO	Bioenergy Technologies Office
BMP	Best management practices
BPT	Bale-picking truck
BSM	Biomass Scenario Model
Btu	British thermal unit
°C	Degrees Celsius
CABComm	Consortium for Algal Biofuels Commercialization
CAPEX	Capital expenditure
CBM	Cellulose-binding module
CBP	Consolidated bioprocessing
CDP	Congressionally directed projects
CH_4	Methane
CHASE	Carbon, Hydrogen, and Separation Efficiencies in Bio-Oil Conversion Pathways
CHG	Catalytic hydrothermal gasification
cm	Centimeter
CO	Carbon monoxide
CO_2	Carbon dioxide
CPBR	Consortium for Plant Biotechnology Research, Incorporated
CRADA	Cooperative research and development agreements
CRP	Conservation Reserve Program
DARPA	Defense Advanced Research Projects Agency
DCR	Davison circulating riser

DOD	Department of Defense
DOE	Department of Energy
DT	Dry ton
EERE	Office of Energy Efficiency and Renewable Energy
EISA	Energy Independence and Security Act of 2007
EMWD	Eastern Municipal Water District
EPA	Environmental Protection Agency
ePBR	Electronic photobioreactor
EtOH	Ethanol
°F	Degrees Fahrenheit
FOA	Funding opportunity announcement
FCC	Fluid catalytic cracking
FFA	Free fatty acid
FLS	Feedstock logistics systems
FT-ICR-MS	Fourier transform ion cyclotron resonance mass spectrometry
FT	Fischer-Tropsch
gal	Gallon
gal/acre/yr	Gallon per acre per year
GBEP	Global Bioenergy Partnership
GCAM	Global Change Assessment Model
gge	Gallon of gasoline equivalent
GHG	Greenhouse gas
GIS	Geographic information systems
g/l	Grams per liter
g/m^2	Grams per square meter
GMO	Genetically modified organism
GPS	Global positioning system
GREET	Greenhouse Gasses, Regulated Emissions, and Energy Use in Transportation
GTAP	Global Trade Analysis Project
GTI	Gas Technology Institute
H_2	Hydrogen
HDO	Hydrodeoxygenation
HTL	Hydrothermal liquefaction
IABR	Integrated algal biorefinery
IAF	Integrated Assessment Framework
IBR	Integrated biorefinery
IBSAL	Integrated Biomass Supply Analysis and Logistics
IEA	International Energy Agency
IES	Institute of Environmental Stewardship

IH2	Integrated hydropyrolysis plus hydroconversion technology
INL	Idaho National Laboratory
IP	Intellectual property
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JBEI	Joint BioEnergy Institute
KDF	Knowledge Discovery Framework
kg	Kilogram
L or l	Liter
LBNL	Lawrence Berkeley National Laboratory
LCA	Life-cycle assessment
LEA	Lipid-extracted algae
LUC	Land-use change
MBI	Michigan Biotechnology Institute
MESP	Minimum ethanol selling price
Mg	Magnesium
mgpy	Million gallons per year
MoS_2	Molybdenum disulfide
MSW	Municipal solid waste
MWh/hectare/yr	Megawatt hours per hectare per year
MYPP	Multi-Year Program Plan
MySAB	Myriant succinic acid biorefinery
NAABB	National Alliance for Advanced Biofuels and Bioproducts
NABC	National Advanced Biofuels Consortium
NaSICON	Sodium Super Ionic Conductors
NC A&T	North Carolina Agricultural & Technical State University
NDA	Non-disclosure agreement
NGO	Nongovernmental organization
NIR	Near infrared
N_2O	Nitrous oxide
NREL	National Renewable Energy Laboratory
OEM	Original equipment manufacturer
OPEX	Operational expenditure
ORNL	Oak Ridge National Laboratory
PBR	Photobioreactor
PDU	Process demonstration unit
PHB	Polyhydroxbutyrate
PI	Principal investigator

PNNL	Pacific Northwest National Laboratory
POLYSYS	Policy Analysis System model
R&D	Research and development
RD&D	Research, development, and demonstration
RDD&D	Research, development, demonstration, and deployment
REAP	Resilient Energy Agricultural Practices
REII	Renewable Energy Institute International
RFP	Regional Feedstock Partnership
RFS or RFS2	Renewable Fuel Standard
RINS or RIN	Renewable Identification Number
R&TD	Research and technology development
RTI	Research Technology Institute
RTP	Rapid thermal processing
SABC	Sustainable Algal Biofuels Consortium
SEO	State energy office
SLT	Self-loading trailer
SOT	State of technology
SPB	Self-propelled baler
SRWC	Short-rotation woody crops
SWAT	Soil and Water Assessment Tool
SzIBR	Solazyme integrated biorefinery
TAG	Triacylglycerol
TAN	Total acid number
TCR	Targeted conversion research
TEA	Techno-economic analyses or assessment
TEES	Texas Engineering Experiment Station
TRL	Technology readiness level
UCSD	University of California, San Diego
UNCP	University of North Carolina at Pembroke
USDA	U.S. Department of Agriculture
USDA-ARS	U.S. Department of Agriculture's Agricultural Research Service
VBI	Vermont BioFuels Initiative
VSJF	Vermont Sustainable Jobs Fund
VTT	Technical Research Centre of Finland
WSU	Washington State University
wt%	Weight percent
WTE	Waste to energy
XI	Xylose Isomerase

INTRODUCTION

In the spring and summer of 2013, the U.S. Department of Energy's (DOE's) Bioenergy Technologies Office (BETO or the Office) implemented an external peer review of the projects in its research, development, demonstration, and deployment (RDD&D) portfolio. The 2013 Project Peer Review took place May 20–24, in Alexandria, Virginia, and assessed many of the funded projects in BETO's portfolio. The Program Management Review took place on July 30, in Washington, D.C., and provided an Office-level assessment of strategic planning and programmatic initiatives. The peer review process enables external stakeholders to provide feedback on the responsible use of taxpayer revenue and develop recommendations for the most efficient and effective ways to accelerate the development of an advanced bioenergy industry. The planning and execution of these reviews was completed over the course of 10 months, and this report includes the results of both events.

A total of 219 projects, across nine distinct technology areas—representing a total DOE value of approximately $1.6 billion dollars—were reviewed by a total of 41 external experts from industry, academia, other government agencies, and the non-profit sector. Each review panel also developed overall recommendations on the focus, management, and impact of the projects in each technology area, and an external Steering Committee developed overall recommendations for the Office based on the Program Management Review.

The nine technology areas reviewed during the 2013 Project Peer Review were as follows:

- Algae
- Analysis and Sustainability
- Biochemical Conversion
- Biodiesel
- Bio-Oil
- Feedstock
- Gasification
- Heat and Power
- Integrated Biorefineries.

Results of the 2013 Peer Review will be used to help inform programmatic decision making, modify or discontinue existing projects, guide future funding opportunities, and support other budget and strategic planning objectives.

BETO Project Peer Review

The 2013 BETO Project Peer Review was implemented over the course of one full week, with seven simultaneous review sessions of all 219 reviewed projects. Over the course of the Project Peer Review, participants also heard overview presentations on each technology area, as well as presentations on key cross-cutting initiatives from the Office, including the achievement of the cellulosic ethanol cost target, the recently published Update to the Billion-Ton Study, and the Office's new priority pathways initiative. This format brought together reviewers, principal investigators (PIs), and other stakeholders along the entire bioenergy supply chain, which creates synergies across technology areas and enables the cross-fertilization of ideas and expertise, while providing for a more comprehensive review process.

Reviewed projects included competitively awarded projects, core research and development projects performed by DOE's national laboratories, and Congressionally directed projects (CDPs). Figure 1 depicts the breakdown of projects reviewed by technology area, as based on their portion of the overall value of DOE funding. The Integrated Biorefinery Technology Area accounts for more than half of BETO's portfolio—around $800 million, most of which is sourced from the American Recovery and Reinvestment Act of 2009. Figure 2 depicts project funding by award type as portions of the overall DOE funding. Nearly 70% of projects were awarded through a competitive funding opportunity process (including consortium projects); of the remaining amount, the National Renewable Energy Laboratory and other national laboratories account for the largest share of funding.

Figure 1: Office Funding by Technology Area

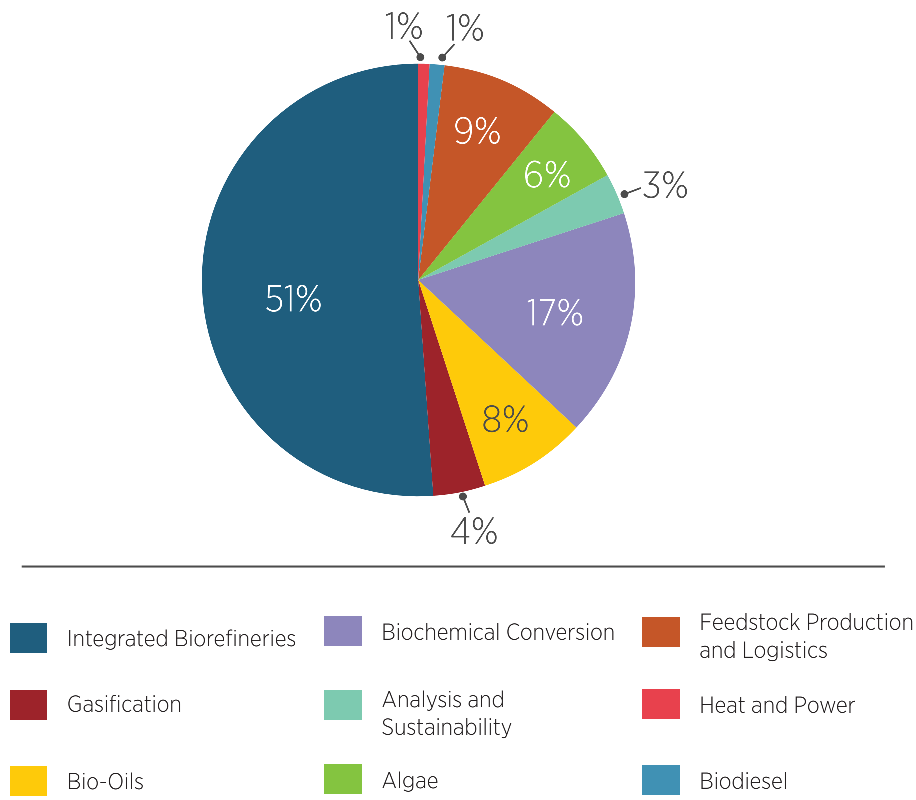
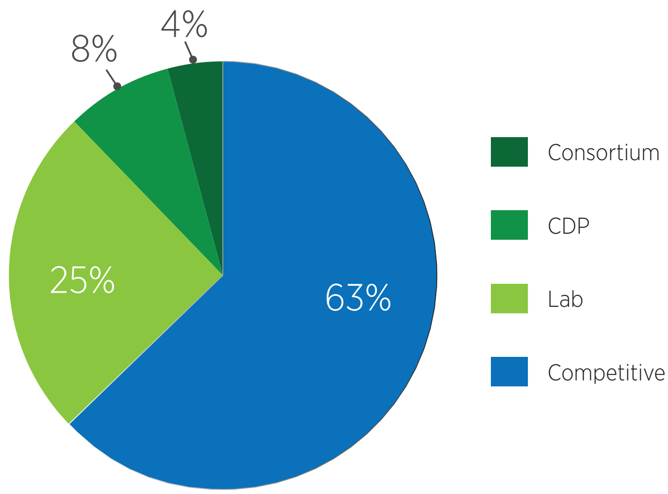


Figure 2: Office Funding by Award Type



The agenda for the Project Peer Review, and complete project abstracts and final presentations for each project, are available on the BETO Peer Review Portal (https://www2.eere.energy.gov/biomass/peer_review2013/Portal/). The Peer Review Portal can also be accessed through bioenergy.energy.gov/peer_review2013.html.

Roles and Responsibilities

Upon initiation of the review process, senior BETO staff members designated an internal steering group that would be responsible for coordinating all aspects of the process, from initiation through completion. This internal group then identified an external Steering Committee to provide independent and impartial guidance on planning activities and selection of external reviewers; to participate in the review process; and to develop cross-cutting recommendations on the Office's overall focus, scope, and strategic direction. Technology area review teams were identified by senior BETO leadership to organize and implement each of the individual review sessions. A team of support contractors from BCS, Incorporated provided overall planning support, built the reviewer evaluation system, facilitated development of report materials, and compiled and drafted the Peer Review Final Report. Table 1 lists the external Steering Committee members. Table 2 lists the members of the internal steering group. Table 3 lists the members of the internal technology area teams.

Table 1: Members of the Peer Review Steering Committee

PEER REVIEW STEERING COMMITTEE	
Jim Dooley	Forest Concepts, LLC
Kelly Ibsen	Lynx Engineering, LLC
Steve Kelley	North Caroline State University
Bob Mantz	Army Research Laboratory
Bob Miller	Consultant, retired Air Products
George Parks	Consultant, retired ConocoPhillips
Mark Yancey	Neatech, LLC

Table 2: Members of the Internal Steering Group

PEER REVIEW INTERNAL STEERING GROUP	
Valerie Reed	DOE
Kevin Craig	DOE
Alison Goss Eng	DOE
Andrew Graves	BCS
George Kervitsky	BCS
Seema Patel	BCS

Table 3: Technology Area Teams

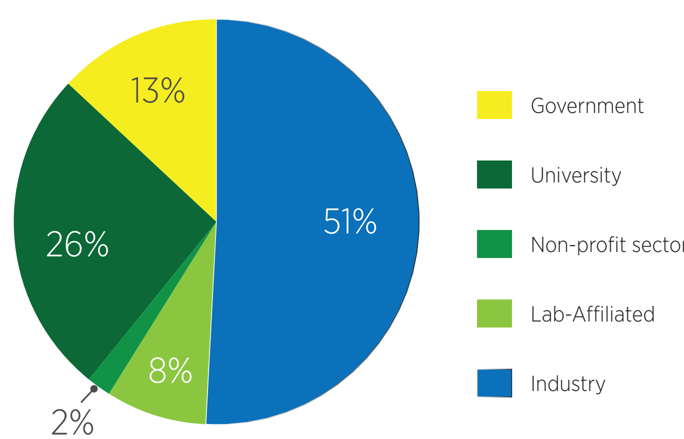
TECHNOLOGY AREA TEAMS		
Technology Area	**DOE Review Lead**	**BCS Support**
Algae	Dan Fishman	Colleen Ruddick
Analysis and Sustainability	Alicia Lindauer, Kristen Johnson	Ashley Rose
Biochemical Conversion	Leslie Pezzullo	Ryan Livingston
Biodiesel	Mark Elless	Bryant Natsuhara
Bio-Oil	Melissa Klembara	Sarah Luchner, Liz Lowry
Feedstock Supply and Logistics	Steven Thomas	Max Broad
Gasification	Paul Grabowski, Prasad Gupte	Liz Lowry, Sarah Luchner
Heat and Power	Elliot Levine	Katherine Barno
Integrated Biorefineries	Travis Tempel	George Kervitsky, Ashley Paulsworth

Reviewers

Completion of the peer review was dependent on nearly 50 external experts from industry, academia, other government agencies, and the non-profit sector. Reviewers were selected on the basis of technical expertise and high-level qualifications in their designated technology area. Approximately two-thirds of the reviewers held doctorates within their field, and the remainder held other advanced technical or business degrees. Efforts were made to ensure balance within the review panel by including a mix of reviewers from the public, private, and university sector, with a range of expertise in the many sub-focus areas within each technology area. Approximately one-third of the reviewers had experience participating in previous DOE peer reviews. No reviewers had served in more than two previous DOE review cycles. Reviewers were also required to sign legal agreements stipulating an absence of a conflict of interest with the projects that they reviewed.

Reviewers were proposed by the BETO technology area teams, and submitted to the external Steering Committee for comment and recommendation. Final decisions on reviewer selection were made by the internal steering group and BETO's acting office director. A total of 41 reviewers comprised 7 individual review panels (averaging 6 per technology area). The Integrated Biorefinery Technology Area panel also reviewed the Heat and Power projects; the Gasification Technology Area panel also reviewed the Biodiesel projects. Individual review panels are listed within each of the technology area chapter reports.

Figure 3: Reviewers by Affiliation Sector



Evaluation Criteria

Reviewers were asked to evaluate projects based on specific criteria. The below criteria and descriptions served as the standard template for the evaluation of each project, but some technology areas, including Analysis and Sustainability, Integrated Biorefineries, Heat and Power, and Biodiesel, used criteria with some slight modifications. Projects received scores and comments on the first five criteria, and only comments on the final two criteria. Reviewers' comments contained in this report represent only those comments provided for the overall impressions criterion. Each comment represents the views of one reviewer. Comments were taken near-verbatim as inputted by the reviewer and were edited only for grammar and context. Each criterion received a different weight as determined by the internal steering group, which was used to calculate the overall average score for each project.

1. Project Approach (10%)

Projects were evaluated on the degree to which:

- The project performers have implemented technically sound research, development, and deployment approaches and have demonstrated the results needed to meet their targets.
- The project performers have identified a project management plan that includes well-defined milestones and adequate methods for addressing potential risks.

2. Technical Progress, Accomplishments, and Plans (40%)

Projects were evaluated on the degree to which:

- The project performers have made progress in reaching their objectives based on their project management plan.
- The project performers have met their objectives in achieving milestones and overcoming technical barriers.
- New project performers have identified viable plans to accomplish their objectives.

3. Project Relevance (20%)

Projects were evaluated on the degree to which:

- The project contributes to meeting the goals of the specific technology area and of BETO, as identified in the Office's November 2012 Update of the Multi-Year Program Plan.
- The objectives of the project have relevance for the bioenergy industry and project performers have considered commercial applications for the expected outputs of the project.

4. Critical Success Factors (20%)

Projects were evaluated on the degree to which:

- The project performers have identified critical factors (including technical, market, and business) that will impact the potential technical and commercial success of the project.
- The project performers have presented adequate plans to recognize, address, and overcome the top two to three challenges (technical and non-technical) that need to be overcome for achieving successful project results.
- The project's successful completion will advance the state of technology and impact the viability of commercial bioenergy applications.

5. Future Work (10%)

Projects were evaluated on the degree to which:

- The project performers have outlined adequate plans for future work, including key milestones and go/no-go decision points.
- The project performers have addressed how they plan to deal with upcoming decision points and any remaining issues.

6. Technology Transfer and Collaborations (Not Scored)

Reviewers provided comments on the degree to which the project coordinates with other institutions and projects to provide additional benefits to both BETO and the industry. Please provide suggestions on additional opportunities for encouraging further coordination.

7. Overall Impressions (Not Scored)

Reviewers provided an overall assessment of the project based on the above criteria for inclusion in the Peer Review Final Report.

BIOENERGY TECHNOLOGIES OFFICE

Overview

The Bioenergy Technologies Office (BETO or the Office) is part of the Office of Energy Efficiency and Renewable Energy (EERE), which is organized around clean energy sectors: Transportation, Renewable Power, and Energy Efficiency. BETO, along with the Vehicle Technologies and Fuel Cell Technologies Offices, now falls under EERE's Sustainable Transportation area in the U.S. Department of Energy (DOE). The Office manages a diverse portfolio of technologies across the spectrum of applied RDD&D within the dynamic context of changing budgets and administrative priorities. The portfolio is organized to reflect the biomass-to-bioenergy supply chain—from the feedstock source to the end user. To meet DOE goals, the Office is focused on developing, demonstrating, and deploying biofuels, bioproducts, and bioenergy technologies in partnership with other government agencies, industry, and academia. More information about the Office can be found in the latest version of BETO's Multi-Year Program Plan, located at bioenergy.energy.gov/pdfs/mypp_may_2013.pdf.

The Office supports four key tenets of the EERE Strategic Plan (which is currently being updated):

- Reduce dependence on foreign oil
- Promote the use of diverse, domestic, and sustainable energy resource
- Establish a domestic bioenergy industry
- Reduce carbon emissions from energy production and consumption.

The mission of the Office is as follows:

Mission	*To develop and transform our renewable biomass resources into commercially viable, high-performance biofuels, bioproducts, and biopower through targeted research, development, demonstration, and deployment supported through public and private partnerships.*

The strategic goal of the Office is as follows:

Strategic Goal	*To develop commercially viable biomass utilization technologies to enable the sustainable, nationwide production of biofuels that are compatible with today's transportation infrastructure, and can displace a share of petroleum-derived fuels to reduce U.S. dependence on oil and encourage the creation of a new domestic bioenergy industry, supporting the EISA goal of 36 billion gallons per year of renewable transportation fuels by 2022.*

The performance goal of the Office is as follows:

Performance Goal	*Through research and development, make cellulosic biofuels competitive with petroleum-based fuels at a modeled cost for mature technology of $3 per gallon of gasoline equivalent ($2011) based on Energy Information Administration-projected wholesale prices in 2017.*

Market Barriers

Biorefineries using cellulosic biomass as a feedstock face market barriers at the federal, state, and local levels. Feedstock availability, production costs, investment risks, consumer awareness and acceptance, and infrastructure limitations pose significant challenges for the emerging bioenergy industry. Widespread deployment of integrated biorefineries will require demonstration of cost-effective biorefinery systems and sustainable, cost-effective feedstock supply infrastructure.

BETO has identified the following key market barriers to the successful and significant expansion of the advanced bioenergy industry:

- Feedstock availability and cost
- Agricultural sector-wide paradigm shift
- Inadequate supply chain infrastructure
- Lack of understanding of environmental/energy tradeoffs
- High risk of large capital investments
- Lack of industry standards and regulations
- Cost of production
- Off-take agreements
- Availability of biofuels distribution infrastructure
- Market uncertainty
- Inconsistent and unpredictable policy landscape and priorities
- Lack of acceptance and awareness of biofuels as a viable alternative fuel
- Poorly understood role of government versus the role of industry.

Approach to Achieving Goals

The Office has developed a coordinated framework for managing its portfolio based on systematically investigating, evaluating, and down-selecting the most promising opportunities across a wide range of emerging technologies and technology readiness levels. This approach is intended to support a diverse technological portfolio in applied research and development (R&D), while identifying the most promising targets for follow-on, industrial-scale demonstration and deployment. This strategy is designed to allow the Office to progressively enable deployment of increasing amounts of biofuels, bioproducts, and bioenergy across the nation from a widening array of feedstocks. This will not only have a significant near-term impact on oil displacement, but will also facilitate the shift to renewable, sustainable bioenergy technologies in the long term.

Key components of the portfolio include:

- R&D of a sustainable, high-quality feedstock supply system
- R&D of biomass conversion technologies
- Industrial-scale demonstration and validation of integrated biorefineries
- Cross-cutting sustainability, analysis, and strategic communications activities.

While BETO's overall mission is focused on developing advanced technologies for the production of fuels, products, and power from biomass, the Office's near-term goals are focused on the conversion of biomass into liquid transportation fuels. Historically, BETO's focus has been on RDD&D for ethanol production from lignocellulosic biomass. However, following the successful demonstration of cost-competitive cellulosic ethanol production technologies in the fall of 2012, R&D efforts now focus on the conversion of biomass into hydrocarbon fuels and intermediates that lead to drop-in replacements for gasoline, diesel, jet fuel, and other petroleum-based products. The Office has recently selected eight priority pathways—covering thermochemical, biochemical, and algal conversion technologies—that will guide its R&D strategy in the near term.

These eight priority pathways have been identified as follows:

- Biological conversion of sugars to hydrocarbons
- Catalytic upgrading of sugars to hydrocarbons
- Algal lipid upgrading
- Whole algae hydrothermal liquefaction
- Fast pyrolysis upgrading and hydroprocessing
- *Ex-situ* catalytic fast pyrolysis
- *In-situ* catalytic fast pyrolysis
- Syngas upgrading to hydrocarbon fuels.

More information about each of these pathways is available online at bioenergy.energy.gov/technology_pathways.html.

The next steps in the Office's R&D strategy will be to identify cost goals and technical targets for each of the conversion pathways and determine priority areas of research. Throughout the next few years, the Office intends to publish design case reports for each pathway. These reports will be used to guide the BETO's overall R&D strategy, inform funding opportunity announcements, and support shifts in focus for core laboratory R&D. In the future, as new data and information become available, design cases will be developed for additional pathways that show promise for near-term commercial success.

BETO also intends to begin assessing the potential for several promising new areas of research, including an incubator program to support the development of "off-roadmap" bioenergy technologies; a waste-to-energy (WTE) initiative to assess near-term market entry opportunities to deploy anaerobic digestion and other WTE technologies; a renewable carbon fiber initiative to work with other EERE offices on the technologies needed to manufacture innovative materials from biomass; and, finally, a natural gas-biomass-to-liquids initiative to explore the potential for technologies that utilize low-cost natural gas and biomass feedstocks to produce liquid transportations fuels.

All of these efforts are designed to accelerate the development of new conversion technologies, hasten the construction of advanced biofuel facilities, and help the United States achieve national goals for reduced oil imports, technology innovation, and environmental sustainability.

FORMAT OF THE REPORT

More than 300 people have provided inputs to this report over a period of approximately six months. Information in this report has been compiled, based on the following sources, as follows:

- **Peer Review Report Introductory Chapter**: This section contains overview information on the peer review process, roles and responsibilities, review criteria, and the program. This section is based on BETO's Multi-Year Program Plan and other sources.
- **Technology Area Chapter Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.
- **Project Scoring Information and Short Names Key**: The final score charts depict the overall weighted score for each project in each technology area. Short names for each project were developed for ease of use in the scoring charts, the table of contents, and other locations. Full project names, along with their designated short names and their work breakdown structure (WBS#), are provided in the Short Names Key.
- **Technology Area Review Panel Summary Report**: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.
- **Technology Area BETO Programmatic Response**: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.
- **Project Reports:**
    - **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space constraints allotted.
    - **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
    - **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and the whiskers depict the range of scores for each category within each technology area.
    - **Reviewer comments** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant by BETO's director were excluded from the final report.
    - **PI responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

- **Steering Committee Summary Report**: The Steering Committee Summary Report represents the overall summary feedback and final recommendations of the external Steering Committee, following the conclusion of the Program Management Review. This report was based on the participation of the Steering Committee in each component of the peer review process, and in several closed-door, facilitated review sessions following the Project Peer Review and the Program Management Review.
- **Overall BETO Programmatic Response**: The Overall BETO Programmatic Response represents the official, cumulative response from BETO leadership on the feedback and recommendations provided by the external Steering Committee throughout the peer review process, and on the overall structure and focus of the Office.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the review panel. This unique formatting was maintained to uphold the integrity of the comments.

ALGAE

TECHNOLOGY AREA

INTRODUCTION

The Algae Technology Area was one of nine key technology areas reviewed during the 2013 Bioenergy Technologies Office (BETO or the Office) Project Peer Review, which took place on May 20–23, 2013, at the Hilton Mark Center in Alexandria, Virginia. A total of 28 projects were reviewed by six external experts from industry, academia, and other government agencies. This review represents a total U.S. Department of Energy (DOE) value of approximately $94 million, which is roughly 6% of the BETO portfolio reviewed during the 2013 Peer Review. The principal investigator (PI) for each project was given between 20–30 minutes to deliver a presentation and respond to questions from the review panel; consortia projects received more time based on their breadth of work. Projects were evaluated and scored for their project approach, technical progress over two years, relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Algae Project Peer Review, including scoring information for each project, summary comments from each reviewer, and summary responses provided by the PI for the project. The Review Panel Summary Report and the BETO Programmatic Response are also included in this section. BETO designated Daniel Fishman as the Algae Technology Area review lead. In this capacity, Mr. Fishman was responsible for review planning and implementation.

ALGAE TECHNOLOGY AREA

OVERVIEW

The Algae Technology Area funds the research and development (R&D) of sustainable algae production, logistics, and conversion to biofuels. Projects within the technology area address a diversity of topics including algal biology; algal cultivation, harvest, and processing logistics; conversion interfaces and conversion technologies; and techno-economic analysis, life-cycle analysis, and resource assessment.

ALGAE SUPPORT OF OFFICE GOALS

Algal feedstocks represent an important resource potential to help achieve the Office Strategic Performance Goals. Algal feedstocks can provide high-yield renewable oils that are well suited to displacing petroleum-based fuels and products.

The Algae Program is described in the BETO Multi-Year Program Plan (MYPP) within the Algae Feedstock Supply and Logistics R&D section. Therein, the program's strategic goal is established.[2]

The algae feedstock supply and logistics performance goal is the demonstration of technologies that make sustainable algal biofuel intermediate feedstocks that perform reliably in conversion processes to yield renewable

Develop algae production and logistics technologies that have the potential to provide secure, reliable, and affordable algal biomass for the U.S. bioenergy industry.

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

[2] *Bioenergy Technologies Office Multi-Year Program Plan*. DOE/EE-0915.Washington, DC: U.S. Department of Energy, 2013. Bioenergy.energy.gov/pdfs/mypp_may_2013.pdf.

diesel, jet, and gasoline fuels in support of the BETO $3 per gallon of gasoline equivalent (gge) of advanced biofuels goal.

For complete details on the Algae Program goals, please review BETO's MYPP at bioenergy.energy.gov/pdfs/myyp_may_2013.pdf.

APPROACH FOR OVERCOMING CHALLENGES

The Algae Technology Area's R&D approach for overcoming challenges and barriers is outlined in its work breakdown structure (WBS), and organized around five key activities—analysis & sustainability; algal feedstock production; algal feedstock logistics research development and demonstration (RD&D); conversion interface; and integration and scale-up. These activities are performed by national laboratories, universities, industry, consortia, and a variety of state and regional partners.

REVIEW PANEL

The following external experts served as reviewers for the Algae Technology Area during the 2013 Project Peer Review.

Algae Reviewers	
Brent Massmann (Lead Reviewer)	Monsanto
Chris Cassidy	USDA
David Hazlebeck	General Atomics
Phillip Marrone	SAIC
Tasios Melis	UC Berkley, Lawrence Berkeley National Laboratory
Emilie Slaby	The Scoular Company

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

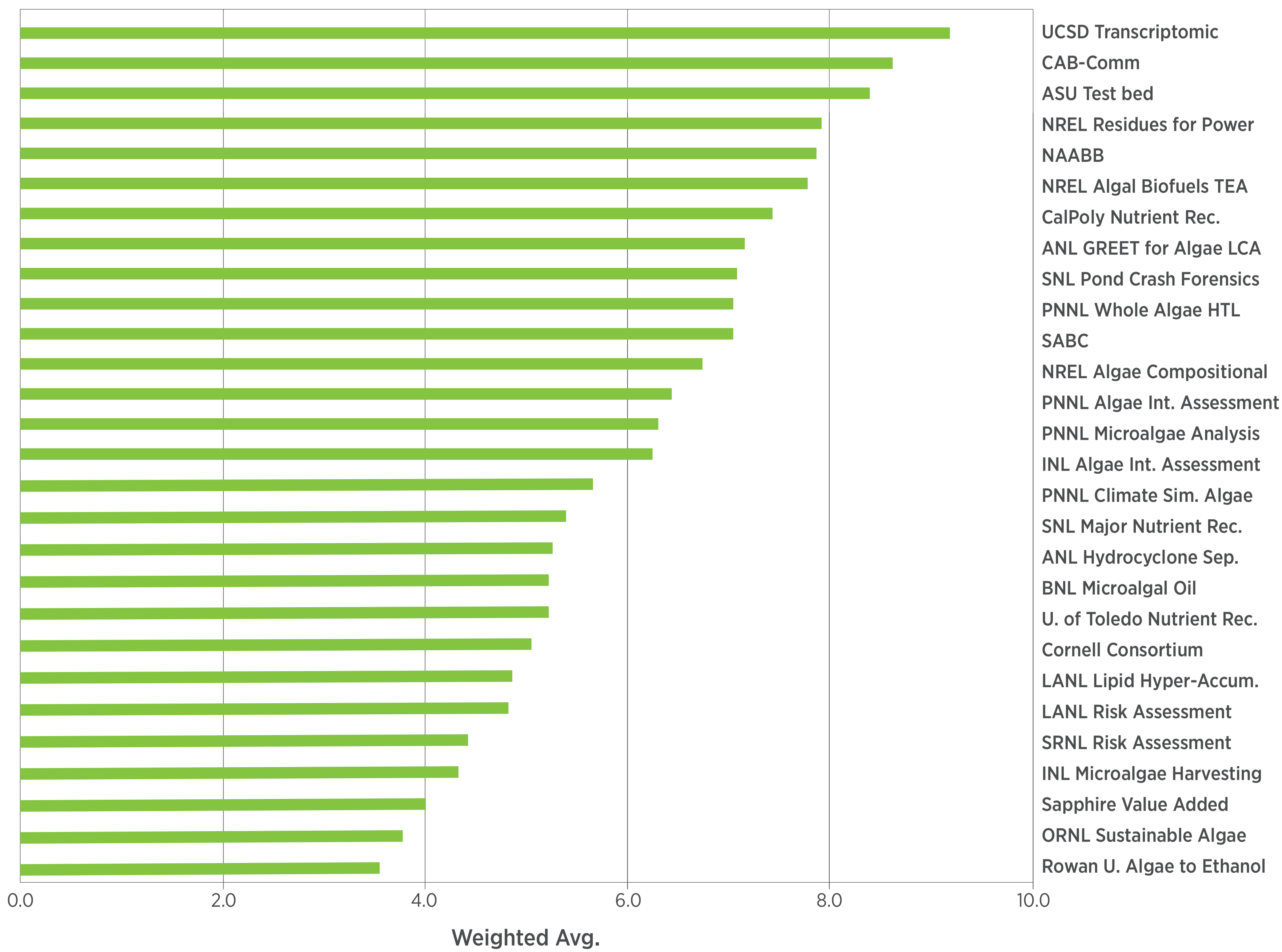
- **Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.
- **Project Scoring Information and Short Names Key**: The final score charts depict the overall weighted score for each project in each technology area. Short names for each project were developed for ease of use in the scoring charts, the table of contents, and other locations. Full project names, along with their designated short names and their work breakdown structure number (WBS #), are provided in the Short Names Key.
- **Review Panel Summary Report**: The Review

Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.

- BETO Programmatic Response: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.
- Project Reports:
    - **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space constraints allotted.
    - **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
    - **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and the whiskers depict the range of scores for each category within each technology area.
    - **Reviewer comments** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant by BETO's director were excluded from the final report.
    - **PI Responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the review panel. This unique formatting was maintained to uphold the integrity of the comments.

TECHNOLOGY AREA SCORE RESULTS



SHORT NAMES KEY

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
9.2.2.2	Development of Renewable Biofuels Technology by Transcriptomic Analysis and Metabolic Engineering of Diatoms	University of California, San Diego (UCSD)	UCSD Transcriptomic
9.5.1.6	Consortium for Algal Biofuels Commercialization	CABComm; UCSD	CABComm
9.1.4.1; 9.1.4.2; 9.1.4.3	Algae Testbed Public–Private Partnership (ATP3)	Arizona State University	ASU Testbed
9.2.2.3	Efficient Use of Algal Biomass Residues for Biopower Production with Nutrient Recycle	National Renewable Energy Laboratory (NREL)	NREL Residues for Power
9.5.1.1; 9.5.1.2; 9.5.1.3	National Alliance for Advanced Biofuels and Bioproducts (NAABB)	NAABB; Los Alamos National Laboratory (LANL)	NAABB
9.6.5.3	Algal Biofuel Techno-Economic Analysis	NREL	NREL Algal Biofuels TEA
9.1.1.2	Recycling of Nutrients and Water in Algal Biofuels Production	California Polytechnic University	CalPoly Nutrient Rec.
9.6.5.2	GREET for Algae Life-Cycle Analysis	Argonne National Laboratory (ANL)	ANL GREET for Algae LCA
9.1.2.2	Pond Crash Forensics	Sandia National Laboratory (SNL)	SNL Pond Crash Forensics
9.3.2.1	Whole Algae HTL Model	Pacific Northwest National Laboratory (PNNL)	PNNL Whole Algae HTL
9.1.4.1; 9.1.4.2; 9.1.4.3	Sustainable Algal Biofuels Consortium (SABC)	SABC	SABC
9.6.1.8	Algae Compositional Analysis	NREL	NREL Algae Compositional
9.6.1.6	Collaborative: Algae–Based Biofuels Integrated Assessment Framework Development, Evaluation, and Demonstration (PNNL)	PNNL	PNNL Algae Int. Assessment
9.6.1.2	Microalgae Analysis	PNNL	PNNL Microalgae Analysis
9.1.3.1	Collaborative: Algae–Based Biofuels Integrated Assessment Framework Development, Evaluation, and Demonstration (INL)	Idaho National Laboratory (INL)	INL Algae Int. Assessment
9.1.2.4	Climate Simulated Algae Cultures	PNNL	PNNL Climate Sim. Algae
9.1.1.3	Major Nutrient Recycling for Sustained Algal Production	SNL	SNL Major Nutrient Rec.
9.5.1.9	Hydrocyclone Separation of Targeted Biochemical Intermediates and Products	ANL	ANL Hydrocyclone Sep.
9.1.2.1	Improving Microalgal Oil Production Based on Quantitative Analysis of Metabolism	Brookhaven National Laboratory (BNL)	BNL Microalgal Oil
9.1.1.1	Integration of Nutrient and Water Recycling for Sustainable Algal Biorefineries	University of Toledo; Montana State University	U. of Toledo Nutrient Rec.
9.5.1.4	Cornell Consortium	Cornell University	Cornell Consortium
9.1.2.5	Production-Scale Performance of Lipid Hyper-Accumulating Algae	LANL	LANL Lipid Hyper-Accum.

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
9.6.1.7	Human Health Risk Assessment of Algae Production Systems	LANL	LANL Risk Assessment
9.6.1.5	Risk Assessment of Algal Production Systems: Impacts on Growth, Biomass-Lipid Quality, and Bioactive Metabolites	Savannah River National Laboratory (SRNL)	SRNL Risk Assessment
9.1.3.2	Microalgae Harvesting-Dewatering Technology Suite	INL	INL Microalgae Harvesting
7.9.5.1	Development of Value-Added Products from Residual Algae to Biomass	Sapphire Energy	Sapphire Value Added
9.6.1.9	Sustainable Development of Algae for Biofuels	Oak Ridge National Laboratory (ORNL)	ORNL Sustainable Algae
7.9.1.1	Algae to Ethanol Research and Evaluation	Rowan University	Rowan U. Algae to Ethanol

REVIEW PANEL SUMMARY REPORT AND BETO PROGRAMMATIC RESPONSE

IMPACTS

1 What are the key strengths and weaknesses of the projects in this technology area? Do any of the projects stand out on either end of the spectrum?

The Algae Technology Area research projects are well-aligned with BETO's MYPP. Several projects in the Technology Area are having a strong, positive impact on the development of algal biofuel.

Techno-economic analysis (TEA) by the National Renewable Energy Laboratory (NREL) and the National Alliance for Advanced Biofuels and Bioproducts (NAABB) has greatly impacted algal biofuel development. The models show that current the state of technology would produce fuel at a cost of about $18 per gge. The models conclude that to reach economic viability, more than a five-fold increase is needed in combined productivity and yield from the current model harmonization value of 13 grams per square meter (g/m^2) per day productivity and 25% oil yield, while also reducing capital costs. Algae productivity in outdoor cultivation is the preeminent enabling factor or a certain failure mode for algal biofuel viability.

The results from extensive projects focused on increasing productivity and yield through screening and selection of strains and strain development through directed evolution have not shown significant improvement relative to the five-fold increase needed. These important results should be impactful. Results from multiple investigators screening thousands of strains over several years strongly indicated that new and innovative approaches to increasing productivity and yield are needed.

Outstanding research by Mark Hildebrand and his team at the University of California, San Diego (UCSD) received the highest peer review ratings out of the 28 projects. The team found that photosynthetic and metabolic processes are substantially different across algal classes. Using production strains, they correlated physiological changes to changes in gene expression. They demonstrated three genetic manipulations that lead to higher triacylglycerol (TAG) accumulation and one genetic manipulation that leads to faster growth.

This project is a tantalizing example of the need for and potential of genetic engineering to strongly contribute to productivity increases.

By working with a model strain, Richard Sayre and his team at NAABB illustrated that attenuation of the light-harvesting antenna size and the coupling the enzyme ribulose-1,5-bisphosphate carboxylase oxygenase to carbonic anhydrase to improve carbon-delivery to the photosynthetic apparatus have potential to increase productivity.

Stephen Mayfield's team at the Consortium for Algal Biofuels Commercialization (CAB-Comm) is showing how the yield potential of algae can be preserved by controlling pests through development of resistant strains, use of chemical pesticides, and cultivation of consortia of strains. Todd Lane's work on pond crash forensics at Sandia National Laboratories (SNL) has the potential to provide a tool for this type of improved cultivation management.

The Algae Testbed Public–Private Partnership (ATP3), led by Gary Dirks, provides an algae testbed with both small and large outdoor cultivation across a range of geographies. This excellent project addresses a key recommendation from the 2011 Project Peer Review.

Some process engineering projects have little or no impact on the development of algal biofuel technology due to lack of concept evaluation using preliminary engineering or lack of economic analysis prior to initiation of research and testing.

The following projects appear to have fundamental engineering and economic problems that should be addressed before spending resources on testing and development: Argonne National Laboratory's (ANL) process using hydroclones and nanoparticles, University of Toledo's project using swelling hydrogels, the completed Idaho National Laboratory (INL) cross-flow filtration project, and the project by Rowan University.

The SNL project for recycling nutrients using struvite appears to have unaddressed fundamental questions about the process flow and mass balance necessary to enable conceptual viability.

The Cornell Consortium appears to be focused on an inherently uneconomical process that is energetically unfavorable with no obvious prospects for improvement.

Some projects have limited impact because the current state of technology development is insufficient to provide necessary inputs. The Oak Ridge National Laboratory (ORNL) Resource Assessment and the Pacific Northwest National Laboratory's (PNNL) Integrated Assessment modeling have a level of sensitivity and detail that is inundated by the uncertainty in input parameters that come from the lack of a defined process. Extensive modeling with parameters from the current state of technology provides distorted results because the modeled scenarios can never be deployed.

2 Is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry in this technology area? Is the government's focus appropriate in light of private-sector investments? Are there any projects that stand out as meeting (or not meeting) this criterion?

The highest rated and most impactful projects have three areas of focus.

The first and most critical area of focus is to increase productivity and yield. These projects are represented by genetic engineering by Hildebrand at UCSD and Sayre at NAABB, as well as by development of advanced cultivation practices by Mayfield at CAB-Comm and Lane at SNL.

The second area of focus for highly successful projects is techno-economic and Greenhouse Gasses, Regulated Emissions, and Energy Use in Transportation (GREET) modeling to guide research projects and to down-select projects. These projects are represented by Davis at NREL, Richardson at NAABB, and Frank at ANL.

The third area of focus for successful projects is development of measurement systems necessary for process improvement. These projects are represented by Dirks' ATP3, which develops a robust measurement system for productivity, and by Lieve Laurens at NREL, which develops measurement systems for compositional yields.

The major private sector investments by Sapphire and by Exxon-Synthetic Genomics have bifurcated into two distinctly different strategies that clearly reflect different perspectives about the magnitude of the barriers to algal biofuel commercialization.

Exxon-Synthetic Genomics' re-scoping of their algal biofuel project to focus on long-term research at the organism level indicates that they see productivity and yield in cultivation as intractable problems that are refractory to conventional approaches, and that they believe several fundamental breakthroughs are needed before commercial viability is attainable. The deep pockets of Exxon can enable this strategy with a timeframe of more than a decade.

Sapphire continues a comprehensive approach to process development, indicating that they believe enabling increases in productivity and yield can be attained in a short timeframe by developing currently available technologies and tools. The venture capital funding of Sapphire effectively dictates this approach.

The current mix of BETO projects in the Algae Technology Area include integrated algal biorefinery funding, fuel conversion, by-product testing, and extensive sustainability and resource modeling. This project mix is a de facto placement into the category of shorter-term development, primarily using available tools and technologies to rapidly reach commercial viability. In light of the lack of progress in improving cultivation productivity and yields since the inception of this BETO Technology Area, a review of this comprehensive approach may be warranted.

BETO Response: Impacts

The Algae Program appreciates the reviewers' sentiment that the Program is pursuing some high-impact strategies to overcome challenges facing the development of algal biofuels. The positive recognition given to specific performers in the Program is useful, and we appreciate the support for our consortia-driven and collaborative strategy. Also, we appreciate the support given to our coordination with other federal agencies, such as our jointly funded project with the National Science Foundation for the metabolic engineering of diatoms for biofuel applications that is being undertaken by Dr. Hildebrand at the Scripps Institute for Oceanography at the University of California, San Diego.

We thank the reviewers for calling out the impact of our techno-economic modeling; the reviewers accurately pointed out that it suggests that a five-fold improvement in algal biomass productivity is the critical path for algal biofuel R&D. We also appreciate the reviewers' acknowledgment of the challenge the Program faces in achieving this aggressive improvement, and we are bolstered by the comments that state some of our projects and latest funding opportunity announcements (FOA) are well aligned to have a strong, positive impact towards achieving our goals.

The Algae Program is very excited to receive the Arizona State University-led ATP3 under award. Once it begins operations, we hope it will serve as a unique and excellent national testbed facility and provider of high quality, long-term algae cultivation data. We greatly appreciate the reviewers' support of the strategy to support the operation of regional testbed facilities, and we appreciate the favorable comments made about the leadership provided to this initial effort by the ATP3 management team.

The Algae Program is also very grateful for the thoughtful and constructive comments made in regards to several specific projects within our portfolio. The Program is very excited about the results of the strain screening work, and while we acknowledge the comment that screening and selection of strains has not yet resulted in a five-fold increase in productivity, we are strongly committed to continuing to sample, quantify, and preserve the vast genetic and phenotypic diversity of algae, with the critical objective of applying strain improvement techniques to robust and production-capable organisms. The library of promising strains collected by NAABB will be made publicly available at the conclusion of the project this year.

In its current form, the Algae Program is directing a very diverse portfolio of work taking place across the biofuel value chain and at both very early and later TRLs. Both incremental and breakthrough advances in fundamental algal biofuel science and technology across the biofuel value chain are occurring as a result of our investments. Advancing the state of the art is critical to realizing the long-term potential of algal biofuels. While we are very receptive to the comments about pursuing rigorous techno-economic, engineering, and scale-up considerations as selection criteria for all algal biofuel technology development, we also assert that notional commercial-scale financial viability is not the overriding metric used in the selection of early TRL R&D, and we will continue to pursue innovative technology development at appropriate levels of investment.

In conclusion, we appreciate the reviewers' finding that there are projects within in our portfolio that are making a high impact towards critical challenges facing algal biofuels. The need to achieve improved algal biomass yields is paramount, and the recognition given to our Program for these efforts is appreciated. Supporting claims and technology development with rigorous performance models is a critical component of algal biofuel R&D, and the support given to our efforts in this area is appreciated. Acknowledging that fundamental questions, such as mass balance closure and measurement variability, remain incompletely addressed is an important lesson learned.

We appreciate the recognition the panel has given to both Dr. Laurens at NREL and Dr. Dirks at Arizona State University for positively advancing the state-of-the-art in this area.

INNOVATION

3 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach these barriers? Do any projects stand out as meeting (or not meeting) this criterion? Can you recommend new ways to approach these barriers?

The level of innovation and the rate of advancement of technologies do not appear to be sufficient to have a high probability of meeting key MYPP goals in the stated timeframe. The goal of achieving 5,200 gallons (gal) per acre of algal lipid production in an open system is very challenging, yet it might not be sufficient to meet the goal of $3.27/gge production cost demonstration by 2022.

Reported productivity and yield results from NAABB and the harmonization values used in modeling are not significantly different than the results from the DOE-funded 1978¬1996 Aquatic Species Program.[3] This lack of progress does not portend success by 2022 using the current approaches and levels of innovation.

The Cornell Consortium project has achieved a productivity of more than 20 g/m^2 per day and a projected fuel yield of 1,365 gallons per acre per year. This might appear to be demonstrating innovations that are making progress toward the productivity goal. However, the

[3] Sheehan, J.; Dunahay, T.; Benemann, J.; Roessler, P. *A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae*. NREL/TP-580-24190. Golden, CO: National Renewable Energy Laboratory, 1998. http://www.nrel.gov/biomass/pdfs/24190.pdf.

2013 capital cost for the cultivation system is $260,000 per acre, or $190 capital per each gallon per year production capacity. The 2013 energy input for cultivation is 32 megawatt hours per hectare per year (MWh/hectare/yr), or about 1.3 times the energy content of the fuel produced when electrical generation efficiencies are included. High capital cost and high energy usage are directly related to the technologies used to achieve the improved productivity. Use of ultraviolet sterilization of source water, initial growth in photobioreactors (PBR), and a two-day cycle in open raceway ponds with harvest at 0.35 grams per liter (g/l) ash-free dry weight (AFDW) create capital and operating cost barriers to this process that is viable for fuel production. The Cornell University Consortium estimates reductions in capital cost for 2015 using the erroneous assumption that capital costs for water handling systems are directly proportional to system capacity. Even accepting this overestimated cost reduction, the cultivation capital cost is still nearly $130,000 per acre or $96 capital for each gallon per year of production capacity. Projected energy input for 2015 cultivation of 26 MWh/hectare/yr is still about 90% of the energy value of the fuel when electrical generation efficiencies are considered. This project indicates that a viable algal biofuel process cannot be achieved by increasing the cost and complexity of cultivation to give greater productivity and fuel yields. Step change improvements in biology and cultivation are needed.

The innovative genetic engineering work shows possibilities for increasing the inherent productivity and yield potential of algae strains but maintains that yield potential in outdoor cultivation could be a daunting challenge. The technology cannot advance toward commercialization without a system for testing in place that provides exposure to outdoor biotic and abiotic stresses for genetically modified strain cultivation.

The hydrothermal liquefaction (HTL) process innovation reduces or eliminates the constraint of having to balance lipid production with overall growth rate and allows for maximizing productivity in cultivation. Given the considerable and unsuccessful efforts searching for productive high-lipid algae species, reducing or removing the lipid accumulation requirement through HTL is a significant development and should be pursued further. This is consistent with PNNL research developing and modeling the HTL process and with BETO's inclusion of HTL as a pathway of interest in the MYPP. However, forgoing co-product feed value may be a significant downside for the process, especially for early deployment. Low crude oil quality and high upgrading costs might be issues.

Lack of economically and technically viable innovation in harvest is evident in past and current projects. None of the processes appear likely to provide improvements over dissolved air floatation, which currently is not economical enough to meet future fuel cost targets.

The innovation of developing electronic photobioreactors (ePBR) for strain selection may have been deployed without rigorous validation. This may have contributed to a lack of progress in strain selection. There may be confounding problems between the ePBR system capability and strain biodiversity. Lack of gains in algae productivity and fuel yield could be due to the inherent lack of desirable production characteristics in the populations screened, or it could be because the ePBR screening tool did not have the capability to discern among productive and non-productive strains. Lack of biotic stresses in the ePBR is one potential cause of poor correlation. ePBR screening might have potential as a powerful tool for strain screening and development, but this measurement system needs to be rigorously validated against multiple strains and consortia, both productive and non-productive, with enough replications for statistical power.

BETO Response: Innovation

The Program thanks the review panel for their helpful conclusions that state significant progress remains to be developed in productivity, harvesting, and processing technologies to realize our aggressive 2022 targets for algal biofuels. The Algae Program's MYPP projection for 2022 select what we believe to be the advancements needed in technical performance, operability, and capital costs to achieve, through scaling the results of representative process and pilot scale work by using process simulation models coupled with office-wide standard financial assumptions, notional commercial-scale biofuel prices that contribute to BETO's goal of $3/gal advanced biofuel. Thus, the 2022 targets are aggressive, but they are also illustrative of an algal biofuel system that could contribute to the overall office goal. The dissemination of these targets allows us to engage with stakeholders and facilitates identification of innovative breakthrough, as well as incremental technology developments. The Program will continue to develop strategies to support innovative technology approaches to algal biofuels. If innovations begin to show promise in advancing the state of the art, we will incorporate them into our projections, provided reproducible results and public data are available.

The Algae Program believes that the operation of the testbed facilities it is supporting through its awards to Arizona State University and the University of Arizona will positively enable innovation by allowing developers access to scaled-up process development facilities. This will allow developers to achieve rapid testing and refinement of concepts in production-relevant settings with access to a broad array of supporting expertise and standardized analytical procedures. The Program acknowledges the constructive spirit of the reviewers' comments and believes that by supporting the availability of the testbeds, as well as continuing to issue focused R&D calls supporting integrated algal biofuel production and processing technology development, we will continue accelerating the development of algal biofuels towards commercialization.

GAPS

4 Are there any other gaps in the portfolio for this technology area? Are there topics that are not being adequately addressed? Are there other areas that BETO should consider funding to meet overall programmatic goals?

There is a need for a stronger foundation on understanding the ecology (species, roles, and interaction of bacteria, algae, and other eukaryotes) and physiology of algae (response to temporal abiotic and biotic environmental changes) in commercially relevant cultivation systems. The technology development is far ahead of the foundational science at this point. This is a challenging problem that requires collaboration between basic science and highly applied science. However, the necessary metagenomic tools are available, and studies in this area would provide information to improve current approaches and are likely to lead to additional novel approaches or advances. Two good examples of the benefits of this approach in prior projects are the CAB-Comm results on grazer resistance and on mixed culture cultivation.

Techno economic and GREET modeling are being underutilized as tools for screening proposals, directing research, and down-selecting projects. Greater use of modeling economically viable scenarios should be used to direct research. Use of simpler models to address specific questions of concept viability could prevent development of non-viable processes.

There is an over-emphasis on nutrient recycling because it is not a primary driver for the economics and is not a sustainability issue for initial technology deployment. In the long-term, sustainable industry may or may not include nutrient recycling depending on the specific process for the integrated system and biorefinery.

There is an under-emphasis, especially in techno-economic analysis, for the process of lipid extraction with sale of protein meal co-product. The value of co-products resulting from this pathway should be determined with robust metrics from ruminant and monogastric feed trials.

BETO Response: Gaps

The Algae Program is grateful for the constructive input on programmatic gaps. We recognize that, relative to traditional bioenergy feedstocks, fundamental knowledge of relevant algal ecology and physiology in commercially relevant settings is comparatively limited, particularly with the comparatively vast diversity of algal systems. We continue to work closely with our federal collaborators at the Office of Science and with the National Science Foundation to design and implement programs that coordinate with and support our applied mission. We appreciate the reviewers' comments on the projects in our portfolio that exemplify this approach, and we anticipate continuing to make investments in this area as it directly enables the improved performance needed in algal productivity.

Starting with the funding opportunity issued this January 2013 and going forward with future opportunities, the Program is making techno-economic and life-cycle modeling required as integrated pieces of project applications and as stage-gate criteria for selected projects. The Program appreciates the desire of the reviewers to apply simple engineering and scaling concept viability tests to R&D proposals and we anticipate implementing such an approach as appropriate in relation to the technology readiness of a given technology development proposal, though we will remain vigilant in resisting the urge to oversimplify complex, interdisciplinary challenges and thus risk limiting options prematurely. The role of animal feed sales as an enabling paradigm for algal biofuels continues to be of interest to the Program, and we will continue to explore options for supporting exploration of co-products from algae while maintaining our core mission space of renewable energy and advanced biofuels.

The role of the Program remains strongly centered on identifying long-term challenges to algal biofuel commercialization at an energy-relevant scale of more than a billion gallons of biofuel per year and developing research and development strategies to overcome those challenges. Therefore, while the Program appreciates the reviewers' comments on the level of prioritization given to sustainability and nutrient recycling, we ultimately feel the panel is not considering the issue and the supporting analysis from the long-term perspective that we employ. The Program believes sustainability-centered concerns will ultimately drive the development of an algal biofuel industry and that the current state-of-technology, if scaled nationally, would not be sustainable from a resource demand perspective even if progress was to be made towards cost-competitiveness. The Program anticipates continuing to prioritize the development of technologies that achieve sustainability improvements in the cultivation and processing of algae for biofuels.

SYNERGIES

5 What synergies exist between the projects within this technology area? Is there more that BETO could do to take advantage of these synergies and better enable projects to meet their objectives?

NAABB process integration analyses produced significant synergies between upstream cultivation strategies and downstream processing characteristics, culminating in the development of an HTL process that produces high fuel yields from faster growing, low-lipid algae feedstocks.

There is strong potential for synergy among strain development projects and cultivation projects that is not being fully leveraged. The lack of synergy is directly related to the gap in foundational understanding of the ecology and physiology of algae in commercially relevant cultivation systems.

The model harmonization efforts advanced NREL, PNNL, NAABB, and ANL modeling projects for TEA, life-cycle assessment (LCA), and resource assessment.

The synergistic loop of process analysis and improvement, process measurement, and process modeling is evident and appears to be strengthening, but more emphasis is needed.

BETO Response: Synergies

The Algae Program has worked hard to encourage synergy in its portfolio and is glad to read that the reviewers appreciate the approach taken, both with the consortia initiative that resulted in the selection of NAABB, as well as the harmonization initiative to synchronize disparate but related performance models. We take the reviewers' comments under close advisement and will continue to strive towards strengthening the synergistic lessons-learned cycle of process analysis, measurement, and improvement. Leveraging the acknowledged strong potential for synergy amongst performers in our portfolio will take active management and review of progress to encourage sharing of results and conclusions amongst our investigators and stakeholders to accelerate overall algal biofuel development. We remain committed to implementing such strategies to the degree possible given our role.

RECOMMENDATIONS

6 Is BETO funding projects at the optimal stage of the technology pipeline? Is there more that BETO could do to orient technologies toward successful commercialization? Are there any projects that stand out as positive or negative examples of this orientation?

Projects need to better define killer issues, as well as design experiments to quickly address these killer issues and to reach go/no-go decisions based on technical and economic criteria. Too many projects have been dead-on-arrival efforts.

The Algae Technology Area needs the flexibility to terminate or redirect projects when early experiments or techno-economic analysis demonstrate that the proposed concept is not feasible. The management structure should better reflect the fact that in groundbreaking research, most approaches won't work and frequent, agile redirection is necessary. Quickly stopping projects that will be dead on arrival is a key to success.

Lessons learned from projects with technical failures or lack of feasibility does not appear to be fully leveraged to orient future projects towards success. Knowing which processes do not work and why they are not viable is critically important to innovation and success. Understanding failures can trigger creativity. Dissemination of this information can also prevent redundant work leading to predictable failures.

Projects need to develop robust measurement systems with capability to discern relevant process responses prior to initiating research and analysis.

Projects developing outdoor cultivation to provide a measurement system for strain performance have lagged significantly behind the optimal timing. The ATP3 project is getting this critical measurement system into place.

Projects on strain screening may have been a duplication of work done under the Aquatic Species Program. It is not clear if a robust measurement system with capability to discern strain performance in outdoor cultivation was used for strain screening.

Projects on oil upgrading and fuel refining and projects on feed co-product testing were completed too early in the development cycle. Algae biomass availability was lacking. Because of the low quality of the biomass used, NAABB valuation of lipid-extracted algae (LEA) feed value is significantly less than the value used by feed industry experts. Future changes in strain and cultivation technologies will affect results for co-products and for fuel conversion. Projects on nutrient recycle are also premature.

The short timeframe of the large consortia projects, as dictated by the American Recovery and Reinvestment Act funding, led to inefficient execution of the research. Activities that should have occurred in sequence were forced to work in parallel. This caused process research to begin before process measurement systems were developed. It caused downstream processing and co-product work to struggle without adequate or representative feedstocks available from upstream production. Modeling efforts did not have basic process information, causing preliminary models to be speculative or based on obsolete processes. The high upfront costs of setting up the consortia and the time and effort to close the projects eroded the time and resources for completing actual research.

7 What are the top three most important recommendations that would strengthen the portfolio in the near to medium term?

- Techno-economic modeling should be used to screen projects, direct research, provide key project metrics, and monitor project progress. Project selection criteria and reviews of all process-engineering projects should include the capital expenditure (CAPEX) and operational expenditure (OPEX) of the baseline process, the CAPEX and OPEX requirements for a viable commercial process, and TEA modeling showing CAPEX and OPEX targets for the project. All other projects should clearly state how they contribute to cost reduction using quantitative measurements where possible.
- BETO should develop a MYPP 2022 projection with more compelling economics and with mitigation of technical risks. The currently projected pathway appears to have a low probability of commercial success. The MYPP 2022 target gives a projected diesel minimum selling price of $3.73/gal. Even if these targets are achieved, this is unlikely to attract tens of billions of dollars of capital for deployment. This price is also subject to significant uncertainty in the TEA model and to large risks of not meeting speculative and very challenging cost reduction goals in cultivation, harvest, and oil preprocessing. The MYPP 2022 projections have harvest and extraction CAPEX and OPEX reduced by 50% from the 2010 state of technology, approximately $1.60/gge in cost reductions with no apparent technical pathway to achieve them. Additionally, there is the assumption that liners are eliminated from ponds. There is no room in the current MYPP for missing these independent, high-risk cost reduction targets.
- A potential value lever for improved economics is sale of a co-product. Deriving this value is very challenging because it constrains strain selection, cultivation, harvest options, and extraction processes, and precludes using HTL to achieve higher fuel yields. It also adds an energy-intensive drying step. However, it appears that sale of a high-quality feed product for approximately $500 per ton or more might be possible. This value is significantly higher than the MYPP scenario of anaerobic digestion with fertilizer recycle. Techno-economic analysis for

the process of lipid extraction with sale of protein meal co-product should be completed with a sensitivity analysis around the feed value. If these initial analyses show favorable economics, the value of co-products resulting from this pathway should be determined with robust metrics from ruminant and monogastric feed trials.

A potential cost lever for improved economics is to increase algae productivity and fuel yield well beyond 30 grams per square meter per day (g/m^2/day) at 50% oil yield. This is a very challenging goal, especially in light of the current failure across the industry to significantly increase algal productivity in cultivation. A shift in paradigm and new, innovative approaches are needed. Fifty g/m^2 per day at 50% fuel yield in open-pond systems—10,000 gallons per acre per year—would create a giant leap that would enable algal biofuel commercialization. This is an attainable objective, given the theoretical maximum of microalgal productivity, which is 75 g/m^2 per day.[4]

- The HTL and the Sapphire fuel extraction processes may create a new mode of operation in cultivation providing higher fuel yields without requiring high levels of lipid accumulation during cultivation.
- To provide greater productivity, there is a need to develop a strong foundational understanding of the ecology and physiology of algae in commercially relevant cultivation systems.
- The demonstrated potential of genetic engineering to increase algae growth rates and oil yield should be developed.
- A robust measurement system using outdoor testing in commercially relevant conditions is needed for algae productivity. A system to test GM strains under conditions with both the biotic and the abiotic stresses of outdoor cultivation in open ponds should be conceived, reviewed, and developed.

BETO Response: Recommendations

The Algae Program is very grateful for the thought and consideration given towards this set of actionable recommendations. As direct results of these recommendations, the Program anticipates incorporating to a greater degree the baseline verification and concept viability analysis for process engineering projects, coupled with stage-gate linkages for improvements in process CAPEX and OPEX. Projects selected under the 2013 Algal Biomass Yield funding opportunity will be subject to the implementation of this recommendation, and in return, the projects will also have the opportunity for longer performance periods should they successfully pass stage-gate reviews and appropriated funds were to be made available. Furthermore, all prior year projects will be invited for internal go/no-go review as appropriate. Another result of these recommendations will be the incorporation of new pathways to algal biofuels in the MYPP 2022 projection, as well as the continued evaluation of alternative pathways that offer greater innovation and/or near-term market development opportunities, such as those that incorporate mid-value co-product sales and/or wastewater remediation services.

We appreciate the strong support the reviewers give to our core national laboratory competencies on performance modeling and compositional analysis, as well as our testbed facilities. We are excited by the reviewers' vision for aspirational goals for the Program, and we will give full consideration to the 10,000 gallon per acre per year suggested paradigm.

[4] Melis, A. "Solar Energy Conversion Efficiencies in Photosynthesis: Minimizing the Chlorophyll Antennae to Maximize Efficiency." *Plant Science* (177), 2009; pp. 272-280.

ADDITIONAL COMMENTS

The 2011 Platform Summary Report recommended development of outdoor testbed facilities with both small and large open systems. This recommendation has been met by the ATP3 project.

The 2011 Platform Summary saw a need for improved criteria for project selection:

"(1) Evidence of a thorough review of the scientific literature to provide context for their work and demonstrate where there is potential for some advancement over the previous work. Transparent preliminary analyses of the current and potential future; (2) costs; (3) net energy balance; (4) LCA of the proposed processes; (5) research goals and quantitative objectives that clearly show how the new work will fill important information gaps or achieve needed performance; (6) a timeline with milestones and deliverables that clearly advance specific Program goals. This format would allow for informed, uniform reviews that could be the basis for defensible funding decisions, including discontinuation of existing projects that are not succeeding. Complex cost, energy balance, and LCA are often not necessary because simple calculations provide most of the information needed for interim project or proposal evaluation."[5]

Several recent process-engineering projects indicate that fundamental technology and economic requirements for process viability are not being defined and addressed in the FOA responses. This has led to several projects that appear to have a low probability of being viable.

The 2011 Platform Summary also included the following recommendations: "DOE needs a mechanism to allow termination of projects found to have untenable economics or LCA or projects that perform poorly in sequential reviews. Evaluation of the six numbered points above could be the basis for termination," and "Many of the projects have tasks or subtopics that need better justification in terms of technical feasibility, projected costs, energy balance, and LCA. Expert review of proposed projects is essential."[6] These are also recommendations from the 2013 Peer Review Panel.

Near the conclusion of the 2011 Platform Summary, the author stated, "A pressing question for the Algae Platform is if and when either microalgae or macroalgae has the potential to become a significant biofuel feedstock. Feedstock viability, production, logistics, and conversion challenges must all be actively studied. The obvious main barriers for algae are resource limitations and economics."[7] The past two years of research, well-managed by BETO and competently executed by the investigators, indicate that the technical and economic barriers are higher than anticipated. The algae strains and cultivation systems have been especially refractory to efforts to increase productivity and yield. Longer-term research targeted at more fundamental understanding of algae ecology, physiology, biochemistry, and genetics may be needed before economically viable productivity and yield in outdoor open cultivation can be achieved. The 2013 Peer Review Panel agrees with the 2011 Platform Summary that steady, longer-term research and development funding focused on commercialization will be needed.

BETO Response: Additional Comments

The Algae Program—Neil Rossmeissl, Roxanne Dempsey, Daniel Fishman, and Christy Sterner—wants to thank the reviewers for both their positive encouragement as well as constructive comments. We remain committed to designing and implementing a relevant, national applied R&D program to accelerate the development of algal biofuels, and we will take these comments under advisement as we continuously evaluate our strategic planning and project execution activities. We share the reviewers' sentiment that steady, long-term R&D will benefit the development of algal biofuels, and we are grateful to read that the panel believes our efforts are well managed and positively impactful. While innovations and breakthroughs cannot be guaranteed, we remain confident that our strategies will continue to be aligned to support and accelerate algal biofuel technology towards commercialization, and we are very grateful for the review panel's support and encouragement in this shared endeavor.

[5] *Biomass Program Algae 2011 Platform Review Report*. DOE/EE-0653. Washington, DC: U.S. Department of Energy, 2012. Bioenergy.energy.gov/pdfs/2011_algae_review.pdf.

[6] Ibid.

[7] Ibid.

CONTENTS

ALGAE COMPOSITIONAL ANALYSIS

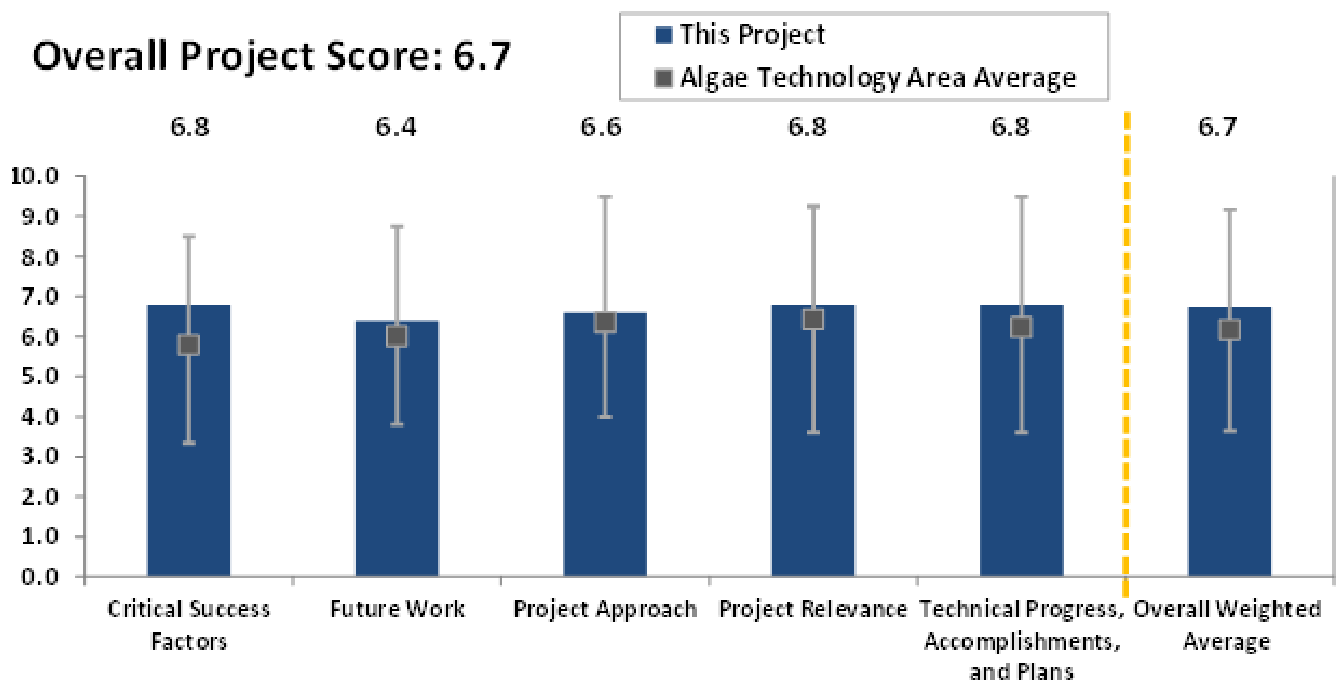
(WBS#: 9.6.1.8)

Recipient:	NREL
Presenter:	Lieve Laurens
Total DOE Funding:	$750,000
DOE Funding FY13:	$750,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012–2017

Project Description

Photo Courtesy of NREL

At the base of all biomass productivity and economic calculations for algal biofuels processes are robust analytical data on lipid, protein, and carbohydrate content, as well as profiles for a subset of target, high-productivity strains. To reduce uncertainties surrounding current harmonized models and productivity claims, analytical procedures for experimentally verified data are needed to support the economic base-case and set realistic process and cost targets for future strain improvements. Similarly, robust data are needed to score progress toward the targets using standardized measurements. The approach taken in this task is designed to establish compositional analysis for mass balance closure around algal biomass and to validate process chemistry and yields in standard and alternative production scenarios. The objective of this task is to develop and implement methodology to reduce uncertainty around the composition of algal biomass and assumed yields for algal biofuels production processes. This task aims to provide experimentally validated procedures that can advance the field of algal biofuels by developing standard analytical methods, data for techno-economic modeling and analysis, and quantitative metrics for process and strain improvement strategies. In addition, the methods will provide insights into the non-lipid components of algal biomass to assist in



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

the development of novel co-products that will improve the overall economics of biofuel production. We have demonstrated a significant reduction in measurement uncertainty by using more rigorous analytical protocols as an improvement from historical wet chemical methods for algae. Our aim is to increase the unambiguous mass balance analysis of algae to more than 90% for at least two strains and make the most robust analytical procedures available by open access online.

Overall Impressions

- Due to the critical need for reliable analytical methods in the algae industry, the overall objective of this project is important. Progress made so far appears to be good, but more convincing evidence is needed of how current results are an improvement over just another proposed method that is good only for the conditions investigated. The focus on closing mass balances and obtaining a fast turnaround is good. The project needs to be sure that it looks at commercially prepared and relevant species. Also, a literature review is needed to ensure that efforts are not being duplicated.

- Dr. Laurens' project is critical to engendering success of the current DOE algae platform. As current technology development and biomass production is decentralized and geographically spread across the nation, standardization of analysis methods is key to understanding whether progress is made with each harvest. Techno-economic success of the algal lipid upgrade (ALU) energy pathway will be dependent on accurate valuation of algae co-products. Composition specifications of feed and food ingredients is currently determined and verified by third-party, independent laboratories (e.g., New Jersey Feed Laboratory, Midwest, Eurofins), which use methods optimized around animal proteins and fats. A rapid and robust protein determination method is needed by those who would buy algae on per protein or per fatty acid bases. There will be interest in making amino acid profiles and fatty acid profiles public using standardized methods from model strains grown by the Algae Testbed Public-Private Partnership.

- This reviewer recommends recommend a change in scope and a new direction for this project.

- The project is making important contributions in the development and validation of analytical procedures to accurately measure the components in algae biomass, and the work on this task is high quality. The outreach from the project to the Algae Biomass Organization analytical standards committee is very positive; it will help ensure relevance and avoid duplication of previously published results. The tasks to develop a new photobioreactor and measure compositional change with growth stage do not appear to provide any significant advancement over prior work that is well documented in the literature. Recommendations include the following:
    - Identifying deficiencies or source of errors in published analytical procedures is as important as developing new procedures to close the mass balance on algal biomass. A valuable result to industry would be an online compendium of the analytical procedures for algae, including documentation of the limitations (what is measured and what is missed with each method), issues that have been encountered with specific species or matrices, and modifications to the methods that have overcome these issues.
    - Drop work on PBR development and measurement of composition over the course of growth. Shift these resources to include more measurements and strains/matrices, or gather more information on industrial practices.
    - Work with commercial laboratories or academic institutions that offer analytical testing services to get these procedures added to their standard portfolios.

- This is a good project with significant impact on industry's ability to execute research on algal biofuels. Clearly stated quantitative criteria for accuracy and reproducibility might help the project stay focused on quickly delivering standardized assays with acceptable performance. Standardization of sampling techniques and sample handling protocols may be needed. The work on cultivation-composition interconnectivity has value for preparation of samples with varying composition for analytical method development. Attempts to develop predictive growth and composition models using laboratory PBRs to predict effects in outdoor cultivation appear to be redundant with other efforts. The use of lab PBRs to predict outdoor cultivation performance does not appear to be validated. Previous efforts by other researchers to screen strains using lab PBRs might not have been effective.

PI Response to Reviewer Comments:

- We appreciate comments from the reviewers regarding the importance of this work relative to ongoing algal biofuels R&D and economic assessments, but we would like to follow up with some points:
  - The first, establishing year of this project prioritized the need for evaluation of historical, literature-based and commercially implemented methods for compositional analysis of algae. We are basing our evaluation of accuracy and precision on established Association of Analytical Communities guidelines, and these results will be incorporated in online laboratory procedures and publications.
  - We included PBR development in this task because controlled cultivation is critical to distinguish between biological, physiological and abiotic variability on biomass composition, biomass-specific method uncertainty, and interferences. The custom-built PBR cultivation generates physiologically controlled biomass, as opposed to commercially available materials where cultivation information is hard to trace back. Through close interactions with the algae testbeds, we are establishing a strong connection to outdoor cultivation, and by leading the analytical harmonization task for ATP3, NREL is able to address large-scale biomass composition concerns, as well as harvesting, sampling, and storage effects.
  - We have reached out to the commercial laboratories for a survey of current commercial analytical practices for algae, where a range of compositional analysis methods are available for testing food and feed but not tailored to algal biomass. We are engaging commercial laboratories and trade organizations (e.g. Algae Biomass Organization and AOCS) towards implementation of algae-specific analytical tools and have an open communication by distribution of recent analytical R&D work in this area.
- In response to the reviewers' comments, future work on this task will focus on algae-specific analytical development, publishing an online repository of procedures for compositional analysis and reducing emphasis on PBR development; include additional organisms alongside model strains to validate and guide analytical development; and increase emphasis on outreach to commercial analytical laboratories and trade organizations.

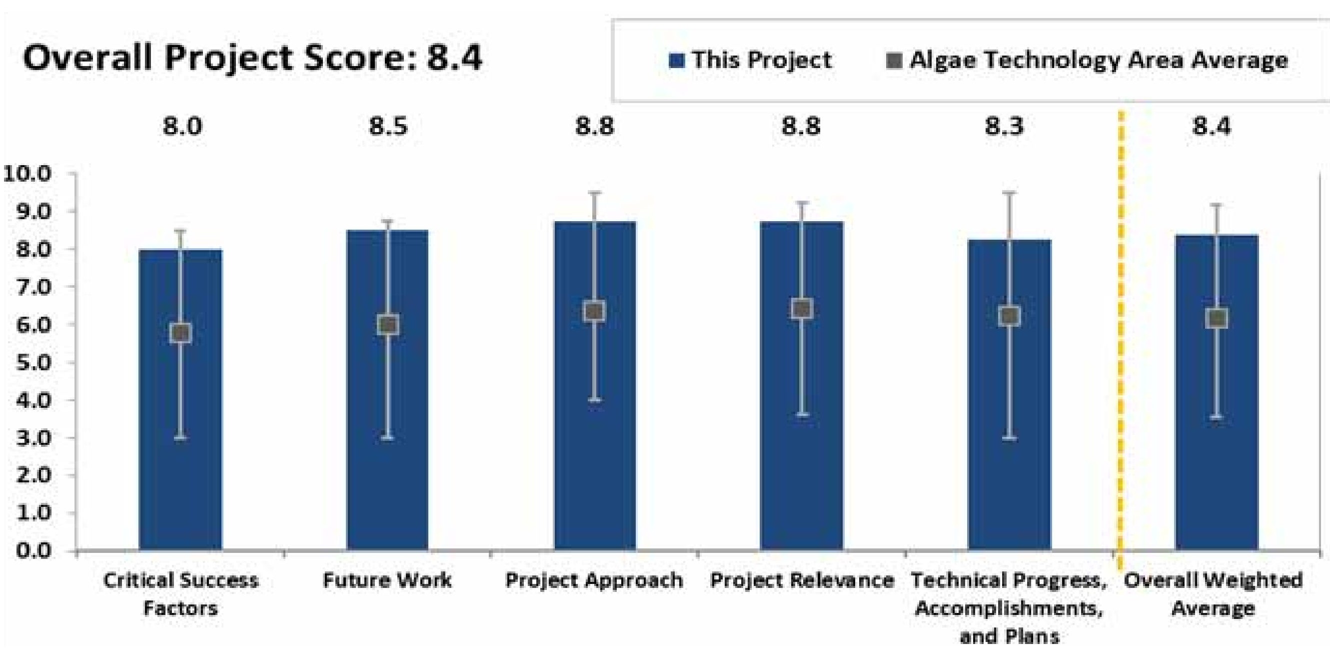
ALGAE TESTBED PUBLIC-PRIVATE PARTNERSHIP (ATP3)

(WBS#: 9.1.4.1; 9.1.4.2; 9.1.4.3)

Recipient:	Arizona State University
Presenter:	Gary Dirks
Total DOE Funding:	$4,600,000
DOE Funding FY13:	$4,600,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013–2018

Project Description

The vision for ATP3 is to establish a sustainable network of regional testbeds that empower knowledge creation and dissemination within the algal research community, accelerate innovation, and support growth of the nascent algal fuels industry. ATP3 will increase stakeholder access to high-quality facilities (function one) by making an unparalleled array of outdoor cultivation, downstream process equipment, and laboratory facilities available, along with world-renowned expertise from a tightly managed multi-institutional and trans-disciplinary team. ATP3 will utilize a powerful combination of facilities, technical expertise, and proactive management structure to support DOE's techno-economic, sustainability, and resource modeling and analysis activities. This will help to close critical knowledge gaps and inform robust analyses of the state of technology by conducting coordinated long-term cultivation feedstock trials at our geographically diverse sites to provide a unique data set regarding reproducibility, scalability, seasonal, and environmental variability (function two). These data are critically important to support TEA and LCA activities that will guide research and development toward the transformative goal of cost-competitive algal biofuels by 2022. Objective 1: Collaborative Open Testbed—Capitalizing on existing infrastructure at geographically diverse sites, ATP3 will establish and provide broad access to a technically superior network of algal biomass testbed facilities and personnel that will enable the acceleration of applied algal research, technology development, investment, and commercialization for biofuels production. ATP3's flexible and responsive—yet comprehensive—intellectual property



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

framework, tiered fee structure, and site access plan incorporate best practices of all sites and users. ATP3 will maintain and supply to the research community high-quality stocks of biomass, algae oil, and residuals. Benefit and Outcome 1: ATP3 will create an accessible, regionally diverse mix of algae biomass cultivation and downstream processing facilities, equipment, multi-disciplined laboratory, and outdoor test operations with the personnel, resources, and capabilities to support the applied algae research community and affiliated industries to lower overall project risk and accelerate the advancement of algal technology innovation and commercialization. Objective 2: High-Impact Data—Objective 2.1, Setting Standards: Leveraging existing infrastructure from previously successful projects, ATP3 will provide closely coordinated, harmonized, and objective standards for operational protocols, data collection and analysis, data management, quality control, modeling and assessment, education, and training for the algae research community and associated stakeholders. Benefit and Outcome 2.1: ATP3 will curate and disseminate scientifically relevant, robust, standardized, and validated protocols for algal biomass and oil production, analytical standards, biomass and oil analysis, and data collection and analysis. Objective 2: High-Impact Data—Objective 2.2, Long-Term Cultivation Trials: ATP3's experienced and qualified personnel will design, validate, and execute long-term cultivation trials that will produce standardized data to enable comparison of promising production strains, algal culture systems, and processes at meaningful scale, across different regional, seasonal, environmental, and operational conditions. Benefit and Outcome 2.2: ATP3's current high-capacity production will be harnessed under a well-designed experimental framework that will inform the current and future state of technology, support modeling to establish economic and sustainability metrics, and contribute to the identification of future targets for algal biofuel production.

Overall Impressions

- The project seems like it should have been done earlier.
- The design of this consortia and project represents an important leap forward from the previous consortia projects funded by BETO. There are a number of promising and innovative attributes in this project—the focus on setting up facilities and resources to attract customers, the cost structure linked to making customer data publicly available, the desire to use customer funding as a mechanism to ultimately wean off of government funding, the almost exclusive focus on outdoor testing under commercially relevant conditions (as opposed to lab-scale work), and the initial focus on harmonization and standardization. The biggest challenge will be managing this large consortium efficiently and in a way that ensures the two distinct functions of this project (customer use of facilities and internal, long-term testing) do not interfere with each other. The consortium appears to at least recognize these challenges and be off to a good start. The resources appear to exist for good long-term testing of many aspects of the algae to fuel process, though a more detailed plan for what long-term tests will consist of is needed to ensure optimal use of the available resources.
- The project has a strong management structure, plans for standardized and harmonized production metrics, data management capabilities, advanced diagnostics, and access to key unit operations. The project has the potential to close a significant gap in producing robust, high-impact data from outdoor cultivation for algal biofuel process evaluation. The project team has a good plan with emphasis on making data broadly available and in a useful format.

- This project has high expectations and the right team in place to meet them. BETO would do well to steer this consortium toward production and validation of downstream handling technologies, and to minimize time spent on improving any modeling efforts beyond Davis' TEA, or time spent on strain selection. It is time to grow and go.

PI Response to Reviewer Comments

- With respect to the challenge of ensuring the two distinct functions do not interfere with one another, we are confident we will be able to effectively balance capacity availability for Function 2 (cultivation trials) and those needed with customers in Function 1. For the unified field studies, the capacity is captive to the long term cultivation trials as these systems were added to all sites for that specific purpose. As for the other established assets, in particular the cultivation systems (larger ponds and PBRs) at our various sites, priority will be given to paying customers. We will always look for synergistic ways to utilize those assets while still generating data useful to the stakeholder modeling community. A significant deliverable of phase one and a key metric for review at our go/no-go will be a detailed phase two experimental plan that lays out the framework for optimal utilization of available resources for completing the cultivation trails. One further point of clarification around the validation of downstream technologies—the scope for ATP3 with respect to the DOE-funded portion is not to look at the full algal to fuels pathway, except in the context of working with customers under Function 1. Part of our scope is growing large scale quantities of biomass to quickly enable downstream handling, processing, and experimentation. However, this is only in the context of when customers are looking and paying for that activity (Function 1) or to the extent we are able to work that in as part of our AFS on larger scale systems at our larger testbed sites that have downstream unit operations vertically integrated.

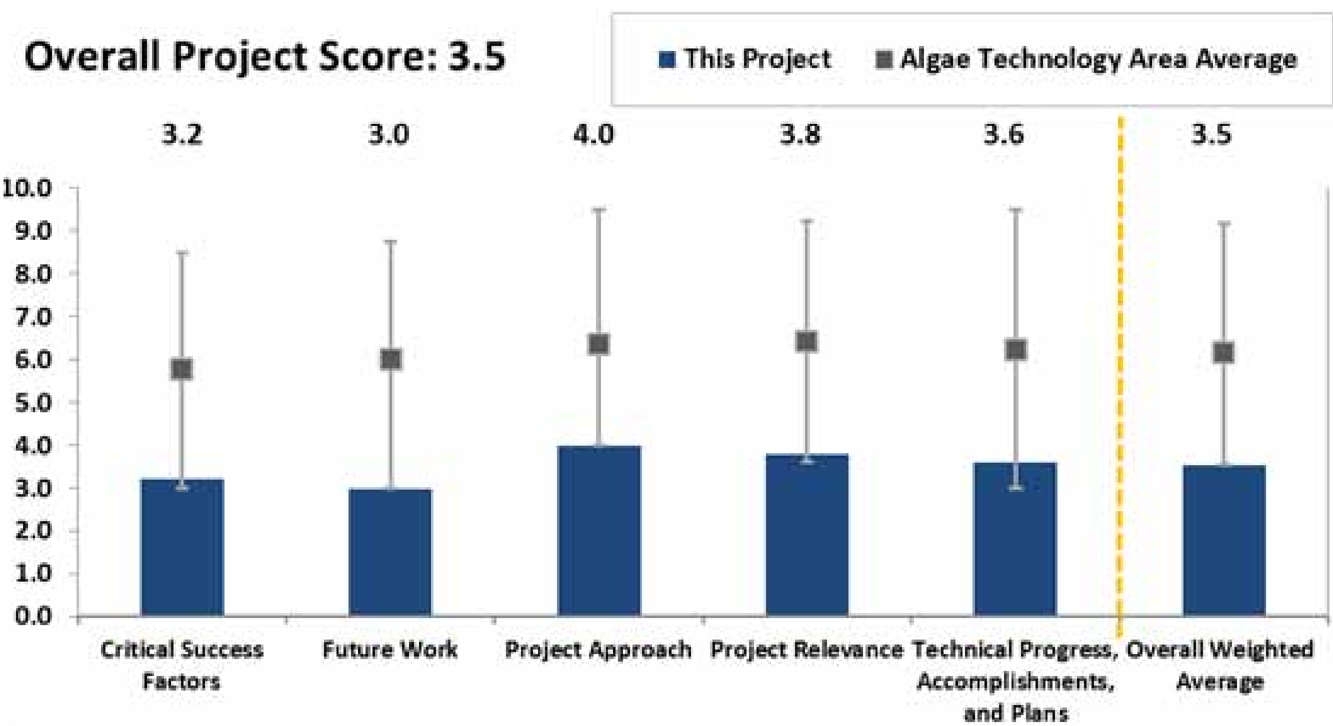
ALGAE TO ETHANOL RESEARCH AND EVALUATION

(WBS#: 7.9.1.1)

Recipient:	Rowan University
Presenter:	Kauser Jahan
Total DOE Funding:	$750,000
DOE Funding FY13:	$74,673
DOE Funding FY12:	$261,493
DOE Funding FY11:	--
Project Dates:	2010–2013

Project Description

This project focuses on applied research with algae to derive biofuel. The objectives of this project were to determine algae species and optimize lipid yield under various cultivation conditions, evaluate carbon dioxide (CO_2) gas transfer characteristics using hollow fiber membrane modules, conduct pilot-scale studies with membrane modules, and evaluate the environmental footprint of the downstream processing for algal feedstocks conversion to biodiesel. *Scenedusmus dimorphus* and *Chlorella vulgaris* were selected for batch experimental studies after a thorough literature search. Results indicated that a light intensity of 400-foot candles and nitrogen-deficient conditions enhanced lipid yield. It was also determined that *Chlorella vulgaris* was able to use glucose as an organic carbon source. The highest lipid yields were obtained under nutrient-deficient mixotrophic conditions. Hollow fiber membrane studies were conducted to deliver CO_2 gas to promote algae growth. The membrane modules were operated in a sealed-end, parallel flow configuration. Model correlations were developed for scale-up studies. Pilot-scale studies conducted with the membrane modules indicated higher algae growth rates in comparison to conventional sparging for short-term studies. Long-term studies will indicate whether membrane fouling is a potential problem. An analysis was performed of the life-cycle emissions associated with downstream processing stages for algal biodiesel. A "base case" was developed for comparison using typical commercial technologies, which revealed that the thermal drying component contributed to the majority of life-cycle emissions. Alternative cases were



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

evaluated for various sequences of mechanical and thermal dewatering techniques. The best case consisted of a disc stack centrifuge, followed by the chamber filter press and a heat integrated dryer. Significant reductions in life-cycle emissions were achieved for all mechanical dewatering alternatives compared to the base case. Additional improvements will require the development of new techniques for water removal or wet extractions.

Overall Impressions

- Additional work on the growth or growth system is not warranted based on the experimental results. Additional work on the membrane CO_2 supply system is not warranted because it is not addressing a key challenge, such as the cost of CO_2 supply. The most interesting results are from the LCA that indicates the choice of dewatering technology (5% solids to approximately 28% solids) does not significantly impact the total energy or emissions, and the LCA that indicates using a vapor recompression dryer for a portion of the drying (28% to 55% solids) has a dramatic impact on the total energy or emissions.
- Advanced the community consciousness; science was initiated and gave students an opportunity for the future.
- It does not appear that sufficient literature review and analysis was performed prior to initiation of experimental research. There is no validation to indicate that research on autotrophic growth rates in the lab PBR is relevant to commercial cultivation scenarios. Heterotrophic growth systems are outside of the scope of the DOE Algae Technology Area. There is no justification presented for using membranes to transfer CO_2 into growth media, and published cultivation studies show that sparger systems are cost effective. Results showing greater growth for CO_2 supplied through membranes instead of spargers indicate improper set up and operation of the sparger system. CAPEX for cultivation systems needs to be reduced. The use of membrane systems to replace sparging is going in the wrong direction. Dewatering and drying research is a rehash of old information. The project did not advance the state of algal biofuel technology.
- This project has generated data in several areas and has pointed out several interesting trends. This project is also providing a significant benefit by exposing students in a primarily undergraduate institution to real-world issues and research opportunities, which is commendable. However, most of the work described in this project is at a basic research level as opposed to work that will help advance commercialization of the algae to fuels industry, which is the primary focus of this BETO funding. The tests performed in this project all utilize lab-scale-size equipment, and designs are conducted indoors under controlled conditions. It is not clear how the results will translate to commercial-scale conditions in outdoor systems. In the remaining time on this project, it is important for the investigators to include an economic assessment of all equipment investigated/utilized in order to assess whether the equipment can be economically viable based on current BETO cost/gallon targets. Remaining research efforts should focus only on work that involves equipment and/or concepts that are potentially viable from an economic and technical perspective.
- While there were several good ideas discussed during this presentation regarding the use of membranes, it did not appear that a lot of new results were generated.

PI Response to Reviewer Comments

- The review committee treated our research as a biofuel commercialization project and as such, many comments are unrelated to our project or appear to be disjointed. There is a major disconnect between the review committee expectations and the scope of our project, which was approved by DOE upon receipt of the award. It is unclear if our project was erroneously grouped with projects that are clearly commercially driven. Economics were not a part of the scope of this project, nor did the DOE project manager who reviewed the scope of the project identify the need for an economic analysis. Commercial cultivation and CAPEX reduction were not the goals of this project. The thrust of current algae cultivation in lab-scale studies is investigating heterotrophic, mixotrophic, and autotrophic cultivation conditions. As such, researchers are focusing on organic carbon sources such as glucose, sucrose, glycerol, acetic acid, fructose, sodium acetate, and etc. The use of membrane treatment for wastewater appeared nearly 30 years ago. At that time, many in industry indicted that the technology was too expensive and would never have successful applications. However, over the past decade, there has been a rapid increase in the volume of wastewater that is treated with membranes to exceptionally high quality standards. In fact, today more municipal wastewater treatment facilities are using membrane technologies than ever, and this number is on the rise as the technology offers unparalleled capability in meeting rigorous requirements. It is premature to conclude at such an early stage that membrane applications are unsuitable for algae-derived biofuel studies.

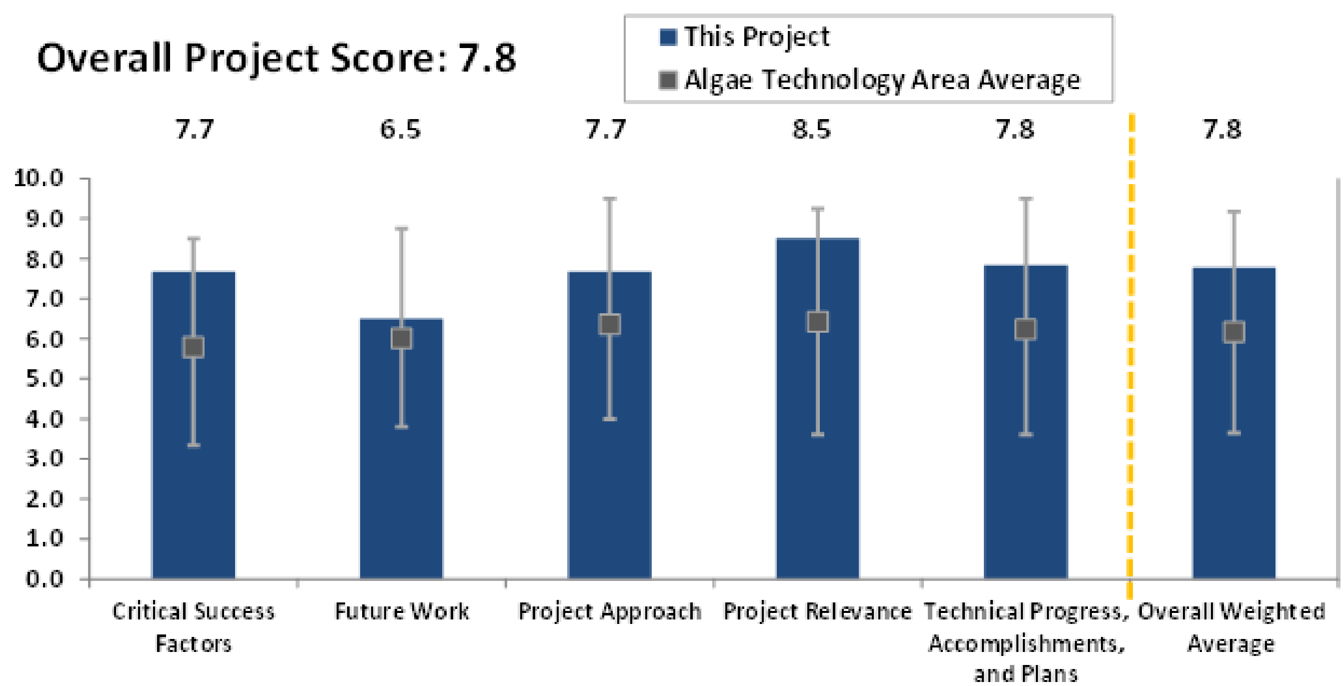
ALGAL BIOFUEL TECHNO-ECONOMIC ANALYSIS

(WBS#: 9.6.5.3)

Recipient:	NREL
Presenter:	Ryan Davis
Total DOE Funding:	$644,000
DOE Funding FY13:	$200,000
DOE Funding FY12:	$210,000
DOE Funding FY11:	$134,000
Project Dates:	2010–2017

Project Description

The objective of the Algal Biofuel Techno-Economic Analysis task is to provide techno-economic modeling and analysis to support the algae-related office research and development activities. The task develops and maintains benchmark models to quantify near-term technology potential using the best public data available. Proposed research and alternative processing strategies can be translated into economics that can be compared to the benchmark case to demonstrate the economic impact toward meeting competitive cost targets. This task is highly relevant to supporting BETO's goals and objectives, as the analysis work provides a process context for activities funded by the office. The project also provides a starting baseline that sets targets to be met by future office research. Moreover, a primary objective of the task is to address the large disparity in public claims regarding technology and cost potential for algal biofuels by establishing rigorous, objective, peer-reviewed cost models. The work is performed collaboratively with other laboratory partners and is also highly leveraged in additional DOE-funded work, such as recent consortia partnerships that include NAABB, the Sustainable Algal Biofuels Consortium (SABC), and ATP3. The Algae TEA task has made significant achievements since the 2011 Peer Review; most notably, the task expanded on preliminary models for autotrophic cultivation through a DOE-supported "Harmonization Initiative." The harmonization effort consisted of subjecting the independent models for TEA, LCA, and Resource Assessment (performed by NREL, ANL, and PNNL, respectively) to external vetting by research and industry stakeholders, and subsequently harmonizing the various models to a



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

common set of assumptions for improved consistency. A number of important results were identified from the work, including the importance of consideration of location- and seasonal-variability in the models. Given the success of the effort, a similar exercise is being repeated in fiscal year 2013 to conduct a harmonization analysis for algal hydrothermal liquefaction technology pathways.

Overall Impressions

- Currently this project represents a critical path for all of the DOE modeling. He would greatly benefit from integrating and training in other DOE-funded modeling efforts to expand TEA modeling capacity.
- This project is good and represents critically important work. It needs to be compared with reality and a design for less-than-peak capacity. Capital expense and operating expense are provided in good detail.
- The development and further refinement of the TEA model in this project represents another important effort for predicting values and trends in costs. Good progress appears to have been made, and several insights into the algae process were provided as part of model outcomes. The ability to identify individual component contributions to the total predicted CAPEX and OPEX values is of significant value to being able to focus efforts on where more work is needed. Initiating harmonization efforts among other relevant models was an important step in establishing an equal basis and output consistency among the models. There is some concern as to how current the data used in the model are because of the stated lack of availability of primary sources. However, this constraint is recognized by the investigators, and attempts are being made to access more recent data. It is important to continue to pursue access to the most recent data to maintain the reliability of the model output.
- The NREL TEA model is a very powerful tool for defining the current state of technology, exploring alternative scenarios, and directing research efforts. The NREL model clearly illustrates that algae productivity and fuel yield will be the preeminent enabling factor for achieving viability or will be a certain failure mode. Step change improvement in combined productivity and fuel yield of about five-fold are needed. This model has very high potential value for properly focusing research efforts; therefore, dissemination should be as broad as possible.
- The TEA modeling effort is central to achieving the goal of $3/gal algae oil, and the effort by this project has been tremendous. As with LCA, the TEA needs to be extended to include the most common approach to algae biofuels—lipid extraction and protein meal co-product. There is also a need to utilize the model more for driving the research and development efforts. The PI should report model results for costs in terms of dollars per metric ton ($/MT) algae biomass per year and $/MT algae biomass, and then look at product routes—HTL, ALU or anaerobic digestion (AD), ALU/protein meal co-product—to obtain product value for component in $/MT and as a composite $/MT based on the component fractions. This would provide more clarity for researchers, as well as DOE decision makers.

PI Response to Reviewer Comments

- We thank the reviewers for their complimentary and insightful comments. Regarding the need for realistic operational data and a comparison of the models with reality, this is a point we recognize and continue to place a high priority on. As the reviewers note, this is typically challenging as much of the data on real-world, large-scale operations are held privately by industry with an understandable reluctance for such data to be utilized in publicly documented models. However, several activities are anticipated to help provide such needed data, most notably the start-up of the newly formed ATP3 consortia in which NREL is a partner, with a primary objective of the consortia to run harmonized, large-scale production trials in test-bed facilities across the U.S., with the resulting production and processing data to be leveraged in NREL and partner models for purposes of validating or improving the baseline model assumptions.

- We will also continue to consider the important implications of seasonality on algal biomass production, including options for optimizing the economics of a modeled integrated facility in terms of designing for peak or off-peak capacity and associated co-product options. Among other options, this may also include further consideration of protein meal co-production, recognizing that this option has also been briefly evaluated in NREL's baseline models and documented in the DOE "harmonization report."[8] In addition, we have also begun to consider explicitly breaking out costs of algal biomass production in terms of dollars per ton, as presented in DOE's most recent May 2013 MYPP.[9] We will continue to evaluate and refine these estimates as additional modeling detail evolves.

[8] David, R.; Fishman, D.; Frank, E.; Wigmosta, M.; et al. *Renewable Diesel from Algal Lipids: An Integrated Baseline for Cost, Emissions, and Resource Potential from a Harmonized Model*. ANL/ESD/12-4; NREL/TP-5100-55431; PNNL-21437. Argonne, IL: Argonne National Laboratory; Golden, CO: National Renewable Energy Laboratory; Richland, WA: Pacific Northwest National Laboratory, June 2012. http://www.nrel.gov/docs/fy12osti/55431.pdf.

[9] See Table B-4 of the MYPP. *Bioenergy Technologies Office Multi-Year Program Plan.*

CLIMATE-SIMULATED ALGAE CULTURES

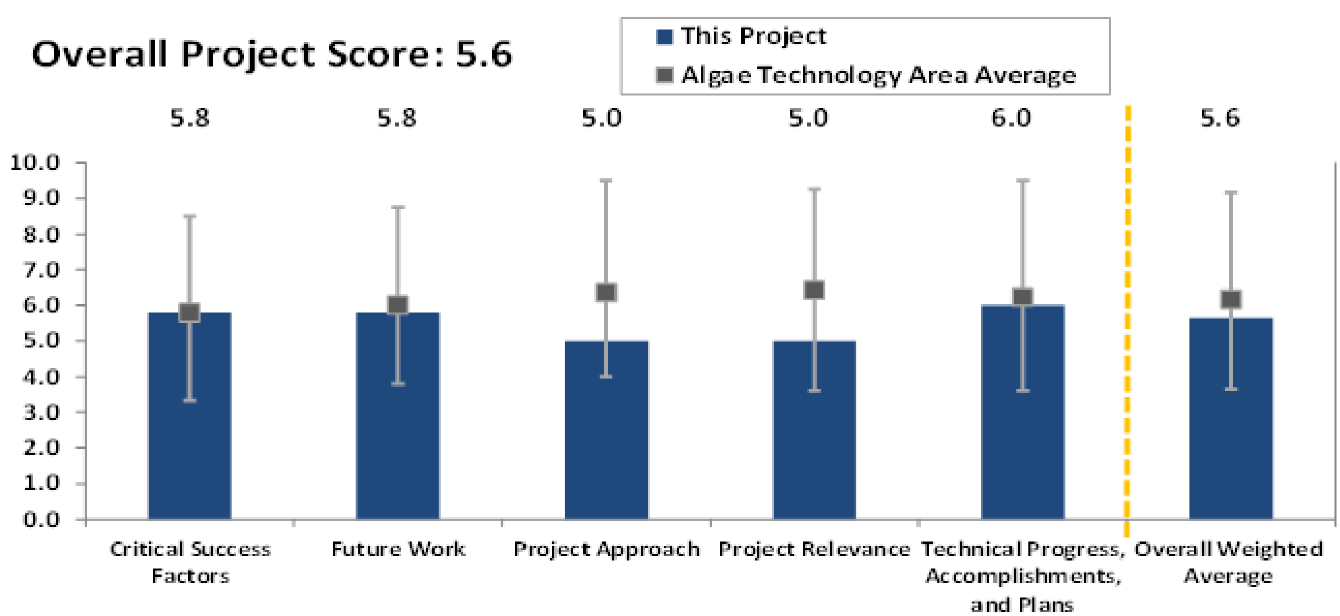
(WBS#: 9.1.2.4)

Recipient:	PNNL
Presenter:	Michael Huesemann
Total DOE Funding:	$200,000
DOE Funding FY13:	$200,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012–2017

Project Description

Photo Courtesy of PNNL

Our goal is to develop and validate an efficient method for optimizing annual productivities by identifying the most suitable geographic/climatic region for open pond culturing of a selected, promising microalgae. Using both the *Picochlorum sp*. wild type and lipid hyperaccumulating strain isolated via fluorescence-assisted cell sorting by the Los Alamos National Laboratory (LANL) as an example case, we measured the biomass light absorption coefficient and characterized their responses, in terms of specific growth rate and photosynthetic oxygen evolution, to temperature and light. We have integrated PNNL's microalgae biomass growth model with PNNL's Biomass Assessment Tool (BAT) and input the above-mentioned species-specific parameters for both wild type and lipid-hyperaccumulator to identify geographic/climatic regions where biomass productivity in open pond culture is optimal. It was found that optimal annual productivity would be achieved in outdoor pond cultures located in southern Florida. The optimal culture depth and dilution rate was determined to be 15 centimeters (cm) and 0.25 day-1. Unfortunately, even under these optimal culture conditions, the model-predicted annual productivity for the wild type was only about 3.9 g/m^2 per day and even less for the lipid-hyperaccumulator strain (i.e., significantly below DOE targets). In order to



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

confirm model predictions, we will measure the biomass productivity of both strains in LED-lighted and temperature-controlled raceways under conditions that simulate the daily and seasonal water temperature and light intensity fluctuations in open ponds at the optimal southern Florida location. The light and water temperature scripts needed to operate the climate-simulation ponds will be provided by PNNL's BAT. This methodology can be applied to determine the maximum annual productivity potential of any promising microalgae strain. Furthermore, the generated strain-specific productivity data can be used as input to the various TEA models being developed by BETO that are crucially dependent on accurate biomass productivity data.

Overall Impressions

- It is likely that different strains will be used throughout the year based on the climate. This project has done an excellent job of developing and validating climate-controlled raceway, as well as collecting the needed climate data for programming the system. The result is a valuable tool for mapping strain productivity versus climate and for developing strain variants applicable to either a broader climate range or a shifted climate range. The use of the tool should be expanded to cover as many high-productivity strains as organizations are willing to supply to the project. The subtasks on BAT development and preparation of productivity maps are interesting, but they do not address key challenges for development of commercial algae biofuels. Therefore, further work is not needed in this area.
- It's time to move out of the lab and into the field. This project should utilize its funding in areas where testbeds do not currently exist. There seems to be potential to collaborate with oceanographic institutions (e.g., Rosenstiel School of Marine and Atmospheric Science) located in areas where the model predicts success, as well as in areas where it does not (e.g., University of Minnesota, University of Chicago/Marine Biological Laboratories).
- The biomass growth model discussed is a unique part of this project because it predicts conditions associated with a specific geographic location for optimal growth. It is not clear from the results presented that the model is fully validated/optimized. There is a need to ensure that the model is validated against pond culture tests for more than one algae species to get the best value.
- The development of a simulation tool for predicting productivity potential of strains has value. A more rigorous plan for validation of the model appears to be needed, starting with strains that have a history of outdoor cultivation and cover a range of productivities, then collecting input data for the model using these strains in the ePBR, and then modeling performance and checking the model results against production data. To have confidence in the model, this needs to be a big effort—multiple strains by multiple locations with replications sufficient to provide statistical power. The gap of not considering abiotic stresses or synergistic consortia will significantly reduce the value of the model. There is a significant risk that the model will provide misleading results. The model should be constrained to include only dilution rates that are commercially viable. Model results indicate an optimum pond depth of 15 cm and a dilution rate of 0.25 day-1 with algae that grows at an average rate of 3.9 g/m^2-day. This gives an average steady state algae concentration of only 0.1 g/l, which is not practical and far below the harmonized TEA model value of 0.5 g/l.

PI Response to Reviewer Comments

- Thank you for the thoughtful comments and review. It has always been our intent to gain additional validation using multiple strains and to test more promising high productivity strains in several outdoor testbed locations across the country, ideally involving collaborations with other institutions. We are excited that these tasks will be part of a new regional algal feedstock testbed project that is led by the University of Arizona. In this collaboration we will validate the biomass growth model with two to four more strains using cultivation data collected at three outdoor testbed locations at Texas A&M University, New Mexico State University, and University of Arizona. We will also validate the climate-simulated culturing concept using the LED-lighted and temperature controlled ponds and will continue to identify additional university and industrial collaborators.
- Regarding the modeling of abiotic stresses (e.g., nutrient limitation of lipid induction) or synergistic consortia (e.g., polycultures), we have already initiated research in this field to further increase the value of the biomass growth model.
- Certainly the model should be constrained to include only dilution rates that are commercially viable. In future modeling runs, we will operate the model at a dilution rate that will result in more practical steady-state concentrations of around 0.5 g/l.
- Finally, we consider the biomass productivity maps (via BAT) to be critical for identifying the optimum pond locations in order to determine the maximum achievable biomass productivity of a given strain and also to generate the light and temperature scripts for climate-simulated culturing. Knowledge of the maximum achievable productivity is essential for the development of commercial algae biofuels, as indicated by the keen interest of industrial partners in the BAT.
- Again, thank you for the useful comments.

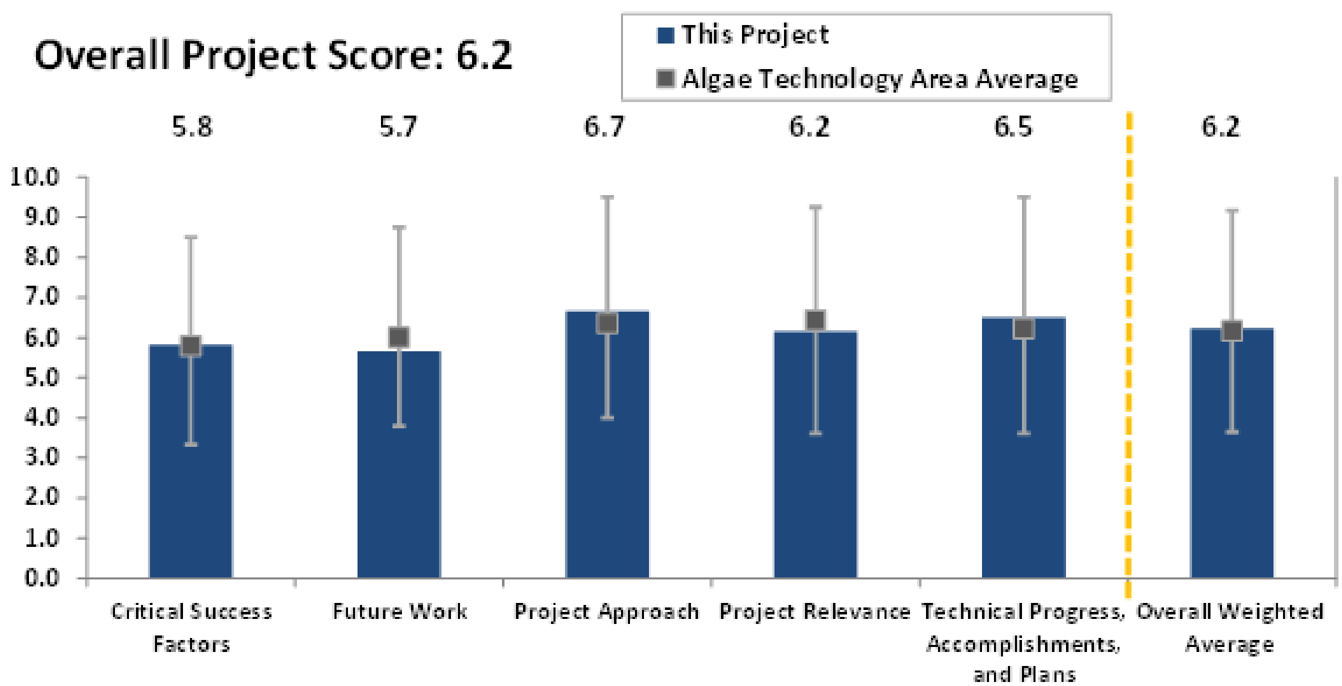
COLLABORATIVE: ALGAE-BASED BIOFUELS INTEGRATED ASSESSMENT FRAMEWORK DEVELOPMENT, EVALUATION, AND DEMONSTRATION (INL)

Recipient:	INL
Presenter:	Jared Abodeely
Total DOE Funding:	$704,000
DOE Funding FY13:	--
DOE Funding FY12:	$352,000
DOE Funding FY11:	$352,000
Project Dates:	2010–2013

(WBS#: 9.1.3.1)

Project Description

Algal resources have been identified as a potential feedstock for meeting the advanced fuel goal of five billion gallons per year established in the Energy Independence and Security Act of 2007. However, numerous challenges exist for making liquid transportation fuels from algae economically feasible. Addressing current challenges associated with algal production systems requires the ability to assess spatial and temporal variability, quickly evaluate alternative algal production system designs, and perform large-scale assessments considering multiple scenarios for thousands of potential sites. The flexible nature of the Algae Logistics Model (ALM) architecture allows the model to interface with a broad range of biomass production and resource assessment models and datasets, interchange processes to enable assessment of current and innovative technologies, and efficiently run multiple scenarios at thousands of locations to assess spatial and temporal impacts on costs. ALM was then coupled with the BAT, a production and resource assessment tool developed by PNNL, within the Integrated Assessment Framework (IAF). IAF is a joint effort between PNNL and INL that utilizes modularity and spatiotemporal granularity to enable investigation of the impacts on cost considering, siting, scaling, technologies, and operating assumptions. Upon crosswalking IAF with the DOE harmonized algal production system design, assessments were performed to investigate the



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

impacts of technologies and operating assumptions on scaling the algal production system and the cost of producing biodiesel. Results showed that there is the potential for reducing costs if the system is scaled appropriately for the sites' productivity potential. Out-year improvements to the IAF include expanding the portfolio of technologies, incorporating additional biofuel pathways, investigating hybrid pathways, incorporating economies of scale to improve accuracy of farm scaling analyses and costs, and integrating additional feedback loops between ALM and BAT.

Overall Impressions

- Both the ALM and IAF models developed in this project represent powerful tools for predicting fuel/product amounts and costs as a function of various process inputs and geographic resource data. The results presented verify the value of this effort. Inclusion of CAPEX and OPEX predictive ability, which is missing from other models, is an important addition. While collaboration with PNNL was necessary to create the IAF model, it is not clear what work in subsequent use of the IAF model was the responsibility of PNNL staff and of INL staff. Without a clear delineation of each laboratory's tasks in using the IAF model, it is hard not to believe that there is some duplication of efforts. The work associated with development and use of the IAF model probably should have been part of one funded collaborative project, as opposed to two separate projects.
- If we succeed, what does the techno-economic deployment of the BAT model look like? The model should work on validation. Land water CO_2 availability for half-ton hectare per day is good to examine. Refineries are big emitters, more pure than flue gas. If land is underutilized, it will be available for renewable energy use. Operational tools, impact of CO_2 to model. Cost of CO_2 is higher use. HTL, AD, and co-products. Robust model, each process step cost/benefit needs to be determined. Rainfall needs to be accounted for. Concept of exceedence needs better explanation.
- The integrated assessment of land, water, and nutrient availability and the effects of geography on productivity is necessary prior to large-scale deployment of algal biofuels. One concern is that the model is far ahead of the state of technology development, resulting in the lack of meaningful parameters for model inputs. Model outputs could vary by nearly an order of magnitude depending on technological developments to enable algal biofuel viability, while modeling current state of technology produces misleading results because the modeled scenario will never happen. The sensitivity analysis illustrates the key point that algal productivity and yield combined will need to increase by about five-fold for algal biofuels to be viable. Model results should always be interpreted in this context. The assessment can continue to expand in complexity, but the real challenge is to determine when additional complexity brings value. It appears that a relatively simple model can be used to determine that resources are available for significant initial deployment of algal biofuels, and the best locations are in a few specified geographies. Premature dissemination of misleading conclusions based on non-viable scenarios appears to be a risk.
- The TEA modeling effort is central to achieving the goal of $3/gal algae oil, and the effort by this project has been tremendous. This TEA approach is particularly beneficial because of the modular approach. As with other modeling efforts, there is a need to extend the TEA to include the two most common approaches to algae biofuels—lipid extraction and protein meal co-product and hydrothermal liquefaction. Also, there is a need to utilize the model more for driving the research and development efforts. The PI should report model results for costs in

terms of $/MT algae biomass/year and $/MT algae biomass, and then look at products routes (HTL, ALU/AD, ALU/protein meal co-product) to obtain product value for component in $/MT and as a composite $/MT based on the component fractions. This would provide more clarity for researchers, as well as DOE decision makers.

- This project was well-designed and well-executed.

Response to Reviewer Comments

- The project was submitted to the 2010 lab call as a single collaborative project. Funds were delivered to each laboratory independently, but there was extensive coordination between efforts as the development of IAF required integration and expansion of the ALM (developed at INL) with the BAT (developed at PNNL) to provide the full functionality provided by the IAF. Exceedence refers to a probability over a 30 year period of exceeding certain productivity at a certain site using a certain strain. The concept of exceedence is key to appropriate scaling of downstream processing to help reduce costs. We agree that additional work is needed to investigate designs and sensitivities that would help reach the BETO goal of $3/gal algal oil. The IAF provides the framework to enable these types of analyses on a site-by-site basis. The modularity and fidelity that the IAF can assess algal production systems enables detailed assessments of CAPEX and OPEX per technology. We recognize that HTL and LE + co-products needs to be included in the model and that these pathways currently have the greatest potential for reaching BETO cost goals. The modeling methodology used enables these items to be quickly inserted given we had the design characteristics for HTL and performed a market analysis for algal co-products. Unfortunately, due to limited time and funding, we were not able to explore many alternatives beyond the baseline algal production system design.

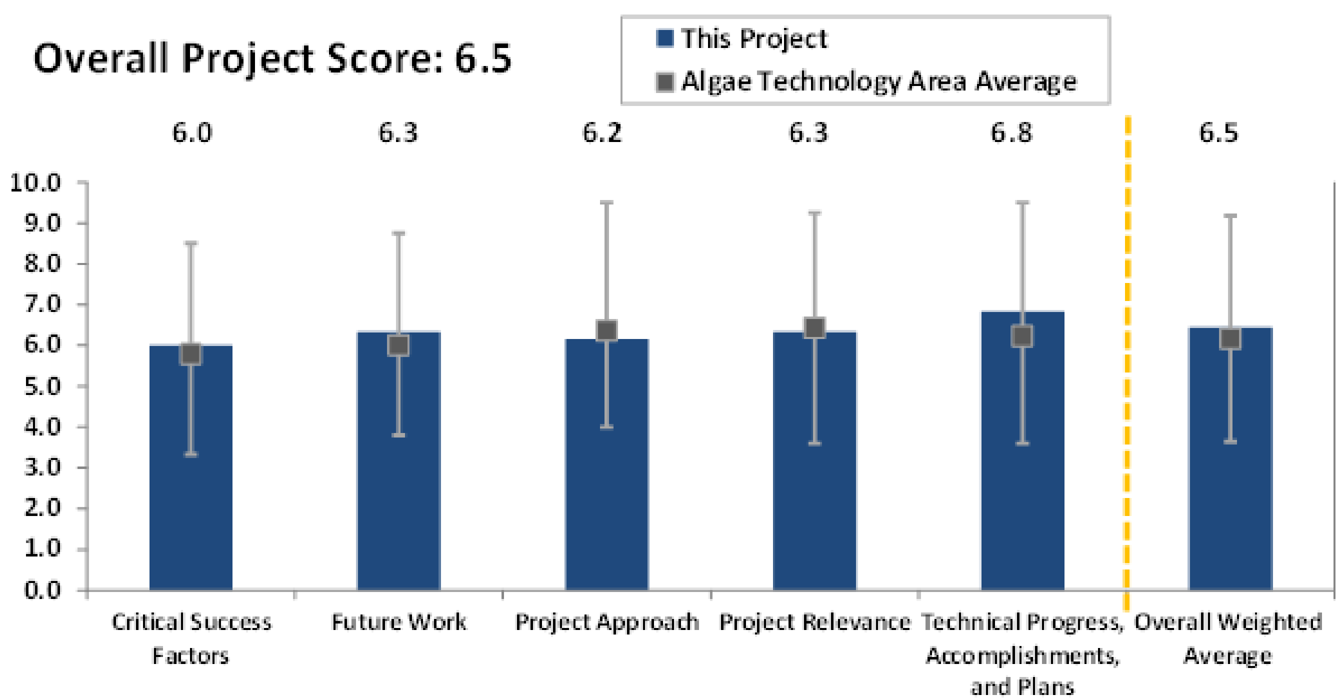
COLLABORATIVE: ALGAE-BASED BIOFUELS INTEGRATED ASSESSMENT FRAMEWORK DEVELOPMENT, EVALUATION, AND DEMONSTRATION (PNNL)

Recipient:	PNNL
Presenter:	Richard Skaggs
Total DOE Funding:	$700,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$500,000
Project Dates:	2010–2013

(WBS#: 9.6.1.6)

Project Description

The objective of the IAF is to serve as an analytical platform, enabling comprehensive assessments of U.S. regional/national algae production capabilities, resource requirements, and required feedstock logistics and infrastructure. The resource assessment capabilities of the IAF include potential locations for microalgae feedstock production, resource demands (water, CO_2, nutrients), economics associated with acquiring and delivering required resources, and biomass/lipid production rates at each identified production site. The production site logistics and costing within the IAF include development of a baseline production system design for moving algae biomass into current biomass feedstock supply systems. Analyses of the design are performed to determine current costs, as well as to identify potential for reducing these costs (e.g., system performance). Specifically, interdependencies between algal feedstock productivity and downstream processing scale and costs are assessed. In addition, the BAT capabilities were expanded to address two key challenges to algal biofuel production—evaluating the impact of nutrient resources availability and evaluating available land and its suitability.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Excellent work adding land cost database, nutrient and CO_2 databases, HTL analyses, and IAF functionality. Initial runs were important at first to provide a sense of where the optimum locations are situated. Continued work to refine or improve these analyses is not worthwhile because it is based on a low-yield, uneconomical process that is not representative of a realistic algae biofuel industry. To get a realistic assessment of the resource utilization and biofuel production potential, the techno-economic model needs to be modified to include scenarios that are economical. Then the analyses would be representative of an algae industry that could actually exist someday, rather than one that's so inefficient and costly that it would never be built. Additionally, the model is not applicable to lipid extraction with protein meal co-product, which is a common path for many industrial efforts. The excellent analytical capabilities that DOE has developed for algae biofuels should be redirected to expanding the TEA to include a model for lipid extraction with co-product sale as a protein ingredient or polymer feedstock so there is a model for both of the principal routes currently being investigated—especially since there are more organizations pursing protein-based co-products than HTL. It should also be redirected to the development of a set of economical scenarios for the two main routes currently being pursued (HTL and lipid extraction with protein co-product) to provide a basis for research targets and for BAT runs that provide a realistic assessment of the potential contribution and resource utilization of a commercial algae biofuels industry.
- The integrated assessment of land, water, and nutrient availability, as well as the effects of geography on productivity, is necessary prior to large-scale deployment of algal biofuels. One concern is that the model is far ahead of the state of technology development, resulting in the lack of meaningful parameters for model inputs. Model outputs could vary by nearly an order of magnitude depending on technological developments to enable algal biofuel viability, while modeling current state of technology could produce misleading results because the modeled scenario will never happen. The assessment can continue to expand in complexity, but the real challenge is to determine when additional complexity brings value. It appears that a relatively simple model can be used to determine that resources are available for significant initial deployment of algal biofuels, and the best locations are in a few specified geographies. Premature dissemination of misleading conclusions based on non-viable scenarios appears to be a risk.
- This project includes several aspects that have already been cited as missing from the BAT model in the earlier presentation by Wigmosta et al., such as CO_2 availability and nutrient resource availability. In this respect, the project is valuable in making an existing model more applicable, with interesting results obtained so far. This is further enhanced by incorporation of the ALM model capabilities. It appears that the combined and upgraded IAF model supersedes the BAT model, and it seems as though the work by Wigmosta et al. and that of this project would have been more efficient and cost effective if combined into one project. As it stands now, it looks as though two projects are working on refinement of the same model.
- This project synergized many partners' modeling contributions, particularly in terms of locating and deploying resources.

PI Response to Reviewer Comments:

- The IAF does not supersede the BAT—this project leveraged existing capabilities of the BAT, added specific capabilities to the BAT related to land valuation and nutrient demand, and integrated the BAT with the ALM to create the IAF. Multiple projects internal and external to PNNL have made use of the BAT, and we view the BAT as a common analysis platform that avoids duplication of effort and provides the ability to link with other developed models, such as the ALM, thus providing synergy and effective use of available resources. Regarding increasing complexity, our development approach has been to "right-size" the model to address a particular question considering available data. Before adding complexity, we conduct an analysis to assess the magnitude of the problem, and if appropriate, we develop and execute an appropriate approach.

- The $20/gal harmonized scenario evaluated by this project provides a baseline that represents a currently plausible production scenario. Further, given the preliminary nature of algal biofuels technologies development, meaningful model parameters for representative technologies within the IAF are limited. Nonetheless, there is considerable value to DOE and industry in having a realistic evaluation of the resource assessment questions and tradeoffs given current and emerging technology, including the following:
    - Where, regionally and nationally, does resource availability (e.g., land, water, nutrients, infrastructure, etc.) pose a threat to sustainable, economic algal biofuel production at target levels?
    - Are there aspects to specific technology pathways that make them vulnerable to particular resource availability constraints?
    - In creating technology development and improvement strategies to assure a sustainable algal biofuels industry, are there particular technology-specific characteristics and associated resource use efficiencies that should be emphasized or avoided?
- In this way, the IAF provides a valuable numerical testbed to identify, evaluate, and guide targeted research to improve the economic viability of algal biofuel production.

CONSORTIUM FOR ALGAL BIOFUELS COMMERCIALIZATION

(WBS#: 9.5.1.6)

Recipient:	CAB-Comm; UCSD
Presenter:	Stephen Mayfield
Total DOE Funding:	$9,000,000
DOE Funding FY13:	$3,000,000
DOE Funding FY12:	$3,000,000
DOE Funding FY11:	$3,000,000
Project Dates:	2011–2014

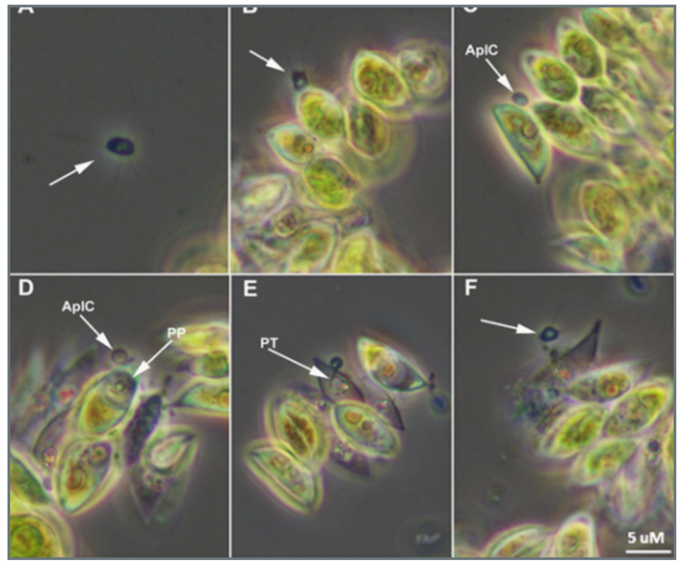
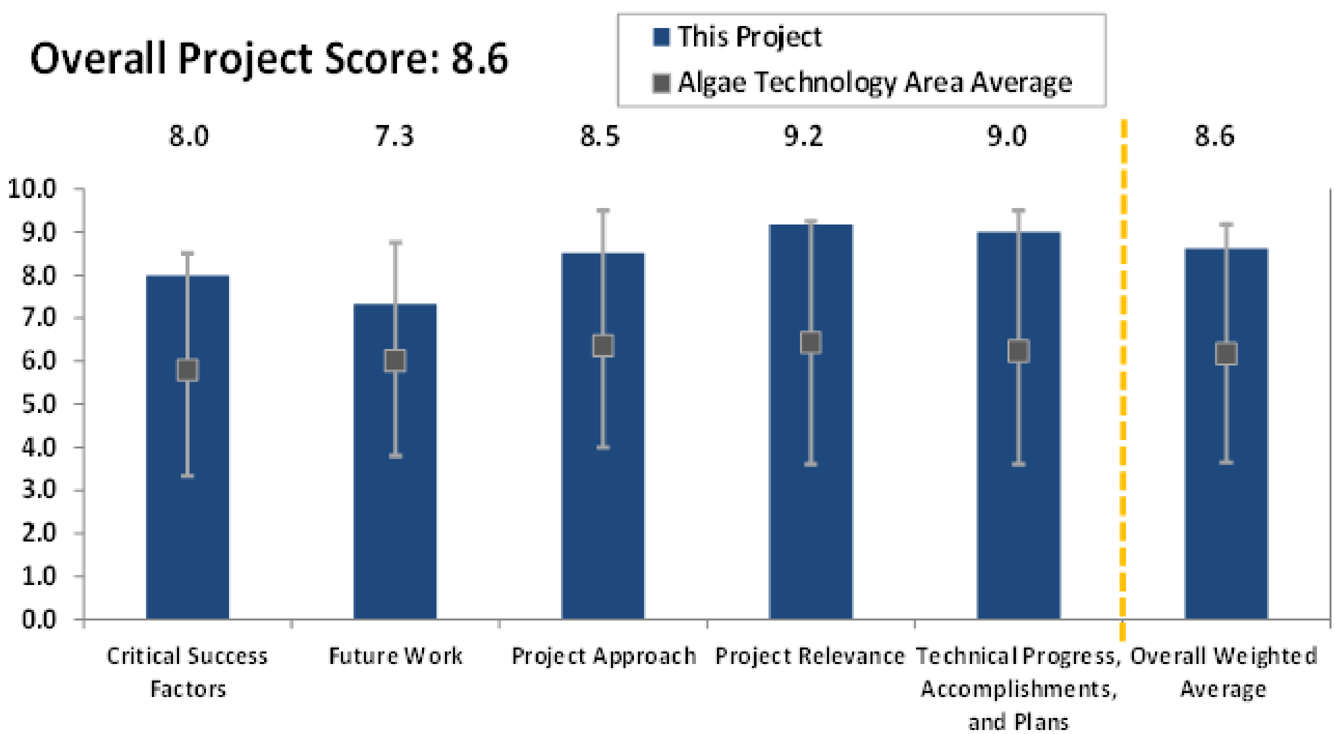


Photo Courtesy of CAB-Comm; UCSD

Project Description

Over the last two years, CAB-Comm has addressed three of the most significant challenges facing the emerging algal biofuels industry. CAB-Comm is composed of 17 academic research laboratories and two commercial partners. The academic laboratories are from the University of California, San Diego; Scripps Institution of Oceanography; University of Nebraska, Lincoln; Rutgers University; and the University of California, Davis. Our commercial cost-share partners are Sapphire Energy and Life Technologies. The three areas of research undertaken are crop protection, nutrient utilization and recycling, and development of genetic tools. Significant progress was made in all 3 research areas, resulting in 40 scientific publications, 6 patent applica-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

tions, and 158 presentations. In crop protection, specific mutations were identified in cyanobacteria that confer grazer resistance, while in green algae, signaling molecules that impart resistance to a key fungal pathogen of a Sapphire production strain were identified. These studies define the new field of algal pathology and show that crop protection will be achievable in algae as it has been in terrestrial crops. In nutrient utilization and recycling, we have been able to demonstrate that the residual nutrients from the Sapphire extraction process can be recycled into algal ponds and have identified key variables in algae for nutrient utilization. In our genetic tools program, we have developed vectors and strains of cyanobacteria and *C. reinhardtii* that are already being provided to the research community through the Life Technologies catalog. Next-generation tools currently being developed will allow for multigene metabolic engineering and high-throughput screening that seems poised to revolutionize algal genetic engineering. Brief descriptions of these breakthroughs will be provided.

Overall Impressions

- Excellent project management and performance. Significantly advanced the state of the art in areas that are important to the development of commercial biofuels. The project presented multiple novel approaches and technology developed in each area and did an exceptional job of technology transfer to make the new genetic tools available to all researchers in the field. Overall, a very successful project that contributes substantially to BETO's goals and objectives.
- The project did a very good job of defining key opportunities to contribute to algal biofuel technology development and pursued these opportunities with logic and science. The project delivered tangible, high-impact results. The project produced gene manipulation tools and made them commercially and publicly available. This will have far-reaching impact on genetic engineering of algae strains for biofuel production. The project yielded strong results in identifying reasons for susceptibility to pests and methods to promote pest resistance. Work on cultivation using consortia of species shows promise. Nitrogen recycle work appears to be in early stages of development but is showing positive results. The keys to success were partnering top flight academic scientists with a commercial partner, identifying high-impact projects, and pursing with logic and science.
- This project developed major breakthroughs in terms of algal species consortia cultivation, crop protection, and genetic kits for future strain research.
- This project appears to have good internal organization and policies and appears to be well run. The work addresses relatively small, but specific and important parts of the algae process. Several significant developments appear to have been made in pest control, genetic modification, and strategies for improving productivity. Specific technical goals and milestones likely exist but were not presented, and no cost information related to developments was presented, so it is difficult to accurately assess the value of the developments presented. Recommendations for future work would help to understand what next steps are necessary. It is unclear in some cases how developments presented will translate to other commercial processes beyond that of Sapphire.

PI Response to Reviewer Comments

- Thank you; we worked very hard on this important area of renewable energy, and we very much appreciate that the review panel recognized our achievements.

CORNELL CONSORTIUM

(WBS#: 9.5.1.4)

Recipient:	Cornell
Presenter:	Mark Huntley
Total DOE Funding:	$9,100,000
DOE Funding FY13:	$9,100,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010–2014

Project Description

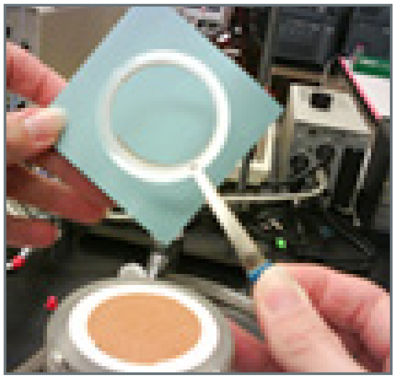
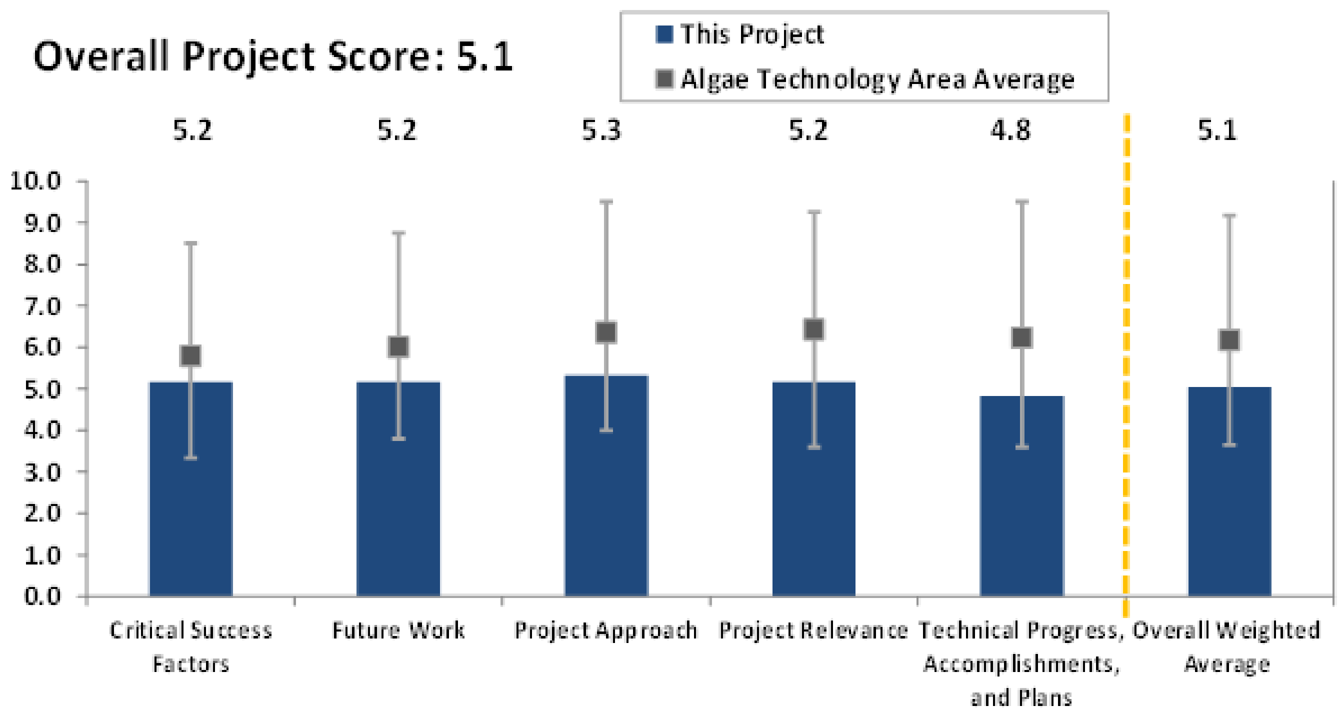


Photo Courtesy of Cornell

This project directly addresses the next two primary objectives of BETO's MYPP for algae feedstocks and supply, namely (by the fourth quarter of 2013) by establishing cost and technical targets for one algae-to-fuel technology pathway, as well as performing a techno-economic analysis for one additional technology pathway—including feasibility and trade-off analysis with co-products. This also includes demonstrating (by the fourth quarter of 2014) productivity of 20 $g/m^2/day$ of AFDW, corresponding to 1,500 gallons per acre per year (gal/acre/yr) biofuel intermediate. Our approach is to develop three fundamentally different technology pathways that all lead to the same end products, and all are evaluated based on actual large-scale performance. Our baseline goal is to demonstrate the ability to produce ton quantities of a purposely selected algae strain in a photobioreactor-pond system, and to process the feedstock to viable extracted oil and co-products by a set of integrated unit operations. Alternate pathways are based on comparable demonstrations. We have developed three fully integrated technology pathways. The baseline pathway is supported by sustained daily production runs (n=100) of the marine diatom *Staurosira*, processed to biofuel and aqua-feed co-products in ton quantities, then tested at scale. Productivity greater than 25 $g/m^2/day$ AFDW results from high nitrogen loading. Biofuel intermediate



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

yield 1,360 gal/acre/yr results from low nitrogen loading. For alternate pathways, non-integrated unit operations have been demonstrated at daily production scale. Commercial viability of co-products is established at pilot scale. Primary success factors are water, yield, and economics. The project was suspended for 21 months (July 2011–May 2013) to transfer prime contractor, but progress has continued steadily. Overall, the project is 50% complete, and delivery of key objectives is expected on schedule, aligned with the MYPP. We have achieved most major milestones. We expect to produce and test two more strains in pre-commercial co-product trials and to complete the design report of comparative integrated pathways by the fourth quarter of 2013.

Overall Impressions

- The project does not appear to be pursuing a process that is scalable to significant algal biofuel production volumes. Capital costs of the hybrid system are too high to be economically viable for fuel production. Energy input is significantly greater than fuel energy produced, with no plan presented to reach acceptable capital costs and favorable energetics. This appears to be a process for high-value lipid production and possible aquaculture and mariculture feed products, with an extremely minor, if any, fuel co-product. There is a relatively small amount of ancillary work around characterization and strain screening that may produce results applicable to biofuel process development. General expertise in algae cultivation and facility availability (ATP3) is relevant to biofuel production.
- The project is on the wrong track and should be redirected before the majority of funding has been committed. The project has already concluded that the process is not economically viable or energy efficient and the team does not have any ideas for how to change this. Also, the only strain being investigated has a maximum lipid production of about 15% with nitrogen limitation, so the protein level will also be low. The project should take advantage of the team's good production capability and strong co-product expertise by selecting strains that are biofuel-relevant (high lipid and high protein), producing enough material for testing with their production system, extracting the lipids, and performing co-product testing to determine the estimated market value of the co-product.
- This project has a singular opportunity to provide the robust validation of algal products and co-products valuation that is missing from BETO's algal biofuels portfolio. Producing robust feed trial data would greatly advance the status of the current TEA model, as well as provide critical information regarding the cost viability of the ALU biofuel pathway.
- This project has been delayed by a hiatus that only recently was lifted. Time will be needed to reestablish connections among consortia members, and it may be difficult to recover from the discontinuity caused by the hiatus. There is concern that the very ambitious objectives (focusing on aspects of the entire algae to fuel process) may not be completed within the remaining period of performance. Some progress had been made before the hiatus, particularly with respect to co-product development. There is concern that the use of two reactor systems for cultivation (bioreactor and ponds) and unproven equipment (e.g., solar drier) will be too expensive; no economic data or models are provided to prove that the proposed process is viable at a commercial size.

PI Response to Reviewer Comments:

- This project is pursuing three technology pathways, all scalable to significant production volumes of biofuel from algae selected for maximum fuel production, all net energy positive, and all economically viable. Two years before this project began, we extensively screened more than 500 novel strains of marine algae, developed a dozen ISO-compliant standard operating procedures (SOPs) for analysis, and harmonized five laboratories. Baseline technology performance has been established by sustained, large-scale, outdoor production—100 daily production batches of the top strain candidate in 2010 generated more than three tons (AFDW) of algae for processing trials of many alternative unit operations at commercial pilot scale. In that first production run, we reached 91% of BETO target fuel production for the fourth quarter of 2014 (1,500 gal/acre/yr), and we exceeded the BETO average productivity goal of 20 g/m^2/day—also 4 years ahead. We produced several tons of a second top candidate strain in 2011 and are completing the analysis of those data. A third strain is now in production. This is the only consortium that has produced ton quantities of several different strains, not only for biofuel production, but also for animal feed co-product evaluation at commercial pilot scale. This project is realizing the singular opportunity to provide a robust evaluation of both algal biofuels and co-products "that is missing from the DOE BETO algal biofuels portfolio," to quote one reviewer. An important and unique contribution of this project is our Design Report—a comparative evaluation by TEA and LCA of three technology pathways, all based on actual large-scale production of the same algal strain, all producing the same products, and deviating only in unit operations that distinguish each pathway. A robust comparison of alternative algae-to-biofuel technology pathways is not possible from the published literature. Our team expects to deliver its first draft of the design report for review by DOE in early 2014.

DEVELOPMENT OF RENEWABLE BIOFUELS TECHNOLOGY BY TRANSCRIPTOMIC ANALYSIS AND METABOLIC ENGINEERING OF DIATOMS

Recipient:	UCSD
Presenter:	Mark Hildebrand
Total DOE Funding:	$224,686
DOE Funding FY13:	--
DOE Funding FY12:	$100,000
DOE Funding FY11:	--
Project Dates:	2009–2013

(WBS#: 9.2.2.2)

Project Description

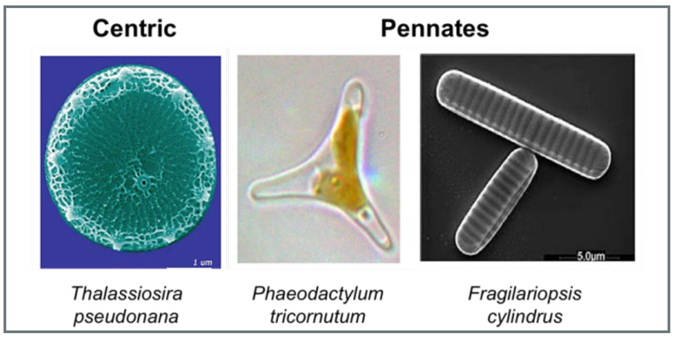
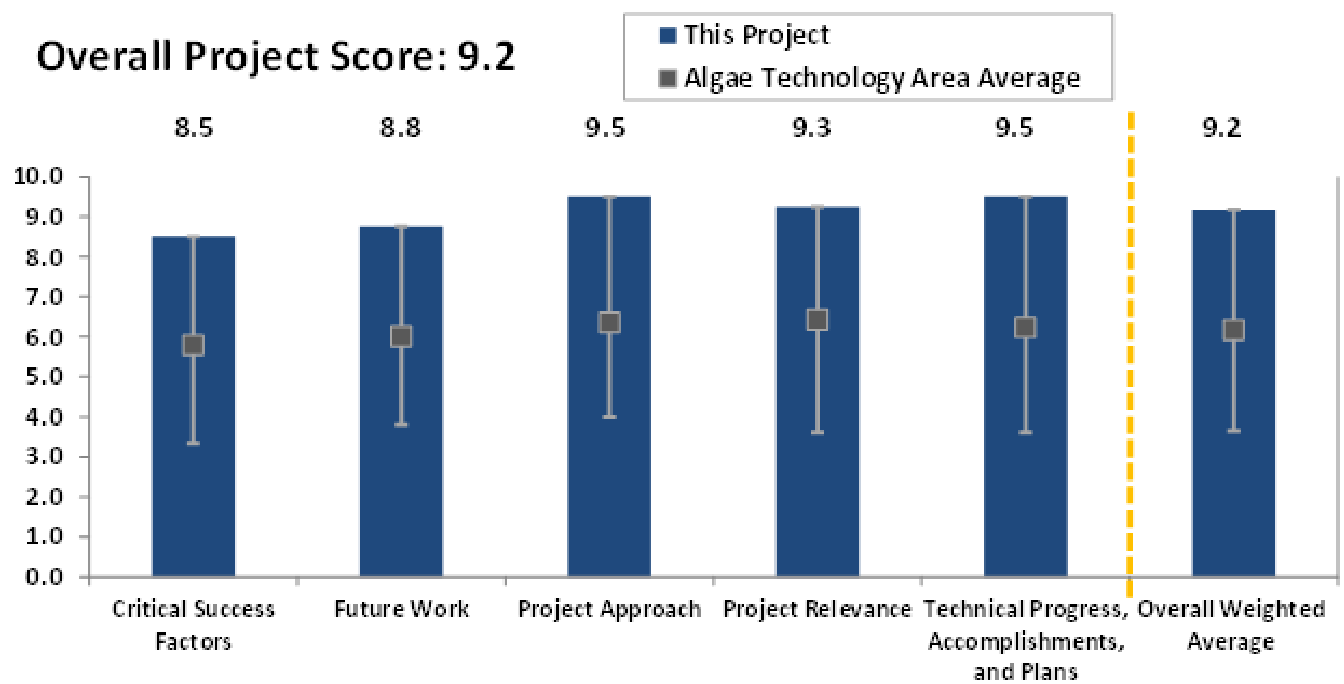


Photo Courtesy of UCSD

The project goal was to develop metabolic engineering approaches for diatoms to improve lipid and TAG accumulation capabilities to increase overall productivity. Specific objectives were to develop a map of carbon flux pathways and identify key regulatory genes controlling carbon flux in diatoms, improve genetic manipulation tools to enable metabolic engineering, and apply metabolic engineering to improve TAG accumulation. Carbon flux pathways were mapped using diatom genome sequences, and results indicated substantial differences in intracellular location of pathway components and highlighted the importance of intercompartmental transport of metabolites. This analysis was expanded into evolutionarily distinct classes of microalgae, indicating that fundamental photosynthetic and metabolic processes substantially differ, precluding generalizations about "algal" metabolism. The genome, methylome, and transcriptome of a model diatom production species, *Cyclotella cryptica*, was determined. A versatile set of genetic manipulation tools was developed, bringing the technology for diatoms on par with other model organisms.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Genetic manipulation approaches were applied with successful increases in TAG levels by reducing carbon flux into storage carbohydrate, increasing the ability to synthesize TAG, or reducing lipid catabolic processes. Improvements ranged from 1.2 to 4.0 fold increases in TAG, and in most cases, without an adverse effect on growth. A native-sequence genetic manipulation approach was developed that avoids genetically modified organism (GMO) classification while enabling a full range of manipulations. In addition to the primary discoveries, novel insights were gained into the following:

- Evolution-based differences in fundamental metabolic processes in microalgae.
- The contribution of compartmentation to intracellular carbon flux and processing.
- The relation between transcriptomic data and changes in cellular metabolic processes.
- The intracellular membrane organization of a secondary endosymbiont.
- The importance of lipid catabolism on overall cellular lipid status.

All objectives were achieved, and approaches were developed to enable their direct application to production systems.

Overall Impressions

- Dr. Hildebrand's delivery of successful results to one of the critical bottlenecks to large-scale algal cultivation, combined with his superior project management skills and efficiency with his budget, make this project one of the standout performances of the current DOE research platform. It would be well worth considering an extension of his funding and integrating his laboratory's strain work within the ongoing ATP3 project.
- The project defined a logical approach for developing a map of carbon flux pathways and identifying key regulatory genes using transcriptomics; improving genetic manipulation tools to enable metabolic engineering using key regulatory genes; then demonstrating improved TAG accumulation characteristics in engineered strains. Given the budget and timeline, the project significantly exceeded expectations, finding that fundamental photosynthetic and metabolic processes substantially vary in different algal classes, correlating physiological changes to changes in gene expression, and demonstrating three genetic manipulations that lead to higher tag accumulation and one manipulation that leads to faster growth. Step change improvements on the order of 400% are needed in algae fuel productivity to enable commercially viable fuel production. This project is a tantalizing example of the potential for genetic engineering to strongly contribute to productivity increases. The approach of using native sequences to engineer organisms might be enabling for initial deployment of this technology. Future work recommendations for continuing to identify gene manipulations to improve fuel productivity and to stack traits should be supported.
- This project appears to be well-managed with straightforward goals and metrics to which significant results were achieved. The techniques developed to increase lipid content appear to be successful, but they need to be verified in a commercial setting as a next step. The ability developed to perform genetic manipulation through native, sequence-based engineering is a significant development in being able to get the benefits of gene manipulation without the restrictions of the GMO label.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

DEVELOPMENT OF VALUE-ADDED PRODUCTS FROM RESIDUAL ALGAE TO BIOMASS

(WBS#: 7.9.5.1)

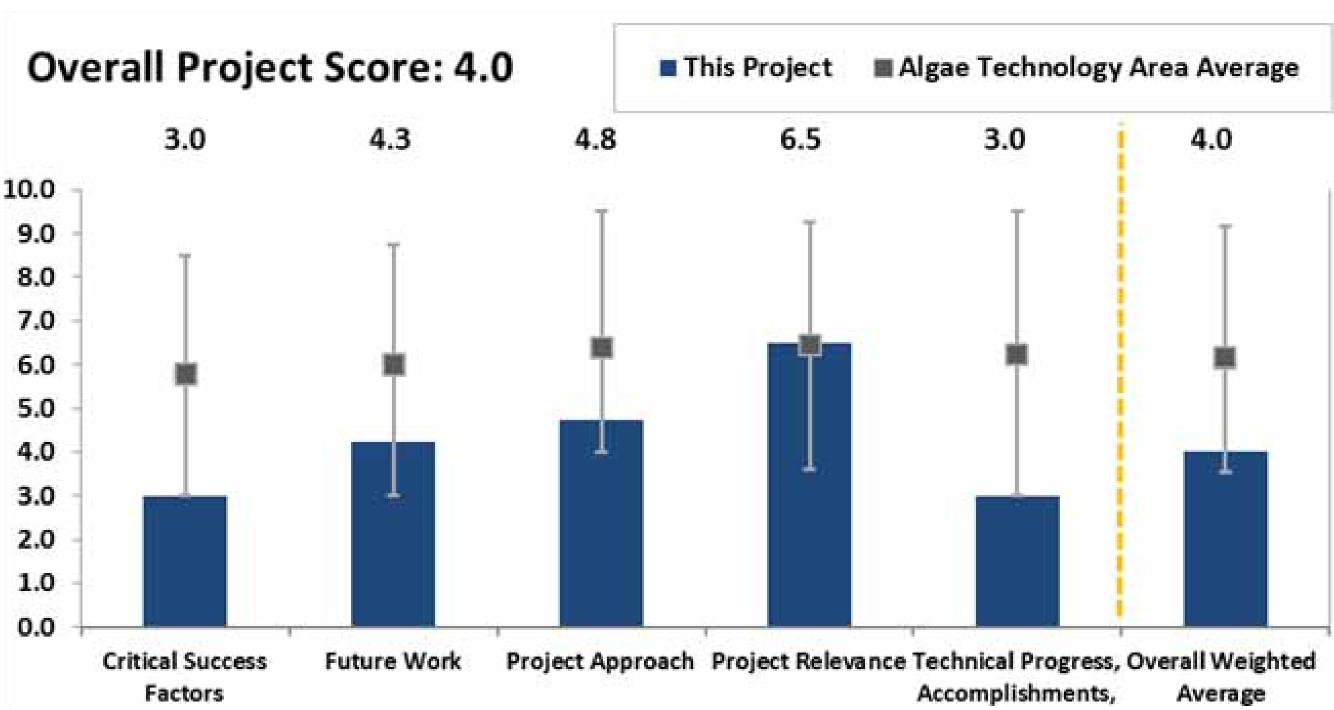
Recipient:	Sapphire Energy
Presenter:	Craig Behnke
Total DOE Funding:	$950,000
DOE Funding FY13:	$180,000
DOE Funding FY12:	$640,000
DOE Funding FY11:	$380,000
Project Dates:	2011–2013

Project Description

The project seeks to develop opportunities for market penetration of algae biomass for the purpose of making biofuel. In any algal biofuel production process, particularly in temperate climates such as the United States, biomass productivity will have seasonal variation, while the fuel production system will have a fixed capacity. By providing an economical outlet for excess biomass so that the fuel production facility is fully utilized but not oversized, animal feed products can improve the overall economics of a biofuel production facility. A potential target market for excess biomass or defatted biomass is animal feed—poultry, swine, and cattle. Initial feeding studies have been completed in poultry and ruminants, and the results of these initial studies are presented.

Overall Impressions:

- A flawed approach prevented the project from attaining the primary objective of determining the value of defatted biomass as an animal feed ingredient. Some good feeding trial data were generated, but it has limited value to BETO or industry because there is no information on the algae strain, cultivation conditions, or post-cultivation processing methods (e.g., harvesting, extraction, and drying).
- At this point in the development of algae biofuels, unknowns about strain selection, cultivation, and harvest process produce a lot of uncertainty about potential co-products, so feeding studies were



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

appropriately limited to feasibility demonstration. One justification for the project was to determine if excess algae production during peak productivity periods could be used as animal feed. This would require installation of dryers and bulk solids handling equipment and larger harvest capacity that would only be used during the period of excess production. Preliminary economic analysis should be presented to determine if the installation of this additional capital can provide necessary returns. Demonstration of the probable feasibility of using three strains of whole algae and one strain of LEA as animal feed helps validate and evaluate process options and pathways.

- The task of finding ways to recover value from excess algae and defatted algae is critical to improving the economics of the overall algae conversion process. This project addresses this concern, but not all data/results were presented. Also, it appears that more could have been accomplished with respect to addressing stated goals with time allotted in this project.
- This project had its heart in the right place, but it did not deliver substantive value for the taxpayers' funding as presented in this forum. This project had great potential as defined, and now in its final report to DOE, there is an opportunity for Sapphire to present what was achieved with the nearly $1 million they received in U.S. congressional funding. As conceived, this project is critically necessary to validating the ALU pathway, and DOE should continue to fund these types of projects—with the caveat that the defined, quantitative metrics expected in the final report be communicated to the funding recipient and that the recipients demonstrate progress toward these quantitative results in order to receive full funding.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

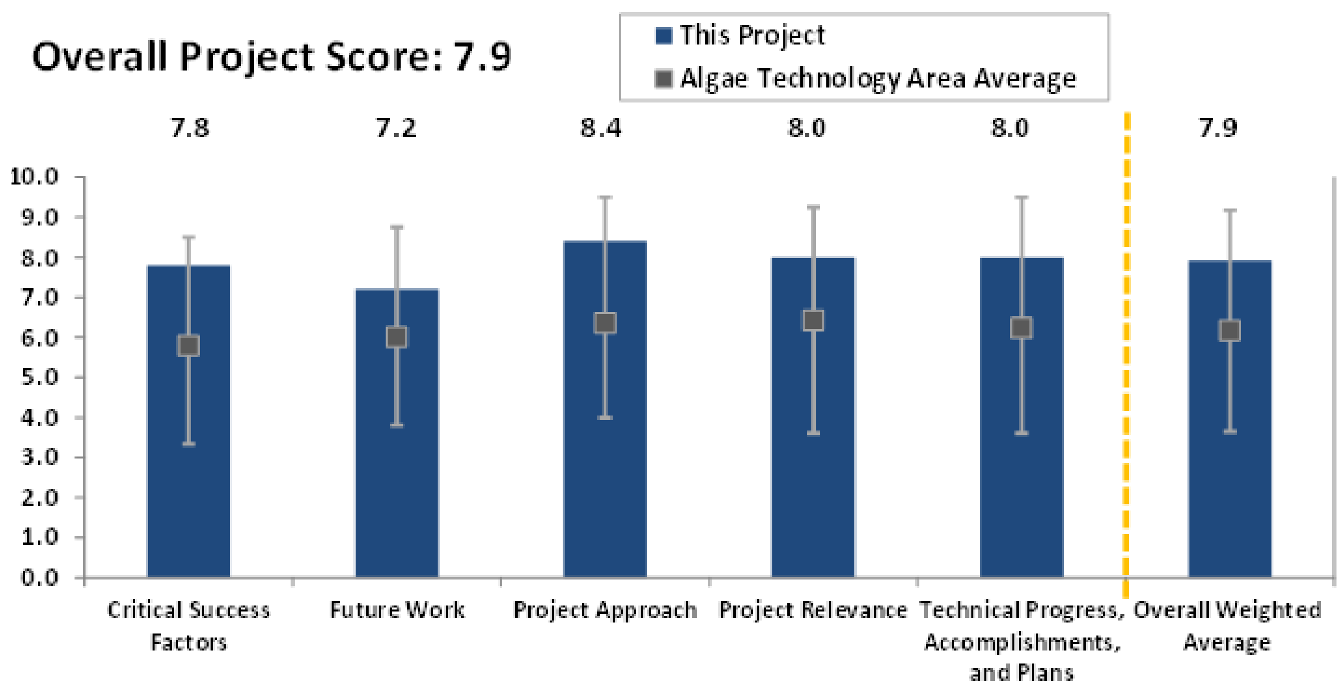
EFFICIENT USE OF ALGAL BIOMASS RESIDUES FOR BIOPOWER PRODUCTION WITH NUTRIENT RECYCLE

(WBS#: 9.2.2.3)

Recipient:	NREL
Presenter:	Eric Jarvis
Total DOE Funding:	$900,000
DOE Funding FY13:	$234,000
DOE Funding FY12:	$447,000
DOE Funding FY11:	$219,000
Project Dates:	2010–2013

Project Description

The economic viability of algal biofuels requires extracting value from the entire algal feedstock, not just the lipid fraction. Lipid-extracted microalgae contain large amounts of fixed carbon and energy, plus most of the inorganic nutrients—nitrogen (N) and phosphorous (P)—that were used to grow the algae. AD is a promising avenue for conversion of extracted microalgae into biogas/biopower and a nutrient-rich effluent that could potentially be recycled to algal growth systems. This approach has been widely assumed in process modeling, and removal of the AD component in NREL's techno-economic models results in a very significant (20%) increase in the fuel selling price. However, there has been relatively little research done to support the concept under process-relevant conditions. The purpose of this project is to answer specific questions regarding yields, loading rates, retention times, inhibitors, and nutrient recycle. We have demonstrated good biogas yields from five disparate microalgal feedstocks—both for extracted and non-extracted materials—and successfully scaled-up to multi-liter digesters for the industrially relevant strain *Nannochloropsis salina*. The specific results from these digestions generally support the modeling assumptions, and the anticipated issues (e.g., ammonia toxicity, C/N ratios, and cell wall recalcitrance) either were not encountered, or they were overcome through careful optimization. We have also demonstrated that algal AD effluent can serve as a superior nitrogen source for re-growth of the original strain. Publication of these results will provide important data to the algal biofuels



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

industry and help to provide confidence around the feasibility of this process component.

Overall Impressions

- The project was well-structured to address key issues around AD and nutrient recycle in the baseline pathway. The project stated clear goals and met the criteria, successfully demonstrating AD of LEA from several species. The project did not present results for phosphorus recycle. Although it was a late development, extending the project to include AD of algae residual from the HTL process would have been valuable. More detailed analysis and presentation of CAPEX, OPEX, and economic value of heat, power, and nutrient recycle is necessary to compare this process to other alternatives.
- This project is important because it addresses a pressing need of how to acquire more value out of process waste (e.g., defatted algae). Results look very promising, although the lack of complete recovering of phosphorus is of concern. Understanding economic tradeoffs between recycle of nitrogen in algae growth versus its value in AD sludge is critical and requires a completed mass balance.
- This project was well-defined, well-planned, and well-run. It used relevant industrial strains obtained from outdoor growing conditions, demonstrated its techno-economic viability, and achieved its objectives.
- This was a very well-planned and executed project. The results are useful for the baseline techno-economic model and life-cycle analyses, and they provide a solid foundation to evaluate algal biofuel process flow sheets that include AD with nutrient recycle. The research confirmed that greater value can be obtained for the co-product algae meal through alternative routes, so AD is unlikely to have a major role in an economical algae biofuel process. Therefore, no additional work should be conducted on AD because it is not a key technology area for accelerating the development of a commercial algae biofuels industry.

PI Response to Reviewer Comment

We appreciate the positive tone of the reviewers' comments, but we would like to follow up on the following points:

- Priority was placed on nitrogen rather than phosphorus because of its greater effect on the techno-economics, life cycle accounting, and the fact that much of the P is entrained in the solids fraction and is therefore more difficult to recycle. However, we recognize that global phosphorus availability is of significant concern, affecting sustainability of the overall process, and is worthy of further study. Note, however, that even if phosphorus cannot be recycled for algal growth, land application of the sludge could provide P for crop plants, thus displacing agricultural P requirements.
- Regarding the request for more detailed analysis of CAPEX, OPEX, and economic value of heat, power, and nutrient recycle, much of this information is contained within the model and more detail was provided in the final report.
- Regarding studies on AD of HTL residues, interest in this area is relatively recent and outside of the scope of this project. This would definitely be an interesting topic for future work.
- More detail around the nutrient mass balances and further discussion on the economics relative to other co-product options was presented in the final report.
- One reviewer stated that AD is unlikely to have a major role in an economical algae biofuel process and that AD is of lower value than other uses for the co-product. This may well be the case. However, this work has helped to fill in data gaps around the AD component to allow meaningful quantitation for such comparisons. The project has also helped to validate the TEA and LCA harmonization models, which is an important step to reduce uncertainty around the benchmark process that can later be optimized as other process options become available.

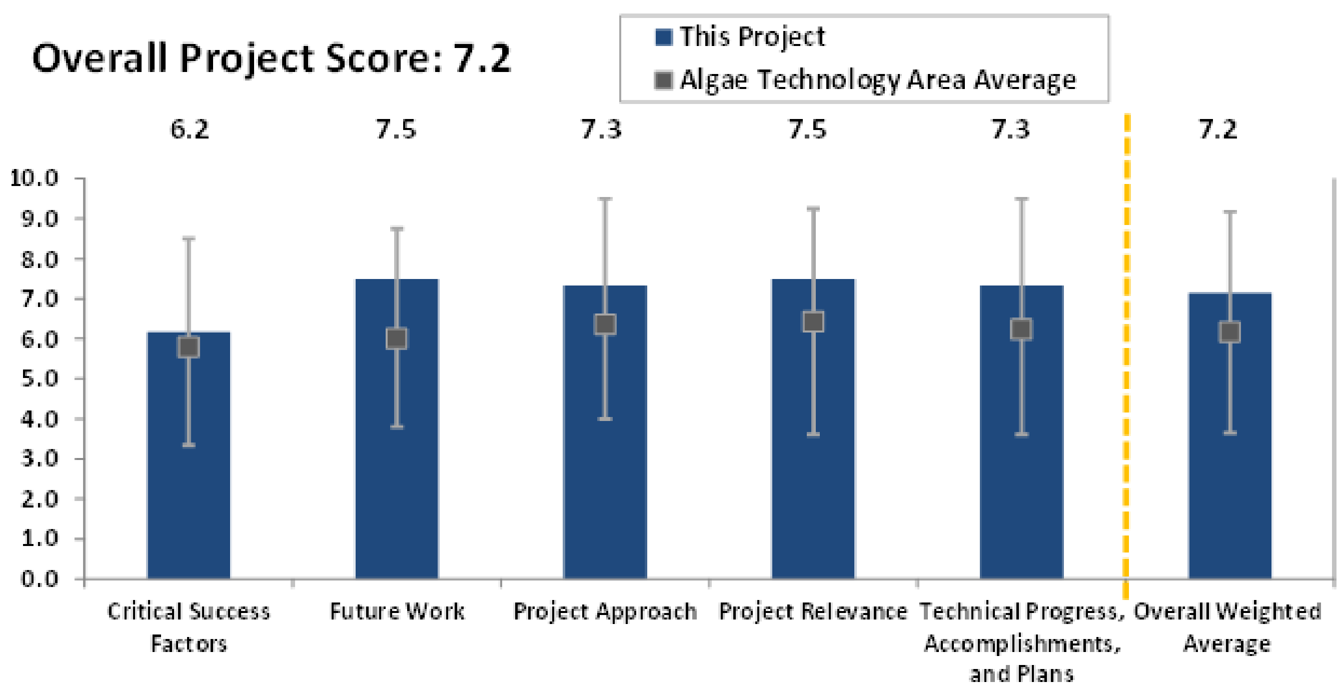
GREET FOR ALGAE LIFE-CYCLE ANALYSIS

(WBS#: 9.6.5.2)

Recipient:	ANL
Presenter:	Edward Frank
Total DOE Funding:	$1,300,000
DOE Funding FY13:	$375,000
DOE Funding FY12:	$400,000
DOE Funding FY11:	--
Project Dates:	2009–2050

Project Description

BETO's MYPP requires evaluation of algal biofuel sustainability and requires comparison with other fuels. LCA addresses sustainability in terms of GHG emissions, petroleum displacement, and criteria pollutants. Project 9.6.5.2, GREET for Algae Life-Cycle Analysis, seeks to determine the reduction in GHG emissions, petroleum use, and fossil energy consumption when algal biofuels replace petroleum fuels. The project also seeks to support program decision making by providing quantitative metrics for system performance. In this project, we extended the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) LCA tool to include algal fuel pathways and applied the resulting tool to defining and studying the core BETO algae pathways. One portion of the project worked in conjunction with techno-economic (NREL) and resource assessment (PNNL) modeling to provide BETO with a harmonized analysis of cost, scale-up potential, and emissions. To date, the project has produced all promised deliverables, has peer reviewed journal articles, and has advanced algae LCA by describing the key variables affecting algal fuels when produced by lipid extraction and hydrothermal liquefaction pathways. The project has reached the point where it can influence pathway design and experimental work. Since GREET includes many biofuel and fossil fuel pathways, the project allows systematic comparison of algal fuels with many other fuels, all using consistent methodology. Public release of these tools supports LCA in the algae community and fosters comparable, transparent, reproducible analysis in the algae community.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Building on the existing GREET model for use as the algal biofuel LCA is a good approach. Several previous sustainability studies for algal biofuels were based on scenarios that are very far from economic viability at approximately $20/gallon fuel minimum selling price. These scenarios create concerns about sustainability issues that will never exist. When algal biofuels technology is deployed commercially, algal productivity will necessarily be about five times higher than current values, with better utilization of inputs. This project should look at the sustainability of algal biofuels for economically viable scenarios that are likely to be deployed with comparison to current state of technology (SOT). The presentation did not make this critical point clear. Uniform LCA across various biofuel and conventional platforms and scenarios is highly valuable. Future work should focus on answering the questions, "If/when algal biofuel technology is deployed, what will the LCA look like? Where do we need to process improvements to achieve acceptable LCA results in viable scenarios?"

- Excellent and important work on algae LCA via the GREET tools with solid initial work and a good plan for future work. The primary near-term focus should be to include lipid extraction with protein meal co-product because that is the main approach being pursued by industry. The second most common approach, hydrothermal liquefaction, is already included in the model. The next priority should be to look at the LCA for economical scenarios.

- Should BETO consider expanding GREET to include algal biomass as a feedstock for other fuels? Where do we need to go to increase performance/seasonality?

- Like several other projects here that rely on data from full commercial-scale algal biofuels production (e.g., sustainability, safety) to produce robust results, this project appears to be slightly ahead of its time.

- This project includes updating of the GREET model for GHG emissions and energy use to include algae processing. The investigators, particularly the PI, have had considerable past experience in formulating the GREET model. Based on the description of the model provided, it is clear that the investigators have put an incredible amount of effort in assembling the many detailed inputs to the model. This has created a powerful model that is able to provide not just the immediate objective of GHG emissions and energy use, but also trends, insights, and tradeoffs (good and bad) that would not have otherwise been obvious. The PI has much experience working with the development of this model, and his understanding and insight resulting from his detailed work were obvious from his presentation and on-point answers to questions. The biggest risk to this project is the use of outdated information due to a lack of access to current data. The investigators recognize this and appear to be doing the best they can to combat this problem by staying in contact with those in the industry who are generating relevant data, as well as with other modelers.

PI Response to Reviewer Comments

- LCA seeks to ensure that economical algae systems are also sustainable. Algae LCA results have been driven by electrical energy consumption and by energy recycling from residuals, e.g., by the operating costs. TEA work shows that algal fuel costs are dominated by capital costs and not by operating costs (like electricity). Therefore, constraining systems by TEA drivers do not have such a large effect on LCA results. On the other hand, LCA results are being found to be relevant to TEA and experimental design, e.g., minimizing water movement and pond mixing energy. Also, as we presented, increasing productivity will have limited effect on improving the GHG emissions results unless one also improves the energy efficiency of the system. Combined LCA and TEA work showed that improving winter performance is important, perhaps more important than peak productivity. Diverting residues to feed co-products harmed preliminary LCA results. Thus, LCA considerations are adding constraints beyond those obtained in TEA and one must do both hand-in-hand in the context of national scale deployment. Therefore, our work sought to identify key variables that can guide process selection and has investigated key relationships affecting algae LCA rather than attempting to give definitive results that compute the (ultimate) GHG and energy improvements derivable from algae. This is why algae LCA work is not "ahead of its time" and is relevant now even though commercial systems are not fully defined. It is important that experimental results be constrained by sustainability requirements, such as reduction of water movement and seasonal stabilization of productivity. We agree that now we have identified the key variables and studied the system interactions, it is time to seek sets of assumptions that achieve LCA performance objectives.

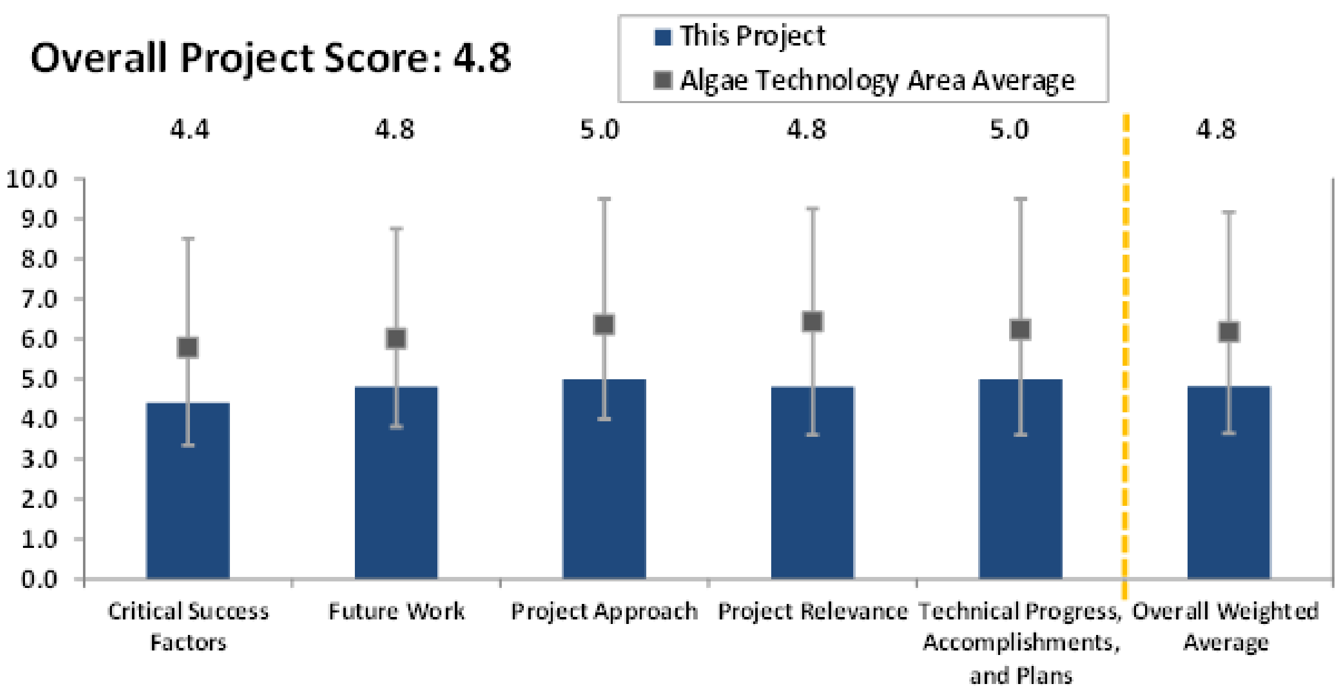
HUMAN HEALTH RISK ASSESSMENT OF ALGAE PRODUCTION SYSTEMS

(WBS#: 9.6.1.7)

Recipient:	LANL
Presenter:	Enid Sullivan
Total DOE Funding:	$1,340,319
DOE Funding FY13:	--
DOE Funding FY12:	$740,319
DOE Funding FY11:	$600,000
Project Dates:	2010–2013

Project Description

The aim of this research was to evaluate scaled growth of algae in outdoor production systems for emergent properties that could potentially impact the environment or human health. Research objectives were designed to broadly consider the potential for risk by identifying hazard(s) and likely exposure route(s) to sensitive end receptors; these findings would then frame the need for detailed risk assessment analyses and development of appropriate mitigation strategies for biofuel production systems. This project was conducted in two phases over a two-year period of performance. Phase one provided a cursory survey of algal production platforms for the occurrence of potential human pathogens or confirmed toxin-producing microbes, cytotoxicity of algal biomass and production waters, emission of noxious volatile organic carbon, and the bio-accumulation of toxic metals/metalloids in produced biomass and water. Phase two involved the design and operation of outdoor experimental raceways to quantify the outcomes of natural environmental perturbations, temporal biofouling (e.g., build-up of competitors and predators), and water chemistry on the production of different biofuel candidate strains of algae. Additionally, statistical linkages were explored between aspects of the water cycle (operational parameters, nutrients, and inorganic chemistry) and elemental composition of the biomass in these systems. Human health risks and environmental impacts related to aquaculture are generally well established; however, little consideration thus far has been extended to the algal biofuel industry. Importantly, this research clearly



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

demonstrates the potential for environmental and human health hazards to arise in association with large-scaled production of algae. Therefore, appropriate risk assessment capabilities and mitigation strategies should be carefully considered in step with the development, expansion, and deployment of algae biofuels.

Overall Impressions

- In terms of the data available, this project appears to be ahead of its time.
- It is very difficult to balance the value of identifying and addressing potential risks with the possibility of being unnecessarily alarmist. This balance is made especially difficult by the nascent state of algal biofuel technology, with large uncertainties in biology and process. I think this project did a pretty good job of maintaining balance and perspective. Although there are clear barriers to collaborating with commercial algae producers, the project could have put the potential for risk into better perspective by consulting with commercial algae operators and analyzing current end uses of algae, which include human nutritional supplements.
- The project provided a reasonable assessment of the potential risks from metals in the media and algae. The liver cell work confirmed that centuries of algae consumption have not resulted in negative health effects. The overall study would have benefited from building on the experience from decades of commercial algae production.
- Though there has been no significant occurrence of toxins in algae production to-date, the need to do a formal assessment of potential human health hazards in algae production is not unreasonable. The data presented do not appear to justify any specific safety concerns that cannot be mitigated by normal industrial safety practice, despite that claim. Analysis of only one algal strain does not allow generalization of results, making value of results more limited.

PI Response to Reviewer Comments

- Our project combined two projects, one addressing water chemistry composition and the other addressing toxins and pathogens in algae biofuel cultivation. We hypothesize that algae biofuel cultivation systems may differ from existing algae cultivation systems (e.g., for food or aquaculture) because of unique methods (e.g., use of wastewater for cultivation) and algae species used. Therefore, potential risks should be evaluated from that perspective. The scope of the study was to examine areas where risk quantification might be needed, but not to calculate actual risk values. At this time, we believe that it is too early to determine quantitatively if harmful pathways or conditions exist in biofuel production facilities. However, this new process warrants the examination of potential pathways and conditions that should continue to be observed as the biofuel industry develops. Our aim is to inform workers, regulators, and others outside of the industry in an unbiased fashion, and to provide a baseline for future, more quantitative evaluations of risks and hazards if they are deemed necessary. We agree that further collaboration with commercial algae operators in development of data and guidelines for operation would greatly improve our contextual understanding.
- The science of algal and microbial genetics, algae toxin production, and the use of alternative water sources (non-potable and non-seawater) for biofuel algae production is changing rapidly. Our aim is to point to future directions where more definitive or quantitative assessments may be appropriate. Normally, a quantitative risk assessment is conducted if there is a specific need to verify a human health risk. Our scope was limited to the few facilities utilizing algae for biofuel production. Sampling of commercial aquaculture facilities could help place our results in context, although these facilities have rarely (based on our literature search) been evaluated for human health risks, and some environmental risks have been identified recently.

HYDROCYCLONE SEPARATION OF TARGETED BIOCHEMICAL INTERMEDIATES AND PRODUCTS

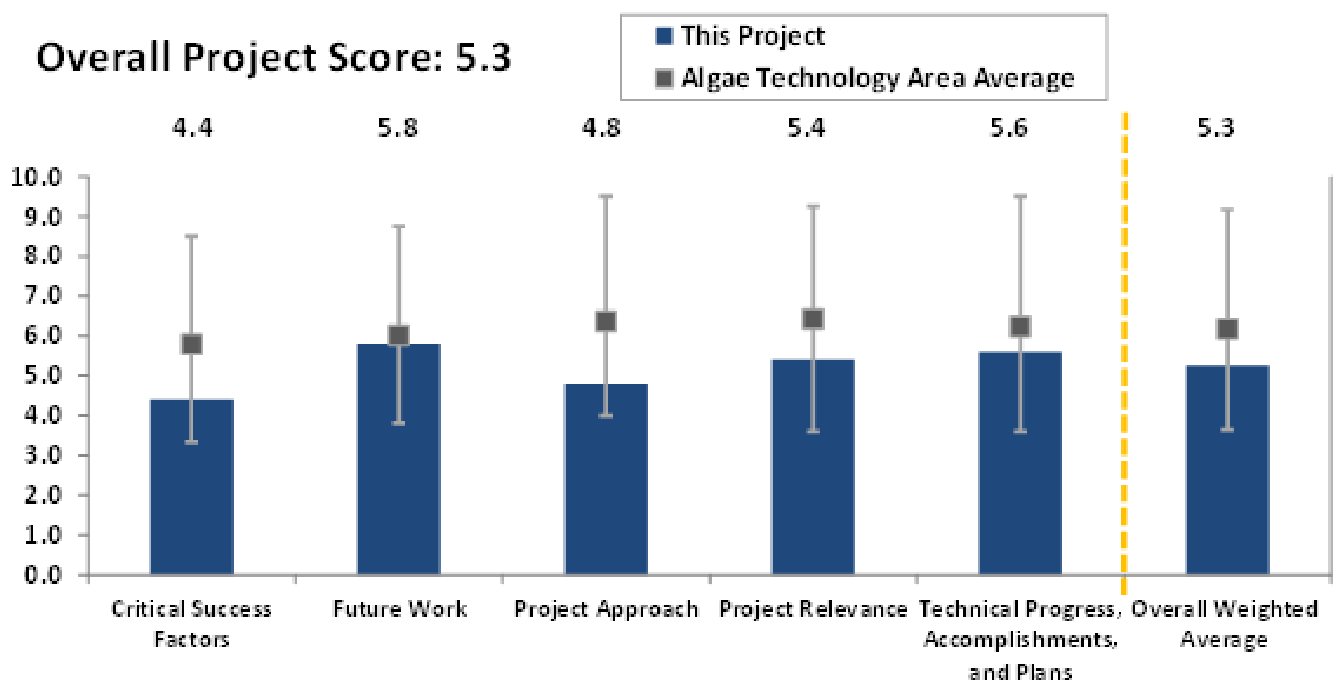
(WBS#: 9.5.1.9)

Recipient:	ANL
Presenter:	Richard Brotzman
Total DOE Funding:	$250,000
DOE Funding FY13:	$250,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012–2015

Project Description

Photo Courtesy of ANL

The program's purpose is to develop and demonstrate a continuous-flow hydrocyclone dewatering process to recover lipid products from algae. This new process is low cost, energy efficient, and it replaces current unit operations based on centrifugation, filtration, and washing. It is also expected to significantly reduce water consumption. The separation process combines hydrocyclones with nanostructured adsorbents to efficiently harvest lipids. This technology spans between biomass processes and is relevant to the development of technically viable, sustainable, and cost-effective fuel production from algae. A hydrocyclone is a classification device that separates components of a fluid mixture based on density and/or size. A hydrocyclone is comprised of a cylindrical-conical body where liquid is fed tangentially at the top, a conical base, and two opposite axial exits. The top exit (overflow) consists of a tube extending into the cylindrical section of the vessel. The bottom exit (underflow) is generally the denser or coarser fraction, while the overflow is the lighter or finer fraction. The performance baseline of hydrocyclones operated under continuous-flow conditions was determined to be a function of cyclone flow stream diameters, system pres-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

sure and flow rate, and hydrocyclone residence time. A new solid-state process capable of controlling chemical nanostructure was employed to synthesize Fe_2Co- and Al_2O_3-based nanostructured adsorbents. Remaining critical success (risk) factors include completing the evaluation of dewatering algal growth medium, the quantification of nanostructured adsorbents adsorption capacity, and the evaluation of separation strategies based on hydrocyclone flow separation aided by adsorption of lipids, followed by flotation and/or magnetic separation.

Overall Impressions

- The project should have better-defined process performance criteria, including mass balance, energetics, and CAPEX and OPEX targets. As part of the proposal, the project should have developed a complete process-flow diagram, including harvest, secondary concentration, cell disruption, oil recovery, and absorbent recycle. Best-case scenarios should be applied to the entire process to determine if the technologies can be viable. A best-case estimate for installed cost should have been made and analyzed at the time of the proposal. A review of previous studies should be completed and key issues addressed—low final solids concentration approximately 4 g/l, performance not robust because it is highly dependent on feedstock characteristics, and hydroclones are relatively energy intensive. Hydroclones with greater than 3,000 gallons-per-minute capacity are available, and systems are relatively simple, so the technology likely could meet capital and operating cost requirements. However, the harvest process needs to concentrate algae from about 0.5 g/l in the pond water to about 100 g/l or higher in harvested algae paste. The limits of hydroclone performance are well understood and modeled. Preliminary modeling could provide best-case scenarios for hydroclone performance. Limitations on underflow discharge viscosity and the small difference in specific gravity will preclude the technology from reaching required final paste concentrations, but hydroclones could be viable for a preliminary dewatering step for certain algae species. Relatively high energy requirements for achieving relatively low concentrations of slurry should be addressed. The economics of using 5 parts by weight of approximately $100 per kilogram (kg) nanostructured absorbent to recover 1 part by weight of approximately0.50/kg crude algae oil appear to be extremely challenging. The absorbent would need to be recycled at greater than 99.9% recovery and reused thousands of times, or a step change reduction in absorbent costs needs to be achieved. The challenges of disrupting algae cells so that the absorbent can contact the oil were not addressed.
- The technology challenges addressed by this project are extremely relevant; the approach seems economically unviable at commercial-scale as presented today.
- The two very different technologies presented for dewatering algae and recovering oil may be beneficial, but it is not clear how they fit together. Hydrocyclone use is relatively inexpensive, but it is not clear how much value it provides over other, more efficient dewatering options. Adsorbents may provide significant breakthrough, depending on how expensive they are relative to the amount of oil recovered. Identifying the amount of adsorbent needed relative to the amount of algae species processed for commercially relevant species is critical to verifying the viability of this approach.
- This project includes a set of novel separation approaches that have the potential to create a process that would improve the economics of algal biofuel production. The initial experimental work on a hydrocyclone for separating flocculated algae is well done. However, there have been insufficient economic analyses to determine the viable options for use of these technologies, or to set appropriate experimental targets. The project team needs to

spend time and effort brainstorming with experts on algal production and algal separation technology to identify options for use of the novel technologies to bring down the cost of algal biofuel production. Then, an economic analysis needs to be completed to set experimental targets that are relevant to BETO goals.

PI Response to Reviewer Comments:

- The project employs process performance criteria and process flow diagrams detailed in References 1-3.[10] This program is evaluating feasibility—best-case estimates will be used in the techno-economic analysis that will be part of the go/no-go decision review.
- Hydrocyclones have not been evaluated for lipid separation in algae for biofuels applications. Literature results indicate a centrifuge outperforms other separation methods for many different types of algae strains and cell lysis methods.[11, 12, 13, 14] However, centrifugation is energy intensive and is a difficult unit operation to design a profitable biofuel production process; in contrast, hydrocyclones have no moving parts and are significantly less energy intensive. The limits of the hydrocyclone with respect to algae dewatering are under investigation; initial results indicate the aggregate size of algae determines the degree of separation and experimental data are required to model the separation process.
- The cost of magnetic nanomaterials was decreased from \$17,000/kg to \$350/kg in the last 6 months. At commercial scale surface treatments are applied to nano-sized cosmetic ingredients for approximately \$1-3/kg. The development vector should yield magnetic material at \$50/kg by the second quarter of 2014. If nanostructured adsorbents employ flotation separation, the cost of 30-nano meter alumina is \$25/kg. Nanostructured adsorbents were shown to adsorb approximately 20% by weight, or approximately 50% by volume, glucose and xylose—5 weight percent-(wt%) of \$25/kg nanostructured adsorbents would recover 1-wt% approximately \$0.50/kg crude algae oil.[15] A turnover ratio of 250 will capture an equal value of oil at 100% recovery. The morphology of the nanostructured adsorbents will be tailored to maximize recovery by forming elastomer networks that are easily harvested from the algal growth medium, assuaging concerns regarding adsorbent loss.
- The literature will be leveraged to determine the best method to disrupt algae cells in the context of this program.[16] Absorbent-recycling methods will be evaluated in the program.

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[10] Frank, E.D.; Han, J.; Palou-River, I.; et al. *Life-Cycle Analysis of Algal Lipid Fuels with the GREET Model*. ANL/ESD/11-5. Argonne, IL: Argonne National Laboratory, August 2011. http://greet.es.anl.gov/files/algal-lipid-fuels.

[11] David, R.; Fishman, D.; Frank, E.; Wigmosta, M.; et al. *Renewable Diesel from Algal Lipids: An Integrated Baseline for Cost, Emissions, and Resource Potential from a Harmonized Model*.

[12] Frank, E.D.; Elgowainy, A.; Han, J.; Wang, Z. "Life Cycle Comparison of Hydrothermal Liquefaction and Lipid Extraction Pathways to Renewable Diesel from Algae." *Mitigation and Adaption Strategies for Global Change* (18:1), 2013, pp. 137-158.

[13] Sobczuk, T.M.; Camacho, F.G.; Grima, E.M.; and Chisti, Y. "Effects of Agitation on the Microalgae Phaeodactylum tricornutum and Porphyridium cruentum." *Bioprocess and Biosystems Engineering* (28:4), 2006, pp. 243-250.

[14] Williams, P.J.B.; and Laurens, L.M.L. "Microalgae as Biodiesel & Biomass Feedstocks: Review & Analysis of the Biochemistry, Energetics & Economics." *Energy Environmental Science* (3), 2010, pp. 554-590.

[15] Lin, Y.J.; and Brotzman, R.W. *Low-energy Magnetic-Field Separation for Direct Sugars Capture - Biochemical Platform*. ANL/ES/BETO/49824-00-155. Argonne, IL: Argonne National Laboratory, 2012.

[16] Lee, J.Y.; Yoo, C.; Jun, S.Y.; Ahn, C.Y.; and Oh, H.M. "Comparison of Several Methods for Effective Lipid Extraction from Microalgae." *Bioresource Technology* (101), 2010, pp. 575-577.

IMPROVING MICROALGAL OIL PRODUCTION BASED ON QUANTITATIVE ANALYSIS OF METABOLISM

(WBS#: 9.1.2.1)

Recipient:	Brookhaven National Laboratory (BNL)
Presenter:	Changcheng Xu
Total DOE Funding:	$954,638
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$600,000
Project Dates:	2010–2013

Project Description

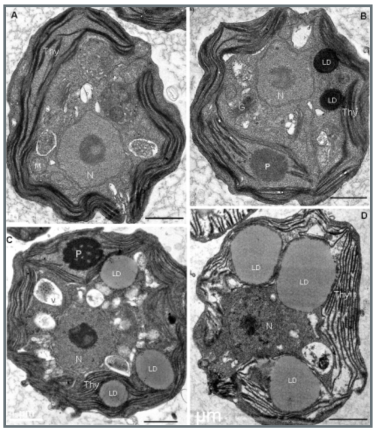
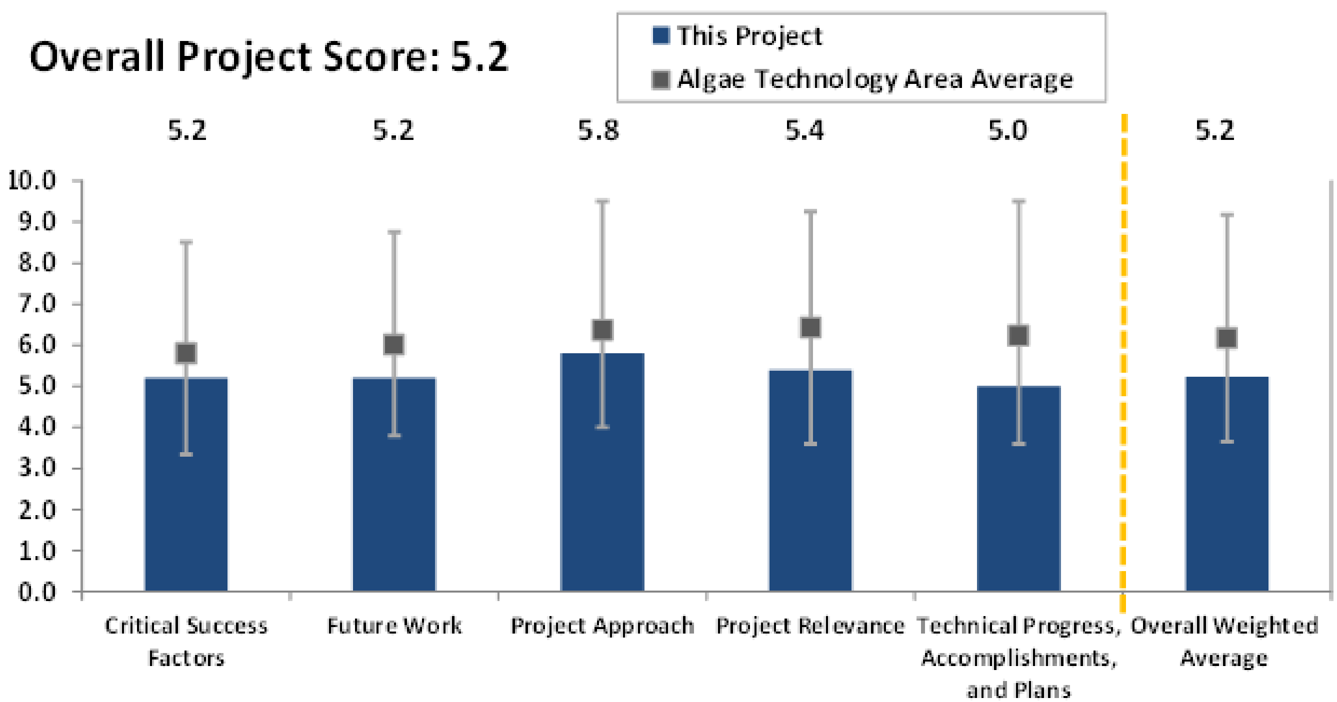


Photo Courtesy of BNL

Microalgal triacylglycerols (TAG) (oils) are promising feedstocks for renewable alternatives to petroleum fuels. Ideally, microalgae could be engineered to convert energy from sunlight directly into oils. However, many obstacles must be overcome.

Algae growing with sunlight as the sole energy source are known to produce substantial amounts of oil when placed under nitrogen stress, but the cultures necessarily stop growing. Preliminary work with a mutant strain of *Chlamydomonas reinhardtii* that is defective in starch synthesis has found conditions where comparably large amounts of oil can be produced by continuously growing cultures using organic compounds as the energy source. We will apply methods of metabolic control analysis and metabolic flux analysis in combination with biochemical and genetic studies to determine effects of different culture conditions on central metabolism and



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

the pathways of fatty acid synthesis and lipid assembly. The goal is to gain a sufficient quantitative understanding of the metabolic pathways involved to be able to genetically engineer strains that efficiently convert energy from sunlight directly into oils under continuous growth conditions.

Overall Impressions

- Improvements in metabolism and storage might be fundamental to improving fuel yields in algae cultivation. The problems with this research were presented by the investigators—the analysis is performed with algae growing on acetate, and the results of the analysis are to be applied to algae growing autotrophically (on atmospheric CO_2). Therefore, manipulation of the targets revealed might be less relevant for autotrophically grown alga. *Chlamydomonas* is not the most suitable species for mass oil production. A successful engineering approach will need to be applied to commercial algal strains. The ectotopic expression of oleasin to increase oil accumulation and identification of a stress sensor are interesting, but they need to be tested in relevant organisms under relevant growth conditions. This reviewer expected more progress in moving these concepts from model system to autotrophic commercial strain.
- The goal of maximizing oil accumulation and the approach taken is important and sound. However, the work appears to have been performed on a species of little commercial value. It is crucial to justify the claim that these results can be applicable to optimizing oil in commercial production strains.
- The project provided interesting and somewhat beneficial basic science results. However, the strain and the cultivation conditions were not relevant to BETO goals, and there is not a feasible path to make the results relevant.
- This approach must be undertaken if there is to be improvement in the yield of TAGs production by microalgae.
- This project did an excellent job in evaluation of one species—*Chlamydomonas*—which, unfortunately, is seemingly not well-suited to fuel production. I would like to better understand to what extent these metabolic pathway manipulations are able to be induced in species with higher oil yields, which are currently considered for use in fuel/co-products production. I would also like to better understand what the cost would be to increase fuel oil yield (per ton of algae) via these techniques.

PI Response to Reviewer Comments

- The reviewers criticized the choice of *Chlamydomonas* as the organism to study for this work. However, we believe that work on *Chlamydomonas* can be of high value for the following reasons:
  - *Chlamydomonas* is the best developed model system to study algal physiology, molecular biology, biochemistry and genetics. Although *Chlamydomonas* is widely dismissed as a potential production organism for biofuel production, it grows rapidly and can accumulate lipids to more than 50% of dry weight.[17] In addition, *Chlamydomonas* is widely used as a commercial production platform for producing animal feed, pharmaceutical proteins and for environmental remediation. Despite the investment of many millions of dollars, a commercially viable platform for algae-based biofuel production has yet to emerge. This begs two important questions: Can we exclude *Chlamydomonas* as a production strain? Do we have the sufficient genetic and biochemical knowledge about fuel feedstock synthesis to enable the engineering of production strains? The second question can be best answered by the

[17] Li, Y.; Han, D.; Hu, G.; et al. "Inhibition of Starch Synthesis Results in Overproduction of Lipids in Chlamydomonas reinhardtii." *Biotechnology and Bioengineering* (107:2), 2010, pp. 258-268.

Exxon-funded algal biofuel project emphasizing why basic scientific research progress is critical for commercial algal fuel development.[18]

- In the BETO algal biofuels roadmap, the report states, "Species with sequenced genomes and transgenic capabilities are the most amenable to investigating cellular processes since the basic tools are in place."[19] Most successful manipulation of basic biological processes can be traced back to model organism studies. We therefore expect that the results and methods generated in our work with *Chlamydomonas* will have a transformational effect on our ability to optimize oil accumulation in commercial production algae.
- *Chlamydomonas* is considered by some as a potential biofuel production platform.[20,21]

[18] Bullis, K. "Exxon Takes Algae Fuel Back to the Drawing Board." *MIT Technology Review.* May 20, 2013. www.technologyreview.com/view/515041/exxon-takes-algae-fuel-back-to-the-drawing-board/

[19] *Biomass Program National Algal Biofuels Technology Roadmap*. DOE/EE-0332. Washington, DC: U.S. Department of Energy, 2010. Bioenergy.energy.gov/pdfs/algal_biofuels_roadmap.pdf.

[20] Siaut, M.; Cuine, S.; Cagnon, C.; et al. "Oil Accumulation in the Model Green Alga Chlamydomonas reinhardtii: Characterization, Variability Between Common Laboratory Strains and Relationship with Starch Reserves." *BMC Biotechnology* (11:7), 2011.

[21] Morowvat, M.; Rasoul-Amini, S.; Ghasemi, Y. "Chlamydomonas as a "New" Organism for Biodiesel Production." *Bioresource Technology* (101:6), 2010, pp. 2059-2062.

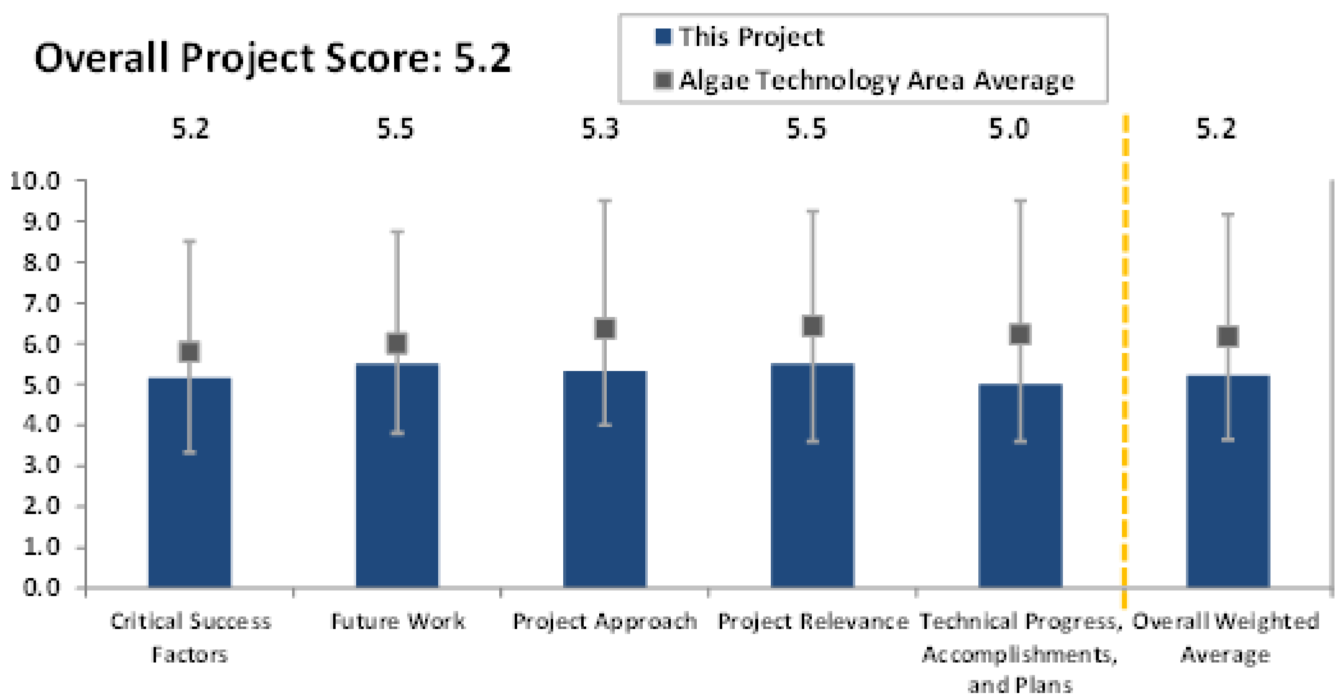
INTEGRATION OF NUTRIENT AND WATER RECYCLING FOR SUSTAINABLE ALGAL BIOREFINERIES

(WBS#: 9.1.1.1)

Recipient:	University of Toledo; Montana State University
Presenter:	Sridhar Viamajala
Total DOE Funding:	$2,999,934
DOE Funding FY13:	$651,645
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013–2015

Project Description

The overall goal of this project is to develop the enabling science and engineering that will result in environmentally sustainable algal biomass and biofuel production with minimal synthetic fertilizer inputs. Nutrient and water flux from farm or municipal waste is sufficient to support relatively small (30–50 tons/day of algal biomass) algal production systems. Nutrient and water recycling would support additional biomass production and would be especially critical for overall sustainability of commercial systems deployed over thousands of acres. The assembled team has successfully isolated and characterized high lipid-producing native alkaliphilic algae, which are less susceptible to detrimental contamination, at least partially due to the higher pH culturing conditions. We have also tested novel smart hydrogel-based, low-energy options for solid-liquid separation that allow for effective water recycle because it does not involve use of contaminating chemicals (e.g., flocculants). In this study, we are evaluating algal growth and lipid production by alkaliphilic organisms using nutrients from waste streams and recycled post-conversion residues, and water recovered from our harvesting methods. Our specific objectives for this project are to evaluate the effects of nutrient integration/recycle options on algae growth and lipid production; develop low-cost and low-energy water recovery methods; characterize the development, structure, and stability of microbial communities in algal systems that contribute to stable algal



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

biomass and lipid production; and perform economic and life-cycle assessments for sustainable algal biorefineries. The primary success factors of this research and development effort are stable and enhanced biomass and lipid productivity through the use of alkaliphilic algal cultures, utilization of nutrients and water from waste streams and post-conversion residues, development of low-cost/low-energy water recovery methods based on smart hydrogels, and a fundamental scientific understanding of microbial interactions in productive algal growth reactors.

Overall Impressions:

- Recommend a simple capital cost analysis.
- Run this at ATP3 testbeds. Don't reinvent the wheel on innovative technology and a risky project. I would like to see logistically how hydrogel works in a small raceway, and then a big one, without gumming up the raceway system. Focus remaining funding on hydrogel and skip all other work. Clarified water recycling has already been demonstrated.
- The project incorporates a novel harvesting process, as well as some other interesting concepts. However, these ideas need to be evaluated as part of an integrated process. Also, an economic model is needed to guide the R&D and provide technical targets so that the project can be relevant to development of a commercial industry.
- There appear to be several issues that may preclude the use of stimuli-sensitive hydrogels for algae dewatering. Using a basis of 0.5 g/l ash free dry weight algae at harvest and 50% fuel yield, 4,000 gallons of water must be harvested to yield 1 gallon of fuel. Harvest rates would be tens of thousands of gallons per minute, even for small commercial plants. Changes in hydrogel hydration state through temperature change is not feasible because it would take 45,000 calories of process heat per gram of fuel recovered—about four times more energy than the energy content of the fuel—and heat recovery over the range of 22° Celsius (C) to 33°C is not economically viable.
- This project involves several tasks, although the most interesting include the use of hydrogels for dewatering and the use of alkaliphilic algae. The hydrogel technology in particular appears to be truly innovative and has a number of potential advantages. However, from the information provided, there is concern that the amount needed at a commercial scale, in addition to the need for a secondary dewatering technology, may make this approach uneconomical for this application. Similarly with alkaliphilic algae, the reliance on carbonate as a carbon source and the avoidance of predators at high pH may not be practical at commercial-scale sizes. To their credit, the investigators recognize that laboratory conditions do not always translate to outdoor conditions, and outdoor rates and yields need to be determined as a critical success factor. Without actual data to show at the present time, the investigators need to provide more evidence (e.g., via mass balance and chemical equilibrium calculations) to justify the claims/predictions made. A cost estimation is also critical to assess whether the approaches proposed in this project will be economically viable for algae. A go/no-go decision gate should also be included as a milestone based on the cost estimate to ensure that effort is not spent pursuing a task that will not meet BETO's commercialization targets. It is unclear what the LCA work will involve; it seems unrelated to the other tasks and repeats work being done by other modeling projects. This project would be better off focusing on the proposed innovative technologies and proving that they can be viable.

PI Response to Reviewer Comments

- Our primary focus is to investigate pH-sensitive hydrogels that swell at high pH (and uptake alkaline media) and shrink when pH is lowered to release the absorbed medium. For bicarbonate buffered solutions (e.g., alkaliphilic growth media), pH shifts between 7 and 10 can be easily accomplished by using CO_2-containing flue gases as the acidifying agent. Equilibrating with atmospheric CO_2 reinstates the solution to its previous alkaline state. Since no temperature change (e.g., heating) is necessary to dewater algal slurries using pH-sensitive gels, this method is expected to have low energy inputs. For temperature-sensitive gels, heat inputs would be lower than predicted by the reviewer at appropriately chosen geographic locations (e.g. south-central Texas where average annual highs are above 25°C). Energy requirements could also be decreased by using low grade heat from co-located power plant flue gas, by combustion of residues or by employing solar thermal systems. Our calculations show that energy recovered from flue gas of a relatively small 50 MW power plant is sufficient to harvest nearly 20 metric tons of biomass per day (nearly 3,000 gal-fuel/day at a fuel recovery of 50%). LCA and economic assessments are integrated throughout the current project to evaluate the feasibility of these unique harvesting technology improvements.

- In our process, bicarbonate added to the alkaliphilic medium is not the sole carbon source. The majority of carbon utilized for photosynthesis is derived from atmospheric CO_2. The bicarbonate in solution maintains high media pH which, in turn, facilitates rapid CO_2 transfer from the atmosphere without the need for expensive CO_2 sparging systems that are required in mesophilic algal cultures.
- Finally, an important aspect of our project (overlooked by the reviewers) is to look at culture stability in “contaminated” wastewater and recycled-nutrient environments. This work complements and extends SNL’s “pond crash forensics” project.

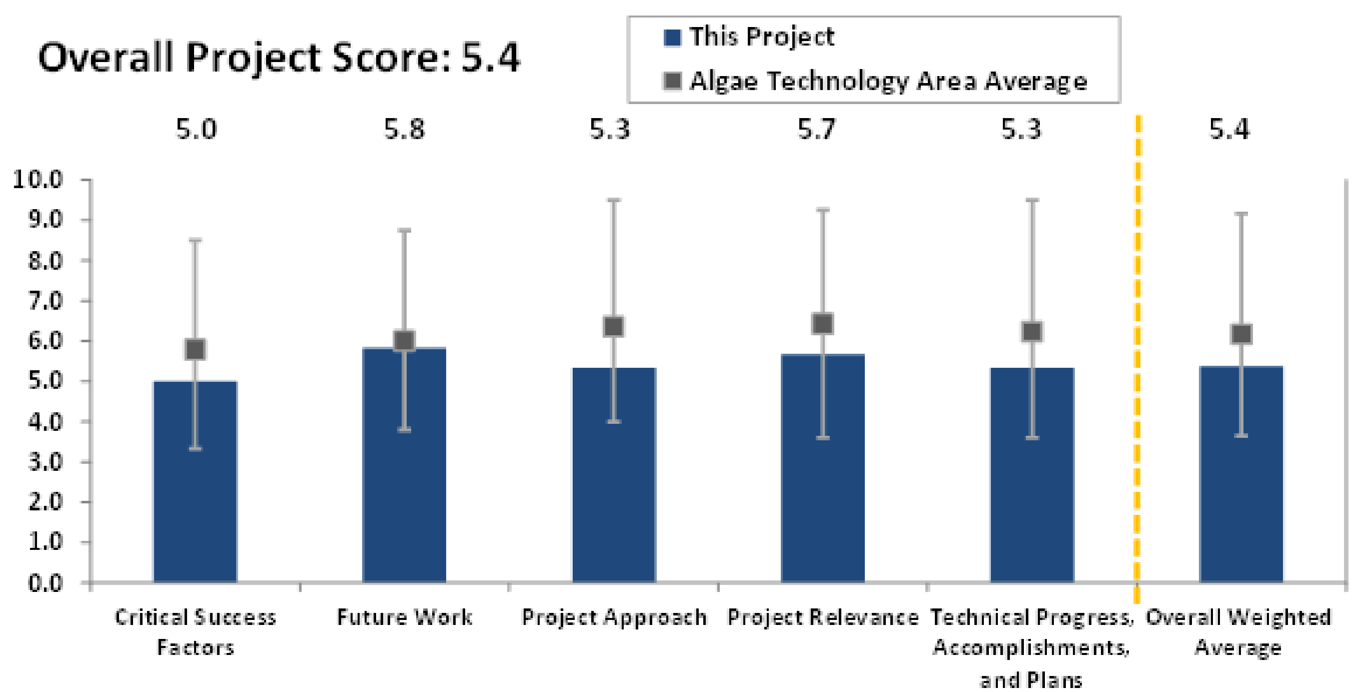
MAJOR NUTRIENT RECYCLING FOR SUSTAINED ALGAL PRODUCTION

(WBS#: 9.1.1.3)

Recipient:	SNL
Presenter:	Todd Lane
Total DOE Funding:	$2,145,000
DOE Funding FY13:	$715,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013–2016

Project Description

Energy production from algae biomass is a compelling solution for sustainable domestic production of fuels. However, recent studies suggest that nitrogen and phosphorus supplies are insufficient to support production of even 10% of domestic fuel supply from algae. Unlike ammonia, phosphate is a non-renewable resource, and a peak in worldwide production is expected as early as 2030. Thus, without significant technological progress to recycle these major nutrients, significant expansion of algal biofuels production can be expected to catalyze a food versus fuel crisis. We will harness the process of remineralization—the biological conversion of organic forms of nutrients to inorganic forms—to develop a novel, cost-effective process for the efficient liberation of phosphate and nitrogen from oil-extracted algal biomass and the conversion of these nutrients into chemical forms that are readily captured and amenable for use as both nitrogen and phosphate sources. This work will leverage research carried out at Sandia National Laboratory under the auspices of the Sustainable Algal Biofuels Consortium for the utilization of residual biomass from algal fuel production. Initially, we will determine the optimal enzyme cocktail for rapid and complete phosphate remineralization and then engineer appropriate microbial strains to produce and export the previously defined enzyme cocktail in situ during conversion of residual biomass. We will combine our phosphate remineralization system with a previously developed process to convert amino acids to ammonium and butanol. To facilitate separation of the liberated nutrients from the



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

bulk phase, we will induce the co-precipitation of ammonium and phosphate in the form of struvite (NH_4MgPO_4). Since this will avoid the expense of moving water associated with recycling nutrients in solution, struvite precipitation will be a low-energy means of recovering the bulk of the phosphorous and at least a portion of the nitrogen. Both butanol and ammonium can be recovered in separate distillation processes.

Overall Impressions

- Consider a cost analysis with a go/no-go decision. Inhibitors may be accumulating struvite as soil amendment from wastewater and growing algae on it. Mass balance of magnesium needs to be addressed; develop data for this. Will have to follow up. Recycle directly. What are the conversion rates and value of co-products?
- The presentation did not clearly illustrate the proposed nutrient recycle scheme using struvite, and there appear to be fundamental problems that are not addressed and could be a go/no-go decision. A stoichiometric amount of magnesium is needed to produce struvite, and there appears to be no mechanism for recycle of the magnesium. It appears that when the algae is harvested, soluble magnesium will be separated into the flow with the water stream back to the pond, and very little magnesium would carry forward in the algae stream. The cost of adding near-stoichiometric amounts of magnesium for each recycle could be a major issue. This will also lead to accumulation of magnesium and counter anion in the pond. The solubility product constant of Magnesium phosphate is very low (1E-25), so risk of precipitation and loss of magnesium phosphate in the pond should be investigated. The plan for hydrolyzing and fermenting sugars and amino acids from algae appears to lack viability because of low sugar and amino acid concentrations causing low titers, which result in unacceptable economics and energetics. Known problems with mixed alcohol inhibition of fermentation at low titer is another go/no-go decision for the amino acid fermentation proposal. This inhibition is likely due to membranes being denatured by the mixed alcohol, so achieving tolerance through directed evolution or genetic engineering is unlikely to be a quick solution. A go/no-go decision point is needed very early in the project (fourth quarter of 2013) to address major issues. This project is very likely not viable if nearly-stoichiometric amounts of magnesium must be added for each cycle due to magnesium not returning with the concentrated algae, or if magnesium phosphate precipitates in the pond. A separate, early go/no-go decision is needed to terminate work if no economically viable proposal for increasing fermentation titers is identified.
- The project includes many innovative and creative approaches. However, it is not clear that achieving the objective will contribute to reducing the cost of algae biofuel production or the development of a commercial industry. Top-level economic analyses need to be performed to determine if the investment in experimental work on enzymatic hydrolysis for nutrient recycle is worthwhile, or whether the effort should be redirected to an area with a bigger economic impact, such as enzymatic lipid extraction or co-product separation.
- This project needs to quickly resolve a few questions regarding techno-economic viability and then decide whether to move forward or not.
- This project, which has just started, provides a clearly defined and interesting pathway for investigating nitrogen and phosphorus nutrient recycle. However, apart from a few instances, not enough quantitative evidence has been provided to justify why this project should be successful. Exactly how nitrogen and phosphorus will be made to co-precipitate in the form of struvite (as opposed to getting other insoluble compounds, like $MgCO_3$ for example) is not clear. In the absence of data that have not yet been gathered, mass balance and chemical equi-

librium calculations should have been provided that would justify the belief that the proposed process is technically viable. In addition, cost information is missing, and a cost estimation needs to be performed to verify that the proposed process will also be economically viable. The inclusion of a go/no-go gate with quantitative milestone targets is a good addition. Cost criteria should also be included in the go/no-go decision to be able to ultimately provide a process that can be utilized commercially.

PI Response to Reviewer Comments

- Project success requires the recycle of phosphorous and nitrogen from algal biomass to the production pond. As long as returned nutrients are bioavailable, the actual chemical form is irrelevant. We believe that struvite is a likely and convenient form for recycled nutrients.
- Seawater is approximately 50 millimolar Magnesium (Mg). Optimal production of algae is achieved at phosphate concentrations of 100 to160 micromolar. Assuming complete assimilation of phosphate, the harvested biomass from one liter of culture should contain 100-160 micromoles of phosphate. With seawater, 2-3.3 mL of culture medium would need to be present in the wet biomass from a liter of culture to provide stoichiometric quantities of Mg for the formation of struvite. In the event that magnesium is not available, calcium phosphates precipitate under similar conditions and are a suitable alternate as described in our proposal. Since Mg will be recycled, new Mg is not required for each nutrient cycle and will not increase the concentration of Mg in the pond.
- Magnesium phosphate may precipitate when the magnesium concentration is at or greater than that of sea water and phosphate concentrations exceed millimolar levels. This level of phosphate is approximately one order of magnitude greater than recommended for cultivation.
- Fermentation of the amino acids in algal biomass has yielded alcohol titers near 4% volume, and may require removal via liquid-liquid extraction during fermentation to limit toxicity. TEA by DOE national laboratories indicates that in the absence of nutrient recycling, the cost of fertilizer contributes on the order of $1/gallon of oil. Without nutrient recycling, this cost is simply prohibitive for fuel production. The sustainability of algae oil production at scale in the absence of nutrient recycling will be a challenge due to competition for fertilizer with food crops.

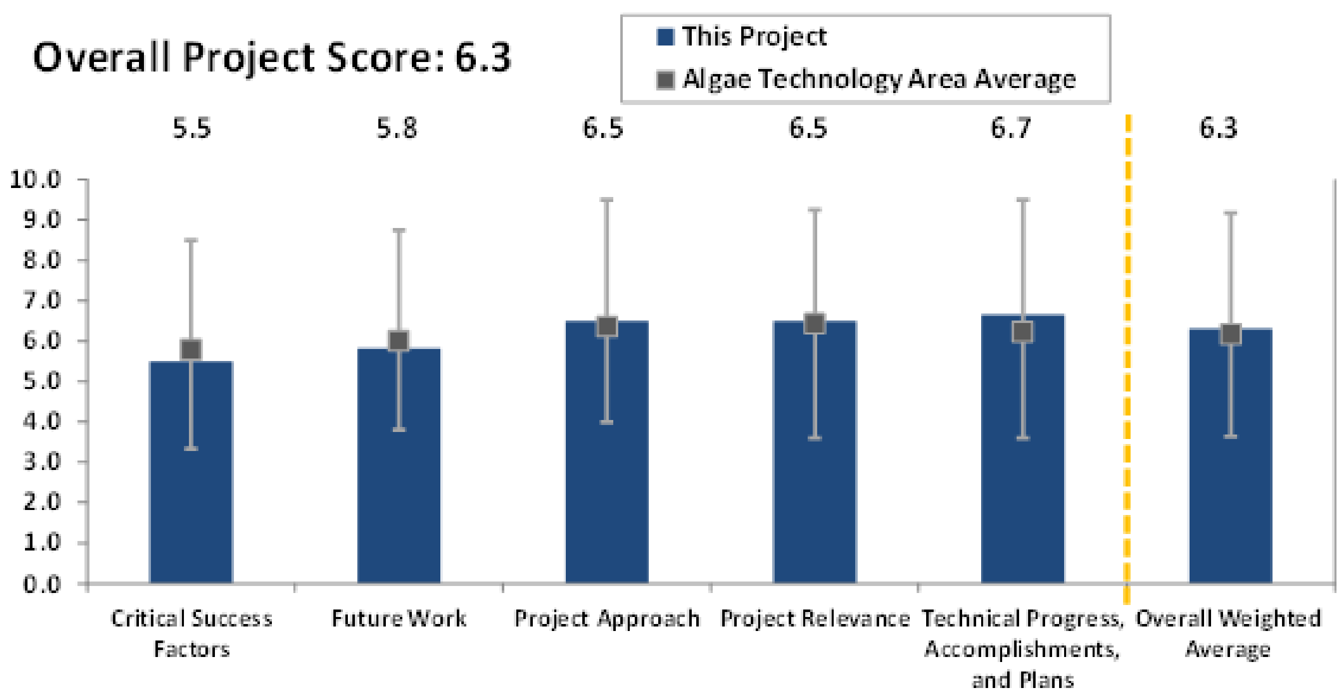
MICROALGAE ANALYSIS

(WBS#: 9.6.1.2)

Recipient:	PNNL
Presenter:	Mark Wigmosta
Total DOE Funding:	$1,293,000
DOE Funding FY13:	$540,000
DOE Funding FY12:	$335,000
DOE Funding FY11:	$365,000
Project Dates:	2010–2050

Project Description

BETO launched an initiative to obtain consistent quantitative metrics for algal biofuel production in order to establish an integrated baseline production scenario by harmonizing and combining several ongoing programs, including national resource assessment, LCA, and TEA. PNNL's BAT was used to select the most favorable consortium of sites with freshwater growth that supports production of five billion gallons per year of renewable biodiesel. The Gulf Coast was identified as the most favorable region to meet this target, while freshwater availability was the most important constraint. Strong seasonality in biomass production caused oversizing of facility capacity with significant impact on cost and emissions. Building on BETO's harmonization effort, we also consider availability of alternative saline groundwater and seawater for use in open pond algae cultivation systems. We estimate that combined, these resources can support 25 billion gallons per year of renewable biodiesel in the coterminous United States. Freshwater availability and saline water delivery costs are most favorable for the Gulf Coast where evaporation relative to precipitation is moderate. As a whole, the barren and scrub lands of the southwestern United States have limited freshwater supplies, and large net evaporation rates greatly increase the cost of saline alternatives due to the added makeup water required to maintain pond salinity. To assess the potential for land competition between terrestrial and algal biomass feedstocks in the United States, we evaluate a scenario in which 41.5 x 109 L yr-1 of biofuels are produced on pastureland, the most likely land base where both feedstock types may be deployed. Our analysis indicates that potential competition for land would be concentrated in 110



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counties, of which 38 to 59 counties could experience competition for upward of 40% of their pastureland. However, this potentially contested pastureland only accounts for 2%–5% of total pastureland in the United States.

Overall Impressions

- Excellent work harmonizing the models and improving the databases. Runs of the BAT and five billion gallons per year assessments were important initially to show feasibility for a significant contribution to the nation's fuel supply. Continued work to refine or improve these analyses is not worthwhile because it is based on a low-yield, uneconomical process that is not representative of a realistic algae biofuel industry. To get a realistic assessment of the resource utilization and biofuel production potential, the techno-economic model needs to be modified to include scenarios that are economical. Then the analyses would be representative of an algae industry that could actually exist someday, rather than one that is so inefficient and costly that it would never be built. The excellent analytical capabilities that DOE has developed for algae biofuels should redirected to the following: expand the TEA to include a model for lipid extraction with co-product sale as a feed ingredient so that there is a model for both of the principal routes currently being investigated, especially since there are more organizations pursing protein-based co-products than pursuing HTL; develop a set of economical scenarios for the two main routes currently being pursued (HTL and lipid extraction with protein co-product) to provide a basis for research targets and for BAT runs that provide a realistic assessment of the potential contribution and resource utilization of a commercial algae biofuels industry; and make the excellent database that has been generated assessable to industry and academia.
- The PNNL model is good and important. It established the baseline that everyone is using; the paper was well received.
- The biophysical evaluation of resource demands has produced a valuable model for assessing geographical locations for algal biofuel production. Using current state of technology input parameters produces misleading conclusions from the model because the current state of technology is very far from economic viability and will never be deployed. When algal biofuels technology is deployed commercially, algal productivity will necessarily be several times higher than current values, with better utilization of inputs. Conclusions drawn under these viable scenarios are dramatically different than \$20/gal scenarios that were modeled and published. The assessment can continue to expand in complexity, but the real challenge is to determine when additional complexity brings value. It appears that a relatively simple model can be used to determine that resources are available for significant initial deployment of algal biofuels, and the best locations are in a few specified geographies.
- The use of the BAT model for resource-related predictions is an important tool for the algae industry. The work described in this ongoing project describes inclusions of increased capabilities with respect to water resources and harmonization efforts with other models. It appears that steady progress is being made with further refinements of the model, which is of benefit to industry users. It is not clear from what was presented to what extent the geographic predictions of water resources, land mass, etc., have been verified with actual conditions in any given region, and a series of random checks using obtained data from actual counties should be made to increase confidence in predictions. It is not clear whether availability and distribution of CO_2 sources and meteorological data on increasingly frequent extreme weather events (e.g., hurricanes or drought)

have been accounted for, and plans to address these potential shortcomings should be considered. The plan to use the model to identify sites to support production of five billion gallons per year of renewable diesel may be more beneficial if modified to make predictions based on the productivity capabilities of industry at the present time.

- This seems like a well-managed project that has achieved much per dollar of funding.

PI Response to Reviewer Comments:

- The $20/gal harmonized scenario provides a baseline that represents a currently plausible production scenario. There is considerable value to DOE and industry in having such a realistic baseline, including:
    - Where do resource issues pose a threat to sustainable and economic algal biofuel production at defined production targets?
    - Are there aspects to specific technology pathways that make them vulnerable to particular resource constraints?
    - For what resources, due to cost or supply limitations, is it most important for consumption to be minimized?
- Only by establishing a consistent baseline for today's economic, environmental, and resource constraints can future performance improvements be tracked. We have also explored the impact of marked increases in baseline production and identified research opportunities for lowering production costs. Whereas DOE's focus is on fuel production, we have also used the BAT to explore co-product issues such as nutrient consumption tradeoffs and market saturation.
- Even with expected advances, it is essential to evaluate biofuel production against resource costs. The BAT includes spatial models to address many resource components including water, nutrients (nitrogen, phosphorous, and flue gas transport), infrastructure, site constructability, and land costs. Most of these are based on well-established civil engineering practices and cost estimation methods. To the extent possible, BAT has been validated against observations. For example, growth model results were compared to observations, evaporative water demand was compared to corrected pan evaporation, and the water-cost models were evaluated against similar construction projects. Our analyses continue to demonstrate the importance of site-specific production and resource evaluation through prioritization of locations by fuel value relative to resource costs. Our published works describe key resource limitations for specific geographic regions. As such, we feel that the BAT, along with TEA and LCA analysis, provides a valuable tool to guide targeted research to improve the economic viability of algal biofuel production.

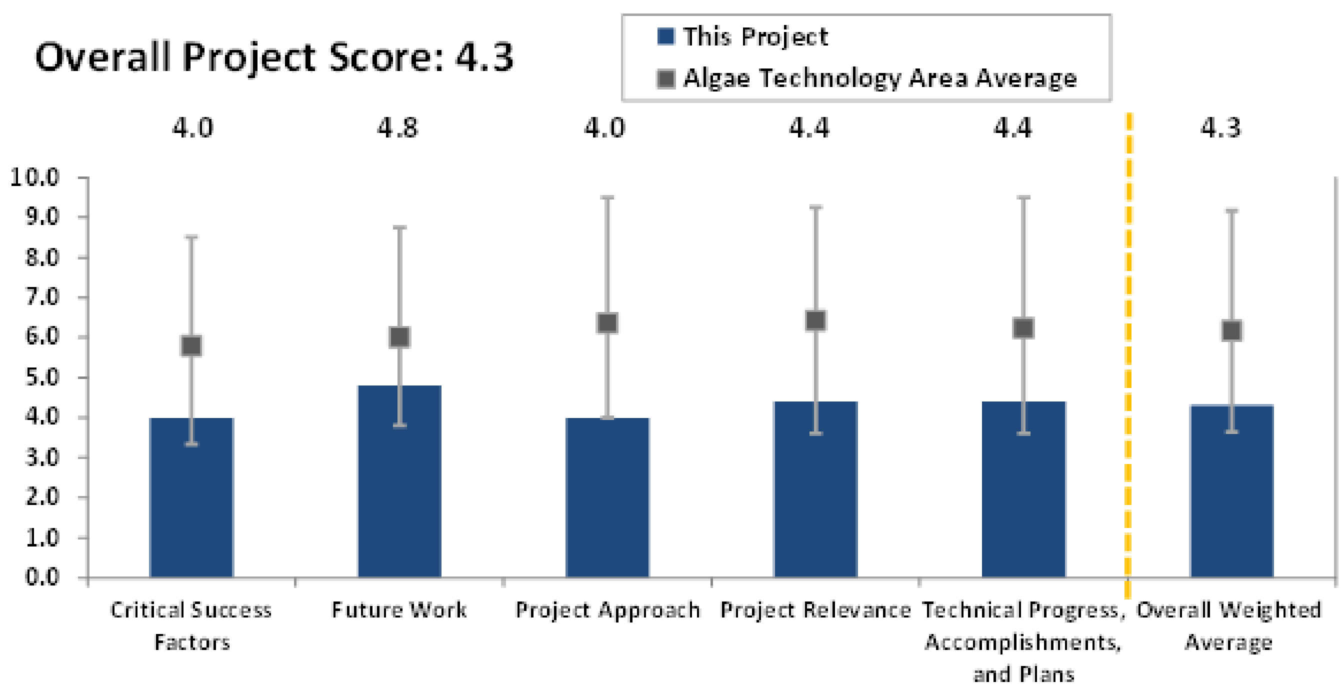
MICROALGAE HARVESTING-DEWATERING TECHNOLOGY SUITE

(WBS#: 9.1.3.2)

Recipient:	INL
Presenter:	Deborah Newby
Total DOE Funding:	$1,200,000
DOE Funding FY13:	$350,000
DOE Funding FY12:	$422,000
DOE Funding FY11:	--
Project Dates:	2010–2013

Project Description

The objective of this project is to advance algal biofuel feasibility through investigation of a novel dewatering approach, consideration of post-harvest stability, and characterization of algae feedstocks. The laboratory research conducted in the first two years of the project focused on analytical assessment of crossflow membrane filtration technology as an algal harvesting approach that is compatible with water recovery/nutrient recovery/recycling processes. Specifically, the team tested INL—developed ceramic-embedded, erosion-resistant membrane technology, comprising stainless steel micro and ultra filters with controlled pore sizes to reduce membrane fouling and enhanced filtration permeation properties with a variety of strains and mixed populations. Flux rates with the embedded membranes exceeded those required for industrial applications, as cited in literature. Once dewatered, it is essential to understand the stability of the algae feedstock, as it will drive many critical design decisions relating to processing, capacity designs, storage, conversion pathways, etc. Feedstock characterization and tracking of algal properties are essential to the investigation of algae in formulated/blended feedstocks. Algae as a stand-alone feedstock have several significant barriers relative to economic viability. However, if algae are considered as a feedstock available for blending, some of these challenges may be removed. Protein and lipid properties of algae suggest that when used as an amendment, they



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

may be able to upgrade low-cost, low-quality biomass. Research results will provide key information toward establishing algae as a sustainable high-impact feedstock in the near term.

Overall Impressions

- The harvest/filtration project should have better-defined process performance criteria, including mass balance, energetics, CAPEX, and OPEX. An estimate for installed cost per m^2 of filer area should have been made and analyzed at the time of the proposal. Prior to initiating experimental work, the project should have developed a process-flow diagram and applied best-case scenarios to determine if the technology is viable. For example, with a basis of harvest at 0.5 g/l and assumptions of 50% AFDW oil yield by HTL, then 4,000 gallons of pond water need to be harvested per gallon of crude oil produced. At a modest commercial scale of 10 million gallons of crude oil per year, 40 billion gallons per year of pond water need to be harvested. Assuming the harvest is 8,000 hours per year, the total filtration rate needs to be about 5 million gallons/hour or about 20 million liters/hour. With a best-case sustained average flux of 100 l/hour/m^2, 200,000 m^2 of filter area would be needed. It seems unlikely that a system of pumps, piping, valves, instrumentation, controls, and support structure for cross-flow filters with 200,000 m^2 of filter area could be installed and operated at viable costs. If, for example, the installed cost is greater than $500 per m^2 of filter area, then the harvest unit would require greater than $100 million capital, and the process is clearly not viable and made even worse considering that maintenance costs are typically 3% of installed capital cost. In the scenario of daily harvesting in a 6 to 8 hour time frame to maximize harvest yield, required instantaneous capacity and capital increases substantially. These simple economic viability calculations should be completed before doing lab testing. Similar systems are installed in waste treatment facilities, which should provide a source for capital and operating cost estimates. Also, evaluation of existing crossflow filtration technology for waste water systems should have been completed before evaluating a system with higher cost. The projects for feedstock stability characterization do not appear to have synergy with the filtration project, and they do not have clearly established goals and milestones. The value proposition for using algae co-product as a biomass binder is not evident.
- The main task of developing improved harvesting is important for algal biofuel commercialization. While the scientists competently performed the harvest experimentation, the inadequate understanding of the economics of the algae process by the partner organization resulted in experimentation and a system that does not have industrial relevance for algal biofuel commercialization. No post-harvest stability data were generated, and these data are not limiting commercialization, as it will become readily available from pilot and demonstration products. The other tasks in the project are focused on nuances that may impact a mature algae biofuel industry, but they do not contribute to accelerating commercialization. In the future, projects should take advantage of the excellent techno-economic modeling DOE has developed to drive the research projects and set go/no-go criteria that include the process economics.
- This project consists of several relevant but unrelated tasks. Cross-flow filtration results have several promising attributes, but investigators need to consider whether size and cost will be practical in full-scale commercial application. Not enough data have been provided on other tasks to judge how effective they will be.

- Though overall it seems economically disadvantageous to develop a two-step dewatering mechanism, I applaud the efforts of this project, as its intent to solve the dewatering challenge is right on the money.

PI Response to Reviewer Comments

- The project is comprised of unrelated tasks as it has been redirected to meet changing program interests and needs.
- This project was selected for funding as part of the fiscal year 2010 competitive lab call. Cross-flow filtration has been used industrially for more than 40 years and has been demonstrated to scale linearly. This project was to assess improvements in cross-flow membrane filtration through the use of novel embedded membranes. A TEA was not part of the proposed work scope, although we agree with reviewers that it does have merit and was performed using the Algae Logistics Model, developed at INL as a separate project. Calculations based on our embedded membrane technology using pre-concentrated algae show potential for cross-flow membrane filtration. Assuming one million gallons of biodiesel production per year and comparing two different initial concentrations of algae, the following are estimated costs.

Direct from pond at 200 L/(m^2*hr):	1.5% solids at 40 L/(m^2*hr):
CAPEX: $19.93	CAPEX: $3.82
OPEX: $0.46	OPEX: $0.09

- The INL team and the program office decided to discontinue work on these membranes at the end of fiscal year 2012 and redirected the project focus in new directions. Fiscal year 2013 represents a transition year in preparation for the new foci starting in fiscal year 2014— formulated feedstocks and algal feedstock stability testing. Introduction of algal blends is an element of the overall programmatic strategy and is driven by the terrestrial biomass efforts. The goal is to understand how to integrate algae into the terrestrial supply chain as a minor blend/additive to assess any positive performance attributes achieved through formulation. Criteria for feedstock stability need to be established and will depend on downstream process selection and co-products. This is a new task to be introduced in fiscal year 2014, and discussions between interested parties such as INL, NREL, and the program office are underway to prioritize and define the specifics.

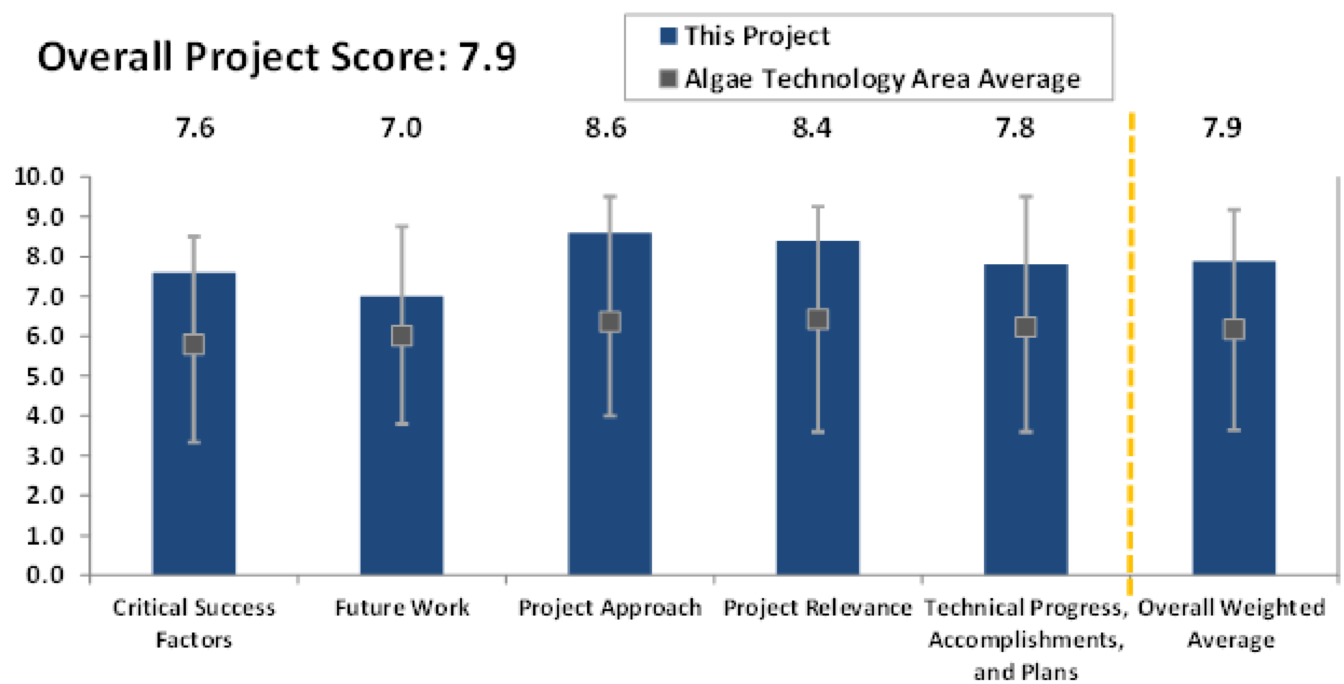
NATIONAL ALLIANCE FOR ADVANCED BIOFUELS AND BIOPRODUCTS

(WBS#: 9.5.1.1; 9.5.1.2; 9.5.1.3)

Recipient:	NAABB; LANL
Presenter:	Jose Olivares
Total DOE Funding:	$48,600,000
DOE Funding FY13:	$14,800,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010–2013

Project Description

NAABB is a consortium of 39 institutions developed to capture and integrate intellectual property, expertise, equipment, and facilities from a diverse set of companies, universities, and national laboratories in order to develop a systems approach to innovation for sustainable commercialization of biofuels and co-products. The formation of this alliance brings together multiple institutions with breadth and depth of knowledge in biofuels research. It creates a dynamic network for the flow of ideas from the bench to the marketplace, quickly and with constructive iteration, so that research and innovation can be tailored appropriately toward successful commercialization. This consortium is in its last year of operations. NAABB was formed to address key barriers across the full value chain of algal biofuels production. As such, it is an integrated program developing tools that facilitate deployment through science and technology. NAABB is bringing innovation across the technology development platforms with core economics and sustainability goals that produce a cohesive picture to all efforts. Several key technical challenges are addressed by NAABB, including algal strains that can be cultivated in real-world conditions and harvested with minimal energy; technologies that are scalable and provide energy return on investment; technology integration with needed nutrient, water, and other recycles; and sustainable technologies with respect to environment, cost, and permitting. An overview of the consortium's vision, goals, progress, and status will be provided.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Critical success factors needed: transfer genes to organism and optimized harvest and extraction systems. Need a thermal tolerant strain that can survive and produce all winter to save water and no evaporation.
- The approach of forming a large public-private consortium to develop algal biology, cultivation, harvest, extraction, fuel conversion, TEA, and sustainability analysis in a very short time was a requirement of the FOA. This was daunting. The management team did a great job of assembling the consortium, maintaining mission and focus, and having agility to explore new developments. NAABB achieved some significant technical successes. Several of the most noteworthy successes include the following:
    - Demonstration of improved algae productivity and oil accumulation through genetic engineering with several successful gene modifications in a model organism. Preliminary results from genetic engineering of the model strain show great potential, but stacking traits into production strains and testing under outdoor conditions is needed.
    - Development of the Algae Raceway Integrated Design pond, which might enable a significant, cost-effective increase of algal productivity during cool seasons.
    - Development of the HTL process, with initial results showing dramatically increased fuel yield without requiring high levels of TAG accumulation during algae cultivation.
    - Development and harmonization of TEA models. Step change improvement in algae productivity and fuel yield of about five-fold is the primary critical success factor determined by NAABB.
- Several weaknesses were also evident. More than 2,000 algal isolates were screened, but no increase in cultivation productivity was evident. There appears to be insufficient analysis of why extensive algae screening did not yield productivity improvement in the pond. It could be because there are not any "long tails" of the biodiversity distribution, presumably because of no evolutionary pressure in nature to create an algae strain with high growth rate and lipid accumulation. It could be that the screening criteria did not have the capability to select strains with characteristics for outdoor production, or maybe not enough strains were tested in outdoor cultivation to draw a conclusion. The ramifications of the answer could profoundly influence future research. It does not appear that the value of research producing these types of negative outcomes is being fully leveraged. It appears that TEA analysis of the use of electroflocculation for harvest indicates that dissolved air floatation remains a better alternative. A rigorous comparison between these two technologies was not presented. Again, it appears that the value of a negative result from excellent research is not being fully utilized to redirect future efforts. The Phenometrics ePBR appears to have been deployed without rigorous validation against outdoor cultivation results from a variety of strains across various geographies with sufficient replication to provide statistical power. The effort in optimizing cultivation agronomics did not appear to be commensurate with the potential upside in productivity that might be achieved. Results from bioprospecting, strain improvement by directed evolution, and other non-genetic modification techniques were not presented in sufficient detail to determine if this approach is likely to succeed.
- This is the only algae-funded project to address all of the major steps in the algae process, from growth through conversion to fuel, made possible by the large number of working teams in this consortia and a very large budget (approximately $50 million). A tremendous amount of valuable data was generated over the past two years, which is a credit to the capabilities and management of the team. Nevertheless, it is not unreasonable to have expected more from the team given the expertise involved

and size of the budget. Testing of a fully integrated process using the best technologies developed (e.g., most productive algal strain, best cultivation techniques, best harvesting technology, best conversion technology) would have provided hard data on the process viability under outdoor (commercially representative) conditions. It appears in some cases that the best results from one team did not get fully translated and utilized by other teams working on downstream technologies. The difficulties in establishing a viable conversion pathway were important to discover, but one would hope that a fully vetted pathway would have been the end result, rather than a relatively last minute shift to HTL as a targeted pathway. The lesson learned here may be that bigger can be better to a point, but not indefinitely with respect to team size and budget in getting the most value on a project, and smaller consortia size may be the way to achieving more cost-effective results in the future. Full disclosure and discussion of all results (good and bad) should be included in the final report to allow future work to build on all that has been accomplished through NAABB.

- This was a large, seemingly unwieldy, very successful first run of BETO algal biofuels production pathways. There were some obvious holes in the ALU pathway (lipid extraction, lipid cleanup, and robust biomass evaluation via feedtrials) that are completely solvable in the next go around. The obvious criticism—the lack of linking together all the best technological processes discovered by NAABB—may only be obvious in retrospect, as there were many moving pieces. This historical effort was well-coordinated and well-led.

PI Response to Reviewer Comments

- NAABB provided both a depth and breadth of technologies and expertise that was possible only within a large, multi-organizational project. The internal peer review that was embedded in our approach enabled cross-fertilization of ideas and forced the highest quality out of each project. By having several projects focused on each step in the value chain of algae biofuels production, we demonstrated the agility to pursue new discoveries and quickly correct technical problems. Some examples are:
    - The strain bioprospecting effort yielded 30 strains that performed better than our bench mark strain (*N. salina*). Four new strains were taken to large outdoor cultivation with excellent results.
    - New tools were developed to evaluate and model productivity under simulated conditions in full light and temperature controlled ponds and were validated against outdoor pond productivity. The Phenometrics ePBR system, which only became available mid-way through the program, provided the team with an invaluable research tool for indoor optimization of cultivation conditions and for evaluating GMO strains.
    - The harvesting and extraction projects went through a rigorous TEA and down-selection process after 18 months, including comparison against conventional technologies such as dissolved air floatation, and resources were then focused on the most promising technologies.
    - A wide range of conversion technologies were evaluated against the cost constraints of harvesting and extraction.
    - Detailed analyses and modeling for economic and environmental sustainability were employed to guide the project throughout. Although full integration of new products across the entire project was not physically possible, we were able to link new products from different teams in several cases and conducted a futuristic analysis of full integration in the final TEA. As suggested by the reviewers, both the negative and positive results from NAABB will be integrated into a final assessment of the progress and recommendations for future research.

POND CRASH FORENSICS

(WBS#: 9.1.2.2)

Recipient:	SNL
Presenter:	Todd Lane
Total DOE Funding:	$800,000
DOE Funding FY13:	--
DOE Funding FY12:	$400,000
DOE Funding FY11:	--
Project Dates:	2010–2012

Project Description

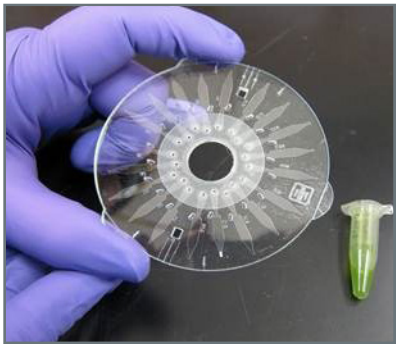
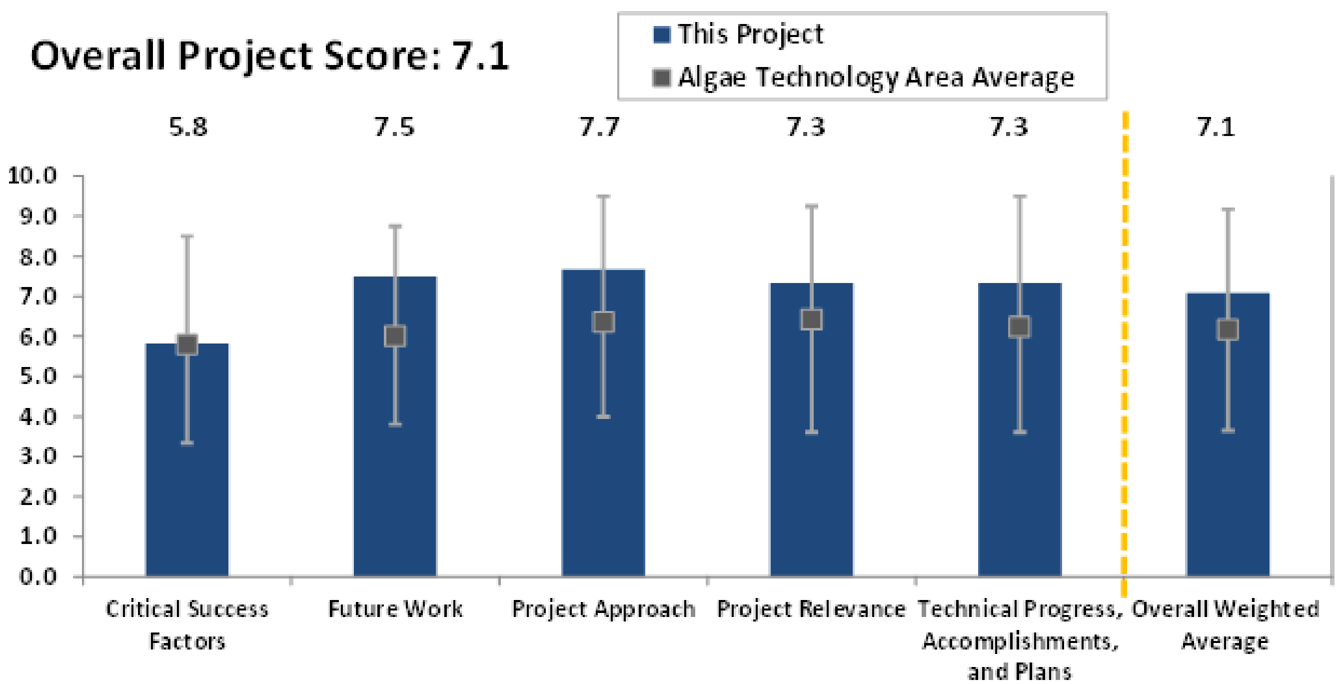


Photo Courtesy of SNL

Pond crashes are often attributed to a biological agent, such as a pathogen or predators. In many cases, it is difficult to determine identity of the etiological agent, so efforts at prediction, prevention, or control are effectively limited. The purpose of this project was to develop analytical tools and methods that can be used to identify the root causes of pond instabilities through the forensic analysis of samples taken from outdoor raceways and photobioreactors post-crash. Diagnosing the root causes of pond crashes is critical to informing the development of inexpensive screening and monitoring tools for early crash detection, as well as engineering and biological countermeasures that will enhance pond stability and increase long-term productivity. Over the last two years, we have developed a two-pronged approach to the identification and detection of the biological agents—forensic analysis of pond crashes and rapid development of pond-side assays for detection. Our pond crash forensics system takes advantage of microbiome analysis by second-generation DNA sequencing to provide a presumptive identification of the biological agent responsible for the pond crash. We have utilized this system to identify pond crash agents in a variety of ponds and photobioreactor systems without the need for the physical isolation of the agent. Once the pond crash agent has been identi-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

fied, we are able to rapidly produce detection assays for that specific agent. We have also demonstrated proof of principal of a potentially low-cost, hand-held, pond-side diagnostics system capable of detection of predators and pathogens in the algal background of pond samples. These assays leverage a Sandia technology, referred to as SpinDX, originally developed for clinical applications. SpinDX assays for algal pond contaminants feature a simplicity of operation and potential price point that would be appropriate given the economic constraints on the algal production industry.

Overall Impressions

- An excellent project that added important data and tools for achieving higher productivity in algal cultivation systems. Recommendations are to continue and expand this effort, and foster closer collaboration with academic groups that are performing similar work to leverage their data and capabilities to augment and accelerate this effort.
- The need to develop methods to avoid crashes in open ponds is clear. The work described in this project is a step in the right direction, but the true value is only as good as the viability of the database from which agents can be identified. More data are needed to prove robustness of detection and hardware under a greater variety of commercially relevant circumstances.
- This project demonstrates that quick and accurate identification of pond crash agents is achievable. It would have been very useful to see a quick OPEX cost analysis presented for a 1,000 acre production facility, as well as a plan to drive down the cost of analyses. The research here is exactly what DOE needs to be funding; in the future, projects such as this one should be strengthened by TEA.
- This is useful work.
- Very good progress is evident in the ability to quickly and economically identify microbiome populations to the genus or species level with great sensitivity. Significant challenges are in the development of causal relationships to predict and mitigate impending pond crashes, to the identification of biotic stresses causing yield reduction, and the determination of the presence of synergistic populations enhancing performance. The relative infrequency of pond crashes and the complexity of causes is a significant hurdle to successful development of the causal relationships needed to realize the benefits of this technology.

PI Response to Reviewer Comments

- In follow-up work (funded though the ATP3 consortium), we are developing collaborations with operators at geographically dispersed sites to increase our database on pond crashes and to develop more knowledge around frequency and causality. We intend to expand the range of contaminants for which we develop and validate assays. We are working to expand the database and extend the identification below genus level for key bacterial species.
- Our current costs are based on the retail price of reagents at the research laboratory scale. The current disc form factor allows for 36 assays on a single disk and the current per assay cost is approximately \$0.2. Therefore, the current costs (excluding labor) for the diagnosis of 24,000 samples would be \$5,000. The number of assays per disc could be increased by changing the form and channel density. Per assay costs for reagents, at production scale, are likely to be lower than those at R&D scale. Costs could be further reduced by commingling samples for initial screening analysis. Clearly, further R&D beyond the scope of the recently completed project, would be required to create a system that could be deployed in commercial operations. Development of a ruggedized fieldable system was not in the stated scope of this project. Such work could be carried out with a commercialization partner in the future.

PRODUCTION-SCALE PERFORMANCE OF LIPID HYPERACCUMULATING ALGAE

(WBS#: 9.1.2.5)

Recipient:	LANL
Presenter:	Taraka Dale
Total DOE Funding:	$225,000
DOE Funding FY13:	$225,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012–2017

Project Description

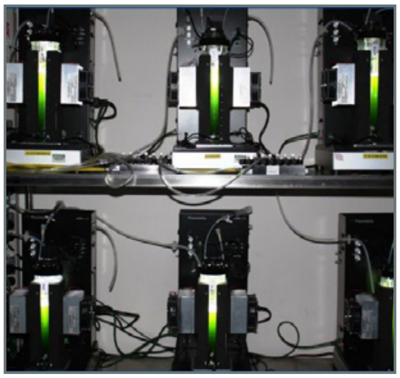
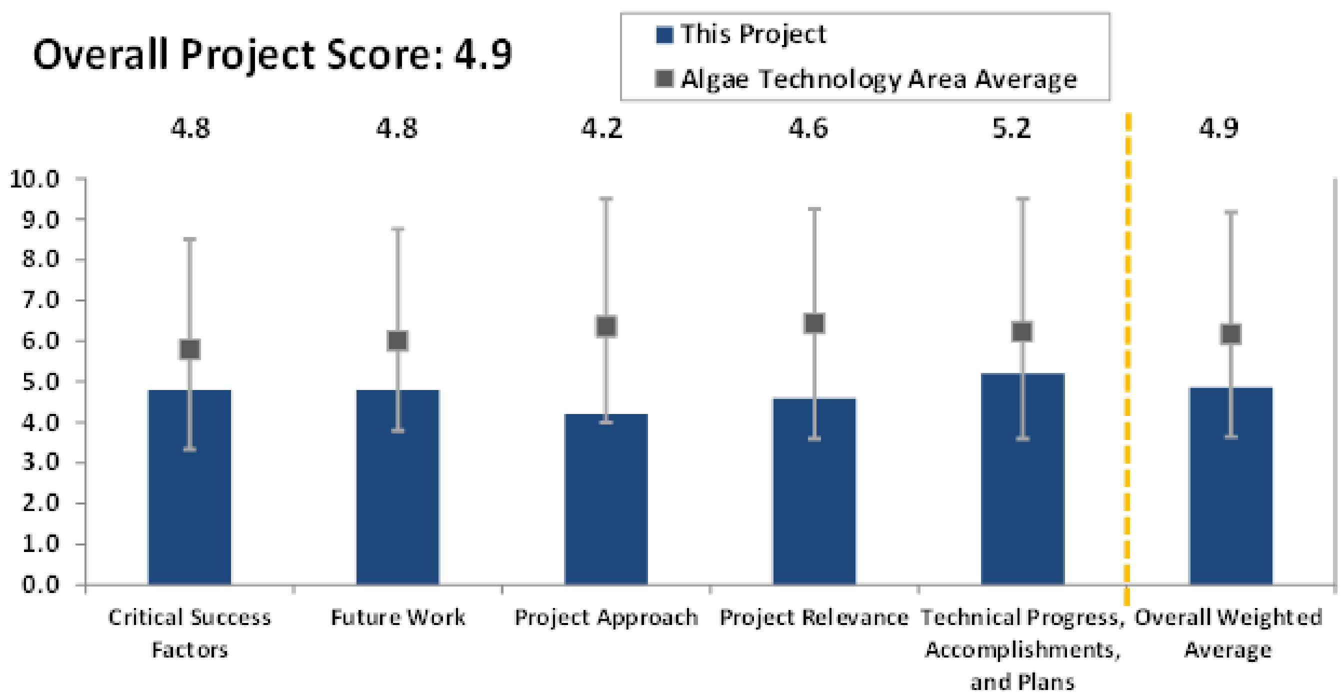


Photo Courtesy of LANL

The primary goal of this project is to develop an integrated pipeline for predicting and validating outdoor performance of any industrial or novel algae strain of interest. Often algae strains do not perform as well or as predictably outdoors as they do in the laboratory. Also, significant resources may be wasted on determining the geographic location that will generate optimal productivities of a strain of interest. To address these problems, we are using a lipid hyperaccumulating *Picochlorum* strain as an example strain to strengthen and validate the BAT, in collaboration with PNNL. Our process involves characterization of improved strains, such as the lipid hyperaccumulator; prediction of optimal productivity locations using the BAT; mid-scale characterization under conditions simulating the climate of the optimal location; and integration of the data to further improve the model. To date, we have characterized our example strain and established growth conditions for it in the ePBRs, completing our first and second quarter milestones. Next, we will use light and temperature scripts to simulate the most productive month predicted by the biomass growth model in the ePBRs. These data will be incorporated into BAT, with growth data generated by PNNL in their



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

environmentally controlled indoor ponds with the same scripts. Thus, we will establish a novel and efficient procedure for determining the maximum achievable annual biomass and lipid productivities for new strains of interest. This pipeline can readily be applied to any other promising microalgae strains, thereby helping advance DOE's goal of achieving annual biomass productivities of 30 $g/m^2/day$. Importantly, our approach will significantly reduce the risks related to large capital expenditures associated with constructing and operating large outdoor ponds by determining *a priori* the locations of optimal biomass and lipid productivity.

Overall Impressions

- It should be a DOE goal to answer this project's two questions within its remaining time, via successfully benchmarking its laboratory and computational modeling to actual outdoor production of biofuel-relevant strains. These questions seem fully resolvable, and with a reconsideration of the direction of these projects, this appears to be a strong team to provide answers.
- The development of a simulation tool for predicting productivity potential of strains has value. A more rigorous plan for validation of the model appears to be needed, starting with strains that have a history of outdoor cultivation and cover a range of productivities, collecting input data for the model using these strains in the ePBR, then modeling performance and checking the model results against production data. To have confidence in the model, this needs to be a big effort—multiple strains by multiple locations with replications sufficient to provide statistical power. The gap of not considering abiotic stresses or synergistic consortia will significantly reduce the value of the model. There is a significant risk that the model will provide misleading results.
- The overall approach of this project has value, but apparent contradictions in different parts of presentation make it unclear exactly how the project will be executed. (Is the biomass growth model validated or not? Will more than one algae strain be investigated? How do results feed back to improve model performance?). The greatest benefit will come from validating the model under commercially relevant conditions with commercially relevant species.
- This project has access to some good tools that could be used in several different ways to contribute to BETO's objectives. The climate-controlled ePBRs could be used to generate database productivity versus climate data for a large number of productive strains. The flow cytometry laboratory could be used for strain development. The current work on strain development was hampered because the strain productivity and lipid content were both low. If further strain development work is done, then a better starting strain is needed, and the project needs to take advantage of the improved procedures that have been developed by other groups that are doing flow cytometry strain development work.

PI Response to Reviewer Comments

- We are confident that our team has the strength to answer these important questions.
- Our goal in this first year was to establish a pipeline that will add multiple strains, additional cultivation parameters, and outdoor cultivation sites in future years. Abiotic stress is being examined, and nitrogen depletion is important to include in the BAT. We agree that consortia effects are important for understanding performance outdoors and that any model without appropriate inputs can lead to misleading results. By increasing experimental data and parameter inputs, we will improve BAT performance to further establish it as an important tool for predicting algae outdoor performance.

- The BAT has been validated for two strains outdoors. Our original work plan includes adding strains and outdoor experiments in the near future. The ePBRs and environmental ponds are important because they allow a level of replicates and environmental regulation not available in the testbeds. Further, they permit the simulation of light/temperature conditions of a given location or month, without having to go to that location or wait for that month. This capability will be an important complement to the outdoor testbed experiments.
- Although *Picochlorum* productivity was predicted to be low, the environmental pond data showed that *Picochlorum* has real productivities of 15.6 g/m^2-day, similar to *Chlorella sorokiniana* (DOE1412), the best-performing strain tested in these ponds to date. Also, lipid productivities for this strain are high under nitrogen-deplete conditions. Therefore, *Picochlorum sp*. has strong potential as a production strain. Regarding flow cytometry procedures, we were one of the earliest groups to present this method for algae strain development at an international conference. Other groups have since attained similar results at an approximately three-fold increase in lipid content. Our flow cytometry methods and results were under-represented in the presentation because strain development was not a goal of this year's work.

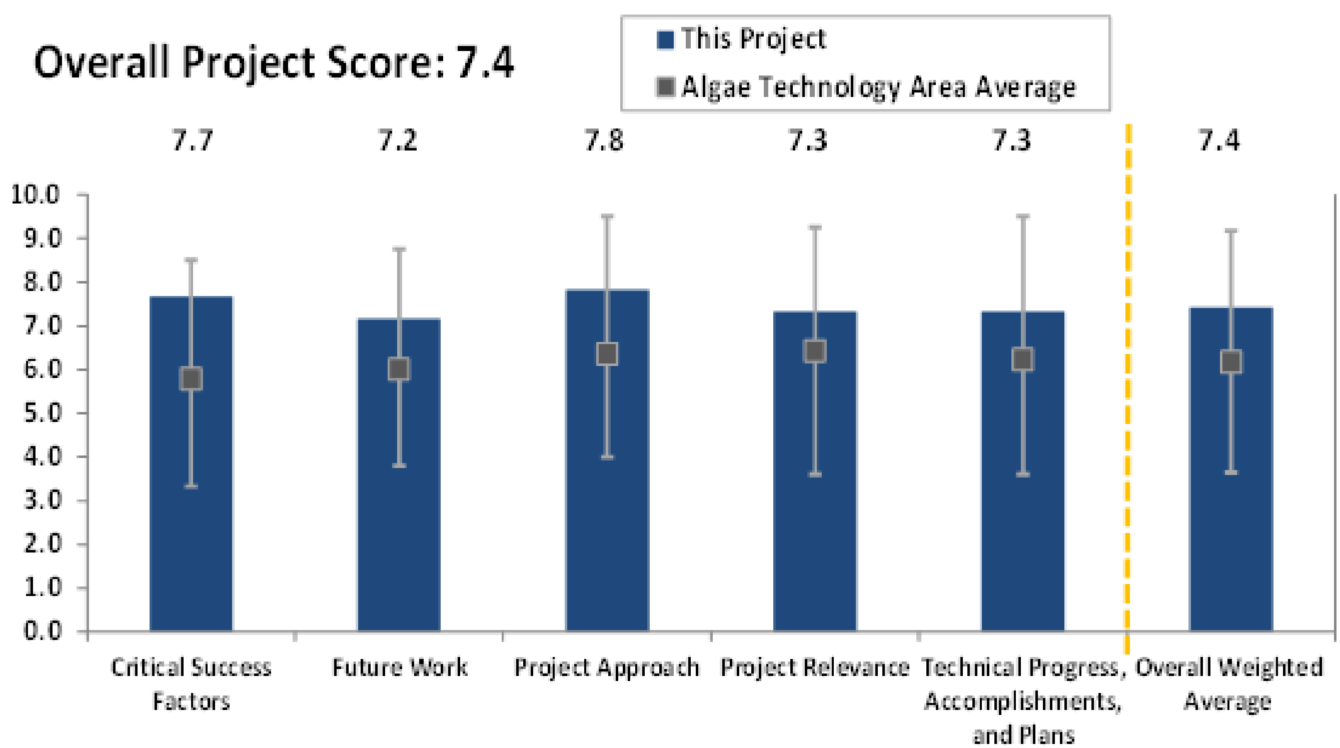
RECYCLING OF NUTRIENTS AND WATER IN ALGAL BIOFUELS PRODUCTION

(WBS#: 9.1.1.2)

Recipient:	California Polytechnic University
Presenter:	Tryg Lundquist
Total DOE Funding:	$1,306,070
DOE Funding FY13:	$290,237
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013–2016

Project Description

The objective of this project is to develop and demonstrate efficient recycling of water and nutrients in algal biofuels production, a fundamental requirement for such processes. The main objective of this three-year research project is to achieve at least 75% recycle efficiency (without significant loss in culture stability and productivity), both for the water recovered after harvesting the biomass and for the nutrients. Anaerobic digestion of the algal biomass will be the initial means of nutrient re-solubilization. Water and nutrient recycle rates of up to 90% will be tested, and factors that limit growth and productivity will be monitored (e.g., either nutrient limitations or the build-up of organic inhibitors). If organic inhibitors are found to limit the recycle potential, the compounds will be identified and removal methods will be tested. This project will operate nine existing experimental 33-m^2 (10-m^3 each) raceway, paddle wheel mixed algae ponds, made available to this project at the City of San Luis Obispo (California) Water Reclamation Facility. The algal biomass will be harvested by a low-cost settling process ("bioflocculation"), aided by centrifugation as needed. The supernatant water will be recycled back to the cultivation ponds. The harvested algal biomass will be anaerobically digested to produce biogas. Prior to digestion, the biomass will be pre-treated, if required, to break the cells (for transportation fuel production, the standard model includes digestion of residual extracted biomass to recycle carbon and nutrients). The digester effluents, containing the entire



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

suite of inorganic nutrients—nitrogen, phosphorous, potassium, and minor nutrients—will be recycled to the growth ponds. Initially, recycle of water and nutrients will be carried out independently, and then together. The results of those operations will be compared to controls without water and nutrient recycling. Make-up water (to compensate for evaporation and any needed blow-down) and nutrients (to compensate for losses) will be provided by settle wastewater or by fresh water and chemical fertilizers. Measurements of the influent and effluent water from the ponds and digesters, along with the N and P content of the algae biomass, will be used to construct mass balances describing the process. Our prior modeling of ammonia volatilization will be used to estimate that loss route. Laboratory algal growth potential studies will be conducted to detect any nutrient limitations appearing during water and nutrient recycle, or loss of growth potential (e.g., reduced productivity) due to build-up of inhibitory compounds. Nutrient and water recycling will be carried out in replicate experiments and over several months of continuous operations to demonstrate a stable process for maximal nutrient and water recycling in algae biomass production.

Overall Impressions

- Great job. Nutrient recovery is the problem. P is the limited resource. Create a large amount of protein with less phosphorus. Very experienced team; strong techno-economic model; work conducted outdoors. Small market opportunity where the essentials, land/waste and sunshine, exist. The project's weakness is that it needs a purge on the recycle. Inerts and metals need a blow-down. Additional thought needs to be executed.

- A well-conceived project that addresses the option of producing biofuel in conjunction with wastewater treatment. The project is based on a sound techno-economic model to drive the research and development and provide good technical targets. While algal biofuel production combined with wastewater treatment does not have as large a market as other algal biofuel approaches, it can materially contribute to algal biofuel production while simultaneously providing a lower energy and lower greenhouse gas emission wastewater treatment process.

- Studying the effects of nutrient recycle from AD in outdoor cultivation for extended times and using these data in TEA and LCA is a good approach. It appears that recycle will be from AD of lysed whole algae, which could affect results compared to HTL residue or LEA. The study will be affected by choice of strains and consortia of strains, and because no commercially viable strain has been developed, there is risk that research results will not apply to future commercial algal biofuel process. In the initial deployment of algal biofuels, nutrient recycle does not appear to be a killer issue, especially if strains with higher levels of carbon fixing to oils are developed. Harvest appears to be a more important short-term barrier to success than nutrient recycle, and bioflocculation could be a significant improvement. Increased research on bioflocculaton is recommended.

- This project focuses on nutrient and water recycle. The availability of a nine raceways at a wastewater treatment plant for use in this project is a significant benefit, as it will allow multiple tests to occur under commercially relevant conditions, as well as allow replicates and control tests to be run for better quality control. The full value of the data gained in these recycle tests will only be achieved, however, if the particular algae process configuration being demonstrated is economically viable. The inclusion of some equipment (e.g., bioflocculation, centrifuge) and the lack of certain basic features (e.g., a purge recycle line) create concern that the investigators do not have an economically viable process design. It is recommended that a cost estimate be performed early on in the project and possibly be included as a go/no-go condition to make sure that the recycle data gathered applies to a relevant design and helps to result in a net cost savings. Also, more details should be provided on the exact number of tests to be run, their duration (e.g., how many recycle loops will be demonstrated), and the conditions to be varied.

- With regard to nutrient recycling, this project is only applicable to the algal HTL pathway. Not to jump on a soapbox, but it is worth noting that in terms of whole world nutrient mass balances, one uses less phosphate per ton of algae protein produced than any other crop. Hence, when algae are grown to produce a protein co-product, one is lowering the worldwide cost of phosphorous (and protein). Utilizing this project's methodology to grow protein will be challenging due to the origin of the water (e.g., pharmaceuticals and hormone-like chemicals, among others in the source water). However, it would be interesting to compare TEA of this method to another approach, which would allow algae-produced protein to be sold as a co-product into the human/animal nutrition markets.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

RISK ASSESSMENT OF ALGAL PRODUCTION SYSTEMS: IMPACTS ON GROWTH, BIOMASS-LIPID QUALITY, AND BIOACTIVE METABOLITES

(WBS#: 9.6.1.5)

Recipient:	Savannah River National Laboratory (SRNL)
Presenter:	Kitt Bagwell
Total DOE Funding:	$1,340,319
DOE Funding FY13:	--
DOE Funding FY12:	$600,000
DOE Funding FY11:	$740,319
Project Dates:	2010–2012

Project Description

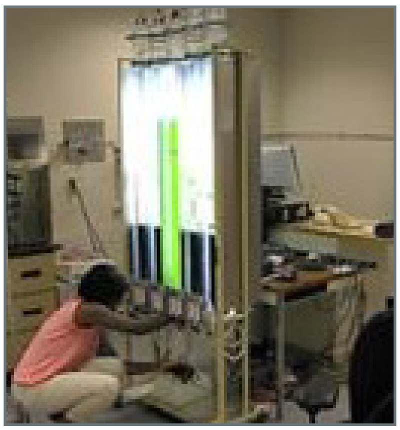
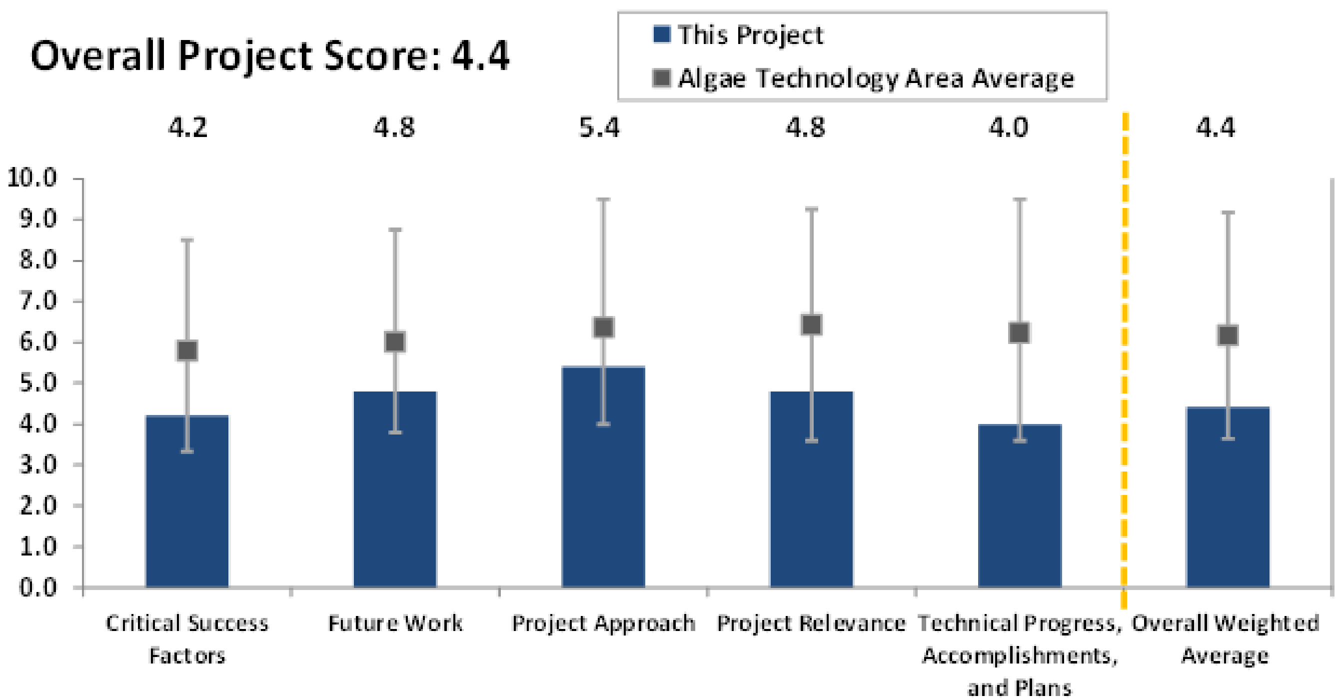


Photo Courtesy of SRNL

The aim of this research was to evaluate scaled growth of algae in outdoor production systems for emergent properties that could potentially impact the environment or human health. Research objectives were designed to broadly consider the potential for risk by identifying hazard(s) and likely exposure route(s) to sensitive end receptors. These findings would then frame the need for detailed risk assessment analyses and development of appropriate mitigation strategies for biofuel production systems. This project was conducted in two phases over a two-year period of performance. Phase one provided a cursory survey of algal production platforms for the occurrence of potential human pathogens or confirmed toxin-producing microbes, cytotoxicity of algal biomass and production waters, emission of noxious volatile organic carbon, and the bio-accumulation of toxic metals/metalloids in produced biomass and water. Phase two involved the design and operation of outdoor experimental raceways to quantify the outcomes of natural environmental perturbations, temporal biofouling (e.g., build-up of competitors and



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

predators), and water chemistry on the production of different biofuel candidate strains of algae. Additionally, statistical linkages were explored between aspects of the water cycle (operational parameters, nutrients, and inorganic chemistry) and elemental composition of the biomass in these systems. Human health risks and environmental impacts related to aquaculture are generally well established; however, little consideration thus far has been extended to the algal biofuel industry. Importantly, this research clearly demonstrates the potential for environmental and human health hazards to arise in association with large-scaled production of algae. Therefore, appropriate risk assessment capabilities and mitigation strategies should be carefully considered in-step with the development, expansion, and deployment of algae biofuels.

Overall Impressions

- It is very difficult to balance the value of identifying and addressing potential risks with the possibility of being unnecessarily alarmist. This balance is made especially difficult by the nascent state of algal biofuel technology with uncertainties in biology and process. I think this project did a pretty good job of maintaining balance and perspective. Although there are clear barriers to collaborating with commercial algae producers, the project could have put the potential for risk into better perspective by collaborating with commercial algae operators and analyzing current end uses of algae, which include human nutritional supplements. Recommended future work to "provide quantitative characterization of bioactive metabolites produced by biofuel algae to enable proper risk assessment to human health and the environment" appears to be premature given the state of technology development. There are too many uncertainties in biology, cultivations, and downstream processes.
- Those who develop methods to screen for contaminants will be driving which contaminants are screened for when fully integrated algal biofuels production commences. This project demonstrates that this task should be revisited when economically feasible pilot/demonstration production is demonstrated and sufficient biomass is produced for quantitative risk assessments.
- Though there has been no significant occurrence of toxins in algae production to date, the need to do a formal assessment of potential human health hazards in algae production is not unreasonable. The lack of quantitative results in this study in favor of more vague qualitative assessments diminishes its usefulness for the amount of money spent. A quantitative and more rigorous risk assessment would have been more cost effective.
- While risk assessments and safety protocols are important, the overall project approach was flawed because it did not look at the decades of algal cultivation and consumption as a primary source to assess risk levels and determine where to focus resources. The end result is that no actual risks were identified, quantified, or assessed. Several areas were probably not worth investigating, such as cytotoxicity, because people and animals have been eating algae for centuries, so there is no generic problem with cytotoxicity. In fact, algae consumption is typically considered a way to improve health.

PI Response to Reviewer Comments

- The aim of this research was to evaluate scaled growth of algae in outdoor production systems for emergent properties that could potentially impact environmental or human health. We openly recognize the limitations of this project and the implications of a risk assessment investigation. This project attempted to span many variables, scenarios, strains, and platforms in order to draw a consensus on the potential for risk and realistic pathways to sensitive end receptors. Perhaps our approach was not ideal, but it was reasonable. This project did capture a snapshot of the industry as it exists now, not in the future as a mature technology. Furthermore, the general foci of this project will remain relevant well into the future; that is the influx of contaminants, propagation of pathogens, water quality, volatile organic carbons, identification of high value co-products, and safe re-use of algal by-products.

- Many of the reviewer's critiques centered on the issue that biofuel candidate strains of green algae were shown to be capable of synthesizing and accumulating bioactive metabolites. First, there is much we still do not know about the fundamental biology of eukaryotic microalgae (e.g., photosynthesis and carbon partitioning), so perhaps it should not be terribly surprising to discover novel metabolites. Secondly, cytotoxicity screening of produced algae was intended to be informative, not alarmist, and the carefully designed, follow-on experiments performed unequivocally verify the production of diverse, cytotoxic metabolites in response to iron limitation. We do not know, nor do we claim that these metabolites pose a specific risk for human or animal consumption but simply that metabolite production occurs in response to a condition likely to occur as a consequence of biomass buildup or intentionally imposed for TAG biosynthesis. We agree that the relevance of this outcome should be explored with industry partners; however, new discoveries like this create opportunities for innovation.

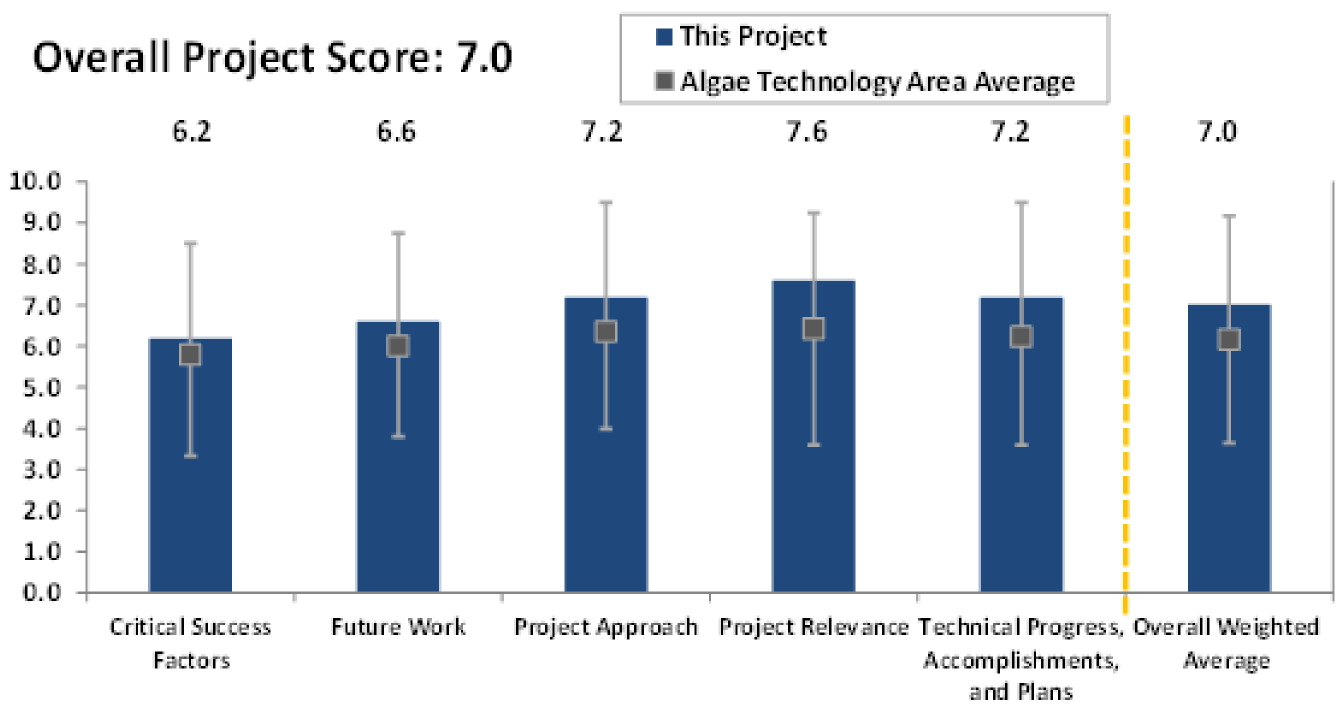
SUSTAINABLE ALGAL BIOFUELS CONSORTIUM

(WBS#: 9.1.4.1; 9.1.4.2; 9.1.4.3)

Recipient:	SABC
Presenter:	Gary Dirks
Total DOE Funding:	$6,000,000
DOE Funding FY13:	$700,000
DOE Funding FY12:	$3,300,000
DOE Funding FY11:	$2,000,000
Project Dates:	2010–2012

Project Description

Assuming moderate algal biomass productivity of 25 g/m^2/day with a 30% oil (triacylglycerol) content (on dry cell weight basis), a biofuels industry that uses approximately 5 million acres cultivating its algal biomass in outdoor open raceway ponds and/or closed photobioreactors would be capable of producing about 13 billion gallons of oil. This level of production would also result in the co-generation of about 116 million tons of lipid-extracted biomass residue per year. Although much thought has been given to development of high-value co-products from algal biomass, few of the proposed co-products match this volume of biomass to be generated. This issue of scale indicates that conversion of algal biomass for the production of additional non-lipid-based advanced biofuels is a requirement for profitable biofuels production and offers realistic solutions for cost-effective biomass utilization, especially in light of the recent progress toward attainment of techno-economic targets for economical production of advanced biofuels. A number of potential process improvements may be realized through biochemical conversion of algal biomass. Biochemical processing of whole algae has the potential to eliminate costly drying and extraction steps, and application of multiple enzyme cocktails to whole algae may enable simultaneous or sequential production of lipid-based and fermentable sugar-based fuel intermediates, allowing for a new paradigm in algal biomass processing. The goal of this project was to evaluate biochemical conversion as a potentially viable strategy for converting algal biomass into lipid-based and carbohydrate-based biofuels and to evaluate the fit-for-use properties of those algal-derived fuels and fuel



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

intermediates. Our approach included a feedstock matrix of algal biomass based on species and growth/process conditions; determining biochemical composition through rigorous, advanced analytical methodology; and exploring multiple enzymatic routes to hydrolyze and convert untreated or pretreated whole algal biomass, oil extracts, and algal residuals into fuels or fuel intermediates. In this way, we have identified a novel process configuration that can make use of all major components of algal biomass (lipids, proteins, and carbohydrates) as feedstocks for biofuel production. This process has the potential to greatly increase the biofuel yield per ton of biomass beyond that of the base-case algal lipid process and beyond that of the current biochemical or thermochemical conversion processes for terrestrial biomass.

Overall Impressions

- It cannot be understated how critically important it was to have developed a large, well-run, well-led consortia of algae researchers. Producing a fully integrated commercial production facility is too large a task for any one laboratory or set of national laboratories. This project demonstrates a collaborative effort that in its next incarnation, the ATP3, will take DOE to the next milestone of commercial production—growing several hundred tons of biomass in order to integrate technological processes and scale-up to a single pilot-scale production facility.
- Successfully pretreating and hydrolyzing algae to produce amino acids and sugars may enable new biofuels and bioproduct pathways. The effects of freezing and thawing algae may have significantly affected experimental results. The project would have benefited from incorporating a preliminary mass balance, assuming best-case process yields into a preliminary process-flow diagram. The very dilute nature of the sugar and amino acid hydrolysates make fermentation and fuel recovery uneconomical and energetically unfavorable. Fermentation of amino acids to mixed alcohols appears to have very significant issues with the alcohols affecting membranes in the fermentation organism, likely limiting titer to uneconomically low values. These are "killer issues" that need to be presented and addressed. If fermentation is pursued, future work must focus on increasing feedstock concentration, fermentation titers, and improving economics. These are extremely challenging barriers. The other potential co-product uses for the amino acids should be investigated. Improving assays for algae lipids, carbohydrates, and proteins was significant. Although success at fuel conversion is nice to have, the ability to convert crude algae oil to fuel does not appear to be a killer issue for algal fuel viability. Bioprospecting for hydrolytic enzymes in rotifers and other grazers might provide interesting leads. In concept, if the right suite of enzymes is developed, whole algae might be digested to provide lipids, sugars, and amino acids for relatively easy separation.
- The work performed focused on several upstream and downstream tasks in the complete algae to fuel process and has generated much useful data. The work on algae strain identification and development of methods has been performed by one or more other BETO projects and may not need to have been repeated here. Even if algae had to be generated (instead of obtained elsewhere) for downstream tests, less effort could have been spent on strain identification and instead devoted to conversion work. The conversion work shows promising results. The novel/unique improvements that have been developed/pursued should be emphasized in the final report and include all work that was not successful so that future work in those areas will not be repeated. The fuel fitness testing was unique among BETO projects. The separate conversion of carbohydrates, lipids, and proteins captures value for all biomass but adds more process complexity (compared to hydrothermal treatment of all biomass, for instance). What is missing is a rough estimate of costs to gauge how viable the proposed process is for commercial implementation. This information is crucial in the evaluation of viable pathways. Achieving technical viability is important but cannot be useful if the cost to perform the given function is too high. Quantitative target values are also necessary to accurately gauge how well the

proposed process performs toward meeting overall BETO goals. Finally, given the effort spent in identifying different algal strains, a discussion on how the downstream data and performance may be affected by use of different species (e.g., how species insensitive are results) would be helpful.

PI Response to Reviewer Comments

- The dilute nature of the sugar and amino acid streams presents significant technical hurdles for economic conversion, but we do not believe this is a killer. Our scope was to explore conversion at a larger scale (than bench), under process relevant conditions (e.g., high-solids loading, using industrial equipment and practices) demonstrating proof of concept using thermochemical conversion and fermentation of the algal liquor, not process optimization. The sugar concentration and ethanol titer is a function of percentage of solids loading of the algal biomass into the batch reactor and subsequent direct steam heating of the algal biomass during pretreatment. We selected conditions that required more time and steam consumption, which diluted our final sugar concentration but allowed better control of the pretreatment process. Based on these preliminary, yet very promising results, we are confident we can increase both sugar concentration and ethanol titer by optimizing steam consumption and increasing solids loading into the reactor. The amino acid titers for fermentation were not reported in the presentation, but we believe that we could achieve 10–15% at scale, but this would depend on the overall algae composition (proteins, carbohydrates, and lipids). These strategies have been used successfully, as evidenced in recent cellulosic ethanol demonstration presented by NREL at the DOE review meeting. Due to logistics associated with the algal production at Arizona State University and the conversion work in Colorado (NREL), every attempt was made to minimize the effect related to both shipment and subsequent freezing. While freeze-thaw cycles could affect algal biomass with thin cell walls, photomicroscopy of the SABC defrosted cultures revealed robust cells with complete cell wall architecture, suggesting minimal change. We agree that future approaches will benefit from pursuit and application of enzyme cocktails allowing for 'one-pot' conversion and ease of separation, and this is something we continue to pursue.
- SABC did not perform strain identification and development as part of this effort. We used commercially relevant species with which we had significant experience growing outdoors. We did spend time on biochemical composition assessment as a function of cultivation conditions to set production process conditions (nutrients and time to harvest), but the cultivation subtask's primary purpose was to supply biomass of controlled composition, allowing for SABC to explore the sensitivities of strain/composition on both analytical measurements as well as downstream conversion processes. We disagree with the opinion that our method was redundant in the context of understanding analytical measurement bias as a function of species and composition, and that the method itself was potentially redundant. We feel this was a seminal piece of work—something that was highly praised at our initial peer review two years ago—and was and is seen as contributing to the body of knowledge in a very practical way for the industry. The work performed on biochemical compositional method improvements and standardization is critical to accurate TEA/LCA, and it is a cornerstone of additional follow on work at the national laboratories, as well as in ATP3. We agree with reviewers that robust TEA would provide key and necessary information to guide development of this or any process; however, this was explicitly not part of our scope. It was within our scope was to make these data available to modelers, in particular for TEA. We have begun building a TEA model for our algal process using the data produced from the SABC work presented at the review meeting. The model builds off of the algal TEA presented by Ryan Davis at the DOE review meeting. The preliminary update of this model's incorporation of SABC data has been submitted to BETO and is under review.

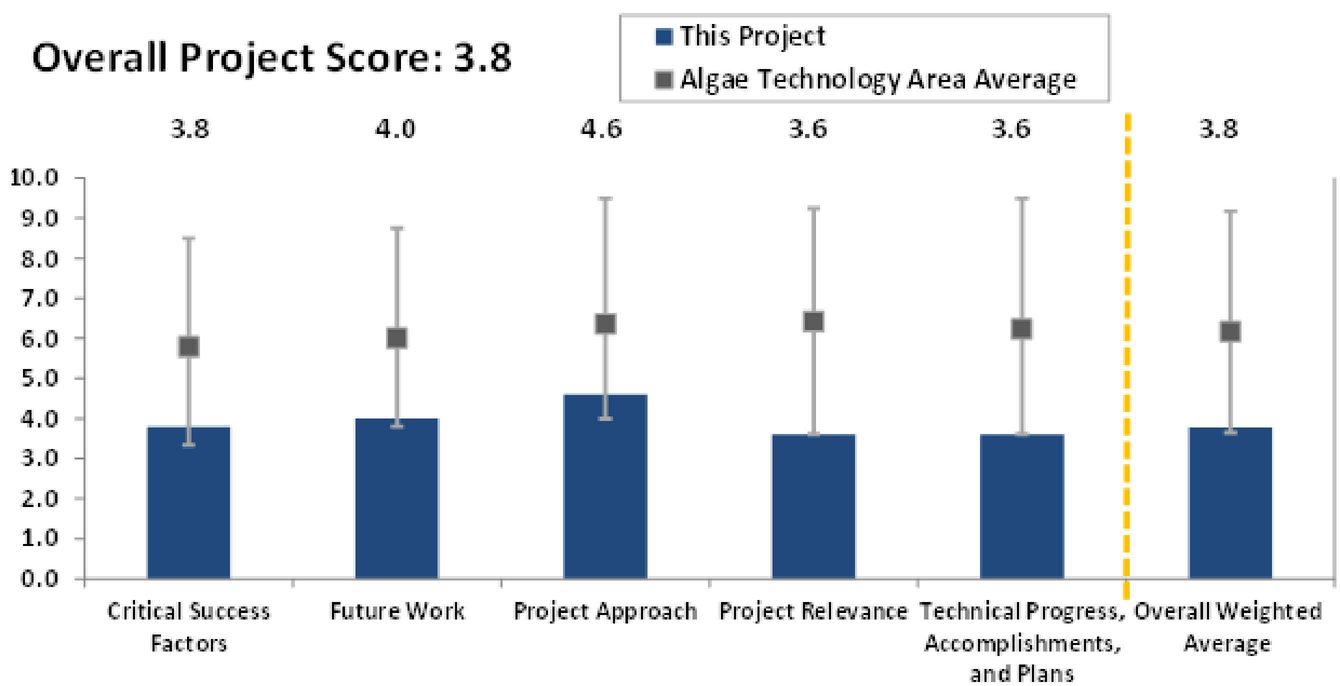
SUSTAINABLE DEVELOPMENT OF ALGAE FOR BIOFUELS

(WBS#: 9.6.1.9)

Recipient:	ORNL
Presenter:	Rebecca Efroymson
Total DOE Funding:	$350,000
DOE Funding FY13:	$350,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013–2018

Project Description

Algae hold promise as a source of liquid fuel, in part because of anticipated sustainability benefits. However, commercial development of algae for biofuels lags behind other feedstocks because of high production costs using current technologies. Sustainability and resource analysis research and development for algae is also behind that of other feedstocks. This project aims to identify sustainability indicators, targets, and best management practices for algal biofuels and modify and apply resource analysis tools for algae. A practical set of indicators will aid in the quantification of benefits and costs of algal biofuel production and use, and it will be instrumental in comparisons of pathways and production sites. In the first task, we evaluate environmental sustainability indicators proposed previously for soil quality, water quality, water quantity, greenhouse gas emissions, biodiversity, air quality, and productivity, as influenced by bioenergy. In the second task, algal resources are being introduced into the economic model used in the *Billion-Ton Update*—Policy Analysis System model (POLYSYS). Collaboration with PNNL suggests that the potential for land competition between terrestrial and algal feedstock production is negligible. The addition of an algae module in POLYSYS allows for projection of potential algae production at expected price scenarios and evaluation of cost reductions needed to make algae production economically competitive with other land uses. Potential production of algae from niche applications (e.g., co-location with power plants) will also be quantified. This is a new project, and completed products include a Beta version of the Algae Production Module in POLYSYS, a paper on land



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

competition between algae and terrestrial feedstock systems, and a webinar to engage the research community in sustainability indicator evaluation. Improved sustainability and resource analyses will focus the commercial development of algal biofuels on viable, sustainable, and competitive scenarios.

Overall Impressions

- Most of the activities in this project are premature because there is no case study or economical system to use for the baseline sustainability and resource analyses. If work is going to be done in this area, even though it is premature, then the most beneficial approach would be to look at a few different cases in which the techno-economic model is modified to incorporate potential improvements that result in an economical process; then perform the resource requirement analyses and LCA on these processes. That would provide new information, and it would provide a substantially more realistic assessment of the impact of a commercial algae biofuel industry because any algae biofuel industry is going to be based on an economical process.
- Several previous sustainability studies for algal biofuels were based on scenarios that are very far from economic viability at approximately $20/gallon fuel minimum selling price. These scenarios create concerns about sustainability issues that will never exist. When algal biofuels technology is deployed commercially, algal productivity will necessarily be several times higher than current values, with better utilization of inputs. This project should look at the sustainability of algal biofuels for economically viable scenarios that are likely to be deployed with comparison to current state of technology scenarios. The presentation did not make this critical point clear. Much of the future work could be premature. Although it is good to get in front of sustainability issues, there is so much uncertainty about algal strains, cultivation, harvest, extraction, and co-products that the sustainability work will be highly speculative. There appear to be risks of premature dissemination of analysis results that are either based on non-viable scenarios that will never happen, or are based on highly speculative scenarios that are unlikely to be correct.
- There seems to be a gap here in the timeliness of using the efforts of this team without duplicating TEA modelers' efforts. The work proposed by this project would be best funded once pilot/demonstration scale of ALU and algal HTL pathways has been demonstrated.
- While the importance of addressing sustainability and resource analysis is clear, the specific approach to be taken by the team appears to lack sufficient detail to know for sure if the plan will be successful. Some specific tasks, such as updating sustainability indicators and the POLYSYS model for algae inclusion, would be valuable.

PI Response to Reviewer Comments

- Regarding the sustainability task, the reviewers note that the uncertainties associated with algal strains, cultivation, harvest, extraction, and co-products make the sustainability work "highly speculative." They also note separately that updating sustainability indicators would be valuable. We are focused for the first two years of the project on evaluating and updating environmental and socioeconomic sustainability indicators. Many scientists and engineers believe that sustainability must be integrated into process design early, before design choices become less flexible. We also note that the sustainability indicators we are proposing are largely independent of algal strain; cultivation, harvest, or extraction method; and particular co-product. We have added a go/no-go milestone for 2014 that will provide a preliminary assessment of potential case studies for applying sustainability indicators. The assessment will use reasonable technical assumptions for processes that experts believe to be moving toward economic viability (per peer review recommendations). These may include algal lipid upgrade and/or hydrothermal liquefaction energy pathways, as suggested by peer reviewers.

- Regarding the resource analysis task, the project was initially focused on developing an algae module for the POLYSYS model. This was in response to industry concerns that the *Billion-Ton Update* had not included algae in its resource analysis estimates for bioenergy. An analysis was conducted to determine where terrestrial and algal feedstocks might compete, and the finding was that competition was unlikely and only might be an issue on a small fraction of pastureland. Future resource analysis work will be aimed at emphasizing the most likely algae production scenarios (e.g., co-location with wastewater resources and/or power plants), but the resource analysis task has been delayed until at least fiscal year 2015 until process costs are better understood. We are taking TEA results (cost targets) as inputs to the resource analysis; we are not duplicating TEA modelers' efforts.

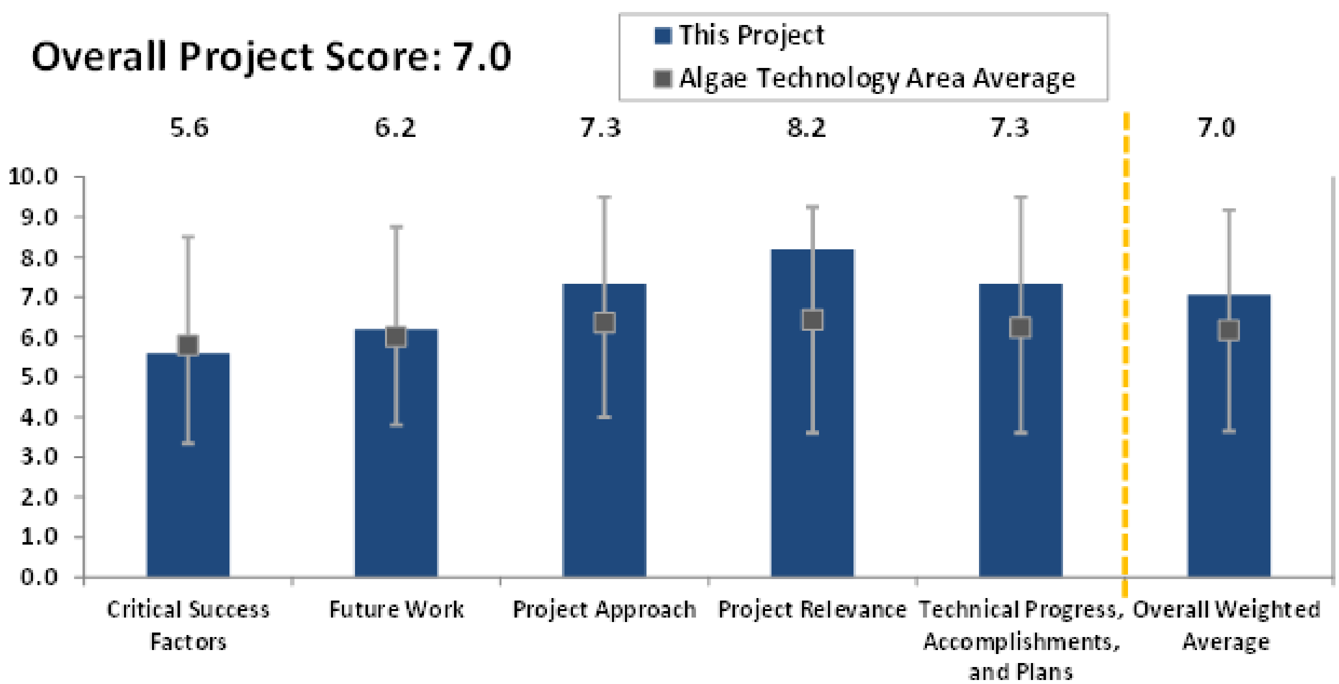
WHOLE ALGAE HTL MODEL

(WBS#: 9.3.2.1)

Recipient:	PNNL
Presenter:	Daniel Anderson
Total DOE Funding:	$243,000
DOE Funding FY13:	$243,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012–2015

Project Description

The project will develop sufficient data to formulate a robust and detailed techno-economic model of the algae HTL process. The integrated algae HTL process also includes catalytic hydrotreatment of the HTL bio-oil product catalytic hydrothermal gasification (CHG) applied to the aqueous by-product. The project is aligned with BETO's goal to achieve annual productivity equivalent to 1,500 and 2,500 gallons per acre per year by 2014 and 2022, respectively, by significantly increasing the yield of fuel form microalgae biomass. The project has leveraged process data from the NAABB to build initial models, complete a tech memo, and provide modeling input to algae model harmonization group in fiscal year 2013. One additional set of experimental data for HTL, CHG, and hydrotreatment is focused on using a freshwater microalgae strain that will be developed in fiscal year 2013 to update the models. The research and development approach relies on using initial process data from NAABB to build process models (HTL, hydrotreatment, CHG), followed by TEA and LCA sensitivity analyses to understand variances and significant impact areas for further optimization. Targeted research and development will be conducted to improve process performance for HTL, CHG, and hydrothermal processes. These results will be used to update models and to direct targeted research in fiscal year 2014–2015 to optimize yields and processing conditions. These data will be used to further update the model, state of technology, and harmonization modeling efforts within BETO.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Enhance the separations and look at operating conditions. What do best-case economics look like?
- Excellent work putting together a TEA model quickly for a process that is widely being pursued and good leveraging of existing models and projects generating data on the HTL process. However, the model is not being adequately used to drive the planned research and development. The model should be used to investigate the potential for economic viability of the process for algae biomass and to set appropriate research targets if there is a path to economic viability. Future work should leverage the extensive HTL work that has been done for terrestrial biomass conversion to understand the challenges and obstacles. Also, since terrestrial biomass production will be 5-10 times less expensive than algae biomass production, there should be a determination of the conditions under which HTL could be economically viable for conversion of algae biomass, even though it is not economically viable for conversion of terrestrial biomass.
- This is a necessary project that would be best implemented in terms of developing cost points for each technology step and sensitivity of the entire pathway to changing algal or cultivation inputs.
- This project appears to be the only one in the current round of projects funded by BETO to focus specifically on algae conversion to fuel via HTL. This project is of high significance given the recent interest from several groups (including NAABB) in this technology as a viable means of algae processing and inclusion of HTL as one of BETO's official pathways to hydrocarbon biofuels. The development of a model that will be harmonized with other DOE modeling efforts and that will be used to direct targeted research and development tests is a good framework, and the team appears to be off to a good start. However, the lack of test details, lack of specific challenges identified related to HTL operation, and shaky answers to some questions given during the presentation lead to some concern regarding the experience of this team with HTL operation. Operation in water at temperatures just below the thermodynamic critical point (as identified during the presentation) is where corrosion can be most severe, especially in the presence of heteroatom species, such as chlorine, sulfur, and phosphorous. Salt solubility may also be poor in this operating region, leading to fouling and/or plugging. Having a good understanding of the feed composition and paying attention to proper materials of construction is vital to avoiding costly delays and shutdowns associated with equipment failure. The model should be formally validated at some point in this project against test data before being used to direct targeted research.
- The project leverages previous NREL modeling, expanding it to include the HTL pathway. The proposed targeted experimental work to better evaluate and develop the HTL process appears to be appropriate. The HTL process provides high fuel yields, even for algae that don't accumulate high levels of neutral lipids. This process appears to be similar to the Sapphire process. Current NREL TEA models do not include adequate details of this process to effectively direct research. This targeted research and model development will enable effective go/no-go decisions in pathway selection. The assumption that three-series stainless steel can be used without risk of stress corrosion cracking should be double and triple checked with metallurgical experts. HTL oil nitrogen content needs to be investigated. As with all modeling development, the utility of the model should dictate the complexity and detail of the model.

PI Response to Reviewer Comments

- We greatly appreciate the comments and suggestions from the reviewers. We are pleased the reviewers agree that this project is of high significance to DOE and that we have made excellent progress putting together the initial HTL pathway model and TEA. We agree that this model and associated sensitivity analysis should be used to drive the planned research going forward. As such, we will direct our future R&D efforts in fiscal year 2014 to focus on the most critical process parameters. As the reviewer suggests, some important parameters will most likely be separations and process conditions. Some of this R&D will be conducted as part of this HTL modeling project and through another DOE-funded R&D project (Thermal Conversion Interface Project) focused on developing some advanced HTL concepts to improve yield, separations, and process integration with hydrotreatment and CHG. We agree that it is important to leverage the R&D efforts focused on the HTL work that has been done for terrestrial biomass. We are uniquely able to take advantage of these synergistic R&D efforts since PNNL is leading the DOE efforts for HTL processing and upgrading HTL bio-oil and catalytic hydrothermal gasification of the aqueous phase for both algae and terrestrial feedstocks. Perhaps we fell short on providing enough details of the experience of our team and our experimental plans the during the peer review. We believe that we have assembled the most qualified team to perform HTL R&D at PNNL, and we are working directly with industrial partners to assist them in the commercialization of the HTL pathway for algal biomass as a validation of our experience and capabilities.

ANALYSIS AND SUSTAINABILITY

TECHNOLOGY AREA

INTRODUCTION

The Analysis and Sustainability Technology Area was one of nine key technology areas reviewed during the 2013 Bioenergy Technologies Office (BETO or the Office) Project Peer Review, which took place on May 20–23, 2013, at the Hilton Mark Center in Alexandria, Virginia. A total of 29 projects were reviewed by five external experts from industry and academia. This review represents a total U.S. Department of Energy (DOE) value of approximately $48 million, which is around 3% of the BETO portfolio reviewed during the 2013 Peer Review. The principal investigator (PI) for each project was given approximately 30–45 minutes to deliver a presentation and respond to questions from the review panel. Projects were evaluated and scored for their project approach, technical progress over two years, relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Project Peer Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI for the project. Overview information on the Analysis and Sustainability Technology Area, full scoring results and analysis, the Review Panel Summary Report, and the BETO Programmatic Response are also included in this section. BETO designated Alicia Lindauer and Kristen Johnson as the Analysis and Sustainability Technology Area review leads. In this capacity, Ms. Lindauer and Ms. Johnson were responsible for all aspects of review planning and implementation.

ANALYSIS AND SUSTAINABILITY TECHNOLOGY AREA

OVERVIEW

Enabling long-term viability of bioenergy systems is a critical component of the Bioenergy Technologies Office's mission to reduce dependence on oil. The Office is focused on developing the resources, technologies, and systems needed to grow a biofuels industry in a way that protects natural resources and maximizes economic, social, and environmental benefits. To that end, the Analysis and Sustainability Technology Area is addressing the challenges related to sustainable bioenergy production and use by supporting analysis, data collection, modeling, and applied research and development (R&D) projects. This Technology Area works collaboratively with industry, academia, national labs, nongovernmental organizations (NGOs), other agencies, and international partners.

The Technology Area plays a cross-cutting role both within and outside the Office. It contributes to portfolio planning and works with other BETO technology areas to develop and advance technology-specific sustainability and analysis objectives. Externally, it monitors and provides technical input to policy, scientific, and international dialogues relevant to bioenergy.

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

ANALYSIS AND SUSTAINABILITY SUPPORT OF OFFICE STRATEGIC GOALS

The Analysis strategic goal is to:

> *Provide context and justification for decisions at all levels by establishing the basis of quantitative metrics, tracking progress toward goals, and informing portfolio planning and management.*

The Sustainability strategic goal is to:

> *Understand and promote the positive economic, social, and environmental effects and reduce the potential negative impacts of bioenergy production activities.*

ANALYSIS AND SUSTAINABILITY SUPPORT OF OFFICE PERFORMANCE GOALS

Strategic Analysis activities provide information necessary for establishing Office goals and priorities. Activities address issues that cut across technology areas and are designed to support BETO decision-making processes, validate decisions, ensure objective inputs, and respond to external recommendations. Complementary activities in the portfolio are aimed at advancing the state of the science and engineering within areas such as land-use change (LUC) modeling, impact analysis, and life-cycle assessment (LCA).

Sustainability activities support accomplishing BETO's goals by proactively addressing issues that affect the scalability, public acceptance, and long-term viability of the Office's technology investments. Sustainability activities also equip BETO with the necessary data, analyses, and expertise to engage in national and global dialogues on bioenergy sustainability. Sustainability analysis and research objectives include reducing the greenhouse gas emissions associated with bioenergy production and use; maintaining or improving soil quality; maintaining or improving water quality and water-use efficiency; minimizing air pollutant emissions; preserving ecological systems; and promoting land-use efficiency and beneficial landscape design.

TECHNICAL AND MARKET CHALLENGES AND BARRIERS

BETO has identified the following key challenges for achieving the goals of the Analysis and Sustainability Technology Area:

SUSTAINABILITY CHALLENGES
Scientific Consensus on Bioenergy Sustainability
Consistent and Evidence-Based Message on Bioenergy Sustainability
Sustainability Data Across the Supply Chain
Implementation of Indicators and Methodology for Evaluating and Improving Sustainability
Best Practices and Systems for Sustainable Bioenergy Production
Systems Approach to Bioenergy Sustainability
Representation of Land Use and Innovative Landscape Design

STRATEGIC ANALYSIS CHALLENGES
Lack of Comparable, Transparent, and Reproducible Analysis
Limitations of Analytical Tools and Capabilities for System-Level Analysis
Inaccessibility and Unavailability of Data

APPROACH FOR OVERCOMING CHALLENGES

The Analysis and Sustainability Technology Area works to overcome the above challenges by developing and disseminating knowledge, tools, and mechanisms for more informed decisions and better resource management. Key partners include national laboratories, including Argonne National Laboratory (ANL), Idaho National Laboratory (INL), the National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and the Pacific Northwest National Laboratory (PNNL); NGOs; academia; industry; and international organizations. This technology area coordinates internally and externally, working closely with BETO's other technology areas, DOE offices, and federal agencies, such as the U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA), the Department of Defense, and the Department of Transportation. Robust stakeholder engagement—through workshops, roundtables, and other means—helps advance cross-cutting objectives.

The Strategic Analysis portfolio is designed to overcome the identified challenges by ensuring high-quality, consistent, and reproducible analyses; developing analytical tools, models, and datasets to advance the understanding of bioenergy and its related impacts; and conveying the results of analytical activities to a wide audience, including DOE management, Congress, the White House, industry, and the general public.

Strategic Analysis projects include resource, techno-economic, and life-cycle greenhouse gas (GHG) assessments, as well as market, scenario, and impact analyses. System-level policy, industry, and environmental analyses inform program direction, help the Office focus its technology development priorities, and identify key drivers and hurdles for industry growth. Techno-economic assessment (TEA) activities identify and compare economics across technology pathways, explore sensitivities, and assess potential for cost reduction. Market assessment focuses BETO technology development priorities in the near, mid, and long term while impact analyses help the Office quantify and communicate the long-term benefits of biomass research, development, and deployment.

Sustainability projects collect and integrate data, develop decision-support tools for better resource management, and complete integrative analyses of bioenergy production scenarios at different geographic scales (field, regional, national, and global) to investigate environmental, economic, and social impacts. A key priority is to analyze trends and tradeoffs across multiple supply-chain components and sustainability categories.

Sustainability projects also generate new empirical data and develop novel practices that improve or maintain environmental performance and promote social benefits of bioenergy sustainability. Activities include developing frameworks to define and measure sustainability through appropriate indicators and metrics, conducting field research on best management practices for biomass production, and developing innovative approaches for spatial and multi-metric optimization.

Outcomes from the Analysis and Sustainability activities are disseminated through publications, web tools such as the Bioenergy Knowledge Discovery Framework, interagency coordination, and domestic and international stakeholder interactions. They are also used by the Office to inform technology research, development, demonstration, and deployment to maximize beneficial outcomes.

For more information on the Analysis and Sustainability Technology Area, please review BETO's Multi-Year Program Plan (MYPP) at bioenergy.energy.gov/pdfs/mypp_may_2013.pdf.

REVIEW PANEL

The following external experts served as reviewers for the Analysis and Sustainability Technology Area during the 2013 Project Peer Review.

Analysis and Sustainability Reviewers	
Shelie Miller (Lead Reviewer)	University of Michigan
Jeremey Alcorn	Logistics Management Institute
Sylvie Brouder	Purdue University
Andras Marton	Independent Projects Analysis, Inc.
John Sheehan	University of Minnesota

FORMAT OF THE REPORT

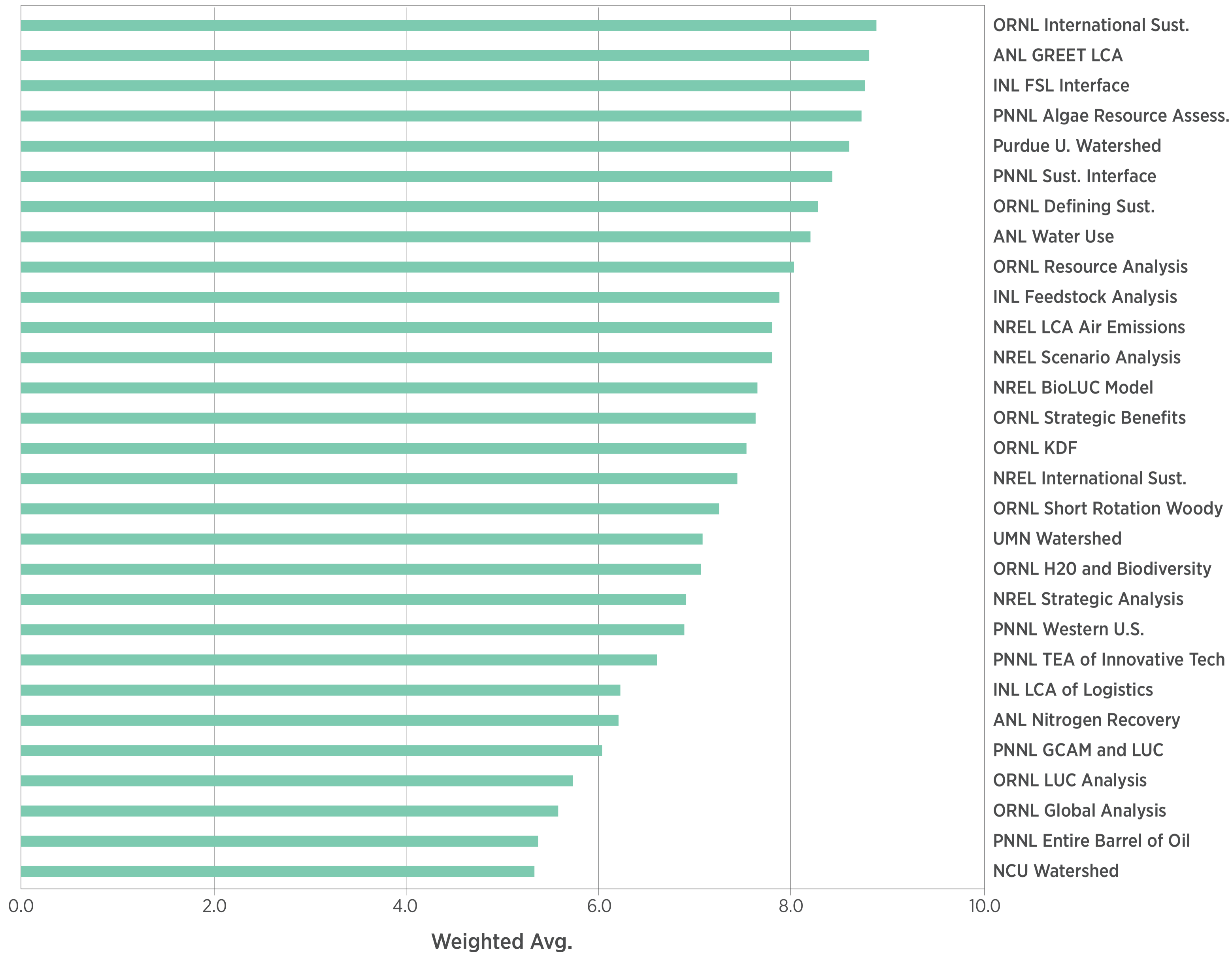
Information in this report has been compiled as follows:

- **Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.
- **Project Scoring Information and Short Names Key**: The final score charts depict the overall weighted score for each project in each technology area. Short names for each project were developed for ease of use in the scoring charts, the table of contents, and other locations. Full project names, along with their designated short names and their work breakdown structure (WBS#), are provided in the Short Names Key.
- **Review Panel Summary Report**: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.
- **BETO Programmatic Response**: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.
- **Project Reports**:
    - **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space constraints allotted.
    - **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
    - **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and the whiskers depict the range of scores for each category within each technology area.

- **Reviewer comments** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant by BETO's director were excluded from the final report.
- **PI Responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the review panel. This unique formatting was maintained to uphold the integrity of the comments.

TECHNOLOGY AREA SCORE RESULTS



SHORT NAMES KEY

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
6.5.8.2; 6.5.1.3	International Sustainability and Standards; Brazil Collaborations	ORNL	ORNL International Sust.
9.6.5.2	GREET Life–Cycle Analysis of Biofuels	ANL	ANL GREET LCA
1.1.1.2	Sustainable Feedstock Production–Logistics Interface	INL	INL FSL Interface
11.2.2.5	Algae Resource Assessment	PNNL	PNNL Algae Resource Assess.
1.7.1.6	Watershed-Scale Optimization to Meet Sustainable Cellulosic-Energy-Crop Demand	Purdue University	Purdue U. Watershed
3.6.1.1; 3.6.1.3; 3.5.1.3; 3.1.2.4	Thermal Conversion Sustainability Interface	PNNL	PNNL Sust. Interface
11.1.1.5	Defining Sustainability	ORNL	ORNL Defining Sust.
11.1.1.1	Impact of Projected Biofuel Production on Water Use and Water Quality	ANL	ANL Water Use
1.6.1.3	Resource Analysis Project	ORNL	ORNL Resource Analysis
1.6.1.9	INL Feedstock Analysis	INL	INL Feedstock Analysis
11.1.1.3	NREL Sustainability Analysis: Life-Cycle Inventory of Air Emissions	NREL	NREL LCA Air Emissions
11.2.6.3	Biomass-to-Bioenergy Supply-Chain Scenario Analysis	NREL	NREL Scenario Analysis
11.2.1.1	BioLUC Model	NREL	NREL BioLUC Model
11.2.3.5	Biofuels National Strategic Benefits Analysis	ORNL	ORNL Strategic Benefits
1.6.1.8	The Bioenergy Knowledge Discovery Framework (Bioenergy KDF)	ORNL	ORNL KDF
6.5.8.1; 6.5.1.1	International Sustainability	NREL	NREL International Sust.
11.1.1.7; 11.1.1.8	Short-Rotation Woody Biomass Sustainability	ORNL	ORNL Short Rotation Woody
1.7.1.7	Pathways Towards Sustainable Bioenergy Feedstock Production in the Mississippi River Watershed	University of Minnesota	UMN Watershed
11.1.1.4	Forecasting Water Quality and Biodiversity	ORNL	ORNL H20 and Biodiversity
11.2.1.2; 11.2.1.3; 11.2.1.4; 11.2.1.5	Overview of the NREL Strategic Analysis Project Portfolio	NREL	NREL Strategic Analysis
11.1.1.6	Biofuel Production Potential in the Western U.S.	PNNL	PNNL Western U.S.
11.2.2.4	Techno-Economic Analysis of Innovative Technology Concepts	PNNL	PNNL TEA of Innovative Tech.
11.2.4.2	Life-Cycle Assessment of Logistics Supply Systems	INL	INL LCA of Logistics
11.1.1.2	Biomass Production and Nitrogen Recovery	ANL	ANL Nitrogen Recovery
11.2.2.1	GCAM Bioenergy and Land-Use Modeling	PNNL	PNNL GCAM and LUC
11.2.3.2	Land-Use Change Data and Causal Analysis	ORNL	ORNL LUC Analysis
11.2.3.1	Global Analysis of Biofuel Policies, Feedstock and Impacts	ORNL	ORNL Global Analysis
11.2.2.2	Opportunities for Biomass-Based Fuels and Products to Address the Entire Barrel of Oil in a Refinery	PNNL	PNNL Entire Barrel of Oil
1.7.1.5	Optimization of Southeastern Forest Biomass Crop Production: A Watershed-Scale Evaluation of the Sustainability and Productivity of Dedicated Energy Crop and Woody Biomass Operations	North Carolina State University	NCU Watershed

REVIEW PANEL SUMMARY REPORT

IMPACTS

1 What are the key strengths and weaknesses of the projects in this technology area? Do any of the projects stand out on either end of the spectrum?

The scope of this Technology Area is impressive, with a wide range of topics covering various elements of technical and sustainability analysis. The portfolio has made great strides in taking a proactive approach to sustainability, moving beyond traditional net energy balances and greenhouse gas accounting in an attempt to inform a more complete assessment of the overall environmental, economic, and social implications of the bioenergy industry. The review panel believed that the Analysis and Sustainability team is in a position to become a leader in sustainability-related research and has created frameworks for sustainability that can be useful for the research community, as well as essential to fulfilling BETO's and DOE's objectives.

It appears that the cross-cutting efforts of the Analysis and Sustainability Technology Area are achieving their intended purpose, with sustainability concepts becoming integrated throughout the BETO platform. Research in all of the projects is appropriately geared toward establishing best management practices and driving technology improvement. TEA reports generated through this Technology Area are used throughout the BETO platform. The TEA research is an essential first step in understanding the major challenges to technology development pathways, and it highlights areas where greater research is needed.

LCA continues to mature in the Office, becoming more sophisticated, robust, and complete. Highlights of the work in this area include research on biofuels' potential impact on water quality and availability, as well as integrating logistical considerations into LCA. A number of projects are beginning to analyze potential tradeoffs regarding energy, water, and land, and comprehensive studies such as these should be continued in order to provide more complete assessments. Projects that analyzed the synergies and tradeoffs of economic and environmental criteria were particularly well received. In order to address the persistent issue of lack of data, a number of projects within the portfolio are specifically designed to address data gaps. These types of projects are necessary to improve the quality of analysis and robustness of the LCA method.

The Technology Area also participates in stakeholder engagement activities with international bioenergy and standardization communities, which are viewed as essential to the success of a U.S. bioenergy industry. Even though it is difficult to measure the effect of having a consistent presence within the international community, these efforts are likely to have a large impact on the future of the bioenergy industry.

The modeling efforts within this Technology Area are generally of high quality, with objectives focused on research questions pertinent to BETO's overall goals. The research portfolio's robustness could be further improved through the creation of guidelines regarding approaches to sensitivity, metric definition, model verification, and validation of results. Although these guidelines should not be prescriptive, they should seek to improve consistency of modeling efforts. In addition, transparency of the modeling efforts and the embedded assumptions within the models should be prioritized. Since much of the research within this Technology Area has the potential to affect the trajectory of the biofuel industry, access to model assumptions, data, and methods by industry practitioners is seen as important. It was suggested that proprietary databases should be avoided when possible in an effort to maximize transparency.

As with any cross-cutting effort of this breadth, this Technology Area faces some challenges regarding organization and communication across projects, particularly in cases where multiple modeling efforts with similar objectives exist, but are conducted at different scales of analysis. The water quality modeling and economic equilibrium modeling efforts were two examples that could benefit from greater coordination across projects, with a well-defined hierarchy of how the modeling efforts fit together. This may allow for clearer project outcomes and reduce the potential for duplication of efforts.

There does not appear to be a clear plan for dissemination of research findings throughout this Technology Area. Some project outcomes, such as those directly related to the *Billion-Ton Study* and the TEA reports, are easily accessible by a broad audience of researchers, practitioners, and policymakers. A plan for dissemination is not clear for many projects within the portfolio, even when there are elements of a project that may have particular relevance to policy or technology design. The Bioenergy Knowledge Discovery Framework (KDF) is a useful platform for some of this work; however, it should not be considered the endpoint when disseminating research findings.

2 Is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry in this technology area? Is the government's focus appropriate in light of private-sector investments? Are there any projects that stand out as meeting (or not meeting) this criterion?

The work being conducted within this Technology Area is crucial to the long-term success of the biofuel industry, particularly in light of current and future regulatory considerations and international standard development. The projects within the portfolio have the potential to significantly advance the state of research within the area.

This Technology Area is of particular importance due to its cross-cutting nature. The analyses within the portfolio generally have a national or international scope, which can inform national strategic development of the bioenergy industry. It is unlikely that private efforts would have the incentive or ability to make significant strides within these areas.

INNOVATION

3 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach these barriers? Do any projects stand out as meeting (or not meeting) this criterion? Can you recommend new ways to approach these barriers?

The overall portfolio is strong. All projects are well-aligned with the goals and objectives spelled out in BETO's MYPP. As a cross-cutting program, the Analysis and Sustainability Technology Area provides strategic guidance and analysis for technology development. The TEAs indicate development pathways that have the strongest potential for success, as well as proactively understanding potential showstoppers.

There have been great strides within the sustainability area that are seen as innovative. Although significant progress has been made through prior and current research, there are more challenges within the Analysis and Sustainability Technology Area that must be addressed to inform a comprehensive assessment of bioenergy technologies.

GAPS

4 Are there any other gaps in the portfolio for this technology area? Are there topics that are not being adequately addressed? Are there other areas that BETO should consider funding to meet overall programmatic goals?

The balance of the portfolio reflects a clear understanding of where serious gaps in knowledge exist, such as in defining and framing sustainability, and in understanding sustainable water use at the watershed level.

Although the portfolio spans an impressive number of research areas, there are some topics that could be better represented. For example, it would seem appropriate to expand research efforts attempting to quantify biofuels' impact on energy security, given the stated goals of the Energy Independence and Security Act of 2007 (EISA). It was also recommended that analysis on algal biofuels be expanded to include brackish and salt water, in addition to the current freshwater focus. The panel also suggested including analyses related to sustainable agriculture and the implications for energy and food security, as well as the ethical implications of biofuels.

In addressing social aspects of sustainability, much work remains to be done. It is unclear whether the Analysis and Sustainability team should support greater research efforts in the social sciences directly, or whether it would be more appropriate to form partnerships with agencies and institutions that have more experience in these fields.

SYNERGIES

5 What synergies exist between the projects within this technology area? Is there more that BETO could do to take advantage of these synergies and better enable projects to meet their objectives?

There are numerous strong collaborations within this Technology Area. There are many instances of researchers from different national laboratories working together to produce analyses with consistent sets of assumptions while leveraging the knowledge and experience of their counterparts. As one of the most widely used LCA databases, the Greenhouse Gasses, Regulated Emissions, and Energy Use in Transportation (GREET) model serves as a solid basis for collaborative opportunities, either as a source of data to inform research or as a potential outlet for research dissemination. The Bioenergy KDF also has the potential to serve this purpose.

Because appropriate assessment of sustainability is so broad, it is important to form partnerships with other research groups that may have a history of expertise in a particular area of analysis. The review panel suggested that this Technology Area continue, improve, or initiate communication and collaboration with appropriate refinery, academic, and interagency partners. In particular, USDA and EPA have relevant expertise on agricultural and environmental aspects that could be better leveraged to inform sustainability research. The Biomass Research and Development Initiative represents an existing opportunity that could be reframed to better incentivize research in strategic areas relevant to the Analysis and Sustainability Technology Area.

RECOMMENDATIONS

6 Is BETO funding projects at the optimal stage of the technology pipeline? Is there more that BETO could do to orient technologies toward successful commercialization? Are there any projects that stand out as positive or negative examples of this orientation?

The Analysis and Sustainability Technology Area is largely prospective, focusing on potential future impacts of a fully realized bioenergy industry in an effort to understand and prevent potential bottlenecks and unintended consequences. This is very appropriate for the Technology Area.

7 What are the top three most important recommendations that would strengthen the portfolio in the near to medium term?

The first major element that could better support BETO's overall goals is improved integration of TEA and LCA. These research areas are strengths of the Analysis and Sustainability Technology Area, even though they are often examined separately. It was generally felt that the strongest projects within the portfolio analyzed the synergies and tradeoffs of economics and environment to capture a more complete assessment of a system. By encouraging integrated TEA and LCA of new technology pathways, the analysis team will facilitate better understanding of instances where improved process efficiency and waste reduction will decrease both costs and environmental impacts, in addition to instances where economic improvements may have negative environmental consequences. This can be useful information when designing new technology pathways.

A second recommendation is to better coordinate projects with similar objectives, evaluating the appropriateness of individual modeling efforts and alignment with the overall portfolio goals. It would be useful to consider how all of the research and modeling conducted throughout the Analysis and Sustainability Technology Area fit in a hierarchical structure—from simple to complex, and/or from strategic to technical. Simpler models and findings should integrate the outcomes from the more complex modeling efforts. The tools and outcomes from this higher level in the hierarchy should be directly linkable to decisions and decision-making processes for the Office. Increased understanding of the relationship between different projects by both management and individual project principal investigators will help streamline the flow of information throughout the Office and reduce duplication of efforts. For example, the projects associated with the water impacts of biofuels could benefit from more explicit mapping of projects to the overarching research needs and goals of the Office. Meanwhile, it was suggested that the Office reevaluate individual modeling efforts, ensuring that modeling approaches are tied to strategic research questions while de-emphasizing reactive modeling efforts that exist solely to disprove criticism of the bioenergy industry. It was generally felt that some of the land-use change modeling efforts fit into this category and may need to be refocused in order to provide meaningful and insightful analysis.

The third major recommendation is creation of a communication and dissemination plan for high-value research, particularly for projects that are policy-relevant or may otherwise have a direct impact on the development of the bioenergy industry. The Analysis and Sustainability Technology Area has made great progress in communicating research results and motivating a more proactive culture with regard to strategic analysis and sustainability; however, these efforts can still be improved. There is a demand for a more explicit description of the process of high-level strategic decision making, such as how decisions are made regarding the promotion of specific technology pathways. In addition, much of the work in this Technology Area has policy relevance. It is unclear the extent to which the outcomes of the research are used to inform specific policies and regulations. The system-dynamics models within the portfolio can be useful tools to translate complex model results into simpler, strategic models that can be used to engage high-level managers, policymakers, and other stakeholders. Designing models specifically with the goal of facilitating discussion may help advance BETO's mission and better disseminate the high-quality research that is being conducted in this Technology Area.

BETO PROGRAMMATIC RESPONSE

IMPACTS

We would like to thank the Analysis and Sustainability review panelists and Steering Committee members for their thoughtful and constructive input during the entire Peer Review process. We greatly appreciate the targeted feedback on both the strengths and weaknesses of this Technology Area. The reviewers provided insightful and actionable recommendations, several of which we have already begun to implement.

We thank the reviewers for recognizing that the work being conducted under Analysis and Sustainability is crucial to the long-term success of the biofuels industry and is filling a role that private efforts would not likely have incentive or ability to undertake. We also appreciate recognition of the progress that has been made in taking a proactive approach to sustainability that involves a holistic assessment of the environmental, economic, and social implications of the bioenergy industry. We are pleased the reviewers view this Technology Area as a leader in sustainability-related research that is developing frameworks that support the research community, as well as BETO's and DOE's objectives.

The reviewers highlighted several areas that could be strengthened to increase the impact of the Analysis and Sustainability Technology Area. We agree that the portfolio would be further improved through the creation of guidelines regarding approaches to sensitivity analysis, metric definition, model verification, and validation of results, as well as continuing to prioritize the transparency of the modeling efforts and embedded assumptions. We will work to standardize these approaches as appropriate to improve consistency across the portfolio, and we will continue our commitment to transparency by prioritizing publically available models and datasets, relying on internal or proprietary databases only when necessary.

The reviewers noted challenges regarding organization and communication across projects, particularly in cases where multiple modeling efforts with similar objectives exist, but are conducted at different scales of analysis. Reviewers also noted that there is not a clear plan for dissemination of research findings throughout the Technology Area. We agree that these are issues that should be addressed to further maximize the efficiency and overall impact of this Technology Area. Under the recommendations section, we provide more detail on our plans to address the weaknesses identified.

INNOVATION

We appreciate that the reviewers noted that the overall Analysis and Sustainability portfolio is strong, that it provides strategic guidance and analysis for technology development, and that the projects are well-aligned with the objectives spelled out in the MYPP. We are pleased that the reviewers believe there have been great strides through prior and current research that are seen as innovative. That said, we agree with reviewers' comments that further work is needed to inform a comprehensive assessment of bioenergy technologies. We will continue to support a range of techno-economic, life-cycle, and environmental analyses for diverse pathways and system designs. As the bioenergy industry expands and evolves, we plan to reassess pathways that have the strongest potential for success, proactively assess potential show-stoppers, and shift focus areas as appropriate.

GAPS

We are pleased the reviewers noted the portfolio aligns with the critical needs and knowledge gaps in bioenergy analysis and sustainability. The reviewers identified several areas where greater focus or expansion is warranted. The panel recommended expanding research efforts related to energy security. Quantifying the impact of biofuels on energy security is critical to the mission of this Technology Area, and we recognize the need to expand efforts in this area. We plan to continue existing analysis efforts aimed at improving understanding of the impact of biofuels on fuel prices and price volatility.

The panel suggested that analysis on algal biofuels include brackish and salt water in addition to the current freshwater focus. This is, indeed, already a strong component of BETO's algae analysis and R&D projects, although this was not included in this Technology Area's presentations.

The panel also suggested strengthening analysis regarding sustainable agriculture and the relationships between energy and food security. With regard to sustainable agriculture, we plan to continue analysis and research efforts on multi-functional landscapes that provide multiple benefits, so that bioenergy can complement and enhance agricultural and forestry systems. We plan to hold at least one workshop in the next year on sustainable landscape concepts that maintain ecological value while increasing biomass and food/feed/fiber productivity.

Furthermore, in coordination with other U.S. agencies, we will continue strong participation and leadership in the Global Bioenergy Partnership (GBEP) and other international partnerships to advance science-based understanding of the relationship between bioenergy and food security, and to contribute to proactive solutions.

We agree that the social aspects of sustainability are equally important as the economic and environmental dimensions to the future of bioenergy. The latter two have received greater attention to date, but the social dimension will continue to be integral to our commitment to bioenergy sustainability. We appreciate the reviewers' recognition that research efforts in the social sciences are not clearly BETO's mission space. Two relevant accomplishments in 2012 and 2013 were a workshop and publication on socio-economic indicators for bioenergy sustainability. We hope this socio-economic indicator framework will facilitate research at other agencies and institutions, and we will consider additional ways to assess and promote the social aspects of sustainability through strategic collaborations.

SYNERGIES

We thank the reviewers for recognizing the strong collaborations within this Technology Area, such as partnerships between national laboratory researchers working on similar objectives to maximize efficient use of resources and expertise. We will seek further opportunities to strengthen our interactions with appropriate academic, non-profit, and industry partners to ensure our work complements existing research efforts and is consistent with the needs and strategic direction of existing industries. For example, we have reinitiated a sustainability roundtable series to bring together federal staff, national lab researchers, and the conservation community to share the latest updates on the Office's sustainability activities, stay informed of emerging concerns, foster collaboration, and gather input. We will also seek further opportunities to elevate analysis and sustainability as focus areas for the Biomass Research and Development Board to maximize use of this existing mechanism for interagency coordination. Participation in the newly formed Analysis Working Group under the Board will be an initial step.

RECOMMENDATIONS

We are pleased that the reviewers found the Analysis and Sustainability Technology Area to be appropriately targeted in terms of taking a proactive approach to understanding and preventing potential bottlenecks and unintended consequences of a fully realized bioenergy industry. The reviewers provided three main recommendations to strengthen this Technology Area to better support overall BETO goals, each of which we are actively working to implement.

The first major recommendation is to better integrate techno-economic analysis and life-cycle analyses. We agree with and appreciate this recommendation. We believe we have made significant progress in this area, particularly in the past year, and we are working to standardize this throughout the Office moving forward. For example, all design cases and state of technology assessments will include a section on environmental sustainability metrics, such as GHG emissions and water use. We will expand that to include air emissions and additional environmental performance measures as more data are available. This information will be used to conduct more thorough analyses of synergies and tradeoffs, and to set targets that optimize across economic, technical, and environmental parameters.

A second recommendation is to better coordinate projects with similar objectives, and to evaluate the appropriateness of individual modeling efforts and alignment with the overall portfolio goals. We agree that organization and communication across projects could be improved, particularly in cases where multiple modeling efforts have similar objectives but are conducted at different scales. We are working to better define what models in our portfolio are best suited to answer specific questions, and how the various models relate to each other. We have already initiated an effort to improve this coordination by requesting that each project identify data flows and intersection points with other projects in the portfolio. We will be using this information to create visual representations of the linkages between projects, models, and data flows that will enable each project and PI to see how they fit into the network of projects. This will also enable us to balance efforts more efficiently and conduct a gap analysis of data and modeling needs.

We also appreciate the third recommendation for a stronger dissemination plan that includes, but is not limited to, disseminating research and analysis results through the Bioenergy Knowledge Discovery Framework. We agree that the data and results generated through this portfolio must get into the public, research, and policy realms to have maximum impact. We are working on a more comprehensive strategy for dissemination of our funded work, such as having discussions with PIs on how to design deliverables with end users in mind. For projects that are policy-relevant, we will make use of our existing relationships with the appropriate entities—such as EPA and DOE's policy office—to support high-level managers and policymakers in making more informed, science-based decisions. The KDF will continue to be a central platform for Office-funded work, but we will seek ways to ensure it does not become an end point, such as improving its usability as a tool and conducting stronger outreach to attract users.

CONTENTS

OVERVIEW OF THE NREL STRATEGIC ANALYSIS PROJECT PORTFOLIO

(WBS#: 11.2.1.2; 11.2.1.3; 11.2.1.4; 11.2.1.5)

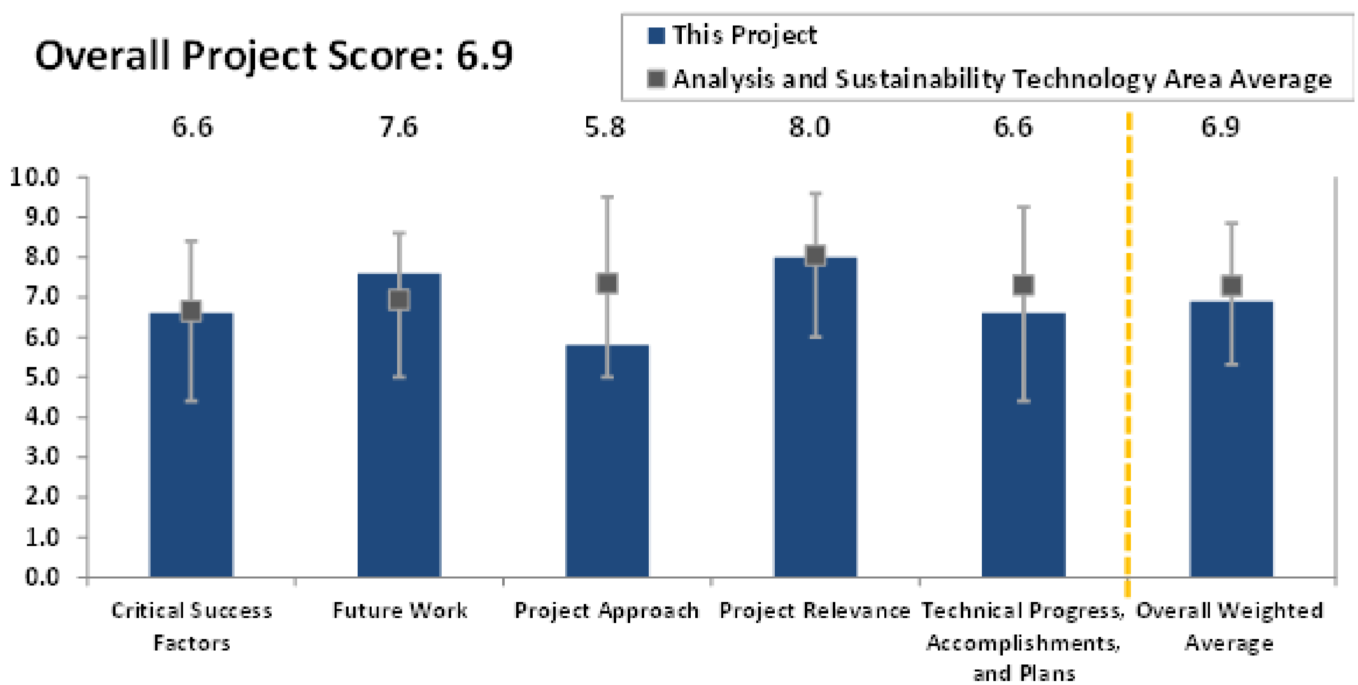
Recipient:	NREL
Presenter:	Mary Biddy
Total DOE Funding:	$2,901,000
DOE Funding FY13:	$900,000
DOE Funding FY12:	$1,100,000
DOE Funding FY11:	$900,000
Project Dates:	2010–2014

Project Description

The NREL strategic analysis project portfolio encompasses a wide set of analytical tools and expertise in support of DOE's Bioenergy Technologies Office. Strategic analysis projects provide models and methodologies to understand the technical, economic, and societal impacts of the development of bioenergy, and serve as an analytical basis for Office planning and assessment of progress. Specifically, these efforts include techno-economic analysis of programmatic technologies' strategic expansions, identification of key drivers and uncertainties in the growth of the biofuels and bioproducts portfolio, optimization of an integrated biorefinery, comparative analysis of the economics of energy production on a levelized cost basis, and estimation of job growth and the broader impact of developing industries. Critical to the success of these tasks is the utilization of high-quality data that is thoroughly documented and vetted. Key stakeholders (e.g., policymakers, bioenergy technology developers, and investors) are actively engaged in developing these analyses. Results of the analyses are communicated to various stakeholders, and uncertainties associated with the analysis efforts are clearly defined and quantified.

Overall Impressions

- At a high level, the project seems important and necessary to numerous aspects of BETO's technology areas. The consistency of analysis seems to be improving and this is beneficial. However, many details were vague including: what are the priorities; who are the stakeholders; what is the process



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

for screening (the decision tree is critical, but not explicit in this presentation); are correct stakeholders solicited for input; and is the apparent non-uniformity of sensitivity approaches not important to comparative outcomes? PIs need to give sufficient details to convey that the approach, methods, etc., really are the best. There was not enough exact detail given to permit full evaluation of project merit and potential impact. The crowded use of largely meaningless terms (e.g., sustainability metrics, societal impacts) was distracting when not provided with supporting strategies.

- Substantial progress towards more systematic portfolio management since last Peer Review. Significant achievements in development of TEAs for selected platforms. Tradeoffs are still not entirely clear. Decision approach for portfolio direction is not entirely clear.
- The presented activities are well aligned with the Analysis and Sustainability Area and are essential to supporting overall BETO goals by providing starting points of analysis for emerging energy technologies and their potential economic outlook. Sustainability aspects beyond economics are less emphasized in the project suite, with job creation the sole social indicator.
- The robust techno-economic analysis, Biorefine.org, and Jobs and Economic Development Impact models are significant work products and contributions to BETO's goals. Strategic analysis as a portfolio does, however, need to broaden its focus to answer other economic, social, and environmental questions, key barriers, and showstoppers in a consistent, robust, and prioritized manner. A suite of representative sustainability metrics needs to be robustly defined; strategically aligned with BETO, DOE, and federal requirements; vetted through broader stakeholder engagement; and developed in a systematic road map moving forward that supports key BETO decision points.
- The techno-economic analysis work at NREL has always been a strong and outstanding aspect of their work. The approach to generating design reports as described here is in that tradition. But there is a sense that the analysis work has become very mechanical. All the right boxes are being checked, but it does not have the feel of a set of tasks actively engaged in the process of setting strategic direction. This is evidenced by the passive and vague description of outcomes involving critically important decisions, such as selecting and then down-selecting technology pathways. The PI tells us that technical memos have been properly submitted and management decisions have been made based on them, but she does not offer any insight underlying these decisions and outcomes. Drawing a clear line between technical analysis done within specific technology areas and technology analysis that is more cross-cutting and strategic is difficult. This can lead to ambiguity and lack of focus. It can also lead to a tendency to limit this work to reactive, fast turnaround exercises. Thus, what was presented in this project came across more as a collection of activities, and not a coherent picture of analysis that has a clear role in linking high-level decision making and strategy with specific and more-detailed analysis efforts that set short-term direction for BETO's individual elements. In addition, this project area needs to establish a clear methodology that balances analyses that are driven by bottom-up considerations of the technology, and research capabilities versus market- and strategy-driven goals established from a top-down perspective. The danger is that, without such a clear distinction, analysts will fall into the trap of biasing the technical analysis for new technology directions to demonstrate an ability to hit strategic targets—a problem that leads to abuses such as the --.67 per gallon technology targets established by DOE in the early 1990s that satisfied decision makers by telling them what they wanted to hear, rather than what they needed to hear

about feasibility of Office goals. There is no evidence that this kind of bias is occurring in the analysis activities of this project; however, there is also little evidence that it is not happening. Targets for 2017 and 2022 are, as the warning in the rearview mirror says, "closer than they appear." So this group should give serious thought as to how to make sure that their view on the technology is as clear and undistorted as possible.

PI Response to Reviewer Comments

- I thank the reviewers for the helpful feedback. The approach for techno-economic analysis was presented to demonstrate that we have developed consistent, well-defined methodologies that allow for transparent, reproducible, and rigorous process designs and TEA.
- I thank the reviewer for sharing insights on establishing analyses that are driven by bottom-up considerations. During the presentation, a detailed example on how NREL developed specific targets and metrics for the production of cellulosic ethanol was reviewed. This is an integrated approach where the TEA team works closely with the R&D teams. While the BETO portfolio has set specific cost targets to ensure economic viability for biofuels, the research targets are set based on a sound scientific and engineering basis. We strive for transparency in our analyses, as demonstrated by the fact that the basis for the targets is documented in the design reports. The design reports go through a thorough vetting process, where key stakeholders from industry, academia and national labs are engaged to review and comment on these designs and the targets.
- With regards to the technology pathways exercise, in March 2012, NREL and PNNL were enlisted to develop and leverage existing TEA models for a suite of potential conversion routes to hydrocarbon fuels. At that time, the primary focus of the core conversion program was on meeting 2012 cellulosic ethanol goals. The pathways work was critical for BETO efforts in moving strategically towards hydrocarbon biofuels routes by developing comparative analysis across a wide range of platforms. As stated during this presentation, the specific details of the technology pathways were covered in a BETO-led plenary presentation. BETO utilized a well-defined set of pathway selection criteria, one of which was the TEA results. The down-select decisions were made solely by BETO.

OPPORTUNITIES FOR BIOMASS-BASED FUELS AND PRODUCTS TO ADDRESS THE ENTIRE BARREL OF OIL IN A REFINERY

(WBS#: 11.2.2.2)

Recipient:	PNNL
Presenter:	Sue Jones
Total DOE Funding:	$320,000
DOE Funding FY13:	$160,000
DOE Funding FY12:	$160,000
DOE Funding FY11:	--
Project Dates:	2011–2014

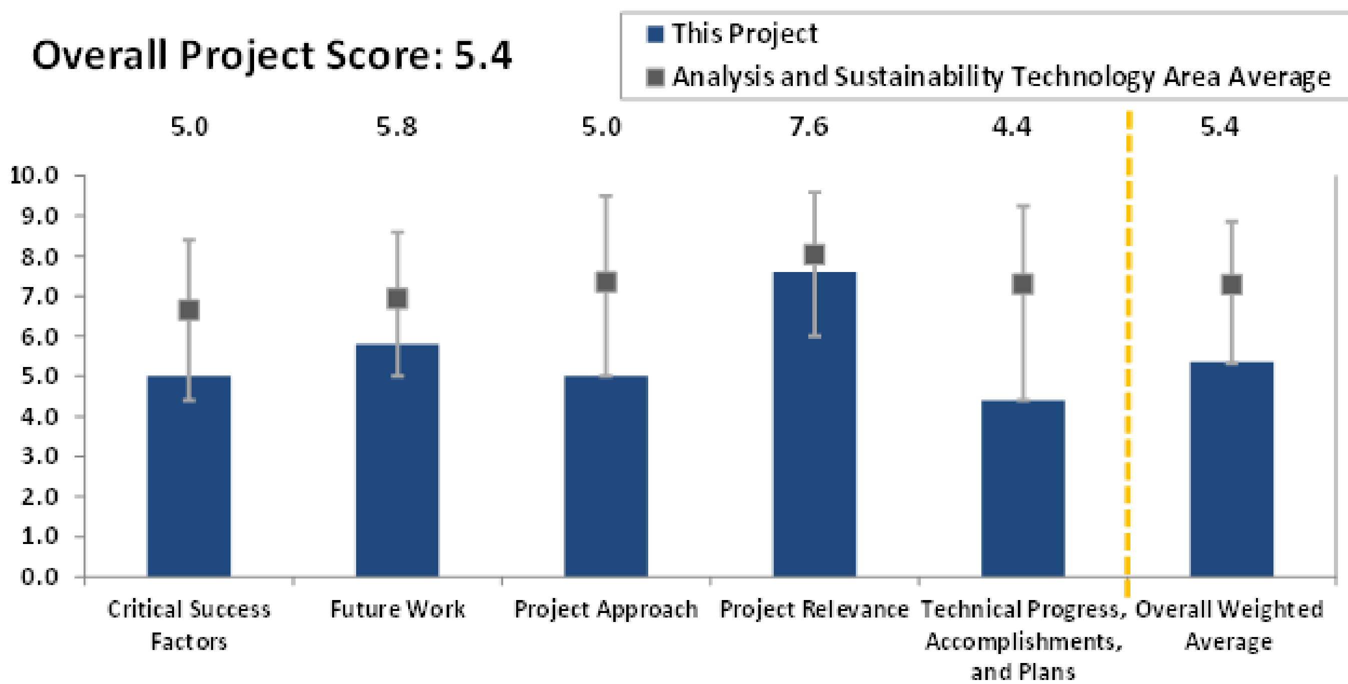
Project Description

Photo Courtesy of PNNL

This project supports the Bioenergy Technologies Office goal of supplanting petroleum-based liquid transportation fuels with renewable resources by providing techno-economic analysis for new hydrocarbon fuel pathways. This project has two distinct tasks. The first task is a joint effort with the National Renewable Energy Laboratory to provide TEA for eleven new pathways to advance biofuels. From this analysis, BETO selected seven pathways to be published as reference material in preparation for setting new research goals for the 2017–2022 timeframe. The second task is a preliminary assessment of the impact of biomass-derived fuel intermediates in a conventional refinery. While sufficient conventional processing units and capacity appears to exist, better characterization of these biomass-derived intermediates are needed to help refiners better understand risks in terms of safety, reliability, predictability, and profitability.

Overall Impressions:

- Engaging refineries to understand the operational and cost risks of introducing biomass intermediate and fuels is an important research and activity area. Matching intermediate producers and refineries with capacity to utilize is an important focus, but the



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

current project approach needs to be vetted more broadly and made more robust prior to moving forward. Future work should be expanded to include distribution, fuel specification, and end-user fuel characteristics and requirements to better understand risks and adoption. The current research team may need to be broadened to ensure sufficiently diverse experience, and contacts are available to do so successfully.

- Overall, the level of detail of this presentation was pretty minimal for understanding exactly what was done. Without more detail, it is hard to understand the impact of the activities given the significant challenges posed by lack of data. Refinery stakeholder input is a good idea but seemed anecdotal.
- The overall purpose of the project is reasonable and the rationale sound. The major issue is one of approach, since the discussion needs to involve more partners from refineries to adequately address the questions that are posed. Even with their partnership, it is not clear that co-processing is feasible given the challenges of refinery integration. In general, the project seems worthy of analysis, but the research questions and overall approach may need to be redefined moving forward.
- This effort needs substantially more input from refinery operations. Understanding hydrocarbon pathways from stream introduction to products for various refinery configurations (crude feed specifications) is critical to make this project meaningful.
- This project touched on two major areas: fast turnaround analyses of new pathways for production of hydrocarbon fuels from biomass, and analyses of how biomass fuels and intermediates influence the overall mix of refinery products. The first area was addressed in the previous project, and should not have been duplicated here. This type of redundancy leads to confusion in the review process. As to the second area, understanding how bioenergy technologies will impact the overall balance of products coming out of the biorefinery is indeed a critical question. Unfortunately, the outcomes of this work are too superficial to be useful, even given the fact that this is an effort that is in its early stages. On the positive side, the project has done a good initial classification of U.S. refiners into categories that identify the specific subset of refiners with the kind of processing capacity needed to make use of biomass-derived hydrocarbons. On the negative side, the analysis of "sufficiency of capacity" is too superficial and arbitrary to be useful. The same can be said of the attempt to compile and compare bio-derived products with the required properties of their petroleum counterparts. This project needs much more engagement from the petroleum industry in order to be successful. This is an industry with a vast amount of information available at its fingertips. To date, the project performers have barely scratched the surface of what could be learned.

PI Response to Reviewer Comments

- Thank you for your review and feedback. We are pleased that the topic is considered relevant. It is unfortunate that the reviewers interpreted this modest project as an end in itself. This initial work was aimed more at determining where the data gaps and needs were at, rather than trying to comprehensively answer all the questions. A notable project outcome was the need for much more publically available information regarding bio-derived intermediates and their effect on co-processing.
- We also agree that refining partnerships are critical for successful future work. Future work will be focused on two highly relevant means of co-processing: hydrocracking and catalytic cracking. Expansion of the project to include NREL will allow leveraging both PNNL's and NREL's connections with industry, as well as access to the ongoing associated experimental work at each laboratory. Additionally it is proposed that an industrial advisory panel including refiners and refinery vendors be formed and briefed on the progress of the project on at least on a semi-annual basis in order to garner their insights and refinements to the project and thus maximize impact from the work.

TECHNO-ECONOMIC ANALYSIS OF INNOVATIVE TECHNOLOGY CONCEPTS

(WBS#: 11.2.2.4)

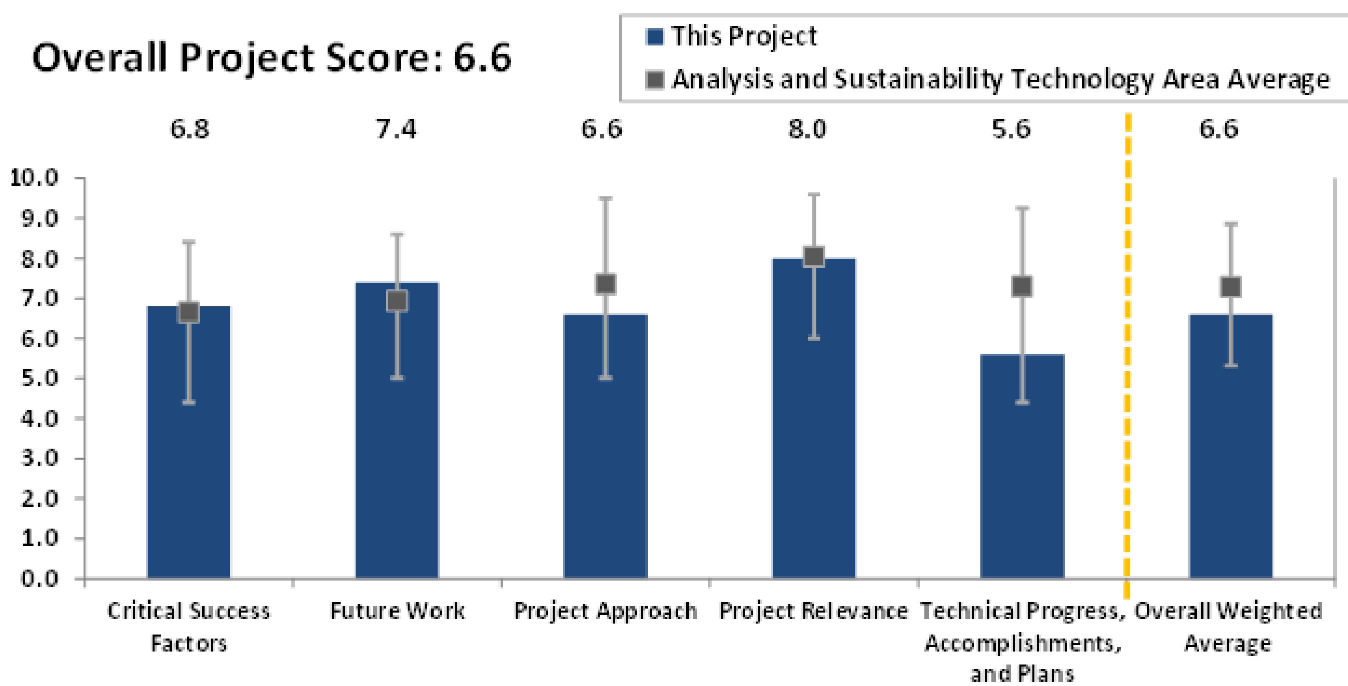
Recipient:	PNNL
Presenter:	Corinne Valkenburg
Total DOE Funding:	$400,000
DOE Funding FY13:	$200,000
DOE Funding FY12:	$200,000
DOE Funding FY11:	--
Project Dates:	2011–2015

Project Description

This task is a joint analysis project between Iowa State University and the Pacific Northwest National Laboratory to rapidly screen four to six potential new pathways to fuels and products. In fiscal year 2012, this included in-situ catalytic pyrolysis, ex-situ catalytic pyrolysis, hydropyrolysis, fast pyrolysis fractionation. The preliminary results from this work were leveraged to assist the Bioenergy Technologies Office with their new pathways-to-fuels analyses. This high-level analysis suggests that the current state-of-technology plant-gate prices are all greater than the BETO target of $3 per gallon of gasoline equivalent. Improvements in yield and reductions in capital cost are needed. The fiscal year 2013 tasks screen gasification and sugars-based routes.

Overall Impressions

- Consistent, quick LCA screening methods with transparent assumptions are an important contribution to the Technology Area's development. The project's efforts to identify pathway-specific cost and tradeoffs are worthwhile, but could be further developed and vetted. In addition, disseminating pathway-screening findings could be used to initiate wider dialogues with BETO and industry stakeholders to check assumptions, address data gaps, and augment screening approaches across the technology areas.
- The overall concept of the project is sound and has the potential to assist identification of promising



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

pathways for technology development. A rapid assessment tool could greatly assist overall BETO efforts. Given the potential impact the project could have on prioritization of technology pathways, results of the project should be well vetted. The project may benefit from guidelines regarding appropriate parameterization to ensure consistency.

- This is a project that is built on a terrific concept. Its approach is to setup a capability for fast turnaround, high-level analysis to explore new ideas. It is further enhanced by engagement with graduate students as a resource for the work, and the work as an opportunity for education for the students; however, the implementation of the analysis is inconsistent. Improvements in the implementation would be needed if this project was to be continued. Tornado plots, as presented in the review, can be very insightful because they can show at a glance the relative uncertainty and proximity of cost performance to goals. But as summarized in this project, most of these plots offer little insight about the comparative advantages of different technology pathways. Thus, the goal of this project is laudable, but the realization of that goal is far from satisfactory.
- This project has the potential to become an important screening tool; however, approach to sensitivity analysis needs some revision.
- The need for the project and its relevance are understandable. Some of the technical challenges seem so daunting that project results might be spurious if the challenges are not directly addressed and overcome or, at least, reduced in magnitude (e.g., better confidence in "what the numbers mean"). Better detailing of methods would be helpful to the evaluation, including methods criteria and boundary and/or sensitivity-analysis criteria.

PI response to Reviewer Comments

- Thank you for the review and comments. We find the critical comments to be on point and extremely constructive. Consistent parameterization, tornado plots showing relative uncertainty and proximity of cost performance to goals, and improved detailing of methods (including discussion of what numbers mean) are currently being incorporated into planning for fiscal year 2014. We agree that this project is conceptually sound, that it offers value to BETO in strategic planning efforts, and greatly appreciate the expert advice on how to improve implementation. We also agree that facilitating wider dialogues between BETO and industrial stakeholders will improve vetting of assumptions, help close data gaps, and augment screening techniques. We are currently developing manuscripts for submission to peer-reviewed journals, as well as an annual technical report that will be publically available, in order to expand dissemination of methods and results.

RESOURCE ANALYSIS PROJECT

(WBS#: 1.6.1.3)

Recipient:	ORNL
Presenter:	Matt Langholtz
Total DOE Funding:	$5,404,000
DOE Funding FY13:	$950,000
DOE Funding FY12:	$566,000
DOE Funding FY11:	$1,390,000
Project Dates:	2007–2018

Project Description

Biomass feedstock price projections are needed to enable biofuels commercialization efforts. This project employs an economic modeling framework (POLYSYS) to report county-level feedstock supplies (e.g., agricultural residues, dedicated biomass feedstocks, and forest resources) as a function of price, scenario, and year. Farmgate prices of about $62.00 per dry ton (first year) are likely required to provide 325 million dry tons in the first year in 2022 to meet EISA and biopower demands. Assuming a yield of 85 gallons per dry ton (first year), this farmgate price alone would comprise almost 25% of a $3.00 minimum ethanol selling price. Thus changing economic conditions and evolving feedstock production strategies warrant maintenance of revised feedstock price projections. Ongoing modeling efforts include maintenance of current underlying data, incorporating up-to-date biomass crop yield and budget assumptions, accounting for sustainability metrics, and adding additional feedstock types such as algae and municipal solid waste. Detailed results are disseminated thought the Knowledge Discovery Framework. Planned future activities include spatially explicit modeling, which can help quantify positive and negative externalities, evaluate logistical strategies, and test the efficacy of policies and strategies designed to optimize feedstock production on the landscape; quantifying uncertainty associated with climate risk and other stochastic variables; and dissemination of biannual revisions through the KDF.

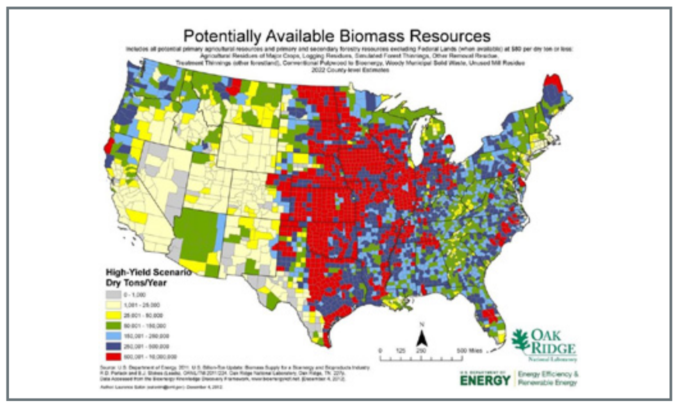
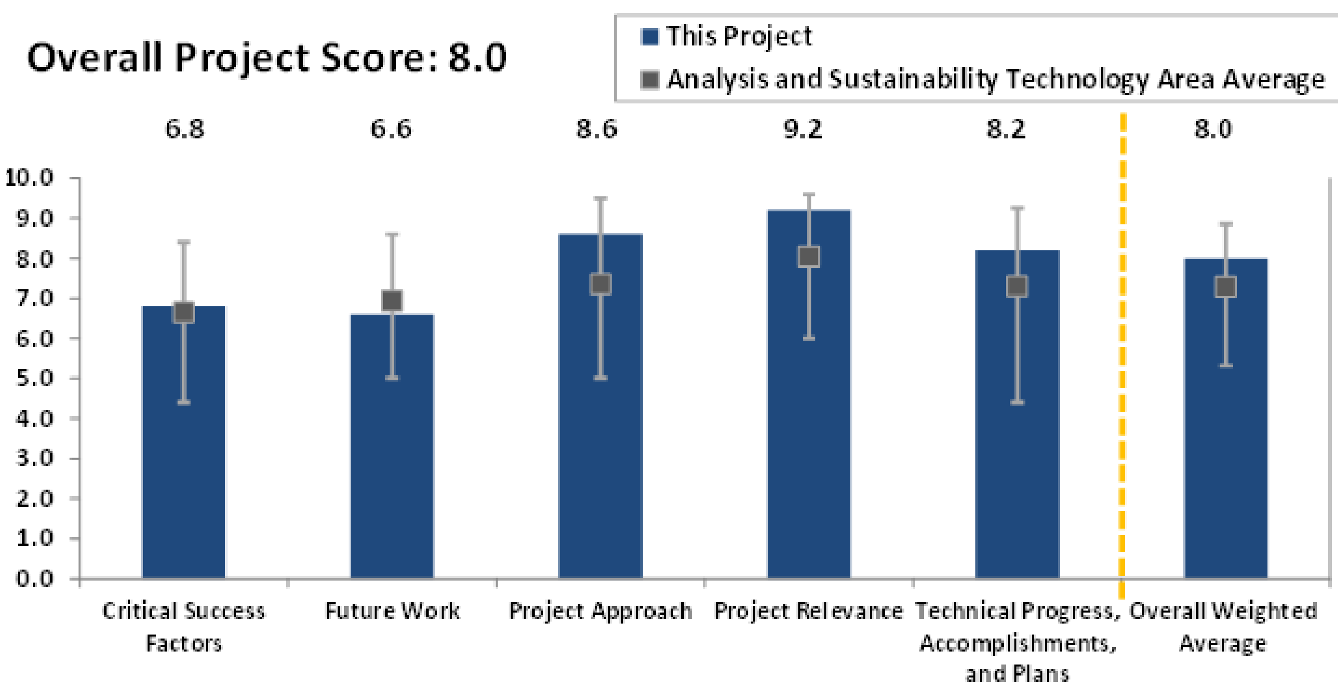


Photo Courtesy of ORNL



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- The POLYSYS-based approach to establishing U.S. feedstock supply curves has been a mainstay of the Office. It provides a critical backbone of analysis to many parts of the Bioenergy Technology Office's research activities. The efforts to roll out the data via the KDF are commendable. The only concern that should be raised at this point is over the proposal to deepen the spatially explicit nature of the model. The value proposition and the appropriateness of the core model and data are already high, and the value added by expanding the resolution of the analysis is not obvious. This may actually be a reasonable direction, but it should be thought through carefully.
- This is a storied effort on the part of BETO and DOE researchers. Given its prominence across a spectrum of flora for planning and researching bioenergy agendas nationwide, the effort clearly has a lot of utility with BETO, as well as to industry, policymakers, and the general public. Although there are flaws in the analysis that can be picked apart, it forms the necessary backdrop against which scientific inquiry and debate can proceed. Thus, it is perhaps important and timely to consider that the growth plan for this project does not have to be limitless, and to undertake a careful goal- and objective-setting exercise to ensure this foundational project remains well aligned with the BETO vision.
- Past and future POLYSYS work provides an important baseline and reference scenarios to frame the analysis of larger policy questions. Future work should focus on updates, core capability enhancement, and making the assumptions and results more accessible. This panelist recommends against trying to extend the model too far past what it was originally designed for, and rather to integrate well with additive models that can build on its reference-scenario outputs.
- There are distinct advantages in a spatially explicit dataset. This project has made significant and important advances to provide a greater understanding of potentially available biomass, and providing insights into the supply chain logistics for feedstocks. Incorporating stochasticity into the model may improve the quality of analysis, although caution should be taken to only expand the model to its logical extent. Specific research questions should drive future development of this tool.
- This project does a very good job studying, maintaining, and disseminating feedstock supply data (availability, pricing, quality, etc.), which is critical to BETO's work.

PI Response to Reviewer Comments:

- We appreciate the constructive review. For clarification, we would emphasize that at this point we are not proposing expanding POLYSYS to run at the parcel level. Rather, we plan to generate spatially explicit realizations (i.e., mapped field-level projections of stochastic land use allocation) of the POLYSYS outputs, which can in turn be used to evaluate resource accessibility, logistics, and environmental impacts. We already do this on the USDA Cropland Data Layer, and we believe with relatively little additional work, we can generate more realistic parcel-level land-use projections by allocating land use to parcels in the USDA Common Land Unit, rather than pixels in the Cropland Data Layer. In simple terms, we are not expanding the model, rather expanding application of the model output, which we believe will offer a high-marginal benefit in analysis capability, considering the relatively low-marginal effort this would require.
- Environmental analysis of bioenergy production requires land management estimations at a higher resolution than what POLYSYS predicts, and our method of realization is consistent with both the projections of biomass availability and land-use decisions made at the farm scale. Higher-resolution estimates are a frequent request of other projects within the BETO R&D portfolio.
- We agree with other feedback presented and will incorporate it in our future work.

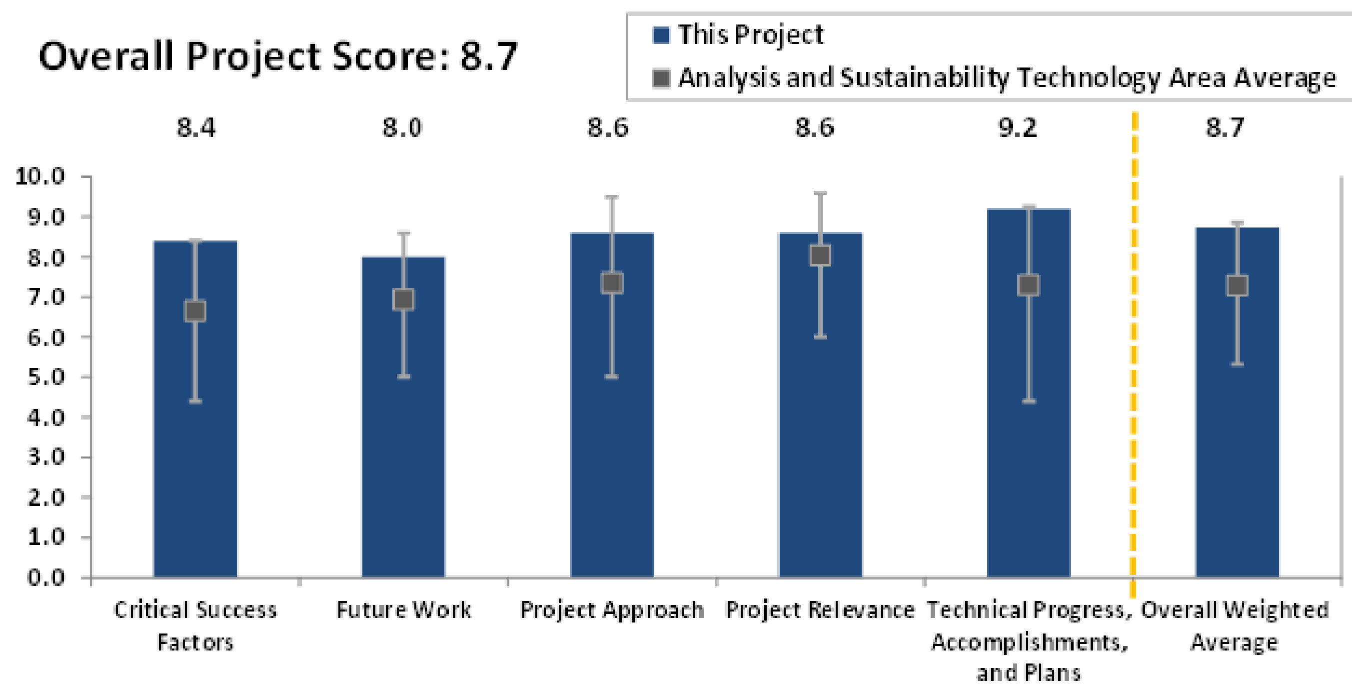
ALGAE RESOURCE ASSESSMENT

(WBS#: 1.6.1.3)

Recipient:	PNNL
Presenter:	Mark Wigmosta
Total DOE Funding:	$184,000
DOE Funding FY13:	--
DOE Funding FY12:	$184,000
DOE Funding FY11:	--
Project Dates:	2011–2012

Project Description

BETO launched an initiative to obtain consistent quantitative metrics for algal biofuel production in order to establish an integrated baseline production scenario by harmonizing and combining the Office's national resource assessment, life-cycle analysis, and techno-economic analysis. The baseline represents a plausible, near-term production scenario with freshwater microalgae growth, extraction of lipids, and conversion via hydroprocessing to produce renewable diesel. The PNNL Biomass Assessment Tool was used to prioritize and select the most favorable consortium of sites that support production of five billion gallons per year of renewable diesel. The Gulf Coast was identified as the most favorable region to meet this target, while freshwater availability was the most important constraint. Strong seasonality in biomass production caused over-sizing of facility capacity with significant impact on cost and emissions. Feedstock site and algal strain selection must place a high priority on increased productivity while minimizing seasonal fluctuations. To assess the potential for land competition between terrestrial and algal biomass feedstocks in the United States, we evaluate a scenario in which 41.5 x 10^9 liters per year of biofuels are produced on pasture land, the most likely land base where both feedstock types may be deployed. This total includes 12.0 x 10^9 liters per year of biofuels from algal feedstocks and 29.5 x 10^9 liters per year of biofuels from terrestrial feedstocks. Our analysis indicates that potential competition for land would be concentrated in 110 counties, containing 1.0 and 1.7 million hectares of algal- and terrestrial-dedicated feedstock production respectively. A land competition index suggests that 38 to 59 counties could experience competition for up-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

wards of 40% of a county's pasture land. However, this combined 2.7 million hectares represents only 2%–5% of total pasture land in the U.S., with the remaining 12.5 million hectares of algal- or terrestrial-dedicated feedstock production on pastureland in non-competing areas.

Overall Impressions

- A good start at addressing the relationship between land characteristics and water availability for algal growth. Needs more breadth and depth moving forward.
- The project is complete. The PI is to be commended for a balanced presentation of results within the context of constraints on assumptions. Going forward, it is evident that the water question will need to be addressed in a more nuanced way. A key consideration for any future project would be that, if the focus on water is a function of data availability, strategies should be developed and explored such that the question(s) can be addressed indirectly for other water quality/sources. Competition for nutrients will also need to be a focus of any future work.
- This is a well-described project that has accomplished its stated objectives. The study acknowledges its limitations while still generating meaningful results that are applicable to potential development of the algae industry. The project did an effective job integrating technical, economic, and environmental information in a meaningful way.
- This project stands out as a remarkable accomplishment. The analysis is comprehensive. It has also been completed with a comparatively small budget over a fairly short timeframe. It is an excellent start on the difficult work of assessing the sustainable resource base for algae. The only downside to this project is its narrow focus on freshwater systems. It is not clear whether the motivation for this narrow initial focus is related to data availability, or whether it reflects the necessity to focus on all forms of aquatic systems (both freshwater and salt water). If the intent here is to develop a full complement of information related to salt water and brackish systems, then it would have been nice to see these plans spelled out in their full context. If this is not the case, then the Office needs to redirect this project to ensure that the salt and brackish water systems are fully incorporated in the resource assessment for algae.
- This project's broad inclusion of several sustainability criteria is a key strength. It pragmatically addresses BETO and industry needs by focusing on algal production limiting factors and building on the *Billion-Ton Update*. The project seemed to be a good value for funds spent and sought to coordinate the findings with other projects to serve BETO's mission. The future efforts to harmonize with other BETO models, water rights, saline water, and nutrient competition should be an important contribution to the Algae Technology Area moving forward.

PI Response to Review Comments

- Thank you for the thoughtful responses and suggestions. We are in complete agreement with the need for more breadth and depth moving forward, in particular, to consider alternative water sources and nutrients. Recently we have developed spatial databases and transport models to allow consideration of brackish/saline groundwater and seawater sources (including blowdown and disposal costs).
- Much of this work is presented in a 2013 Environmental Science and Technology publication "A geographic information systems (GIS) model to assess the availability of freshwater, seawater, and saline ground water for algal biofuel production in the United States."
- We have also begun to consider nutrient demand and recycle for lipid extraction and hydrothermal liquefaction technology conversion processes. This work is presented in a 2013 manuscript accepted by

Biomass and Bioenergy, "A National-Scale Comparison of Resource and Nutrient Demands for Algae-Based Biofuel Production by Lipid Extraction and Hydrothermal Liquefaction."

- In addition, we are looking at commercial availability of delivered carbon dioxide (CO_2), as well as modeling transport and economics of flue gas using a detailed national database of sources, volumes, and purities.
- These advancements have allowed us to conduct multi-object tradeoff analysis considering biomass production potential, water demand and alternative supply, nutrient demand, and CO_2 demand and supply.
- We have also begun to consider the impacts of pond operational strategies and downstream processing pathways (i.e., lipid extraction versus hydrothermal liquefaction) on biofuel production potential and resource demand.

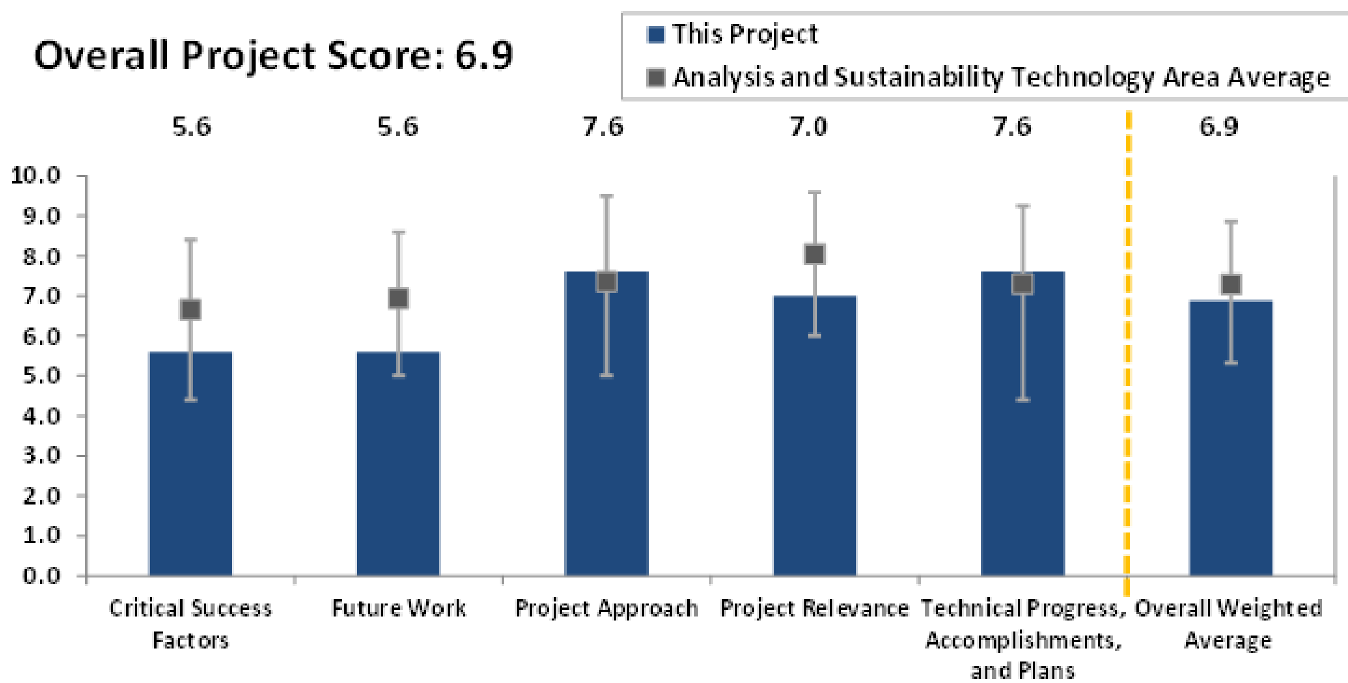
BIOFUEL PRODUCTION POTENTIAL IN THE WESTERN U.S.

(WBS#: 11.1.1.6)

Recipient:	PNNL
Presenter:	Mark Wigmosta
Total DOE Funding:	$664,000
DOE Funding FY13:	$150,000
DOE Funding FY12:	$180,000
DOE Funding FY11:	$225,000
Project Dates:	2010–2050

Project Description

The *U.S. Billion-Ton Update* does not consider the use of irrigation for energy crop production; it does, however, note that in the western United States, most crops—including hay crops—are grown under irrigation. Irrigated energy crops will never compete economically with high-value irrigated crops, such as fruits and vegetables, but may be able to compete with lower-valued crops like hay and small grains. One potential energy crop species for irrigation in the western United States is switchgrass. There also may be opportunities to rotate some annual energy crops with some high-valued crops. This project complements the *Billion-Ton Update* by providing a detailed, systematic assessment of the potential for integrating energy crops into the existing western United States crop mix to increase national biofuel production and economic benefit without increasing net water use or adverse environmental impacts. USDA's National Agricultural Statistics Service's Cropland Data Layer data were used to identify location-specific crop rotation patterns at the field scale. Data from energy crop field trials collected in the West by USDA-Agricultural Research Service and Washington State University collaborators were evaluated and used to parameterize the PNNL Adaptive Landscape Classification Procedure for evaluation of energy-crop biomass production and water demand. We present a preliminary, high-spatial resolution analysis of production potential in the West for irrigated Alamo, Kanlow, and Blackwell switchgrass.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Despite a tremendous amount of field work, this project is really a preliminary attempt to look at the irrigated-dedicated bioenergy crop question. There are serious limitations to the overall approach that will curtail interpretation. Future work would benefit from a refinement of hypotheses and a better understanding of critical experimental conditions or attributes (e.g., what is marginal land refined to a biophysical set of factors; what is hay or pasture, refined to a specific species and management class; etc.). Finally, a broader valuation of water should probably precede any further/detailed (closer to the ground) study on specific crops and rotations to assign any economic values of yields, as the economic value of the yield cannot be divorced from other costs.
- Overall the data collected by this project is of great value. Analysis needs to broaden to marginal areas and to include impact of climate change.
- The project was well executed for the limited data available. Although some assumptions were simplified, the project represents a reasonable approach to generate estimates on overall feasibility of bioenergy production in a challenging climate. The analysis is well planned and will give a better picture of actual potentials in the western U.S. It is unclear whether additional efforts will provide significant added value.
- This project addresses important water demand, nutrients, and economics for switchgrass cultivation. It has laid the groundwork for an important conversation in the western U.S. regarding irrigated crops and their relative value moving forward. Future work on crop rotation and climate variability may provide some important crop selection and results to integrate with the Policy Analysis System model (POLYSYS).
- This project takes a courageous step into the previously forbidden idea of understanding what western, irrigated biomass resource systems might be able to provide. While it is far from certain that such a direction for feedstock production will be sustainable, the project represents an appropriate step of due diligence to understand what the opportunity for biomass in the western U.S. actually is. They have minimally constrained their analysis in terms of sustainability by requiring that the biomass production not add any new demand to current irrigation systems. This serves to set the bounds on the opportunity, but does not complete the puzzle in terms of sustainability of the proposed production. The analysis is, at best, a first cut attempt to estimate the size of the resource for the West, but it does show that the amount of biomass resource potentially available is significant. Due diligence requires us to at least understand the size of this opportunity. The project performers have done a good job in sketching this out. But it also requires the research to move in the future toward a deeper understanding of the sustainability of such production by considering the negative effects of continued irrigation on local watersheds, and the broader life-cycle implications of including irrigated crop production in the supply chain for biofuels.

PI Response to Reviewer Comments:

- We agree that the results presented are preliminary, though they do represent a first look at switchgrass potential (multiple varieties) in the western U.S., which has largely been ignored by the broader community. The significant yield results obtained in the modeling justify an effort to research the potential further by considering additional objectives around economics, sustainability, resource use, refined land selection, and evaluation of total life cycle in the biofuel supply chain. Our general modeling approach starts with a broad-level look to evaluate potential barriers, after which we begin the process of adding additional details to drive towards informative and refined estimates. Other irrigated land will be evaluated in addition to those currently used for pasture, hay, and small grains. We will also evaluate the potential to integrate oil-seed biomass crops into current crop rotations. Additional sustainability metrics will be considered, including soil health, water quality (nutrient loading), erosion and water use. We concur with the need to better define marginal land—our initial switchgrass effort only considered currently irrigated lands for pasture, hay, and small grains. As we evaluate the use of marginal lands, we will develop a more refined definition based on biophysical parameters including climate, soils, landform, and water availability relative to energy crop needs. In fiscal year2014, we will begin a limited climate change assessment in addition to providing resource assessment results to ORNL to support POLYSYS runs with irrigated switchgrass.

THE BIOENERGY KNOWLEDGE DISCOVERY FRAMEWORK (BIOENERGY KDF)

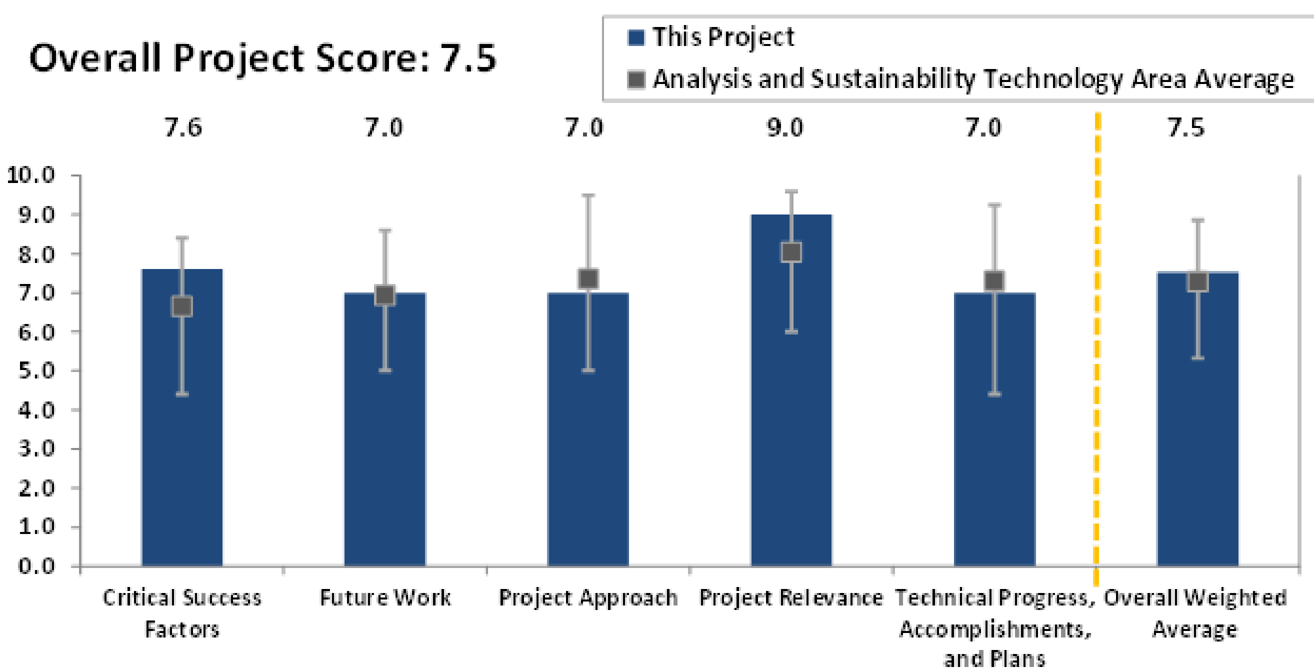
(WBS#: 1.6.1.8)

Recipient:	ORNL
Presenter:	Aaron Myers
Total DOE Funding:	$4,425,000
DOE Funding FY13:	$400,000
DOE Funding FY12:	$750,000
DOE Funding FY11:	$1,000,000
Project Dates:	2008–2015

Project Description

Photo Courtesy of ORNL

There are many issues in the biofuel cycle, from production to delivery, that have to be addressed in order to foster a viable biofuel industry. Infrastructure issues related to generation, distribution, and delivery of biofuels include finding the optimal locations to site biorefineries to minimize cost with adequate availability of feedstock resources nearby. Some of these issues have a strong geospatial component to them. For example, mapping the spatial distributions of the available, sustainable biomass feedstock can identify production regions and supply sources for biofuel refineries. In addition, there may be unanticipated consequences of scaling up a biofuel industry, such as effects on climate change, rural development, changes in agricultural practices, and land-use change. These indirect feedbacks also need to be well understood. The Bioenergy Knowledge Discovery Framework is a collaborative platform for knowledge creation, collection, curation, and discovery to support DOE's effort to develop a sustainable biofuel industry. The Bioenergy KDF facilitates informed decision making by providing a means to synthesize, analyze, and visualize vast amounts of information in a spatially integrated manner. The Bioenergy KDF enables data harmonization from different sources, serves as a source of authoritative and



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

benchmark datasets, and provides integrated decision-making capabilities to its different stakeholders. It serves as an open platform, and leverages collaborative aspects of the social Web to catalog and share datasets and other relevant information. The Bioenergy KDF will also host applications addressing different bioenergy-related problems. These applications will include techno-economic models, routing models for transportation, and visualization of different feedstock-production scenarios.

Overall Impressions

- The KDF can play a critical role in advancing biofuel sustainability analysis and providing a platform through which to disseminate data, results, and findings. It will be able to do so more effectively with a more standardized pathway categorization and boundaries definition. By doing so, the KDF has the potential to not only serve DOE's bioenergy research partners, but also to fill a federal interagency research need.
- The goals of this project are laudable and critical. The importance of the project to BETO and industry as generally conceptualized (distinguished from the specific approach) cannot be understated. The data aggregation and ability to use and reuse data for purposes beyond the original experiments in which they were collected is increasingly recognized as a critical aspect of sound research sponsorship and investment, as highlighted by current Office of Science and Technology Policy directives on open access for data. Given such directives, the relevance of the KDF to BETO is self-evident and the rationale for open access data itself speaks to the myriad of anticipated benefits to industry and the tax-paying public of being able to search for and repurpose already-collected and curated data. However, it seems some critical aspects and attributes are being overlooked or remain unaddressed. These include key aspects of data repositories, including metadata and searchability, data standards and interoperability, workflows to ensure curation and provenance, etc. These are all critical to ensuring that this infrastructure for DOE does not become a "silo" among the broad array of other related and ongoing data community efforts (e.g., the National Science Foundation's DataONE, National Agricultural Libraries data repository for USDA's Agricultural Research Service, etc.). Finally, project PIs working with the Sustainability and Analysis Technology Area team are well advised to explicitly consider a long-term "sustainability plan" for how the KDF will persist and be maintained beyond the life expectancy of this project.
- This is a necessary project to centralize and share databases that may ultimately have a strong impact on the bioenergy research community. It is a tremendous undertaking that will face many inherent challenges in order to make it effective. It was good to see the initial streamlining effort, recognizing that the tool cannot be everything to everybody. Prioritization will continue to be key to successful implementation. Greater efforts will be necessary to encourage adoption of the tool for data sharing among the research community, and to actually get researchers to use the tool and upload their data. Greater discussion regarding how failures can be shared among the scientific research community (particularly those under the shared DOE umbrella) could be potentially very useful in making overall research efforts more efficient. Recognition that the KDF is a useful tool for collaboration and communication, but not an end to dissemination, is essential. Additional mechanisms should be put in place beyond the KDF that will help disseminate knowledge found within the KDF to the appropriate audiences.
- This is a project that seems to have come a long way. It has developed the KDF as a useful research tool and mechanism for both information dissemination and collaboration among diverse research

efforts in the Office. The performers are wise in their efforts to narrow their customer focus to researchers, rather than trying to succeed at meeting the needs of all possible users of data. They cannot be Wikipedia and at the same time have sufficient resources to be stewards of complex and constantly changing datasets and modeling tools. Overall, this is a well-done project.

- This tool is critical to foster a collaborative and transparent progress of DOE's efforts. The project has accomplished a lot since the last review; data is broader and more usefully presented. Some work is needed to enhance ease of use, searchability, and data documentation.

PI response to Reviewer Comments:

- The Bioenergy KDF has proven to be a useful tool for disseminating bioenergy-related information and providing complete access to data generated by the bioenergy research community (e.g., *Billion-Ton Update*). By focusing on researchers, the KDF aims to more fully achieve its goals of building a bioenergy knowledge base, curating data, and facilitating information and data exchange. It is imperative to engage the research community during all aspects of KDF design and development in order to extend its reach, to integrate critical and emerging capabilities and data, and to ensure that it does not become a "silo." Increasing ease of access to and searchability of site content is one way to do this, and is greatly facilitated by an enhanced awareness of the research community's metadata requirements, but a balance should be struck between those requirements and a researcher's willingness and/or ability to provide a complete set of metadata. Given the complex and dynamic nature of bioenergy research, finding a reasonable balance is a constant challenge, but one that should be addressed to the maximum extent possible. Another important approach is to foster a sense of ownership and acceptance of the KDF within the research community. New capabilities such as Featured Research and Researcher Profiles are designed to do this through promoting valuable community efforts and highlighting the accomplishments and expertise of its members. There is a growing need to share information among systems, agencies, and varied research communities. The KDF is well positioned to play a key role in meeting this need and promoting the adoption of open data standards within the federal government.

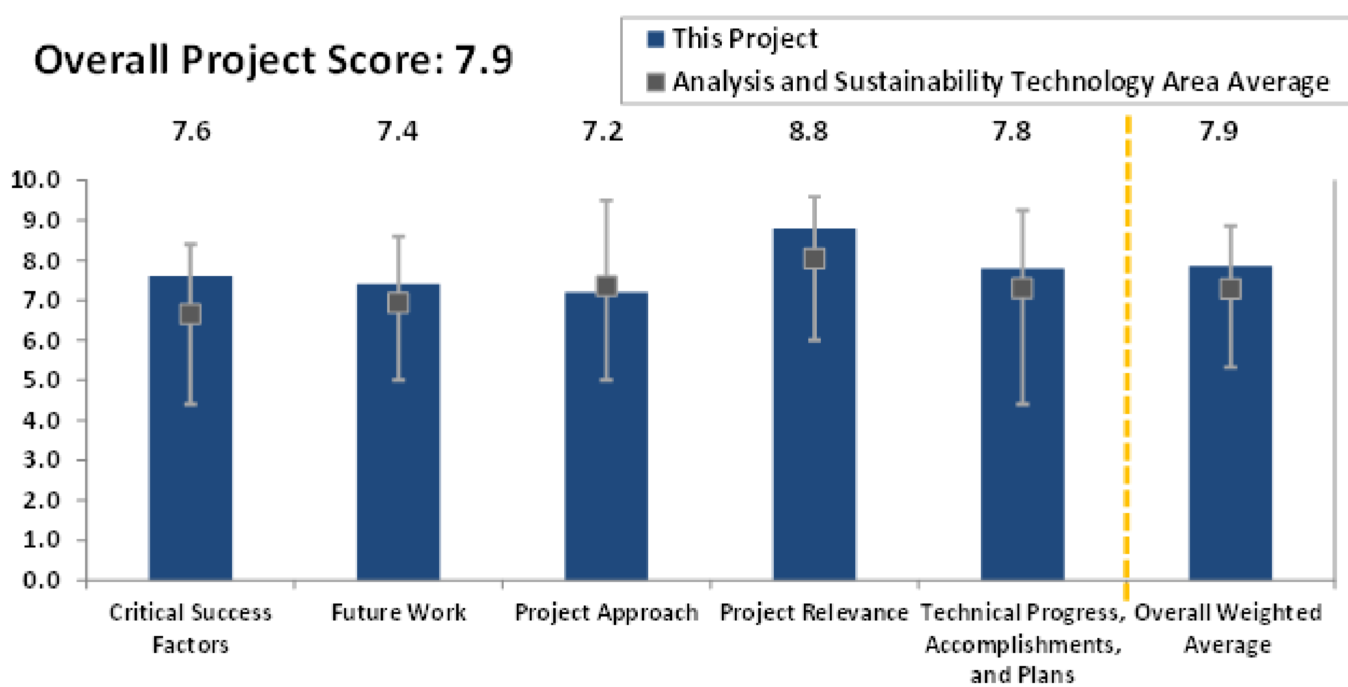
INL FEEDSTOCK ANALYSIS

(WBS#: 1.6.1.9)

Recipient:	INL
Presenter:	David Muth
Total DOE Funding:	$1,600,000
DOE Funding FY13:	$750,000
DOE Funding FY12:	$400,000
DOE Funding FY11:	$450,000
Project Dates:	2009–2017

Project Description

This project is titled Feedstock Analysis Integration. The project is focused on developing and delivering analytic capability that sustainably maximizes the biomass resources entering the supply chain, decreases delivered feedstock cost, and achieves biomass feedstock performance requirements. It is led by Dr. David Muth at Idaho National Laboratory. It is funded through the Bioenergy Technologies Office Feedstock Technology Area and is tightly coupled to several activities within the Strategic Analysis and Sustainability Area. Historically, supply chain analyses have focused on determining the cost of operating a minimum set of equipment required to get biomass material into a biorefinery reactor. A number of supply chain analysis challenges have emerged, including variability in feedstock quality properties, the introduction of advanced preprocessing technologies, and the need to understand sustainability metrics. This project was developed to provide an integrated analysis framework and associated set of methodologies to overcome these challenges. Four primary products have been delivered over the past two years. The first product is the feedstock supply chain analysis framework, which has been integrated with the Biomass R&D Library data management system. The Library has more than 60,000 biomass samples and provides real-time biomass quality data to support supply chain analytics that effectively capture the impacts of supply chain operations on feedstock quality. The second product is an explicit numerical coupling of the biomass resource supply curves with the feedstock supply chain analytics. This is an important engineering supply chain that actively manages critical biomass-quality parameters. The third product is an integration framework for



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advanced preprocessing models. The fourth product is the integration of sustainability-assessment capability. These products are being used to support BETO, industry, and other research community partners in performing advanced biomass supply chain analytics.

Overall Impressions

- Project accomplishments include the development of a 60,000 sample library with the computational infrastructure to catalog the samples by an array of specifications, allowing users to query the database to understand means and variances for specifications within and among feedstocks. The value of this library is self-evident, given that conversion technologies are unsettled and candidate pathways, once surfaced, must perform suitably across heterogeneous materials. What is less clear were the accomplishments (and their importance) in least-cost formulation. While the approach is important in animal feed, the premise with biofuels is a bit different and the value in the context of a flexible blending approach less certain. Given the demonstrated importance of things such as moisture content variation in feedstocks, a better approach and more useful accomplishment might be to characterize specification variation in the context of process (e.g., conversion) sensitivity. The project impact could then be more focused on identifying robust processes for further refinement versus highlighting the costs of tailoring a feedstock to a process. Given the unsettled nature of commercial processes, this may be the more useful outcome for industry.
- This is a strong project overall. Using a spatially explicit basis to link feedstock variability and logistics provides a more realistic picture of bioenergy feasibility within a region. There are some issues regarding data availability and appropriateness of extrapolation, but these are acknowledged with a plan in place to address analysis gaps.
- This project addresses an important need for the bioenergy research. Characterization and analysis of feedstocks, as well as accumulation of more and better data on feedstocks, will continue to be an important need for the nascent bioenergy industry. The project's focus on being a repository of both samples and data is excellent. The performers have demonstrated how the data can be used in quantifying feedstock quality with respect to process specifications. The project has established a very interesting methodology for developing a least-cost formulation of feedstocks, aimed at meeting specifications using as diverse an array of feedstocks as possible within the supply shed of a given processor. This formulation has been used to support cost analysis for DOE's goals, and is a good framework for future industrial users as well. That said, the project team should be careful not let the least-cost formulation analysis dominate their efforts at the expense of focusing on data collection. In the end, given the complexity of biomass properties and the many independent factors that influence them, least-cost formulation will be fraught with difficulty. This can be seen in the highly variable nature of the feedstock over time. Detailed optimization of feedstock mix is likely better addressed at the individual commercial developer level. The project team can aid such companies, but should not see it as its job to fully establish this technique. Their value has come from demonstrating the utility of this approach and the need for data to support it.
- This project provided some very relevant data collection and categorization to address feedstock characteristic issues. Analysis and analogy to feedstock blending is interesting, however, its limitations due to the low-value, high-volume nature of feedstock (versus feed) are unexplored.

- This project skillfully utilizes existing BETO data to focus on practical questions for design cases and framework-oriented analysis, and offers possibilities for integrating other sustainability criteria. Its current weakness is that the animal-feed-based, least-cost approach needs to be validated as an industry need, and industry must be engaged on the project's refinement to ensure it provides value added.

PI Response to Reviewer Comments:

- Least-cost formulation is a relatively new concept that we have just started researching. The initial impacts of blending are significant enough to warrant further research along this path. We have developed a set of tools for analyzing regional data based on *Billion-Ton Update* data, as well as logistics costs. The outcome of these tools is shown in spatial graphs of costs on a county-level basis. The tools were not highlighted as part of the accomplishments, but perhaps should have been. Least-cost formulation is only one of many options being explored that will decrease costs and increase volumes. Its current weakness is that the animal-feed-based, least-cost approach needs to be validated as an industry need, and industry must be engaged on the project's refinement to ensure it provides added value.
- Analysis and analogy to feedstock blending is interesting, however, its limitations due to the low-value, high-volume nature of feedstock (versus feed) is unexplored. We do have some research that shows that blending is not only possible, but is, in fact, beneficial to some conversion processes.[2] We also have some in-house data on impacts of blending on densification, and again the results show improvement over a single feedstock. There are lots of unanswered questions yet on blending and formulation, but the initial results seem to support that it is at least a viable option that should be researched.

[2] Shi, J.; Thompson, V.S.; Yancey, N. A.; Stavila, V.; Simmons, B.A.; and Singh, S. "Impact of mixed feedstocks and feedstock densification on ionic liquid pretreatment efficiency." Biofuels, (4:1), 2013; pp. 63-72.

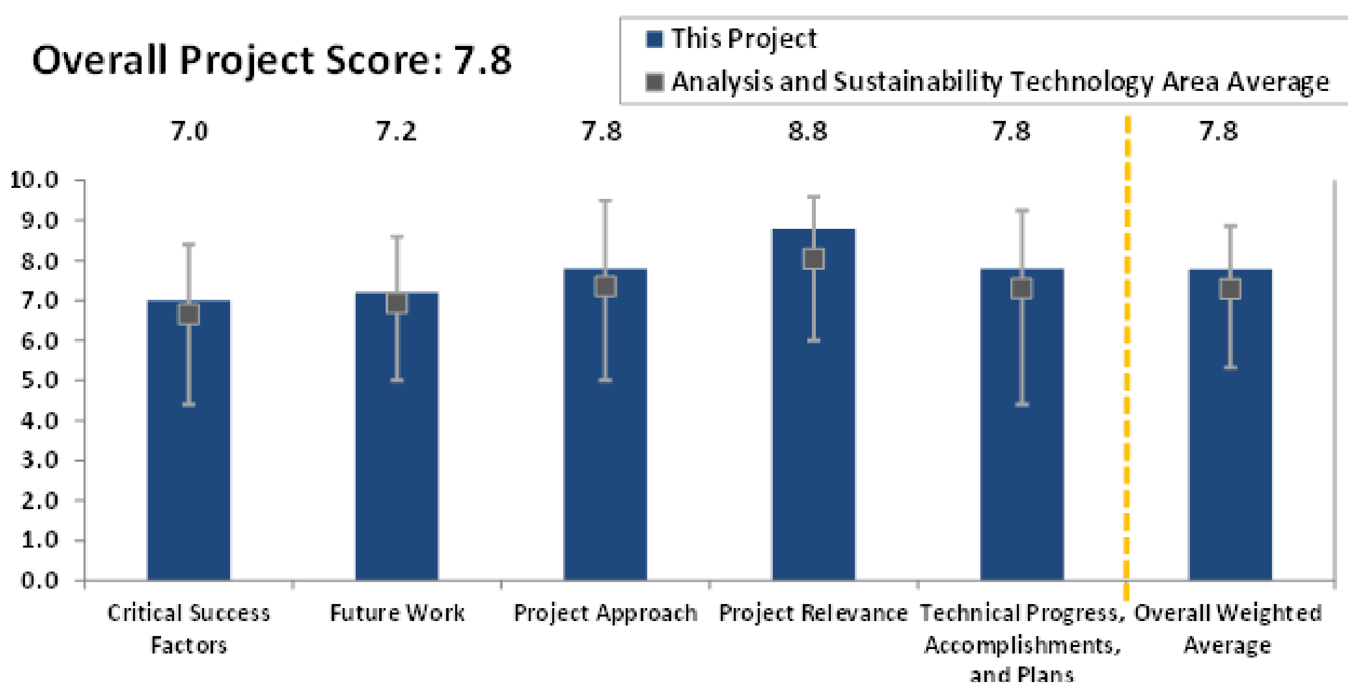
BIOMASS–TO–BIOENERGY SUPPLY–CHAIN SCENARIO ANALYSIS

(WBS#: 11.2.6.3)

Recipient:	NREL
Presenter:	Brian Bush
Total DOE Funding:	$4,080,000
DOE Funding FY13:	$800,000
DOE Funding FY12:	$780,000
DOE Funding FY11:	$800,000
Project Dates:	2006–Ongoing

Project Description

The Biomass Scenario Model (BSM) is a unique, carefully validated, state-of-the-art, third-generation model of the domestic biofuels supply chain that explicitly focuses on policy issues and their potential side effects. It integrates resource availability, behavior, policy, and physical, technological, and economic constraints. The model uses a system-dynamics simulation—not optimization—to model dynamic interactions across the supply chain. The BSM tracks the deployment of biofuels given technological development and the reaction of the investment community to those technologies in the context of land availability, the competing oil market, consumer demand for biofuels, and government policies over time. It places a strong emphasis on the behavior and decision-making of various economic agents among ten geographic regions domestically. The BSM has been used to develop insights into biofuels industry growth and market penetration, particularly with respect to policies and incentives applicable to each supply-chain element (volumetric, capital, and operating subsidies; carbon caps/taxes; R&D investment; loan guarantees; tax credits). The model treats the major infrastructure-compatible fuels, including biomass-based gasoline, diesel, jet fuel, ethanol, and butanol. In general, scenario analysis based on the BSM shows that the biofuels industry tends not to rapidly thrive without significant external actions in the early years of its evolution. An initial focus for jumpstarting the industry typically has strongest results in the BSM in areas where effects of intervention have been identified to be multiplicative;



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

due to industrial learning dynamics, support for the construction of biofuel conversion facilities in the near future encourages the industry to flourish. In general, we find that policies that are coordinated across the whole supply chain have significant impact in fostering the growth of the biofuels industry and that the production of tens of billions of gallons of biofuels may occur under sufficiently favorable conditions.

Overall Impressions

- Overall, the project presentation was clear and direct, though the model is complex. True validation of the model developed through this project is not possible. Some calibration can occur, but other parts of the model/project are highly speculative with projections (outcomes) that are more uncertain than others. It is of note that PIs have not attempted a policy analysis calibration/validation for scenarios in Brazil, although this seems both plausible to accomplish and informative of model utility. Such an analysis seems like an obvious, low-hanging fruit given validation opportunities are so sparse. One overarching question regarding BETO projects that is highlighted by this proposal concerns when the complexity of the model itself overshadows utility—especially when calibration/validation cannot be achieved in any real context. I envision this as a key go/no-go criteria in any future work with this and other model-of-models, where modules themselves produce highly uncertain results.
- The development of system-dynamics tool for learning and insight is an impressive accomplishment. This project represents a rare example of model development that truly supports dialogue and development of insights, as opposed to typical modeling efforts that seem geared toward forecasting and prediction. Models such as the BSM could play a vital role in strategic decision making within and outside the DOE Office. The project team is to be commended for recognizing this important role, and for using the model in workshops to catalyze thinking and discussion. The model appears to be in a maintenance phase, an important milestone for the project. It is good to see this work shifting from model expansion and improvement to maintenance and application. In the review presentation, actual examples of insights and output from the model were somewhat disappointing. The team should be encouraged to simplify both the output and the nature of the questions the model is being used to address, and avoid obscure technocratic descriptions. Core questions of cost versus benefit need to be stripped down to their basic points in order for stakeholders and DOE management to make the best use of the tool. Ideally, this tool would become a central part of strategic planning discussions (as opposed to strategic planning justification).
- The project addresses a critical part of the Analysis portfolio, thoroughly covers the supply chain of biofuels, and takes into account a broad range of external factors that can influence the future of biofuels. The system should be used to inform policymakers to ensure policies and incentives are appropriate for desired outcomes.
- This high-level model attempts to depict the system complexity of the biofuels industry, including technical, economic, and policy factors. As with any model of this nature, uncertainty is inherently large, but the project team acknowledges these issues and seeks to validate model data as best as possible. Using this model to gather insights regarding potential system bottlenecks and appropriate policy interventions can be useful to guide the overall Sustainability and Analysis portfolio, as well as provide good opportunities to engage with stakeholders.

- This project's strength is that it sought to answer policy questions about impacts and costs to taxpayers. However, the model's structures, function, validation, and strengths/weakness need to be made more accessible to enable user trust. Interagency stakeholders and policymaker engagement and training sessions should be a good mechanism to help address this challenge.

PI Response to Overall Impressions

- The PIs agree with the reviewers that the BSM is complex, but feel that the model has the level of detail appropriate to support the real-world complexity of the biofuels supply chain. Moreover, the project team has endeavored to limit the scope of the model to the key aspects of the biofuels supply chain that affect the overall evolution of the biofuels industry and its responsiveness to government policy and other external factors. For the past two years, the team has included sensitivity studies in its analyses and has delivered the results of those to the project sponsors; in general, this quantitative, statistical approach to identifying the biggest drivers (points of leverage and bottlenecks) has confirmed the results of the system-dynamics-based analyses of the supply chain.
- Using historical data from countries with biofuels experience such as Brazil is feasible for model validation, but it requires substantial data collection efforts and analysis resources. Much of the validation work for the BSM has emphasized reproducing the historical experience with starch-based ethanol production in the U.S., matching the long-term agricultural forecast from USDA, mimicking empirical observations of industrial learning in the bioenergy and analogous industries, and similar validation opportunities relevant to single elements of the biofuels supply chain.
- The PIs agree that accurately and transparently communicating results from dynamic models like the BSM as simple intuitions is challenging, particularly in venues where time is limited. The project team plans on pursuing the reviewer's suggestion to increase the clarity of analysis insights, to focus on core questions of cost/benefit, and to engage in strategic planning discussions. The team's engagement with stakeholder groups in workshop settings has steadily improved the effectiveness of the communication of BSM analysis results.

BIOLUC MODEL

(WBS#: 11.2.1.1)

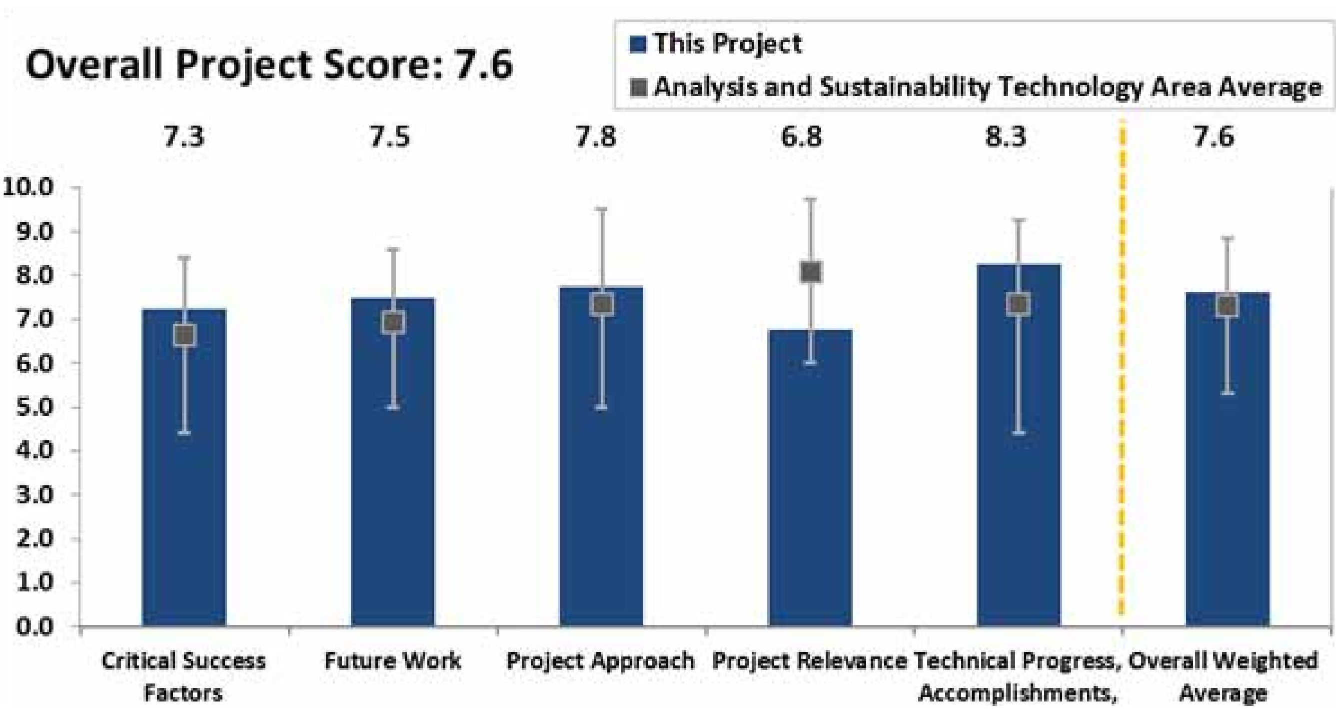
Recipient:	NREL
Presenter:	Daniel Inman
Total DOE Funding:	$1,000,000
DOE Funding FY13:	$200,000
DOE Funding FY12:	$300,000
DOE Funding FY11:	$100,000
Project Dates:	2009–2013

Project Description


Photo Courtesy of NREL

Our objective is to develop and utilize a systems dynamic model that incorporates the key drivers of land-use change to help better understand the role of biofuel production as a driver of LUC. The BioLUC model has been developed specifically as a transparent and simple approach to LUC modeling. Results from this project address the following barriers, outlined in the 2012 MYPP: St-B, Scientific Consensus on Bioenergy Sustainability; St-C, Sustainability Data Across the Supply Chain; and St-F, Systems Approach to Bioenergy Sustainability.

The BioLUC modeling effort is focused on improving our understanding of how bioenergy and LUC interact. We have achieved all planned milestones and have published our results in peer-reviewed literature. This project will be complete at the end of fiscal year 2013, at which point the model will be released publicly along with the datasets we have processed. We expect the model to facilitate much discussion among stakeholders, as well as provide an accessible medium upon which groups may test different assumptions and datasets. Having a transparent and relatively simple model (i.e., runs quickly, isn't very large, etc.) will add tremendous value to the community as a whole. It is our hope that the release of this model will stimulate an "open-source" level of interest and external development.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- A simpler (not simplistic) approach to land-use change as developed in this project represents a much more constructive and fruitful approach to engaging in the controversies associated with land-use change and biofuels. The BioLUC model could prove to be a powerful future catalyst for discussion about the highly important questions of global agricultural land management. Analysis results as presented in this review are, however, disappointing. The results from the model seem limited to safe, generic conclusions. Perhaps as the model is moved out into the public domain, it will be used to delve more deeply into the pressing questions for biofuels as a sustainable part of the global agricultural land system.

- Good contribution the complex challenge of land-use change dynamics. The project addresses challenging gaps in an open and understandable manner that could be focused on providing a means to address indirect food versus fuel issues. Future efforts should explore the linkage to the Biomass Scenario Model to better understand international dynamics that can inform the policy debate.

- Land-use change modeling is a complex and controversial subject that is under great scrutiny. This effort represents a reasonable alternative to economic equilibrium approaches and has the advantage of better transparency. Framing the tool as a mechanism to provoke discussion and reflection rather than providing definitive results is very appropriate given system complexity and uncertainty. Greater validation efforts and benchmarking with other tools would be useful to better understand the overall dynamics of LUC and whether different modeling approaches lead to similar results.

- The basic concept of the model is well thought out, however, it is hard to judge if the right balance between simple and not detailed enough is achieved. Scenario results presented do not clearly show the impact of biofuel production.

- This is a project where the model itself may be more interesting than the output in terms of potential project results' impacts. The tool itself should be promoted for its educational capacities in critical thinking. At present, there is a pronounced dearth and an articulated demand for tools that are easy to use and that promote inquiry and conversation. Stella has a strong history in educational programming for numerous reasons and this project may achieve its greatest result if it can be made available for integration into curricula for educating future scientists.

PI response to Reviewer Comments

- The results presented during the peer review were simplistic because the model was still being developed and our results needed to be simplistic to allow for vetting. It is also our hope that, once the model is publically available, it will be used to probe deeper into the issues of LUC.

- We expect to use the BioLUC with the Biomass Scenario Model in future studies. This is a very logical and potentially useful linkage.

- We have worked with ORNL on comparing BioLUC's results to GTAP's results. We are providing multiple datasets to the public upon the release of the BioLUC model to allow for multiple data comparisons.

- It is true that the scenarios presented at the Peer Review show a large impact from biofuels on global LUC because population growth and meeting food demands is the primary driver of LUC in the scenarios examined.

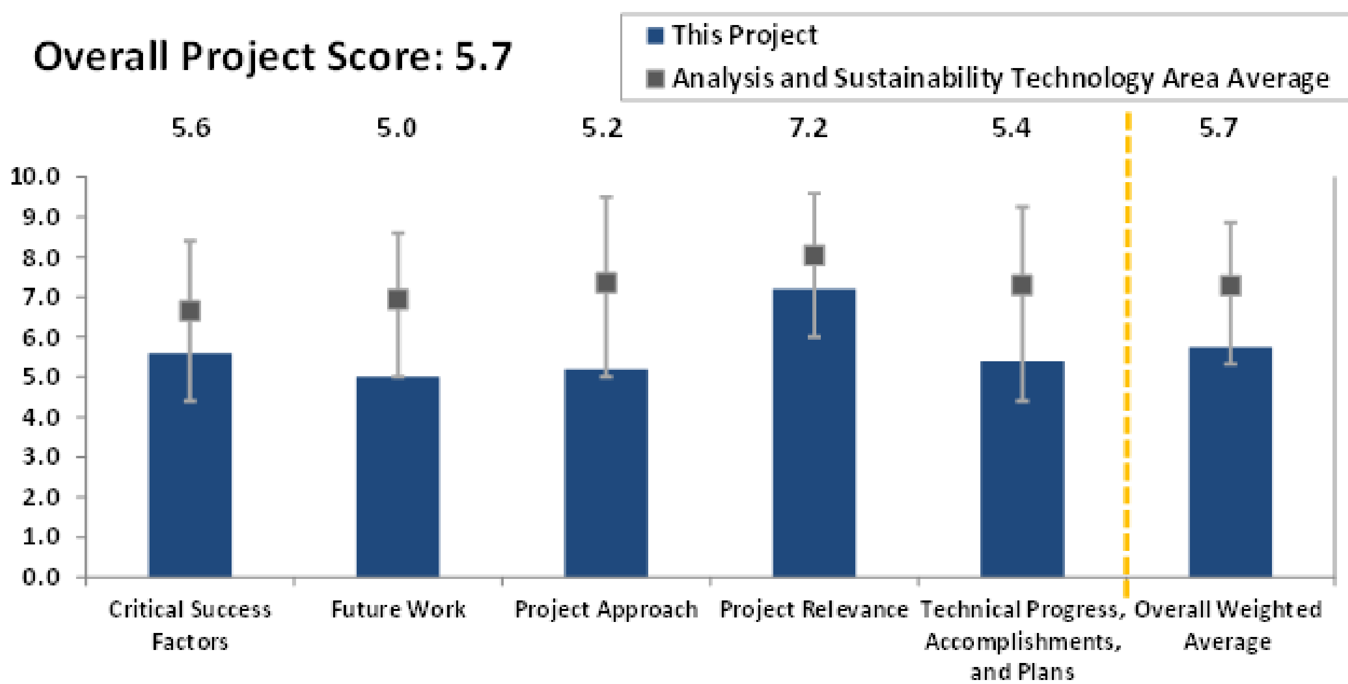
LAND-USE CHANGE DATA AND CAUSAL ANALYSIS

(WBS#: 11.2.3.2)

Recipient:	ORNL
Presenter:	Nagendra Singh
Total DOE Funding:	$800,000
DOE Funding FY13:	$200,000
DOE Funding FY12:	$200,000
DOE Funding FY11:	$200,000
Project Dates:	2010–2015

Project Description

Land-use change LUC is one of the more contentious issues affecting the development of bioenergy technologies. How LUC is estimated affects net greenhouse gas emissions, food security, water, and many other sustainability factors. Our research has shown that existing efforts to quantify LUC have unacceptably large uncertainties. Problems arise from inappropriate use of data, methods (such as two-point, pixel-level comparison), temporal limitations in data series, uncertain land classifications, subjective aggregation of classes, and lack of understanding of variability in reference systems. Existing approaches also fail to adequately incorporate the drivers of LUC. Evidence for causal linkages must be improved to properly inform policymaking decisions. This project aims to design and develop tools and assessment methods to establish a better scientific basis for simulating effects of bioenergy policy on land cover and management. It focuses on two key issues affecting LUC analysis: weaknesses in data and attribution of change. We are developing and testing a spatio-temporal change detection method analyzing biweekly normalized difference vegetation index from the Moderate Resolution Imaging Spectroradiometer satellite. One advantage is that these data are archived since 2000 and provide a consistent record against which to assess changes. This method takes advantage of recent advances in high-performance computing to permit timely analyses of massive data files. In addition, a causal analysis framework has been developed to attribute LUC in particular locations to probable social, economic, policy, and environmental drivers operating at different scales. The emphasis is on discerning how bioenergy policy



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

interacts with these drivers. Initial testing of the tools is focused on the U.S. Midwest. A case study for Iowa found no evidence that land-cover change trends had been influenced significantly by bioenergy.

Overall Impressions

- The intention of this project is to move beyond characterization of LUC to be able to understand the major drivers of LUC and bioenergy's role in the context of this complex system. This uses a spatially explicit dataset to better understand land cover/land use and changes over time. The rationale behind the project is sound and relevant to the goals of the Office. Addressing these questions in a robust and verifiable way is inherently challenging. It is unclear whether current methods will be able to yield useful results.
- The project started with a pragmatic data approach and novel integration of an epidemiology approach. It tries to focus on some important causal mechanism that can inform sustainability analysis, but faces some substantial challenges prior to becoming the envisioned operational detection system. A major weakness is that its remote sensing approach may be working at too high a level to address causal attribution of land-use change.
- This is a well-intended project that is trying to apply sophisticated techniques for satellite data processing and epidemiological approaches to causal analysis of land-use change and biofuels expansion. However, the basic approach may be fatally undermined by the impossibility of trying to measure an arguably small effect of bioenergy on global land-use change. When pushed on this point, the best answer the researchers could offer to this challenge was that they would at least prove that there is no evidence for land-use change effects from biofuels. Such a negative finding contributes little to the debate about the real and plausible problem of land-use change effects from biofuels.
- Overall, the causal/attribution framework seems very vague. Further, PIs seem unclear on the relevance of the work of others on food security, the other side of the same coin from the objectives of this project. A key unaddressed question concerns what sort of ground truthing will be done, and how/when will the model be trained and validated with data? What data will be used? Given the described scope of the project objectives, it is not clear how 60% of the project can be characterized as complete. Other questions requiring explicit consideration include the utility of the effort, given that the approach cannot really detect land-management change, only true vegetation change. Finally, the presentation lacks convincing detail on how to operationalize the attribution framework
- This project could potentially supply valuable data and analysis to assess land-use changes as a result of biofuel production. The project, however, has gaps: lack of clarity on data uncertainty and resolution of key drivers of uncertainty, lack of clarity on causal analysis framework for land-use/land-cover change, and lack of insight into the impact of land-management changes.

PI Response to Reviewer Comments

- The project aims to provide scientific analysis that increases clarity for how bioenergy interacts with drivers of land-use and land-cover change. We stress the importance of clearly defining changes in management, as well as cover and other attributes. If scientific and political communities actually agreed that biofuel-driven LUC were "too small" to be of significance, this research would be unnecessary. Given that public perception and current policies in the U.S. (e.g., EPA, California Air Resources Board) and the European Union coincide in assigning significant penalties to biofuels for land-use change, we agree with reviewers on the importance of this work. Moderate resolution imaging spectroradiometer satellite data are used because they are the only available data with consistent temporal and spatial resolution as required for accurate estimates of LUC. We are collaborating with USDA to collect ground-truth data that will be used for training and validation.

- LUC is driven by interactions of policy, social, economic, and environmental factors at local scales. The causal analysis framework will be clarified via manuscripts in preparation under this project. The project focuses on an empirical approach to causality, rather than projections of effects based on a collection of unconfirmed assumptions. Our examination of drivers in key regions could cast policy-relevant doubts on assertions about the link between bioenergy policy and LUC. If the project is able to show if and when bioenergy policy is a credible driver for observed changes such as deforestation, then it will be successful. The 60% estimate was a prescribed calculation of progress based on elapsed time compared to an initial proposal. The team includes expertise in food security, although this is not the project focus. Understanding how bioenergy policy affects LUC and productivity is critical for relationships to food security and other sustainability indicators.

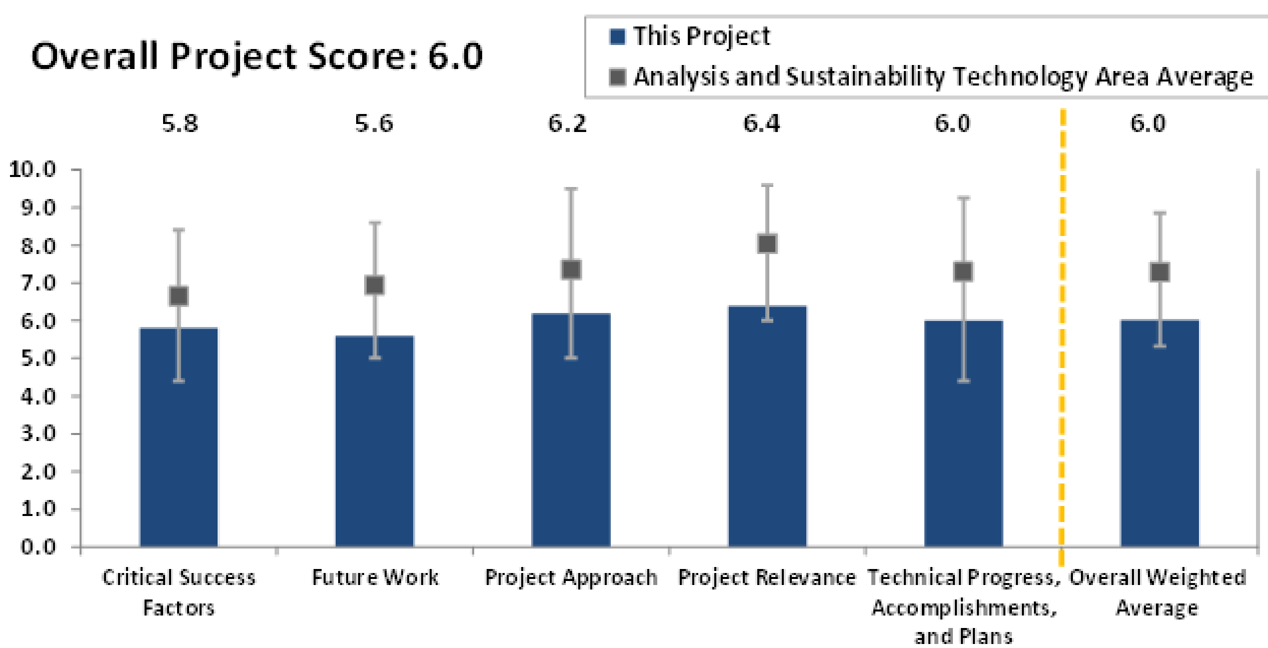
GCAM BIOENERGY AND LAND-USE MODELING

(WBS#: 11.2.2.1)

Recipient:	PNNL
Presenter:	Marshall Wise
Total DOE Funding:	$700,000
DOE Funding FY13:	$100,000
DOE Funding FY12:	$200,000
DOE Funding FY11:	$200,000
Project Dates:	2010–2017

Project Description

The purpose of this project is to provide global, long-term modeling and analysis of bioenergy using the PNNL Global Change Assessment Model (GCAM). This project is relevant to BETO's Analysis and Sustainability Technology Area as it provides an integrated, global economic context for analysis of biomass systems, technologies, and policies that considers the entire energy and agriculture systems. The GCAM modeling project is an established, multi-client effort ongoing for more than two decades. GCAM is widely used by DOE and EPA, participates in international analysis efforts such as the Intergovernmental Panel on Climate Change and the Stanford Energy Modeling Forum, and is a community model available to all. This BETO project leverages this effort to focus on improving modeling capabilities, data, and analysis in key areas related to bioenergy production and use. Beginning in 2010, technical accomplishments include global modeling and published analyses about lignocellulosic bioenergy crops, bioenergy technologies for liquid fuels and power, and bioenergy with CO_2 capture and storage. From fiscal year 2011 and fiscal year 2012 efforts, a paper has been submitted exploring the impact of current and hypothetical expansions of biofuels policies internationally on global energy use, agricultural production, crop prices, and net carbon emissions from energy and land-use change. Fiscal year 2013 efforts and milestones are based on incorporating GCAM water-demand parameters for bioenergy refining based on LCA and other analyses from BETO projects. This effort is highly leveraged from the larger GCAM global water modeling development effort led by funding from the DOE Office of Science. Future proposed efforts will incorporate water demands and the economic choice of irrigation for bioenergy in the context of competing uses in the agriculture system.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions:

- In some ways, the presentation was not a great articulation of the overall utility of the effort. The model seems so large and unwieldy that outcomes will be determined by inputs, which begs the question: what does the model tell you that you couldn't intuit with similar uncertainty without the model? However, while it is a bit of a black box model that is somewhat indecipherable—accessibility claims conferred by the community model attribute, aside—its use in other important contexts that DOE should link to, such as the Intergovernmental Panel on Climate Change (IPCC), as well as it being a community (versus a membership model such as GTAP), give credence to the effort. It will be critical that project PIs be rigorous and exhaustive in the documentation of assumptions, constraints, and conditions.
- This project highlighted significant accessibility challenges associated with GCAM and the difficulty in understanding the contribution to BETO's MYPP goals. Future efforts to incorporate water demand from bioenergy seem more relevant to BETO, foreign assistance, and national security communities. Two recommendations are to focus on enhancing the accessibility and understandability of this community model and to focus future projects on answering a high-priority policy question.
- Land use is a complex issue. Testing the global effect of bioenergy policy is of definite relevance and use of economic equilibrium models has the potential to provide overall insights. Although the project has conducted some interesting analyses, the overarching objectives and the specific research questions that the project is trying to address are unclear. Because of difficulties with model validation, it is important to contextualize model outputs in terms of potential insights to the system rather than using them as definitive results.
- The biggest advantage of this project is the high level of visibility and credibility the GCAM model brings to the analysis of land-use effects for bioenergy. In addition, the work leverages a lot of work in the development of the GCAM model; however, the GCAM model also suffers from the same problem that other general and partial equilibrium models have—a degree of complexity that makes them very difficult to understand. The PI presenting the results openly stated that it takes months to learn how to run the model, and maybe years to become an expert with it. For that reason, this work may only lead to further confusion in a battle of black box models. There are undoubtedly many assumptions being made in the model that have not been made clear in the limited results presented during the review meeting. Finally, the presentation showed only very limited results related to estimates of land devoted to cellulosic biomass production, as well as a confusing plot of price changes for a variety of agricultural commodities under three different biofuels expansion assumptions. As reviewers, we were left with very little sense of the added value of this latest attempt to quantify the linkage between land clearing and bioenergy expansion.
- This project can be critical in understanding tradeoffs among objectives. The modeling approach appears complex—perhaps more complex than needed—while the impact of assumptions errors and uncertainties are not reflected in model output. Model validation is also lacking.

PI Response to Reviewer Comments

- This project complements other BETO modeling efforts with its global, long-term scope. GCAM is a consumer of BETO technology analysis and LCA, considers bioenergy in a global economic context, and provides insights into the potential scale of bioenergy use.
- In an integrated assessment model like GCAM, there is always a tradeoff between completeness, which we need, and complexity. We have had years of success simplifying our representations of complex interactions and generating useful published insights.
- On the comment of GCAM' "accessibility," we believe this refers to its difficulty rather than availability. The GCAM code and data are freely available to all for download as a community model. It is fair to consider GCAM as more of a research tool than a simulation model that could be mastered quickly, but it should be considered relative to the time and education required to learn models such as the Community Earth System Model at the National Center for Atmospheric Research. We have had successful collaborations on research and publications with researchers in several organizations internationally.
- In the presentation, results for land-use-change emissions were not shown in the interest of the 20-minute limit. Instead, we chose to focus on other results, including regional production of bioenergy crops, production of liquid fuels by source, and food crop prices. We have since provided slides with the land-use change and emissions results to BETO.
- Validation of GCAM in the community of integrated assessment models has been through participation in model comparison exercises such as the Stanford Energy Modeling Forum. In the past year, however, we have begun a formal model evaluation project with the DOE Office of Science, and validation to history will be a key area for focus and publication.

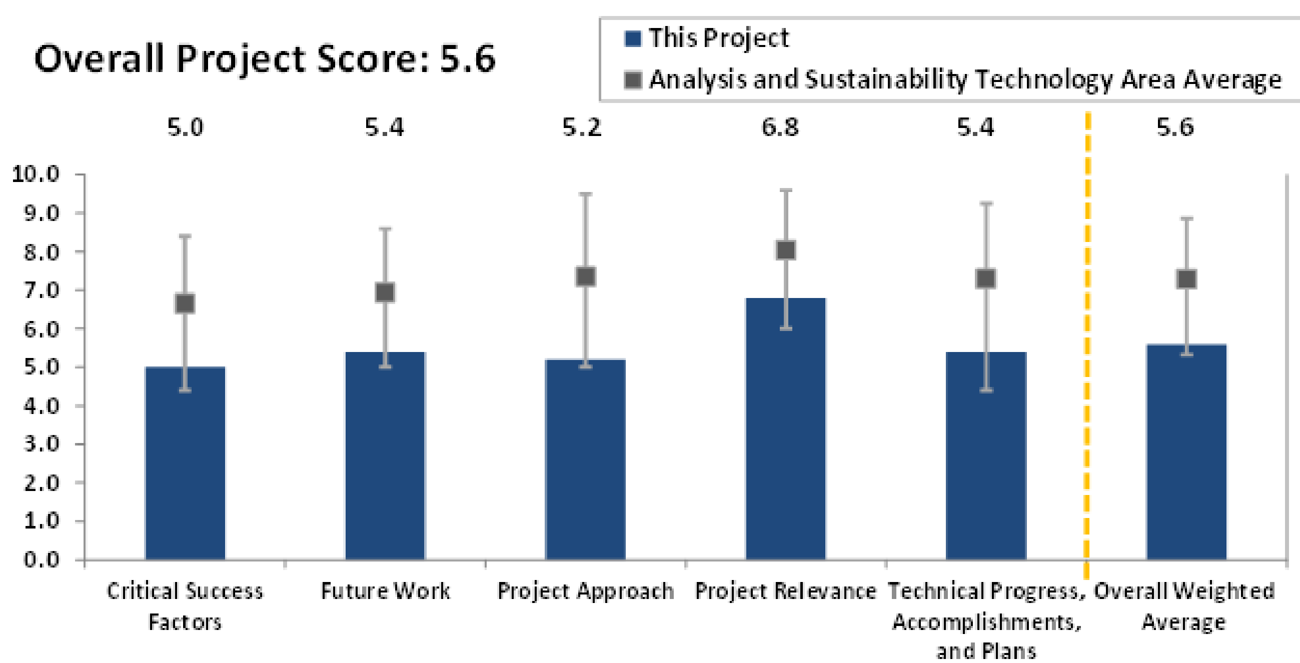
GLOBAL ANALYSIS OF BIOFUEL POLICIES, FEEDSTOCK AND IMPACTS

(WBS#: 11.2.3.1)

Recipient:	ORNL
Presenter:	Gbadebo Oladosu
Total DOE Funding:	$1,800,000
DOE Funding FY13:	$250,000
DOE Funding FY12:	$300,000
DOE Funding FY11:	$370,000
Project Dates:	2010–2015

Project Description

A strategic goal towards meeting the Renewable Fuel Standard (RFS2) targets is to "deepen the understanding of the environmental, economic, social, and energy security benefits of biofuels, biopower, and bioproducts" (per BETO's November 2012 MYPP). This project supports research to improve DOE's capacity to assess the environmental and socioeconomic impacts of biofuels, and the crucial role of global interactions on the viability of the domestic biofuel industry. The global market for biofuels and other commodities affect the domestic biofuel industry through competitive forces that may spur or slow its development. In addition, there is a need to understand and document the indirect national and global socioeconomic costs and benefits of biofuels. Developing this understanding requires methods and capabilities to analyze biofuels in the global context, and to evaluate alternative scenarios of technologies, policies, and market conditions for a sustainable, national biofuel industry. The primary approach under this project is the development of a global modeling framework for the comprehensive assessment of the benefits and indirect effects of biofuel policy. The current version of the model incorporates data and specifications that are uniquely adapted to capturing the dynamic responses of the global economy to biofuel policies. The project also provides estimates of the global indirect LUC impacts of biofuels, as well as projections of cellulosic feedstock supply functions. Indirect land-use change is a major factor in meeting the GHG emission thresholds for biofuels under RFS2. Comprehensive and peer-reviewed economic analyses of RFS2 based on the results of this project have been published. These capabilities help demonstrate the positive impacts of biofuels on the U.S. economy and their minimal impacts on global food security and land use, among other things.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- The project attempts to model global economic aspects of meeting U.S. bioenergy goals. The next steps are to better understand sustainability impacts, although the specific metrics of analysis were not well articulated. There seems to be a need for better integration or clearer definition of the different LUC models that are being used, the research questions appropriate for each, and the appropriateness and limitations of each, as well as a need for better coordination of efforts.
- This project's strength was its highly pertinent research and policy questions. This same approach could be expanded to help understand the policy options and potential impacts of implementation. The application of this study's results and runs could contribute to the sustainability metrics discussion moving forward. Future efforts should include stakeholder engagement planning to both disseminate results and solicit policy question that need pressing answers.
- While GTAP is a widely used model, it is not open source and has been criticized for a lack of transparency. The analysis highlighted from this project seems a bit self-serving, in that it paints a very positive picture of wide-scale bioenergy crop deployment. Initially, this will be well received by the bioenergy industry, but should be cause for concern and discussion as the lack of transparency coupled with U.S.-centric results may reduce the acceptance and impact of these results. Overall, this project highlights the real challenge for BETO, which will be sorting out the meaning of all the different modeling results. At this point, it is not clear who might best assume this responsibility, but this question should be addressed across all technology areas as soon as possible.
- So far, the project uses an overly complex modeling system to look at the relatively small effect of conventional biofuels. It is unclear if the biofuel impact predicted by the model is significant, given the uncertainties on assumptions. The project only looked at conventional biofuels so far, and not much progress was made on advanced biofuels.
- There seems to be very little value in continuing a "battle of the modelers" over land-use change effects for biofuels. None of the published studies are sufficiently transparent to enable policymakers to come to clear conclusions. This project merely prolongs a technical debate that has lost any real credibility in the policy arena. The contrary results published from this project will only further reduce trust in the models by showing how the same model can be used to generate completely conflicting findings. That, per se, would not be a problem if there were some attempt being made to rationally explain the differences. Given the obscure nature of the models, even this kind of reconciling of results might not lead to any useful insight. The crux of the difference in the results is explained by the PI as being due to land savings in the Middle East and Africa from reduced consumption of oil. That is not an intuitively obvious explanation, and no basis for why oil production could possibly have such large land-use impacts is offered.

PI Response to Reviewer Comments

- Thanks for your comments and for highlighting the current and potential contributions of this effort to the evaluation of biofuel policy options and benefits, as well as the sustainability implications of biofuels. In addition to the main simulation results, this project has contributed to other analytical aspects of biofuel sustainability as summarized during the review. Future efforts under the project will evaluate alternative states of the world and other sources of uncertainties, elaborate on the sustainability implications of the project outcomes, and promote better integration with other BETO projects.

- The issues associated with biofuel policy are interconnected and complex. As such, the scope, data requirements and models to adequately address these issues are likely to reflect such complexities. This project offers a unique comprehensive framework for evaluating the potential benefits and global, indirect effects of biofuel policy, which are often at the core of policy discussions about biofuels.
- The results of our simulations demonstrate that biofuels provide net positive economic benefits to the United States; however, these results also show that there are important tradeoffs in all regions of the world as highlighted during the review, and discussed in detail in the related publications.
- With all due respect, we strongly disagree with the characterization of this project and its outcomes in the last paragraph of the reviewers' overall impressions. Our published results show that the simulation results are indeed consistent with much of the existing literature, where comparable. However, other aspects of our results are not comparable with the existing literature because our model captures additional responses to biofuel policy. In particular, our simulations reflect the important role of biofuels in bidding down prices in the tight oil market of the last decade, as well as the dynamic interactions of biofuel policy and the global economy.

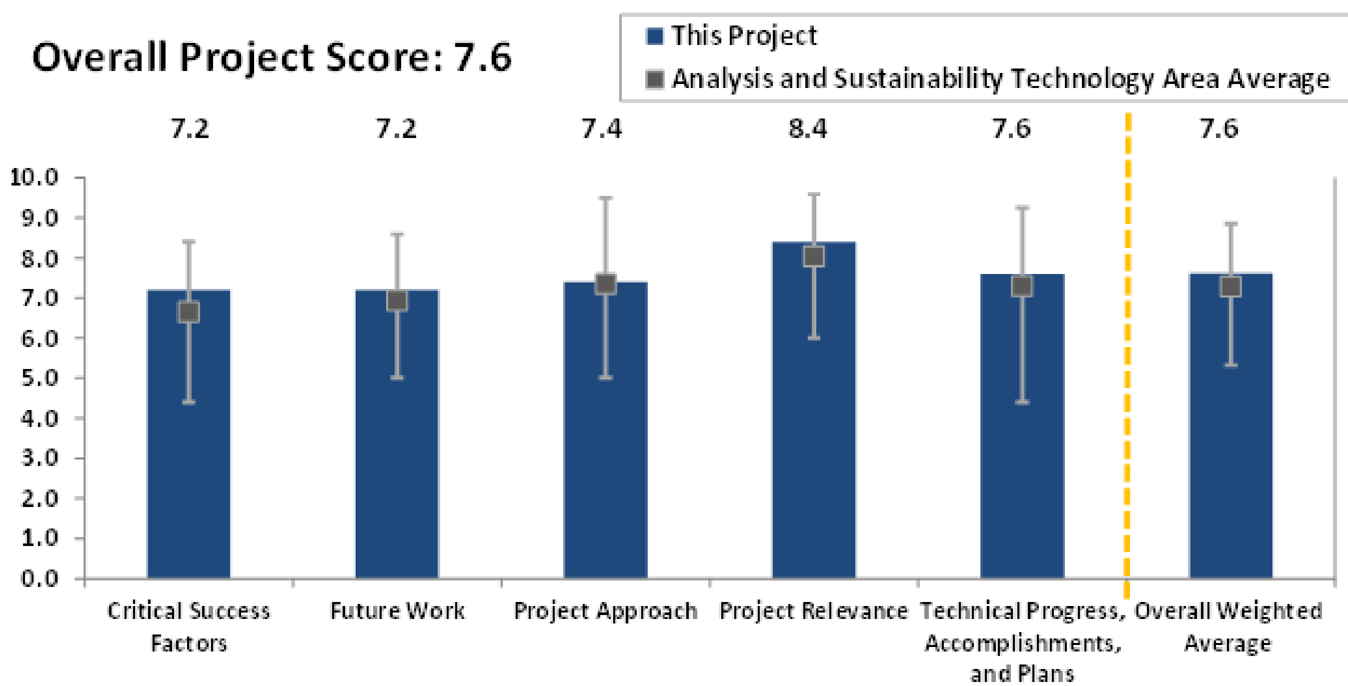
BIOFUELS NATIONAL STRATEGIC BENEFITS ANALYSIS

(WBS#: 11.2.3.5)

Recipient:	ORNL
Presenter:	Paul Leiby
Total DOE Funding:	$500,000
DOE Funding FY13:	$300,000
DOE Funding FY12:	$200,000
DOE Funding FY11:	--
Project Dates:	2011–2015

Project Description

This project explores the feasibility, costs, and benefits of expanded biofuel use. Its national, strategic focus complements BETO's project portfolio by exploring potential market interactions among biofuel pathways and petroleum-derived fuels. This project assesses barriers to market implementation of biofuel pathways that are technologically ready or nearly ready for commercial deployment. It evaluates strategies for addressing those barriers. Another goal is quantifying the energy-security value derived from biofuels that depends on system configuration and the risk and correlation of agricultural and energy commodity shocks. Further, the project is attentive to economic risk for biofuel producers and market participants, with an interest in economically secure and sustainable biofuels. We combine three approaches to quantify national costs and benefits of biofuels: a detailed mathematical programming model depicting the biofuel supply and demand landscape, building on BETO's research in different segments of the supply chain; econometric analyses of the relationship between biofuel and gasoline markets; and an evolving framework for calculating energy security benefits. To date, after 16 months of funding, we have developed the working model and completed two research initiatives: first, estimating the attainable percentage of RFS2 objectives under alternative scenarios and, second, estimating the effect of ethanol on gasoline price levels over the last decade. Under reference conditions and if relying exclusively on ethanol, the estimated percentage of attainment of the cellulosic RFS2 objective from 2010–2022 is approximately 60%. The transition modeling framework reveals roles for E15, increased



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

flexible-fuel vehicles sales, and drop-in biofuels in expanding the level of RFS2 attainment. Cost-competitive biofuel technology may be market limited by infrastructure or other barriers. Preliminary econometric results using vector autoregressive models/structural vector error correction methods indicate that the effect of ethanol on gasoline markups (the spread between product and crude price levels) is weaker than previously estimated, but still there is evidence of reductions in some regions.

Overall Impressions

- From the 30,000-foot view, the idea seems good, although this is the opinion of a non-expert. I could not be sure that the model would actually capture certain market happenings and/or shocks from a policy perspective. I think this project would benefit from efforts on the part of DOE to align all of its modeling projects to highlight complementary projects and redundancy, as well as opportunity.
- The framework attempts to better understand the economic dynamics of the national biofuel infrastructure to assess how market changes affect the overall system, both from the overall perspective of the transportation fuels industry and the biofuels market specifically. It stands to reason that if a major rationale for biofuel development is energy security and independence, the analysis portfolio should measure biofuels' potential impact on energy security and the resilience of transportation fuel infrastructure. The overall goals of the project are well-articulated and the project appears to be generating plausible and interesting results.
- The importance of this work cannot be overstated. A successful policy needs to not only address economic feasibility, but also stability and resilience; therefore, understanding and controlling transient effects is critical to the successful growth of a new industry.
- The project's focus on and analysis of the U.S. economic and energy security results of various biofuel portfolios is important work. It could be further augmented with additional national security community dialogue to refine terminology and solicit interagency policy questions on this topic.
- This project uses classical economics-based mathematical models to address energy security valuation in the context of price impacts associated with price disruption and monopoly. It builds on similar models built for other alternative fuel technologies under DOE's Office of Energy Efficiency and Renewable Energy. There is value in this type of analysis, though most of the results are relatively unsurprising and not especially impactful in the context of broader sustainability issues for biofuels. To the extent that DOE has a need for economic translation of energy security, this may be a worthwhile line of research. One concern is that it appears (at least from the presentation submitted to the reviewers) that the modeling work builds on other modeling results. Uncertainties of the Global Trade Analysis Project (GTAP)-based and Annual Energy Outlook-based model results that seem to serve as input in this project are being propagated in the models developed in this project.

PI Response to Reviewer Comments

- We are very grateful that some reviewers see this work, related to energy security and the strategic benefits of biofuels, as important and relevant to BETO's mission. We currently address energy security value in two ways: with the cost per barrel of biofuels energy security premium, and with measures of biofuels supply chain resilience under shocks. In keeping with these helpful comments, we will work to both broaden and clarify the metrics for energy security. This includes our planned consultation with a wider range of stakeholders and experts to develop a broader perspective on energy security considering national security, and regional or sectoral energy security implications.
- While BioTrans is not critically dependent on any of the models we show as linked, it seeks to draw on common model resources for some inputs. Reviewer comments importantly highlight the challenges of building a model that both focuses on specific topics while requiring inputs from other sources to characterize technological detail and rest-of-system behavior, and seeks to be complementary and comparable to other modeling analyses. While this necessarily creates some interdependencies and poses challenges, such as for benchmarking, it is arguably an important part of the scientific process. It allows people familiar with the models from which we draw inputs to understand more of the basis for our modeling results. To mitigate the risk of error propagation, we need to keep our information sources explicit and high quality, monitor confidence levels on inputs, and take care to present uncertainty in results.
- Finally, we agree that this project will benefit from an effort to align DOE/BETO modeling projects by comparing them and highlighting synergies, complements, and redundancies. We discussed a proposed fiscal year 2014 model review for this purpose with BETO, presented some ideas on how it might be undertaken, and look forward to being actively involved.

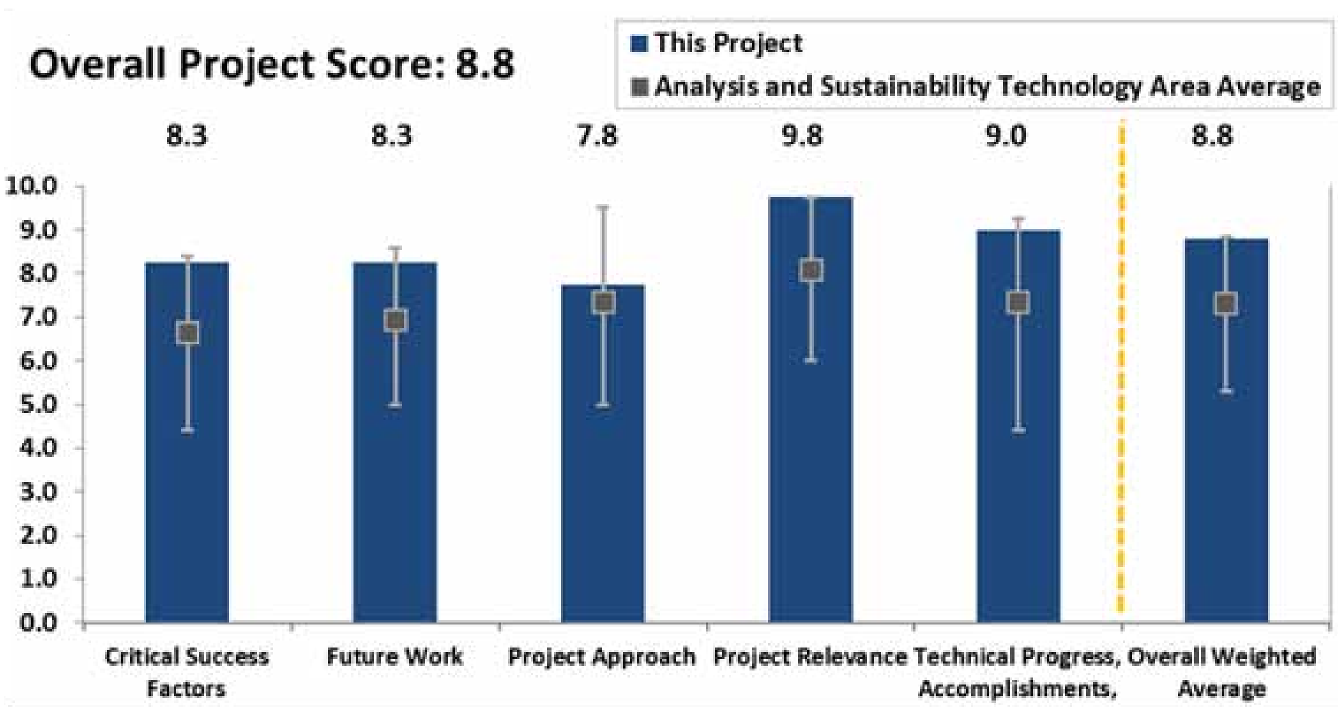
GREET LIFE-CYCLE ANALYSIS OF BIOFUELS

(WBS#: 11.2.5.1)

Recipient:	ANL
Presenter:	Michael Wang
Total DOE Funding:	$4,100,000
DOE Funding FY13:	$1,300,000
DOE Funding FY12:	$1,300,000
DOE Funding FY11:	$1,500,000
Project Dates:	2007–2050

Project Description

With support from several Energy Efficiency and Renewable Energy programs since 1995, Argonne National Laboratory develops and applies the GREET model. GREET examines the life-cycle energy and emissions effects of more than 85 vehicle/fuel systems. The model and related publications are available online at greet.es.anl.gov. Biofuels are an important fuels group in GREET. Recently, with BETO support, Argonne has updated and expanded bioethanol pathways; added an aviation fuel module to GREET; refined and expanded pyrolysis-based pathways; updated and expanded land-use change GHG emissions to include cellulosic ethanol; developed a new, high-resolution LUC model; and continued to develop the GREET model in Excel and .net platforms. GREET bioethanol pathways were refined by adding new feedstocks (*miscanthus* and short-rotation woody crops) and incorporating enzyme and yeast consumption. Relative to petroleum gasoline, ethanol from corn, sugarcane, corn stover, switchgrass, and *miscanthus* can reduce life-cycle GHG emissions by 19–48%, 40–62%, 90–103%, 77–97%, and 101–115%, respectively. These reductions include new estimates of LUC GHG emissions for these feedstocks. GREET now includes a detailed analysis of renewable gasoline and diesel from pyrolysis of corn stover or forest residue. These results are used independently and in the new aviation module. Pyrolysis fuels are estimated to offer GHG reductions compared to their petroleum-derived counterparts of 60–112%, dependent on assumptions about the fate of co-produced biochar and the source of hydrogen (H_2) used for upgrading bio-oil. The GREET model provides open and transparent information for the



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

debate over biofuels' energy and emission effects. In the future, Argonne plans to expand GREET to include BETO's priority biofuel pathways, marine fuels, and biorefinery chemical intermediates and by-products. Argonne will continue to engage agencies, researchers, and the biofuel community to use biofuel LCA results to pursue clean, efficient biofuel pathways.

Overall Impressions

- It is impossible to underestimate the tremendous impact GREET has had and continues to have for the Bioenergy Technologies Office. While both the history and funding for this project are very high, the payoff has been worth it. GREET has achieved success in answering pressing questions of sustainability and has helped to set direction for the Office in a profound way. Its adoption by a large community of users adds to its power as a mechanism for informing the renewable energy and policy community. To take its success to the next level, it may now be necessary to bring in a deeper level of software design expertise to help envision a path for this software that will make it even more accessible and influential.
- GREET is and remains the fuel pathway LCA standard. Its utility is growing and can be developed further to provide a foundation for many of the necessary sustainability analysis and metrics needed by BETO, federal partners, and industry. Future efforts to develop user-friendly enhancements, added pathways, end-use fuels, and a complementary water model will augment this model's utility. The upcoming addition of a marine diesel pathway is an important contribution to address Navy and marine transportation sector needs for sustainability analysis results.
- GREET is widely recognized as the major publicly accessible life-cycle database and is used as the primary source in many analyses. It allows for a consistent basis among analyses. Through its consistent and thorough maintenance and updating, it provides a useful tool for the research and policy communities. GREET appears to be at a critical juncture regarding expansion. The limitations of the Excel framework are recognized, even though it is a framework that provides the greatest amount of user accessibility and transparency. Migration to a .net interface may represent a logical step forward; consultation with software engineers to help oversee the transition may be useful, if not already ongoing.
- This is a project with much past success and a clear service role to the emerging bioenergy industry. Moving forward, PIs should carefully consider new items beyond the important—but perhaps formulaic and somewhat uninteresting—task of updating such a widely used model. The new items needing the most consideration are those that extend PIs beyond their disciplinary boundaries, such as water-quality modeling. Likewise, the conversion to a.net version may allow continued expansion, but at the cost of a loss in transparency. Is there a way to both expand the model and maintain transparency? Finally, PIs may wish to consider the development of a data repository that is distinct from the excel modeling, perhaps in conjunction with the KDF. PIs stated that they needed to be the quality-control mechanism for the data underpinning the model, but this creates a significant bottleneck to adding to sparse data to make modeling efforts more robust. Done correctly (and there are many models emerging in the library sciences), this could improve both quality and quantity of data.
- This project is critical to provide clear understanding of LCA impacts of biofuels. The project is well thought out and significantly progressed. The tools developed should be used more effectively to inform policy.

PI Response to Reviewer Comments:

- We continue to explore transparent and clear ways to display data in GREET, which itself is a significant database. We will continue to make GREET serve that role, in addition to functioning as an LCA model. While GREET is designed for users to incorporate their own data, we have a vigorous process to choose GREET default data for data representation and reliability because, as the GREET developers, we do shoulder the responsibility for the data quality within the model. In our development of the .net platform, our team of software engineers is striving to retain transparency while optimizing ease of use. We continue to solicit feedback from users of GREET.net to improve it.

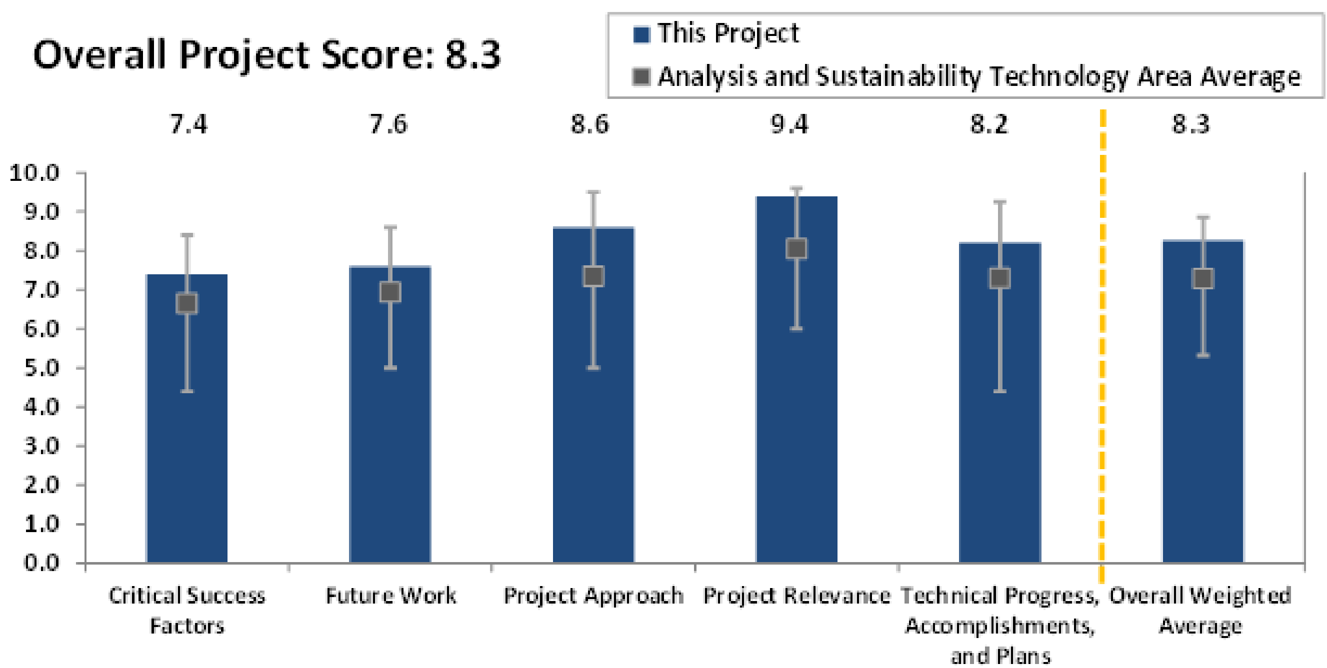
DEFINING SUSTAINABILITY

(WBS#: 11.1.1.5)

Recipient:	ORNL
Presenter:	Virginia Dale
Total DOE Funding:	$3,185,000
DOE Funding FY13:	$700,000
DOE Funding FY12:	$684,000
DOE Funding FY11:	$1,000,000
Project Dates:	2008–2017

Project Description

The objective of this project is to identify ways to characterize and monitor sustainability of bioenergy systems from cradle to grave. The work is designed to advance common definitions of environmental and socioeconomic costs and benefits of bioenergy systems, and quantify opportunities and risks associated with all aspects of sustainable bioenergy in specific contexts. This work supports efforts of the Bioenergy Technologies Office to develop "the resources, technologies, and systems needed to grow a biofuels industry in a way that protects the environment," as well as "promoting economic development and providing conditions that support human and societal health" (per BETO's MYPP). The work is being accomplished by using a combination of model projections and empirical data to test scientific approaches for assessing and monitoring bioenergy production processes at various stages of the supply chain. The end result of this project will be the development of best management practices for sustainable bioenergy production. To date, the team has worked on defining sustainability for bioenergy crops, evaluating existing case studies, collecting relevant data, developing conceptual frameworks and models of key processes and parameters, and collaborating with other groups conducting related research—including targeted contributions to international cooperation for bioenergy sustainability standards and analyses. The project team has worked with a large group of collaborators to identify and publish 19 environmental indicators and 16 socioeconomic indicators across 12 bioenergy sustainability categories. ORNL is using energy crop plantings around Vonore, Tennessee, to test this approach, both because switchgrass was planted in a watershed design and because this area has some of the best combined environmental and socioeconomic datasets available to



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

represent the diverse aspects of sustainability. Future work includes completing and testing our framework for sustainability assessment and determining BMPs for bioenergy sustainability in particular contexts.

Overall Impressions

- This project is a foundational effort and is already an important reference point for the biofuel sustainability community. The framework, process, field validation, and development of best practices are all important contributions. Future efforts should extend the approach to additional downstream communities and policy stakeholders, as well as consider the federal sustainability mandates and regulatory considerations.
- The effort to build consensus toward minimum datasets, standardized metrics, and metadata is increasingly being viewed as essential to the progress of science across the spectrum from medicine to agriculture. This project has made good progress to date. Moving forward, continued success and full realization of the objectives (which include "interoperability" of data from disparate sources, although not specifically described as such in this project) will require that increasing efforts be allocated to outreach and consensus building beyond DOE and its bioenergy technology areas. It would be to the benefit of the Sustainability and Analysis Technology Area to prioritize this follow through, even if progress seems slow and direct or immediate benefits, specifically to DOE (versus other organizations), less obvious when compared to other, less diffuse projects. It is also paramount that the project engages a broad array of outside entities and expertise beyond that just within the DOE lab system. The domain expertise of human dimension scientists should be engaged as true partners for the development of social indicators, etc. In order to achieve buy-in by those beyond the DOE lab system, a systematic effort needs to be made to bring outside entities and expertise to the table in a true collaborative effort for a transparent and inclusive process. Absent this process, it is unlikely that the full array of indicators (with metrics and measures) will be adopted.
- The framing work being done in this project for establishing sustainability metrics is a cornerstone for all of the work being done under BETO's Sustainability and Analysis Technology Area. Both the approach and technical progress on this project have been outstanding. Accomplishments include a logical and clear framework for measuring sustainability, a sound context-specific approach to evaluating sustainability, and significant progress in measuring sustainability for the specific context of a Vonore, Tennessee, switchgrass production and conversion test case. While there is some risk that the project may be heading toward a somewhat complex framework involving 35 different metrics, it is hard to think of what metrics might be removed at this point. The researchers may be overly ambitious in setting their sights on a set of metrics that are broadly applicable across many different applications and scenarios. It may be more realistic to think about allowing for more flexibility in the exact form of these metrics for a given context. DOE should be encouraged to continue the effort of developing a full suite of best management practices for the Vonore, Tennessee, case study that is now underway. This case study could end up being an important example for the nascent bioenergy industry. One area for improvement would also be a more explicit handling of the ethical and political aspects of sustainability. By this, I do not mean simply bringing in social science-based metrics (though these are indeed needed), nor am I talking about acknowledging that stable and just political systems are needed for sustainability. I am talking about exposing the core ethical questions of what defines quality of life and what justice means for citizens and stakeholders when designing a sustainable bioenergy system. The lack of dialogue at this level is part of what hinders the development of true consensus in establishing sustainable systems. With this core ethical foundation established, it will then be possible to move

on to more quantifiable social metrics that are the domain of the social sciences. Finally, it is worth highlighting a result from the work in Vonore that captures in a very powerful way the value of the broad sustainability metrics they have established. The optimization analysis conducted for Vonore, where individual metrics versus a whole set of metrics was done, showed in a profound way how there can be an unnecessarily large set of tradeoffs among goals when metrics are considered independently versus optimized together. Particularly insightful is how a single focus on profit can lead to very lopsided outcomes.

- This is certainly an important effort to capture the overall umbrella of sustainability beyond fairly simple quantification of GHGs or job creation. This pushes the Office to consider the overall broader context, which is certainly difficult. The scope of the project is quite large and it is difficult to evaluate each individual element in detail given the time limitation of presentation formats. Data is always going to be a limiting factor in analysis, particularly with ecological indicators where geography is important. That begs the question whether such analyses will be feasible and implementable by other researchers even with technological transfer of the framework approach. Even so, definition of an overarching framework is a step in the right direction.
- This project is critical in identifying a broadly applicable framework to assess sustainability impacts of the growing biofuels industry. The project made significant progress and, most importantly, highlighted that careful balancing of sustainability and profit leads to minimal sacrifices in both categories.

PI Response to Reviewer Comments

- This project is establishing elements and framework for uniform evaluation of biofuels sustainability across multiple DOE labs and projects. Our metrics and framework build upon existing work by many researchers in agencies, academia, and the private sector, with whom we continue engagement.
- We are building consensus toward minimum datasets, standardized metrics, and metadata. Our interdisciplinary team includes environmental and human dimension scientists. We work with a diverse spectrum of researchers and applied scientists in developing and applying sustainability metrics. The proposed social indicators were discussed at a DOE sustainability workshop prior to finalization. The findings from this workshop can be found online at bioenergy.energy.gov/pdfs/social_aspects_of_sustainability_workshop_report.pdf. The majority of attendees at this workshop were social scientists.
- Ethical issues are part of sustainability, and such concerns are incorporated in our indicators of food security, depletion of nonrenewable natural resources, public opinion, transparency, effective stakeholder participation, and risk of catastrophe. The social wellbeing indicators of employment, household income, and work days lost due to injury may be considered with respect to an equitable distribution of benefits. We consider legal and regulatory compliance and governance to be prerequisites for bioenergy sustainability.
- We agree that the 35 indicators are still a large number for a producer to measure. Our next step is to determine ways to deal with this large number—initially by focusing on the 12 categories and using multivariate analysis to identify most essential measurements of sustainability in particular cases.
- We look forward to extending our research on tradeoffs and synergies between multiple sustainability objectives. Further focus on the Vonore case study will be an important aspect of that analysis.
- Our framework is being disseminated through publications, conferences, and email requests for information to a large number of domestic and international collaborators. Our website has had more than 500,000 hits in the past year. We are working with several other groups to have them adopt the framework.

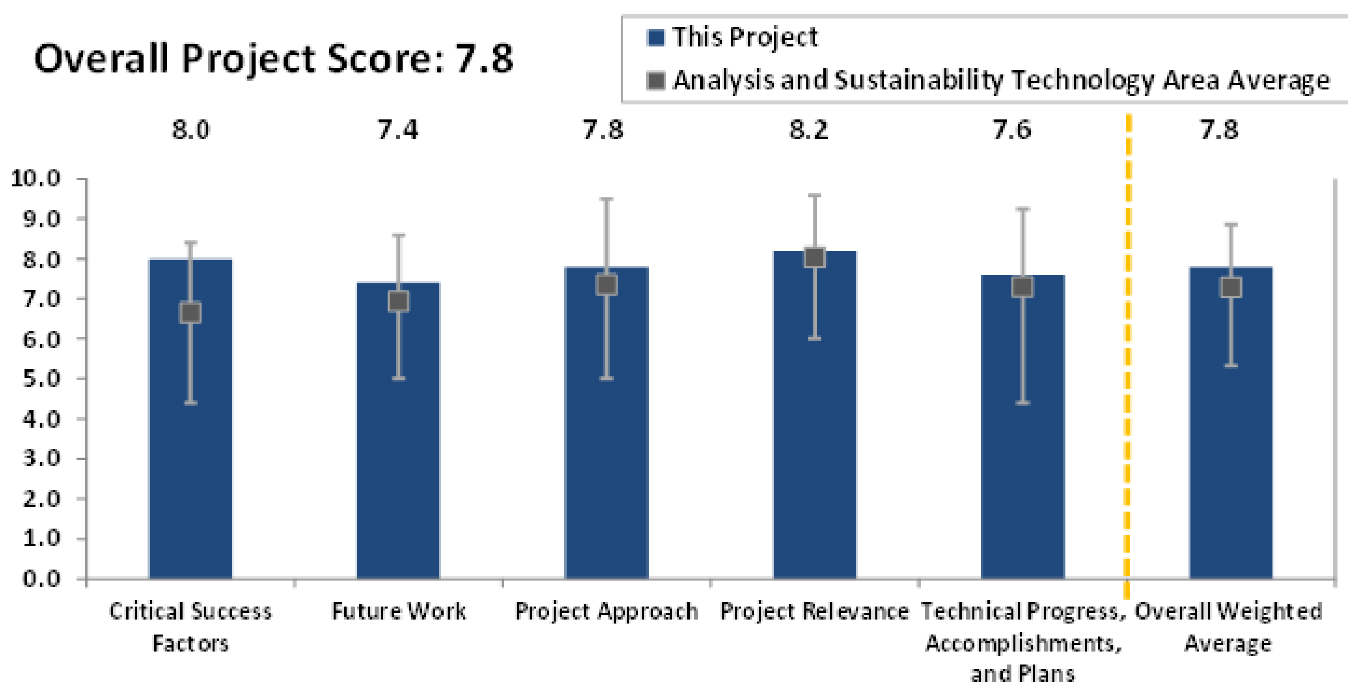
NREL SUSTAINABILITY ANALYSIS: LIFE-CYCLE INVENTORY OF AIR EMISSIONS

(WBS#: 11.1.1.3)

Recipient:	NREL
Presenter:	Garvin Heath
Total DOE Funding:	$1,590,000
DOE Funding FY13:	$500,000
DOE Funding FY12:	$690,000
DOE Funding FY11:	--
Project Dates:	2009–2017

Project Description

The objective of NREL's Sustainability Analysis Task is to provide quantitative analyses that help the Bioenergy Technology Office meet its short- and long-term sustainability goals for renewable biofuels in terms of climate, water, and air quality. This task is involved in four (of six) sustainability focus areas listed in the 2012 MYPP (p. 2-86): climate (reducing GHG emissions associated with biofuel production and use); water quality and quantity (increasing water-use efficiency); air quality (maintaining or improving air quality); and land use (minimizing negative LUC impacts). Our air-quality project is the largest within NREL's sustainability task and is the focus of our Peer Review presentation. The primary programmatic goal of this multiyear project is to assist BETO in meeting its MYPP goals for evaluating and selecting appropriate air-quality indicators, establishing baselines, setting targets, and implementing best practices for air pollutant emission reductions that will lead to more environmentally sustainable biofuels across their life cycles. The project eventually aims to estimate and monetize health impacts attributable to air pollutant emissions from large-scale biofuel production. We will consider all life-cycle phases, from feedstock production, to distribution, to end user; our focus in fiscal year 2012 and fiscal year 2013 has been the feedstock production and biorefinery stages. We are developing spatially, temporally, and chemically explicit emissions inventories of air pollutants that lead to the formation of secondary particulate matter (2.5 and 10) and ozone, which together cause the greatest monetized health damages from air pollutants. We have developed a model for estimation of air emissions from feedstock



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

production that allows for rapid evaluation of alternative scenarios, addition of new feedstocks, and changes to crop budgets and logistics. We have also developed a tool to model the complex, kinetic formation of ozone and particulate matter precursors from selected unit processes at the biorefinery.

Overall Impressions

- This project contributes in important ways to DOE's efforts to ensure sustainability of the advanced bioenergy industry. Its findings will take DOE to a much deeper understanding of the air quality impacts of the industry. Up to now, impacts of air quality have been limited to inventories of specific emissions and some simplistic impact categories. Adding geospatial specificity to the emissions allow for more rigorous public health and ozone formation calculations. The team is making very good progress, and is on track to establish a modeling tool that can be used to quantify and minimize human health effects from criteria air pollutants. Likewise, the project is generating useful modeling results for lignin combustion. Here, however, a more concerted effort to collect real-world data on combustion would greatly enhance this project. The biggest concern for this project is the suggestion made in the review of turning to monetizing of human mortality and morbidity estimates as a metric for air quality. Such monetizing is fraught with difficulties, and should be considered only after consultation with the broader research community working on measuring and defining sustainability for bioenergy.

- The project will provide some valuable projection estimates on an understudied impact—air-quality emissions in a spatially explicit context. To be of most use, these predictions will need to be validated. Careful consideration should be given to the metric in which results are conveyed. A monetized metric may misrepresent or cause misinterpretation of results if it becomes confounded with health costs (including mortality).

- This project is important to establishing location-specific emissions resulting from the growing biofuels industry. The project achieved much in the area of emission modeling and presented a clear path forward to complete air pollution investigation, but not much was presented on water and GHG issues. The project is critically useful in identifying process components with a big impact on emissions, thus can be useful to identify critical technical components for targeted development towards reduction of air-quality impact.

- This project represents greater attention to air-pollutant modeling beyond those typically modeled in GREET, such as spatially and temporally explicit modeling, and can be used to update and increase completeness of the GREET dataset. It's unclear if this is not just marginal improvements to data that already exists. It seems like future work is drilling down in details that may not have major impacts on overall results (i.e., transportation distances generally don't control an LCA), so PIs need to be sure to target expected hotspots. Greater collaboration with other air-quality modelers would likely help leverage project funding.

- This study's detailed analysis seemed to be a valuable contribution. Current and future efforts should focus on other life-cycle stage impacts (2 & 3) to enhance the approach's systematic utility for pathway comparison and supply chain siting. Additional work leveraging the Feedstock Production Emissions to Air Model and chemical kinetics results for regulatory planning is important for improving the LCA inputs to design teams. The project approach has good applicability for supporting future siting-planning analysis. This panelist recommends careful consideration of the questions being posed and to focus on these core functions prior to expanding pathway coverage or extending the model further into regulatory impact assessment applications.

PI Response to Overall Comments

- The team appreciates the constructive comments from the review panel. Although much of the presentation and accompanying material was focused on air quality, this project also addresses both water use and GHG emissions. This project is also an integral component to DOE's efforts to measure and establish baselines and targets for sustainability metrics. Over the next fiscal year, the sustainability metrics work, including water and GHG, will be moved to the technology areas to more tightly link it to the techno-economic analyses performed by those groups, while the focus of this project will be directed on spatial-air-quality modeling and the establishment of baselines and targets for a range of conversion technologies.

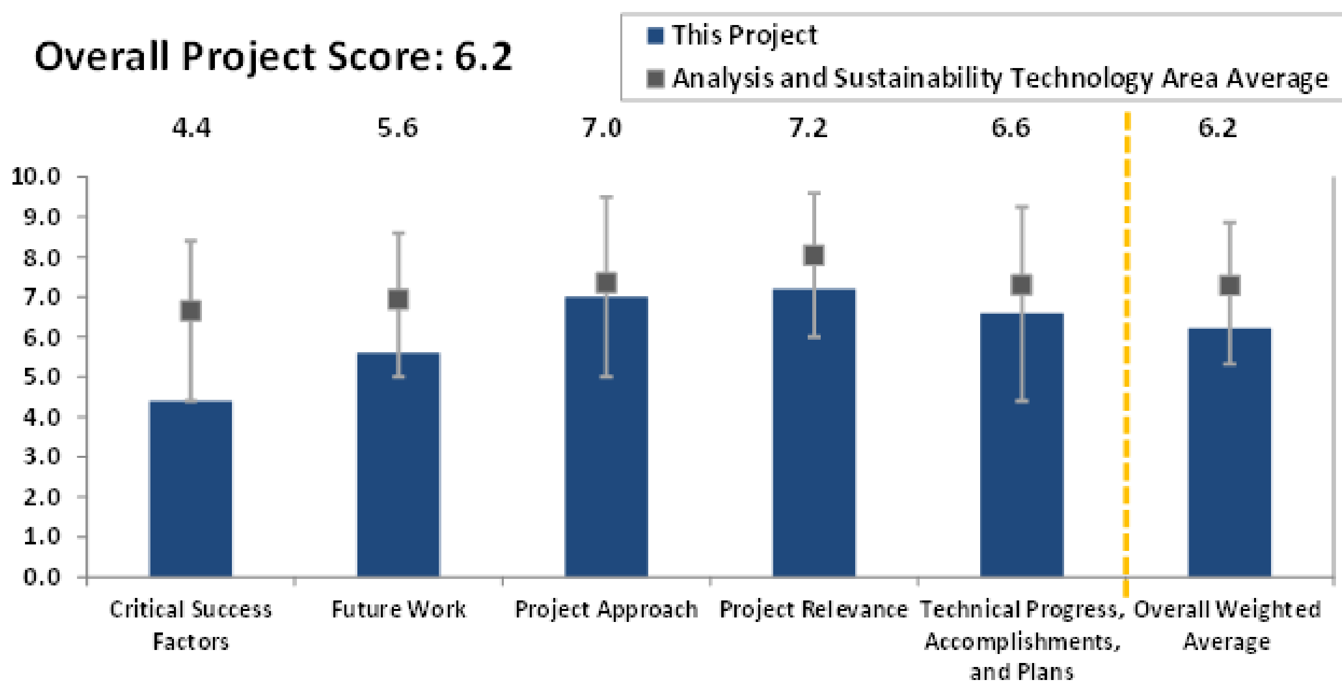
LIFE-CYCLE ASSESSMENT OF LOGISTICS SUPPLY SYSTEMS

(WBS#: 11.2.4.2)

Recipient:	INL
Presenter:	Kara Cafferty
Total DOE Funding:	$180,000
DOE Funding FY13:	$90,000
DOE Funding FY12:	$90,000
DOE Funding FY11:	--
Project Dates:	2011–2013

Project Description

This project is titled Life-Cycle Analysis Support and is focused on developing the methodology and data to establish the sustainability metrics for the biomass logistic supply systems. Life-cycle analysis is the methodology used to estimate the greenhouse gas emissions and global warming potential for engineered systems. INL has developed biomass supply system designs and, in collaboration with NREL, has adapted LCA methodology to support the analyses of these designs. The project is one of the original projects funded under the Bioenergy Technologies Office Analysis and Sustainability Technology Area. The original feedstock logistic LCA work was supported by the National Renewable Energy Laboratory. At the time, INL did not have the in-house expertise to perform detailed LCA analyses and was relying on NREL to perform these analyses. INL has since developed this capability and has assumed the task of performing the LCAs for every logistic supply system design. This has helped expedite the analysis because INL was able to couple their Biomass Logistic Supply Model with the data engines that supply information to the LCA software. INL is now able to establish both the cost and sustainability metrics for each supply system that is analyzed. The sustainability metrics are important for establishing that biofuel qualifies as an advanced or cellulosic biofuel at Renewable Fuel Standard levels. The LCA now allows for establishing the sustainability metrics for the overall supply system, assesses what the contributions are from each process, and identifies any barriers that would impact the qualification of a conversion pathway. This toolset was used in updating the 2012 MYPP, supported the analysis in the thermochemical and biochemical sizing papers, and established the sustainability metrics for the 2012 Feedstock Supply Joule Milestone.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- This effort is a good application of tradeoff and optimization analysis for system design. Its linkage of the TEA and LCA should be built upon. Moving forward, additional sustainability performance factors need to be expanded past GHG to better address BETO gaps and goals.
- Project results have been validated against GREET, giving credence to the overall effort. The need to use SimaPro is linked to the need to go a level deeper than currently permitted in GREET. However, this transition may make transparency less easy to discern and this cost should be weighed carefully against the benefit of added detail. Additionally, the project raises but does not fully address the key question of whether you can actually show that what is bad in economics is bad in water quality, etc., highlighting the need/benefits of close collaboration with TEA.
- The overall project is worthwhile and coupling logistics into the modeling effort will allow flexibility in determining the effect of feedstock changes. Coupling the results of the analysis with economic data would be an interesting path forward to determine the decision variables that will improve both economic and environmental performance, as well as those that have inherent tradeoffs.
- The project is close to completing the analysis of feedstock logistics supply system scenarios in a simple, straightforward way. Close collaboration with technical experts and the development of a user-friendly, customizable tool to quickly analyze GHG effects of various scenarios is important to make this project useful to the Office. Project could be expanded to look beyond GHGs.
- This is a sound project. It is one of several LCA-related activities across the Bioenergy Technologies Office. It is providing a useful, deeper dive into the LCA of the supply logistics for biomass, and takes good advantage of the existing BETO research at INL on supply logistics. Two areas for improvement in the work are, first, to include in future work an effort to address coordinating and linking the LCA work with other LCA efforts across BETO (this may involve a shift away from the use of proprietary data and software such as SimaPro); and second, that the LCA work should also include an effort to explicitly understand the linkages and relationships of the techno-economic analysis of the logistics for biomass handling to the impact assessments generated as part of the life-cycle analysis. More broadly, the project should contribute to an effort to optimize multidimensional sustainability of the overall bioenergy supply chain.

PI Response to Reviewer Comments

- The Life-Cycle Assessments of Logistics Supply Systems project was a two-year endeavor to support the Bioenergy Technology Office sustainability efforts. This project laid the framework for determining sustainability performance for feedstock supply systems. This project focused primarily on greenhouse gas emissions due to the nature of the conventional supply systems evaluated. As more advanced supply systems come into play with more intricate processes, additional metrics will need to be evaluated, including air quality, water, etc. However, the supply chain unit operations greatly stipulate which metrics are of importance.
- By design, this project was separate from the ongoing techno-economic analysis of supply systems in order to establish an approach for evaluating sustainability components. Moving forward, however, future LCA analysis will be an integral element of feedstock logistics techno-economic analyses. This integration of techno-economic and sustainability analyses will provide interesting insights to supply system design tradeoffs.
- This project made use of the proprietary software (SimaPro) in order to achieve individual process-level assessments, which is a finer resolution of analysis than what is available in GREET.

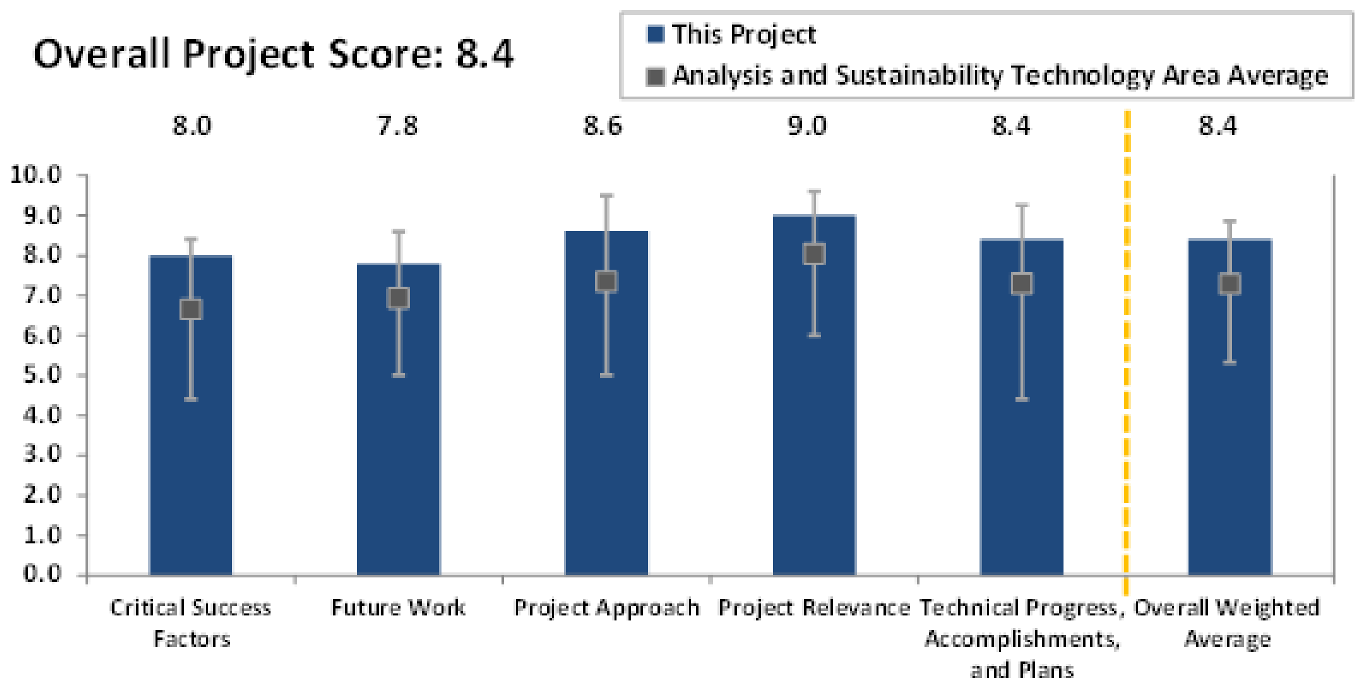
THERMAL CONVERSION SUSTAINABILITY INTERFACE

(WBS#: 3.6.1.1; 3.6.1.3; 3.5.1.3; 3.1.2.4)

Recipient:	PNNL
Presenter:	Lesley Snowden-Swan
Total DOE Funding:	$450,000
DOE Funding FY13:	$125,000
DOE Funding FY12:	$125,000
DOE Funding FY11:	$100,000
Project Dates:	2009–Ongoing

Project Description

The Bioenergy Technologies Office is developing cellulosic biofuel technology pathways to support the EISA RFS2 mandate of 36 billion gallons of annual biofuel use by 2022. One of BETO's key objectives is to support development of fuels that meet the RFS2 biofuel definitions for GHG reductions relative to baseline petroleum fuels. Furthermore, BETO is going beyond GHGs to integrate all aspects of environmental sustainability into the design and application of biofuel production systems. This project directly supports these objectives by establishing sustainability metrics for comparison of biomass conversion technologies, quantifying these metrics for emerging pathways, and identifying critical design parameters that will facilitate optimization of processes for both economic and environmental sustainability. The approach of this project is to integrate experimental research, techno-economic analysis, and sustainability analysis to provide optimized designs for biofuel conversion facilities. Sustainability analysis is performed in conjunction with techno-economic analysis and updated regularly with data emerging from experimental research. A set of sustainability metrics for biomass conversion pathways was established and quantified for the fast pyrolysis and bio-oil upgrading pathway, and was integrated into the 2012 state-of-technology report. Life-cycle GHGs were estimated for fast pyrolysis and upgrading, catalytic pyrolysis and upgrading, and a renewable hydrogen case for fast pyrolysis and upgrading. Critical conversion aspects for GHGs include fuel yield, natural gas consumption, and electricity usage, which are interdependent variables in the design. For fuels made via hydrocarbon-based intermediates that require deoxygenation, there is a tradeoff between carbon-to-fuel yields (and lower cost) and fossil energy needed for hydrogen and electricity. Isolating key process parameters for meaningful sensitivity analyses is a key success factor, and a challenging one due to the complexity of processes (e.g., pyrolysis chemistry, oil composition), interdependence of variables (integrated refinery), and limited experimental data.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- This is one of several LCA-related projects in the BETO portfolio. The approach for the work is sound, and is already providing important insights about technology choices and R&D directions that will influence the sustainability of the thermochemical pathways for drop-in ready fuels and hydrocarbon intermediates for petroleum refineries. The efforts to build deep links between the process design and LCA is commendable. The project has identified several important areas of conflict between what is good for the economics and not good from a life-cycle sustainability point of view, such as the ever-present problem of the tradeoff between low-fuel yield leading to high cost, but high greenhouse gas credits for co-product electricity. The project performers are encouraged to push hard to find these kinds of relationships, and to take this idea even further by looking for ways to optimize across the full spectrum of cost and environmental metrics that underpin the technology's sustainability. Furthermore, when apparent conflicts occur, they should be highlighted as opportunities for R&D aimed at eliminating these conflicts. The project is well-plugged into the broader LCA team supported under the Bioenergy Technologies Office, but ways to link more deeply should always be sought out, particularly with regard to ensuring efficient use of resources.
- This project features a coupled-process design evaluated against multiple criteria with careful articulation of those criteria. The outputs/outcomes of this project should direct TEAs. The project is a good example of critical collaboration—economics and sustainability often go hand in hand, but this is not necessarily one of those situations, thereby illustrating the importance of linked analyses to illustrate tradeoffs.
- This project piloted the integration of a TEA and LCA and is an example of an important innovation that the technology areas, Analysis and Sustainability portfolio, and BETO should develop moving forward. Doing so will enable more effective platform design and analysis collaboration that will ultimately result in better-optimized BETO Office outcomes. Future work can be enhanced by refining and broadening the metrics suite, such as water, land, air quality, etc.; providing more analysis transparency; and ensuring alignment with existing GREET and EPA's Office of Transportation and Air Quality's LCA models.
- This project successfully highlighted the importance of technology-specific LCA to identifying critical sustainability factors and their implications on project profitability. The project's future progress is critical to developing a sound strategy for thermal conversion technology development.
- This seems like a reasonable and well-thought-out research project. The analysis that incorporates cost and GHG emissions together is a good one. This would be good to see in more of the analysis results of the overall portfolio. Determining a framework for thinking about how to forecast best-case scenarios for future development pathways could be a good thing for BETO to pursue, either through this project or others. The project did a reasonable job trying to use potential improvement analysis focusing on the specific technological aspect of hydrogen requirements, but it is a bit ad hoc and would be nice to be able to apply it more broadly.

PI response to Reviewer Comments

- The reviewers' comments and suggestions are very much appreciated and well taken. Regarding improving linkages with the broader BETO LCA team and community, we will continue to interface with the ORNL team to ensure consistency with their metrics framework, the NREL team on the expansion and refinement of metrics for biomass conversion technologies, and the ANL team on integration of conversion-stage inventory data into the GREET and water-footprint-modeling frameworks. While GREET documents fuel life-cycle emissions for BETO technology pathways, it is critical to perform sensitivity analysis at the process development and modeling level to fully understand and facilitate improvement of the cost and environmental implications of key variables in the design, as well as to elucidate any impact of conversion design changes on upstream stages. A critical enabler to this is not just the seamless integration with the techno-economic analysis team, but also the concomitant interaction with the experimentalists. This project is uniquely positioned to capture the cross-fertilization and rapid identification of positive synergies emerging from the conflux of techno-economic analysis, experimental development, and sustainability modeling.

IMPACT OF PROJECTED BIOFUEL PRODUCTION ON WATER USE AND WATER QUALITY

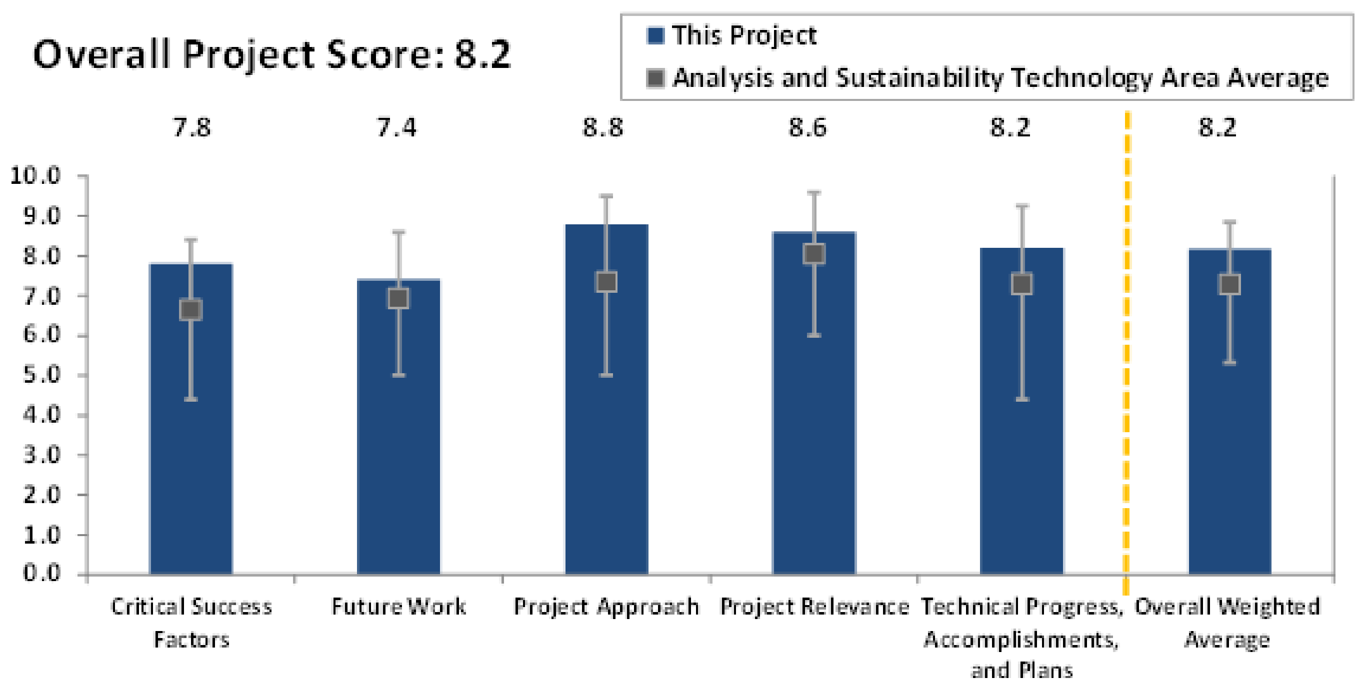
(WBS#: 11.1.1.1)

Recipient:	ANL
Presenter:	May Wu
Total DOE Funding:	$2,800,000
DOE Funding FY13:	$550,000
DOE Funding FY12:	$595,000
DOE Funding FY11:	$700,000
Project Dates:	2007–2050

Project Description

Photo Courtesy of ANL

The sustainable production of bioenergy requires the development of the needed resources, technologies, and systems that maximize the economic, social, and environmental benefits associated with bioenergy while protecting natural resources. Water sustainability includes water demand and the impact of water use on water quality. This project supports BETO in evaluating and comparing the sustainability of biofuels produced from agricultural residue, energy crops, forest resources, and algae by developing an analytical framework that is spatially explicit and able to link the hydrologic cycle to the production pathway. Key aspects of the project include hydrologic modeling at the river basin scale, the county-level water footprint of various biofuel pathways, and the demand for and availability of water resources. Since the inception of the project, Soil and Water Analysis Tool (SWAT) models have been developed for the Upper Mississippi River Basin and Ohio River Basin to establish baseline water quality (nutrients and suspended sediment). Future scenarios of man-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

agement, production, and climate were implemented, and the watershed responses were analyzed. The water footprint of biofuels produced from corn grain, corn stover, soybean, wheat straw, switchgrass, *miscanthus*, and forest resources has been estimated at the county level. Comparative study provides the blue water consumption from an energy-use perspective for biofuels and fossil fuels. A web-based water footprint tool has been developed to present the results for quick analysis by stakeholders and the biofuel industry, government agencies, academia, and NGOs. The analytical framework can be used to support informed decision making by providing an analysis to identify region-specific, low-water-footprint feedstock mix; identifying refinery sites that have minimal impact on local water resources; and simulating management programs/cropping systems that reduce the potential negative impacts on nutrient and sediments loadings. The project contributes to BETO's goals of understanding and promoting the positive economic, social, and environmental effects of bioenergy production activities, as well as reducing the potential negative impacts of those activities.

Overall Impressions

- It is exciting to see the level of progress that this project has made in building tools and generating results related to the critical goal of sustainable water use in the advanced biofuels industry. The project's approach builds on a water-footprint methodology consistent with the International Organization for Standardization's (ISO) standards to understand water consumption impacts, while relying on hydrological modeling in SWAT as a basis for water-quality impact assessment. Both pieces are important, and their approach and progress on each is excellent. ANL appears to be the central hub for water sustainability work. Given its role in life-cycle assessment, this is a very appropriate role. To the extent possible, this project team should extend its reach into all of the projects supported by the Office that have any relation to water. Tools such as the water-footprint model are valuable outputs from the work. The research is already providing important insights about water-quality impacts.
- This project can be viewed as a foundational or framing project for Sustainability and Analysis water-quality projects focused on finer scales and/or as the upper end in the array of water-quality impact modeling projects scaling from the individual field level to the gross regional (country) level. Given that the collective array of water-quality-simulation projects within the portfolio represent a nested array of results, the best return on investment lies in explicit integration of results across scales and projects. At present, it is not clear that this project is well integrated in real time with others that are exploring finer scales. This is especially important given the need to validate model predictions across scales with field data; the field data that exists appears to be most available to projects operating at the field or small watershed scale.
- This project does a good job at effectively modeling the future water use of biofuel production through a standardized water-footprint methodology, with collaborations of key data holders and field verification of results. The model developed in this project will be critical for both planning purposes and solving transient problems in an effective manner.
- This project fulfills a knowledge gap regarding water use and quality that is necessary to assess the sustainability of biofuels. The efforts regarding water use were clearer than those representing water quality. Integration among some of the projects regarding water analysis is already apparent, but there could be greater coordination and it would seem that this is the logical project to integrate overall portfolio efforts.
- This project is a timely and worthwhile effort. I look forward to its further development and ultimate

availability for integration into broader sustainability analysis and best practices. We recommend focusing on core analysis capabilities for water quantity across pathways and water-quality-impact interfaces with regulatory regimes. Climate change impacts will be important, but could be deferred to out-years until the core capabilities are fully developed.

PI Response to Reviewer Comments

- We are grateful for your valuable insights into the project, as well as your insightful suggestions for improvements. Your critiques will help us stay on track as we work to accomplish BETO's overarching goals.
- Water sustainability is an essential component in overall environmental sustainability. Water quantity, quality, and availability are interlinked; therefore, a framework that is able to address the relationships between biofuel and bioenergy production and water quality, quantity, and resource availability at different scales would be desirable. By developing water-footprint tools and SWAT models for the Mississippi River Basin, we are developing such a framework. Thanks to your unique expertise, you are providing the project direction we need to develop a successful framework.
- We also appreciate your advice on finer-scale watershed modeling to address sustainable landscape management and practices for biofuel feedstock production. We value your thoughtful comments on the need to validate the results of our water-footprint analyses. To address that need, we will use field and/or watershed testing data available through our collaborations on BETO-supported, field-testing projects. We expect greater collaboration in the future to improve data validation. We are also very encouraged by your positive feedback on our approach to filling data gaps, which involves developing rigorous procedures for screening data while continuing to collaborate with professionals from other national labs, federal agencies, industry, academia, and NGOs.
- Of particular value is your input on strategies for interacting with researchers working on other BETO projects and how the water analysis should be integrated to achieve broader sustainability indices. We have included your recommendations in our new annual operational plan. As you recommend, we will play a more active role in BETO-supported watershed modeling and analysis.
- In summary, we thank you all for the time given to review this project. We really appreciate your exceptional support!

FORECASTING WATER QUALITY AND BIODIVERSITY

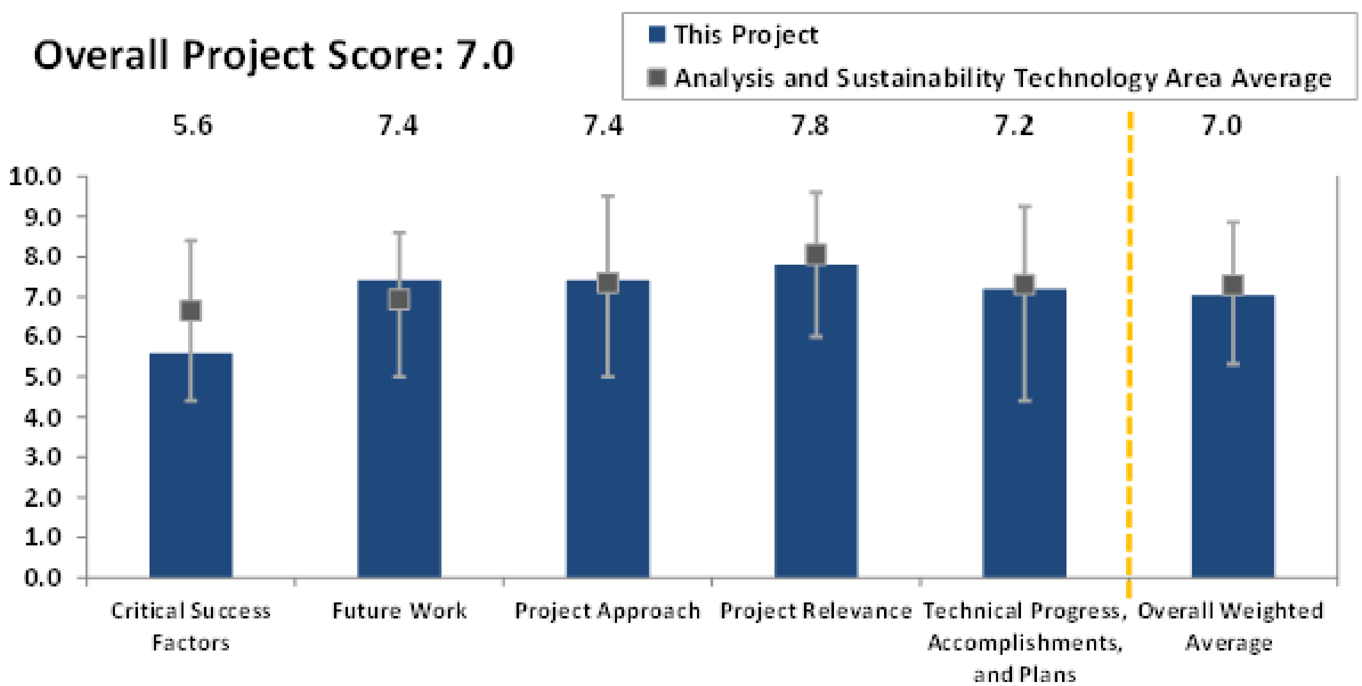
(WBS#: 11.1.1.4)

Recipient:	ORNL
Presenter:	Henrietta Jager
Total DOE Funding:	$1,025,000
DOE Funding FY13:	$225,000
DOE Funding FY12:	$200,000
DOE Funding FY11:	$200,000
Project Dates:	2009–2016

Project Description

Photo Courtesy of ORNL

The widespread use of corn as an energy feedstock has raised public concerns about water quality and thwarting progress in reducing the hypoxic "dead zone" in the Gulf of Mexico. Our project used science-based forecasts and scenarios to address goal St-B in the Sustainability section of the MYPP to project changes in water quality under a future scenario that meets the EISA standard. Methods were developed for representing conventional crops and future energy crops, such as switchgrass, poplar, sorghum, and stover (corn and wheat) in a river basin model. We compared a 2030 economics-based future scenario (assumed farmgate price of $50/dry ton and 1% annual increase in yield) with a business-as-usual scenario for the current landscape that simulated future tillage practices and enhanced yields. To measure the effect of future bioenergy, we tailored the McBride, et al., water quality indicators for regional-scale projections (goal St-D in the MYPP). We reported the median change in each of three water-quality indices (nitrate, total phosphorus, and total suspended sediment concentrations). The median decrease in 2030 concentrations was large (greater than 9%) for both



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

nutrients but small for sediment, and responses varied spatially. To understand how assumptions about fertilization and other management practices influenced our results, we conducted a sensitivity analysis for pasture and mapped geographic variation in the optimal amount of fertilizer required by switchgrass. Most recently, we solved a linear programming problem that used simulated water-quality sensitivities to individual crop replacements to maximize reductions in nutrients and sediment, thus producing more ambitious targets than those from the economic *Billion-Ton Update* scenario. This effort will address two goals: determining how land conversion can maximize environmental benefits (St-G in the MYPP), and identifying synergies and tradeoffs between economic and environmental objectives (St-F in the MYPP).

Overall Impressions

- A better understanding of the watershed impacts of bioenergy seems like necessary work to support BETO's efforts. Beginning to transition from estimation of impacts to prioritization and protection of sensitive areas is important. This project offers the potential to conduct improvement analyses to determine the places most sensitive to changes in management practices and the extent of water quality improvements possible.
- This effort made good use of the *Billion-Ton Update* scenarios to better understand the impacts on water quality and biodiversity. Its focus on the optimization of planting and BMPs selection is a strength. Collaboration is likewise a strength, but could be made more robust by coordinating with other optimization efforts regarding the criteria, tools, and ability to inform user decisions.
- This is an interesting project where results and project outcomes will be optimized when viewed through the lens offered by the complementary Soil and Water Analysis Tool (SWAT) modeling projects, which extend down to the field scale and up to the scale of the greater Mississippi River watershed. This should include standardized approaches or best practices and sensitivity analyses for model calibration/validation to strengthen the overall portfolio of results. For BETO to realize the best return on their water quality modeling investment, SWAT PIs should be encouraged and facilitated in an active collaboration with an eye toward linking to the broader USDA and academic communities dedicated to water quality modeling.
- This project developed good tools to develop a biofuel feedstock strategy that has a positive impact on water quality. The team developed a detailed model with good spatial resolution. Expansion of approach to other river basins and dissemination of findings will be critical to fully capture the value created by this project.
- This project is one that was difficult to assess. This is due, in part, to this reviewer's lack of expertise in watershed modeling. There seems to be a case to be made that the choice of watershed (the Arkansas-White-Red basin) makes sense from the vantage point of potential for switchgrass production, but there was little context for understanding the ultimate value of achieving 10% changes in nutrient release (as determined in this project) in the larger context of the Mississippi River watershed, nor how much bioenergy production is represented in this area. These are questions that no doubt the researchers have answers to, but the review materials did not shed much light on them.

PI response to Reviewer Comments

- We acknowledge that this project serves an important purpose in quantifying regional-scale impacts. This comment guides us in the direction of finding places and practices where further improvements can be made. We will attempt to move in this direction through a new task added in fiscal year 2014 that seeks to optimize placement of selected BMPs in sensitive areas or areas that have high potential to improve water quality and enhance biodiversity.

- The new task will coordinate optimization efforts with researchers at other national labs, across sustainability and resource analysis platforms.
- We agree that our efforts are related to those at USDA and others in academia. We are actively seeking collaboration with USDA for the optimization task. Our USDA collaborator has agreed to provide data needed to implement water quality models. We have also contacted USDA staff responsible for national-scale modeling who are located at Texas A&M University. We originally subcontracted Dr. Raghavan Srinivasan for SWAT expertise. We continue to interact closely with him and he is a co-author on our publications.
- Thank you for noting the value of our tools. With regard to the suggestion that we should expand to other river basins, we are now beginning work on the Tennessee River basin on an accelerated schedule. We have also addressed the request that we disseminate findings by preparing a manuscript on our results for the Arkansas-White-Red river basin that will be submitted in October 2013.
- We have not yet made the determination of how the benefits of planting cellulosic feedstocks in the Arkansas-White-Red basin will accrue downstream in the Gulf of Mexico, but we intend to address this question in the future.

OPTIMIZATION OF SOUTHEASTERN FOREST BIOMASS CROP PRODUCTION: A WATERSHED-SCALE EVALUATION OF THE SUSTAINABILITY AND PRODUCTIVITY OF DEDICATED ENERGY CROP AND WOODY BIOMASS OPERATIONS

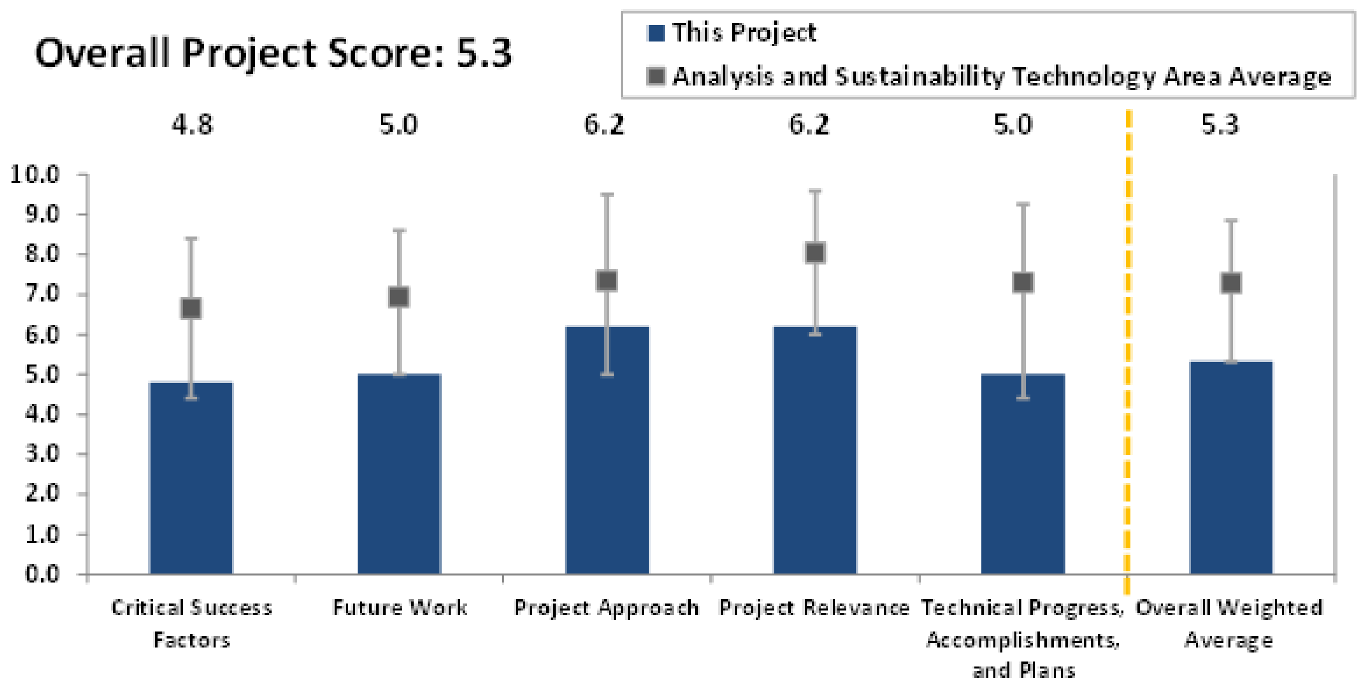
(WBS#: 1.7.1.5)

Recipient:	North Carolina State University
Presenter:	George Chescheir
Total DOE Funding:	$2,092,892
DOE Funding FY13:	$442,073
DOE Funding FY12:	$400,947
DOE Funding FY11:	$417,426
Project Dates:	2010–2015

Photo Courtesy of North Carolina State University

Project Description

The overall goal of this project is to develop and disseminate science-based information for sustainable production of forest biofuel feedstock in the southeastern U.S. Biofuel feedstock production evaluated in this project will be compatible with high-value timber production, whereby perennial energy crops will be interplanted between widely spaced loblolly pine trees. This project consists of plot-scale and watershed-scale experimental studies linked with a modeling effort that will enable us to apply our experimental results broadly across the region. Watershed- and plot-scale experiments have been initiated and three years of data



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

have been collected to quantify the impacts of feedstock production on soil quality, biodiversity, and water quantity and quality. Matched watershed studies have been established in North Carolina, Mississippi, and Alabama. Each installation includes at least four, small, operational-scale sub-watersheds that are instrumented to provide data on stream discharge, weather, water table, and water quality. Biomass treatments that will be applied to the sub-watersheds will represent a spectrum of biofuel management intensities: typical pine plantation, about 15 years old; young pine (high-value timber regime); young pine (interplanted with switchgrass); newly planted pine (interplanted with switchgrass); and switchgrass only. Additional projects are being conducted on the watersheds to study soil productivity, nutrient and carbon cycling, biodiversity, economics, and safety. Processed-based watershed-scale models are being calibrated and validated with the field-measured data. The validated models will be used to simulate alternate scenarios and to develop realistic land-use inputs for landscape scale models, such as SWAT. The field-collected data will be used along with watershed and landscape models to develop best management practices and decision tools.

Overall Impressions

- Given the difficulties in switchgrass stand establishment, it seems unlikely that good, robust data on all treatments will be adequate for any sort of bona fide treatment-effect analysis within the timeline of the project. Indeed, three to five years post-establishment are likely a minimum experimental timeframe in order to see treatment effects against spatiotemporal variation associated with weather and temperature effects on growth. Given the project is at its midpoint, the moment is opportune for a rigorous evaluation of initial objectives among the collaborating partners. Such a review will ensure that project personnel activities are targeted to maximum benefit and will optimize project success, regardless of whether some or all objectives are retooled.
- The concept of intercropping is intriguing and the objectives of this project are to explore the potential for intercropping. Unfortunately, the project has encountered a variety of problems establishing the intercropped system, which may suggest that questions regarding the feasibility of such systems are justified. Even if an acceptable switchgrass stand can finally be established this summer, it is unlikely that sufficient experimental results will be obtained before the end of the funding period. A contingency plan should be discussed to determine next steps.
- This project focuses on a specific land-use scenario with unclear economic advantages. The project collects extensive valuable data, however, suffers from issues with the establishment of treatments. The project will need substantially more time to clearly establish the relationship between data collected and treatment. Data collection could also be optimized to ensure viability of longer-term data collection.
- This project seems to have started with an interesting idea for a potentially sustainable approach to interplanting of switchgrass and pine. However, it now seems plagued with problems related to the ability to successfully implement this treatment. Furthermore, we did not see evidence of the commercial feasibility for this interplanting scheme, though there must be some value proposition of interest here, given the participation of Catchlight and Weyerhaeuser. The project efforts have been tremendous, but the failed attempts at establishing switchgrass have raised the level of uncertainty about the project's ability to glean useful results within the remaining two-plus years of the project life. This project may need to pause at this point and rethink what is achievable and what is the most sensible direction for the work. This includes the possibility of cutting losses at this point.
- This project's field research, to regional modeling, to BMP-integration approach seems worthwhile. If the results, modeling, and BMP advance as planned,

it could be a good, new applied-research contribution. However, the project can be strengthened through greater coordination of model development and use with other BETO-funded projects using SWAT. Additional value would be yielded by validating the treatment benefits and impacts, particularly as the BMP(s) was deployed later than planned. There also needs to be more effort defining impacts and contingencies regarding replantings and thinnings.

PI Response to Reviewer Comments:

- We would like to address the primary reviewer concerns: treatment establishment and project relevance.
- Our research was established using the most promising treatments for dedicated biomass in a forested setting using switchgrass, a species with high biomass feedstock potential, as a model for an energy crop. We installed and monitored 14 watershed study sites (11 to 27 hectares each), and also conducted research on 28 0.8-hectare plots in a companion study. Four watersheds are long-term research sites with more than 20 years of silviculture data. Our treatments represent low to high intensities in multiple settings.
- We replanted or overplanted switchgrass sites as necessary to ensure that our hydrologic parameters reflect the energy crop and not competing vegetation. While some watersheds show low establishment rates, we have successful stands of each treatment, allowing completion of analyses and models. While we certainly prefer complete replicates, this project is collecting high-quality data on environmental sustainability of forest-based biofuel systems, particularly on the effects of site preparation and stand establishment on hydrology and water quality. Our research team and external advisors thoughtfully assessed our operational and scientific options, and we are moving forward with a plan for analysis and modeling that optimizes our field dataset under current constraints.
- We have made significant progress towards very relevant goals, which are to understand and quantify environmental sustainability of forest-based biomass systems and develop best management practices that are applicable under a wide range of practice intensities.
- To summarize, our research represents the most relevant of topics—operational implementation of practices that may be applied across the southeastern United States. By studying at-scale treatments (with all of the inherent problems) instead of small, homogenous and highly managed research plots, we are evaluating the true environmental consequences of these new technologies.

WATERSHED-SCALE OPTIMIZATION TO MEET SUSTAINABLE CELLULOSIC-ENERGY-CROP DEMAND

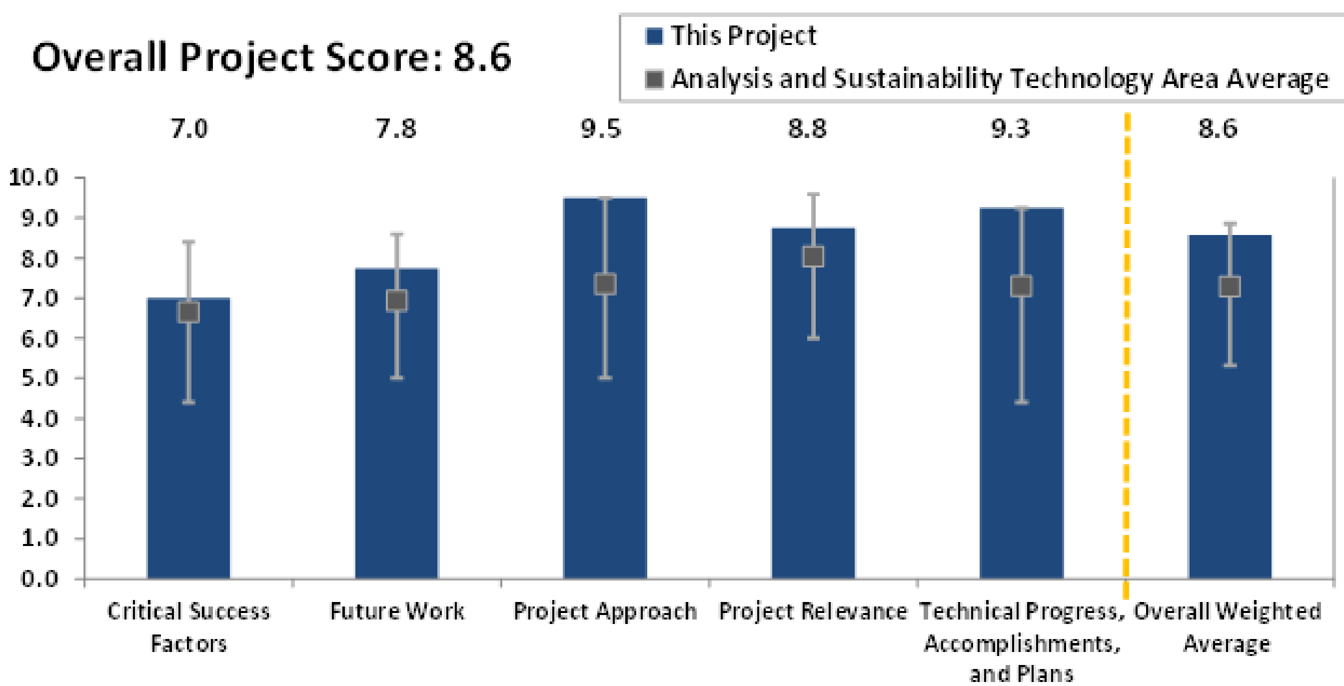
(WBS#: 1.7.1.6)

Recipient:	Purdue University
Presenter:	Indrajeet Chaubey
Total DOE Funding:	$1,592,385
DOE Funding FY13:	$343,055
DOE Funding FY12:	$448,083
DOE Funding FY11:	$440,143
Project Dates:	2010–2014

Photo Courtesy of Purdue University

Project Description

One of the grand challenges in meeting the U.S.' biofuel goal is supplying large quantities of lignocellulosic materials that are produced in an environmentally sustainable and economically viable manner. In this project, our team is conducting a watershed-scale sustainability assessment of multiple species of energy crops and removal of crop residues within two watersheds representative of conditions in the upper Midwest. The sustainability assessment includes bioenergy-feedstock-production impacts on environmental quality, economic costs of production, and ecosystem services. We are conducting this assessment through a series of eleven tasks under two objectives. The first objective is to improve the simulation of cellulosic energy crops, such as *miscanthus*, switchgrass, and hybrid poplar, in the Soil and Water Assessment Tool model. We have developed parameters and processes through a synthesis of existing data and collection of new data on field plots of these energy crops, and have validated the model improvements using field- and watershed-scale



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

biomass, hydrologic, and water-quality data. The second objective is to use the improved model to evaluate the environmental and economic sustainability of likely energy-crop scenarios on a watershed scale, including sensitivity to climate variability. We are developing watershed-landscape scenarios or experiments representing various combinations of energy crops in collaboration with local stakeholders, and are evaluating their sustainability using SWAT model simulations, economic analyses, and ecosystem-impact models. Sustainability metrics include soil erosion and its impact on long-term productivity; water quantity, including high-flow frequency, streamflow distribution, streamflow variability, low flows, and groundwater recharge; water quality, including suspended sediment, nitrogen (nitrate, Total Kjeldahl Nitrogen, total), phosphorus (dissolved and total), and pesticides; biomass and crop production; profitability; and aquatic biodiversity and associated ecosystem services. The third objective is to identify and communicate the optimal selection and placement of energy crops within a watershed for sustainable production. We have developed methods to optimize selection and placement of various energy crops using SWAT with a genetic algorithm. We plan to compare results with targeting strategies to determine the optimal design and implementation strategies for the sustainable production of selected energy crops and other cellulosic-feedstock-production systems at the watershed scale. We will communicate results and methods, including the modeling system, through reports, papers, presentations, a website, and workshops. We have published project results in five peer-reviewed journal articles. In addition, we have made presentations at 34 regional, national, and international conferences based on results obtained from this project.

Overall Impressions

- This project covers a variety of objectives related to modeling water-quality impacts of dedicated energy-crop production. The project has accomplished a great deal in terms of technical merit. There are certain elements where the project may be making models that are beyond the level of complexity necessary for analysis of biofuel policy. It appears that less-complex tools may be able to provide similar results, and dissemination of these tools could have a larger impact than limited dissemination of complex analyses; however, the overall approach of the project is solid and it is expected that the quality of the analysis will be high.
- This project goes into an in-depth study of impact of energy-crop production on watershed by targeted field-data collection and a well-thought-out modeling approach. The project's progress is substantial; however, details around future plans and the process by which findings are disseminated to stakeholders were limited.
- This project is one of the best examples of a research plan that is disciplined in its approach and comprehensive in scope. Not satisfied to use default values for upland switchgrass, the project team worked assiduously to collect the data needed to establish 25 parameters that did not exist for the crops studied (*miscanthus* and upland switchgrass). This data has now been used to look at a broad range of sustainability measures for these energy crops. None of the other watershed projects has done as thorough a job in including economic analysis as one of the metrics evaluated. BETO will likely be able to leverage the results of this project in important ways. This is an outstanding project.
- This project's field research, to regional modeling, to BMP-integration approach is commendable. The project is being executed in a focused and disciplined way that should be replicated. This reviewer recommends developing SWAT community-engagement opportunities to share this new process so it can be leveraged by others across BETO. One added benefit of this effort is that the model results can be used to optimize bioenergy crop placement.

PI response to Reviewer Comments

- We are using the Soil and Water Assessment Tool model to quantify impacts of bioenergy crop production on hydrology, water quality, and aquatic ecosystem health. This model is a widely applied and supported model with more than 1,200 peer-reviewed journal articles published on the application of the model. We also plan to use the SWAT model to optimize selection and placement of various energy crops in the two study watersheds. We realize that optimization is a complex task. We plan to use the optimized results to develop simpler models that can be used to develop strategies for spatial location of various energy crops (e.g., switchgrass and *miscanthus*) in a landscape that will meet environmental sustainability and biomass production goals.
- We will document the modeling and optimization methods developed in the project so that they can be implemented in other watersheds and by other researchers and agencies. Methods and results will be presented at various conferences and published in peer-reviewed journals. We will conduct workshops on optimization methods, and share methods with other SWAT modelers funded by DOE. Presentations and written materials will be made available on the project website. We will develop a report on how to design and implement energy-crop-production strategies at the watershed scale, and a report detailing the experimental design, the data collection, and conclusions. Dr. Chaubey is working with the SWAT development team to incorporate all model improvements made as a result of this project into the version distributed to global SWAT-model users.

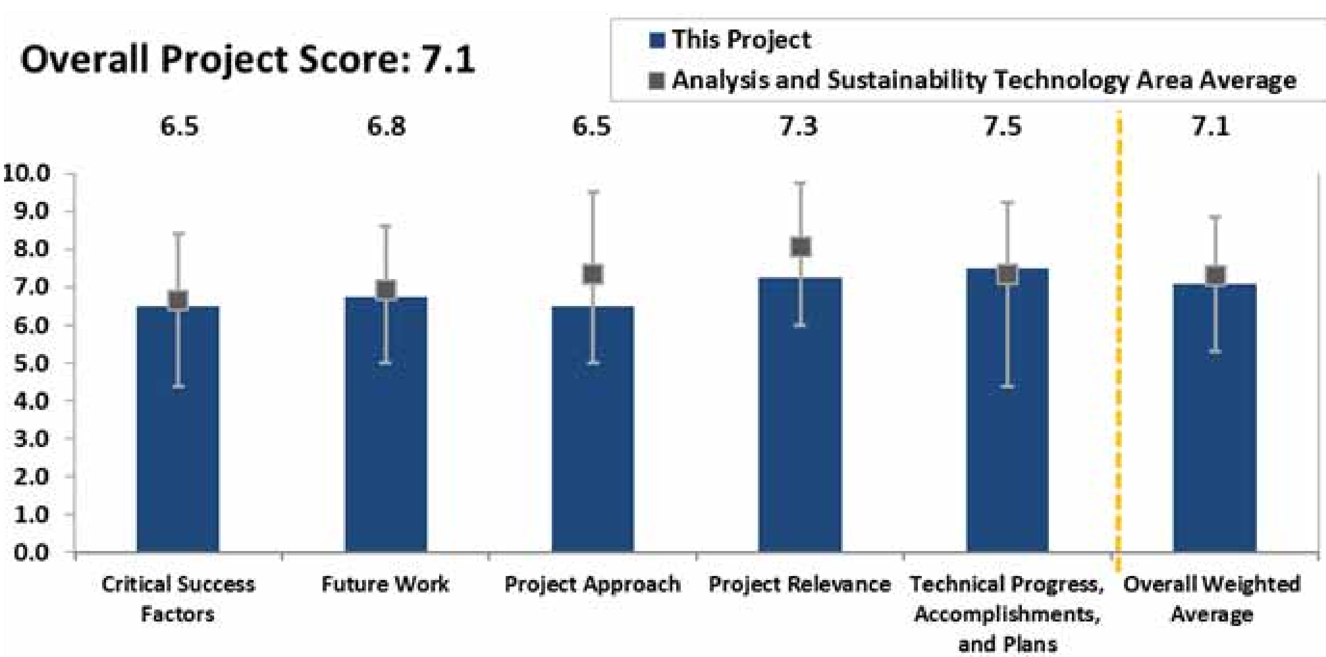
PATHWAYS TOWARDS SUSTAINABLE BIOENERGY FEEDSTOCK PRODUCTION IN THE MISSISSIPPI RIVER WATERSHED

(WBS#: 1.7.1.7)

Recipient:	University of Minnesota
Presenter:	Jason Hill
Total DOE Funding:	$185,000
DOE Funding FY13:	$52,000
DOE Funding FY12:	$105,000
DOE Funding FY11:	$28,000
Project Dates:	2010–2015

Project Description

The overall goal of this project is to use an ecosystem-service framework to evaluate the environmental impacts of various biomass production options and their placement on the landscape so as to guide the bioenergy industry toward greater sustainability. To this end, we are evaluating the biophysical and socioeconomic tradeoffs of bioenergy production to provide relevant results useful to a broad range of stakeholders, including farmers, investors, the bioenergy industry, policymakers, regulators, and the general public. The modeling domain is the Mississippi River watershed, which has been identified as having the potential to support a diversity of biomass feedstocks ranging from dedicated crops and crop residues, both herbaceous and woody. Analytical tools being used include the Integrated Valuation of Environmental Services and Tradeoffs and Agricultural Integrated Biosphere Simulator models. Work to date has included scenario development, including consideration of existing biomass production scenarios; Integrated Valuation of Environmental Services and Tradeoffs-model runs in the southern Minnesota subdomain to quantify the economic value of ecosystem services under conversion of marginal land in corn/soy rotation to prairie grasslands; Agricultural Integrated Biosphere Simulator-model runs in the upper Midwest subdomain to consider changes in evapotranspiration, soil carbon, and net ecosystem productivity under corn stover removal and irrigation; and the advancement of spatially and temporally explicit life-cycle assessment methods for the simultaneous consideration of supply



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

chain impacts in addition to landscape-level impacts. Future work will include expanded model runs to cover the entire Mississippi River watershed, and the continued addition of likely biomass feedstocks given-market conditions and end goals for environmental benefit. The outcome of this project will be an actionable set of recommendations for guiding sustainable growth of the bioeconomy by assisting stakeholders in making informed decisions about what bioenergy feedstocks to use, where to produce or collect them, and what environmental impacts they will have.

Overall Impressions

- The project seeks to find equilibrium between economical and ecological impact of biofuels by the assignment of a cost/value. This approach is somewhat undermined by the subjective nature of establishing ecological costs. For this reason, sensitivity to cost/value assumptions is critical to correctly utilize the product of this study.
- The results to date from this project seem of limited value to the Office. This project may need serious rethinking to see how better to meet the goals of landscape-level assessment of bioenergy in the Mississippi River basin.
- This is a potentially useful study that is well aligned with the goals of the BETO Analysis and Sustainability portfolio. The benefit of using ecosystem service valuation is the ease of incorporation into economic studies for direct cost-benefit comparison. Although there are inherent problems associated with monetization of ecosystem services that have been discussed in detail in the literature, studies of this nature can inform the discussion of potential policy levers that can incentivize preferred land-use changes, as well as identifying those that are likely to be less effective.
- This is a project that may seem to lie somewhat on the periphery of BETO's purview and is perhaps close to the mission of other agencies. However, it represents a relatively small investment and allows BETO to leverage the investments of other agencies in related projects. By supporting this project, BETO will gain benefits from beyond their initial investment, including resources for a further refinement of the *Billion-Ton Update*.
- This project is an interesting synthesis of LCA and valuation of ecosystem services to internalize these costs to society. The effort has the potential to contribute to regional impact and valuation scenarios that could be useful to inform policy decisions. Additional transparency, enhanced level of user comfort, and potential policymaker engagement would be needed to realize great potential and relevance.

PI Response to Reviewer Comments

We thank the reviewers for their comments. We share their opinion that ecosystem-service valuation plays a critical role in the comprehensive understanding of the impacts of bioenergy production. Substantial public and private resources are being invested in the development of next-generation bioenergy with the expectation that it will provide environmental benefits such as the reduction of greenhouse gas emissions or the mitigation of nutrient runoff into waterways. The concept of ecosystem services allows for the real economic value of these environmental benefits to be estimated using objective, quantitative methodologies. Accordingly, we recognize the inherent uncertainty involved in estimating the economic value of ecosystem services, which is why we are conducting extensive Monte Carlo simulations in our modeling efforts. Ecosystem service valuation is increasingly being applied to decision making, and we thank the Department of Energy for providing us with the opportunity to extend its application to bioenergy and, in doing so, assist the public in understanding the true value of its investments in renewable energy.

BIOMASS PRODUCTION AND NITROGEN RECOVERY

(WBS#: 11.1.1.2)

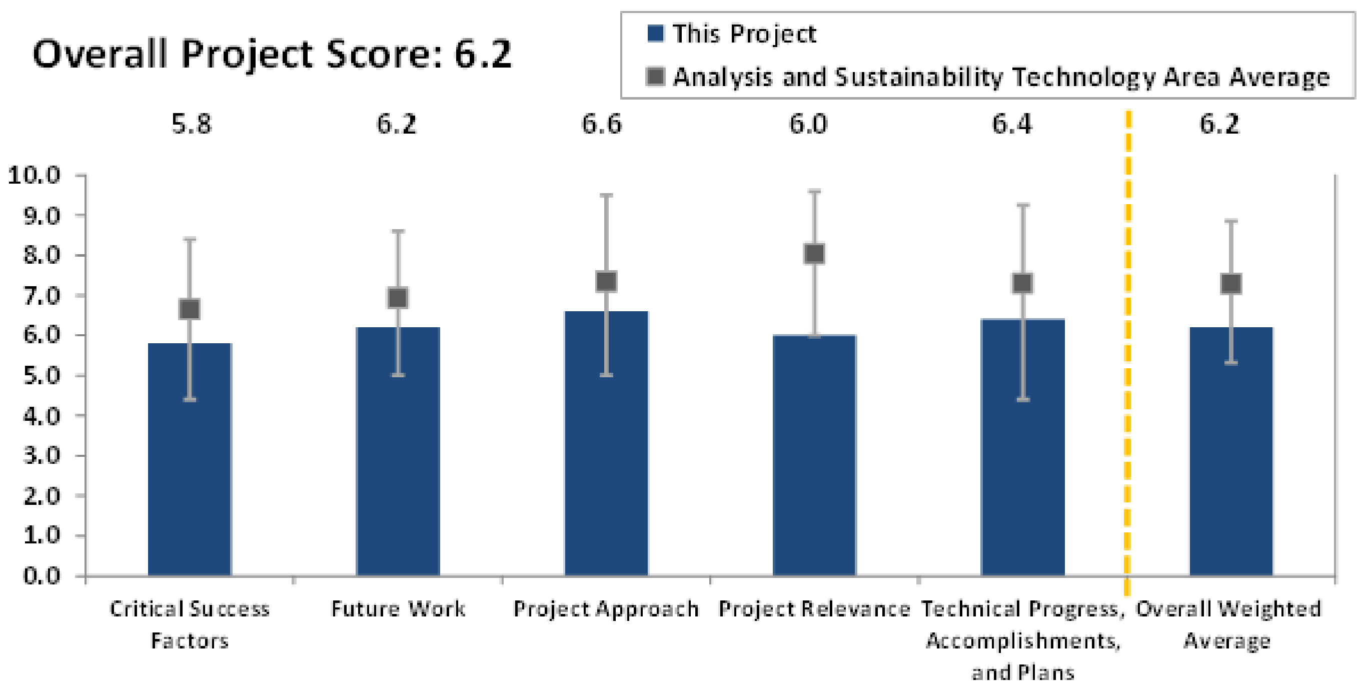
Recipient:	ANL
Presenter:	Cristina Negri
Total DOE Funding:	$1,500,000
DOE Funding FY13:	$450,000
DOE Funding FY12:	$350,000
DOE Funding FY11:	$700,000
Project Dates:	2010–2015

Project Description

Photo Courtesy of ANL

Science-based strategies need to design sustainability into biomass production to fulfill EISA and RFS2 requirements. This project evaluates the sustainability of a biomass production system based on the recovery of landscape elements such as marginal land, nutrients, and impaired water. A collaborative effort with a national conservation organization, industry, Illinois' Livingston County Soil and Water Conservation District, and rural stakeholders, the approach tested incorporates the passive reuse of water-borne nutrients to support increased biomass production in sub-productive land.

GIS analysis, modeling, and proof-of concept field work conducted by Argonne in years past have highlighted a significant opportunity to increase the land available for sustainable biomass production if underproductive acreage in edge-of-field, riparian, and roadway buffers is used, even partially, and to dramatically increase yields if impaired water and entrained nutrients from grain farming are passively reused. Field-scale research conducted in this project evaluates the main environmental and economic sustainability indicators (water quality and quantity, soil quality, greenhouse gas emissions, yields) of a bioenergy buffer deployed in sub-productive land to recover nitrogen lost by corn. After a baseline data collection season, the willow crop planted in 2012 was impacted by the severe drought that affected most of the Midwest, and is now being replanted. This work



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also provides the basis for a future scale-up of the research to the watershed scale encompassing the entire Indian Creek Watershed (a tributary to the Illinois River in the Mississippi River Watershed). This rural watershed is analyzed through GIS studies and stakeholder involvement activities to determine where bioenergy crops could fit in the landscape. Potential benefits from this approach the support of sustainability goals by proposing options for biomass production that provide diversified farmer economic returns, lower transportation costs, better farm nitrogen-use efficiency, restoration of contaminated water, and mitigation of greenhouse gas emissions from both biomass and grain crops.

Overall Impressions

- The project collects and analyzes valuable data, however, large-scale applicability is limited by the extensive testing required to establish ideal buffer zones and the by the significant logistical costs associated by small, dispersed production of biomass.
- This project has accomplished a lot of work with a very limited budget. It is well into the monitoring phase of a field test of willow use as a buffer strip planting for landscape management of a corn farming system in the Midwest. Buffer strips deserve attention, particularly from the point of view of reducing erosion and runoff into surface waters. The project's original aim had been just that—an effort to use riparian buffer strips as a way to prevent surface runoff. To the credit of the researchers, they responded in real time to the findings of their research in recognizing that surface flow was not the problem in this field. They changed course as a result, and turned instead to design of a contour buffer that runs through the field as a way to manage groundwater leaching problems. The project performers are to be commended for their nimbleness, and their sensitivity to economic (e.g., yield) considerations in the placement of the contour buffer. Also highly commendable in this project is the active effort to involve local farmers in the work. After all, it is these farmers who will need to be relied on to adopt the kinds of landscape management techniques evaluated in this study. All of this speaks to the strengths of this project. In the question and answer period with the reviewers, several weaknesses surfaced that should be addressed. First, the researchers should respond to concerns raised about the appropriateness of willow in the buffer strip, in lieu of planting switchgrass or other perennial grasses. Second, one observation that comes out of the work done so far is that there are regions of low yield (including the region where the contour buffer has been placed) that are being over-fertilized. This raises the possibility that the need for jumping to a buffer system to treat nitrogen leaching may be premature, at least as more precise application of nitrogen appropriate to the yield potential across the field might alleviate much of the problem being mitigated by the landscape redesign. Finally, researchers should—sooner rather than later—do some basic economic analysis of the collection logistics for energy crops grown in buffer strips at the watershed scale. A buffer strip approach is an inherently "low intensity" approach to energy crop production because it uses a relatively small fraction of the land. At the watershed scale and at the scale of collection for a biofuel processor, this could make the economics of collection and transport problematic.
- This project represents an integrated approach of experimentation, analysis, and stakeholder engagement. The study is nicely designed and significant progress has been made. It represents a proactive approach to environmental management of bioenergy production. The critical success factor for the project is its economic viability, which was not adequately addressed. If actually viable, the analytical process for determining the appropriate location of buffer zones will need to be streamlined to realize large-scale implementation.

- This solutions-oriented project is built on existing research and executed with the design outcomes in mind from the start. It is a good blend of hard science and stakeholder participation that will aid in deploying best management practices for design. The project's weakness is its inability to scale-up and be used more broadly outside of the current field plot. Recommend a greater focus on phosphate cycling due to freshwater impacts and strategic supply availability implications.
- While the goals of this project are laudable and the objectives important, there are some real limitations to its implementation that will greatly curtail scientific outcomes and contributions to knowledge gaps regarding landscape optimizations. Fundamental problems range from the fact that the field has not been previously managed with best management practices for corn, and that implementation of variable-rate nitrogen management for corn could remove or greatly ameliorate the problem that the willow planting is supposed to solve. Overall, it seems that this project lacks good agronomic input from an appropriately trained extension specialist (or similar professional), and thus results may be subject to challenge by those prone to think that willows represent a solution in search of a problem. In other words, I am not sure it is fair to discuss treatment impacts on water quality in the context of best management practices when the farmer is not pursing best management practices for nitrogen control on corn. Furthermore, the ability to extend results to a broader inference space than this particular field under these specific experimental conditions is likely limited. This project appears more of a demonstration than a rigorous scientific study, despite all the intensive monitoring.

PI Response to Reviewer Comments

- We appreciate the importance of an economic analysis of the proposed approach; however, attempts at conducting it earlier were stopped because of insufficient data. This work is now planned for the upcoming watershed-scale study, when we will have a better understanding of the logistics and system-wide implications of growing biomass in a distributed system and overall intensified landscape.
- The purpose of the field trial was to begin benchmarking treatment targets and identify key study parameters for scale-up. It was not to draw larger scale inferences. Future watershed-scale work will allow us to develop a method to simplify biomass landscape-placement strategies and support large-scale deployments.
- The field site has been managed with periodic soil analysis and split nitrogen applications. The level of management adopted at this site is typical of this region, making the field site a legitimate one. Precision nitrogen application techniques are not yet commonly adopted here and could not be utilized at this field. Moreover, even under the most advanced nitrogen management practices, there may be water-quality impacts depending on weather events and accrued inventories. If riparian buffers and wetlands are an acceptable approach to mitigate nutrient problems even as advanced management techniques are implemented, so should bioenergy buffers be.
- Our approach is crop-agnostic. We selected willows after careful consideration of pros and cons between willows, *miscanthus*, and switchgrass. Even though switchgrass emerged as the ideal crop for this landscape, we did not find sufficient data for experimental purposes on its measured consumptive water use, hydraulic control ability, luxury nitrogen consumption, and root-readiness for spring nitrogen capture. Willows have several attractive features, like their ability to begin water uptake early in spring when nitrogen losses are highest and grasses still leafless, resilience to drought once established, and adaptability to poor soils and flooding.

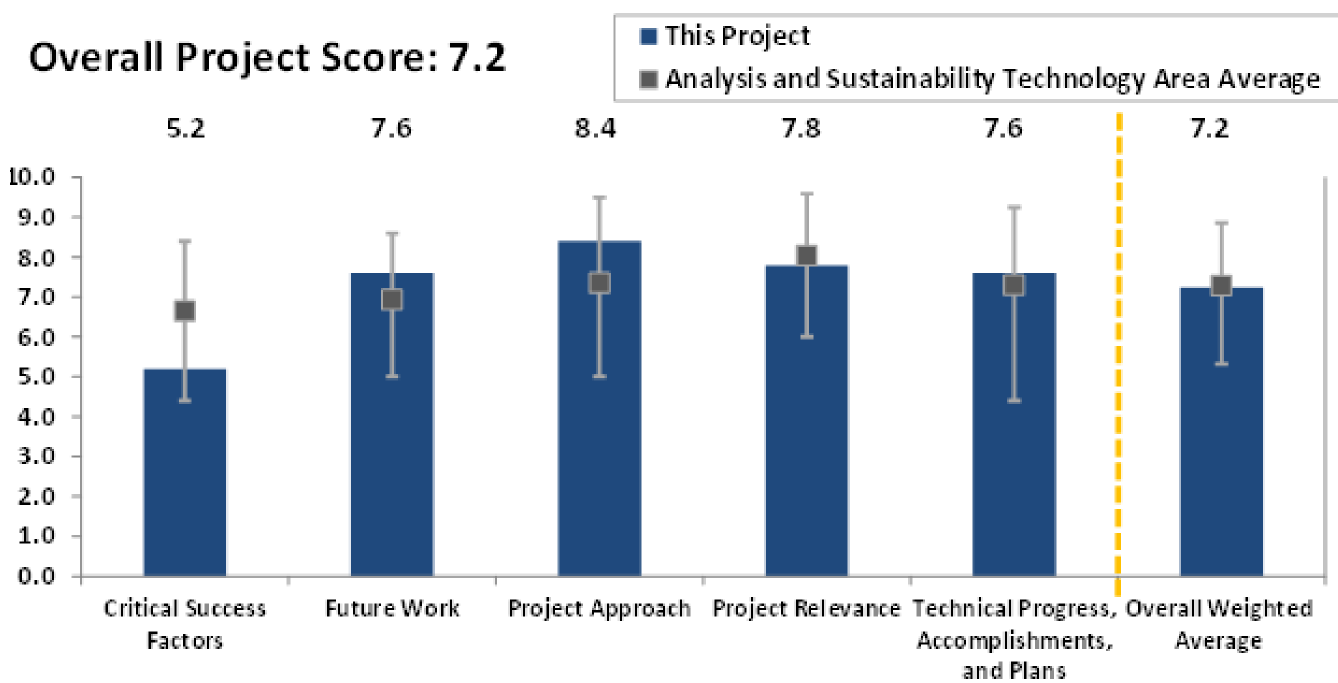
SHORT-ROTATION WOODY BIOMASS SUSTAINABILITY

(WBS#: 11.1.1.7; 11.1.1.8)

Recipient:	ORNL
Presenter:	Matt Langholtz
Total DOE Funding:	$2,800,000
DOE Funding FY13:	$670,000
DOE Funding FY12:	$489,000
DOE Funding FY11:	$913,000
Project Dates:	2010–2018

Project Description

Increasing bioenergy's contribution to renewable energy goals requires increased production accomplished in concert with protection of water quantity and quality to be environmentally sustainable. Intensive silviculture practices (e.g., advanced genetics, weed control, fertilization, whole-tree harvesting, and shortened rotation age) can increase average annual production; however, these intensive practices have not been adequately validated at the watershed scale relative to current best management practices. Our project uses a watershed-scale experiment along with a distributed watershed-modeling approach to evaluate environmental sustainability (water quality, water quantity, soil quality, and productivity) of intensive short-rotation pine practices for bioenergy in the southeastern U.S. The experiment uses a before-after control-intervention design to study three adjacent watersheds (two treatment, one control) at the Savannah River site in South Carolina. The watersheds were characterized and instrumented beginning in fall 2009, and baseline data were collected from all three watersheds for two years (2010–2012). Starting in spring 2012, more than 40% of the two treatment watersheds were harvested, prepared (summer 2012), and planted with loblolly pine seedlings (winter 2013). Intensive silvicultural activities (herbaceous weed control and fertilization) will occur over time (2013–2018). Baseline hydrology and water quality measurements suggest that groundwater rather than hillslope water will be the dominant connection between silvicultural activities and streams in these watersheds. Specifically, measurements, experiments, and HYDRUS 2D modeling together show a high threshold for interflow (lateral water



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

flow through hillslope soils), suggesting that only large rainfall events would initiate interflow. In addition, groundwater and stream flow observations coupled with isotopic and water chemistry data have demonstrated that riparian groundwater is a dominant source of stream flow. Hydrological and water-quality measurements will continue as silvicultural activities are implemented. Data will inform a distributed watershed-scale model to broaden the applicability and context of the results.

Overall Impressions

- The project addresses a specific scenario of feedstock production. The project uses sound experimental approach, and progressed well both in the field and with simulation. Some tools developed will be transferable; however, the findings of the study will be largely limited to the site.
- This is an ambitious and complex project. Results will be a contribution to the greater knowledge gap regarding impacts of bioenergy crop production on water quality. However, it is important to note that watershed-scale, before-and-after studies are notoriously difficult to interpret, often because overall project timelines are inadequate to truly capture before-and-after conditions. The project goals and objectives are important, but additional research beyond this effort will likely be needed to derive full benefits from the work conducted here and to fully realize project objectives.
- This project is making good progress on its assessment of intensive production of southern pine. It appears on track to generate reasonable data on soil and water impacts at the watershed level. Researchers are thinking in terms of how best to use the hydrological-modeling results to generalize for other basins in the region.
- This project nicely planned and integrated long-term field experiments with direct BMP and watershed model outcomes. The deliberate thought and dissemination of these results to targeted end-user communities needs to be planned early and made a focus for the remainder of the project. This panelist recommends stakeholders be engaged to discuss and develop a plan to ensure wider applicability of the scaled-up model and standard operating procedures to enable its use more widely.
- This project takes an experimental approach to monitor water-quality and hydrology changes due to loblolly pine production at different management schemes in the southeastern U.S. The project appears well executed and represents a portion of the overall BETO portfolio that seeks to collect data to support overall sustainability efforts. The water-quality impacts of woody biomass production are expected to be relatively small when compared to dedicated field crops. Greater efforts can be employed to determine the representativeness of the data collected through this project.

PI Response to Reviewer Comments:

- We greatly appreciate the reviewer comments and would briefly like to highlight the following items in the bullets below: our critical success factors, our modeling plan for broadening the study applicability, and our plans to disseminate findings.
- Our study will determine if intensive woody crop production with current forestry BMPs is successful, meaning that impacts to soil and water do not exceed regulatory or narrative standards for forestry while still reaching target productivity yields (7–10 megagrams per hectare per year). If water or soil resources are impacted, this project would still be successful by identifying these conditions and by using field measurements and modeling results to inform short-rotation woody crop-specific BMPs. We will be successful in this project by collecting high-quality data and scaling our results using models to inform whether short-rotation woody crop production for bioenergy is environmentally sustainable in the southeastern U.S.

- This summer, Dr. Vache has begun work to scale-up our findings to the entire Savannah River Site, and then to the Upper Coastal Plain by incorporating Oregon State University's Envision modeling platform into the catchment model in combination with extensive vegetation, soils, and water resource databases.
- Dr. Jackson regularly interacts with the water quality committee of the Southern Group of State Foresters, an organization that coordinates BMP revisions across the southeast, and the National Council for Air and Stream Improvements, a research organization of the timber and wood products industries. Dr. Jackson and other project participants will continue to present research findings to these groups and continue to coordinate technology transfer with BETO. Additionally, Dr. Vache works closely with EPA staff that are using the Envision model in their work. Adoption of this common modeling platform as part of our work going forward is designed to facilitate the dissemination of the models themselves.

SUSTAINABLE FEEDSTOCK PRODUCTION–LOGISTICS INTERFACE

(WBS#: 1.1.1.2)

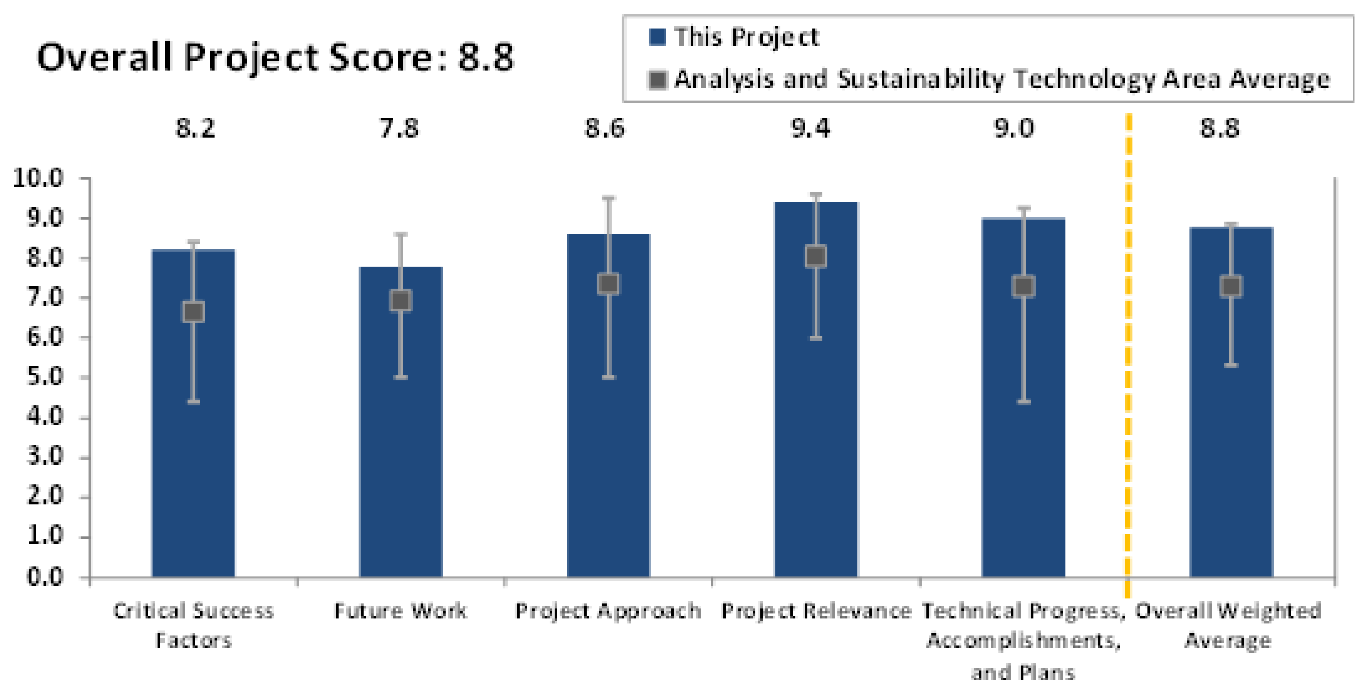
Project Description

Photo Courtesy of INL

This project is titled Sustainable Feedstock Production-Logistics Interface and is focused on designing innovative, integrated production systems that increase the total productivity of the landscape, decrease feedstock cost, and increase environmental performance.

Recipient:	INL
Presenter:	David Muth
Total DOE Funding:	$600,000
DOE Funding FY13:	--
DOE Funding FY12:	$300,000
DOE Funding FY11:	$300,000
Project Dates:	2011–2017

This project is led by Dr. David Muth at Idaho National Laboratory. The project was initiated under the DOE Regional Biomass Feedstock Partnership Program to develop tools that support sustainable agricultural-residue-removal decisions. The project is now funded under the Bioenergy Technologies Office Sustainability Area. Fiscal year 2013 represents a transition point for the project moving from an almost-exclusive focus on sustainable agricultural-residue removal decisions, to a broader, integrated-landscape design focus. The fiscal year 2011 and fiscal year 2012 work reviewed in this Peer Review process will represent final development and deployment of the core agricultural residue removal work. Over the previous two years, the project has delivered four key products: a revised national assessment that couples with the sustainable residue-removal coeffi-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

cients used for the *Billion-Ton Update*; a sub-field-scale assessment framework that has characterized the impact of sub-field variability in surface topography, soil characteristics, and grain yields on sustainable residue removal; an analytical assessment and toolset for engineering precision agricultural residue removal equipment; and multiple deployments of decision-support tools being used across the public and private sectors. The primary deployment of the residue tool is an open source code library called the Landscape Environmental Assessment Framework. The framework's tools are currently being used by multiple industry and research partners to perform sustainable residue-removal analyses. The Landscape Environmental Assessment Framework has also been used to produce a mobile application called SustainR2, which is available in the Apple App Store. SustainR2 was used to evaluate more than 1,100 residue removal scenarios this past fall.

Overall Impressions

- This is a distinct advance from anecdotal studies to a more systematic approach to residue removal. It provides a decision-support tool to determine sustainable residue-removal rates in a spatially relevant context. The work represents a significant advancement from prior approaches and can continue to provide more nuanced analyses to assist in precision agriculture.
- This project has pushed the level of debate over sustainable residue to a whole new level of refinement and quantification. In the late 1990s and early 2000s, the debate was broadly about whether residue collection was, in black and white terms, sustainable or unsustainable. Early studies using the same types of models and tools being used in this project helped to close the gap between the advocates and opponents of residue removal by showing that there were, indeed, scenarios in which it was possible to collect stover without dramatic negative impacts, but that if done badly, residue management could be very harmful. That debate has shifted to the question of whether variability within fields might unravel these early findings. The high-resolution modeling applied in this study is clearly helping to resolve this new challenge for stover collection. This is a major milestone for industry. At the same time, the lessons learned from the erosion and soil-carbon modeling have been applied in this project to improve DOE's national assessment of the size and cost of a sustainable supply of residue, and the U.S. development of decision tools for farmers is now being rolled out by the project team. These tools will catalyze commercial deployment of agricultural residue collection as a feedstock for bioenergy. These tools, in the end, not only make it possible to ensure sustainable use of residue, but could improve the overall sustainability of conventional corn farms by helping farmers optimize management practices to reduce erosion and water-quality problems that are increasingly a threat to farmers. This is an outstanding project.
- This project is practical and has outputs (decision-support tools) that have the potential to improve the sustainability of bioenergy crop management at the field scale. It is critical that, moving forward, project PIs continue active collaboration with USDA's Agricultural Research Service, the Natural Resources Conservation Service, and industry for this potential to be realized. The plans for future work were grandiose but vague, and should be refined (beyond what was presented under future work) prior to significant effort investment.
- This project's pragmatic use of existing data and models within a preexisting conservation framework is a positive contribution to informed farmer decisions at field scale. This is a practical end-use application development effort using existing con-

servation framework and available data, and delivering decision support in an accessible manner. The project is a model of collaboration, disciplined focus on pragmatic and innovative BMPs, and deployment and use by growers.

- This study is critical to sustainable utilization of crop residues. The project follows a sound approach, collaborates at the appropriate level, and has shown significant progress. The challenge is to come up with a low-cost, low-hassle solution that the farmers will be happy to implement.

PI Response to Reviewer Comments

- This project has developed a framework in which direct sustainability questions can be answered in a fully integrated fashion, providing robustness to the results and ease of use to the end user. It is definitely an advancement from anecdotal studies where manual integration of sometimes-very-different data inputs were required to get results. This more systematic approach provides confidence that the sustainability factors either are or are not being met and why. It goes so far as to tell you what changes could be made to move a system to be more sustainable.
- It does have challenges requiring further development. For example, we understand that using the Daily Century Model for assessing soil-organic carbon has limitations. Developers of the Daily Century Model at Colorado State University's Natural Resource Ecology Laboratory are currently working on expanding the depth for which soil-organic carbon is monitored. In addition, the developed model integration framework enables coupling of additional agronomic and environmental models. We plan to provide a suite of models that assess environmental factors within a dynamic, model-integration framework. Thus, the framework allows INL to work directly with model developers to not only enhance the Residue Removal Framework, but the supporting models as well.

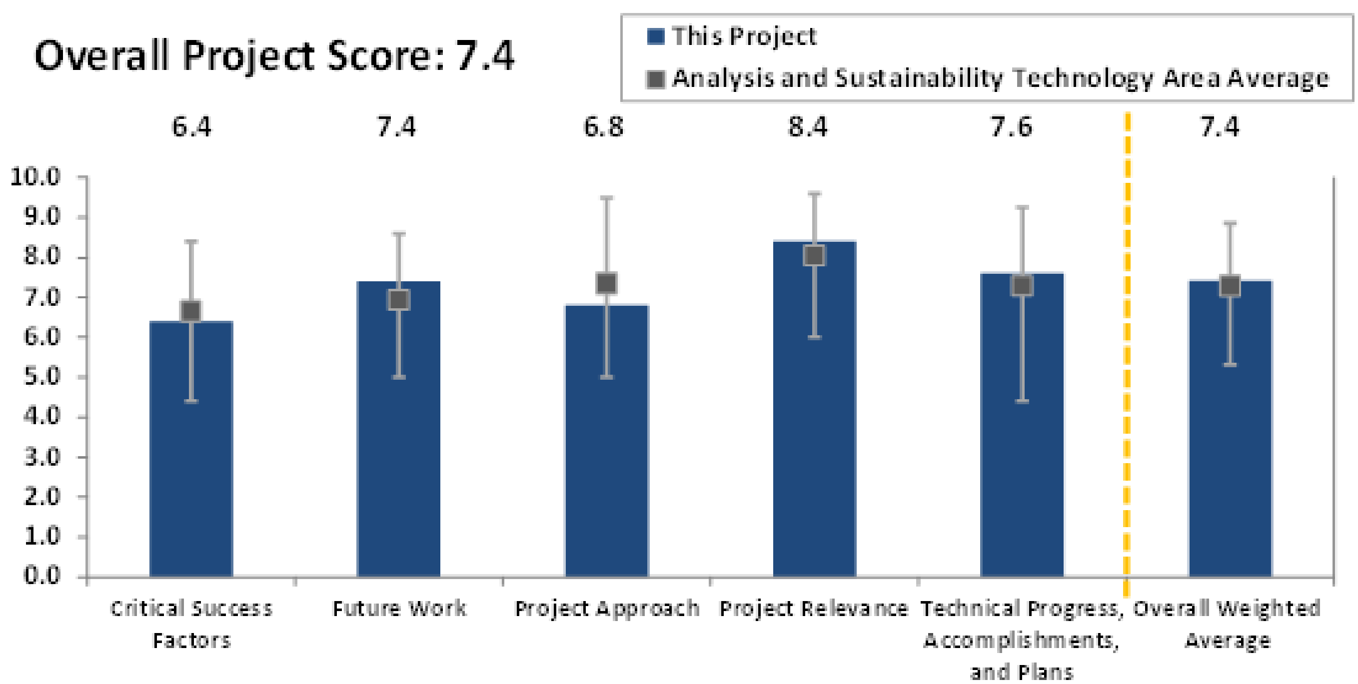
INTERNATIONAL SUSTAINABILITY

(WBS#: 6.5.8.1; 6.5.1.1)

Recipient:	NREL
Presenter:	Helena Chum
Total DOE Funding:	$500,000
DOE Funding FY13:	$100,000
DOE Funding FY12:	$100,000
DOE Funding FY11:	$225,000
Project Dates:	2009–2015

Project Description

The assessment or evaluation of sustainability is a difficult and complex problem—addressing simultaneously environmental, social, and economic pillars. BETO/DOE efforts through the International Sustainability tasks develop worldwide working relationships with key parties and organizations to yield a more comprehensive and credible set of analyses, complementary to those ongoing by the U.S. government. The International Sustainability research and analysis task provides technical expertise and support on best practices in sustainability of biomass and bioenergy systems, shares lessons learned, and advances sustainable bioenergy globally. Key aspects of the International Sustainability project involve the synthesis and dissemination of information from and to the BETO Technology Area participants and stakeholders. The project is also facilitating sustainable expansion of the U.S. industry(ies). These efforts contribute to BETO's Sustainability Technology Area goal, "to understand and promote the positive economic, social, and environmental effects and reduce the potential negative impacts of bioenergy production activities," and can lead to methodologies, best practices in the three-pillared indicators for sustainability, and trends on sustainability. We provided baseline and benchmarking knowledge of today's commercial ethanol industry in the two lead producing countries, the United States and Brazil. For the U.S., initial data aggregation for the corn dry mill industry shows that rapid implementation in 2005–2010 improved performance in fossil energy use, GHG emissions as calculated by regulatory LCA, and direct land use. The data so far will enable follow up analysis of the Global Bioenergy Partnership's "government consensus sustainability indicators." GBEP and participating countries use examples of developed countries' practices (e.g., evolution with time) to help developing countries identify data needs and method-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

ologies appropriate for their conditions. International collaborative efforts with the International Energy Agency (IEA) Bioenergy tasks examined global sustainability certification, as required of the U.S. industry trading in the European Union because of legislative requirements. Such standards activities can bring more credibility, accountability, and transparency to supply chains by collecting and verifying information related to production and trading practices at various stages of production (solid biomass fuels, liquid, and products). They could also be used to erect trade barriers. We provided significant input on the U.S. system and, of the Americas, more than 90% of the ethanol market; this is different from the EU countries, which hold approximately 45% of the biofuels market and our expertise in bioenergy voluntary multi-stakeholder certification schemes. Future work will focus on the preparation of high-impact publications on bioenergy and sustainability, and improvements of LCA methodologies.

Overall Impressions

- It is clearly important for the U.S. to remain participatory in international conversations; DOE has an important role in bioenergy agendas. The ongoing complex and heated disputes among international entities regarding deployment of genetically modified organisms stand as a cautionary tale with respect to inattention and/or disregard of international concerns and agendas. Unfortunately, the nature of this particular presentation was such that it was difficult to discern the structure of activities—many seem ad hoc—as well as their relative importance. In regards to this particular comment, I am not sure that the criticisms of previous reviews were addressed. While it may be defensible to be a bit ad hoc given the extent to which international activities can be disrupted by externalities, if investment dollars are constrained or are relatively minimal, it is important to have a strategy to allocate money to the most important activities. This was not clear from the presentation; failure to clarify and justify the selection of activities may leave the Office open to criticism and lack of support from entities uncertain or less certain of the value of ongoing international engagement.
- The partnering and stakeholder engagement is the core value added of this task. The participation, dialogue, and analysis support to international and certification bodies is a complementary strength. The synthesis of the life-cycle GHG emissions, regulatory levels, and certified trade provide the basis for an important technology transfer and dissemination of U.S. progress and efforts in biofuel sustainability.
- This is a very high-level project that attempts to address a number of objectives that fit into BETO's goals regarding international sustainability. The work of this group appears far reaching, with international efforts ranging from partnerships with Brazil to IPCC studies. Although difficult to measure the impact of these efforts in terms of metrics, there is an obvious need to have personnel working on certification standards and representing U.S. interests through international efforts.
- This project has a broad international objective with the main focus on collaboration, alignment, and dissemination of information. The project's value is common understanding and clarity around trade. Because the project addresses many-sum objectives, its organization and management is somewhat unclear; nevertheless, the progress is significant.
- This project provides an open line of communication with the international community now making important judgments and decisions about the sustainability of bioenergy globally. For that reason, the kind of minimal presence that the project team brings to these activities is important. The efforts to participate in studies with IPCC, IEA, and the United Nations Educational, Scientific, and Cultural Organization should most certainly be continued. The project's support of the U.S.-Brazil bilateral partnership is another valuable component of the work. It would good to see this project develop a more focused sense of desired outcomes for this work.

PI Response to Reviewer Comments

- We agree with the very helpful comments and thank the reviewers for their insights and suggestions.

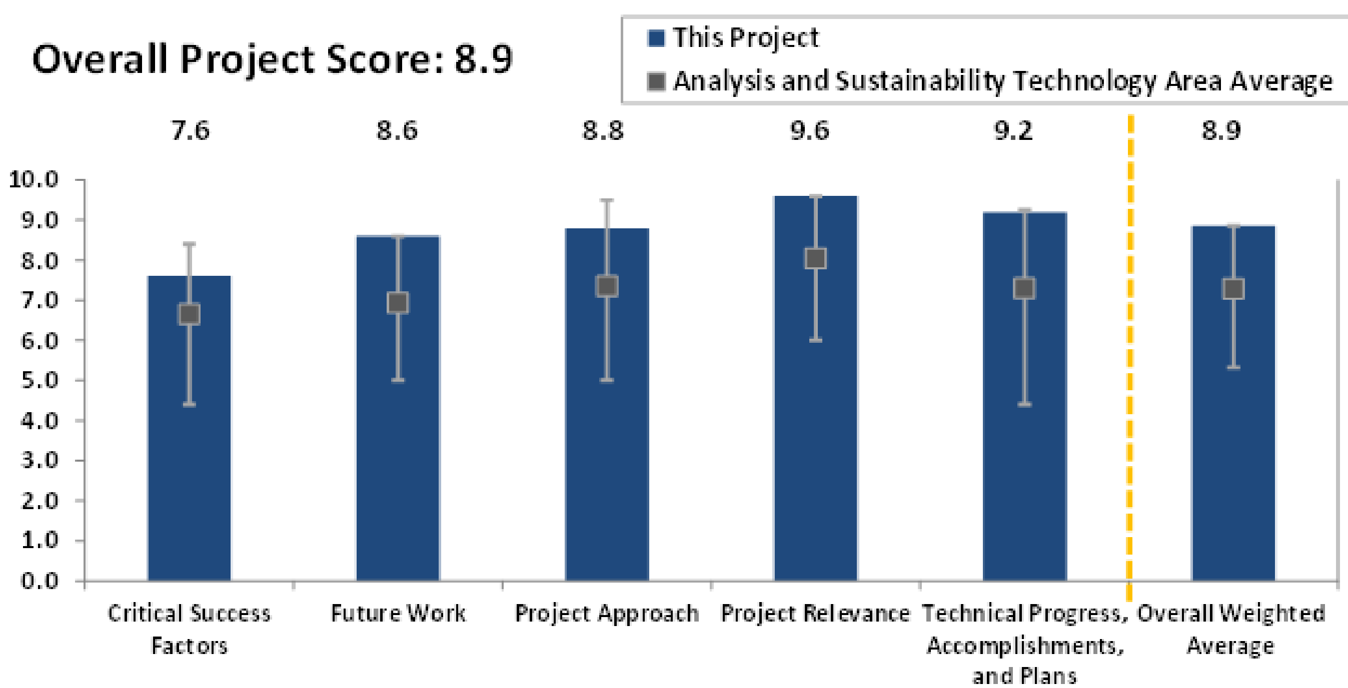
INTERNATIONAL SUSTAINABILITY AND STANDARDS; BRAZIL COLLABORATIONS

(WBS#: 6.5.8.2; 6.5.1.3)

Recipient:	ORNL
Presenter:	Keith Kline
Total DOE Funding:	$463,000
DOE Funding FY13:	$100,000
DOE Funding FY12:	$158,000
DOE Funding FY11:	$130,000
Project Dates:	2010–2013

Project Description

The objectives of these projects are to build strategic collaborations with Brazil and international consensus around criteria, definitions, and measurement methods required to assess the sustainability of bioenergy technologies and pathways. It supports DOE goals to "promote the positive economic, social, and environmental effects and reduce the potential negative impacts of bioenergy production activities." Current focus supports development of a new ISO Standard 13065, "Sustainability Criteria for Bioenergy." The project also provides reviews, outreach, and targeted contributions to other international projects and reports, such as the IPCC Fifth Assessment, IEA Bioenergy tasks, GBEP, the Roundtable for Sustainable Biofuels, and others. The project leverages DOE research results, increasing program impacts. International agreements on criteria, indicators, and standards for consistent measurement help to reduce uncertainties and transaction costs; break down barriers to market entry and expansion for U.S. producers; and facilitate trade, lowering costs and accelerating deployment of clean bioenergy technologies. The project enhances global understanding and expertise to define and apply effective indicators for bioenergy sustainability. Recent achievements include substantive contributions enabling the completion of a committee draft standard on bioenergy sustainability criteria and ISO internal reports on food security and indirect effects. International cooperation is required to achieve sustainable bioenergy development. Scientific exchanges are critical to address key social and environmental concerns (e.g., food, biodiversity, equity) and to build consensus on practical solutions, including the definitions and measurement methods needed to assess bioenergy pathways. The



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

development of international standards for sustainable bioenergy supports BETO's objectives to develop consistent, defensible, sustainability metrics, baselines, and targets for bioenergy pathways and technologies.

Overall Impressions

- Importance of this process is critical for establishing a workable global framework for sustainable biofuels. This project's approach and achievements are high level.
- This is an important project to maintain a presence in the international community as international standards and criteria for measurements are defined. Standardization of sustainability criteria for biofuels will dictate the ability of a U.S. industry to participate in global biofuels trade, which makes it essential to have some influence in how these standards are defined. Although the effectiveness of these efforts is difficult to measure, this is obviously an important role in the overall Technology Area's portfolio.
- In the past, the Office of Energy Efficiency and Renewable Energy has often been hesitant to be an active member of the international community of researchers and policymakers working on renewable bioenergy, often with good reason. This is an activity that can be endless and all-consuming. In light of this, DOE's support for this project and the project's success in achieving significant milestones are commendable. Developing efficient and fair international standards for sustainability is a critical success factor for biofuels in the U.S., as well as abroad. Within the myriad of activities on which it could focus, this project has targeted the unprecedented efforts of the ISO—a leading and highly respected institution charged with international standardization in many industries—to establish standards for sustainable bioenergy. The project team has correctly identified ISO's efforts as potentially helping to bring consistency to industry standards for bioenergy. The project team has shown a nimbleness and flexibility in targeting its efforts that has paid off. One outstanding example is in the area of indirect land-use change, where the team has worked hard to bring very strict language into the standards. By building off of ISO's preference for science-based standards, the team has succeeded in limiting the discussion of metrics for indirect land-use change to effects that are measurable. This has the potential to exclude the often-questionable and highly speculative nature of modeling results on indirect land-use change that have, to date, dominated and confused this technical and policy debate about biofuels. This project is also building strong ties with Brazilian researchers, who have been at the cutting edge of biofuels' sustainability issues for some time. There are two areas of concern for this project. One involves expansion of the U.S. team that is participating in the ISO process. The team seems somewhat insular. It is not sufficiently broad and inclusive. An effort should be made to bring in more voices from agriculture, environmental groups, and industry in the U.S. to ensure that the outcomes of the ISO process truly reflect a balanced U.S. position. On a practical level, without this kind of inclusion, there is a risk of backlash as the standards are rolled out by ISO. The second area of concern involves the project's emphasis on tactical victories on issues such as land-use change, versus long-term strategic victory. Narrowing the land-use issue to one of measurable impacts may win the day for now, but it is also potentially problematic. Playing a hard line on measurability is dangerous because it ignores the essentially future-focused nature of sustainability. There is a legitimately speculative element in sustainable development. The key is to make sure that this kind of speculative assessment of bioenergy is done in a responsible way that accommodates the inherent uncertainty without shutting down debate merely because it involves uncertainty.

- This project effort is making an important contribution to U.S., multilateral, and industry success in addressing biofuel sustainability. Leading discussions and providing important, technically-sound input into the international standards development serves U.S. interests and accelerates progress to maturity for the bioenergy industry globally. The effort is helping to develop a consistent framework, criteria, definitions, and rigorous indicators that are needed for greater industry certainty, to minimize possible impediments to trade, and to improve many of the current sustainability certifications. We recommend additional thought on interagency and industry engagements to develop U.S. community consensus to avoid divergent or conflicting messages with industry groups, such as the Commercial Aviation Alternative Fuels Initiative.
- This project encompasses a very important array of activities for the overall, long-term success of the BETO portfolio; however, while diplomacy clearly has a role in DOE investment success, it will be hard to measure success and demonstrate short-term and/or immediate impact(s). Regardless, this is an important project, good choices have been made regarding investments of time and energy, and the overall resource commitment on the part of DOE is very small, even if the returns may be hard to quantify at any given moment. I strongly support continuation of this activity.

PI Response to Reviewer Comments:

- We thank reviewers for their thoughtful comments and unanimous support to continue strategic international collaborations. We agree that the collaborations with ISO and Brazil are "critical for establishing a workable global framework for sustainable biofuels." We appreciate the high scores received and agree with reviewers that the work is highly relevant and important to achieve DOE and BETO bioenergy goals.
- One reviewer noted that the project serves U.S. interests and accelerates progress to maturity for the bioenergy industry globally, but it should expand engagements across U.S. industry groups. In response, we agree on the importance of building consensus and underscore that efforts are based on a code of conduct (see www.iso.org) to ensure the process is open and transparent. The ISO committee involves stakeholders across all relevant sectors and the U.S. mirror committee includes leading industry representatives.
- This project focuses on building consensus through more informed and open discussion of contentious issues. The project takes advantage of an international platform that resolves conflictive issues by applying procedures that ensure transparency. Debate is not shut down, rather, the process dictates that issues be resolved within a timeframe or set aside for a subsequent review (repeated every five years). Our contributions aim to improve understanding about the different types of uncertainty and to help the committee understand that uncertainty cannot always be measured, but cannot be ignored. We are engaged in an external process that will go forward with or without U.S. participation. By bringing ever-better data and analyses to the table (including results from the broader DOE team), we strive to improve the quality of debates and outcomes.
- We thank reviewers for the recommendations to continue our work on science-based standards and strategic international collaborations including Brazil.

BIOCHEMICAL CONVERSION

TECHNOLOGY AREA

INTRODUCTION

The Biochemical Conversion Technology Area was one of nine key technology areas reviewed during the 2013 Bioenergy Technologies Office (BETO or the Office) Project Peer Review, which took place on May 20–23, 2013, at the Hilton Mark Center in Alexandria, Virginia. A total of 29 projects were reviewed by six external experts from industry, academia, and other government agencies. This review represents a total U.S. Department of Energy (DOE) value of approximately $264 million, which is approximately 17.6% of the BETO portfolio reviewed during the 2013 Peer Review. During the review, the principal investigator (PI) for each project was given approximately 30–45 minutes to deliver a presentation and respond to questions from the review panel. Projects were evaluated and scored for their project approach, technical progress over two years, relevance to BETO goals, identification of critical success factors, and future plans.[1]

BETO designated Leslie Pezzullo, Bryna Berendzen, and Joyce Yang as the Biochemical Conversion Technology Area review leads. In this capacity, Ms. Pezzullo, Ms. Berendzen, and Dr. Yang were responsible for all aspects of review planning and implementation. In the sections that follow, overview information on the Biochemical Conversion Technology Area, along with full project scoring results, summary comments, analysis, PI response, the Review Panel Summary Report, and the BETO Programmatic Response, can be found.

BIOCHEMICAL TECHNOLOGY AREA

OVERVIEW

Building on the successful development of biochemical conversion processes to cellulosic ethanol, BETO continues to investigate a broad range of biological and chemical conversion routes to advanced biofuels and products. The Biochemical Conversion Technology Area is focused on reducing the cost of converting lignocellulosic biomass to mixed, dilute sugars and other processable intermediates, and further conversion of these chemical intermediates to liquid transportation fuels or other bioproducts. Processes pursued include low-temperatures pretreatments, hydrolysis, biological and chemical catalysis, and novel separation pathways. Biochemical conversion routes may also be able to leverage existing investment in biorefinery infrastructure, such as corn mills, thereby reducing capital costs. Biochemical Conversion research and development (R&D) also includes feedstock/conversion interfaces focused on improving overall cost effectiveness and productivity to enable larger sources of feedstocks to be used in producing fuels and chemicals via a biological, chemical, or hybrid routes.

BIOCHEMICAL CONVERSION SUPPORT OF OFFICE STRATEGIC GOALS

The Biochemical Conversion Technology Area supports R&D at a wide variety of institutions to develop and validate technologies that when integrated and deployed, enable BETO to meet the following goal: to develop and deploy sustainable, commercially viable biomass conversion technologies to produce biofuels that support meeting Energy Independence and Security Act Renewable Fuel Standard (RFS) targets.

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

The Biochemical Conversion project portfolio directly addresses and supports development of technologies necessary for producing fuels and bioproducts from high impact feedstocks, including herbaceous, woody, algal, and some waste factions such as municipal solid waste (MSW).

The Biochemical Conversion Technology Area's strategic goal is to:

> *Develop commercially viable technologies for converting biomass feedstocks via biochemical routes into energy dense, fungible liquid transportation fuels, as well as bioproducts or chemical intermediates, and bioenergy.*

BIOCHEMICAL CONVERSION SUPPORT OF OFFICE PERFORMANCE GOALS

The overall performance goal of Biochemical Conversion R&D is to reduce the estimated mature technology processing cost for converting cellulosic feedstocks to hydrocarbon fuels via biochemical pathways. The goal is to achieve the overall Office performance cost goal of $3 per gallon of gasoline equivalent ($2011) based on data at the integrated pilot scale by 2022.

The 2013 performance milestone for the Biochemical Conversion Technology Area is to establish out-year cost goals and technical targets for biologically derived hydrocarbon fuels based on techno-economic analysis for at least one technology pathway.

The 2017 performance goal of the Technology Area is to validate the integrated production of a hydrocarbon fuel or fuel blend stock from cellulosic or algal biomass via at least one biological or chemical route at bench-scale to measure progress against an interim modeled cost goal (nth plant, $2011), to be set in 2013.

TECHNICAL AND MARKET CHALLENGES AND BARRIERS

BETO has identified the following key challenges for achieving the goals of the Biochemical Conversion Technology Area:

Inherent to Biomass Utilization	Technical R&D Barriers to Processing Biomass
Biomass Utilization	Biomass Fractionation
Biomass Recalcitrance	Pretreatment Processing
	Pretreatment Costs
	Cellulase Enzyme Production Cost
	Cellulase Enzyme Loading
	Cleanup/Separation
	Catalyst Development
	Biochemical Conversion Process Integration

APPROACH FOR OVERCOMING CHALLENGES

Current efforts are focused on overcoming the recalcitrance of biomass; validating advanced conversion enhancements such as increased solids loadings, improved separations, and milder process conditions; developing more robust conversion processes such as fermentation and catalysis; and integrating conversion technologies with upstream feedstock collection/transport processes. Research that addresses the key technical barriers is performed by national laboratories, industry, universities, and multi-disciplinary consortia. Relevance of the R&D portfolio to industrial and commercial applications will be ensured via project stage gate and biennial portfolio reviews with a panel of external experts, partnering with industry as appropriate, as well as through patenting and publishing of the results.

For more information on the Biochemical Conversion Technology Area, please review BETO's Multi-Year Program Plan (MYPP) at bioenergy.energy.gov/pdfs/mypp_may_2013.pdf.

REVIEW PANEL

The following external experts served as reviewers for the Biochemical Conversion Technology Area during the 2013 Project Peer Review.

Biochemical Conversion Reviewers	
Carol Babb (Lead Reviewer)	SAIC
Kevin Gray	Chemtex
Jim Kellis	DuPont Industrial Biosciences
Robert Kelly	North Carolina State University
K. Thomas Klasson	U.S. Department of Agriculture's Agricultural Research Service
Matthew Lipscomb	OPX Biotechnologies, Inc.

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

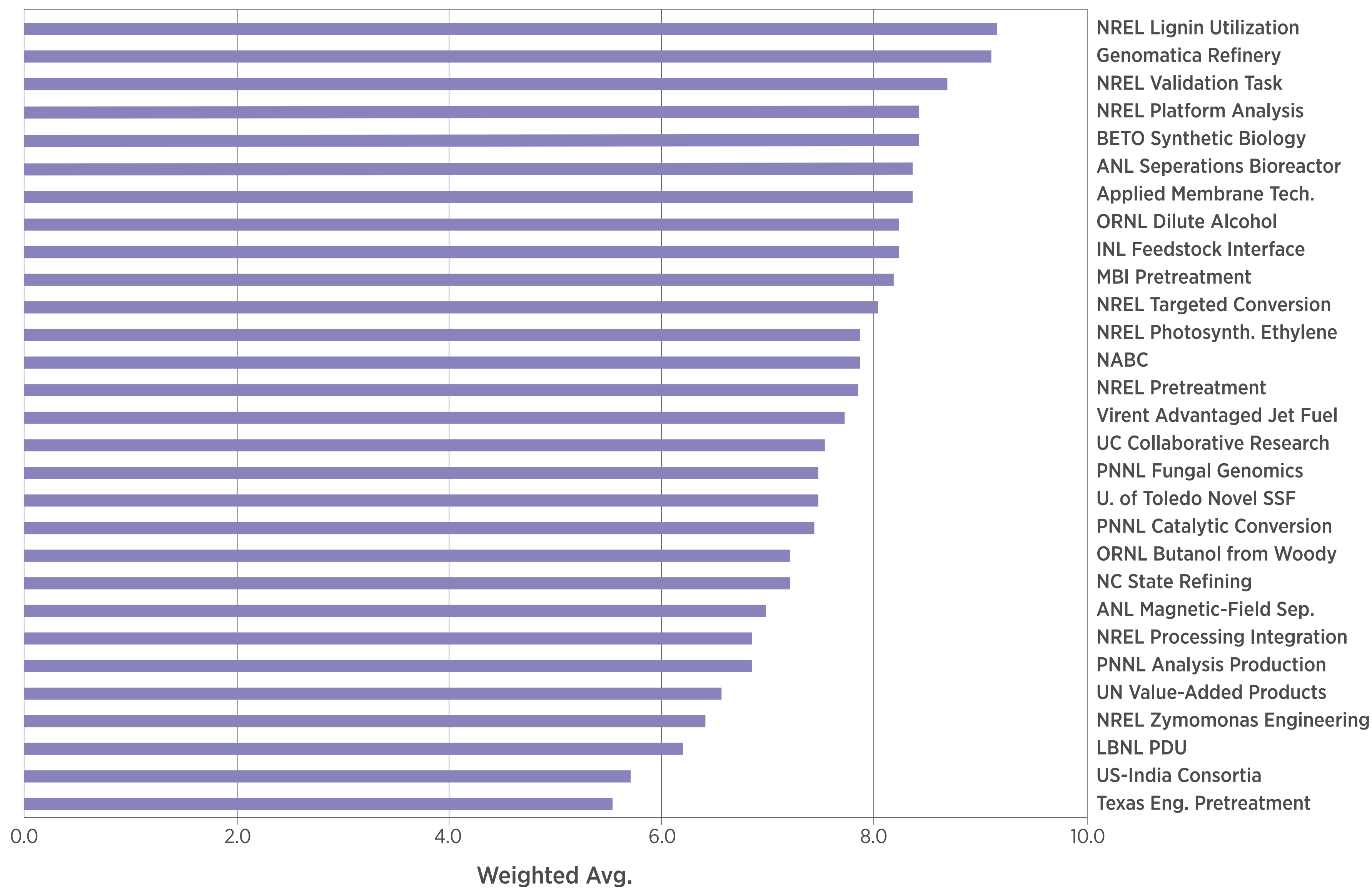
- **Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.
- **Project Scoring Information and Short Names Key**: The final score charts depict the overall weighted score for each project in each technology area. Short names for each project were developed for ease of use in the scoring charts, the table of contents, and other locations. Full project names, along with their designated short names and their work breakdown structure (WBS#), are provided in the Short Names Key.
- **Review Panel Summary Report**: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.
- **BETO Programmatic Response**: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.
- **Project Reports**:
    - **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space constraints allotted.
    - **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
    - **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and

the whiskers depict the range of scores for each category within each technology area.

- **Reviewer comments** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant by BETO's director were excluded from the final report.
- **PI Responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the

TECHNOLOGY AREA SCORE RESULTS



SHORT NAMES KEY

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
2.2.3.1	Lignin Utilization	NREL	NREL Lignin Utilization
2.3.2.10	Development of an Integrated Biofuel and Chemical Refinery	Genomatica, Inc.	Genomatica Refinery
2.3.1.7	Validation Task - Integrated Process	NREL	NREL Validation Task
2.6.1.1	Biochemical Platform Analysis	NREL	NREL Platform Analysis
2.5.7.2	Synthetic Biology	BETO	BETO Synthetic Biology
2.3.1.5	Integrated Biorefinery - Separations/Separative Bioreactor - Continuous Bioconversion and Separations in Single Step	ANL	ANL Separations Bioreactor
7.4.5.2	Development of Applied Membrane Technology for Processing of Ethanol to Biomass	Compact Membrane Systems, Inc.	Applied Membrane Tech.
2.3.4.1	Direct Catalytic Upgrading of Current Dilute Alcohol Fermentation Streams to Hydrocarbons for Fungible Fuels	ORNL	ORNL Dilute Alcohol
2.1.1.1; 2.1.1.3; 2.1.1.8	Biochemical Feedstock Supply Interface	INL	INL Feedstock Interface
2.2.1.6	Process Improvements to Biomass Pretreatment for Fuels and Chemicals	MBI	MBI Pretreatment
2.4.1.1	Targeted Conversion Research	NREL	NREL Targeted Conversion
2.3.3.3	Producing Transportation Fuels Via Photosynthetically Derived Ethylene	NREL	NREL Photosynth. Ethylene
3.3.1.1	National Advanced Biofuels Consortium (NABC)	Alliance for Sustainable Energy, LLC	NABC
2.2.1.1	Pretreatment and Enzymatic Hydrolysis	NREL	NREL Pretreatment
2.3.1.8	Cellulosic Biomass Sugars to Advantaged Jet Fuel	Virent	Virent Advantaged Jet Fuel
2.3.2.9	Engineering Yeast Consortia for Surface-Display Complex Cellulosome Structures: A Consolidated Bioprocessing Approach from Cellulosic Biomass to Ethanol	University of California Riverside	UC Collaborative Research
2.4.1.2	Fungal Genomics	PNNL	PNNL Fungal Genomics
2.3.2.8	A Novel SSF Strategy for Efficient Co-fermentation of C5 & C6 Sugars using Native Non-GMO Yeasts	The University of Toledo	U. of Toledo Novel SSF
2.3.1.12	Catalytic Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels	PNNL	PNNL Catalytic Conversion
2.3.2.11	Butanol from Woody Biomass by SSF Processes	ORNL	ORNL Butanol from Woody
7.1.4.1	Integrated Biomass Refining Institute at North Carolina State University	North Carolina State University	NC State Refining
2.3.1.11	Low-Energy Magnetic-Field Separation Using Magnetic Nanoparticle Solid Absorbents	ANL	ANL Magnetic-Field Sep.
2.3.1.1	Biochemical Processing Integration Task	NREL	NREL Processing Integration
2.6.1.2	Analysis for Production - Technical and Market Analysis	PNNL	PNNL Analysis Production

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
7.2.1.1	University of Nebraska-Lincoln, Bioenergy Demonstration Project: Value-Added Products from Renewable Energy Fuels	University of Nebraska-Lincoln	UN Value-Added Products
2.3.2.12	Zymomonas Engineering	NREL	NREL Zymomonas Engineering
2.3.1.6	LBNL PDU Support	LBNL	LBNL PDU
2.3.2.13	U.S.-India Consortia for Development of Sustainable Advanced Lignocellulosic Biofuels Systems Project	University of Florida	US-India Consortia
2.2.1.5	Novel Mechanical Pretreatment for Lignocellulosic Feedstocks	Texas Engineering Experiment Station	Texas Eng. Pretreatment

REVIEW PANEL SUMMARY REPORT

IMPACTS

1 What are the key strengths and weaknesses of the projects in this technology area? Do any of the projects stand out on either end of the spectrum?

STRENGTHS:

Diversity: The projects selected and reviewed represent a diverse portfolio—based on the types of technology and the actual stage of development. The technology readiness level (TRL) varied from projects in the early stage of R&D to projects where prototypes had been built and demonstrated.

Relevance: The key to the success of these technologies and their ultimate commercialization lies in their economic viability and relevance to the market, as well as demand for the products. The projects are relevant to the Biochemical Technology Area and are focused on topics that aim to improve economics and drive toward parts of the process that will have the largest impact.

Project Management: DOE insists that key project management processes must be implemented and followed. Strong project management has helped the completed projects succeed, and coordination between the projects and the DOE office is evident. It is apparent that milestones/criteria and project management are emphasized. The DOE technology managers are well informed regarding office/Technology Area and are proficient in project management.

Validation: DOE has implemented a validation step that is conducted by a third party—the National Renewable Energy Laboratory (NREL)—to review the projects upon award and validate the actual status. The peer review panel was unanimous regarding the importance of the validation process and recommends that the process be expanded.

Deployment: The program provides opportunities for small businesses, such as licensing of technology leading to deployment. The program is effectively de-risking technology for the benefit of industry/financial markets and giving investors confidence.

WEAKNESSES:

Incorporate the techno-economic analyses (TEA): The importance of understanding the economic viability of a technology, or the possible solution to a process challenge, cannot be overstated. The use of this tool (TEA)—either via NREL's Aspen model or the project's own in-house process—on a consistent basis and early on in the project life is important and encouraged.

Benchmark the State of Technology (SOT): The projects need to understand and present a clearer understanding of the SOT and what exactly they are trying to replace/displace and why. The projects should, regardless of the TRL, clearly benchmark where the existing technology is and what the current market is for the product.

How the Projects Fit into BETO's Plan: Understanding BETO's platform, including goals, objectives, and how the projects can advance the platform, needs to be clearly understood.

2

Is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry in this technology area? Is the government's focus appropriate in light of private-sector investments? Are there any projects that stand out as meeting (or not meeting) this criterion?

The current biochemical portfolio represents a good diversity of projects and technologies, as well as a good distribution on the TRL scale—ranging from projects at relatively early stages of R&D to projects that are ready to be licensed or moved into deployment. Based on the peer review panel's ratings, the impact and significance of the biochemical portfolio demonstrated a bell curve distribution, indicating that a few projects were rated as extremely significant and a few were considered much less significant. Overall, the Biochemical Technology Area's goal to advance cellulosic ethanol was considered successful and to have a high impact toward the area's goals and objectives. The challenge for BETO over the next few years will be to understand and take advantage of where the lessons learned of these past projects can be leveraged to meet the new goals and objectives surrounding the new hydrocarbon platform. In addition, BETO needs to maintain the role of problem solver and remain in front of, or on the leading edge of, these new technologies so as not to compete with industry. DOE plays a critical part in assisting and funding research, investing in relevant technologies, and de-risking technology in order to facilitate investment from the private sector. Another challenge for the Technology Area's technical managers is to facilitate increased coordination between deployment projects and R&D that will help the area focus on barriers that are not being solved.

The projects identified by the peer review panel as strong, relevant, and high impact include the following:

- Genomatica Refinery
- NREL Lignin Utilization
- NREL Target Conversion Research and NREL Validation Task
- Argonne National Laboratory's (ANL) Separations Bioreactor – needs to continue.

The projects identified by the Peer Review Panel as weak include the following:

- NREL Zymomonas Engineering
- US-India Consortia
- Texas Eng. Pretreatment
- The Lawrence Berkeley National Laboratory (LBNL) Process Development Unit.

It should be noted that the weaker ratings of the projects does not necessarily reflect concerns with the level or quality of research or the principal investigators, but rather the applicability of the projects to the program goals moving forward.

INNOVATION

3 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach these barriers? Do any projects stand out as meeting (or not meeting) this criterion? Can you recommend new ways to approach these barriers?

Most of the projects dealing with the development of cellulosic biofuels are innovative and focused on barriers that need to be resolved in this industry. The projects target different areas in the process—from feedstock in to product out—and address many of the genetic, chemical, biological, and process/equipment challenges that have been identified as problems from either a technical or an economical vantage point. The advances made by the projects, specifically in the cellulosic ethanol area, have significantly contributed to moving this industry forward. The transition to the hydrocarbon platform is recent and makes it more difficult to qualify success at this point. However, the projects that have been selected under the hydrocarbon platform appear to be relevant and on track in the early stages of development. Barriers and programmatic milestones have not yet been defined for this platform, and as they are set, it is expected that the projects selected will be focused accordingly.

In general, the seed projects that were presented were found to be innovative, interesting, valuable, and worthy of continued funding. The consideration and inclusion of seed projects effectively broadens DOE's portfolio.

Coordination and cooperation with other offices—such as the Advanced Research Projects Agency-Energy (ARPA-E), DOE's Office of Science, etc.—is viewed as a viable path to bringing new and unique technologies to the program that may not be captured by BETO acting alone. The program has done this in the past and is encouraged to continue doing so moving forward with the new hydrocarbon platform. Co-evaluation of funding opportunity announcements (FOA) should allow for projects to transition through the different offices at different stages of TRL.

GAPS

4 Are there any other gaps in the portfolio for this technology area? Are there topics that are not being adequately addressed? Are there other areas that BETO should consider funding to meet overall programmatic goals?

The projects reviewed encompassed pre-treatment and deconstruction of lignocellulosic biomass, development of fermentation organisms, and upgrading of sugar intermediates to hydrocarbons and fuel-blend oxygenates. The projects spanned the biochemical conversion pathway, including feedstock supply and quality, hydrolysis and improvement of enzyme efficiencies, and product recovery and downstream processing. With the introduction of the hydrocarbon pathway, there are several areas in which the program should focus. The *Billion-Ton Update* provides extensive information on the quality and quantity of various feedstocks in different regions of the country. Overlaying this study with the actual biochemical conversion feasibility would be an important source of information for the Technology Area. This overlay would facilitate a better understanding between feedstocks and the impact on downstream chemistries and processes.

With the program's shift to the hydrocarbon platform, there is a high-level need to understand what can be leveraged from the cellulosic ethanol work. An internal gap analysis could identify where new barriers may exist—ones that were not an issue with the ethanol platform—as well as barriers that may be applicable to the hydrocarbon focus, which still needs a viable solution. The use of third-party industry experts and the inclusion of economics would be beneficial in this exercise. It would also be beneficial if the program took a hybrid approach to overlapping lessons learned and accomplishments from other platforms.

Moving forward, the biochemical pathway encompasses two pathways for the production of hydrocarbons:

- Biological Pathway
    - High-quality strain optimization work is a priority and should be based on a strong process, economic metrics, and the ease of recovery/production of hydrocarbons/products.
    - Reactor design/engineering should be a focus going forward.
- Catalytic Pathway
    - Reactor design/engineering should also be a focus for this pathway.
    - Catalyst development and optimization work should be based on strong process and economic metrics.

Funding for both the biological pathway and the catalytic pathway should include FOAs for higher-value products that will enhance the economic viability of the hydrocarbon platform. Lignin utilization is a key co-product that needs continued research. Also, building on issues identified in the ethanol program, hydrolysate cleanup and all aspects of separation remain barriers that still need solutions.

SYNERGIES

5 What synergies exist between the projects within this technology area? Is there more that BETO could do to take advantage of these synergies and better enable projects to meet their objectives?

There appears to be a variety of synergies that BETO could and should take advantage of. The feedstock—including physical properties and how it is grown, pretreated, stored, and shipped—can have an impact on downstream processing and, ultimately, yields. Idaho National Laboratory (INL) supplies much of the feedstock to these projects, and the projects need to provide INL with more feedback on the feedstock it is distributing. This exchange of information continues to be very important to the new hydrocarbon platform. In addition, interaction between national laboratories and exchange of information and areas of research is highly encouraged. The synergies of seemingly unrelated research cannot be fully captured unless the laboratories are actively engaging in open discussion. We appreciate that this collaboration poses some challenges regarding intellectual property, but the benefits of this cooperation could be significant in advancing the Technology Area and overcoming barriers.

Synergies also exist between the different platforms and technologies, and a structured sharing of lessons learned among all of the platforms would be beneficial and could facilitate a focus on barriers that have not been solved elsewhere. There is significant overlap and a need for understanding exists in order to better focus how dollars are spent. Movement toward industrial-type processes blurs lines between technology areas, and learning can be leveraged between areas.

RECOMMENDATIONS

6 Is BETO funding projects at the optimal stage of the technology pipeline? Is there more that BETO could do to orient technologies toward successful commercialization? Are there any projects that stand out as positive or negative examples of this orientation?

Overall, the current portfolio is appropriately varied across the R&D pipeline. Moving forward, the program should be bold in its funding efforts and not be afraid to chart new paths. It is not expected that every project selected will be a "winner;" rather, it is anticipated that research efforts will cover a range of technologies, which will result in some of them moving on to deployment. A more consistent and transparent collaboration with other offices—such as ARPA-E and the Office of Science—is recommended and encouraged, which will facilitate exposure to a portfolio of research topics that may not be identified by the Technology Area alone. As Technology Area planning and development of FOAs progresses, the peer review panel recommends that there should be some leeway in the specificity of the hydrocarbon end product. BETO has selected the C15 molecule as the targeted hydrocarbon; however, it is recommended for future FOAs that the end product be specified as Cx or greater where "x" may be something less than or equal to 15.

There appears to be a wide diversity of performance, motivation, and urgency at the national laboratories. It is anticipated that much of the strain and catalyst development will be carried out in the laboratories, which is critical to the success of the program. Although the peer review panel does not present the answer, we would ask the program to consider ways to bring all of the laboratories' research up to a consistently high level, such as a competition. The overall use of metrics as a management tool is very good throughout the Technology Area. The use of a graded level of metrics and milestones tailored to the TRL status of each project is encouraged and may make the "smart" milestones more realistic to the projects in the early TRL stage.

The overall program management by the Technology Area technical managers and their oversight of the validation, stage gates, and best project management practices are very good, and it seems that the odds of a project's success are increased as a result. The continued insistence by the program on these good project managements principles coupled with validation is highly encouraged.

ADDITIONAL COMMENTS

The Biochemical Conversion Technology Area objectives for the 2011/2012 timeframe are well defined, and the projects are generally consistent with those objectives. The emphasis on project management oversight by the technical monitors, including the validation process, has had a positive impact on the performance of the projects individually and the platform in general, and is highly encouraged. Overall, the cellulosic ethanol progress to-date has been significant and on track with the program goals. Currently, the Technology Area objectives are in a transition period, which reflects BETO's overall focus of moving away from cellulosic ethanol and toward hydrocarbons. Incorporating the introduction of the new hydrocarbon platform is still a work in progress; however, even at this early stage, the Technology Area has funded projects that are moving in the hydrocarbon direction. Moving forward, the hydrocarbon efforts and specific objectives will need some additional focus from the Technology Area technical managers to gain clarity and structure.

Virtually all of the projects reviewed fall within the program goals. However, some of the projects were deemed to have less significance and impact than others. In this regard, the limited funds for this Technology Area would be better spent by shifting funding to the projects with a greater likelihood of generating applicable knowledge for advancement of the goal.

The peer review panel encourages support for public projects in conjunction with industry projects to ensure that information garnered from funded work is made available to the public to the greatest extent possible.

BETO PROGRAMMATIC RESPONSE

IMPACTS

The Office appreciates the candid comments provided by the peer review panel and the delineation of five areas of strengths and subsequent weaknesses related to impacts. These comments are consistent with the on-going efforts of the BETO program in the Biochemical Conversion Technology Area to achieve successful impacts. Relative to the weaknesses, BETO appreciates the guidance given to emphasize and increase the use of initial technical and economic benchmarking to help guide R&D and to help quantify the potential and impact of each project/technology. A stronger linkage between TEA modeling and each project will continue to be a point of emphasis in all projects funded by the Office. In addition, the Technology Area continues its transition to a broader portfolio of fuels and products projects and researchers, applying new technologies and sciences to address the new Technology Area goals and objectives. These goals and objectives will be updated in the multiyear program plan so that projects may better understand where they fit within the evolving Technology Area.

INNOVATION

BETO's Biochemical Technology Area appreciates the panel's acknowledgement of the innovation associated with the successful conclusion of the cellulosic ethanol R&D effort. The transition to funding R&D for hydrocarbon fuels and products began in 2011 and is ongoing. The Office expects many of the technologies that have been developed in the deconstruction activity area to be leveraged and further developed to support the needs of a hydrocarbon industry. In accordance with the panel's recommendations and available funding, the Technology Area will continue to seek out seed projects to broaden the project portfolio with novel approaches and thinking. The Technology Area will continue to look to seed projects (smaller dollar, novel technology applications) and advancements from the Defense Advanced Research Projects Agency, ARPA-E, and the Office of Science as avenues for introducing new and innovative technologies into the portfolio. BETO is well positioned to be the logical next step in project development for the R&D projects coming out of these fundamental R&D programs, and in fact, many of these completed projects have already applied to recent BETO funding opportunity announcements. Coordination with other DOE offices continues to be pursued through quarterly meetings and co-evaluation of funding opportunities, potentially with ARPA-E and/or Office of Science, as well as possible collaboration with other agencies such as the Department of Defense. In the coming year, the new incubator program is expected to broaden the technologies within the portfolio even further.

GAPS

The panel's assessment of gaps and potential R&D directions for the portfolio is welcome during this transition period, and the Technology Area will implement the recommendations as appropriate. The suggestion of performing a third-party gap analysis of BETO strategic plans will be considered in future iterations of program plan development. Within the last year, many key barriers to the conversion of biomass to hydrocarbons have been identified through internal and external road-mapping activities. The team acknowledges that this list is not exhaustive and is working to recognize additional barriers not yet captured, as well as to determine the milestones, activities, and metrics necessary to overcome these R&D barriers. The specific gap areas identified by the review panel had previously been designated as areas for future R&D and line up nicely with the new work breakdown structure developed for the Biochemical Conversion Technology Area. We agree with the panel's assessment that a necessary next step is to utilize lessons learned to advance development of other advanced biofuels. Moving forward, the Technology Area will continue to identify points of collaboration between other areas of BETO, especially the Feedstock and Deployment teams, to reduce overlap and improve coordination. BETO is moving towards a consolidated conversion team and identifying linkages between technology areas and hybrid technology opportunities. Additional efforts to achieve better integration will include participation by personnel from the Biochemical Technology Area in reviews of the other technology areas within the office.

SYNERGIES

The Biochemical Technology Area appreciates the guidance to increase the interface with the Feedstock Technology Area and with INL in particular. This is an effort that will continue to be addressed through continued funding of feedstock interface projects and increased participation in the Feedstock Technology Area efforts. The Biochemical Technology Area has been proud of its efforts to bring laboratories together to address issues of importance to the Technology Area such as the technical and economic analyses jointly performed by laboratories. In addition, the Technology Area intends to support seed efforts that involve multiple laboratories. Such efforts will be part of the Technology Area strategy for long term development.

RECOMMENDATIONS

The recommendations by the panel are very relevant, particularly in the transition to program goals and objectives beyond cellulosic ethanol. The Technology Area will continue to engage in funding opportunities, when budgets allow, that broaden our pathways and portfolio to include other advanced biofuels and bioproducts in an attempt to chart new paths. Application of a graded level of metrics, incorporating specific, measurable, attainable, relevant, and time-bound milestones will be applied when appropriate depending on the TRL or stage of a given project.

The hydrocarbon end-products targeted are being broadened to include fuel ranges and fuel blendstocks. To this end, BETO has supported the development of the first of two design cases for hydrocarbon fuels. These design cases are modeled example routes through the priority pathways selected by the program. In addition, the design case addressed the impacts of having lignin-based high-value co-products and the effect of using lignin's effect on the facility life cycle (including greenhouse gas production). While lignin-to-products research has been ongoing for a number of years, some recent efforts through seed projects and in the biomass community have revitalized the prospects of finding meaningful opportunities to create higher-value products from lignin, including carbon fiber applications. This design case was recently submitted for external review and those comments are being incorporated.

The Biochemical Technology Area initiated validation activities pursuant to more direct active project management approach for every FOA in 2007, and the Office welcomes the panel's positive feedback and comments on the relative value of these types of efforts. Similar validation efforts are expected to continue in fiscal year 2014 and beyond. Opportunities to potentially cosponsor FOAs with other parts of DOE or the program will be evaluated, particularly in the feedstocks and catalysis technology areas.

The suggestions and recommendations made by the panel are appreciated, particularly in this transition period. We welcome such input in the future and appreciate the candor and insight the panel provided in this biennial review.

CONTENTS

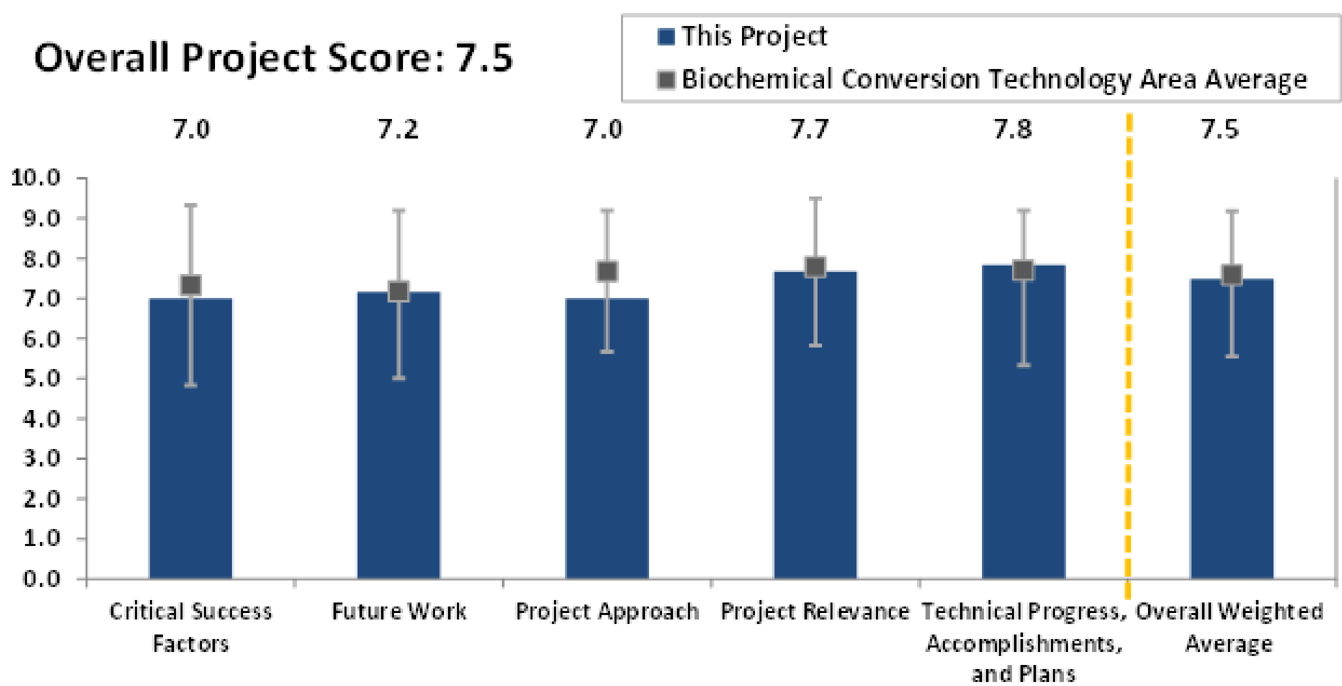
A NOVEL SSF STRATEGY FOR EFFICIENT CO-FERMENTATION OF C5 & C6 SUGARS USING NATIVE NON-GMO YEASTS

(WBS#: 2.3.2.8)

Recipient:	The University of Toledo
Presenter:	Sasidhar Varanasi
Total DOE Funding:	$499,784
DOE Funding FY13:	$165,694
DOE Funding FY12:	$106,725
DOE Funding FY11:	$99,652
Project Dates:	2008–2013

Project Description

Economic bioethanol production is critically dependent upon the ability to convert both the C6 and C5 sugars resulting from cellulose and hemicellulose. C5 sugars are not readily fermentable by native *Saccharomyces cerevisiae*. Genetically modified organisms (GMOs) are designed to ferment xylose, but their stability, environmental impact, and survival under conditions of industrial fermentation are unproven. In this project, we developed a novel approach for efficient fermentation of both C5 and C6 sugars using native *S. cerevisiae* by exploiting its ability to produce ethanol from xylulose—the keto-isomer of xylose. While the isomerization of xylose to xylulose can be accomplished via commercially (and cheaply) available xylose isomerase (XI), this conversion has an extremely unfavorable equilibrium (xylose:xylulose is about 5:1). To address this, we developed two alternate strategies that exploit the selective affinity of ketoses to binding agents to produce high ketose yields. In the first strategy, the two enzymes XI and urease are co-immobilized on solid support particles to enable complete isomerization of xylose to xylulose under pH conditions suitable for fermentation, in a simultaneous-isomerization-fermentation mode. The ability of our technology to conduct isomerization of xylose under pH conditions suitable for both saccharification and fermentation allows for simultaneous saccharification and fermentation of both C5 and C5 sugars with native *S. cerevisiae*. We have implemented



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

this strategy with filtered and unfiltered biomass hydrolysate in the presence of soluble ketose binding agents; filtration of hydrolysate improves the process economics by enabling lignin recovery and affords process modifications that permit XI recovery and reuse. In the second strategy, a sequential isomerization and fermentation mode of operation that uses packed beds of immobilized binding agents and commercially available XI pellets leads to high-yield conversion of xylose to xylulose, while simultaneously concentrating the ketose sugar. In addition to facile recovery and reuse of both the XI and the ketose binding agent, this approach affords considerable flexibility in fermentation of the sugars to products.

Overall Impressions

- A technical tour de force. Perhaps too complicated and expensive for commercial implementation in the foreseeable future.
- This reviewer thinks the project demonstrates the average success of a smaller university-funded project. Some success was demonstrated, and this type of project has a place within BETO's project portfolio, if the Office realizes that some of these projects will be considered average in their contributions to BETO's goal and strategic plans.
- Some innovation for dealing with C5 sugars may have problems with process operation without a lot of attention. Dealing with only a small piece of the overall problem. Why is the project so concerned with GMO use? Seems like a somewhat complicated approach for such a low-value product
- This is a truly unique process. Using the commercially available isomerization enzyme and non-GMO native yeast takes away much of the risk encountered in other technologies but still possesses many challenges moving forward.
- This project is a creative combination of engineering and biology to address fundamental issues of different environmental needs (pH) of the isomerization and fermentation. Questions regarding the cost of the proposed process still remain, though they are being addressed separately by the patent licensee. The emphasis on the use of a native yeast for the production of fuel ethanol should be evaluated. That being said, there may be opportunities for this technology to be applied to other industries where the use of an engineered organism is not viable, such as the natural products market.
- Very interesting concept and chemistry but also a very complex process that may be difficult to industrialize.

PI Response to Reviewer Comments:

We are pleased with the reviewers' assessment regarding the novelty of our technology, the quality of the science, and its successful demonstration during the project. Below are our responses to the overall impressions stated above:

- In this project, we proposed two alternatives for fermenting C5 and C6 sugars with native *S. cerevisiae*. The second of these alternatives uses packed bed columns of immobilized XI and immobilized sugar-complexing agent and produces separate C5 and C6 sugar streams that can be converted to ethanol in traditional fermenter configurations. This approach, in a sense, is a combination of commercial high fructose corn syrup (HFCS) and traditional corn-ethanol. Based on our industrial partner's internal proprietary techno-economic evaluation, they are conducting the scale-up of the process and are close to completing a pilot-scale demonstration of the technology.
- Co-utilization of C5 and C6 sugars by microbes to produce ethanol is a research area of immense activity and importance for the past two decades. The only solution that has been put forth thus far is the use of GMOs, yet GMOs are not used on a commercial scale to date. The robustness, cost, and

regulatory issues with GMOs are still hurdles that need to be overcome, particularly with regards to a commodity product of the scale of fuel ethanol. Our approach based on native yeast is non-trivial in scope or importance. We believe that the evaluation of the project's accomplishments should not be based on the reputation or the size of the institution performing the work.

- While all preliminary evaluations of the process economics do indicate that the process is viable for ethanol production, we agree with the reviewer that with other products, the profit margins will be higher. Indeed, we have just demonstrated that the xylulose produced through our technology can be converted to furfural very profitably.

ANALYSIS FOR PRODUCTION - TECHNICAL AND MARKET ANALYSIS

(WBS#: 2.6.1.2)

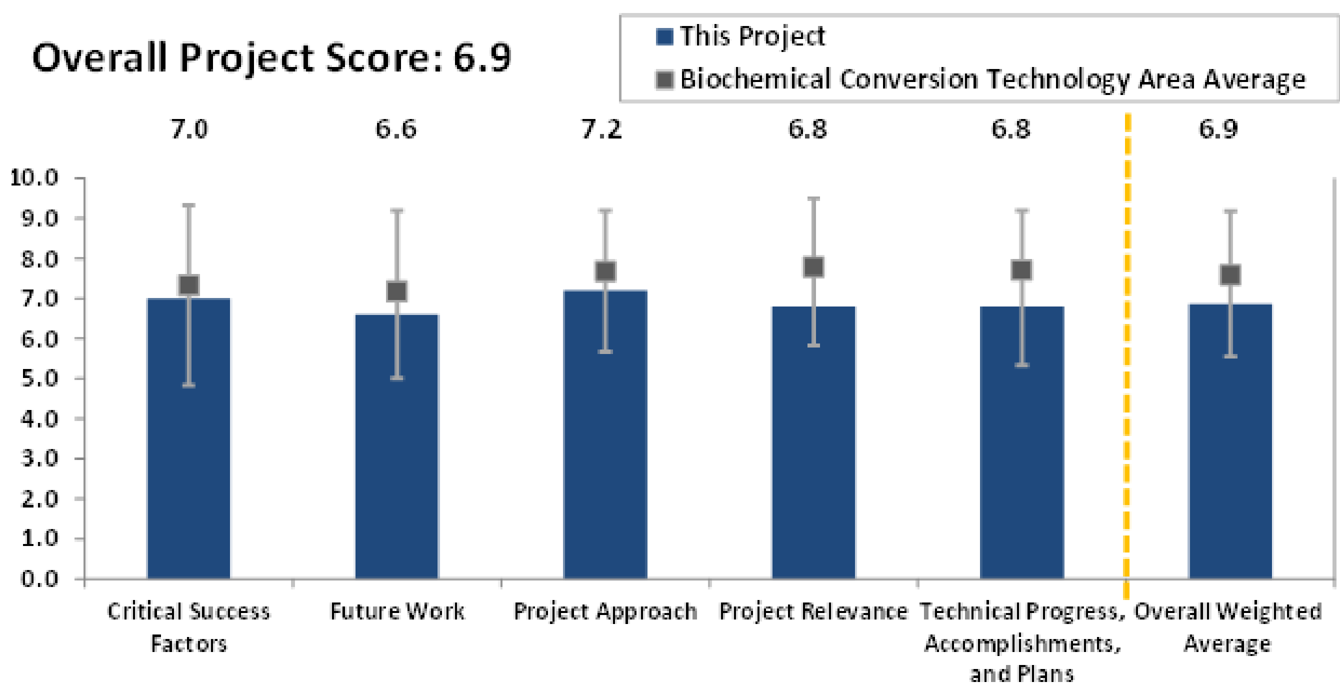
Recipient:	Pacific Northwest National Laboratory (PNNL)
Presenter:	Sue Jones
Total DOE Funding:	$3,608,000
DOE Funding FY13:	$190,000
DOE Funding FY12:	$270,000
DOE Funding FY11:	$250,000
Project Dates:	2003–2015

Project Description

This project supports BETO's programmatic goal to reduce the estimated mature technology processing costs for converting cellulosic feedstocks to hydrocarbons via biochemical pathways by providing techno-economic analysis of promising pathways. Under this project, preliminary economics of a co-products scheme was assessed. In this study, potential organic acids are reviewed for their market size and value. Co-production of the acids in a serial, blocked, continuous fashion avoids chemical market saturation. A second study was undertaken to consider the costs associated with hydrocarbon fuel production from oleaginous yeast. A metabolic model of the yeast, coupled with experimental work, is being developed to further inform the process and economics models. Lastly, this project supports the analysis and documentation for the BETO pathways analysis for sugars conversion.

Overall Impressions

- Definitely needed work in order to understand the technical/economic issues of hydrocarbon production prior to start doing R&D. The initial conclusion though is that it doesn't appear possible to achieve $3/gal unless there is some co-product value of the lignin (or something else).
- This reviewer is not sure that he identified many strengths in this work. It would appear that from an economical modeling standpoint, there could be



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

significant overlap between the work presented here and the work presented by NREL. A consolidated approach may be advantageous and should be considered (e.g., rather than two national laboratories developing economic models, let one take the lead).

- Project makes sense within BETO scope. Needs to integrate bioinformatics tools for pathway design.
- The ethanol co-product modeling work provided valuable analyses and identified potential routes to reduce overall costs. The hydrocarbon TEA work to date would suggest that this process is not feasible (e.g., even maximum theoretical yield plus additional process improvements would not achieve $3/gge). It seems that enough information is already available to make the go/no-go decision. In light of the enormous challenges of the proposed hydrocarbon process and organism, the value of continuing the metabolic modeling work with the proposed organism is questionable.
- This work is progressive and the theoretical modeling is complex, but relevant. The incorporation of actual test results in the future will be important. There are several scenarios that this type of modeling could be applied to in the future.

PI Response to Reviewer Comments:

- Thank you for your review and feedback. We are pleased that the development of bio-informatics as a new tool was well-received. We also agree that hydrocarbon production through biochemical means will be challenging both technically and economically. As noted in the presentation, lignin usage is an important part of meeting the overall economics and we plan to address this next year.
- Although NREL and PNNL are both targeting hydrocarbon fuel production via biochemical conversion, our respective analysis efforts are complementary. NREL has the technical lead in this area and they are developing the design case for the hydrocarbon pathway. Their main focus has been on metabolic engineering in *Zymomonas* bacteria, whereas bioconversion work at PNNL has been exclusively focused on fungi and yeasts. Supporting more than one bioconversion approach for hydrocarbon fuel production may reduce risk for BETO, especially if engineered metabolic pathways can be made transferable across organisms to maximize bioconversion yield and efficiency.

BIOCHEMICAL FEEDSTOCK SUPPLY INTERFACE

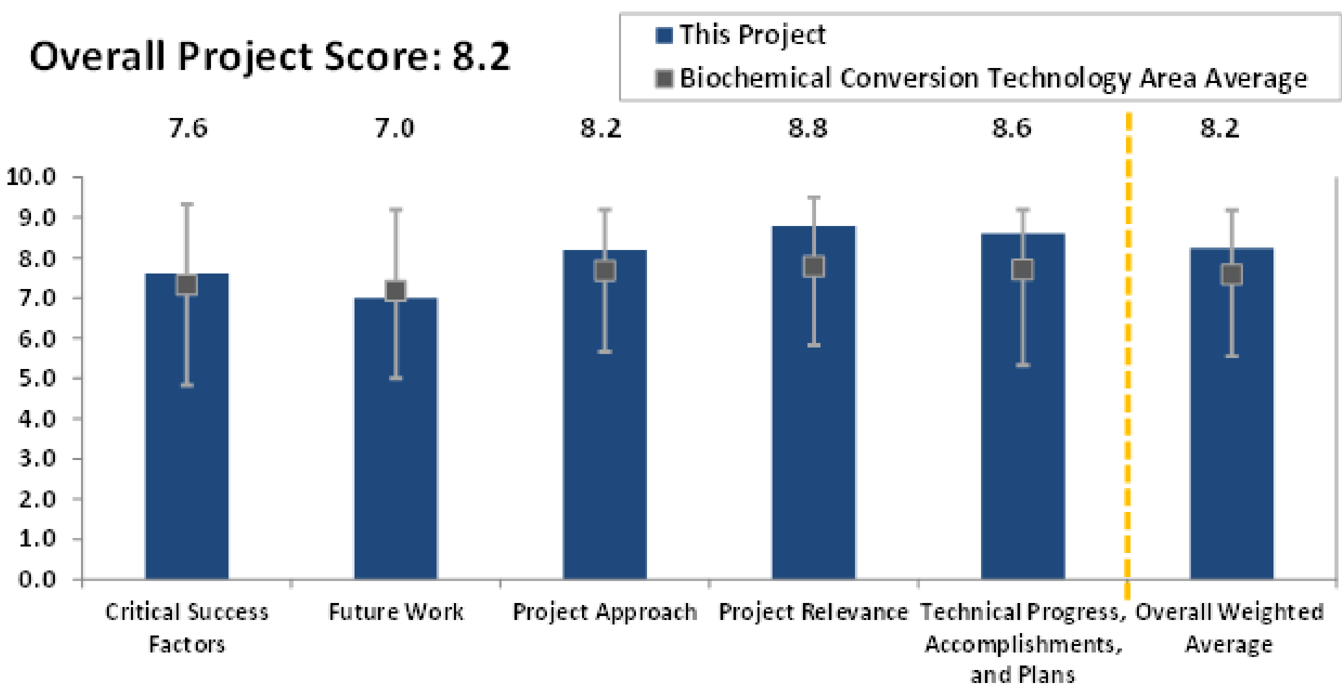
(WBS#: 2.1.1.1; 2.1.1.3; 2.1.1.8)

Recipient:	INL
Presenter:	Gary Gresham
Total DOE Funding:	$12,960,000
DOE Funding FY13:	$1,500,000
DOE Funding FY12:	$1,850,000
DOE Funding FY11:	$1,520,000
Project Dates:	2005–2022

Project Description

Photo Courtesy of INL

This collaborative laboratory effort focuses on supporting a sustainable and economically viable, domestic bioenergy industry that produces renewable biofuels and bioproducts via the biochemical conversion process. The collaborative Biochemical Feedstock Interface Project's core efforts navigate and mitigate the often incongruent needs and requirements of biochemical conversion processes with the limitations of feedstock supply and logistics. Ultimately, the goal is to reduce the cost of converting lignocellulosic biomass to mixed dilute sugars and other process intermediates by reducing the risk and cost associated with feedstock materials. The Interface Project aides in achieving these goals by establishing the boundaries of feedstock variability and quality attributes through characterization of commercial-scale feedstock materials, definition of preliminary feedstock quality targets and specifications of biomass feedstocks, development of screening and predictive methodologies to determine feedstock quality and process performance, and validation of the impact of feedstock variability and preprocessing on biochemical conversion processes. Most importantly, the Interface Program acts as the fa-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

cilitator or guide to solve key incongruities that require explicit collaboration of both the Feedstock & Logistics Technology Area and the Biochemical Technology Area. The efforts of the Interface Project balance the objectives of the Feedstock Technology Area to facilitate development of sustainable, commodity-scale feedstocks systems that meet biochemical conversion feedstock cost and quality requirements, thereby reducing overall risk to the biomass conversion refineries. The cornerstone of this effort is the Biomass Resource Library, which encompasses biomass characterization capabilities, physical storage and maintenance of biomass feedstock samples, and a comprehensive data management system. This effort supports the development of representative sample materials for various classes of biomass and continued development of tools and predictive methodologies to evaluate feedstock costs and quality for biochemical conversion. Research to develop a fundamental understanding of the effect of densification is reported, together with preprocessing methods to reduce intrinsic ash content and advanced agronomic methods to investigate and understand variability. This project represents a compilation of the three projects conducted at NREL and INL:

- Feedstock - Process Platform Interface
- Preprocessing and Storage Systems Development & Qualification
- Densification Subtasks

Overall Impressions:

- A good project; needs to get beyond the analytical method development aspect and look at bioprocess issues.
- Absolutely spot on and highly relevant program.
- Feedstock quantification, incorporation into library, densification and rapid tool development, and potential impact on downstream processes significant and very important to all technology areas in the Office and the bioenergy industry overall.
- Most of the presentation was spent on progress and accomplishments. Very little time was spent on the other topics; maybe only five minutes total. If this had been a technical presentation to an audience interested in the technical aspect of the work, it would be received very well. However, as a program review that should highlight how the project fits into the overall picture and how well it is managed and carried out from a programmatic aspect, the presentation was lacking. The strength of the project is the relevance to further understand the critical characteristics of the feedstock and how it may affect process conditions, as well as how this information can be used for feedstock blending purposes or on-the-fly process conditions can (or must) be altered to maximize output.
- Overall, a well-intentioned and much-needed project. The importance of establishing quality metrics for biomass feedstocks cannot be understated. The project needs more detail and needs to define success metrics. It is not clear that work is complete for single feedstock.

PI Response to Reviewer Comments:

- We thank the reviewers for their valuable comments and participation in the peer review process. The reviewers' comments provided good insight into how to better focus the research efforts of the program and the need for defined success metrics. Research efforts will continue to focus on the DOE goals of reducing the cost of converting lignocellulosic biomass to sugars and other fuels while addressing specific Feedstock Supply and Biochemical Conversion Technology Area barriers. The research emphasis and future focus of this program addresses critical technical challenges and barriers related to biochemical conversion, including biomass quality, variability, and biomass recalcitrance.

BIOCHEMICAL PLATFORM ANALYSIS

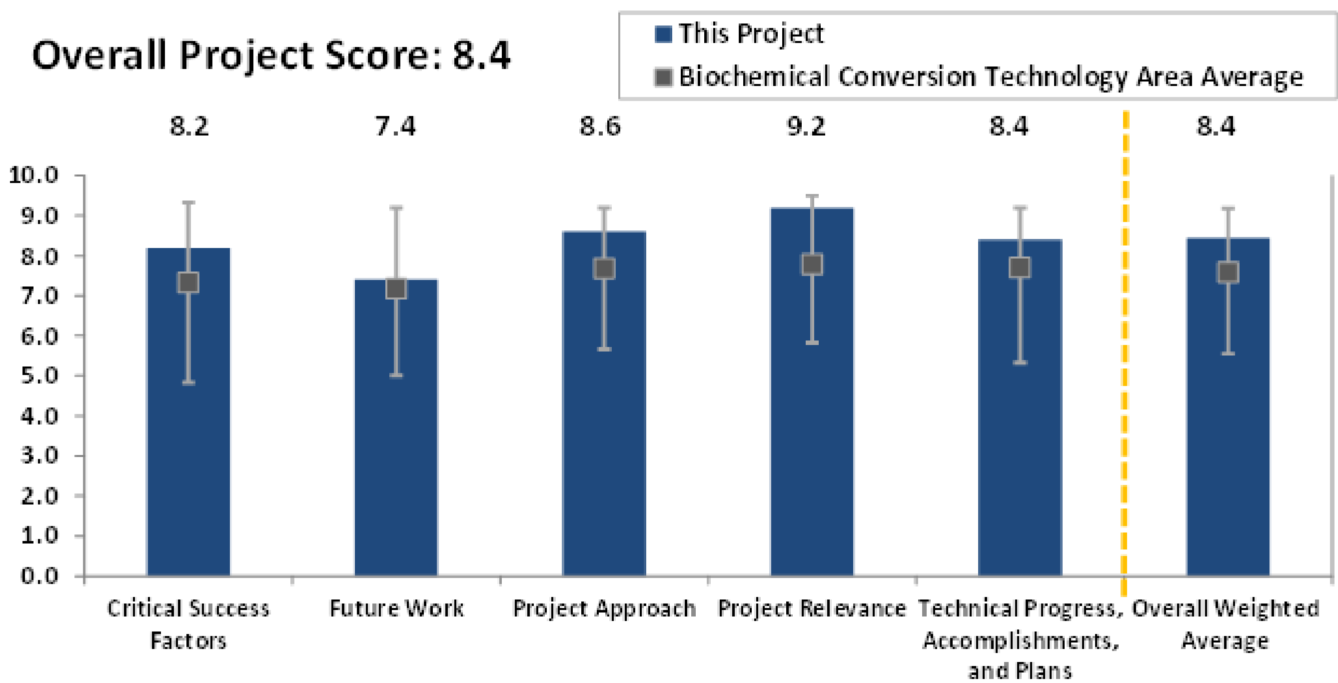
(WBS#: 2.6.1.1)

Recipient:	NREL
Presenter:	Ryan Davis
Total DOE Funding:	$6,005,000
DOE Funding FY13:	$850,000
DOE Funding FY12:	$700,000
DOE Funding FY11:	$750,000
Project Dates:	2002–2017

Project Description

Photo Courtesy of NREL

Biochemical Platform Analysis investigates the process economics that can be used to assess cost-competitiveness and market penetration potential for a given technology conversion pathway. Platform Analysis also helps to direct research by maintaining benchmark models describing the current conceptual state of technology. Proposed research and anticipated results can be translated into economics that can be compared to the benchmark case. This process helps to indicate the economic impact of core research toward meeting competitive cost targets. This task is highly relevant to supporting BETO's goals and objectives, as the analysis work provides a process context for the R&D activities funded by the Office. The techno-economic models provide a framework that ties technical performance to cost reductions within a biorefinery, providing important guidance on R&D targets and quantifying modeled conversion costs. Additionally, the task tracks sustainability metrics to quantify important parameters such as greenhouse gas (GHG) emissions, fossil energy consumption, and consumptive water use across the biorefinery conversion step. The analysis work is peer reviewed and thoroughly documented in objective, transparent design reports that are publicly disseminated. The Analysis task has made significant achievements since the 2011 Peer Review, including establishment of an updated design report with more rigorous process and costing assumptions to further reduce uncertainty; demonstration of



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

achieving the 2012 DOE target of meeting a modeled minimum ethanol selling price (MESP) of $2.15/gal (2007 dollars) based on performance observed at the pilot-scale; and quantification of reduced GHG and fossil energy profiles associated with NREL's pilot demonstration runs, relative to targets established in the updated 2011 design report. Moving forward, the task is shifting its focus from ethanol to hydrocarbon fuels and blendstocks, and is currently evaluating process and economic potential, uncertainties, and research needs for the technology pathway from the context of an integrated commercial-scale model.

Overall Impressions

- This reviewer considers this task crucial to the success of BETO. It identifies the bottlenecks (as far as cost), and can—and should—be taken into account in developing new Office objectives and strategies.
- The engineering modeling team is a strong and valuable contributor to BETO's mission. If anything, this team is underutilized. BETO and EERE would be well served to put greater emphasis on engineering modeling earlier in their programs.
- The model and analysis in the reports that NREL prepares and publishes are not only relevant and important to the Office, but also to the private sector. Cooperation with the other laboratories and industry players has been important to the quality of the reports.
- This kind of work is worth doing, but it needs independent verification.
- Very important to be able to track costs and direct R&D efforts. On-site enzyme production is a questionable approach.

PI Response to Reviewer Comments

- We thank the reviewers for their complimentary and insightful comments and appreciate the acknowledgment of the importance of integrating modeling efforts with directed R&D, which is a primary objective we strive to support. Regarding the need for independent verification of the models, one means of achieving this important step is the peer review process, which is undertaken by NREL's design reports that document the details of established models prior to publication and the release of these reports. This process solicits feedback from stakeholders in industry, academia, and other national laboratories with representation that spans all technology areas covered in the given pathway model. In many cases, the models and resulting cost estimates are modified as a direct result of the peer review feedback received prior to publication of the final report. Additionally, NREL maintains working relationships with outside partners, and strives to capitalize on opportunities for additional modeling feedback, validation, and/or improvement through these channels, as we are able to incorporate such inputs in publicly available reports.
- As noted in recent design report documents,[2] the primary intention for inclusion of on-site enzyme production is to improve transparency in determining the true cost of cellulase enzymes for large-scale production of cellulosic ethanol (or other biofuels). The intention is not to imply a judgment call about whether or not the industry should align to this mode of enzyme distribution. Further rationale for this approach in the context of NREL's integrated biochemical process models may be found in the above-cited design report documentation.

[2] Humbird, D.; Davis, R.; Tao, L.; et al. *Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol*. NREL/TP-5100-47764. Golden, CO: National Renewable Energy Laboratory, May 2011. http://www.nrel.gov/docs/fy11osti/47764.pdf

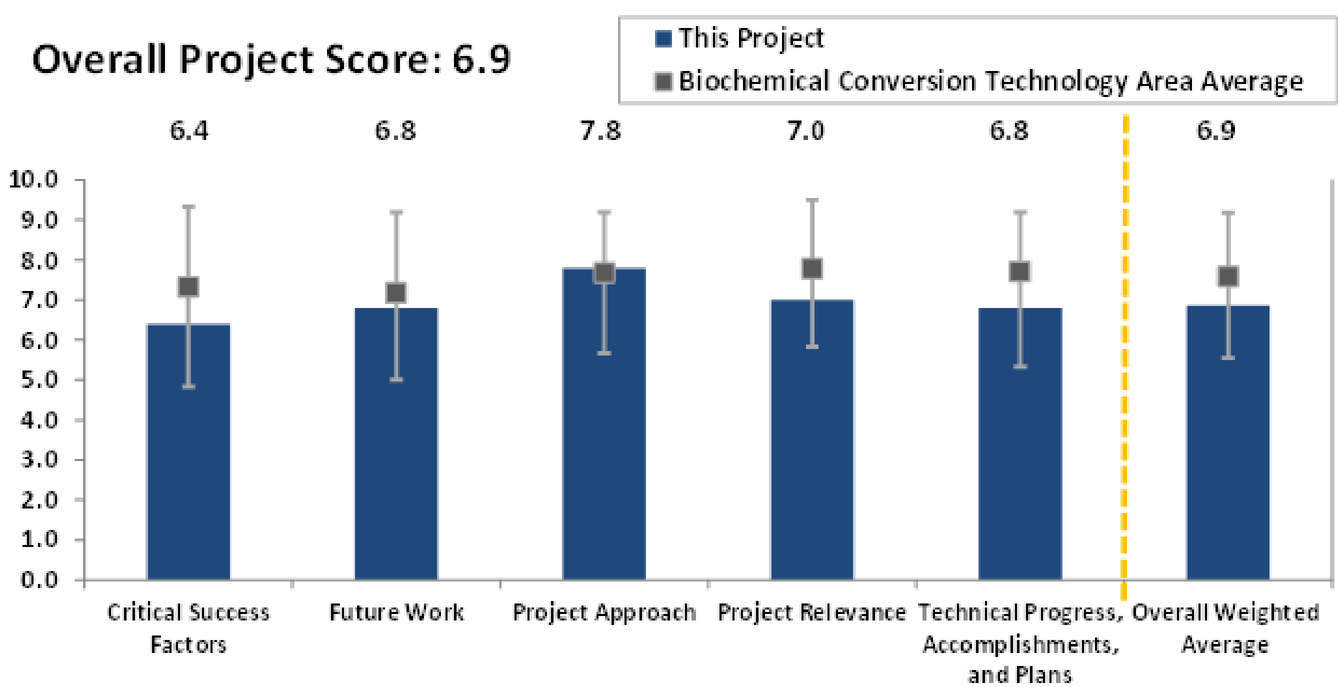
BIOCHEMICAL PROCESSING INTEGRATION TASK

(WBS#: 2.3.1.1)

Recipient:	NREL
Presenter:	Dan Schell
Total DOE Funding:	$57,200,000
DOE Funding FY13:	4,800,000
DOE Funding FY12:	6,800,000
DOE Funding FY11:	6,800,000
Project Dates:	2001–2017

Project Description

The high-level project objective is to produce integrated pilot-scale data that, when evaluated using a techno-economic model, meets BETO's biofuel cost targets. We serve a critical role in evaluating how the major unit operations work together, and through such assessments, we identify strategies to improve performance and reduce production cost and risk. We also identify and examine other key process integration issues such as intra-process water recycle, process power requirements, and biocatalyst robustness early in the process development and scale-up effort, and then transfer this knowledge to industry. In fiscal year 2011–2012, the project was organized into four focus areas: developing and improving biomass analytical methods; producing a new genomically integrated, glucose-xylose-arabinose utilizing *Zymomonas mobilis* strain; generating bench-scale integrated process performance data; and performing integrated pilot-scale runs producing results that meet the 2012 cellulosic ethanol cost target. The analytical development effort continues to improve the widely accessed biomass analytical methods, and we reached an impressive number of hits (19,000) over the last two years on our website that houses these procedures. We significantly improved the speed of biomass compositional analysis by two- to three-fold and continue to improve and deploy rapid spectroscopic methods for biomass analysis. We also successfully produced an integrated strain of *Z. mobilis* that is able to convert arabinose to ethanol. Over the last six years, we generated bench-scale integrated performance data to track progress toward the 2012 yield targets established in 2007. The bench-scale work investigated process options, one of which was tested in pilot-scale demonstration runs using biocatalysts supplied by industry. The presentation



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

shows historical progress and the main technological improvements that contributed to meeting the goals. The theoretical ethanol yield improved from 50% in 2005 to close to 80% in 2012. Integrated pilot-scale runs were performed in the summer of 2012 and produced data meeting the Office's 2012 cost target. This goal was achieved by a combination of yield improvements and cost reductions. Beginning in fiscal year 2013, we will investigate integrated production of hydrocarbon fuels from biomass with a focus on meeting the Office's 2017 and 2022 cost targets. This work will involve continued development of analytical methods, integrated bench-scale performance testing, and development of the pilot plant's capabilities with a focus on future integrated runs.

Overall Impressions

- Excellent progress over the last 10 years or so in process integration and process economics for cellulosic ethanol production. This reviewer has reservations about hydrocarbon production, especially since there are a number of companies doing similar work, and this reviewer questions the economic viability of converting sugars to hydrocarbons.
- Integrated bench- and pilot-scale work that stayed focused and evolved. Significant learning curve was incorporated into process and applicable to future work. Deacetylation step is an interesting addition to the process. Analytical methods are applicable to future work.
- Not a strong project; could be done better in academia or industry.
- Overall this is not a strong project. The stated objective of integrated process performance and translating performance from bench- to pilot-scale was not adequately addressed. Data were provided for only six pilot-scale runs during the last year for this project, two of which had severe contamination issues. It seems that process integration and successful scale-up are critical areas in which the NREL team can truly shine. Unfortunately, the presentation did not effectively convey this expertise. Rather than performing a pilot-scale dose response curve for enzyme loading, it would have been more beneficial to select the enzyme loading at the bench scale and then perform replicate pilot-scale runs using a single, well-defined process. The demonstration of successful process integration and scale-up must address reproducibility—this is an area where NREL could add significant value.
- Part of the work (e.g., development of laboratory analytical procedure's, process integration, and pilot-scale verification) is very important to the Office.

PI Response to Reviewer Comments

- In addition to developing and disseminating chemical analysis methods to academia and industry and developing integrated process technology at the bench scale, this project ultimately brought together various newly developed process improvements to produce integrated pilot-scale (one dry ton per day) performance data meeting BETO's 2012 cellulosic ethanol cost target. We achieved this goal using a combination of research advances from NREL projects, academia, and industry and improved biocatalyst developed by industry.
- This success was made possible by many years of bench-scale exploratory work, which culminated in identifying a process that was demonstrated at pilot scale. By the middle of fiscal year 2012, bench-scale work identified the best conditions (e.g, pretreatment operating conditions, enzymatic hydrolysis solids loadings, etc.) that minimized cost, but there was accumulating evidence that enzymatic cellulose conversion yields were better in the pilot-scale, high-solids enzymatic reactors because these reactors promote better mixing compared to bench-scale reactors. After the fact, analysis verified that pi-

lot-scale enzymatic cellulose conversion yields were 10% greater than yields achieved in bench-scale reactors. Therefore, varying enzyme loading and assessing enzyme cost versus performance (yields) while holding other operating variables constant allowed us to identify the operating condition meeting BETO's cost goal. Because pilot-scale runs are expensive and time consuming, this condition was replicated once.

- We believe addressing and overcoming the contamination problem was one of the most significant accomplishments of this project—an experience that we hope will be extremely valuable for the emerging industry. Our enzymatic hydrolysis reactors were not designed for aseptic operation, and we acknowledged the fact that commercial facilities will also not be designed for aseptic operation, so learning to handle contamination will be a necessity for industry. It took pilot-scale operations for this issue to become apparent, understood, and solved.

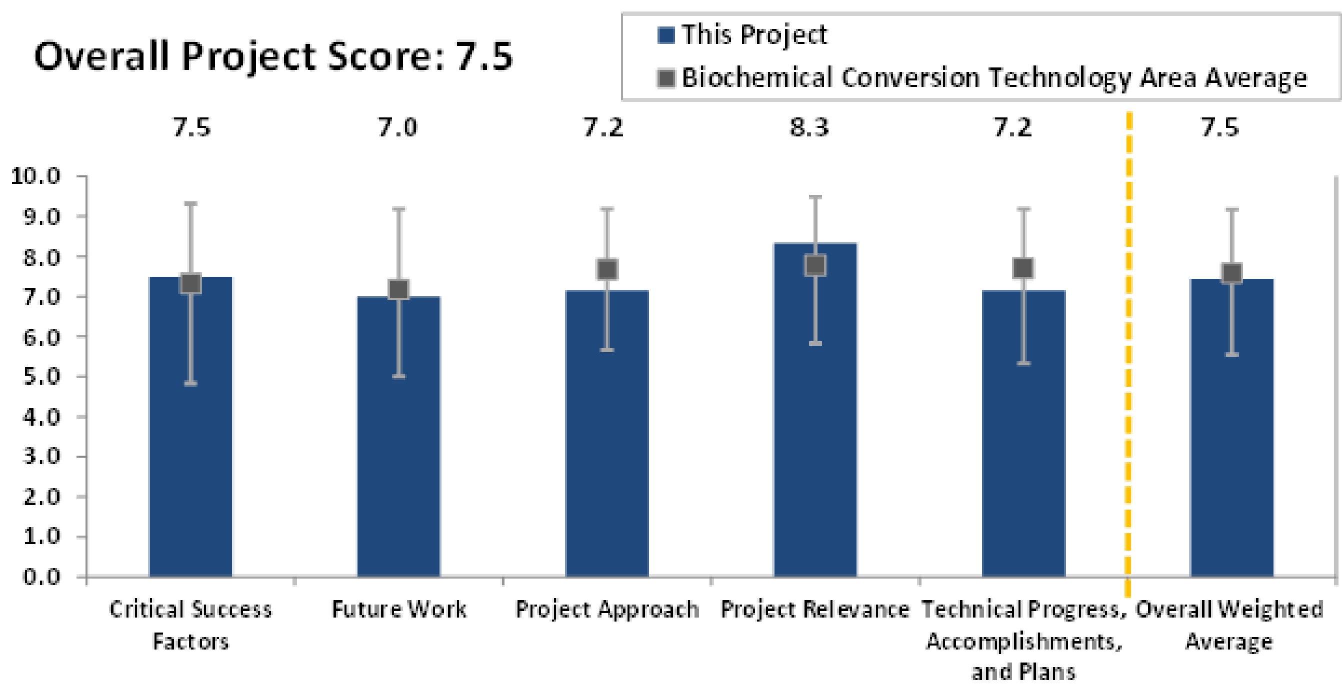
CATALYTIC CONVERSION OF LIGNOCELLULOSIC BIOMASS TO HYDROCARBON FUELS

(WBS#: 2.3.1.12)

Recipient:	PNNL
Presenter:	Mike Lilga
Total DOE Funding:	$400,000
DOE Funding FY13:	$400,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012–2015

Project Description

This is a new project that started in November 2012. The goals of this project are to develop direct, low temperature and pressure routes to hydrocarbon fuels from lignocellulosic feeds; use catalytic processes to convert lignocellulosic feeds more efficiently than current thermal approaches; maximize uses of cellulose, hemicellulose, and lignin for fuel and product production; develop pathways to paraffinic and isoparaffinic fuels (for diesel and aviation needs), rather than aromatic and cycloparaffinic fuels (the primary output of pyrolysis/liquefaction); improve hydrogen efficiency; and decrease capital requirements. The approach presented is complementary to liquefaction and aqueous phase reforming but makes a different slate of products. These products will serve other transportation fuel markets and will fill the existing gap in the production of 100% biorenewable transportation fuels from cellulosic biomass. A variety of thermochemical catalytic processes will be used. In fiscal year 2013, a novel pretreatment and deconstruction technology is being developed that uses a novel sugar stabilization mechanism to minimize degradation, contamination, and humin formation. Early results indicate the potential of the technique to break down biomass into fragments amenable to biochemical and catalytic processing, and to allow for independent processing of cellulose, hemicellulose, and lignin fractions to improve carbon efficiency. Also studied this fiscal year is the conversion of levulinic acid to hydrocarbons, especially via heterogeneous ketonization catalysis to build carbon number while deoxygenating without H_2. Production of olefin intermediates is the goal because of the range of options available for olefin conversion to linear and iso



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

products appropriate for diesel and jet fuels. This project addresses key MYPP barriers, including Bt-A Biomass Fractionation, Bt-D Pretreatment Chemistry, and Bt-J Catalyst Development. Work will continue to improve selectivity and yield of desired products and gain a better understanding of process parameters. Successful outcomes include high carbon yields, milder process conditions, and desirable linear and iso hydrocarbon fuels.

Overall Impressions

- A good addition to BETO's portfolio of projects. This is fundamental research that should continue.
- In my opinion, it sounds like the deconstruction process will be expensive, so the TEA on the products will be important. Production of fuels may not be viable using these methods.
- Project seems to be a 'one-off' from some previous work in the literature. Project team needs to make a better case for why the project should go on.
- The deconstruction method of biomass and the ultimate production of linear hydrocarbon is a novel approach that would fill the void in this area. The project is in its very early stages, and the PI has posed several questions that need to be addressed in the future work.
- This is a scoping project to evaluate a novel biomass deconstruction method and a chemical conversion process for the conversion of levulinic acid to higher value product. The advantages of the biomass deconstruction effort should be more clearly communicated. The chemical conversion of levulinic acid seems that it would benefit from efforts to understand the fundamental chemical reaction mechanism(s) that are being explored.
- Very early in the project cycle, but it appeared that the team has a good plan. My main concern is that it appears to be two projects in one—biomass deconstruction to sugars and levulinic acid conversion to hydrocarbon fuels. Integration appears to be missing.

PI Response to Reviewer Comments

- Thank you for your comments. The economic viability of the overall approach is yet to be determined, but it is a key consideration in the design of the project and in process development. Regarding deconstruction, there are several potential economic and technological advantages over the current state of the art that I was unable to comment in an open review due to a positive breakthrough that is being utilized to seek intellectual property. After the patent application is public, there will be significantly more disclosure. Overall, the process was designed to maximize carbon efficiency, a critical need in developing an economical process. Continued experimentation will assess the process robustness and lead to the quantification of economic advantages.
- Early slides in the presentation showed how individual steps in the proposed process integrate for the conversion of biomass to hydrocarbon fuels. The steps include biomass deconstruction, separate conversion of C5 and C6 sugars (or oligomers) to levulinic acid as a common intermediate, and conversion of levulinic acid to ring-opened fuel precursors. The two tasks for initial studies, deconstruction and levulinic acid upgrading, were chosen because they are key steps in the process and they are novel and untested. While they appear disconnected, they are really individual steps in an overall cohesive strategy. Conversion of oligomers or sugars to levulinic acid will be conducted later, based upon the results of earlier tasks and guided by literature precedent, to complete the process.

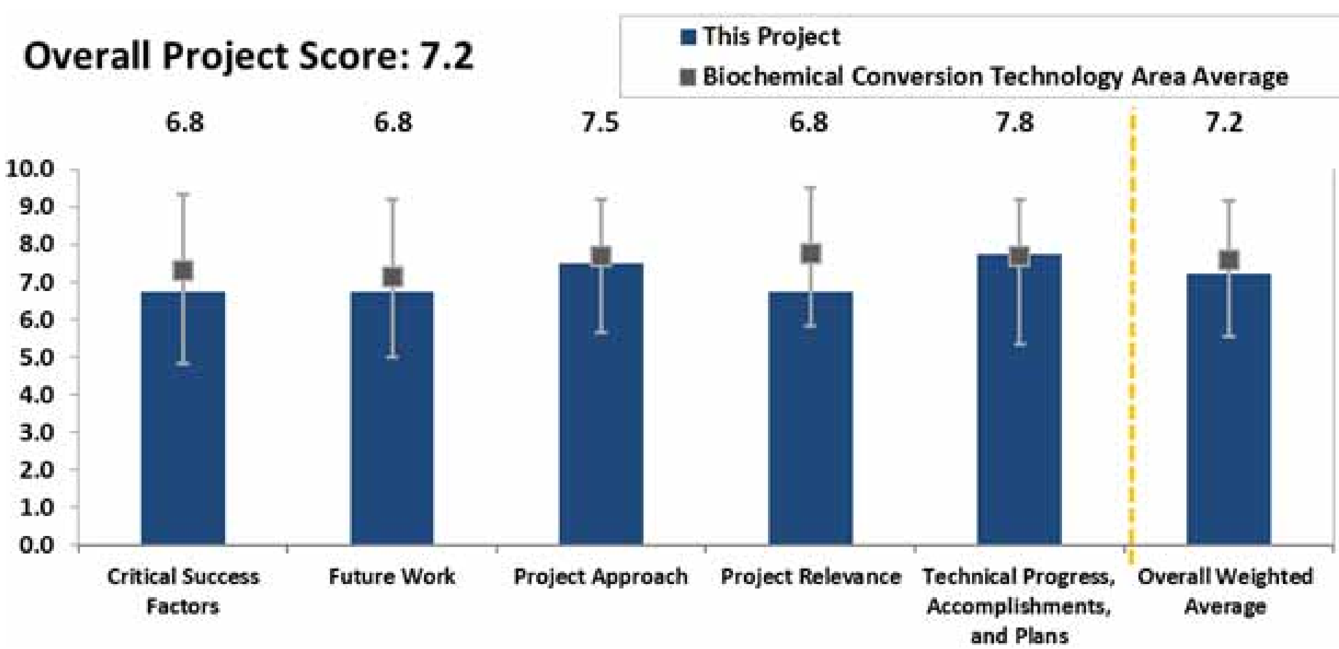
BUTANOL FROM WOODY BIOMASS BY SSF PROCESSES

(WBS#: 2.3.1.12)

Recipient:	Oak Ridge National Laboratory (ORNL)
Presenter:	Jonathan Mielenz
Total DOE Funding:	$225,000
DOE Funding FY13:	$0
DOE Funding FY12:	$0
DOE Funding FY11:	$150,000
Project Dates:	2011–2014

Project Description

Production of the potential "drop-in" biofuel butanol as part of the ABE fermentation process has historically been obtained by a corn or simple sugar-based fermentation. Developed at the University of Illinois by Professor Hans Blaschek, *Clostridium beijerinckii* BA101 is a multiple biomass sugar-utilizer (including xylose and arabinose) and a hyper-butanol producer. A commercial spin-off company has successfully completed a 6,000 gallon pilot run using corn glucose feedstocks with this strain. However, research aimed at conversion of lignocellulosic biomass to butanol has not been completed. Therefore, this seed project aims to evaluate the fermentation of woody (Populus species) biomass to butanol using this hyper-butanol producing *Clostridium beijerinckii* strain with the target of producing longer chain alcohols from biomass. Results have demonstrated that *Clostridium beijerinckii* BA101 is able to ferment cellulose and hemicellulose with simultaneous saccharification and fermentation after hydrolysis with industrial enzymes using SSF approaches, but it appears to fail to complete the conversion leading to simple sugar build-up. Use of separate hydrolysis and fermentation (SHF) approaches overcomes this limitation, so SHF is superior to SSF. With high biomass loadings during hydrolysis, fermentations of the Populus hydrolysate sugars produced high levels of butanol and acetone with high conversion yields.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- An excellent seed project resulting in a potential commercial technology.
- Development of butanol fermentation is important research. Drop-in fuels still have a place in the biofuels future. This project has made good progress in this area. We need to see the 11g/l titer improved, but the progress is positive.
- This reviewer is not convinced of the relevance of this project.
- This was a small-scaled study to evaluate the feasibility of using a particular clostridium strain and biomass feedstock for the production of butanol. Within that framework, this project was carried out efficiently and effectively. The team completed a significant amount of characterization work on a very limited budget.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

CELLULOSIC BIOMASS SUGARS TO ADVANTAGED JET FUEL

(WBS#: 2.3.1.8)

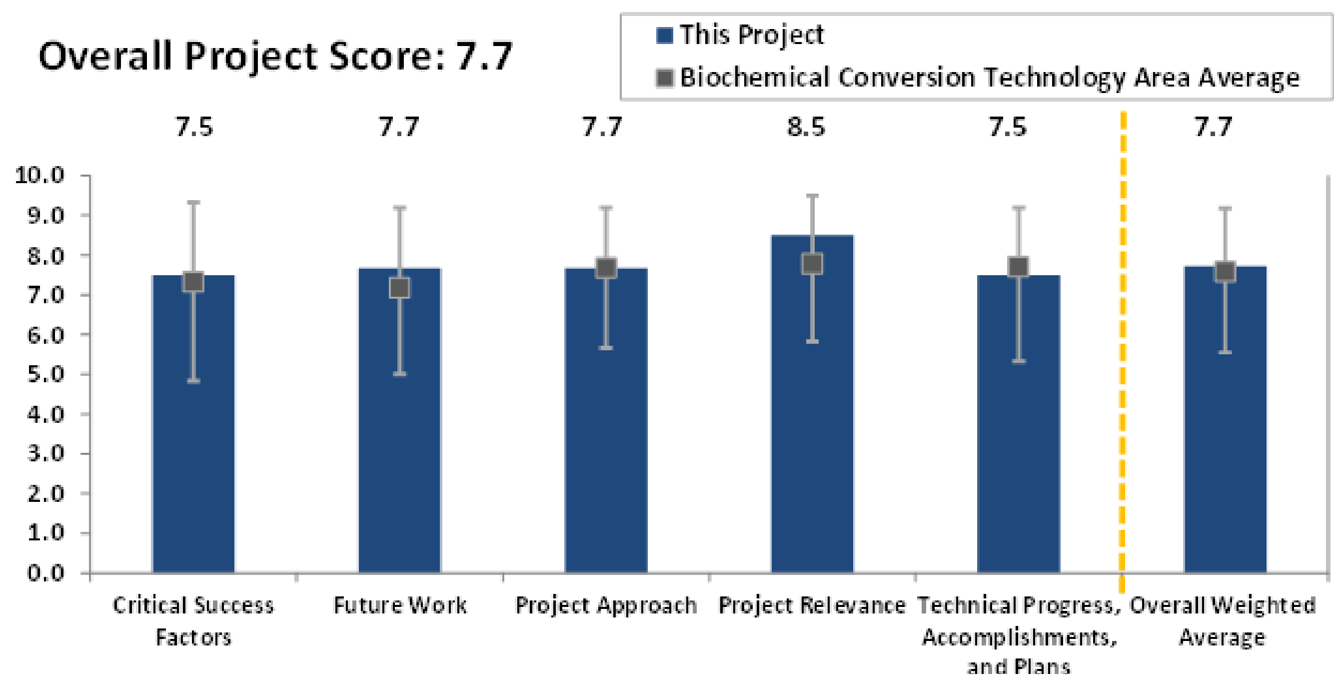
Recipient:	Virent
Presenter:	Randy Cortright
Total DOE Funding:	$6,690,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2011–2014

Project Description

Filtering Basket Centrifuge

Photo Courtesy of Virent

The purpose of this project is to demonstrate the technical and commercial feasibility of producing liquid fuels, particularly jet fuel, from lignocellulosic materials such as corn stover. To achieve this, NREL's expertise in corn stover deconstruction has been paired with Virent/NREL hydrolysate conditioning capabilities and Virent's novel BioForming® process to produce an advantaged jet fuel that has been shown to meet or exceed specifications for commercial and military jet fuel through Fuel Readiness Level 3. In addition to the core technology at NREL and Virent, the project is leveraging the skills and expertise of INL for the procurement, storage, and analysis of the corn stover; Northwestern University for fundamental modeling of lignin deconstruction to improve overall carbon recovery; and NREL's catalyst characterization capabilities to understand catalyst deactivation mechanisms. Since inception in the fourth quarter of 2011, the program has successfully progressed through benchmark validation and has made substantial progress towards the intermediate validation targets. Specifically, enzyme usage has been reduced in the deconstruction process, hydrodeoxygenation catalyst development has led to a substantial reduction in catalyst cost guided by condensation model feed studies, and jet fuel selectivity has been improved by 22%. In addition, the project team continues hydrolysate conditioning improvement efforts (solid-liquid



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

separations, purification, and evaporation) and condensation catalyst development. In the fourth quarter of 2013, this project will undergo intermediate validation to measure continued progress toward overall Office objectives followed by a DOE go/no-go stage gate review. Following successful completion of the stage gate review, future work will be centered on process intensification, as well as continued process economic improvements through improved yields and reduced operating costs.

Overall Impressions

- Excellent work, though this reviewer is concerned about the requirement to clean up the sugar stream and its impact on the overall economics. This reviewer is also concerned about the linkage to NREL's pretreatment / hydrolysis process, which may not have the best economics.
- Overall, seems like a well-run project with novel approaches. How do they segregate the DOE-funded aspects of the project from other projects?
- The overall objectives of this research are right on focus, including the catalyst characterization, the improvement of yields to jet fuel, and lowering the freeze point, and the achievement of thermal stability better than JP8 is a plus. There is a significant amount of research to do, and extending the catalyst life looks pretty challenging. Overall a really interesting approach.
- The project is well-run and has clear objectives. There are several potential pitfalls to commercial implementation of this technology, including the unlikelihood of eliminating enzymes from pretreatment, the extensive processing required for hydrolysate conditioning, and issues with catalyst lifetime, reactivity, selectivity, and poisoning.
- The work with the National Advanced Biofuels Consortium (NABC) is different than what was presented here. Here they are working mainly for jet fuel. The main problem is driving down the cost for hydrolysate conditioning and cleanup. It is unclear if they had any commercial success on other projects.
- This project utilizes a thermochemical process for the conversion of cellulosic sugars to hydrocarbon molecules—notably jet fuel. Due to confidentiality concerns, not many details were provided with respect to technical progress completed or for work remaining.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

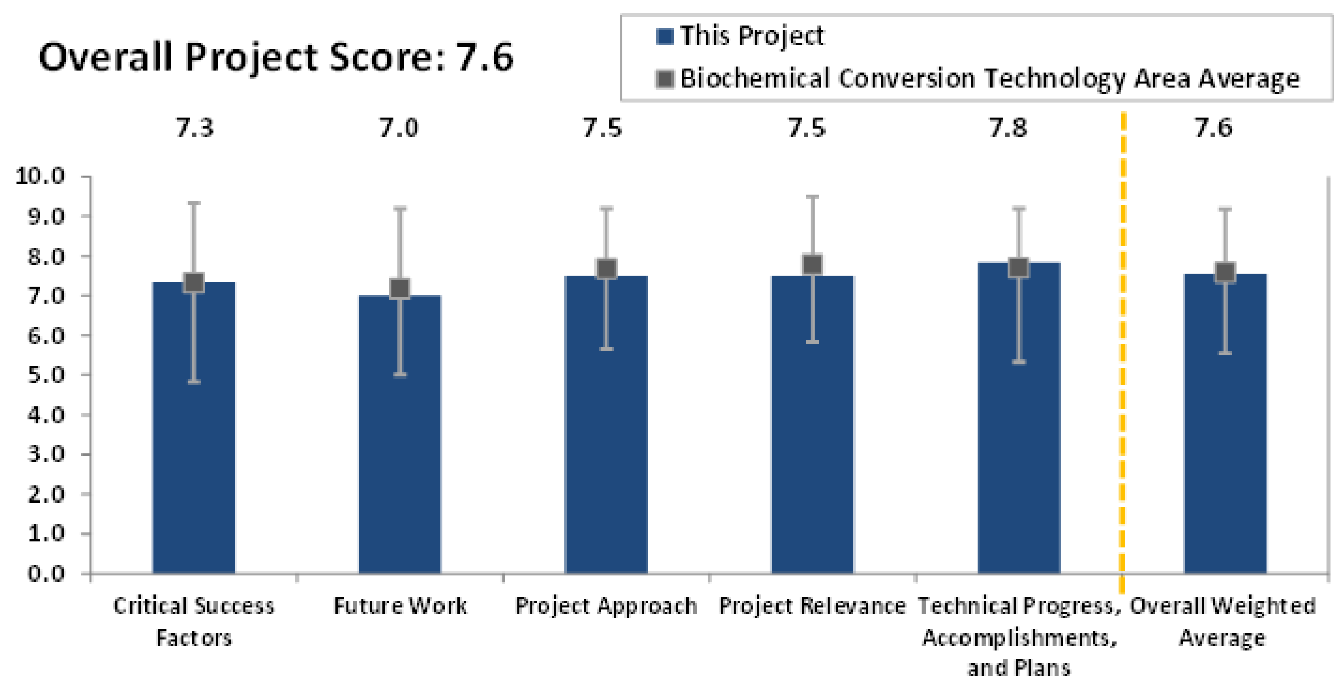
COLLABORATIVE RESEARCH: ENGINEERING YEAST CONSORTIA FOR SURFACE-DISPLAY COMPLEX CELLULOSOME STRUCTURES: A CONSOLIDATED BIOPROCESSING APPROACH FROM CELLULOSIC BIOMASS TO ETHANOL

(WBS#: 2.3.2.9)

Recipient:	University of California Riverside
Presenter:	Wilfred Chen
Total DOE Funding:	$599,966
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2009–2013

Project Description

The development of alternative energy technology is critically important due to economy, security, and environmental issues. Biochemical conversion of biomass—the only domestic, sustainable, and renewable energy resource—has significant advantages over other alternative strategies. However, the high cost of overcoming the recalcitrance of biomass has so far been the primary obstacle impeding the market for biofuels. Enormous efforts have been made for developing cost-effective processes for converting cellulosic biomass into liquid fuels. Consolidated bioprocessing (CBP) that combines simultaneous saccharification of lignocellulose with fermentation of the resulting sugars into a single step is promising, as it avoids a separate and dedicated process step for cellulase production. One of the most promising approaches toward CBP is the use of a complex cellulase system known as the cellulosome. Cellulosomes are composed of scaffolding that contains a powerful cellulose-binding module (CBM) and several cohesions that tightly bind to the complementary dockerins in the catalytic subunits. Compared to the non-cellulosomal system, the celluolsome exhibits much greater degradation potential due to its highly ordered structure, which enables substrate targeting and enzyme proximity synergy. In this project, we created a highly ordered complex cellulosome structure on the yeast surface, which can



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

control the position and ratio of each enzyme in the cellulosome structure. A dramatic and nonlinear enhancement in enzyme activity with the increasing complexity of cellulosome structures was observed, resulting in the improvement of ethanol production. This result strongly suggested that higher enzymatic synergy can be employed to reduce the amount of enzyme needed, leading to a substantial reduction in the cost of biofuel production. To our best knowledge, this is the first report of using a yeast consortium approach for CBP of cellulose.

Overall Impressions

- A significant amount of work in CBP development has been done in general. This research contributes to the positive steps needed to develop a productive, all-encompassing organism to do it all in one pot. Impact on cost reduction is a big driver.
- A well-executed project generating interesting and worthwhile results that are being communicated in excellent journal publications. The project is highly relevant to the long-term goal of consolidated bioprocessing. These results are laying the groundwork for future efforts in yeast protein display and cellulosome design and reconstitution. This technology is a long way from commercialization, but it is sound fundamental research.
- This reviewer appreciates the novel aspect of the work, but it felt as if this work is about 10 years late. The consolidated bioprocessing for ethanol (as far as engineering a superbug) is simply too much of a departure from the current approach of ethanol from biomass, a technology that is very near commercialization.
- Interesting from a conceptual standpoint, but maybe not technologically relevant. Getting much more complicated, but maybe without the desired yields.
- This project is an early-stage applied science project. The team has been successful in demonstrating proof of concept for the successful expression and functionality of a cellulosome using a yeast consortia. Hypotheses have been generated for the current bottlenecks that may be preventing commercially relevant ethanol production rates and titers.
- Well-carried-out project that is making good progress.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

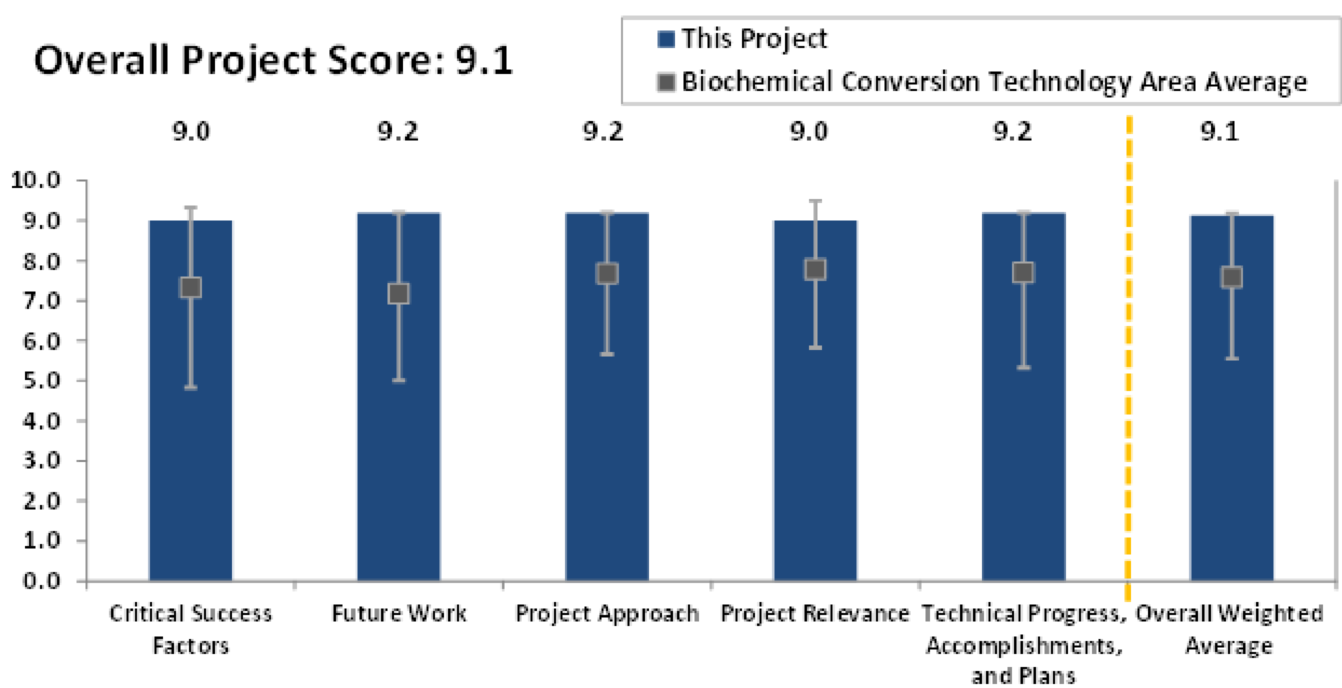
DEVELOPMENT OF AN INTEGRATED BIOFUEL AND CHEMICAL REFINERY

(WBS#: 3.2.2.4; 3.2.2.32; 3.7.1.2; 3.2.2.5)

Recipient:	Genomatica, Inc.
Presenter:	Mark Burk
Total DOE Funding:	$4,999,116
DOE Funding FY13:	$253,588
DOE Funding FY12:	$852,555
DOE Funding FY11:	$541,971
Project Dates:	2011–2014

Project Description

PIs Mark Burk (Genomatica CTO) and Nelson Barton (VP, R&D), with Project Lead John Trawick (Research Fellow), led this three-year program to demonstrate the commercial readiness for low-cost production of the industrial chemical 1,4-butanediol (BDO) from biomass. To reach these objectives, biomass sugars have been tested with Genomatica BDO production strains. Results were used to assess the main limitations on fermentation performance. High concentrations of non-fermentable impurities limited BDO production. A program to minimize non-fermentable impurities was organized with the hydrolysate supplier and led to marked improvements in performance. All BDO production strains have a limited diauxic response to mixed sugars; one of these strains was evolved for co-consumption of glucose and xylose, the mutant allele for this trait identified by genomic DNA sequencing and introduced into a current BDO strain. This enabled co-utilization of the major C6 and C5 sugars, with a further increase in performance. On improved lignocellulosic biomass hydrolysates with the glucose, xylose, and arabinose co-utilizing BDO production strains, titers of 89 g BDO/L with productivities approaching 2 g/L/hr have been achieved. These exceed some of the goals of this grant and represent five-fold gains over the initial benchmarking and two-fold improvements during 2012. However, increased yield and further increases in performance will ultimately be required for commercialization. To determine remaining constraints on BDO production, flux analysis, metabolomics, and metabolic modeling have been employed to identify targets to improve adenosine triphosphate availability and metabolic flux of all components needed for BDO synthesis. These improvements are being implemented by further strain engineering and fermentation process development. Given the striking successes



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

to date with this program, we anticipate being able to achieve or exceed the goals for both laboratories.

Overall Impressions

- A superior project. Excellent plan and implementation. Good diversity of technical approaches; well integrated together. Highly relevant to the crucial area of bio-production of chemicals from biomass. Well-executed collaboration with feedstock supplier.
- Overall, this is an exceptional project for the BETO portfolio. The performer has demonstrated commercially relevant metrics from cellulosic biomass in a few short years. The collaboration with Chemtex to supply feedstock and develop acceptance criteria has clearly been a productive relationship.
- Pathway development of stains to develop BDO is a positive alternative to ethanol. Progress and accomplishments of this research is significant. Successful scale-up and viable economics will be interesting areas in the future.
- Very focused and successful work based on past experience and commercialization of BDO.
- Very nice project with impressive progress and results. Good leveraging of previous process development work to extend to biomass.

PI Response to Reviewer Comments:

- Genomatica would like to take this opportunity to thank the reviewers for their participation in the public review and for their feedback. In addition, we would like to thank the combined DOE/NREL validation team for their feedback and guidance during phase one of this work. The Genomatica team remains confident that the work we are doing with the support of this DOE grant will ultimately lead to the development of a commercially viable integrated (biomass-to-BDO) biorefinery. It is gratifying to receive feedback from the reviewers that further supports this view.

DEVELOPMENT OF APPLIED MEMBRANE TECHNOLOGY FOR PROCESSING OF ETHANOL TO BIOMASS

(WBS#: 7.4.5.2)

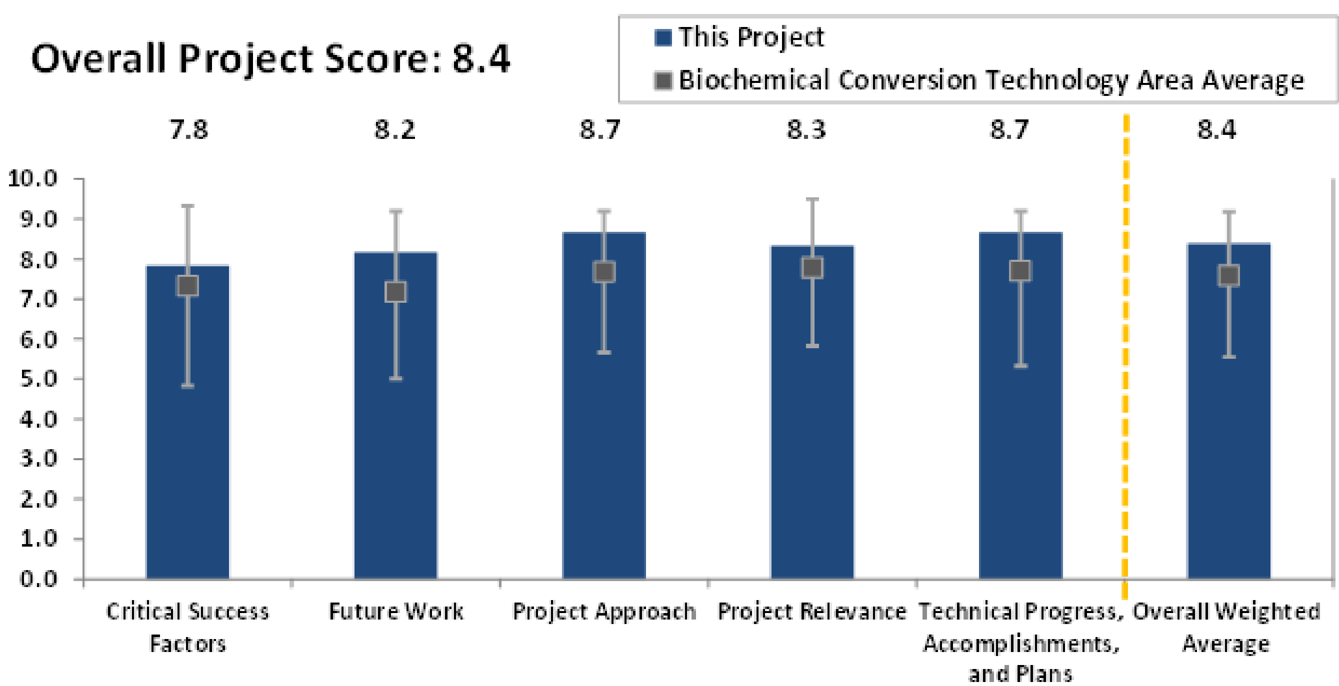
Recipient:	Compact Membrane Systems, Inc.
Presenter:	Stuart Nemser
Total DOE Funding:	$988,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2006–2013

Project Description

The purpose of this project is to develop and demonstrate a membrane system for drying bioethanol to produce fuel-grade ethanol. Fuel-grade ethanol must contain no more than 0.5% water. The goal was accomplished successfully. A chemically and thermally resistant membrane for drying ethanol at up to 120°C was developed. The membrane consists of a thin layer of a perflourinated polymer coated on a hollow fiber support. This was incorporated into a system that includes ethanol and thermally resistant components (potting, gaskets, wrap). This system was demonstrated to efficiently dry bioethanol to fuel-grade ethanol standards. In medium-sized bioethanol plants, the membrane system competes favorably with conventional drying methods, such as molecular sieves. The membrane system dries bioethanol while consuming less energy and at lower costs when compared to molecular sieve technology.

Overall Impressions

- An excellent, focused project. Commercial implementation is key. Adequate manufacturing capability is also crucial.
- Could be a good fit and save some capital and energy costs in the bioenergy industry.
- Excellent, clear, and compelling project. The only thing that may have improved the presentation aspect would have been to be a bit more preparation to explain the importance of the work as part of BETO's technology areas and how it fits into their



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

official plans and goals. At this point, no additional plans exist to continue the project within BETO; however, this reviewer thinks that their technology may have applicability in advanced biofuels.

- How much of an economic impact will there be by replacing molecular sieves with this system? It would be most appropriate for a green field plant and not an installed plant, since the major cost saving would be on capital. What is going to convince a producer to use this system versus molecular sieves?
- This was a lightly funded project that has reached completion. The presenter was very cognizant of the "sweet-spot" for their technology—both in terms of technical and economic feasibility. They are actively marketing their product to both the initial design target (e.g., ethanol), as well as for a variety of other water removal applications. This is a success story for BETO.
- Very focused and successful project.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

DIRECT CATALYTIC UPGRADING OF CURRENT DILUTE ALCOHOL FERMENTATION STREAMS TO HYDROCARBONS FOR FUNGIBLE FUELS

(WBS#: 2.3.4.1)

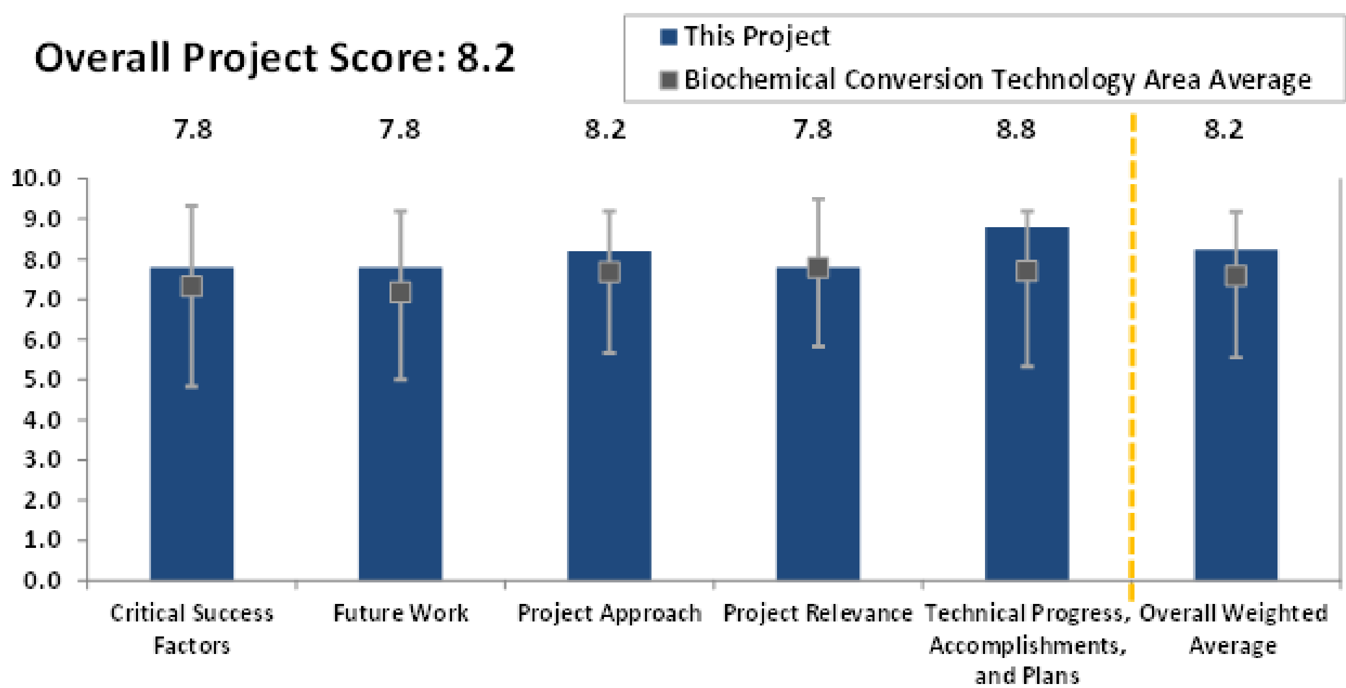
Recipient:	ORNL
Presenter:	Chaitanya Narula
Total DOE Funding:	$550,000
DOE Funding FY13:	$400,000
DOE Funding FY12:	$150,000
DOE Funding FY11:	--
Project Dates:	2011–2015

Project Description

The program objective is to take ethanol upgrading technology from readiness level 2 to readiness level 3 and beyond during the course of investigation. Our initial success has led to discovery of a catalyst that operates at 350° Celsius and atmospheric pressure. Nevertheless, the side reactions produce coke, which impedes the primary reaction of ethanol to C3+ hydrocarbons. Periodic decoking is required to remove coke. We plan to focus on improving the durability of the catalyst for use with a bioethanol at any stage of purification; the work will also allow us to develop detailed mass balance and energy balance data that are needed for techno-economic analysis. We will also carry out fractional collection of blendstocks and have blendstocks tested on gasoline, diesel, and jet engines.

Overall Impressions

- A very solid project in a vital area. Good mechanistic work and convincing preliminary engine testing. Future work testing non-ethanol streams should definitely be pursued.
- Catalytic conversion of ethanol into longer chain molecules offers a number of advantages, but could be economically challenging if those longer chain



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

molecules are of equivalent or lesser value than the ethanol itself.

- This reviewer thinks that the project was very well presented. It also appeared that the relevant testing was done from a practical standpoint. I think that the techno-economic analysis will be very interesting to see. This reviewer also thinks that additional work is required for the durability of the catalyst.
- Interesting research. The results are very encouraging but positive economics will be critical to a path forward.
- This is a strong project and a good example of applied basic science.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

FUNGAL GENOMICS

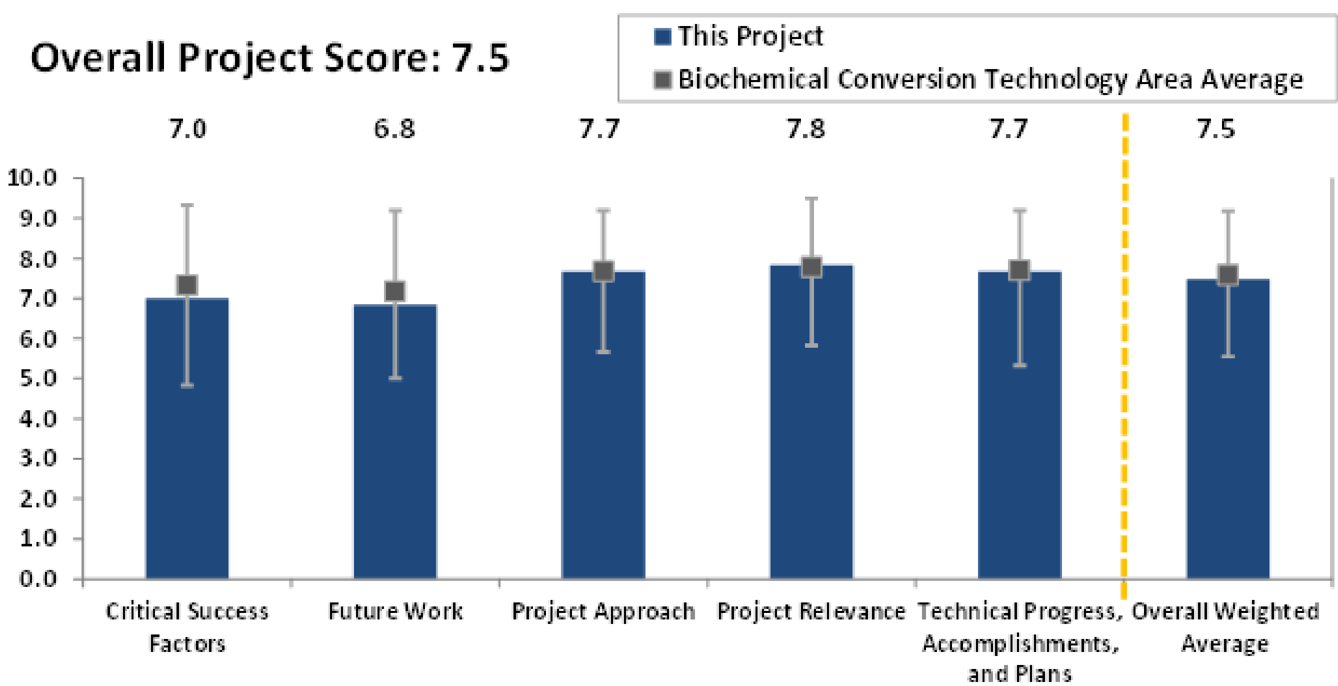
(WBS#: 2.4.1.2)

Recipient:	PNNL
Presenter:	Jon Magnuson
Total DOE Funding:	$13,729,760
DOE Funding FY13:	$1,500,000
DOE Funding FY12:	$2,250,000
DOE Funding FY11:	$2,500,000
Project Dates:	2004–2017

Project Description

Photo Courtesy of PNNL

Our goal is to enable accelerated development of bioprocesses using fungi that are industrially relevant. We pursue an application-oriented approach to development of fungal bioprocesses, which incorporates systems biology, genetic engineering, and bioreactors for understanding, manipulating, and assessing the native or genetically manipulated strains of the bioprocess organisms. For fiscal year 2013 we have a new focus on fungal production of lipids, which are excellent precursors for hydrocarbon biofuels. This new direction correlates with BETO's focus on infrastructure-compatible fuels. We continue to utilize the industrial fungus *Aspergillus niger* as a platform organism that is well understood and easy to manipulate genetically. We are also employing *Lipomyces starkeyi*, an oleaginous (oil-producing) yeast that converts a variety of feedstocks to large amounts of oils (lipids) that can be converted to hydrocarbon biofuels. Systems biology tools (genomics, proteomics, and transcriptomics) are being used to investigate the behavior of *A. niger* and *L. starkeyi* and identify genes that are important for the lipid-producing bioprocesses. Recently, we succeeded in developing a genetic system for *L. starkeyi* that allows us to express genes to improve organism performance. We are also developing a metabolic model to understand lipid production in *L. starkeyi*, as well as to provide targets for genetic engineering. The model will be re-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

fined with experimental data on *L. starkeyi* derived from bioprocess runs in our 30-liter fermentors that mimic many aspects of industrial fermentors. Oil yields that exceed our first-year targets have been obtained. One of our challenges is to improve the bioprocess by focusing on the most impactful areas for alteration as informed by techno-economic analyses being performed in other projects. Although the yeast is very productive and efficient, there is still room for improvement in titer, rate, and yield that can help increase the economic viability of oleaginous fungal bioprocesses.

Overall Impressions:

- It is hard to say how this project has gone. The project seems to lack focus and a proper level of justification. Presentation lacked excitement and did little to motivate the work.
- The project has a sharpened focus on biofuel precursors. It has been a funded project for a while and for fiscal year 2013 has been refocused to hydrocarbon production.
- The overall research and focus on fungal conversion processes to make lipids from sugars is important research. The team seems to have adopted BETO's new direction of hydrocarbon focus, and the research has been built on previous accomplishments.
- The team has completed a significant amount of work in a short period of time to benchmark their baseline understanding of the strain and process systems, and to help refine the path forward. A TEA for this proposed approach to the generation of hydrocarbon has been completed independently (also at PNNL). As a comment for DOE, the performer in this project is attempting to leverage their experience with fungal systems towards the goal of \$3/gal hydrocarbon. For non-fuel products (with higher cost targets), this could be a valuable research thrust. However, in light of the engineering model—which was not able to identify any feasible route to achieve \$3/gal fuel for this proposed approach—DOE might consider refocusing the efforts of this project.
- This is a good project. It is essential to carry out fundamental work in fungal biotechnology, and this is a good context in which to accomplish this. The new focus on lipid production is appropriate.
- This project appeared to be in transition and they are retooling. They have made significant progress on the work with the new fungi.

PI Response to Reviewer Comments:

- Our team thanks the reviewers for their supportive comments and suggestions. We have recently developed a new research and development direction that is aligned with BETO's primary emphasis on the production of hydrocarbon fuels. Since this new direction built on the existing strengths of our team in fungal biotechnology, we have been able to rapidly transition our focus to the production of hydrocarbon precursors (lipids) using fungal processes. To guide our research, we are working with the techno-economic analysts in order to concentrate on those technical challenges to the implementation of heterotrophic lipid-production bioprocesses that are likely to make the greatest economic impact.

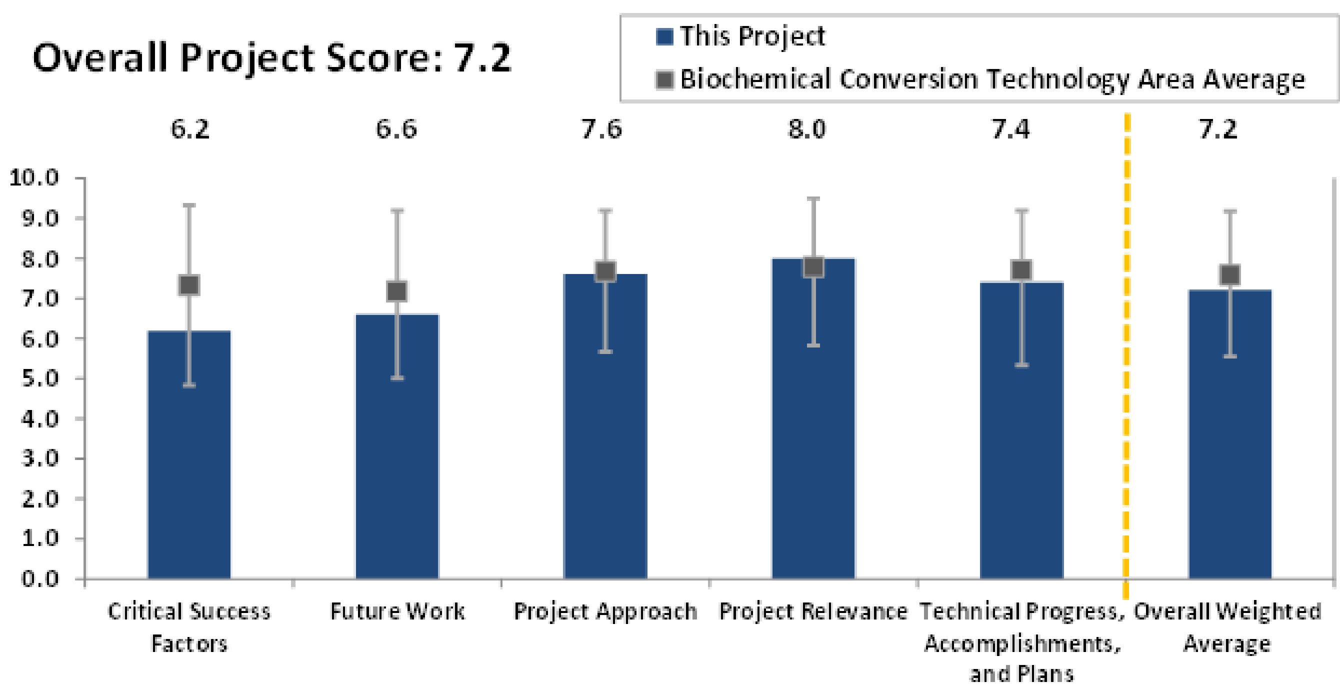
INTEGRATED BIOMASS REFINING INSTITUTE AT NORTH CAROLINA STATE UNIVERSITY

(WBS#: 7.1.4.1)

Recipient:	North Carolina State University
Presenter:	Sunkyu Park
Total DOE Funding:	$3,192,405
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$1,000,000
Project Dates:	2009–2013

Project Description

In BETO's Biochemical Conversion Technology Area work breakdown structure, our project efforts fall within pretreatment and hydrolysis and saccharification, in which we worked in testing novel pretreatment methods for woody biomass and corn stover with benchmarking by collaborators at Novozymes North America. Given our location, our primary feedstock is woody biomass (hardwood and softwood), which is common across the southeastern U.S. Considering that softwood is the most recalcitrant feedstock, we have focused on the fundamental issues of biomass reactivity such as lignin inhibition, cellulose crystallinity, and biomass accessibility. We have developed novel analytical techniques, employing nuclear magnetic resonance to characterize residual lignin and lignin carbohydrate complexes. That information was the basis for determining their impact on sugar yield. The major challenge for pretreatment is to increase biomass reactivity while reducing enzyme loadings. We have implemented and evaluated refining technology commonly used in the pulp/paper industry to enhance biomass accessibility, leading to reduced enzyme requirements. Novozymes provided insight with both standard and enhanced enzyme systems. Industrial partners helped to ensure that realistic operating conditions and equipment were considered. Conversion systems included both novel organisms and process modeling that provided fundamental insights. In the areas of alternate sugar conversion and consolidated processing, we have worked to enhance cellulase activity and to develop fermentation systems for simultaneous saccharification and fermentation with development of online Raman fermentation monitoring.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- An impressive diverse set of projects. Good dissemination of results through publications and presentations. Where does the work go from here?
- Excellent progress on a very relevant problem.
- Interesting research. It would be interesting to better understand the impact of refining on different feedstocks and the economics.
- Overall, this reviewer thinks that there was a lot of positive aspect of this project, namely the lignin and the refining. It probably would have made it more relevant if the team was working closer with the biomass-to-ethanol community and less with the paper and pulp community.
- This presentation was not conducive to assessing the performance of the project. A significant amount of work was presented on a wide variety of topics that were loosely related to biomass. The presentation gave the perception that the work being conducted has a "shot gun" approach and lacks a central unifying theme or thrust. This particular presentation is more suited for an academic conference.

PI Response to Reviewer Comments

- No official response provided at time of report publication

INTEGRATED BIOREFINERY - SEPARATIONS/SEPARATIVE BIOREACTOR - CONTINUOUS BIOCONVERSION & SEPARATIONS IN SINGLE STEP

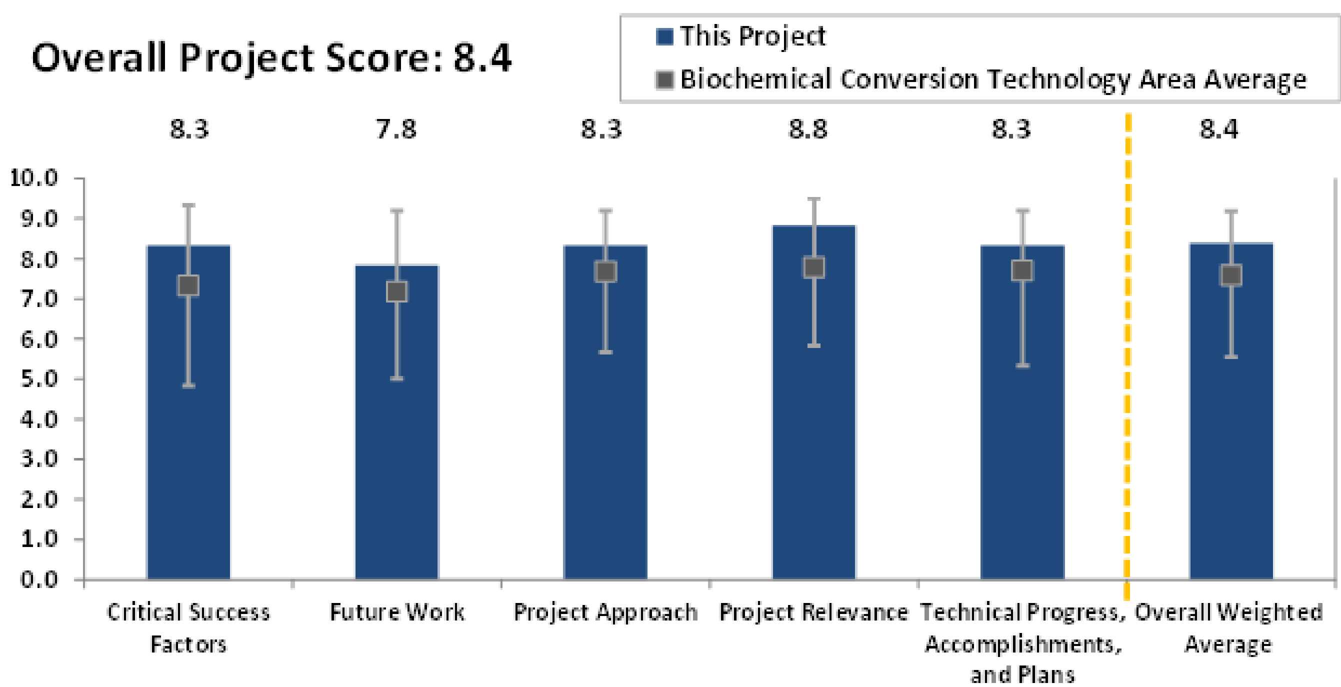
(WBS#: 2.3.1.5)

Recipient:	ANL
Presenter:	Yupo Lin
Total DOE Funding:	$5,658,984
DOE Funding FY13:	$30,000
DOE Funding FY12:	$750,000
DOE Funding FY11:	$1,409,000
Project Dates:	2004–2013

Project Description

Photo Courtesy of ANL

Separations are a critical factor in the cost-effective production of cellulosic biofuels and biobased products. To address this issue, Argonne is developing energy-efficient technologies to separate neutral and charged species in biochemical processes. The objective is to identify and overcome technical hurdles and to demonstrate the technical and economic feasibility of integrated membrane separations to produce biobased chemicals and biofuels. Our R&D addressed the MYPP barrier of Bt-I, cleanup/separation, specifically conditioning of acid pretreatment streams in the biochemical platform for cellulosic biofuels. Specific tasks carried out and progress that will be discussed in the review presentation are pilot-scale demonstration of resin wafer electrodeionization (RW-EDI) platform to remove acids and salts from the liquid fraction of mixed cellulosic sugar pretreatment streams; application of pulse flow microfiltration to extract the liquid fraction from acid pretreated biomass hydrolysate slurries; and development of advanced resin wafer manufacture technology to significantly increase separation productivity and reduce the footprint, capital equipment, and process op-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

erating costs. ANL has successfully extracted the liquid fraction of acid-pretreated hydrolysate slurry from corn stover using a newly installed pulse flow microfiltration system. This solid/liquid separation system can handle up to 15 wt% solid slurry. The extracted hydrolysate liquor (filtrate) was used directly in a pilot-scale RW-EDI system to remove sulfuric, acetic acids and other charged species. No membrane fouling was observed in the RW-EDI device. The permeate flux decline in microfiltration could be mitigated by applying clean-in-place procedures. Preliminary processing cost of conditioning the hydrolysate slurry was estimated. A new technique was developed to fabricate the third generation resin wafer for RW-EDI. The new generation resin wafer could potentially reduce the capital size and energy consumption for RW-EDI applications.

Overall Impressions

- Good project resulting in potentially viable technology. The project uses well-executed leverage of earlier work on HFCS desalination and immobilized enzymes. Extension of the technology to catalytic conversion is intriguing.
- This reviewer thinks this is a very good project, but it has been operated in an isolated fashion away from the main players in techno-economic analysis and lignocellulosic ethanol production. The project uses good technology that may fit into the lignocellulosic platform. Before any more is done, the TEA should be done by NREL.
- Nice innovation; it's important to determine long-term operating data on variable hydrolysates.
- This is a strong project. The performers have done an exemplary job of demonstrating fundamental understanding of their system, combining that knowledge with techno-economic analyses, and completing focused development and scale-up in a relatively short period of time.
- It is a very applicable technology that can be broadly used in the market.
- Project provides very promising technology. It could ultimately be used in a variety of applications within the Technology Area and beyond. We would like to see continued research funded.

PI Response to Reviewer Comments

- We would like to have the opportunity to incorporate the current process performance results into NREL's TEA model. After the project review, we demonstrated further improvement of dilute acid pretreated hydrolysate processing economics using new generation of ion-exchange resin wafer material. This technology is currently being applied on organic acids removal from bio-oil. Over the decade, there were 15 U.S. patents and patent applications and three international patent applications based on this technology that cover broad market areas. We will continue to apply this technology in catalytic upgrading of sugars into fuels. Finally, we would like to thank the full support from the program manager of Biochemical Conversion in developing this platform technology.

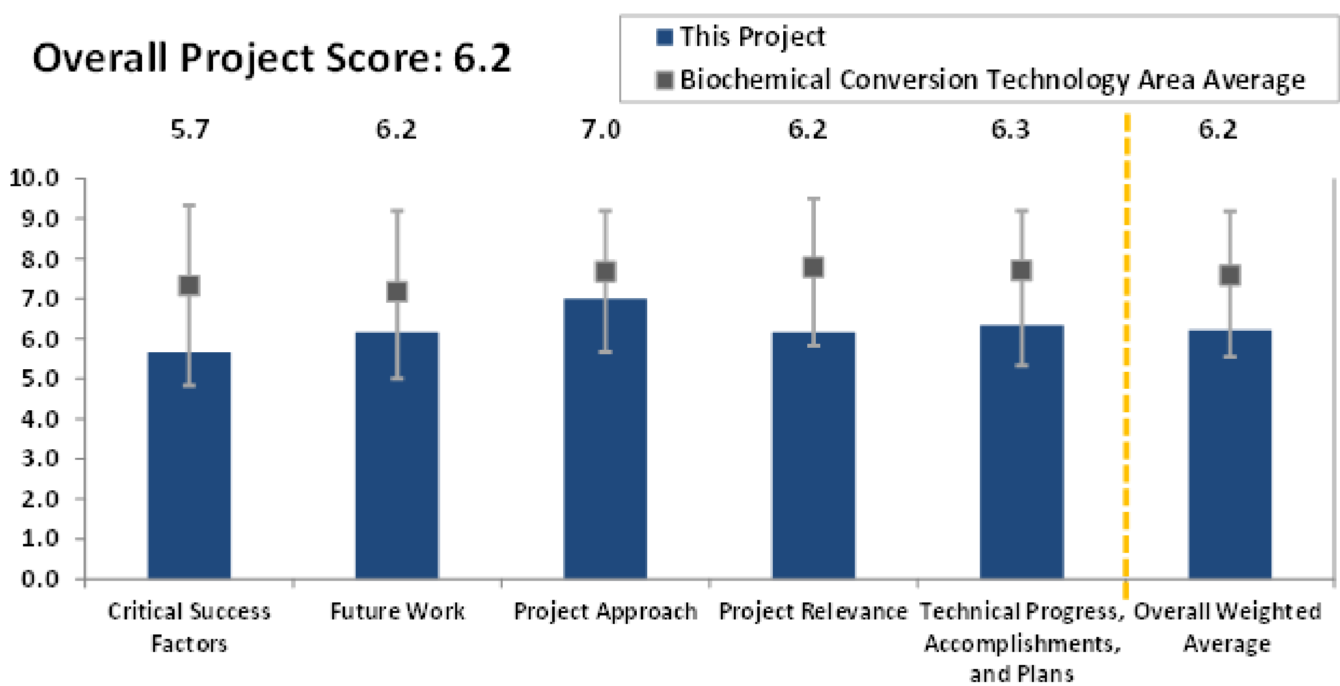
LBNL PDU SUPPORT

(WBS#: 2.3.1.6)

Recipient:	LBNL
Presenter:	Julio Baez
Total DOE Funding:	$23,000,000
DOE Funding FY13:	$2,750,000
DOE Funding FY12:	$3,000,000
DOE Funding FY11:	$1,250,000
Project Dates:	2010–2015

Project Description

The Advanced Biofuels Process Development Unit (ABPDU) was established in 2012 to enable public and private researchers to evaluate, adapt, develop, demonstrate, and transfer commercially viable, high-performance biomass deconstruction and biofuels/biochemical production technologies creating biorefineries compatible with the existing industry infrastructure. Its core competency is implementing improved performance pretreatment and saccharification methods adapted to diverse feedstocks (lignocellulosics, cellulosics, algae, gases) to produce advanced biofuels and biochemicals while creating value from all residual by-products, leading to cost-effective, environmentally acceptable biorefineries. During the ABPDU's first year of operation, four projects from the Joint BioEnergy Institute (JBEI) were completed, establishing the readiness of all the unit operations as illustrated by successful technology transfer and demonstration of use of ionic liquids for pretreatment of lignocellulosic biomass; saccharification of ionic liquid pretreated biomass; production of ionic liquid-tolerant thermophilic cellulases; and production of an advanced biofuel—bisabolene. The results of these activities will be discussed in the presentation. These studies demonstrated the implementation of novel, improved efficiency pretreatment and saccharification technologies, along with generation using fermentation of suitable tolerant thermophilic enzymes to deliver sugars for advanced biofuel and biochemical production. These studies also suggested that novel biofuels such as bisabolene could be a cost-effective alternative to other biofuels, while providing improved cold temperature performance. At ABPDU, we also integrated techno-economic and life-cycle analyses in all projects, and we are considering novel technologies to better serve



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

clients (e.g., gases as feedstock and plant expression systems for processing enzymes). In conclusion, during its first year of operation, the ABPDU developed effective collaborations with DOE research centers—including JBEI, the Great Lakes Bioenergy Research Center, and INL—and more than 10 companies working in the development of improved technologies for biomass/post-consumer product deconstruction and biofuel/biochemical production.

Overall Impressions

- Having a facility like this appears useful and serves a need; however, this reviewer would be cautious to have several of these facilities around the country. If you want several facilities, you have to make sure that they are significantly different. There is significant overlap with NREL's Process Demonstration Unit (PDU).
- Having a pilot lab that industry can pay to use is important, but it seems like there are several similar laboratories out there trying to do this. Why is this unique? The ability to scale-up and perform techno-economic analyses is key. The lab personnel seem to be highly qualified to guide future research projects. We would like to see a business plan developed to make the lab self-sustaining.
- Most of the work is directed towards JBEI's activities, so shouldn't JBEI support the center and not DOE?
- Not sure that I understand why this facility was built when other government laboratories have access to facilities that are similar. This project should be self-supporting.
- Overall, this is a welcome addition to the BETO portfolio. The availability of a fee-for-service facility for scale-up of feedstock and fermentation-based processes is a critical need within the community. That being said, there is still an unmet need for small-scale (e.g., two-liter) fermentation resources that is not currently addressed by ABPDU because of the limited equipment resources at this scale. This is a major lost opportunity for this facility.
- This project seems like it is primarily a process development laboratory for JBEI. This laboratory needs to market itself as a contract research organization and generate self-sustaining funding. Increasing small-scale fermentation capability might be a good way to cater to the needs of small biotechnology firms.

PI Response to Reviewer Comments

- The ABPDU is a unique facility in its flexibility, scale, and industrial client orientation. Its flexibility is derived from its multidisciplinary staff, facility design, and customized equipment to successfully meet the needs of a wide variety of clients and projects. The ABPDU's operational envelope allows clients to demonstrate the capability for commercialization of their research projects at a scale (100 kg biomass/day, 300L fermentation) that differentiates us from other DOE process demonstration facilities, such as NREL, that are working at the scale of 1 ton per day, 8,000-liter fermentation. The ABPDU is a new facility that has to address the challenges that any new contract research organization/process demonstration unit confronts to attract paying clients—lack of track record, new team, new equipment, and differentiation with established PDUs. As a start, the ABPDU has successfully demonstrated its capabilities through collaborations with the Great Lakes Bioenergy Research Center and JBEI. These collaborations have demonstrated the capabilities of our team and our flexible state-of-the art equipment and analytics to be applied to deconstruct diverse feedstocks and the use of fermentation to produce enzymes and biofuels. The ABPDU conducts in-house techno-economic and life cycle analyses as an integral part of all projects. We are currently evaluating 15 projects at different stages of development. The majority of these projects are with private companies (approximately 10 projects). The ABPDU recognizes the ability to attract and to retain clients through its flexible technology, experienced staff, and the timely delivery of milestones is essential to its success and keeping its relevance to BETO's mission.

LIGNIN UTILIZATION

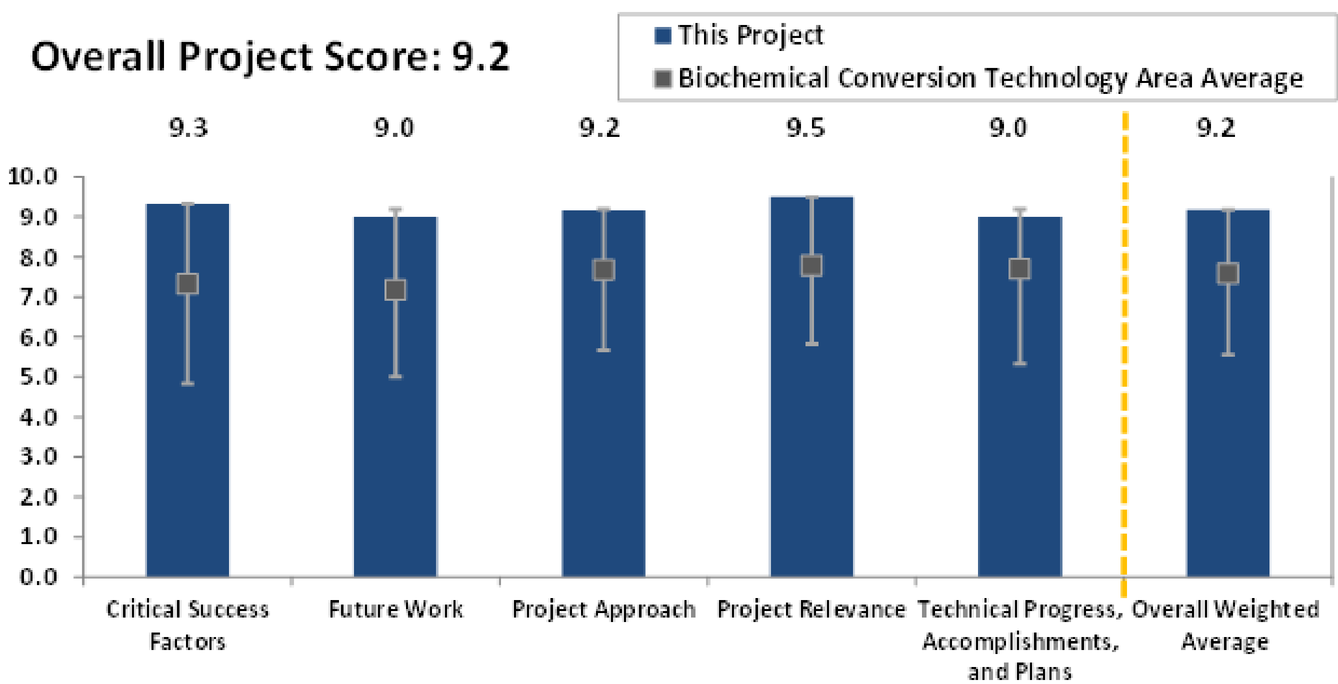
(WBS#: 2.2.3.1)

Project Description

Recipient:	NREL
Presenter:	Gregg Beckham
Total DOE Funding:	$1,150,000
DOE Funding FY13:	$1,000,000
DOE Funding FY12:	$150,000
DOE Funding FY11:	--
Project Dates:	2012–2017

Photo Courtesy of NREL

Techno-economic analysis of both sugars-to-hydrocarbons pathways suggest that to meet the DOE cost targets, it will be necessary to increase total carbon efficiency or otherwise produce higher-value products. Thus, the newly formed Lignin Utilization task focuses on process development to convert lignin to fuels and/or chemicals using a fundamental, interdisciplinary approach. The overall objective of this task is to develop integrated, bench-scale processes that consider the fate of both carbohydrates and lignin for both pathways, and to utilize techno-economic and life-cycle analyses (LCA) to identify major cost-drivers and refine process options for subsequent scale-up to meet cost goals. Our approach addresses two primary aims—to develop viable method(s) to obtain lignin in a suitable form for upgrading in the context of the biological conversion and catalytic upgrading of sugars-to-hydrocarbons pathways, and to design new method(s) to upgrade intermediates to value-added fuels or chemicals in a manner that avoids saturation of niche chemical markets. In the last eight months, we have focused on initial evaluations of lignin isolation approaches, quantification of reduced cellulase loadings for enzymatic hydrolysis upon upstream lignin removal with advanced enzyme cocktails, development of catalysts to further depolymerize lignin-to-liquid-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

phase species for upgrading, and developing novel processes for upgrading oxygenated, monomeric aromatics to value-added intermediates. Going forward to 2017, we will focus the lignin isolation research on the most promising approaches evaluated by TEA and LCA, and expand the lignin upgrading efforts to the production of a broad range of fuels and large-market chemicals. Overall, this work aims to enable lignin utilization approaches in the context of a carbohydrate-focused biorefinery, and as such, it will benefit industrial stakeholders in the production of fuels and chemicals from carbohydrates, accelerate development of the biomass value chain, and help meet the DOE hydrocarbon fuel cost targets.

Overall Impressions

- Excellent project! Very impressive with great progress in less than a year.
- Overall, this is a strong project that addresses one of the key hurdles to achieve the 2017 and 2022 MYPP goals; namely, the utilization of lignin to create value-added products to support replacement of the whole barrel of oil and achieving the $3/gal metric. This project is a good example of the application of fundamentals-driven science and techno-economic analyses.
- Seems like a great project; it is too early to see where this will end up but it has promise. How will this be different from other lignin upgrade efforts? PIs need to keep an eye on development of low-lignin transgenic plants.
- This is a very strong project. The highest and best lignin utilization is an essential component of bioenergy and biochemical production. As the PI mentions, lignin heterogeneity is a major hurdle.
- This project tackles a very difficult technical challenge that has been studied extensively. The outcome of using lignin and taking to intermediates to make higher-value chemicals could be significant.
- This is a very relevant and important project that allows low-cost feedstock for fuels and chemicals.

PI Response to Reviewer Comments:

- We thank the reviewers for their positive comments. Regarding the work on plants with genetically modified lignin, we are currently collaborating with several groups on this topic to understand the influence of less recalcitrant lignins on the lignin removal, deconstruction, and upgrading. The genetically modified lignin feedstocks may offer a dramatic reduction in processing costs and simplify lignin upgrading processes, which certainly could be a revolutionary change in biomass conversion.

LOW-ENERGY MAGNETIC-FIELD SEPARATION USING MAGNETIC NANOPARTICLE SOLID ABSORBENTS

(WBS#: 2.3.1.11)

Recipient:	ANL
Presenter:	Richard Brotzman
Total DOE Funding:	$350,000
DOE Funding FY13:	$200,000
DOE Funding FY12:	$150,000
DOE Funding FY11:	$0
Project Dates:	2011–2014

Project Description

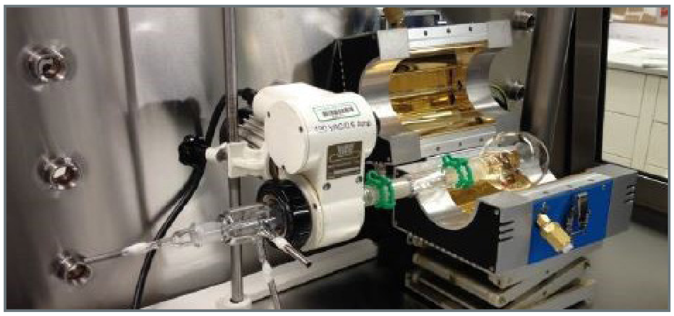
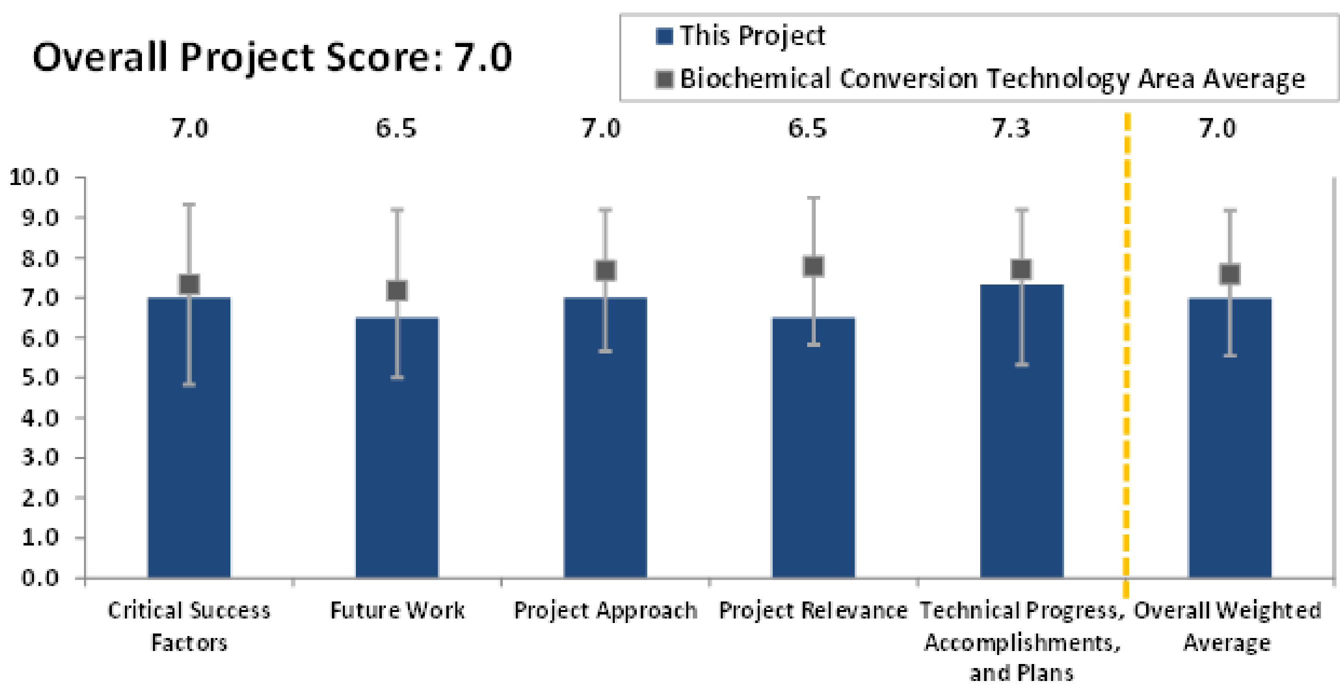


Photo Courtesy of ANL

Low-energy, magnetic field separation of hydrocarbon fuels will be explored to reduce process energy use and improve process economics. Nanostructured adsorbents (NA), comprised of superparamagnetic nanoparticles with a single magnetic domain tethered together, will be integrated into fermentation systems to establish a prototype separation process for hydrocarbon fuels.

This technology spans biomass processes and is relevant to the cleanup and separation of targeted products and intermediates. A new solid-state process capable of controlling chemical nanostructure was employed to synthesize Fe_2Co-based NAs. The process is commercially scalable and offers substantial economic advantages over current colloidal synthesis techniques. C20 (diesel)–C10 (gas/jet)–C5 (gas) isoprenol adsorption from doped fermentation broth will quantify the adsorption capacity of NAs. A three-liter scale prototype magnetic capture process was installed and operationally qualified. This process will quantify NAs separation of hydrocarbon fuels from fermentation broth, and be used to investigate strategies to separate NAs from the fermentation broth—degree of mixing, magnetic removal



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

from flowing stream, flotation with subsequent magnetic capture of NAs, etc. Remaining critical success (or risk) factors include recovery of hydrocarbon fuel from NAs, meeting adsorption and recovery target metrics, and demonstrating NA stability and reuse. If successful, magnetic NAs will be incorporated in bioprocesses that make a distribution of hydrocarbons to investigate quality requirements and hydrocarbon intermediates and products. Bioreactor-integrated separations that enable hydrocarbon fuel production and recovery in concert are envisioned.

Overall Impressions

- An intriguing approach that should be investigated. Perhaps the technology is too complex to economically handle the large scale needed for commercial viability. The researchers should not get too complicated too early. For example, they should characterize removal of hydrocarbons from simple water solutions before moving onto the much more complex situation of fermentation broth.
- It is hard to imagine that this will be pragmatic. It is interesting science. What are they using as a benchmark technology? What metrics are being used? This project is better as a polishing step. It needs to start with a very simple system!
- If the economics of this technology look reasonable at all, this process could be applied in many ways, including removing toxic products to ultimately increase the titers in the fermentation. This could make the difference in making or breaking some types of fermentations/technologies.
- This is a creative approach to addressing the separation of hydrocarbon products from a fermentation broth. It is early stage, high risk, and potentially high reward. The work to date is appropriate. This reviewer recommends that near-term future work be refocused to address more basic understanding of the chemistry of the proposed targets, and that proposed adsorbents be addressed prior to addressing process issues.
- This is a project that is very high risk. It has to be compared with traditional separations technology (e.g., solvent extraction and traditional sorbents, such as activated carbon).
- It is very interesting work and concept, but this reviewer thinks it will be more costly relative to standard separation methods, though it could be useful for toxic molecules in a continued mode. There is also a concern around specificity or lack thereof. The project should spend more time on basic characterization of the adsorbents and specificity (model systems in water).

PI Response to Reviewer Comments

- Request was made to conduct initial work on hydrocarbon products in water—this will be done. Adsorbent design for different molecules and adsorbent specificity will be conducted subsequent to initial work on water systems to understand competing sorption complexes and role of ionic strength.
- An evaluation of process economics will be conducted as part of the final report and compared with solvent extraction and fractional distillation. Scale-up cost projections will be made in the final report.
- Flotation as well as magnetic separations is possible. This would further reduce process cost.
- Desorption target is 75%.

NATIONAL ADVANCED BIOFUELS CONSORTIUM (NABC)

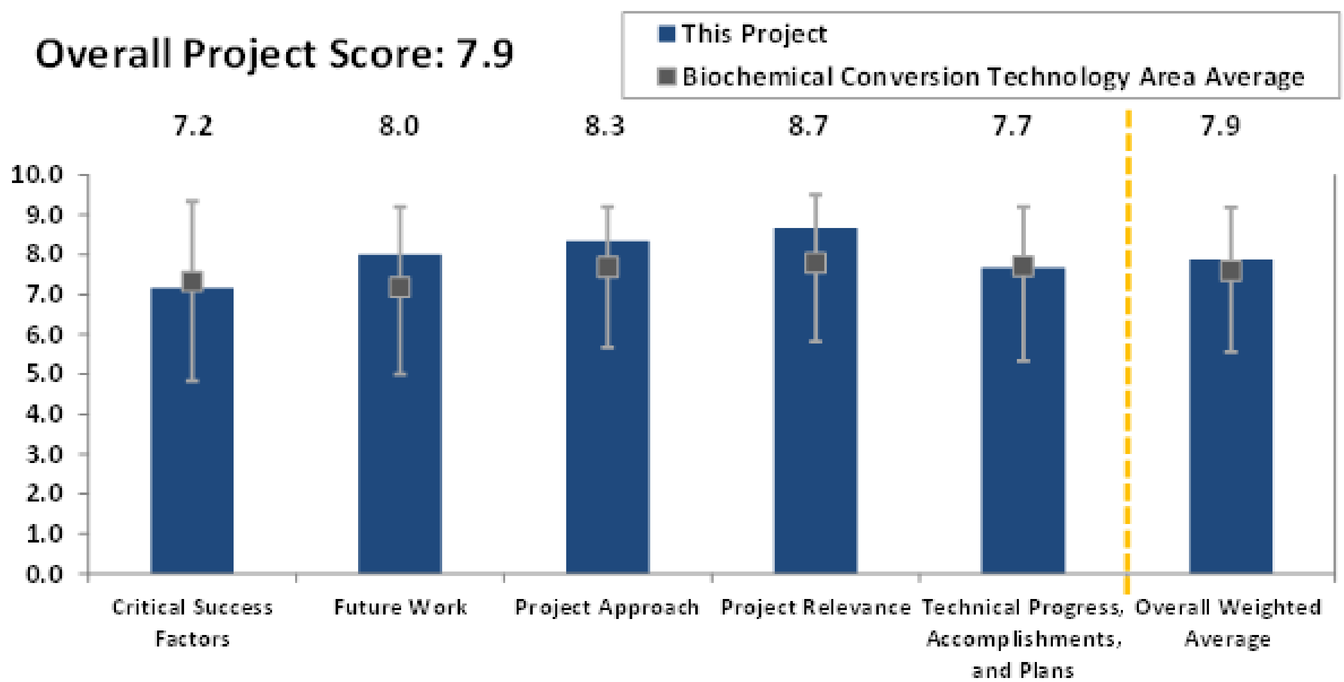
(WBS#: 3.3.1.1)

Recipient:	Alliance for Sustainable Energy, LLC
Presenter:	Tom Foust
Total DOE Funding:	$34,949,784
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010–2013

Project Description

Photo Courtesy of Alliance for Sustainable Energy

NABC is a collaboration among DOE national laboratories, universities, and private industry that is developing technologies to produce infrastructure-compatible, biomass-based hydrocarbon fuels. The consortium, led by NREL and PNNL, is funded by DOE under the American Recovery and Reinvestment Act and by NABC partners. NABC is in its third year of a three-year program. The goal of NABC is to accelerate development of technologies for sustainable, cost-competitive, drop-in, fungible hydrocarbon fuels from lignocellulosic biomass to a pilot-ready state. Displacing oil at the refinery gate avoids cost in new infrastructure and increases the rate of broad deployment into the existing fleet. This approach provides a cost-effective way to supplement the existing market with drop-in fuels made from biomass, and achieve DOE goals of U.S. energy security, reduced greenhouse gas emissions, and the creation



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

of economic opportunities across the nation. NABC is developing technologies from both thermochemical and biochemical platforms to produce the best processes for hydrocarbon fuels. Stage one, the first year of NABC, focused on a rigorous evaluation of advanced biofuel conversion technologies culminating in a down-select to those that met the criteria to be pilot-ready by the end of NABC. Stage two of NABC is focusing on development of the two selected technologies to a pilot-ready state, while also working on another two promising technologies to address major technical challenges. In addition, cross-cutting activities focus on refinery integration sustainability and the fundamentals associated with each technology.

Overall Impressions

- An excellent, well-managed, consortium that is doing work with great relevance to BETO goals and the bioenergy industry.
- Appeared to be a very focused effort targeting technology-ready processes and demonstrating them on a pilot scale together with rigorous cost and analysis data. I think this demonstrates a very good use of Recovery Act funds. Even though it will not continue, I would suggest continuing to track the project and how it turns out.
- This reviewer is not sure why this project was done. It seems that industry will drive this kind of effort if it makes sense. Is this effort to allow DOE to learn how the various processes considered build into the biofuels arena? How does an intellectual property (IP) agreement work? Did any valuable IP result as measured by continued commercial development?
- The consortium approach is an excellent vehicle to accelerate the R&D efforts. The "team" is composed of experts from all key areas and allows the right people or groups to focus on the technical challenges that need to be overcome. It appears this consortium was organized, focused, and cooperated with each other.
- The work on fundamentals and modeling generated a large amount of basic understanding on a variety of topics. This was a valuable part of the consortia. Insufficient quantifiable information was presented on the two key process strategies (fermentation and catalysis of lignocellulosic sugars) to allow for an adequate review.
- This is a very successful project on many fronts.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

NOVEL MECHANICAL PRETREATMENT FOR LIGNOCELLULOSIC FEEDSTOCKS

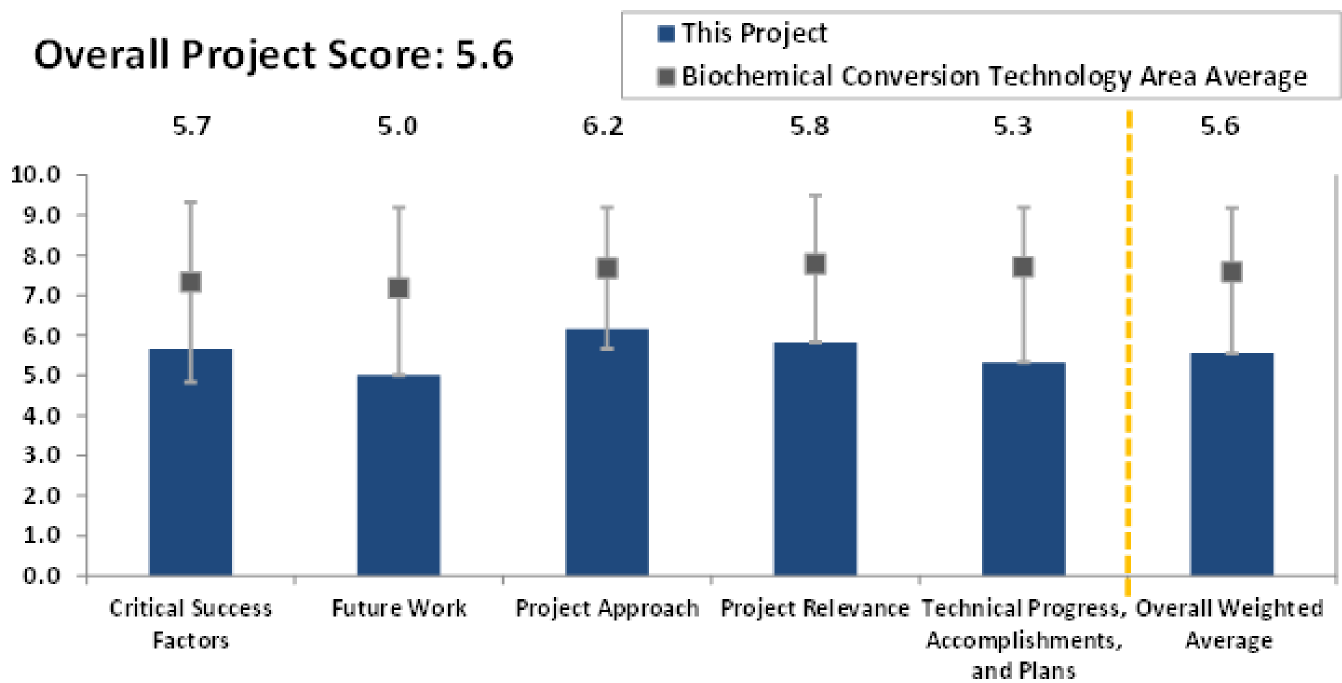
(WBS#: 2.2.1.5)

Recipient:	Texas Engineering Experiment Station
Presenter:	Mark Holtzapple
Total DOE Funding:	$2,263,007
DOE Funding FY13:	$786,795
DOE Funding FY12:	$676,212
DOE Funding FY11:	$800,000
Project Dates:	2011–2014

Project Description

Photo Courtesy of Texas Engineering Experiment Station

Shock treatment is a novel pretreatment method for lignocellulose. The shock vessel has a vertical cylindrical section located at the vessel bottom. Above is a conical section that narrows towards the vessel top. The apex is connected to a small-diameter cylindrical tube. The lignocellulose is slurried in water and placed in the cylindrical portion of the shock vessel. An explosion initiated in the cylindrical tube produces a shock wave that expands in the conical section and impacts the water surface. The shock wave propagates through the aqueous suspension and mechanically disrupts the lignocellulose, thereby enhancing enzymatic reactivity. Initial studies were performed using a 3.56-inch-diameter, 20-inch-long, 2-liter shock vessel that employed a shotgun shell to produce the explosion. Initial studies used five substrates—corn stover, sugarcane bagasse, switchgrass, sorghum, and poplar wood. All substrates were treated with oxidative lime. Compared to raw biomass, oxidative lime treatment increased enzymatic digestibility (72 h, 5 filter paper units per gallon of glucan) by 20–50%, and shock treatment increased it



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

by an additional 15–30%. The primary purpose of this DOE project is to scale-up shock treatment of oxidative lime-treated corn stover by systematically evaluating the following variables: vessel depth, shock pressure, slurry concentration, and vessel diameter. Using a shotgun shell, study one shows that vessel depth can be successfully increased. Study two shows that the digestibility benefit occurs even at lower pressure, and study three shows that substrate concentration can be increased. All of these results have positive economic implications. Study four is underway. In an industrial system, the shotgun shell will be replaced by igniting an explosive methane/air mixture. The construction of the methane/air apparatus is nearly completed and testing will soon begin. Preliminary economic estimates indicate that shock treatment costs are less than $5/ton.

Overall Impressions

- A lot of data were presented, but this reviewer questions the economic feasibility of the process.
- Project is interesting but need to see a lot more data to validate the concept.
- Project is not convincing and doesn't look feasible. There are too many slides. No peer-reviewed publications.
- The presentation was voluminous, and it became very hard to distinguish what has recently been accomplished. Significant amount of editing should have been performed. Slides should have been reduced to about 30. The work may be relevant to BETO objectives, but this reviewer is not sure how realistic it is for full-scale application.
- This is truly unique and innovative research but scale-up will be challenging.
- This project evaluated a very creative approach to the physical modification of biomass to complement more widely accepted pretreatment methodologies. Though it was not readily apparent, the team did follow a rational, hypothesis-driven approach to develop the technology. The performers are encouraged to develop a greater level of fundamental understanding about the proposed shock technology. This may prove invaluable down the road for technology transfer and scale-up.

PI Response to Reviewer Comments

- **Technical Feasibility** – Prior data from the Holtzapple research group show that shock treatment improves enzymatic digestibility of lime-treated biomass by 1.3 to 2.0 times. Prior data from Dr. Tedeschi's group show shock treatment increases rumen digestibility of lime-treated biomass by 1.25 times. Literature data (Xiong et al.) show shock increases acid hydrolysis by 2.0 times. This DOE project shows shock treatment reduced enzyme requirements by 2.0 times to achieve the same conversion (80%). This DOE project shows shock treatment increased mixed-acid yields by 1.15 times.
- **Insufficient Data** – Before taking more data, we were waiting to complete the 20-L shock vessel. The vessel is now completed and is ten times larger than the previous vessel.
- **Scale-up** – Recently, we demonstrated a ten times increase in scale. At the larger scale, the rate of pressure rise increased by 74 times compared to the smaller scale, so it scales well.
- **Economic Feasibility** – The residence time is short (30 to 90 seconds), so vessels are small. Equipment and operating costs are minimal. Total cost is estimated to be about $5/tonne. This compares favorably to conventional chemical pretreatments, which cost about $45/tonne. Economic studies show that shock saves about $0.44/gal by reducing enzyme requirements.
- **Fundamental Understanding** – We fully agree that increased fundamental understanding is desirable; however, the focus of this project is scale-up. We must seek other funding sources to understand the fundamentals.

- **Publications** – Only recently have we completed constructing the 20-L vessel. Now that it is complete, we can take the data to produce publications.
- **Lengthy Presentation** – Shock treatment is extremely new. To provide context for reviewers to fully understand the technology, it was necessary to accomplish the following: explain why mechanical treatment is needed to complement chemical treatment, establish that conventional mechanical treatments (e.g., ball milling) are too expensive, and explain how shock treatment works. These requirements added length.

PRETREATMENT AND ENZYMATIC HYDROLYSIS

(WBS#: 2.2.1.1)

Recipient:	NREL
Presenter:	David Johnson
Total DOE Funding:	$50,100,000
DOE Funding FY13:	$5,750,000
DOE Funding FY12:	$5,060,000
DOE Funding FY11:	$6,500,000
Project Dates:	2004–2017

Project Description

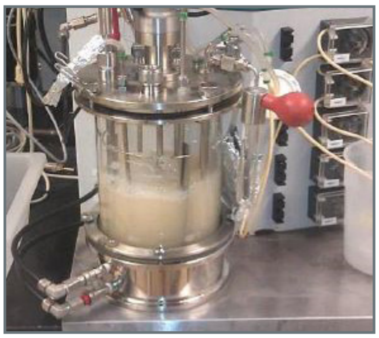
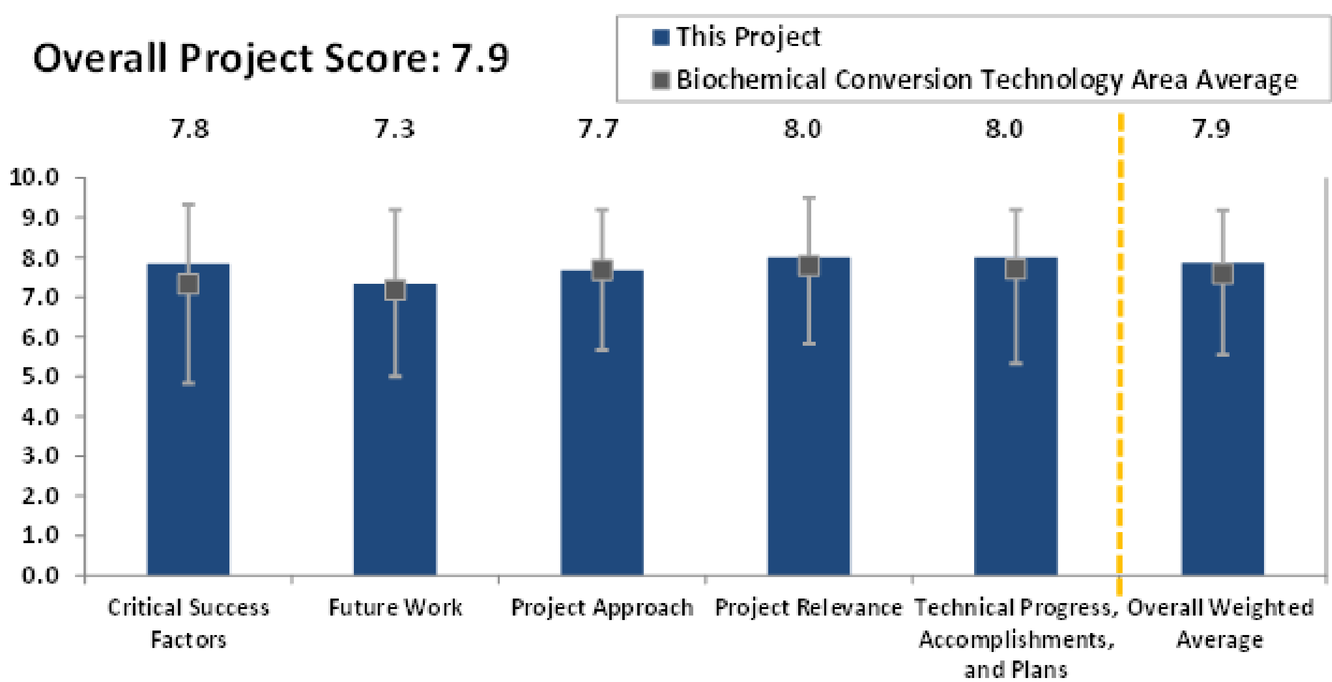


Photo Courtesy of NREL

The Pretreatment and Enzymatic Hydrolysis task applies fundamental pretreatment reaction and process knowledge to high-solids and continuous pretreatments and related deconstruction techniques to achieve high-recovered yields of sugars and/or other acceptable soluble carbon compounds while reducing pretreatment catalyst usage and formation of inhibitors. It also investigates the underlying hydrolysis process science to enable proper design of high-solids saccharification, solid-liquid separation, and hydrolysate concentration equipment, and seeks to understand how the presence of generated inhibitory compounds affects downstream upgrading processes. The process development work is guided and supported by foundational studies involving chemical and enzymatic hydrolysis, slurry rheology, hydrolysis reaction kinetics, enzyme component efficacy studies, hydrolysate composition characterization, and fermentation inhibitor identification and mitigation to enable effective fermentation of sugars by micro-organisms at robust process conditions. Feedstock preprocessing strategies, such as modification and scale-up of a deacetylation approach that improved sugar yields from less severe dilute acid pretreatments, were developed. This provided a more fermentable hydrolysate that allowed achievement



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

of higher ethanol yields and product concentrations. Additionally, various mechanical refining options were tested to identify a cost-effective approach to provide high enzymatic digestibility of more mildly pretreated slurries. Many of these developments were directly used in process operations associated with the 2012 Biochemical Platform lignocellulosic ethanol technical and cost target process demonstration at pilot scale. Activities that the Pretreatment and Enzymatic Hydrolysis task formerly conducted within a lignocellulosic ethanol context are being leveraged to provide a starting basis for application to hydrocarbon biofuels from sugar-derived soluble intermediates via biological and/or catalytic upgrading routes. The task also now includes a subtask to develop chemical transformation routes that can efficiently convert biomass-derived intermediates into fuel products that are compatible with the existing fuel distribution infrastructure, which fit within the specifications for gasoline, jet, or diesel fuels.

Overall Impressions

- NREL's pretreatment and hydrolyses evolution has been reasonable, fairly progressive, and productive. The techno-economic evaluation will be an important next step to this work. The pathways proposed for the hydrocarbon research are reasonable. Achieving cheap sugars is critical to the future.
- Solid presentation. There is an impressive array of tasks and progress. The PI has excellent command of overall effort.
- The ethanol work has been well done. The hydrocarbon work is well targeted, but it is very early to assess viability. Success depends greatly on the downstream operations.
- The overall impression was good. A well-presented project with innovative approaches that is forward thinking on aspects well beyond pretreatment (e.g., chemical synthesis of hydrocarbons).
- The work completed in support of the cellulosic ethanol targets was rigorous, thorough, and contributed to the successful pilot-scale demonstration of the 2012 cost targets. It is acknowledged that the initial work plans and feasibility experiments in support of the new hydrocarbon production technology area are very early stage. That being said, this group could benefit from additional direction from BETO and from greater interaction with the engineering modeling group. The establishment of appropriate goals and milestones for the hydrocarbon program will be critical to the success of this work.
- Very good summary and progress over the funded period. The project team needs more interaction with the TEA team to drive them.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

PROCESS IMPROVEMENTS TO BIOMASS PRETREATMENT FOR FUELS AND CHEMICALS

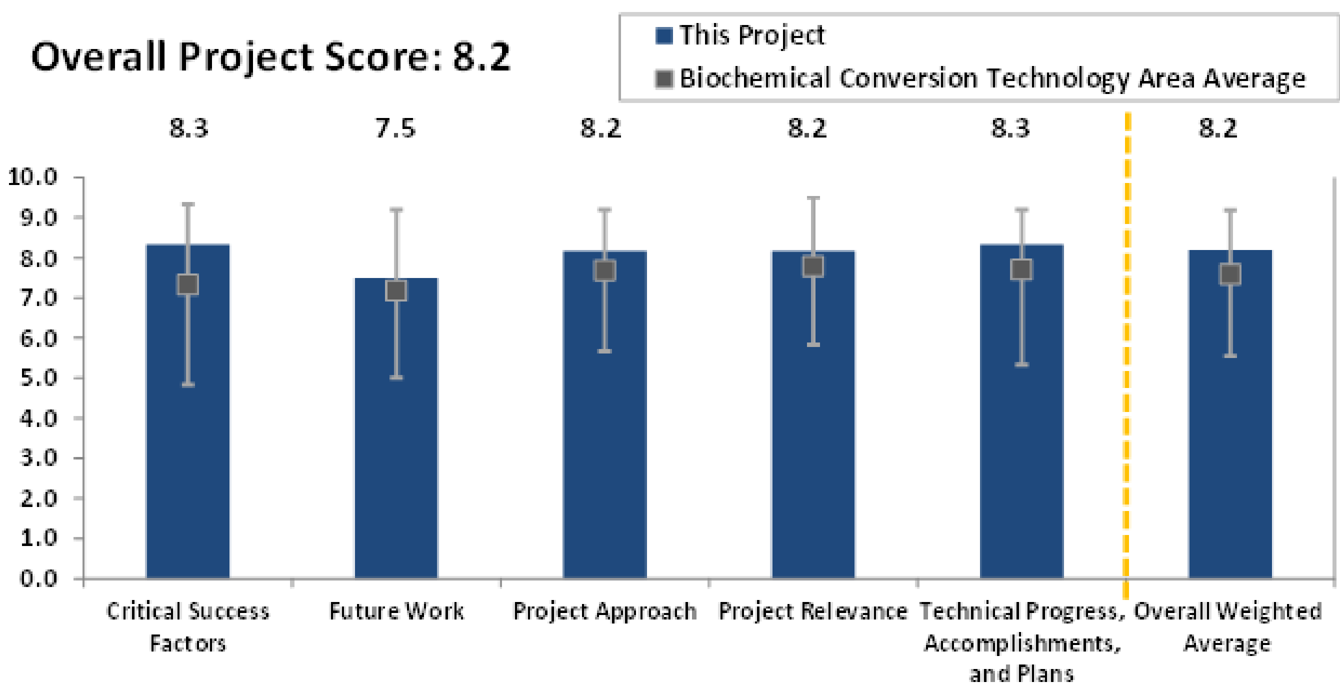
(WBS#: 2.2.1.6)

Recipient:	MBI
Presenter:	Farzaneh Teymouri
Total DOE Funding:	$3,676,944
DOE Funding FY13:	$1,425,650
DOE Funding FY12:	$1,425,650
DOE Funding FY11:	$118,807
Project Dates:	2011–2014

Project Description


Photo Courtesy of MBI

The Michigan Biotechnology Institute (MBI), a 501(c)(3) company focusing on de-risking and scaling up bio-based technologies, has teamed up with Michigan State University and Idaho National Laboratory to develop and demonstrate process improvements to the ammonia fiber expansion (AFEX) pretreatment process. The logistical hurdles of biomass handling are well known, and the regional depot concept—in which small, distributed biopro-cessing operations collect, preprocess, and densify biomass before shipping to a centralized refinery— is a promising alternative to centralized collection. The AFEX technology has traditionally been envisioned to be applied within a biorefinery, but it has several unique factors among pretreatments that would make it desirable as a pretreatment prior to densification at the depot scale. MBI has designed a novel approach to AFEX that can be scaled down economically to the depot scale at a 50% reduction in capital cost compared to the traditional design of AFEX. Thus, the purpose of this project is to develop, scale-up, demonstrate, and improve this novel design. The key challenges in this design are the recovery and purity of ammonia, consistent and complete pretreatment performance, and the overall throughput



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

of the reactor. To date, we have improved the process at the laboratory scale and designed and installed a 1-ton per day facility. Key factors demonstrated at the laboratory scale include greater than 95% ammonia recovery and greater than 70% sugar yields at high solid loading. Our current economic model shows a 57% reduction in AFEX capital cost at the 100 ton/day scale.

Overall Impressions

- Excellent presentation and progress, but the cost increase to biomass may be prohibitive. There could also be questions regarding safety issues for a large-scale facility.
- Good, well-focused project. Economic viability is questionable, but this assessment is part of the project plan.
- This is a nice extension of AFEX work; so far, it looks like this will be a useful approach.
- Overall this is a strong project. The approach is rigorous and logical, the milestones are quantitative, and the team is knowledgeable. The team's routine use of engineering modeling to support and inform research decisions is exemplary.
- This is significant research. The concept of a remote biomass treatment introduces some logistics issues that need to be addressed, and the overall techno-economic impacts incorporating the downstream production need to be completed, but the overall research is positive.
- This project has very good work if relevant to the overall goals of BETO.

PI Response to Reviewer Comments

- Our project addresses the key technical barriers of pretreatment cost and biochemical conversion process integration. Regional biomass processing depots can simplify biomass handling logistics and biochemical conversion process integration. AFEX-treated biomass in pellet form can be easily handled, stored, transported, liquefied, and fermented in a format similar to corn grain. This can lead to larger scale refineries, thus aligning biofuel production with the scale of oil refineries. To achieve these goals, it was necessary to reduce the cost of pretreatment at a depot. This led to the development of the packed bed AFEX, which is the focus of this project.
- A recent analysis by NREL suggests that pellet logistics and transportation can reduce the MESP for ethanol by approximately $0.30/gal if the refinery size is increased to 10,000 tons/day. Current analysis at Michigan State University confirms strong reduction in ethanol costs by using AFEX pellets and increasing the size of the centralized refinery. Increasing the size of the refinery can help to maintain the cost competitiveness of AFEX relative to other pretreatments.
- At commercial scale, we expect that AFEX can be run safely. Most ammonia releases occur from illegal methamphetamine production and farm related incidents. AFEX uses anhydrous ammonia similar to ammonia refrigeration systems, which is essentially a closed system where the ammonia is cycled between a vapor state and a liquid state using compressors. Lindborg (2009) reports that less than 6% of accidents in the refrigeration industry result in serious injury and that the probability of fatalities from ammonia handling in refrigeration systems has been estimated at less than three per billion. Accidents are primarily due to equipment failure and human error, both of which are preventable. After steam stripping, only a small amount of ammonia is left in biomass, which will be safe to handle.

PRODUCING TRANSPORTATION FUELS VIA PHOTOSYNTHETICALLY DERIVED ETHYLENE

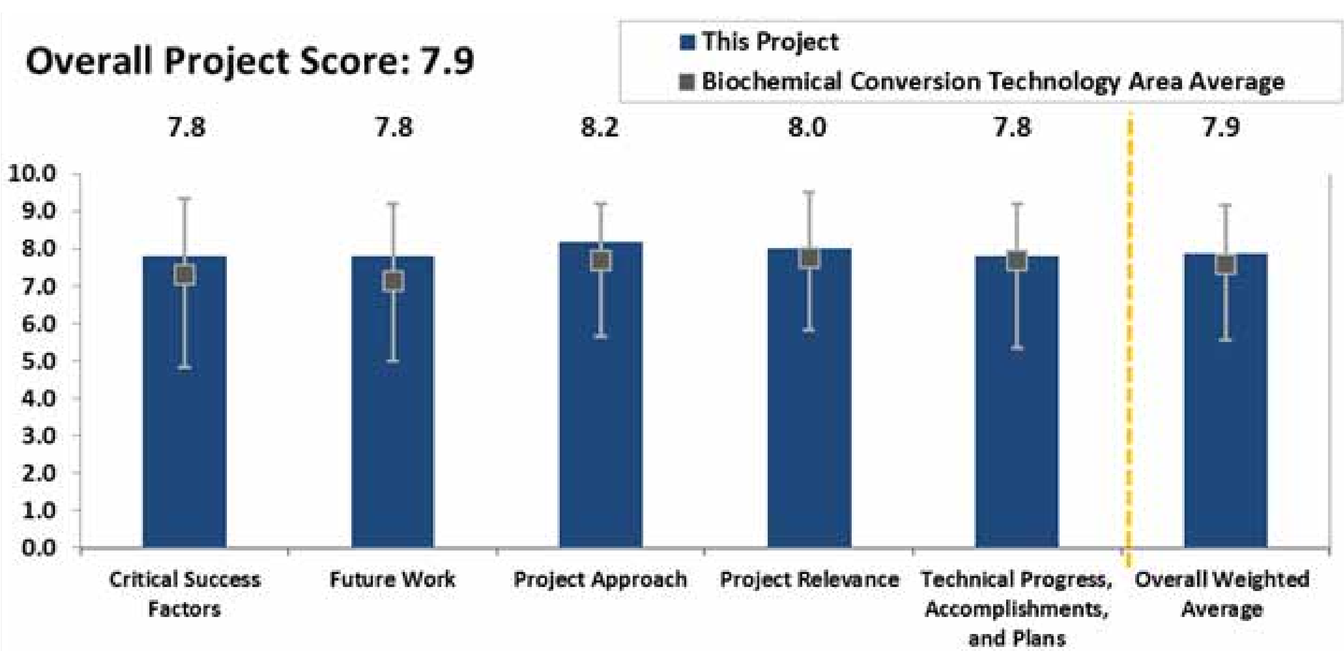
(WBS#: 2.3.3.3)

Recipient:	NREL
Presenter:	Jianping Yu
Total DOE Funding:	$480,000
DOE Funding FY13:	$180,000
DOE Funding FY12:	$150,000
DOE Funding FY11:	$150,000
Project Dates:	2010–2018

Project Description

Photo Courtesy of NREL

The objective of this task is to develop a novel photosynthetic CO_2-to-ethylene conversion system using genetically modified cyanobacterium. Ethylene is the most versatile building block for the production of diverse fuels and chemicals. Direct photosynthetic conversion of CO_2 to ethylene has the potential to reduce the nation's reliance on fossil fuels and lower GHG emission. Started as a seed project in fiscal year 2011, we have demonstrated sustained CO_2 to ethylene conversion in transgenic *Synechocystis* 6803 expressing the efe gene encoding ethylene-forming enzyme from the bacterium *Pseudomonas syringae*. A number of barriers were identified and overcome. The current peak productivity of at least 10 mg/L/Hr is among the highest in algal biofuels production. Ethylene is a gas, and therefore can be harvested from head space, avoiding cell harvesting and oil extraction in algal lipids production. We also demonstrated that sea water (with additional N and P nutrients) can support ethylene production. In addition, long-term ethylene production in day/night cycles demonstrated ethylene production over several weeks. Transgenic strains that can utilize xylose have been generated and have shown enhanced ethylene production with xylose utilization. Systems biology and genetic engineering approaches will be taken in order to identify and overcome current and future rate-limiting steps in cyanobacterial conversion of CO_2 to ethylene. The protein levels of ethylene-forming enzymes will



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be increased using synthetic ribosome binding sites in fiscal year 2013; new capability will also be established on metabolic flux analysis in *Synechocystis* 6803.

Overall Impressions

- As a technology area, this is a promising technology. The project has been well executed. Ethylene production, although attractive, does have drawbacks such as safety. Competing with petrochemical ethylene may be unrealistic, as it is extremely cheap and is produced in huge quantities.
- For relatively new research, this project has made significant progress and demonstrated a viable photosynthesis pathway to make ethylene that can be made into fuels and higher-value products.
- Interesting idea. Team should look at TEA to make sure this concept makes sense. The team needs to look at yields/rates. There could be safety issues with combustible gases.
- Obviously this is a very different project in the BETO portfolio. It is very interesting and unique. It is innovative, but at some point, it also has to become practical. Gas recovery from a photosynthetic commercial-sized system may be impossible. It would be very interesting if there were any relevant, large algae systems that are operated or have been operated to see if there is any chance of success, even if the strain could produce significant amounts of ethylene.
- Proof of concept has been demonstrated for the production of ethylene from CO_2 using a photosynthetic organism. Key hypotheses for further development of this work have been posed. It is recommended that an engineering model be created to assist in prioritizing future R&D efforts. Also, in light of the cheap availability of ethylene (approximately 0.60/lb), consideration should be given to the economic feasibility of this proposed pathway from both cellulosic sugars, as well as photosynthetic routes.
- Very impressive work and important in the long term for photosynthetic organism development.

PI Response to Reviewer Comments

- The PI appreciates the positive comments pertaining to the establishment of proof-of-concept and on-strain development. The concerns regarding safety, scaling, and commercial viability are valid, and addressing them requires industrial partners with expertise in culturing systems and ethylene processing. Accordingly, we at NREL have teamed with two such partners to address these concerns in our algal biomass yield proposal. In addition, we are developing TEA models for photosynthetic ethylene production, harvesting, and related conversion processes.
- We are aware that the current abundant supply of natural gas poses serious economic challenges for this project. However, development of alternative technology for the renewable production of fuels and chemicals remains a worthy goal for a number of reasons that are beyond the scope of this response. Nevertheless, we would like to point out that we have increased the ethylene volumetric production rate by a thousand-fold in only 2.5 years, to 30 mg/L/hr. This is among the highest photosynthetic productivities reported to date. There is still significant room for improvement, and we have developed a plan for enhanced productivity through metabolic engineering. The overall progress in ethylene production rates makes the reviewers' comments regarding the need for process engineering studies (outlined in the proposal) a high priority for future R&D efforts.
- Producing combustible gases certainly requires careful safety evaluations and measures. We have been working on bio-hydrogen production for many years, and that experience has helped with both strain development and risk mitigation. In the laboratory, when a photobioreactor is used for continuous ethylene production, the reactor is continuously flushed with CO_2 and air, so that the headspace ethylene concentration remains below 1%. Whether the same strategy or an alternative will be applicable at a large scale is under consideration.

SYNTHETIC BIOLOGY

(WBS#: 2.5.7.2)

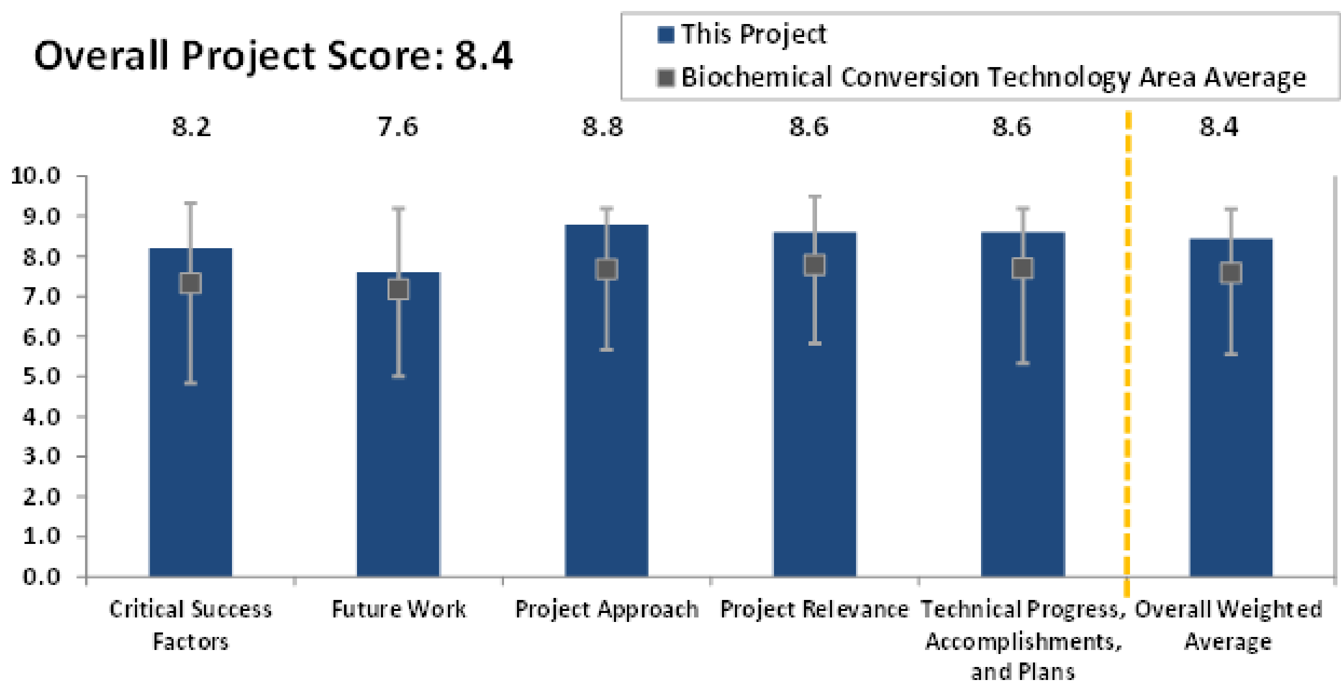
Recipient:	BETO
Presenter:	Gene Petersen
Total DOE Funding:	$10,200,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013–2015

Project Description

BETO solicited applications for research and development at TRL levels 2-4 in the area of applying synthetic biology to biochemical conversion of lignocellulosic biomass to fuels and chemicals. This complemented a similar FOA from the Office of Science in synthetic biology by requesting applications that would address specific barriers to effective use of biomass for fuels and chemicals. The FOA focused on the following two topic areas:

- **Topic Area 1**– Intermediate Production: Innovative synthetic biological approaches to the cost-effective fractionation of lignocellulosic biomass—both terrestrial and aquatic—into process-able components such as fermentable sugars, modified lignin suitable for conversion to higher-value materials, and oligomeric sugar fractions or biopolymers that are more easily converted to monomers for further processing.
- **Topic Area 2** – Intermediate Transformations: Innovative synthetic biological approaches to the cost-effective and high-yield conversion of process-able component fractions into advanced biofuels and high-energy impact bioproducts.

The FOA process and the selections are presented, as well as the expected impact on BETO's goals.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- A very interesting approach taken by a traditionally applied research program office. The advantage of doing it this way versus letting the Office of Science manage the basic research should probably be highlighted.
- It is encouraging to see BETO funding early stage research. Based on the limited information presented for each performer, it seems that BETO has selected a diverse group of awardees. It is too early to assess progress on any of these projects.
- This area of research is interesting and far-reaching. Potential impact on the future bioenergy program could be significant. This approach seems like a reasonable research pathway to find a "magic bullet."
- This reviewer would have liked to see more creative targets of projects. The methods are innovative, but problems are not all at the forefront of the field (e.g., cocktails of enzymes). This reviewer is not sure that this is what people would call a synthetic biology technology area-driven project.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

TARGETED CONVERSION RESEARCH

(WBS#: 2.4.1.1)

Project Description

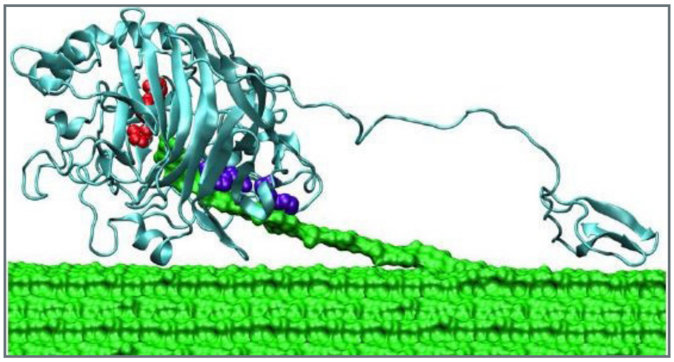
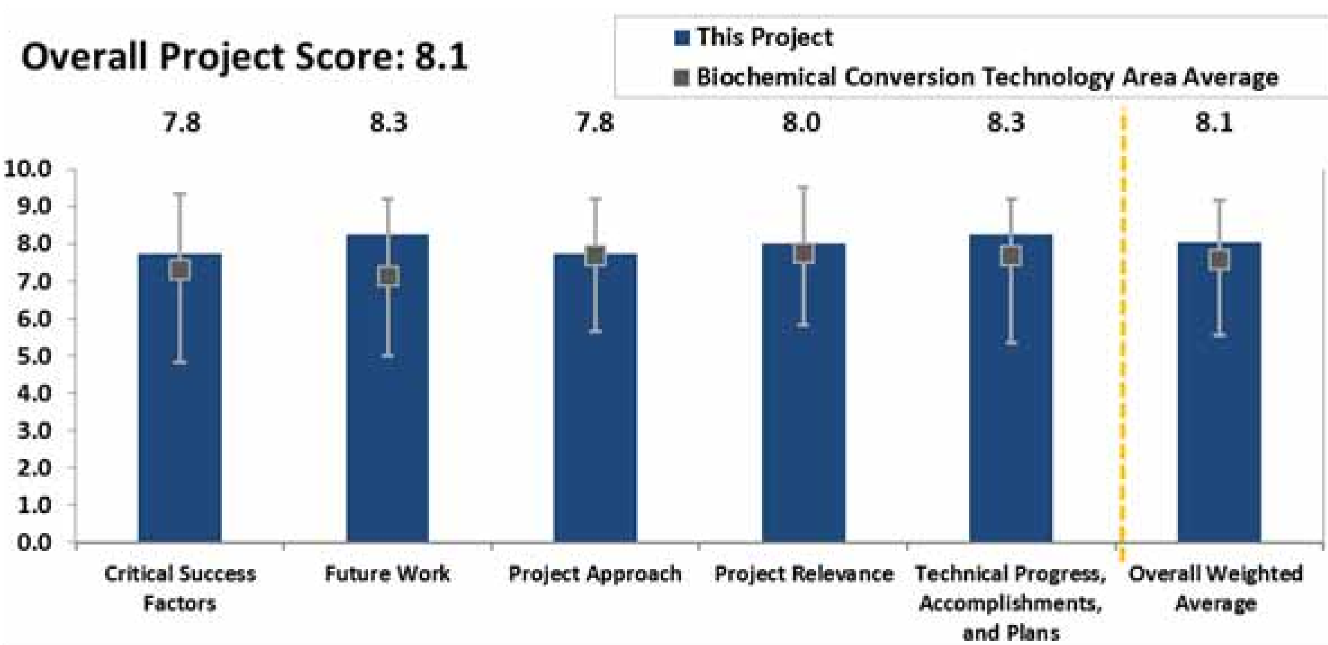


Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Mike Himmel
Total DOE Funding:	$38,900,000
DOE Funding FY13:	$4,750,000
DOE Funding FY12:	$5,000,000
DOE Funding FY11:	$6,500,000
Project Dates:	2001–2017

Work in the Targeted Conversation Research (TCR) task addresses multiple priorities stated in the EERE Strategic Plan. The TCR work plan will conduct research designed to help reduce dependence on foreign oil by developing cutting-edge technologies that enable the development of a variety of advanced fuels from biomass. In response to the 2017 goals and beyond, we will develop a platform that targets the production of a variety of high-energy intermediates, which will be suitable for use in the production of multiple advanced fuels. In fiscal year 2011, we began to evaluate and develop the microbial production of advanced biofuels. Our goals for 2013 are to address the 2017 BETO objective to develop new hydrocarbon fuels from biomass that will enable the Office to meet or exceed the renewable fuels standard targets. Additionally, technology developed by TCR will generate new understandings in the production of advanced hydrocarbon biofuels, maintaining the cutting-edge science and reputation required to achieve DOE's goals, and continue to provide the basic understandings of conversion technology to this



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burgeoning industry. This work will ensure the availability of new scientific knowledge needed by industry to develop future biorefinery processes. In parallel, conducting the critical core research of understanding enzyme structure-function relationships, cellulase-substrate interactions, and the correlative development of promising microbial strains to convert biomass directly to advanced fuels will ensure attainment of DOE's post-2012 goals. To achieve the DOE goal of enabling new technologies to provide 60 billion gallons of biofuels by 2030, considerable improvement in enzyme saccharification of plant cell walls must be achieved, as well as the development of new advanced drop-in fuels (e.g., hydrocarbons) from biomass. Toward these goals, we have applied protein engineering principals to a fungal cellobiohydrolase and increased its specific performance by more than two-fold. We have also recently demonstrated that lipogenic yeast can express active fungal cellulases and that long chain hydrocarbons can be produced by fungi growing on sugars.

Overall Impressions:

- Extensive amount of research going on in this project. It seems like there are numerous tasks and findings all going on simultaneously. The cycle back and forth between enzyme development and pretreatment is important. Several publications generated from this research to date are significant.
- The inclusion of basic, fundamental research in the portfolio is a good investment in the long-term viability of BETO's mission. The output of this work may not be immediately viable for commercialization, but the knowledge that is created may prove to be invaluable down the road. The government is uniquely positioned to fund this type of work and it should be maintained.
- This is not a single unified project, but rather, an evolving group of projects. It has a strong track record and will certainly continue to be productive. The advanced biomass deconstruction aspect is the strongest. The structure component (both x-ray and bioinformatics) of the structure, simulation, and theory aspect is strong, but this reviewer has reservations about practical knowledge arising from application of simulation and theory to these complicated systems. The direct microbial sugar conversion aspect will be very challenging, but it is important to gain this fundamental knowledge despite the extreme technical difficulty.
- This is very fundamental research to get a better understanding of what's happening at the molecular level, which will result in improved enzymes and decreased costs.
- This is a very impressive body of work demonstrating how fundamental knowledge may benefit applied project goals. This reviewer just wishes there had been more highlights demonstrating technology impact.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

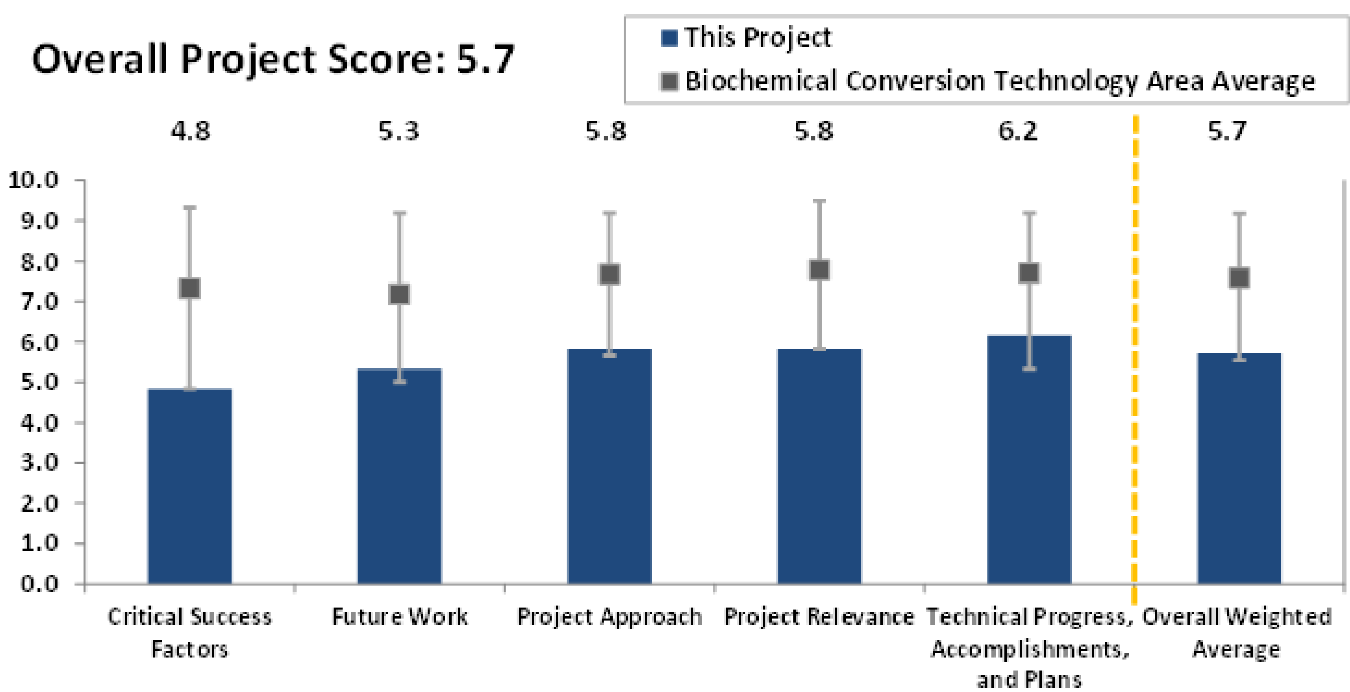
U.S.-INDIA CONSORTIA FOR DEVELOPMENT OF SUSTAINABLE ADVANCED LIGNOCELLULOSIC BIOFUELS SYSTEMS PROJECT

(WBS#: 2.3.2.13)

Recipient:	University of Florida
Presenter:	Pratap Pullammanappallil
Total DOE Funding:	$2,576,853
DOE Funding FY13:	$1,397,702
DOE Funding FY12:	$1,179,151
DOE Funding FY11:	--
Project Dates:	2012–2017

Project Description

This project is a collaborative effort between institutions and researchers in the U.S. and India to address the second-generation biofuel R&D priority area of the U.S.–India Joint Clean Energy Research and Development Center. It emphasizes sustainable feedstock cultivation and supply, biochemical conversion technologies for production of second generation biofuels with minimal environmental impact, and analysis of overall sustainability and supply chain of feedstocks and biofuel. The project addresses all aspects of biofuel production and supply, including feedstock production, conversion technologies, and supply chain analysis. The project is divided into three work program areas encompassing feedstock development and supply, biorefinery technologies, and sustainability analysis. The specific objectives of the U.S. component of the project are outlined here. The objectives for the feedstock development and supply program area are to improve switchgrass and biomass- sorghum feedstocks (both production potential and feedstock quality) using genomics and breeding tools, and to identify locally adapted cultivars and their optimization for large-scale production. Additional goals include developing production logistics and identifying soil and environmental criteria to ensure a commercially successful, advanced feedstock production system using marginal lands. The objectives of the biorefinery technologies work program area are to develop a biocatalyst for the production of butanol from switchgrass hydrolysate, and to develop products from biorefinery waste streams that minimize environmental impact and



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

maximize revenues. Objectives of the sustainability analysis program area include analysis and development of certification protocols and sustainability standards, assessment of energy requirements and emissions, and performance of economic analyses and supply chain management analysis. Successful completion of the project is expected to result in benefits for both the U.S. and India by delivering a commercial working model for feedstock production and supply, biochemical conversion approaches, other biorefinery technologies that have been validated on pre-commercial-scale systems, and overall economics and sustainability of biofuel production and supply systems.

Overall Impressions

- International cooperation is a good thing. The overall project is all-encompassing from growing the feedstock to obtaining the final product. The goals are pretty ambitious for the length of schedule. The schedule seems to be very aggressive.
- Most of this work appears repetitive of previously funded work at NREL and elsewhere.
- The overarching purpose and scope of this project looks good from a distance, but it is lacking substance and detail.
- This project is way too ambitious. It cannot possibly be completed in this amount of time. It is very possible that you could demonstrate the proof of concept for many of the activities, but it will—in the end—look like a lot of unfinished tasks. My recommendation would be to review the project, select a couple of significant, important tasks, and fund them separately. It does not look like the project is very well integrated as an international project. They are using different crops and this reviewer doesn't think it was ever communicated what the partners in India and U.S. contribute to the joint project, other than work on biofuel.
- This project seems to be a high-risk, low-reward program. As other reviewers have noted, the agricultural aspects of this program have been addressed at length over many years. The proposal to use a new engineered strain and pathway for the production of butyric acid (with subsequent conversion to butanol) is extremely high risk. This risk seems to be underappreciated by the performers; appropriate risk mitigation strategies should be developed.
- This is a very challenging project to manage. It has some solid partners, but it needs to emphasize teamwork to be successful.

PI Response to Reviewer Comments

- We are aware that the project may appear to be ambitious and requires hard work on the part of the participants both in India and in the U.S. to accomplish the objectives. However, we understand the importance of the need for alternate fuel in both countries. We hope to have at least one crop evaluated from the field through the pilot plant scale during the project period to provide necessary LCA information to evaluate the overall process for potential commercial deployment. This information will be extremely useful as we extend to other crops. We already have a pilot plant under operation utilizing sugar cane bagasse as feedstock. In our experience, the information gained from sugar cane bagasse process is readily transferable to other grass-based feedstocks with appropriate modification.
- This project addresses three areas of research that relate to feedstock production, biochemical conversion and evaluation of the overall sustainability and economic analysis of the biofuel production process. Feedstock production will focus on using marginal lands for switchgrass cultivation, the details of which are given below. The biochemical conversion aspects will primarily investigate a novel approach for butanol production via butyric acid fermentation. As far as we are aware, previous NREL projects have not addressed these aspects.

- We are using one common crop—sorghum—and conducting joint research by screening 250 cultivars in India and the U.S. We are also investigating nitrogen and water use efficiency by using appropriate techniques including stable isotopes. The U.S. team is training the Indian team in the use of 15N stable isotope. While the other species are different (switchgrass in the U.S. and pearl millet in India), they are both C4 bunch grasses.
- Although many agronomic aspects of growing sorghum, switchgrass, and pearl millet have been explored over the years (including in our programs), we are exploring research questions that have not been addressed by our team or any other team elsewhere. There are unique challenges faced by landowners in growing these biofuel crops on marginal land, land that is prone to drought, floods, and salinity. Simple screening work to identify genotypes that can be deployed on such harsh landscape had not been conducted until we started this project.
- We do not think metabolic engineering of bacteria for production of butyrate is high risk. Bacteria such as Clostridium butyricum naturally produce butyrate as a fermentation product, although at a lower yield. Butanol-producing recombinant bacteria have been reported by several laboratories. In contrast to butanol production, butyrate production is redox-balanced and appropriately engineered bacterium, such as a recombinant Escherichia coli, is expected to produce butyrate as a required part of anaerobic growth. We have already cloned the needed genes and constructed a synthetic operon encoding the needed enzymes for the butyrate pathway. We are in the process of optimizing expression of these genes. Additional strategies to enhance butyrate productivity are underway.
- We are developing an overarching project management plan that will encompass research carried out by both India and U.S. partners that will include quantifiable milestones for scope of work by consortia. Project progress will be measured against these integrated milestones.

VALIDATION TASK - INTEGRATED PROCESS

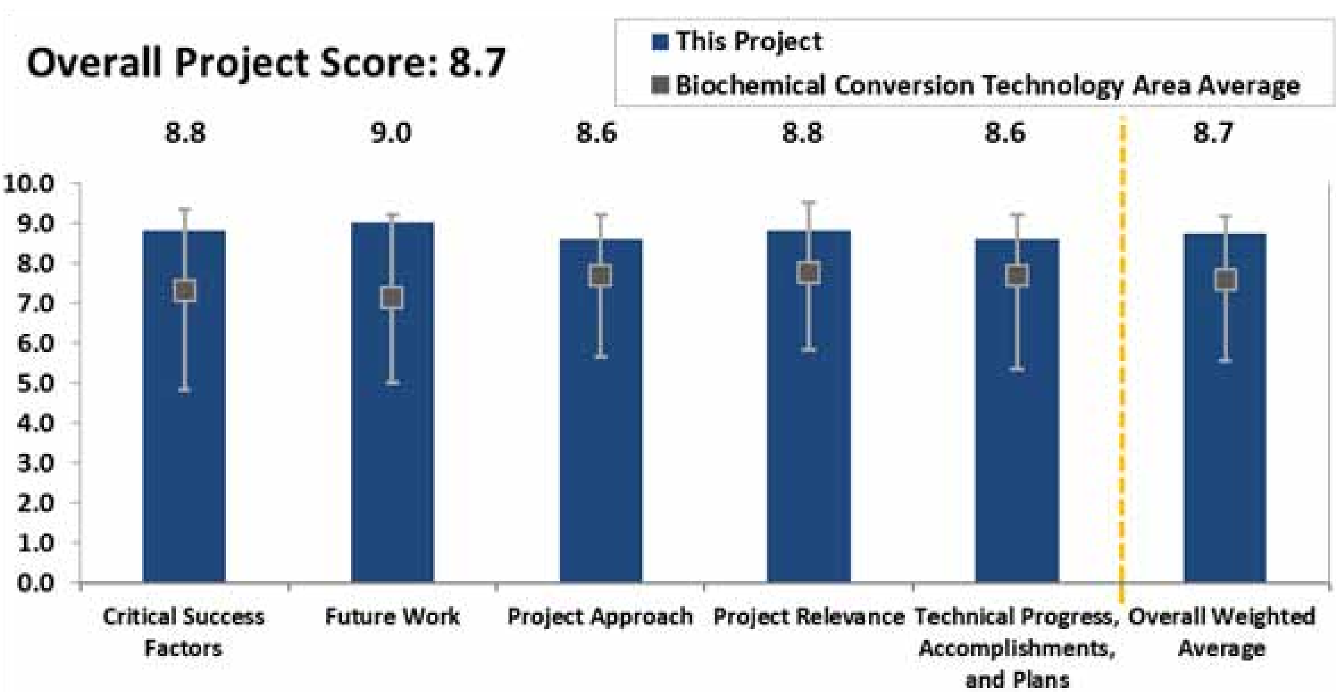
(WBS#: 2.3.1.7)

Recipient:	NREL
Presenter:	James McMillan
Total DOE Funding:	$850,000
DOE Funding FY13:	--
DOE Funding FY12:	$850,000
DOE Funding FY11:	--
Project Dates:	2010–2015

Project Description

Photo Courtesy of NREL

This task validates the biochemical process performance and cost improvements (BC Process Improvements) being achieved in five DOE cost-shared projects to improve sugar platform technologies for converting lignocellulosic feedstocks to advanced hydrocarbon biofuels or chemicals. Three of the projects focus on improving a single unit operation, either the pretreatment step in the case of MBI and Texas Engineering Experiment Station (TEES), or the biomass sugar-to-product conversion step in the case of Genomatica. The other two projects—being performed by Virdia and Virent—focus on improving integrated operations across multiple unit operations spanning primary conversion of lignocellulose to sugars and secondary conversion of sugars to product. Virdia's project is based on saccharification using concentrated hydrochloric acid, followed by microbial upgrading of sugar to product. Virent's project is based on saccharification using pretreatment and enzymatic hydrolysis, followed by catalytic upgrading of sugar to product. This task validates each project by verifying the integrity of its methods and reported results, both baseline performance results and cost estimates as originally proposed or established during initial project validation, as well as progress towards achieving intermediate and final improvement targets made through the course of the project. Project validations—initial, intermediate, and final— are carried out



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

by reviewing each project's performance measurement and cost estimation methodologies, conducting site visits to directly observe key performance tests, and having appropriate "unknown" samples (composition known to validation team) analyzed using the project's standard analytical procedures. In fiscal year 2012, this task completed initial project validations establishing baseline project performance levels for the processes or process technologies being developed by Genomatica, MBI, TEES, and Virent. The initial validation for Virdia was completed in early fiscal year 2013. Intermediate project validations are scheduled to start in the second half of fiscal year 2013.

Overall Impressions

- A good portfolio of projects with sound timelines and measurable milestones.
- It is an absolutely required process and is very well managed.
- The implementation of the validation task provides a welcome level of quality assurance to BETO's portfolio. The group has implemented many of the quality attributes and methodologies that are more typically found in a regulated industry, such as pharmaceuticals. One additional positive outcome of this work could be to provide to the community-at-large with a summary of non-confidential lessons learned during the validation process.
- This is clearly a work in progress. We will have to see if this level of oversight is necessary and effective. This effort may be redundant. Should this be more of a consulting service to performers?
- Validation is a very viable process to understand where the projects are and the real achievements they have made. This process keeps the projects honest and accountable to DOE.
- This is a very important activity to monitor research awards and their progress. What is not exactly clear is how the merit review fits into this.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

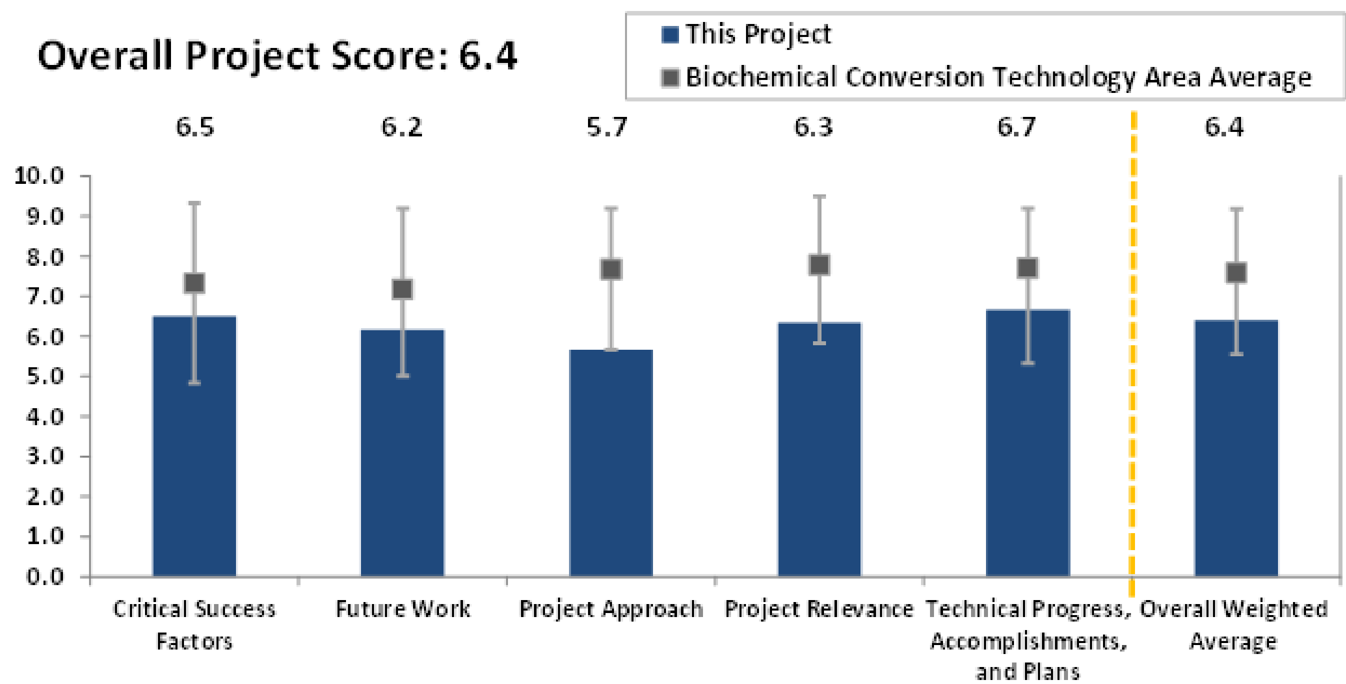
ZYMOMONAS ENGINEERING

(WBS#: 2.3.2.12)

Recipient:	NREL
Presenter:	Min Zhang
Total DOE Funding:	$500,000
DOE Funding FY13:	$500,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012–2017

Project Description

The project applies metabolic engineering and synthetic biology tools to engineer *Zymomonas mobilis* for synthesis of high-energy fuel molecules that can be converted into renewable fuels, and it also seeks to identify, understand, and overcome the critical barriers for conversion of lignocellulosic feedstocks to hydrocarbons. This project supports one of the critical pathways for utilization of biomass sugars for advanced fuels production and contributes to achieve the goal of producing renewable gasoline, renewable diesel, and renewable jet fuel from cellulosic biomass at $3/gge by 2017. We have demonstrated production of farnesene (C15) from glucose and xylose in *Z. mobilis*, as well as production of fatty acids (C12–C18), by expressing heterologous genes for the respective hydrocarbon synthesis pathways. Critical success factors and challenges are to meet near-term and future technical targets for DOE's 2017 goals for advanced biofuels. Future work will focus on continuing to develop effective synthetic biology tools to down-regulate the carbon flux from pyruvate to ethanol formation to eliminate or reduce formation of this by-product. We will up-regulate hydrocarbon producing pathways and over-express key pathway genes to enhance the hydrocarbon production. Understanding of the impact of hydrocarbon synthesis on bioenergetics and redox with improved omics technologies can provide insights to devise strategies to overcome the technical



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

barriers. This will lead to the development of robust strains that are capable of producing hydrocarbons at high yield, rate, and titer from biomass sugars. This work leverages the recent successful 2012 demonstration of cellulosic ethanol conversion process using this organism.

Overall Impressions

- This reviewer questions using *Z. mobilis* as a production host in this case. It seems that it was chosen because there has already been a lot of work done with *Z. mobilis* at NREL. It was originally isolated in the production of tequila, so it is very appropriate for cellulosic ethanol, but not necessarily for other hydrocarbons. The physiology of *Z. mobilis* may not be able to support high level production of a non-ethanol product.
- NREL has done a tremendous amount of research on *Zymomonas*. Building on this knowledge makes some sense, but it will be important to look ahead at the go/no-go decision points and objectively make a decision to either stay the course or look at alternative organisms.
- This is an ambitious, high-risk project. It requires much technical work that may be beyond the scope of the available funding and staffing.
- This project, the work to date, and the proposed future work are appropriate for this early-stage scoping project. Effort should be placed on completing the TEA as soon as possible so that it may inform future research targets. In light of the significant economic challenges of producing a hydrocarbon fuel from biomass sugar feedstock, it is recommended that the performer consider higher value products. Comments to DOE: DOE needs to fish or cut bait on these approaches. If DOE decides there is value in establishing an "in-house" strain/platform to evaluate and validate the various proposed hydrocarbon approaches, then significantly more resources should be deployed to develop the necessary metabolic engineering tools to support this effort. The research, development, demonstration, and deployment path from point of contact to commercial relevance is incredibly long, and the amount of funding necessary to advance this work will be significant.
- This reviewer is very concerned that the genetic tools will become advanced to the point where significant advances in metabolic engineering can be achieved.
- Work has already been done on some of these compounds (Peralta-Yahya et al., 2011, Identification and microbial production of a terpene-based advanced biofuel. Nature Comm. 2, 483) in both *E. coli* and *S. cereviciae*. Why are we doing it in *Zymomonas*? What are the big benefits to doing it in that strain? This reviewer simply could not see any particularly good reason to do it in another strain without some compelling evidence that it represents a better choice in the current environment where the other strains appear to be the choice of most biofuel applications and commercial favorites.

PI Response to Reviewer Comments

- *Z. mobilis* intrinsically possesses several unique properties (the membrane lipids contain very abundant triterpenic isoprenoids and unique fatty acid composition) that potentially make it well suited to serve as an anaerobic microbial platform for hydrocarbon (hydrocarbon) production from lignocellulosic biomass. *Z. mobilis* is well known for both its high specific glucose uptake rate and rapid catabolism and is engineered to metabolize all the major biomass sugars. We seek to take the advantages of the organism's metabolic capabilities and are attempting to redirect the carbon flow to other energy-dense fuel products. It is a good idea to consider high value products as well. Concerns about using *Zymomonas* for hydrocarbon production are well taken. There are a number of go/no-go decision points in year two and year three to help us measure whether we should continue the research activities on *Zymomonas* or redirect resources to investigation of alternative organisms. TEA analysis will be conducted to provide guidance on economically relevant research targets. This is an ambitious high risk and potentially high return project and additional funds will certainly provide more resources to advance the project at a faster pace. Researchers showed very promising results using both *E. coli* and *S. cerevisiae* through metabolic engineering approaches to enhance the production of hydrocarbon from a few milligrams per liter to hundreds of milligrams per liter. Our initial attempt of introducing the farnesene synthase gene has so far resulted in achieving a titer of approximately 35 mg/L. Our goal is to improve the product titer and yield using the available genetic tools developed in the ethanologen project and apply new metabolic tools as they become available.

UNIVERSITY OF NEBRASKA-LINCOLN, BIOENERGY DEMONSTRATION PROJECT: VALUE-ADDED PRODUCTS FROM RENEWABLE ENERGY FUELS

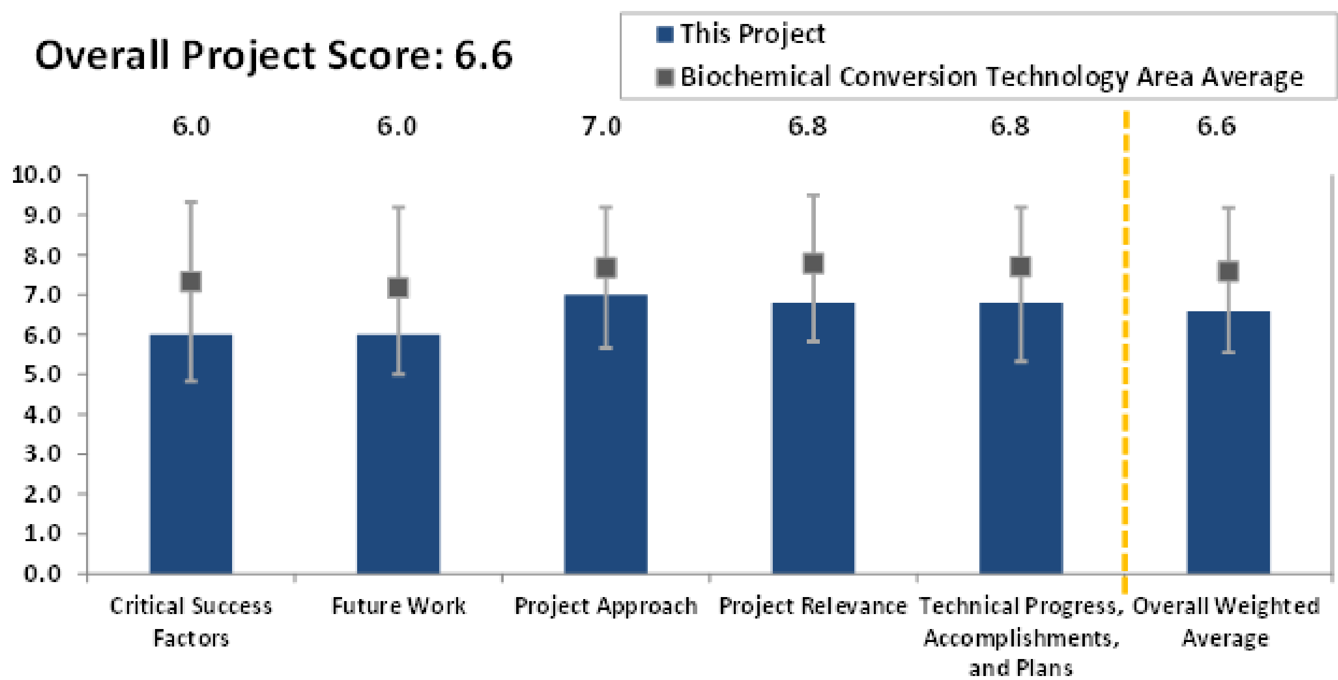
(WBS#: 7.2.1.1)

Recipient:	University of Nebraska-Lincoln
Presenter:	Paul Blum
Total DOE Funding:	$1,920,175
DOE Funding FY13:	$50,000
DOE Funding FY12:	$50,000
DOE Funding FY11:	$50,000
Project Dates:	2008–2013

Project Description

Photo Courtesy of University of Nebraska-Lincoln

Third-generation cellulosic ethanol is an emerging solution that will make strong contributions to U.S. domestic energy needs. Technology underlying this process will replace commodity enzymes with engineered microbes to convert biomass-derived lignocellulose feedstocks into biofuels and value-added chemicals. The approach used here is based on consolidated bioprocessing. Thermoacidophilic microbes belonging to the *Domain Archaea* will be employed for the deconvolution and saccharification of lignocellulose to maximize biofuel yields. Biomass pretreatment (hot acid) will be combined with fermentation using an extremely thermoacidophilic microbial platform. The identity and fate of released sugars will be controlled using metabolic blocks combined with added biochemical traits where suitable. Liquid chromatography-mass spectrometry (LC/MS) analysis supported through the newly established Nebraska Bioenergy Facility will provide general support for bioenergy researchers at the University of Nebraska. The primary objectives are to screen thermoacidophilic taxa for the ability to deconvolute lignocellulose and depolymerize associated carbohydrates; evaluate and respond



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

to formation of "inhibitors" that arise during incubation of lignocellulose under heated acidic conditions; identify and engineer "sugar flux channeling and catabolic blocks" that control and, where necessary, redirect metabolic pathways to maximize sugar concentrations; expand the hydrolytic capacity of extremely thermoacidophilic microbes through the addition of deconvolution traits; and establish the Nebraska Bioenergy Facility (NBF) at the University of Nebraska-Lincoln.

Overall Impressions

- Interesting research on cell lines and compatibility in hydrolysates.
- Overall impression was good. It was a very modestly funded project (after the equipment had been purchased). For the small amount of money they received, they presented some interesting results.
- This is a somewhat unfocused project. Aspects of the project are potentially promising, but the data provided aren't compelling and raise as many questions as answers.
- This is a variation on other CBP programs that could contribute to cost reduction, but the final production process may be complex.
- This is an early-stage, basic research project. The team could benefit from stepping back and thinking about the problem holistically and possibly refocusing their efforts on the highest priority issues. The use of a TEA would facilitate this effort. The presentation would benefit from the use of a process flow diagram to clearly communicate the vision of the project.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

BIODIESEL

TECHNOLOGY AREA

INTRODUCTION

The Biodiesel Technology Area was one of nine key technology areas reviewed during the 2013 Bioenergy Technologies Office (BETO or the Office) Project Peer Review, which took place on May 22, 2013, at the Hilton Mark Center in Alexandria, Virginia. A total of 12 projects were reviewed by four external experts from industry, academia, and other government agencies. This review represents a total U.S. Department of Energy (DOE) value of approximately $25 million, which is roughly 2% of the BETO portfolio reviewed during the 2013 Peer Review. The principal investigator (PI) for each project was given approximately 30 minutes to deliver a presentation and respond to questions from the review panel. Projects were evaluated and scored for their project approach, technical progress over two years, relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Project Peer Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI for the project. Overview information on the Biodiesel Technology Area and full scoring results and analysis are also available in this section. BETO designated Mark Elless as the Biodiesel Technology Area review lead. In this capacity, Dr. Elless was responsible for all aspects of review planning and implementation.

BIODIESEL TECHNOLOGY AREA

OVERVIEW

All biodiesel projects reviewed at the 2013 Peer Review were funded as Congressionally-directed projects (CDP), meaning that Congress specifically directed allocation of funds for a particular project (e.g., earmark). Projects funded in this manner avoid the merit-based or competitive allocation process established by the Executive Branch. This is often done so without consideration of the needs of the Office overseeing these projects.

BIODIESEL SUPPORT OF OFFICE STRATEGIC AND PERFORMANCE GOALS

BETO is overseeing nearly two dozen CDPs related to biodiesel. However, BETO has not placed a heavy focus on biodiesel in its program and has avoided competitive selections for biodiesel projects for a variety of reasons, including the following:

1. Food versus fuel debate: 54% of biodiesel is still made with soybean oil, which is edible oil.
2. Temperate oil crops that are typically used for biodiesel have a fairly limited energy density per acre (e.g., soybeans, rapeseed, sunflower, corn, camelina, etc.), which makes them uneconomical for use as fuels (without subsidies).

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

3. The potential impact of additional federal research funds is regarded as low (excluding algal oils):
    a. Biodiesel may be considered a mature technology, with the industry reaching Renewable Fuel Standard (RFS2) targets for biodiesel each year, when subsidized
    b. The chemistry of the transesterification and/or esterification process for producing biodiesel from fats and oils is well known, and only incremental advances to the production of biodiesel are expected.

TECHNICAL AND MARKET CHALLENGES AND BARRIERS

BETO has identified the following key challenges for achieving the goals of the Biodiesel Technology Area.

Market Challenges	Technical Challenges
Food Versus Fuel Debate	Low energy density per acre limits usefulness as fuel
Requires Subsidies to Meet Renewable Fuel Standards Targets	Transesterification and/or esterification process is well understood with little room for major technical advancement

REVIEW PANEL

The following external experts served as reviewers for the Biodiesel Technology Area during the 2013 Project Peer Review.

Biodiesel Reviewers	
Foster Agblevor	Utah State University
Suresh Babu	Brookhaven National Laboratory
Jack Lewnard	Gas Technology Institute
John Scahill	Thermal Biofuels Consultants, LLC, retired National Renewable Energy Laboratory and Golden Field Office

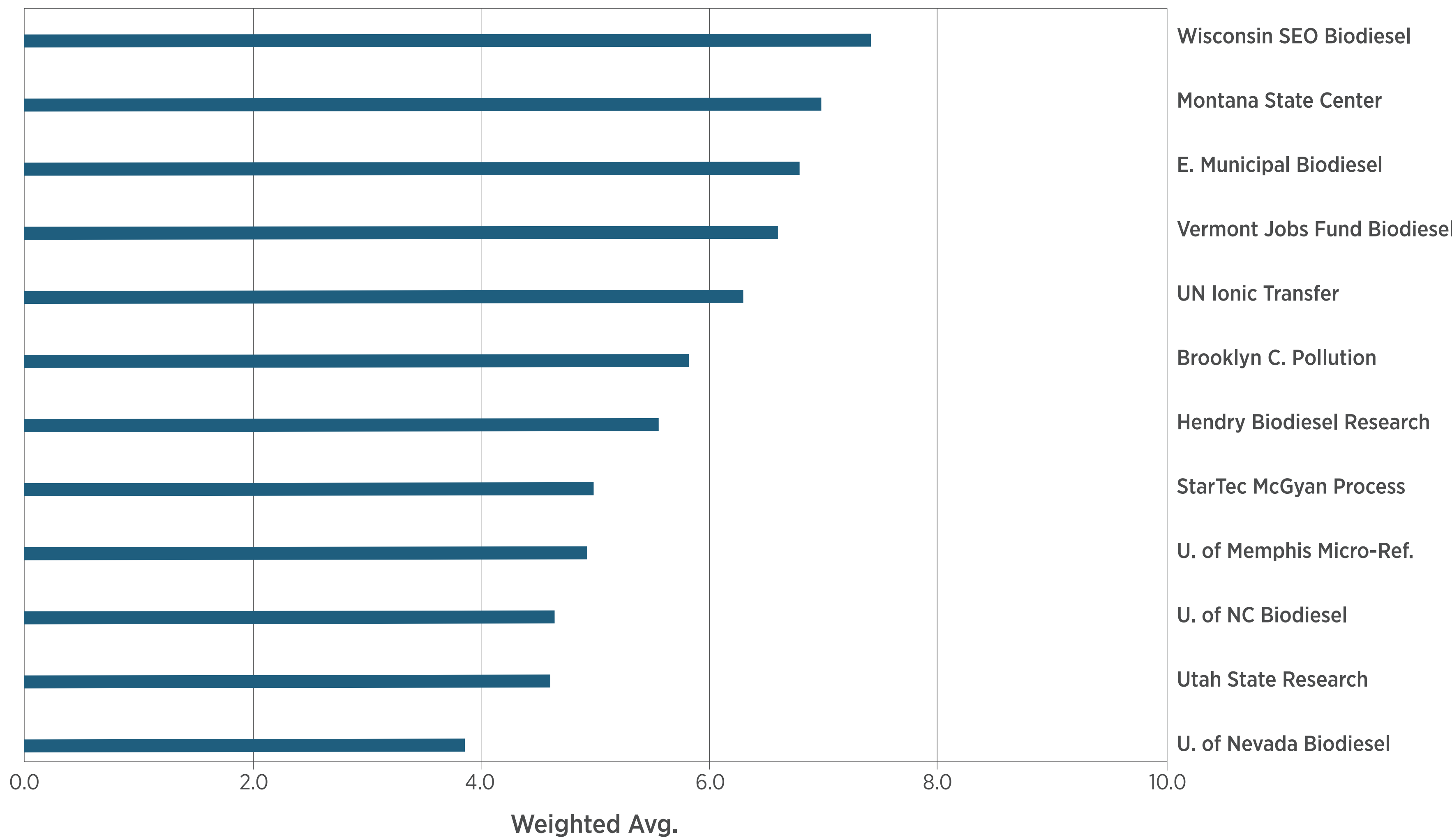
FORMAT OF THE REPORT

Information in this report has been compiled as follows:

- **Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.
- **Project Scoring Information and Short Names Key**: The final score charts depict the overall weighted score for each project in each technology area. Short names for each project were developed for ease of use in the scoring charts, the table of contents, and other locations. Full project names, along with their designated short names and their work breakdown structure (WBS#), are provided in the Short Names Key.
- **Review Panel Summary Report**: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.
- **BETO Programmatic Response**: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.
- **Project Reports**:
    - **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space constraints allotted.
    - **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
    - **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and the whiskers depict the range of scores for each category within each technology area.
    - **Reviewer comments** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant by BETO's director were excluded from the final report.
    - **PI Responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the review panel. This unique formatting was maintained to uphold the integrity of the comments.

TECHNOLOGY AREA SCORE RESULTS



SHORT NAMES KEY

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
7.8.1.22	Biodiesel Blending Program	Wisconsin State Energy Office (SEO), Office of Energy Independence	Wisconsin SEO Biodiesel
7.6.2.7	Montana Bio-Energy Center of Excellence	Montana State University-Northern	Montana State Center
7.8.1.21	Biodiesel Production from Grease Waste	Eastern Municipal District	E. Municipal Biodiesel
7.4.5.8	Vermont BioFuels Initiative	Vermont Sustainable Jobs Fund	Vermont Jobs Fund Biofuels
7.4.1.1	Development of Biofuels Using Ionic Transfer Membranes Phase III	University of Nevada, Las Vegas	UN Ionic Transfer
7.7.2.18	Development of Pollution Prevention Technologies	Brooklyn College	Brooklyn C. Pollution
7.1.5.12	Biodiesel Cellulosic Ethanol Research Facility	Hendry County	Hendry Biodiesel Research
7.5.3.1	Use of Inedible Energy Crops for Production of Advanced Biofuels with the McGyan Process	SarTec Corporation	StarTec McGyan Process
7.8.1.25	Biofuel Micro-Refineries for Local Sustainability	University of Memphis	U. of Memphis Micro-Ref.
7.8.1.26	Development of an Economic and Efficient Biodiesel Production Process	University of North Carolina at Pembroke	U. of NC Biodiesel
7.7.2.21	Alternative and Unconventional Energy Research and Development	Utah State University	Utah State Research
7.7.2.20	Biodiesel from Food Waste	University of Nevada, Reno	U. of Nevada Biodiesel

CONTENTS

BIODIESEL BLENDING PROGRAM

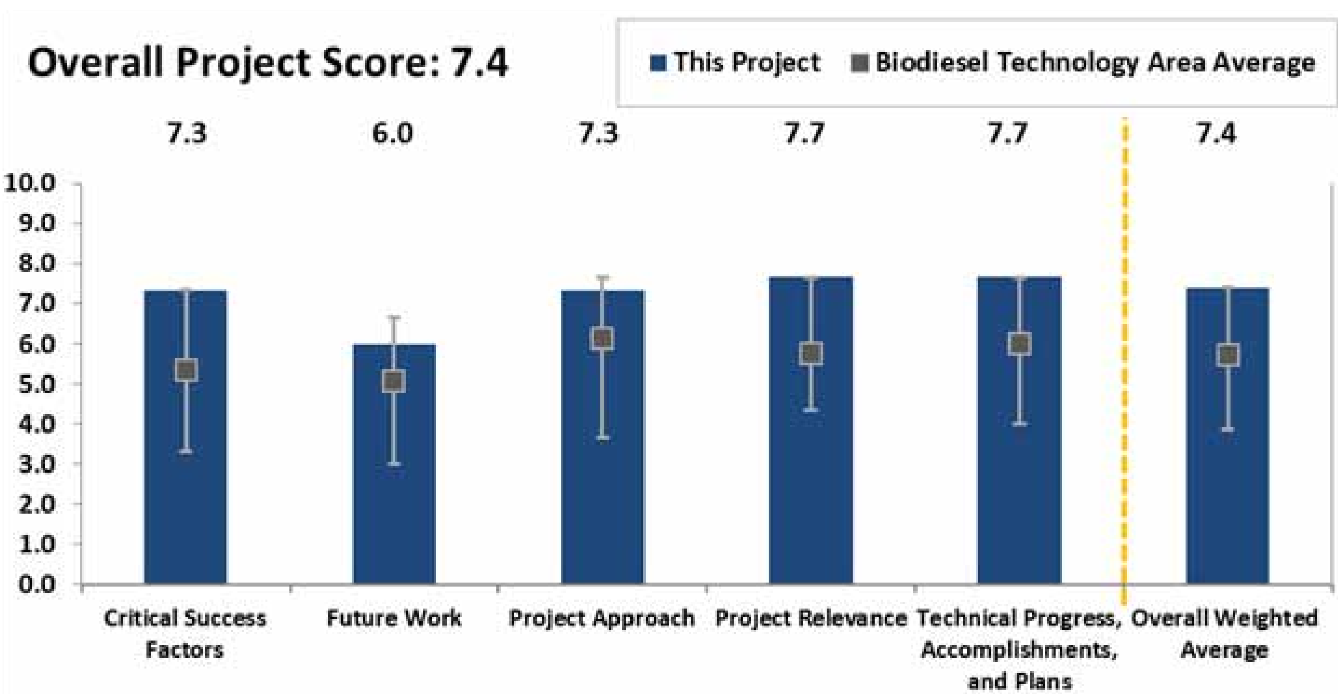
(WBS#: 7.8.1.22)

Recipient:	Wisconsin Office of Energy Independence
Presenter:	Dave Jenkins
Total DOE Funding:	$600,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$600,000
Project Dates:	2010–2012

Project Description

Photo Courtesy of Wisconsin SEO

The Wisconsin SEO's primary mission is to implement cost-effective, reliable, balanced, and environmentally friendly clean energy projects. To support this mission, the Wisconsin Biodiesel Blending Program was created to financially support the installation infrastructure necessary to directly sustain biodiesel blending and distribution at petroleum terminal facilities throughout Wisconsin. SEO (formerly the Wisconsin Office of Energy Independence) secured a federally directed award of $600,000 over 2.25 years. With these funds, SEO supported the construction of inline biodiesel blending facilities at two petroleum terminals in Milwaukee, Wisconsin. The Wisconsin SEO competitively solicited participation from companies at current terminals, such as those members of the Wisconsin Petroleum Marketers and Convenience Store Association and the Wisconsin Petroleum Council that showed interest in participating in the biodiesel distribution effort. The federal funding provided through the state provided a little less than half of the necessary investment to construct



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

the terminals, with the balance put forth by the partners. Wisconsin is now home to two new biodiesel blending terminals. Fusion Renewables on Jones Island (in the city of Milwaukee) will offer a B100 blend to both bulk and retail customers. CITGO is currently providing a B5 blend to all customers at its Granville, Wisconsin, terminal, which is north of the City of Milwaukee. The Milwaukee Terminal is CITGO's first fully operational biodiesel blending facility.

Overall Impressions

- This project at least had a competitive component to dispensing of federal dollars unlike most other CDP projects. By incorporating competition, along with a well-defined set of objectives to base proposals on, the probability of achieving something useful to the local community was enhanced.
- Nice project, well executed.
- This project is an example of a successful community project, which is effective in educating consumers to accept the new fuel. This type of project strategy should be adopted for other biofuels being developed by BETO to make it easier for the community to accept and adopt the new technologies.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

MONTANA BIO-ENERGY CENTER OF EXCELLENCE

(WBS#: 7.6.2.7)

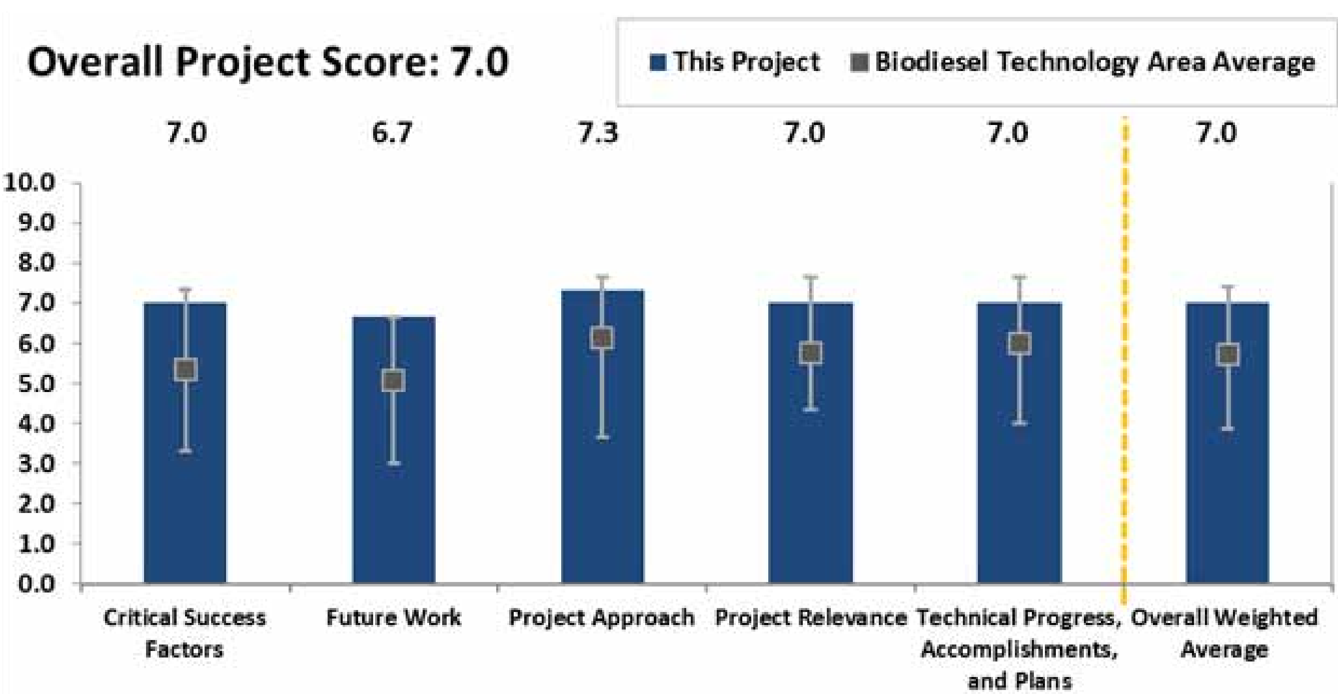
Recipient:	Montana State University-Northern
Presenter:	Greg Kegel
Total DOE Funding:	$2,250,000
DOE Funding FY13:	$48,418
DOE Funding FY12:	$1,272,640
DOE Funding FY11:	$260,056
Project Dates:	2010–2013

Project Description

Biomass Reactor

Photo Courtesy of Montana State University Northern

The Bio-Energy Center at Montana State Northern was established to support regional economic revitalization through research and technology development in the emerging green industry with a primary focus on biobased transportation fuels. DOE funding will assist the Bio-Energy Center in becoming a regional Center of Excellence by establishing new laboratories and funding for critical research staff. The Bio-Energy Center will focus on applied research technologies in developing biobased jet fuel, biodiesel fuels, and fuel additives by using locally grown feedstocks. The Center's approach is to develop economically competitive fuels through energy and water-conservative processes that utilize locally grown feedstock. This fuel production process will be a regional solution to transportation fuel needs. The Center used DOE funding for the following tasks: laboratory renovation to install new heavy-duty engine performance and emission analysis lab; development of alternative biobased aviation fuel based on lignin; development of camelina oil derived fuel for navel applications; viability of using straight plant oils in agricultural operation; performance of locomotive engine fueled with bio-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

diesel; engine exhaust emission from off-specification biodiesel; outreach and education to support green fuel initiative; and technical assistance to Montana and North Central regional biobased companies.

Overall Impressions

- Good practical work. Well executed.
- This was an excellent educational program, but weak technical research. Although this program does not fall in BETO's core mission, the effective public education and graduation of students from this program is laudable.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

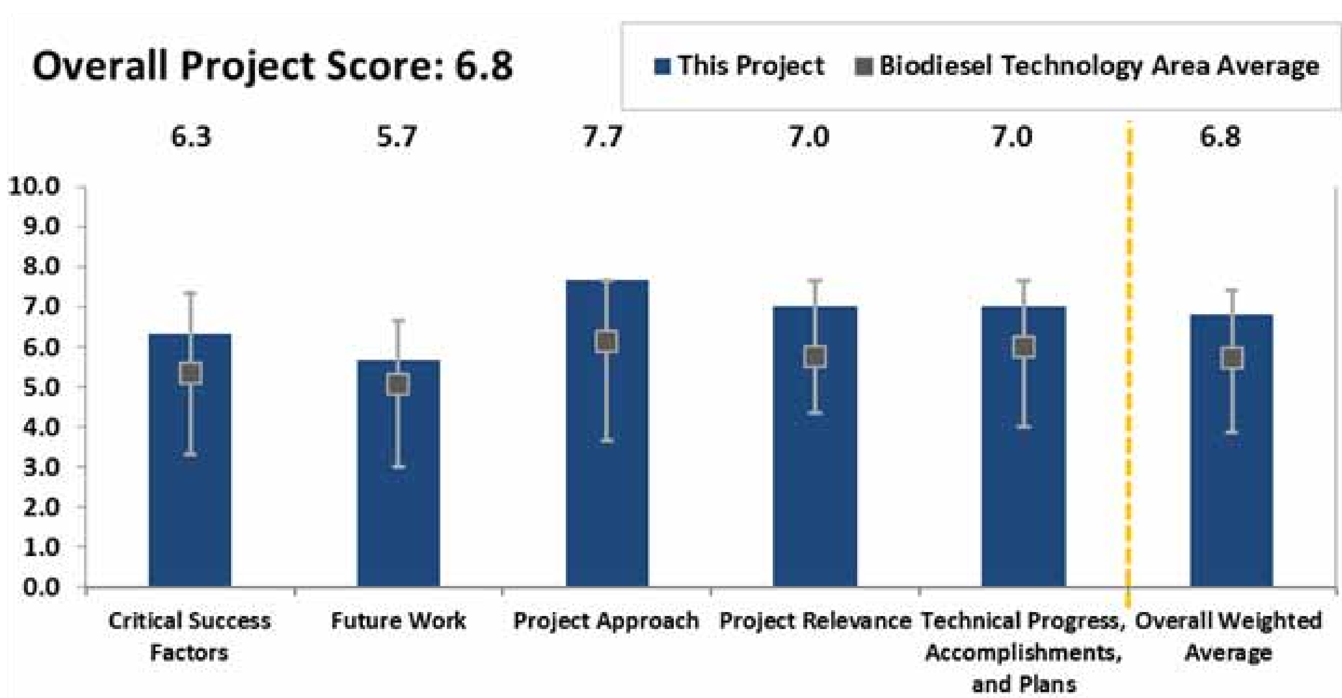
BIODIESEL PRODUCTION FROM GREASE WASTE

(WBS#: 7.8.1.21)

Recipient:	Eastern Municipal District
Presenter:	Mike Luker
Total DOE Funding:	$250,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2011–2012

Project Description

Within Eastern Municipal Water District's (EMWD) service area alone, grease waste totals more than 5,000,000 gallons per year and is primarily disposed of in landfills. This waste material has the potential to produce 125,000 gallons of biodiesel suitable for subsequent use in the District's fleet of diesel-powered vehicles and stationary engines. Local and regional support for this project can be found with the grease trap pumpers and haulers, as this project would reduce their transportation costs. EMWD's Biodiesel program would decrease the number of miles these trucks have to travel to dispose of the grease waste—reducing the amount of diesel necessary to transport the waste and reducing the greenhouse gas (GHG) emissions from the trucks. EMWD has retained a design consultant to produce bid-ready documents to proceed with construction of the waste grease purification facility at the Perris Valley Regional Water Reclamation Facility. Once constructed, EMWD staff will operate the facility to produce a feedstock for processing into biodiesel for consumption in EMWD's vehicle fleet. EMWD has successfully completed the pilot phase of this project, which produced 2,500 gallons of pure B100 biodiesel from approximately 85,000 gallons of restaurant grease. Therefore, EMWD is ready to proceed to design and construct the full-scale waste grease-to-oil purification facility. EMWD expects to produce at least 125,000 gallons of B100 biodiesel from the oil extracted from the grease waste. This is more than the amount currently consumed by EMWD's fleet. The remaining B100 biodiesel will be marketed to other agencies or general consumers.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Incremental progress on a tough environmental problem.
- This is an impressive proposal that generates fuel, solves waste disposal problems, and has the potential to produce irrigation water. Such projects should be encouraged and developed to commercial scale.

PI Response to Reviewer Comments

- No official response provided at time of report publication

VERMONT BIOFUELS INITIATIVE

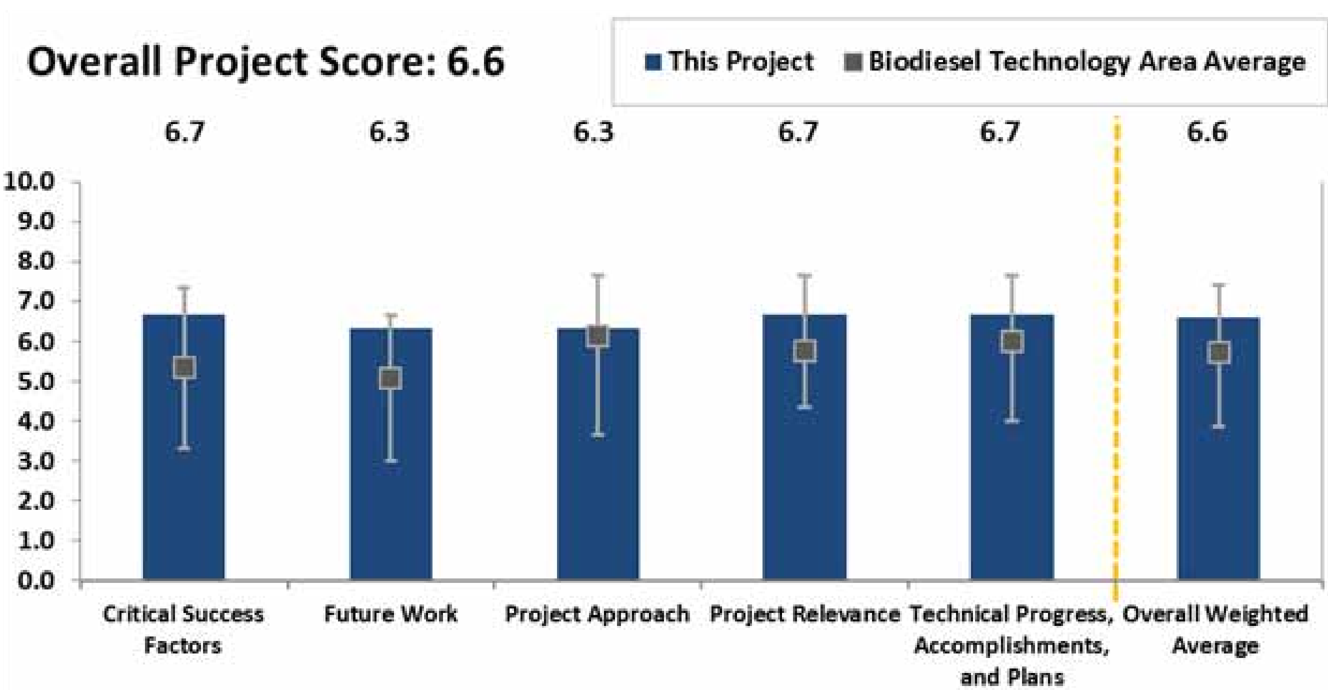
(WBS#: 7.4.5.8)

Recipient:	Vermont Sustainable Jobs Fund
Presenter:	Ellen Kahler
Total DOE Funding:	$3,161,250
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2006–2015

Project Description

Through the Bioenergy Initiative, the Vermont Sustainable Jobs Fund (VSJF), along with its project partners, provides grants and technical assistance to Vermont farms, businesses, and academic institutions, supporting the development of a viable and sustainable biomass-to-biofuels industry that uses local resources to help the state meet 25% of its energy needs from renewable sources by 2025. Through the Vermont BioFuels Initiative (VBI), we are developing a portfolio of bioenergy fuels and the raw materials needed to produce them here in Vermont. In this presentation, VSJF will focus on its oilseed crops and biodiesel program, which has received the majority of the funding and attention under VBI. Prior to the start of VBI in 2005, no commercial oilseed crop or biodiesel production existed in Vermont, yet the benefits of displacing fossil fuels with biodiesel had been well established. VSJF uses a strategic, long-range, market-sector development approach with a combination of grants, technical assistance, and educational opportunities that drive the infrastructure and technical know-how needed to jumpstart biofuels supply and demand toward the following goals:

- Expand the local production and distribution of bioenergy fuels and feedstocks
- Reduce dependency on petroleum
- Promote entrepreneurial activity in the biofuels sector
- Educate the public about sustainably and locally produced biofuels.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Four on-farm facilities have now installed 756,000 gallons per year of biodiesel production capacity, and each of them is seeing financial, GHG emission and energy return on energy invested benefits, dramatic reductions in their use of petrodiesel, and overall savings on their farms. Two commercial fuel dealers have installed heated biodiesel storage and injection blending (critical in our severe winters), and together, they are distributing 4.5 million gallons of bioheat each year (6% of Number 2 oil sold in Vermont). Additionally, an existing biodiesel producer is expanding this spring with its new biodiesel production facility by using waste vegetable oil from the region.

Overall Impressions

- Although this appeared to be outside the mission of DOE, the project was very well organized and executed, and it is money well spent. The project had an excellent educational component through its extension service. The ability of this project to not only produce biodiesel, but to do effective education for the farmers to accept and adopt the fuel, is laudable. BETO should support similar projects in other biofuel applications.
- Not a good expenditure of scarce federal research and development (R&D) dollars.
- This is a valuable program, and the team has done a nice job. It doesn't belong in DOE. In the future, perhaps the U.S. Department of Agriculture or some kind of jobs/economic stimulation bill should take up this type of work.

PI Response to Reviewer Comments

- Two reviewers questioned whether DOE was the appropriate agency for funding VBI. Our May 22 presentation focused on two out of five integrated "programs" of the VBI; on-farm biodiesel from oilseed crops and commercial biodiesel production and blending systems. Yet the comments appear to have addressed only on-farm biodiesel, which represents just a portion of the funding we've received from DOE since 2005. VSJF has used DOE grants to stimulate research, demonstration, education, and commercialization of multiple feedstocks along several biofuel pathways. These include microalgae to biofuels, perennial grasses for thermal combustion, new bulk fuel delivery systems for wood pellets, and college-level biomass-to-biofuels courses, as well as commercial-scale and on-farm biodiesel production. Within every program of VBI, VSJF can point to successful subrecipient projects that have met their objectives and are still moving forward, and we simply could not have developed as comprehensive an initiative under the U.S. Department of Agriculture.
- Regarding the use of "scarce federal R&D dollars," without these types of congressionally directed awards, our experience has shown that early stage R&D projects called for in areas outside the Midwest would not get the funding they need. For example, the production, use, and knowledge of biofuels simply did not exist in Vermont prior to the arrival of federal funds. And the commercial sector responded! Also, our local production for local use model within a regional context has great merit in other rural Northeast and Mid-Atlantic states as well. Only with the aid of federal R&D dollars has a small state like Vermont demonstrated how local sourcing of even a small percentage of the state's energy supply and demand can lead to real gains in terms of lower GHG emissions, energy return on investment, and positive impacts to the local economy.

DEVELOPMENT OF BIOFUELS USING IONIC TRANSFER MEMBRANES PHASE III

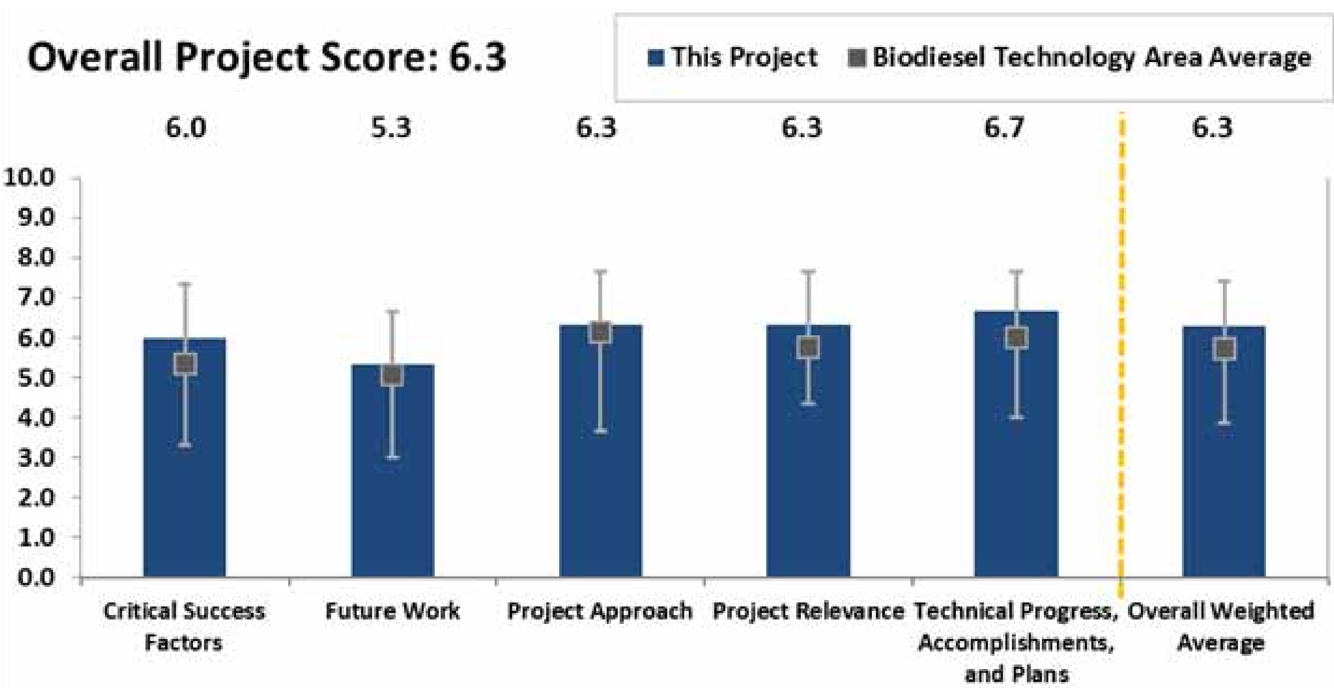
(WBS#: 7.4.1.1)

Recipient:	University of Nevada, Las Vegas
Presenter:	Kristina Lipinska
Total DOE Funding:	$5,494,167
DOE Funding FY13:	$490,000
DOE Funding FY12:	$726,000
DOE Funding FY11:	$824,000
Project Dates:	2011–2013

Project Description

Photo Courtesy of University of Nevada, Las Vegas

The University of Nevada, Las Vegas and an industrial partner, Ceramatec, are developing a tubular Sodium Super Ionic Conductors (NaSICON) membrane-based process that produces high-purity sodium methoxide from low-cost aqueous sodium hydroxide. An electric field is applied across the membrane-based electrolytic cell to selectively transfer sodium ions from a sodium hydroxide solution across the sodium conductive membrane in order to combine with methanol on the second side of the two compartment cell, which will form sodium methoxide. The highly corrosive, caustic solution degrades and reduces the lifetime of the membrane, which impacts the process economics. A first approach to improve the membrane lifetime is to develop a ceramic structure with elemental substitution to increase the thermodynamic stability of the NaSICON ceramic membrane and to protect it against corrosion from the electrochemical transfer of sodium ions across the membrane. A second approach is to alter the fabrication route; to modify grain boundary phase—structure,



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

as well as texture—within the ceramic bulk material; and to create a microstructure that will enhance the NaSICON ceramic's stability and its ionic conductivity. A third approach to extend the lifetime of the membrane is to further develop organic coating materials that protect the surface of the ceramic membrane and are able to conduct sodium ions. We investigate the design, building, and testing of several NaSICON tube and shell configuration-sized development cells with several tubes stacked in an efficient arrangement. We demonstrate that it is possible to fabricate ceramic membranes with an operational lifetime longer than 12 months. It is anticipated that a sodium phosphonated coating polymer will transport sodium ions more efficiently than the previously investigated sodium sulfonate polymer. An alternative and new NaSICON ceramic's fabrication route, which makes use of controlled nucleation of a precursor glass of NaSICON composition, is investigated. Statistical lifetime performance is conducted and evaluated to establish the stability phenomenon of membranes with engineered properties and coated membranes.

Overall Impressions

- This project has demonstrated innovations relative to production of sodium methoxide onsite at improved costs, while addressing serious safety concerns associated with conventional production methods. With the successes achieved to date, they should be able to attract private-sector support to assess long-term technical viability of the catalytic membrane.
- An interesting project, but limited impact even with success because it doesn't seem very material to biodiesel cost.
- This is a very impressive technology that showed great promise for eventual commercialization.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

DEVELOPMENT OF POLLUTION PREVENTION TECHNOLOGIES

(WBS#: 7.7.2.18)

Recipient:	Brooklyn College
Presenter:	Juergen Polle
Total DOE Funding:	$900,000
DOE Funding FY13:	$47,592
DOE Funding FY12:	$151,708
DOE Funding FY11:	$619,599
Project Dates:	2010–2013

Project Description

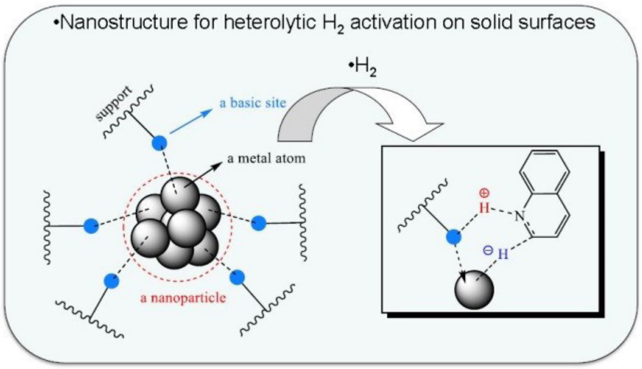
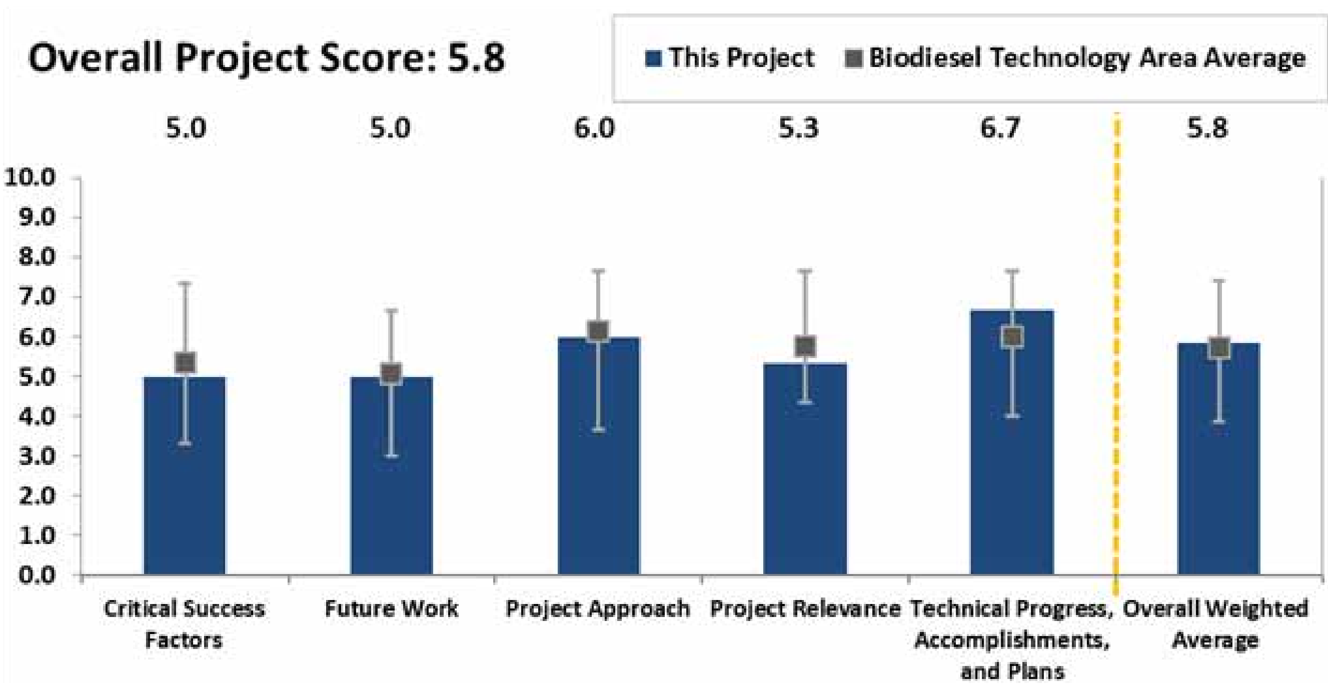


Photo Courtesy of Brooklyn College

Two technologies addressing biomass conversion and feedstock supply are being investigated that may reduce environmental pollution. These technologies address reduction of pollution by generating cleaner fuel, and reducing the amount of fossil fuels to be burned by replacing fossil fuels with fuels derived from renewable feedstocks.

The first research project in the area of catalysis investigates high-performance catalysts derived from transition metal complexes or nanostructured materials that are being studied for hydrogenation reactions. The application of these new catalysts is expected to lead to the production of cleaner-burning fossil fuels or the synthesis and stabilization of biodiesel.

In the second research project, microalgae are investigated for feedstock production to address the production of renewable fuels. First strains of microalgae from an existing collection of microalgae are being screened by ultra-high performance liquid chromatography with



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

time-of-flight mass spectrometry for their lipid composition to determine novel strains with superior composition of biofuel molecules. Many microalgae store triacylglycerides in so-called oil bodies; from the first screen, multiple candidate strains were selected that accumulate oil bodies for further biochemical analysis because almost nothing is known about the basic biochemistry of these oil bodies. Understanding sequestration of triacylglycerides in intracellular storage compartments is essential to developing better strains for achieving high oil productivities by microalgae.

Overall Impressions

- Although this project is 85% complete, it has delivered relatively little to the knowledge base regarding improved catalysts for processing of algal lipids to biodiesel. There is clearly not $900,000 in value in terms of the deliverables noted by the PI.
- Liquid chromatography work on characterization very interesting.
- Overall, this project falls outside BETO's core mission of energy R&D, but it complements BETO efforts in that it trains workforce to implement biofuel technologies.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

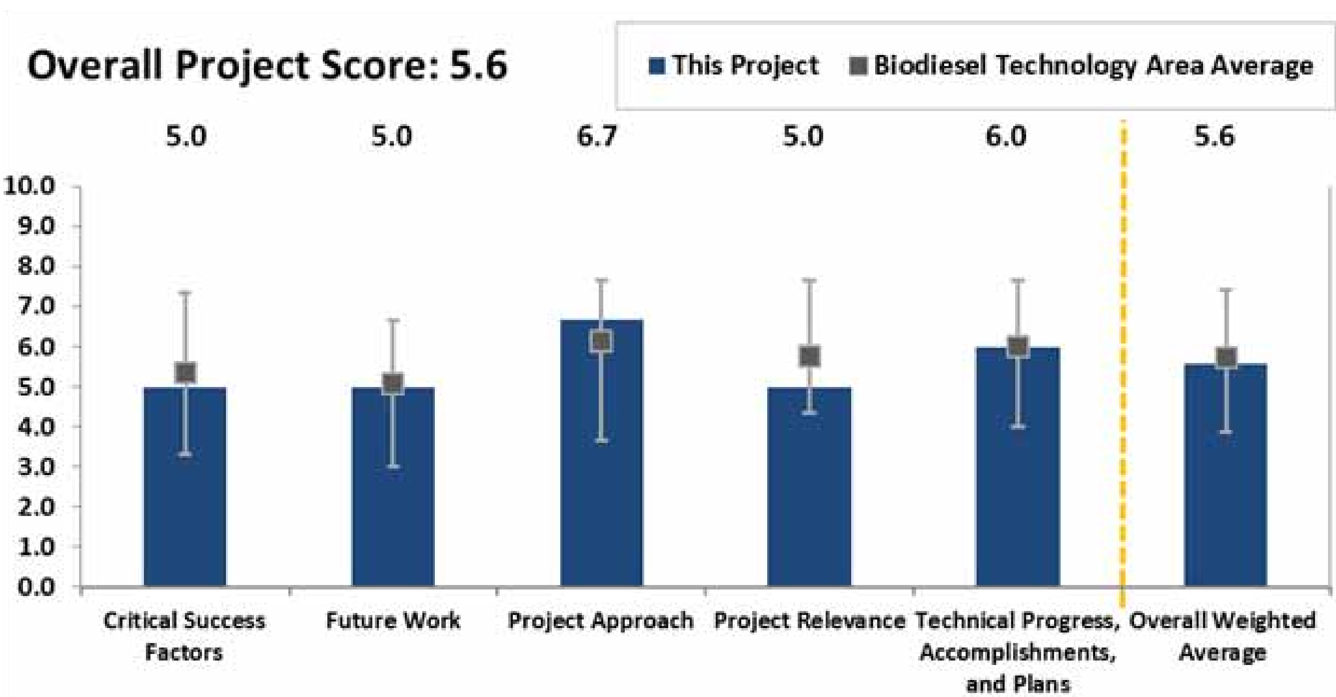
BIODIESEL CELLULOSIC ETHANOL RESEARCH FACILITY

(WBS#: 7.1.5.12)

Recipient:	Hendry County
Presenter:	John Capece
Total DOE Funding:	--
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010–2013

Project Description

The purpose of this proposal is to create a center/facility for a sustainable biofuel industry in rural South Florida focused on Hendry County's current primary crops and alternative biomass crops. The mission of the applied research center is to create a framework for evaluating the biofuels system components and integrating the traditional externalities. Current agricultural production systems are dependent upon single revenue streams (commodity markets) and therefore seek to maximize yield above all other considerations. A sustainable system would incorporate multiple income streams, including food, energy, and ecosystem services. These ecosystem services include water storage, nutrient recycling/removal, and carbon credits. For example, a typical externalized cost is the loss of organic soil containing 80% carbon. A sustainable biofuel system would consider soil carbon loss in the overall carbon/energy balance. Also, incorporating water storage into the farming system reduces the organic soil oxidation and its associated carbon loss. In South Florida, water storage has recognized economic value. It therefore represents an additional potential agricultural revenue stream, particularly for those farms located on private lands targeted for federal/state acquisition. To piece together these and the many other elements of a new farming system for state and private lands, the applied research center would require natural resource economists working closely with engineering, science, and management professionals, both at the center and at the various regional agricultural research institutions. The formal education program of the center will impart to students of regional secondary



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

schools and colleges an understanding of what constitutes an integrated, sustainable agricultural system and will train agro-environmental experts and technicians. The workforce development component will introduce students and workers to related career paths and their educational requirements. The outreach component will target two audiences: the general public who needs to understand the goals and benefits of sustainable industrial development, and the agricultural and support services business leaders who will actually build the new biofuels industry.

Overall Impressions

- Challenging area. There may be good insights for DOE teams looking at land-use issues.
- Project will not contribute much to the advancement of bioenergy use.
- The major contribution of this project is its excellent educational effort in land usage and sustainability of biofuel technologies.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

USE OF INEDIBLE ENERGY CROPS FOR PRODUCTION OF ADVANCED BIOFUELS WITH THE MCGYAN PROCESS

(WBS#: 7.5.3.1)

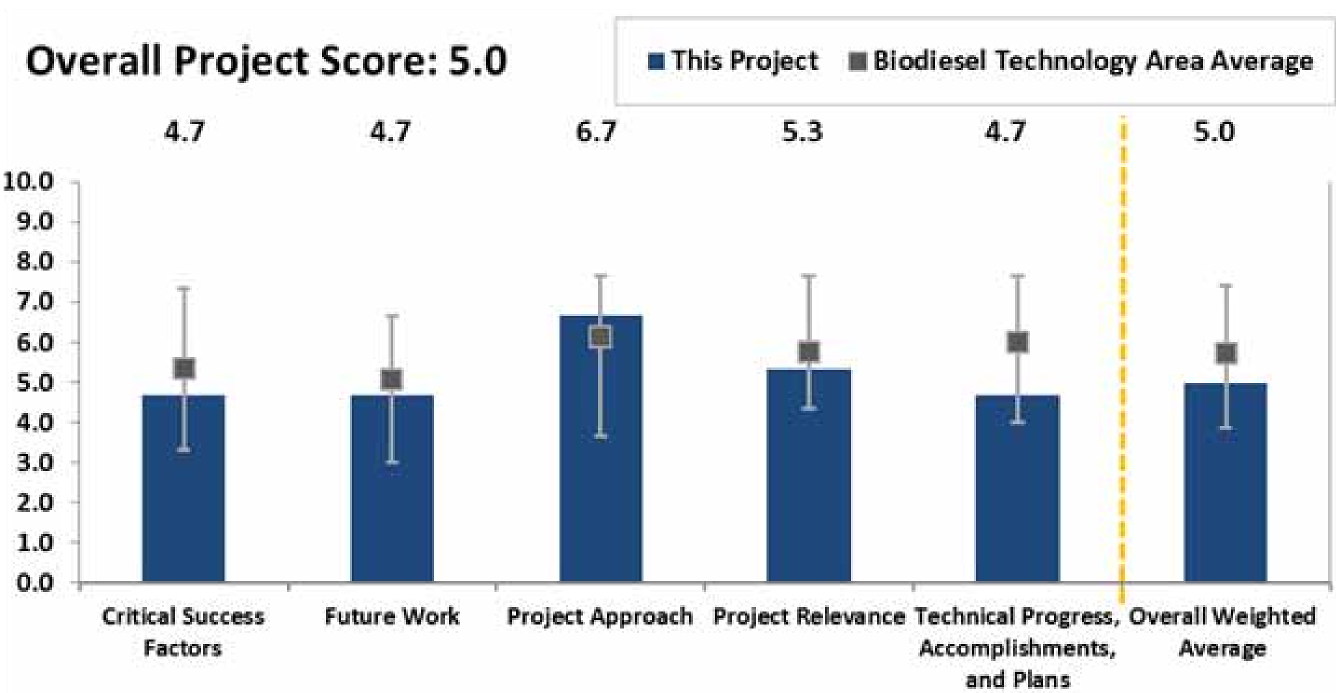
Recipient:	SarTec Corporation
Presenter:	Peter Greuel
Total DOE Funding:	$500,000
DOE Funding FY13:	$16,247
DOE Funding FY12:	$114,800
DOE Funding FY11:	--
Project Dates:	2011–2014

Project Description

Photo Courtesy of SacTec Corporation

In 2006, SarTec developed a one-step oil-to-biofuel production process termed the Mcgyan® process. The process simultaneously performs a catalytic conversion of triglycerides and free fatty acid (FFA) into biodiesel fuel. The Mcgyan biodiesel production process offers several advantages over the traditional base catalyzed process, including the ability to convert FFA containing feedstocks into biodiesel. Feedstocks such as pennycress and camelina oil that have an appreciable FFA content can be converted into biodiesel with the traditional process; however, the FFA portion of the oil must be removed (typically by distillation). With the Mcgyan process, the entire lipid feedstock can be converted into biodiesel.

In this research, we have contacted people who have pennycress and camelina seeds to sell, and we procured them for planting. We have contacted local farmers in the central plains region of the United States and worked with them to secure contracts for growing low-impact, non-food-based pennycress and camelina crops for oil production (with an emphasis on double cropping). An



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

oil-pressing system was designed and constructed for use in pressing the oil from the pennycress and camelina seeds after harvesting. The resultant oil from these non-food crops is being pressed and will be transported to a 3-million-gallon-per-year commercial biodiesel facility (Isanti, Minnesota) that employs the Mcgyan process. At this facility, the pennycress and camelina oil will be converted into biodiesel, which meets American Society for Testing and Materials D6751 grade specifications. Farmers continue to be selected and educated on how to plant, grow, and harvest these low-impact pennycress and camelina crops. The potential benefits and outcomes of the project include the production of biodiesel from non-food energy crops, such as pennycress and camelina, at commercial scale; an improvement in rural economies; and, most importantly, a demonstration that farmers are able to produce these novel, low-impact feedstock crops in addition to their normal production of food crops.

Overall Impressions

- The operating costs of the process appear to be high relative to the scale of operation intended.
- This is a poorly executed project because the chemistry and the fundamental science are not understood. The process parameters are so severe that this process will not be profitable unless there are major changes in catalyst and reactor designs. The project should either be redirected to a more viable process technology, or it should be terminated. A canola oilseed process could be used in place of the current press to improve on the oil recovery, and a conventional biodiesel process method (using homogeneous catalysts, such as potassium or sodium hydroxide or methoxide) can be used in place of the heterogeneous catalyst to make the process viable.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

BIOFUEL MICRO-REFINERIES FOR LOCAL SUSTAINABILITY

(WBS#: 7.8.1.25)

Recipient:	University of Memphis
Presenter:	Srikant Gir
Total DOE Funding:	$500,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$500,000
Project Dates:	2011–2014

Project Description

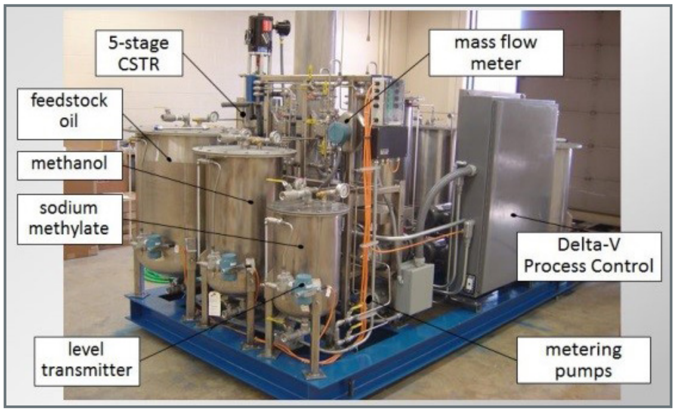
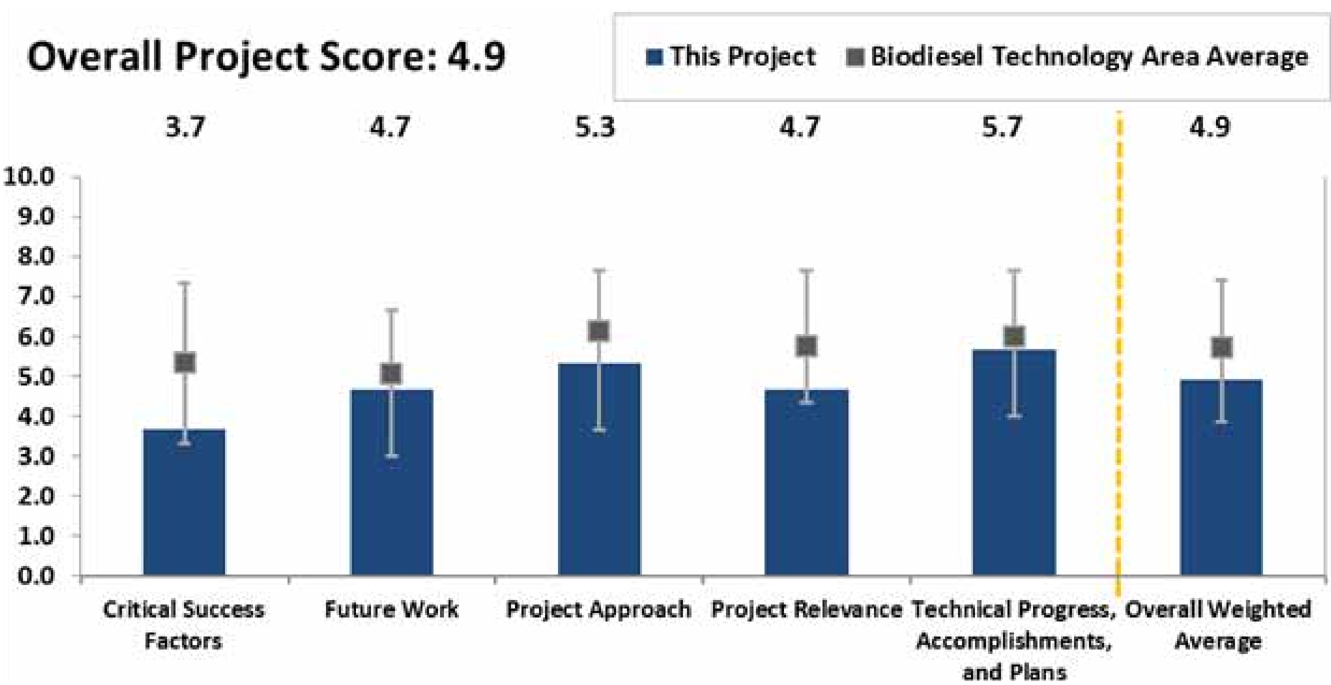


Photo Courtesy of University of Memphis

The purpose of this research is to demonstrate the feasibility and economic viability of a biodiesel micro-refinery and a micro-scale biomass gasification facility. A fully integrated, demonstration-scale biodiesel micro-refinery is being built upon a recently developed core subsystem. The biomass gasification unit is being designed and built from scratch. Although off-the-shelf components are being used to the maximum extent possible, it was necessary to design and build some key components: a five-stage continuous stirred tank reactor (biodiesel) and a 100-kilogram-per-hour gasifier (biomass gasification). Time and budget permitting, a novel, low-cost (approximately $1,500/kilowatt electricity) Organic Rankine Cycle will be adapted to harness exhaust heat from the gasification unit. This is a demonstration-scale project because it is intended to commercialize both facilities at the micro scale. At this scale, these facilities can serve as cornerstones of a sustainable energy system in which locally available feedstock (crops, waste streams) power local economic development.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Really good teaching opportunity, lots of enthusiasm. Suggest focus on biodiesel scope and collaboration with agriculture extension to get this into the field/production.
- The performers showed impressive skills in designing and operating the biodiesel micro-refinery. Effort should be made in educating the farmers to adopt the unit for farm operations, especially in places like Vermont where the farmers are enthusiastic about biofuels.
- This is redundant work to what has already been successfully developed under competitive DOE awards. Additionally, the prior development work is essentially commercial at Community Power Corporation.

DEVELOPMENT OF AN ECONOMIC AND EFFICIENT BIODIESEL PRODUCTION PROCESS

(WBS#: 7.8.1.26)

Recipient:	University of North Carolina at Pembroke
Presenter:	Tom Dooling
Total DOE Funding:	$750,000
DOE Funding FY13:	$298,649
DOE Funding FY12:	$227,706
DOE Funding FY11:	$223,645
Project Dates:	2010–2013

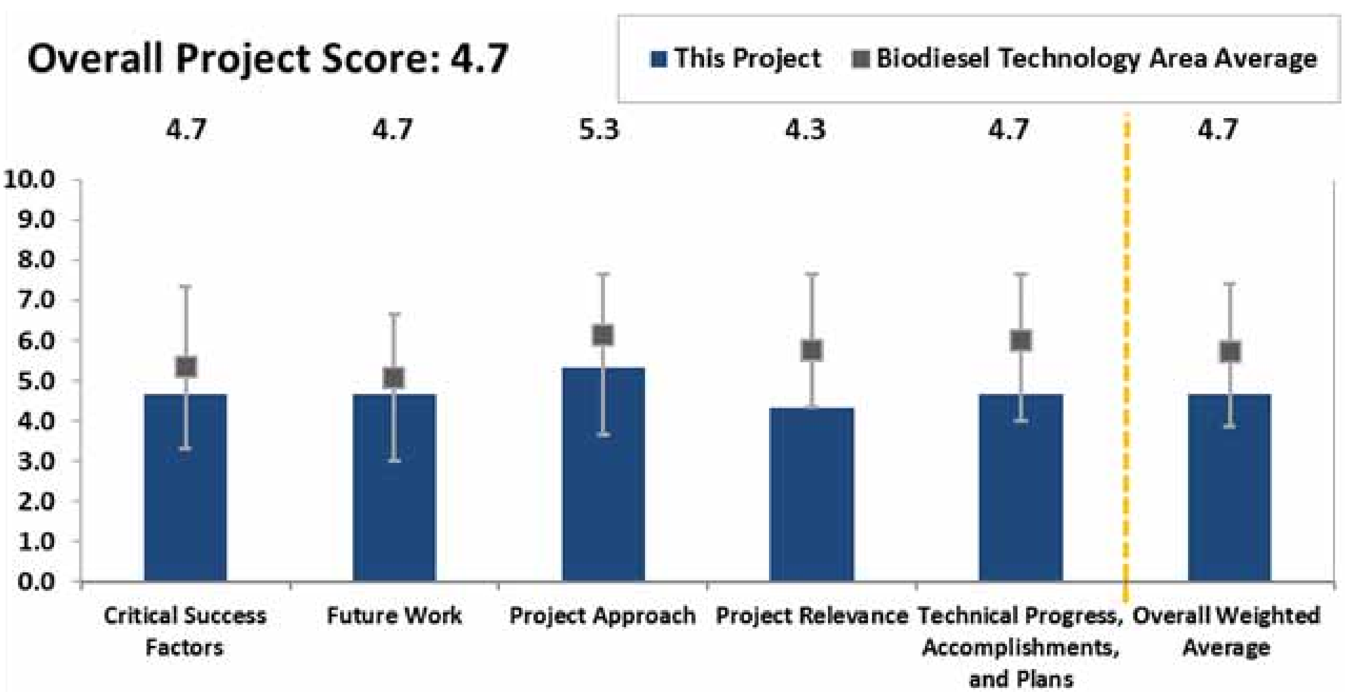
Project Description

Photo Courtesy of UNCP

The University of North Carolina at Pembroke (UNCP) and North Carolina A&T State University (NC A&T) worked jointly on a project to develop new biodiesel catalysts and encourage the production of biodiesel in the south central area of North Carolina. NC A&T developed a new heterogeneous zeolite-supported base catalyst. UNCP developed and refined reaction parameters for tetramethylammonium hydroxide and choline hydroxide. Workshops were held with farmers in the local community to explain how biodiesel is produced and encourage the production of feedstock for making biodiesel. Also, an analysis of the economics of biodiesel production is included.

Overall Impressions

- The educational objectives of the project were noble, but unfortunately, both the technical and educational objectives were very disappointing. The refusal of the local rural communities to accept and adopt the technology contributed to its demise. Instead of using waste cooking oils, if the project



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

encouraged the cultivation of oilseed crops for the biodiesel production, it may have been more fruitful than the waste oil approach. Of course, the local rural communities realized that there were not much waste cooking oils available, so they lost interest.

- A main technical goal of the project was the development of a heterogeneous catalyst. This was accomplished. A prototype benchtop reactor was constructed using the new heterogeneous catalyst, and this does meet a stated technical goal of the project. There was also successful work in the development of a biodiesel reactor using new types of homogeneous catalysts.
- Research on this project involved extensive use of undergraduate students. Results of their work were presented at conferences inside and outside of North Carolina. Laboratory experiments have been developed and are used to teach students the technical details of biodiesel production and purity testing. The project also resulted in a paper at the 2nd World Energy Congress in Xi'an China, and the team hopes to complete two more articles by the end of the year. One article will be aimed at publication in the Journal of Undergraduate Chemistry Research, and another one in the Journal of Chemical Education.
- Contrary to the reviewers comment, the processing of waste cooking oil was not a primary goal of the project. There was discussion and outreach to local area farmers on growing both canola seed and rapeseed for oil to be used as a fuelstock.
- The farmers are resistant to growing these new crops because there is no market in place at the present time to buy their crop. A weak biofuel industry is in no position to offer a three-year contract to farmers. In fact, it is for this reason that a majority of biodiesel producers in North Carolina today are using yellow grease as fuelstock.
- The farmers "lost interest" because there is no economic incentive to produce biodiesel fuelstock in large quantities.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

ALTERNATIVE AND UNCONVENTIONAL ENERGY RESEARCH AND DEVELOPMENT

(WBS#: 7.7.2.21)

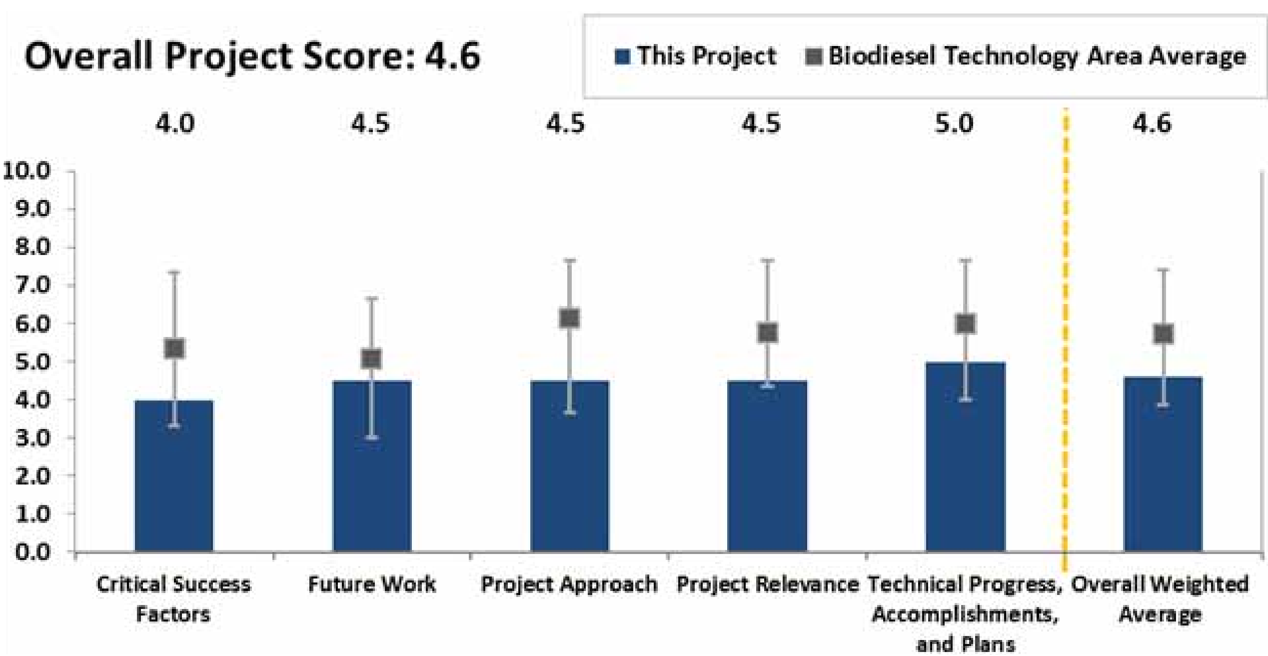
Recipient:	Utah State University
Presenter:	Byard Wood
Total DOE Funding:	$10,000,000
DOE Funding FY13:	$216,746
DOE Funding FY12:	$981,623
DOE Funding FY11:	$754,323
Project Dates:	2011–2013

Project Description

In order to achieve DOE's goals of 2,500 and 5,000 gallons of biofuel intermediate per acre per year by 2018 and 2022, respectively, significant improvements to cultivation systems and process methods must be validated at a commercial scale. This is the guiding principle for the research reported herein. It is focused on obtaining a better understanding of the physical and environmental parameters that affect areal and volumetric microalgal biomass yield in both open and closed cultivation systems, as well as harvesting and conversion to biofuels and other products. Experimental and analytical studies have been performed to address the following:

1. *Precision stress to optimize biomass and lipid yields*—Nitrogen stress can be used to optimize the growth and lipid content tradeoff in microalgae. The time course of lipid accumulation and the magnitude of nitrogen deficiency required to stimulate lipid formation were investigated in six species of oleaginous green algae, comparing high and low levels of deficiency. Accumulation of high lipid content and high growth rates were achieved and attributed to a positive response to minimal stress.

2. *Advances in raceway design to increase algal productivity*—Vertical mixing in aquaculture medium for open raceway ponds is necessary for uniform distribution of sunlight, carbon dioxide (CO_2), and nutrients for microalgae. Accepting the premise



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

from published literature that mixing increases algal production, low-cost, delta-wing vortex generators were selected to computationally and experimentally evaluate the relationship between mixing and productivity. The flow was characterized using Acoustic Doppler Velocimeter, Particle Image Velocimetry, and Computational Fluid Dynamics. The use of delta wings can increase algal biomass productivity by 27%–31% for Chlorella vulgaris and Scenedesmus dimorphus.

3. *Advanced harvesting and pre-processing technology development*—Harvesting and drying microalgae prior to lipid extraction and conversion has proven to be a formidable technical and cost barrier for algal biofuels. A novel energetically favorable liquid-liquid extraction technique that efficiently extracts lipids from cell slurries of oleaginous microorganisms containing as little as 2% solids is being developed. Extraction of oil from cell slurry of oleaginous microorganisms is achieved with greater than 95% efficiency when combined with an appropriate solvent and high-speed mixing with a favorable net energy ratio.

4. *Engine performance comparisons with biodiesel from oleaginous microorganisms*—Biodiesel made from oils extracted from microalgae, yeast, and bacteria was evaluated in a 10-kilowatt engine. Engine performance and exhaust emissions were comparable to standard #2 diesel and commercial-grade biodiesel from soybean oil. Emissions of nitrogen oxides were significantly reduced with the algal biodiesel.

5. *Scalability and resource assessment*—The large-scale feasibility of microalgae-based biofuels has been evaluated based on the metrics of net energy, environmental impact, and scalability. This study presents the use of a validated modular engineering process model to evaluate the resource requirements for multiple large-scale microalgae to biofuels process scenarios. Simulation models include sensitivity to product and co-product end use. The scalability assessment leverages model results with nutrient availability of various nutrient sources (fertilizer, seawater, wastewater, etc.).

Overall Impressions

- Many student education opportunities.
- Project is average in execution and accomplishments.

PI Response to Reviewer Comments:

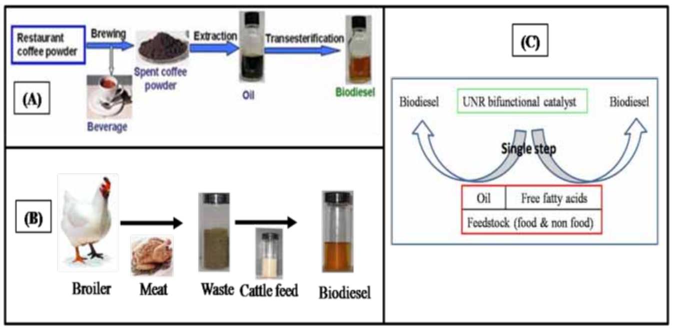
- No official response provided at time of report publication.

BIODIESEL FROM FOOD WASTE

(WBS#: 7.7.2.20)

Project Description

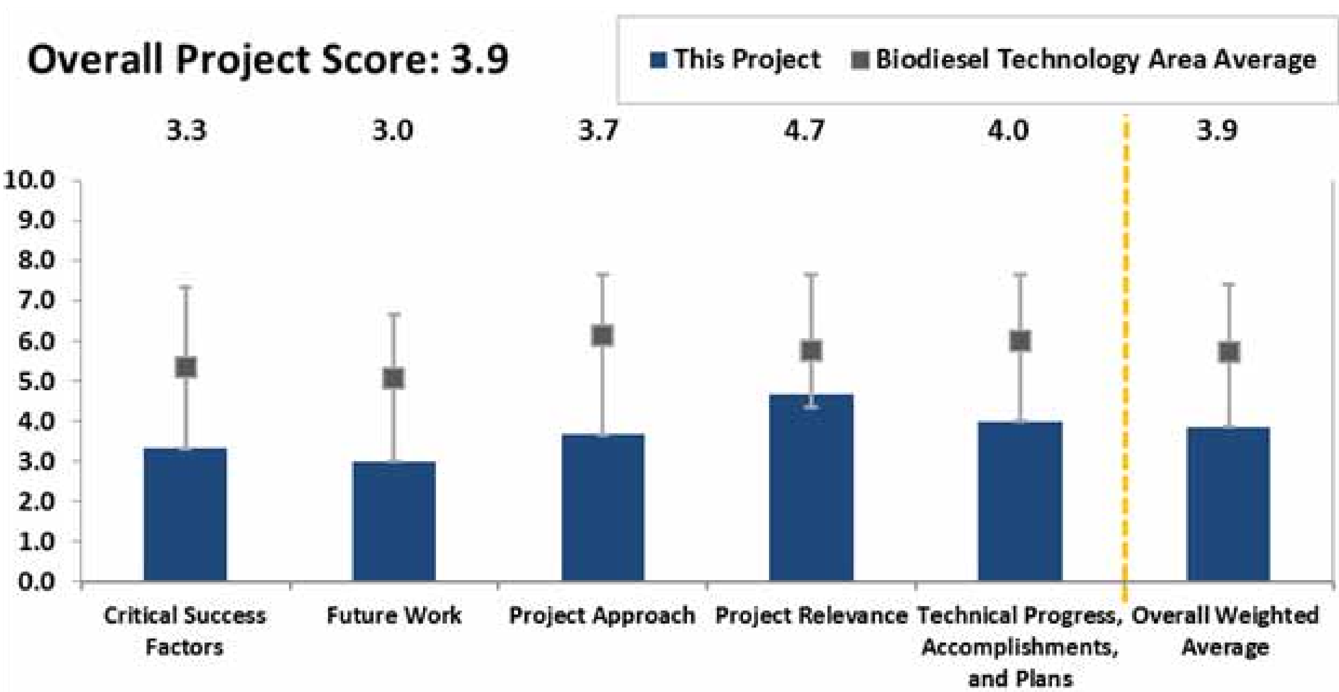
Photo Courtesy of University of Nevada, Reno



In the United States, soy, corn, rapeseed, and other crops are the primary sources of biodiesel production. There is a great need to find alternative non-food and waste materials for biodiesel production. Biodiesel from coffee grounds, chicken fats, and other waste materials can produce several billion gallons of biodiesel each year.

Recipient:	University of Nevada, Reno
Presenter:	Dev Chidambaram
Total DOE Funding:	$1,000,000
DOE Funding FY13:	$75,439
DOE Funding FY12:	$119,732
DOE Funding FY11:	$276,814
Project Dates:	2010–2013

The objectives of this proposed R&D project are to find alternative, non-food based materials for biodiesel; to develop a novel heterogeneous catalyst for the transesterification process; and to find an alternate and economically attractive use for the glycerin. In this research project, oil from coffee waste, grease from feather meal, and other waste material will be used as a feedstock. The triglycerides and oil will be extracted using hexane extraction and/or supercritical carbon dioxide. The initial transesterification will be conducted using the conventional base-catalyzed process. It is known that a base-catalyzed transesterification process is not suitable for higher-FFA-content oil and is expensive. The second



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

objective of this project is to develop a novel nanostructured heterogeneous catalyst for the transesterification process. In addition, an alternate use will be developed for glycerin, the by-product of the biodiesel production. We have accomplished all of the above tasks. The last task is to optimize the system and develop a pilot-scale integrated production system, which is pending completion.

Overall Impressions

- Unusual project, perhaps rationale based on local opportunity

PI Response to Reviewer Comments

- No official response provided at time of report publication.

BIO-OIL

TECHNOLOGY AREA

INTRODUCTION

The Bio-Oil Technology Area was one of nine key technology areas reviewed during the 2013 Bioenergy Technologies Office (BETO or the Office) Project Peer Review, which took place on May 20–23, 2013, at the Hilton Mark Center in Alexandria, Virginia. A total of 42 project presentations were reviewed by five private-sector experts representing industry and academia. This review comprised a total U.S. Department of Energy (DOE) value of approximately $128 million, which is around 8.5% of the BETO portfolio reviewed during the 2013 Peer Review. One principal investigator (PI) for each project or project grouping was given an allotted time to deliver a presentation and respond to questions from the review panel and the audience. The allotted times were based on the total project funding and ranged from 20–45 minutes. Projects were evaluated and scored for their project approach, technical progress, relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Project Peer Review, including full scoring information for each project, summary comments from each reviewer, and the PI's responses to the summary comments. Overview information on the Bio-Oil Technology Area, the Review Panel Summary Report, and the BETO Programmatic Response are also included in this section. BETO designated Melissa Klembara as the Bio-Oil Technology Area Review Lead. In this capacity, Ms. Klembara was responsible for all aspects of review planning and implementation based on guidance from the Steering Committee and steering group, and with support from BCS contractors Sarah Luchner and Liz Lowry.

BIO-OIL TECHNOLOGY AREA

OVERVIEW

The Bio-Oil Technology Area, which is part of the Thermochemical Conversion Research and Development (R&D) platform, is focused on developing innovative technologies that convert lignocellulosic and algal feedstocks to fuels (including renewable gasoline, diesel, and jet fuel), chemicals, and heat or power (such as renewable heating oil). This Technology Area encompasses thermochemical deconstruction technologies that make bio-oil intermediates, such as fast pyrolysis, catalytic fast pyrolysis (*ex situ* and *in situ*), hydropyrolysis, hydrothermal liquefaction, solvent liquefaction, and other alternative processes. R&D efforts also include stabilization and upgrading of bio-oil intermediates to produce finished fuels, power, and products that can be blended with or used as direct substitutes for fossil fuels, and that are compatible with existing fossil-fuel processing and distribution infrastructure, such as petroleum refineries.

BIO-OIL SUPPORT OF OFFICE STRATEGIC GOALS

The goal of the Office is to develop commercially viable biomass utilization technologies to:

- Enable sustainable, nationwide production of advanced biofuels that are compatible with today's transportation infrastructure and can displace a share of petroleum-derived fuels to reduce U.S. dependence on oil
- Encourage the creation of a new, domestic bioenergy industry supporting the Energy Independence and Security Act of 2007 (EISA) goal of 36 billion gallons per year of renewable transportation fuels by 2022.

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

The Bio-Oil Technology Area's strategic goal is to:

Develop commercially viable technologies for converting biomass feedstocks into energy-dense, fungible liquid fuels, such as renewable gasoline, jet fuel, and diesel, bioproducts and chemical intermediates, and bioenergy.

The projects in the portfolio represent some of the thermochemical conversion pathways that have the potential to support BETO's cost target of $3 per gallon of gasoline equivalent (gge) by 2017. BETO's mission is to develop and transform our renewable biomass resources into commercially viable, high-performance biofuels, bioproducts, and biopower through targeted research, development, demonstration, and deployment supported through public and private partnerships.

BIO-OIL SUPPORT OF OFFICE PERFORMANCE GOALS

The Bio-Oil Technology Area R&D performance cost goal is to reduce the estimated mature-technology processing cost for converting lignocellulosic and algal feedstocks to advanced biofuels. The near-term performance cost goal is currently based on a design case for fast pyrolysis with catalytic upgrading to produce gasoline and diesel blendstock. The purpose of the design cases is to show example pathways that could potentially achieve the BETO cost target of $3/gge by 2017 (near term) or 2022 (long term). In 2013, the existing design case for fast pyrolysis with catalytic upgrading was updated and will be published. In 2014, design cases will be developed and published for two additional pathways covering both *in-situ* and *ex-situ* cases for catalytic fast pyrolysis to gasoline and diesel blendstock. The Technology Area conducts annual state-of-technology updates to track progress toward achieving the mature-technology processing cost projections outlined in the design cases. The Bio-Oil Technology Area performance goal discussed below only represents the conversion cost portion of the BETO $3/gge cost target, and does not include feedstock supply and logistics costs or grower payments.

- The 2017 performance goal of the Bio-Oil Technology Area is to achieve a conversion cost of $1.83 per gallon of total blendstock ($1.73 /gge, $2011) via a bio-oil pathway.[2]

Performance milestones for the bio-oil pathways under investigation are as follows:

- By 2013, define requirements for characterizing heating oil from biomass and establish an R&D strategy.
- By 2014, establish out-year (2017, 2022) cost goals and technical targets based on completed techno-economic analysis for two additional bio-oils technology pathways.
- By 2015, validate bench-scale, semi-integrated conversion processes for a high-impact biomass feedstock to renewable gasoline or diesel via a direct liquefaction conversion process with bio-oil processing to a finished fuel at a scale sufficient enough for transfer to pilot-scale operation to support the 2017 targets.
- By 2017, validate fully integrated, pilot-scale conversion processes for a high-impact biomass feedstock to renewable gasoline or diesel via a direct liquefaction conversion process with bio-oil processing to a finished fuel.

[2] Jones, S.B.; and Snowden-Swan, L.J. *Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating and Hydrocracking: 2012 State of Technology and Projections to 2017.* PNNL-22684, Richland, WA: Pacific Northwest National Laboratory, 2013.

TECHNICAL AND MARKET CHALLENGES AND BARRIERS

BETO has identified the following key challenges for achieving the goals of the Bio-Oil Technology Area:

Technical Challenges and Barriers
Sustainability Data
Sustainability Indicators and Methodology
Feeding Dry Biomass
Feeding or Drying Wet Biomass
Pyrolysis of Biomass and Bio-Oil Stabilization
Catalyst Development
Validation of the 2017 Cost Target
Sensors and Controls
Bio-Oil Process Integration

APPROACH FOR OVERCOMING CHALLENGES

The Bio-Oil Pathways R&D approach for overcoming the technical challenges and barriers is organized around five key areas: analysis and sustainability, feedstock interface, conversion technologies, conversion-enabling technologies, and integration and scale-up. The Office currently has R&D investments in multiple bio-oil pathways for the production of renewable gasoline, diesel, or jet fuel, as well as co-products such as chemicals and power (i.e., heating oil).

For more information on the Bio-Oil Technology Area, please review BETO's Multi-Year Program Plan (MYPP) at bioenergy.energy.gov/pdfs/mypp_may_2013.pdf.

REVIEW PANEL

The following external experts served as reviewers for the Bio-Oil Technology Area during the 2013 Project Peer Review:

Bio-Oil Reviewers	
Don Stevens (Lead Reviewer)	Cascade Science and Technology Research, retired PNNL
Paul Bryan	Consultant, formerly with Chevron and DOE
Caroline Burgess Clifford	Pennsylvania State University
Dean Draemel	University of California – Berkeley, College of Chemistry
Thomas Phillips	Intellection, LLC

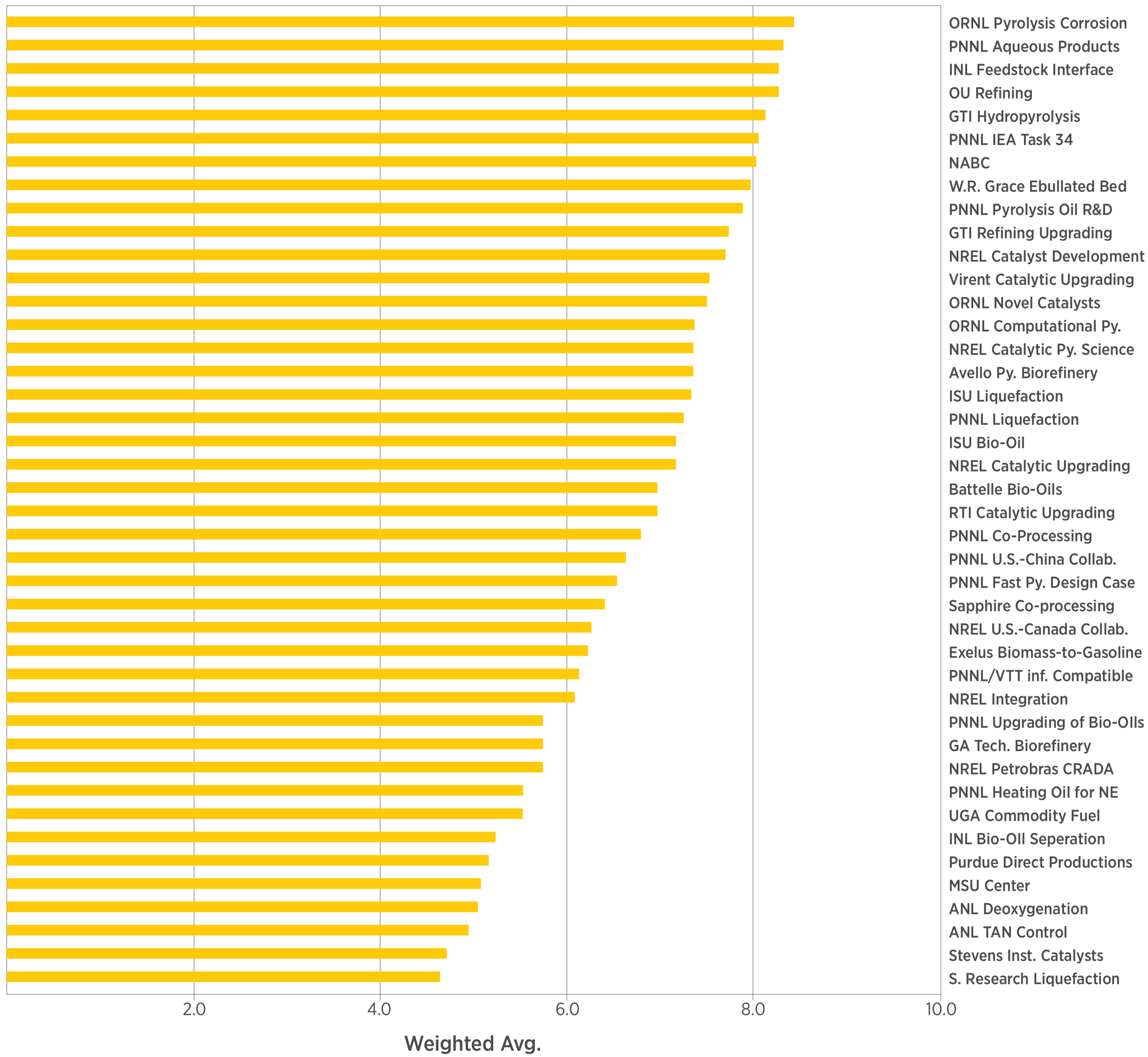
FORMAT OF THE REPORT

Information in this report has been compiled as follows:

- **Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.
- **Project Scoring Information and Short Names Key**: The final score charts depict the overall weighted score for each project in each technology area. Short names for each project were developed for ease of use in the scoring charts, the table of contents, and other locations. Full project names, along with their designated short names and their work breakdown structure (WBS#), are provided in the Short Names Key.
- **Review Panel Summary Report**: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.
- **BETO Programmatic Response**: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.
- **Project Reports**:
    - **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space constraints allotted.
    - **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
    - **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and the whiskers depict the range of scores for each category within each technology area.
    - **Reviewer comments** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant by BETO's director were excluded from the final report.
    - **PI Responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the

TECHNOLOGY AREA SCORE RESULTS



SHORT NAMES KEY

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
3.2.2.16	Biomass-Derived Pyrolysis Oils Corrosion Studies	ORNL	ORNL Pyrolysis Corrosion
3.2.2.34; 3.2.2.30; 3.2.2.33	Characterization and Treatment of Aqueous Products from Direct Liquefaction (DL) Processes; Conversion of DL Process Aqueous Phase Organic Products into Liquid HC Fuels and H2	PNNL	PNNL Aqueous Products
3.1.2.3; 3.7.1.3; 3.1.2.1; 3.1.2.2	Feedstock Interface & Feedstock-Thermochemical Interface Equipment	INL; NREL; PNNL	INL Feedstock Interface
7.3.4.1	University of Oklahoma Biofuels Refining	University of Oklahoma	OU Refining
3.2.2.18	Long Term Processing in the Production of Gasoline and Diesel from Biomass Using Integrated Hydropyrolysis Plus Hydroconversion Process (IH2 Process)	Gas Technology Institute	GTI Hydropyrolysis
6.3.2.25	IEA Task 34 Fast Pyrolysis	PNNL	PNNL IEA Task 34
3.3.1.1	National Advanced Biofuels Consortium (NABC) (Presented in conjunction with the Biochemical Conversion Technology Area)	Alliance for Sustainable Energy, LLC	NABC
3.2.2.21; 3.2.2.22; 3.2.2.23	New Ebullated Bed Technology for Hydroprocessing Bio-oils to Produce Gasoline, Diesel and Jet Fuels	W.R Grace & Co	W.R. Grace Ebullated Bed
3.2.2.4; 3.2.2.32; 3.7.1.2; 3.2.2.5	Pyrolysis Oil R&D, Hydrotreating of Physically Stabilized Pyrolysis Oil & CapEx	PNNL; NREL	PNNL Pyrolysis Oil R&D
3.3.1.16	Refinery Upgrading of Hydropyrolysis Oil from Biomass	Gas Technology Institute	GTI Refinery Upgrading
	Catalyst Development/Testing: Deconstruction	NREL	NREL Catalyst Development
3.3.1.10	Catalytic Upgrading of Thermochemical Intermediates to Hydrocarbons: Conversion of Lignocellulosic Feedstocks to Aromatic Fuels and High-Value Chemicals	Virent Energy Systems, Inc.	Virent Catalytic Upgrading
3.2.2.2; 3.2.2.29	Bio-oil Upgrading with Novel Low-Cost Catalysts and the Synergistic Evaluation of Novel Catalytic Metals for Bio-Oil Upgrading	ORN; PNNL	ORNL Novel Catalysts
3.6.1.X; 3.6.1.11	Computational Pyrolysis Consortium	ORNL	ORNL Computational Py.
3.6.1.6	Catalytic Pyrolysis Science	NREL	NREL Catalytic Py. Science
3.2.2.25	Demonstration of Pyrolysis-Based Biorefinery Concept for Biopower, Biomaterials and Biochar	Avello Bioenergy	Avello Py. Biorefinery
3.3.1.23	Liquefaction of Agricultural and Forest Biomass to "Drop-In" Hydrocarbon Biofuels	Iowa State University	ISU Liquefaction
3.2.2.31	Improved Hydrothermal Liquefaction Bio-Oil Production	PNNL	PNNL Liquefaction
3.3.1.21; 3.3.1.24	Stabilization of Bio-Oil Fractions for Insertion into Petroleum Refineries	Iowa State University	ISU Bio-Oil
3.3.1.12	Catalytic Upgrading of Pyrolysis Products	NREL	NREL Catalytic Upgrading

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
3.2.2.19; 3.2.2.20	Upgrading of Intermediate Bio-Oil Produced by Catalytic Pyrolysis	Battelle Memorial Institute	Battelle Bio-oils
3.3.1.10	Catalytic Upgrading of Thermochemical Intermediates to Hydrocarbons	Research Triangle Institute	RTI Catalytic Upgrading
3.3.1.1; 3.3.1.25; 3.3.1.26	Optimizing Co-Processing of Bio-Oil in Refinery Unit Operations Using a Davison Circulating Riser (DCR)	PNNL	PNNL Co-Processing
6.5.2.2	U.S.-China Collaboration - Thermochemical Conversion of Biomass	PNNL	PNNL U.S.-China Collab.
3.6.1.3; 3.6.1.1	Thermochem Platform Analysis - Fast Pyrolysis Design Case and Sustainability Interface	PNNL	PNNL Fast Py. Design Case
3.3.1.20	Optimized Co-Processing of Algal Bio-Crude through a Petroleum Refinery	Sapphire Energy	Sapphire Co-processing
6.5.9.1; 6.5.9.2	CA-02 Pyrolysis and Upgrading Collaboration with Canada	NREL; PNNL	NREL U.S.-Canada Collab.
3.2.2.17	Advanced Biomass-to-Gasoline Process	Exelus, Inc.	Exelus Biomass-to-Gasoline
3.2.2.26	PNNL/VTT Production and Upgrade of Infrastructure Compatible Bio-Oil	PNNL; INL; BNL; ORNL	PNNL/VTT Inf. Compatible
3.3.1.13; 3.7.1.1	Integration and Scale-Up	NREL	NREL Integration
3.2.2.24	Upgrading of Biomass Fast Pyrolysis Oil (Bio-oil)	PNNL	PNNL Upgrading of Bio-oils
7.5.7.3	Southern Pine Based Biorefinery Center	Georgia Tech	GA Tech. Biorefinery
6.5.1.1	Brazil Bilateral: Petrobras– NREL CRADA	NREL	NREL Petrobras CRADA
3.2.2.26	Renewable Home Heating Oil in the Northeast	PNNL	PNNL Heating Oil for NE
3.3.1.22	Development of Bio-Oil Commodity Fuel as a Refinery Feedstock from High-Impact Algae Biomass	University of Georgia Research Foundation	UGA Commodity Fuel
3.3.1.19	Bio-Oil Separation and Stabilization by Supercritical Fluid Fraction	INL	INL Bio-Oil Separation
3.2.2.7	A Low-Cost High-Yield Process for the Direct Production of High Energy Density Liquid Fuel from Biomass	Purdue University	Purdue Direct Production
7.7.4.8	Mississippi State University Sustainable Energy Center	Mississippi State University	MSU Center
3.3.1.11	Selective Deoxygenation Catalysts / Prevention of Deactivation of Supportive Metal Catalysts	ANL	ANL Deoxygenation
3.2.2.27	TAN Control of Bio-Oil	ANL	ANL TAN Control
3.3.1.18	Pt-based Bi-metallic Monolith Catalysts for Partial Upgrading of Microalgae Oil	Stevens Institute of Technology	Stevens Inst. Catalysts
3.3.1.17	Mild Biomass Liquefaction Process for Economic Production of Stabilized Refinery-Ready Bio-Oils	Southern Research Institute	S. Research Liquefaction

REVIEW PANEL SUMMARY REPORT

INTRODUCTION

The focus of the Bio-Oil Technology Area is to enable technologies that produce hydrocarbon fuels capable of replacing gasoline or diesel fuels, and—as needed—jet fuels and chemicals. DOE's cost goal for these fuels is $3 per gallon of gasoline equivalent by 2022, as measured in 2011 dollars.

The main focus of the Technology Area is pyrolytic conversion of biomass to bio-oils, followed by subsequent upgrading and refining to produce hydrocarbon fuels. Pyrolysis is the high-temperature decomposition of biomass feedstocks in a reductive (or oxygen-lean) atmosphere. The pyrolytic process generates three product streams: pyrolysis bio-oil, light gases, and carbon-rich char. The bio-oil composition and yield is dependent on the biomass feedstock and the specific characteristics of the pyrolysis process. Bio-oils typically contain 15–35% oxygen by weight and are not directly miscible with petroleum crude oils. Because of their initial characteristics, bio-oils require catalytic upgrading in one or more steps to convert the product into hydrocarbon fuels. The Technology Area is focusing on three bio-oil pathways:

- ***Fast pyrolysis to form bio-oils that are subsequently upgraded***: The pyrolytic decomposition of biomass occurs in a few seconds to form bio-oil vapors. The upgrading step(s) can occur while the bio-oil is still a vapor or after it has been condensed into a liquid.
- ***Hydrothermal liquefaction of biomass, particularly high-moisture feedstocks such as algae, to create a liquid bio-oil that is subsequently upgraded:*** Hydrothermal liquefaction occurs at moderate temperatures and high pressures in the presence of a solvent, typically water. The liquid bio-oil is subsequently upgraded.
- ***Hydropyrolysis and other approaches:*** Hydropyrolysis occurs when biomass is pyrolyzed in the presence of hydrogen or other hydrogen donors. This approach has the potential to produce a higher quality bio-oil that requires less upgrading. DOE also considers other innovative approaches.

Table 1. Bio-Oil Pathways

Technology Area	Pathway
Thermochemical Conversion: Bio-Oil Pathways	Fast Pyrolysis and Upgrading
	Catalytic Pyrolysis – *ex situ*
	Catalytic Pyrolysis – *in situ*
	Hydropyrolysis
	Hydrothermal Liquefaction

The raw bio-oils can be upgraded either at the location where biomass is pyrolyzed or, dependent on the pathway, transported to a petroleum refinery for upgrading. Ongoing research is helping determine how the refinery expertise can best be utilized. In all cases, government approval for motor fuels derived from non-petroleum sources will be required.

BETO also conducts a variety of cross-cutting research, including techno-economic analysis (TEA), life-cycle analysis (LCA), and feedstock interface activities to guide its work.

PROJECT REVIEW

The 2013 Peer Review included 42 evaluated presentations covering 65 individual projects. The projects were evaluated and scored for their project approach, technical progress over two years, relevance to BETO goals, identification of critical success factors, and future plans. Reviewers also commented on technology transfer potential and overall impressions, which were not scored. All projects were evaluated by review panel members, and the average weighted scores were used to establish a ranking of the projects. It must be noted that the scores for this Technology Area have not been normalized against those of other technology areas; direct comparisons of average scores, ranges of scores, and standard deviations across other technology areas are approximate. The ranking of projects is shown in Table 2.

Table 2. Ranking of Bio-Oil Technology Area Projects

RANK	PROJECT	RANK	PROJECT	RANK	PROJECT
1	ORNL Pyrolysis Corrosion	15	Avello Py. Biorefinery	29	PNNL/VTT Inf. Compatible
2	PNNL Aqueous Products	16	NREL Catalytic Py. Science	30	NREL Integration
3	INL Feedstock Interface	17	ISU Liquefaction	31	PNNL Upgrading of Bio-oils
4	OU Refining	18	PNNL Liquefaction	32	GA Tech. Biorefinery
5	GTI Hydropyrolysis	19	ISU Bio-Oil	33	NREL Petrobras CRADA
6	PNNL IEA Task 34	20	NREL Catalytic Upgrading	34	PNNL Heating Oil for NE
7	NABC	21	Battelle Bio-oils	35	UGA Commodity Fuel
8	W.R. Grace Ebullated Bed	22	RTI Catalytic Upgrading	36	INL Bio-Oil Separation
9	PNNL Pyrolysis Oil R&D	23	PNNL Co-Processing	37	Purdue Direct Production
10	GTI Refinery Upgrading	24	PNNL U.S.-China Collab.	38	MSU Center
11	NREL Catalyst Development	25	PNNL Fast Py. Design Case	39	ANL Deoxygenation
12	Virent Catalytic Upgrading	26	Sapphire Co-processing	40	ANL TAN Control
13	ORNL Novel Catalysts	27	NREL U.S.-Canada Collab.	41	Stevens Inst. Catalysts
14	ORNL Computational Py.	28	Exelus Biomass-to-Gasoline	42	S. Research Liquefaction

The numerical scores can be used to gain an overall view of the Bio-Oil Technology Area portfolio. Average weighted scores for individual projects ranged from a high of 8.42 to a low of 4.64.

The top ten projects have average scores ranging from 7.72 to 8.42. The top-rated project was the bio-oil corrosion work by Oak Ridge National Laboratory (ORNL) and other laboratory partners. This project is providing important information on rates and mechanisms of corrosion of relevant metals. Three additional projects were ranked closely in positions two through four, including the Pacific Northwest National Laboratory's (PNNL) work on aqueous phase products, Idaho National Laboratory's (INL) feedstock interface, and the University of Oklahoma's work on catalytic upgrading. Of the projects ranked in the top ten, seven were led by national laboratories, two by the Gas Technology Institute (GTI), and one by a university. The seven national lab projects included two with major industrial participants, such as the National Advanced Biofuels Consortium (NABC) and Grace; several with multiple labs; and some with single-lab participation. As noted in previous reviews, the national laboratory contribution to the Technology Area continues to be important.

The ten lowest-rated projects had scores ranging from 4.64 to 5.72. These included five projects led by national labs, three by universities, and two by research institutes. The reviewers noted that several of these were recently awarded projects, granted both on a competitive basis (e.g., Stevens Institute of Technology and Southern Research Institute), as well as directly funded annual operating plan (AOP) projects, including Argonne National Laboratory's (ANL) selective deoxygenation catalysts, ANL's total acid number (TAN) control, and

INL's supercritical fluid extraction. The recent start of these projects was not a factor in the ratings. Rather, the low ratings occurred because the concepts were perceived to have little probable commercial relevance to the Technology Area even if successful, the technical approach and execution was flawed, and/or insufficient information was provided to convince the reviewers that success was possible. Efforts to improve selection of new projects are needed, and additional discussions are provided below.

IMPACTS

1 What are the key strengths and weaknesses of the projects on this technology area?

Strengths:
The Bio-Oil Technology Area made significant technical progress over the last two years. The field of bio-oils for hydrocarbon fuels is advancing very rapidly, and BETO is a major factor behind these advancements. The entire area of bio-oil stabilization and upgrading is much better understood than a few years ago, including processing methodologies and fuel specification issues. Examples of progress include successful early-stage, pilot-/demonstration-scale work, improved catalytic stabilization and upgrading techniques, and a better understanding of basic corrosion rates and mechanisms.

BETO is focusing exceptional intellectual capabilities, facilities, and equipment on the bio-oils pathway, including resources from industry, national labs, and academia.

Potential technology breakthroughs have occurred at the early pilot scale. An example of this success is the hydropyrolysis work at GTI.

A better understanding of the refinery requirements/interface has been established, as requested in 2011. While there is still work to do, the Technology Area overall has developed a better understanding of finished fuel specifications, as well as requirements for co-refining or blending bio-based hydrocarbon products. This effort needs to be continued and strengthened because government approval will be needed for any motor fuel derived from non-petroleum resources.

Capability is now in place to produce tens of gallons of near-finished hydrocarbon products. The ability to generate these volumes is crucial in characterizing the product and allowing for petroleum industry evaluation.

BETO has worked successfully to establish successful projects with a breadth of strong partners, typically including a mix of industry, academia, and national labs. The reviewers believe that, in general, these types of projects perform better.

Weaknesses:
As noted in the 2011 Peer Review, there continues to be a lack of uniformity in TEA/LCA across many projects, particularly those outside the national labs. The detailed BETO design cases are useful to DOE, but they are complex, time consuming, and too rigid to fully deal with the rapidly changing bio-oil field. The design cases are not used by industry business planning or decision making, and their complexity prevents all but the labs from producing consistent analyses. The Office needs a simpler techno-economic analysis tool that can be applied uniformly across the Technology Area, perhaps similar to the Hydrogen and Fuel Cell Technologies Office's H2A models. The reviewers agree with the comment from 2011 that BETO should require a consistent TEA of all applied/demonstration projects and most fundamental projects at an early stage. This consistent analysis should extend over all technology areas, including bio-oils, so meaningful comparisons can be made.

The reviewers feel there is the potential for overlap of effort in some areas. Actual overlap was noted in similar corrosion studies being performed at ORNL and at a university. Perhaps because of the short nature of the presentations, the reviewers also perceived potential overlap with the catalytic bio-oil upgrading projects. DOE needs to continue internal coordination efforts to minimize the potential for overlapping work.

Despite progress by the Technology Area as a whole, some participants are still minimally familiar with refinery requirements, needs, and fuel specifications. Several university partners, as well as a few industry partners, were unaware of the characteristics their fuel products will have to meet, or how they will interface with the fuel infrastructure. DOE needs to continue to improve the refinery interface for all participants. Recommendations are provided below.

2 Is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry in this technology area? Is the government's focus right in light of private-sector investments?

The projects, taken as a whole, have great potential to continue advancing the state of the art. The Technology Area has identified an appropriate number of the bio-oil pathways, and the research appears to be progressing rapidly. The reviewers believe overall plans for future research are good.

There is currently a good balance of funding for technologies across various technology-readiness levels (TRL), and progress is significant. Fundamental research is resolving underlying issues, such as corrosion and kinetic modeling. Bench-scale research is providing important information on critical topics, including catalytic upgrading. Moderate-scale facilities are now capable of producing tens of gallons of hydrocarbon products, which is crucial to the refinery interface. Industry early-stage pilot plants and demonstrations are making progress, such as RTI and GTI. Bio-oils technology is rapidly reaching the state where larger-scale unit-operation demonstration and pilot facilities will be needed. In moving forward, DOE will soon need to provide higher funding to the projects at advanced TRLs.

Some projects have shown particular potential for breakthroughs. For example, the hydropyrolysis work at GTI could have the potential to significantly change and improve the way biomass is pyrolytically converted to hydrocarbon fuels. DOE needs to ensure that appropriate funding opportunities are available so the most promising projects have increased chances for future success.

A few projects started several years ago have not kept pace with the rapid change of the state of the art. These projects are still using capabilities that are no longer relevant to the Technology Area—such as the gasifier at Mississippi State—or are making fuels that are a lower priority for BETO. These projects should be refocused or terminated by BETO.

The AOP funding to national labs (non-competitive) does not always seem to be well spent. There is the perception of overlap in some projects, and some of the technologies appear to have no real potential for commercial applications. Additional information is provided in other sections of this report.

INNOVATION

3 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach there barriers?

The Technology Area overall is innovative and is focusing its resources on the correct technical barriers. The current emphasis on stabilization, upgrading, and refinery integration is appropriate. Many individual projects were innovative in their approach, and we enjoyed hearing about where the state of art is now and how rapidly it has advanced.

National lab projects may be innovative and sophisticated in terms of methods, analysis, etc., but are not always innovative in advancing the commercial state of the art. Several industry—and a few national labs and academic—projects are innovative in this commercial sense. BETO should consider methods to increase linkages between industry needs and lab/academia capabilities.

In some cases, innovative approaches were proposed, but these approaches have very little probability of commercial implementation. Some of the novelty was not relevant to BETO. For example, the ANL atomic-layer deposition (ALD) work was viewed as commercially undeveloped, expensive, and with limited application for bio-oil even if successful. Some of the novelty is relevant but not practical, such as INL's supercritical fluids project, which was not strongly focused.

The reviewers agree that the incubation-type projects proposed by BETO in going forward are a good way to get new innovations with the potential for major breakthroughs into the Office. As noted, however, some of the lowest rated projects—both competitively awarded and AOP lab projects—were those recently awarded to explore new concepts. DOE needs to strengthen its mechanisms for both defining opportunities and selecting projects to ensure that innovative ideas are relevant and have a reasonable chance of evolving into commercial projects if successful. DOE will also need to establish strong metrics for the innovative work to ensure progress can be documented.

GAPS

4 Are there any other gaps in the portfolio for this technology area? Are there topics not being adequately addressed? Are there other areas that BETO should consider funding to meet overall program goals?

In identifying gaps, the review team noted that separation technology is more of an issue than we were aware of. Improved capabilities are needed in many aspects, such as recovery of aqueous-phase organics, separation of higher value chemical products, and many others.

Coal-related expertise is largely absent from the Office and could be leveraged. For example, coal-derived liquids have refinery-significant oxygen contents. While lower than bio-oil oxygen contents, the coal-related expertise could potentially help to achieve BETO goals. Collaboration in the area of separations and others could also be beneficial. In one or two cases, current projects are taking advantage of relevant expertise.

There is a need to look at continuous catalyst-regeneration technology for low-temperature hydrodeoxygenation (HDO). These technologies offer potential advantages over current approaches, if successful.

Refinery-fuel product connections have improved but are still insufficient. Additional recommendations are provided below.

There is currently no mechanism to ensure that successful breakthrough projects, identified by external review, have the opportunity for continued advancement. Projects that make significant technology breakthroughs may find current, relevant funding opportunities are off-cycle from needs, thus stopping progress.

Because the field of bio-oils is advancing rapidly, there will be a need for larger-scale studies of unit operations, as well as pilots and demonstrations, to keep successful concepts moving forward toward commercial reality.

Areas BETO Should Consider Funding:

Improved commonality for TEA is needed, as also recommended in 2011. DOE should coordinate development of consistent TEA/LCA modeling tools and force all applied, pilot/demonstration projects, and most fundamental projects, through the same process. Even fundamental projects need to understand how their work could impact economics. The commonality of analysis is needed to standardize economics so projects aren't "cooking the books." Yields reported at this review seem to be gamed in a lot of ways, and the need to establish a standardized framework for the economic analysis still exists.

The national laboratories seem to have a good understanding of the fundamentals but are not necessarily innovative in advancing the commercial state of the art. The industry-led projects are commercially innovative, but not strong in fundamentals. One of the barriers for industry working with the national labs is the cost of the national labs. One solution worth considering is developing a mechanism for AOP funding to allow industry to collaborate at a cost lower than going directly to the labs. The reviewers are not experts on government contracting mechanisms, but BETO should consider mechanisms that encourage expansion of the lab-industry interaction.

To help improve the refinery interface for fundamental projects, we suggest forming a DOE-funded technical group with specialization in refinery utilization of biocrudes/oils. This could be organized as a consulting resource, a committee, a consortium, or a formal advisory board, or in other ways that would be useful to the Technology Area. This group would serve as a resource for new- or early-stage work, particularly for TRL 1–3 projects. The reviewers suggested the group could potentially operate in several ways, ranging from a simple consulting resource to a first- or second-level gatekeeper, depending on how it is set up.

Process and blend modeling needs to be done on bio-oils fed into a refinery's key process units to look at refinery and economic impacts. UOP and AspenTec, for example, have these types of models.

SYNERGIES

5 What synergies exist between projects within this technology area? Is there more that BETO could do to take advantage of these synergies, and better enable projects to meet their objectives?

Existing Synergies:

There are many synergies among the various national labs already in place. National labs have very strong capabilities, and there are existing synergies with industry and academia.

Additional Needs:

Too many projects are trying to do everything, and specialized projects are often weakly linked to others. The overlaps in corrosion studies and in bio-oil characterization are examples. DOE needs to ensure these types of efforts provide synergies rather than duplication.

Although synergies already exist, DOE needs to further improve integration and coordination among national labs. This could potentially include more competitive awards and DOE management of non-competitive AOP funding.

Performers need relationships with refineries or fuel infrastructure. For smaller projects, DOE needs to provide resources, such as the advisory resource previously discussed.

The reviewers would like to see more synergy between industry-led projects; however, it is difficult to implement with proprietary information involved.

BETO should make the Bio-Oil Technology Area's connection to integrated biorefineries the Office of Science, the U.S. Department of Agriculture, the National Science Foundation, DOE's Office of Fossil Energy, and more, clearer.

RECOMMENDATIONS

6 Is BETO funding projects at the optimal stage of the technology pipeline? Is there more that BETO could do orient technologies toward successful commercialization?

In moving forward, the Bio-Oil Technology Area will need to fund research at higher TRLs with larger-scale equipment. This will include scaled-up unit operations, as well as integrated pilots and demonstrations. Scale-up of unit operations, such as filtration of bio-oil vapors and/or liquids, catalytic processing, and fuel finishing, is needed to resolve questions about operability of key components under realistic conditions. The scale-up work on unit processes does not generally need to be performed in integrated units. As progress is made with unit operations, or as breakthroughs are made, scale-up with integrated pilots and demos will also be needed.

7 What are the top three most important recommendations that would strengthen the portfolio in the near to medium term?

The Bio-Oil Technology Area funding is not fully adequate for large-scale pilots and demonstrations, but within the current funding levels, the balance of TRLs is reasonable.

Key Recommendations:

Functional, consistent, process techno-economic models need to be developed earlier in the process-development cycle. Too much time is being spent on fundamentals before plugging it into real-world processes. We recommend that DOE develop a consistent TEA methodology that is applied uniformly and consistently across most, if not all, projects. The current design cases are not appropriate or relevant for this use. BETO needs to develop a common methodology, perhaps similar to the H2A work from the Hydrogen and Fuel Cells Technologies Office, which can be applied uniformly across the Technology Area. This recommendation was also made by reviewers in 2011, but has not been implemented. The methodology needs to be applied across all BETO technology areas, including Bio-Oil, so meaningful comparisons can be made.

BETO should increase the requirement for refining expertise or collaboration as part of all projects. It is crucial for all performers to understand the refinery interface, but it is also impractical for all projects to establish separate interactions with the petroleum industry. We recommend BETO continue the current requirement for inclusion of a refinery partner for all projects at TRL 4 and beyond. For projects TRL 1–3, we recommend the use of an advisory group resource or similar mechanism as discussed previously.

Some BETO dollars seem to be poorly spent. Some reasons for this are that poor projects make it through the merit review and AOP selection process. DOE needs to strengthen their merit review and AOP selection processes to ensure projects have relevance, that all performers understand how they can potentially improve economics, and that all projects establish quantifiable metrics by which their progress can be measured.

Additional Recommendations:

DOE needs to focus more R&D and scale-up on processing equipment (i.e., feeders, reactors, filters, etc.) that will be used in real-world systems. For example, it has been known for many years that biomass is difficult to feed. Conversion systems that cannot overcome known operational difficulties will not be successful.

Biofuels added to the motor fuel markets will impact those markets if the ratio between gasoline and diesel components is different than that at current refineries. BETO should do sufficient analysis to understand potential market impacts from introducing differing ratios of bio-oil-derived diesel versus gasoline in the petroleum fuel mix.

DOE should perform additional analysis to inform developers of the relative merits of pyrolysis on a small-scale, distributed basis compared to centralized conversion. Smaller-scale, distributed pyrolysis facilities will have lower feedstock transportation costs, but those may be offset with reduced capital costs and the absence of bio-oil transportation costs at large, centralized facilities. The tradeoffs will depend on the particular bio-oil pathway. Analysis is needed to help resolve questions about these tradeoffs.

BETO PROGRAMMATIC RESPONSE

IMPACTS

- We acknowledge the review panel's comments regarding some lack of uniformity in TEA/LCA across the projects, particularly the need to have competitive project data and lab project data in meaningful, comparable models. We are making an effort to address this concern using some best practices, such as models of the type developed by NABC and the Hydrogen and Fuel Cells Technologies Office.
- We recognize that there was some redundancy in the portfolio. Since the peer review and as part of the annual planning process, we have worked with the lab core R&D portfolio to integrate projects and reduce any redundancy or overlap in activities.
- We will continue to ensure the national labs are working on commercially relevant technologies by requiring TEAs as a deliverable for early TRL seed projects to justify continued development, and we will encourage early collaboration with industry.
- BETO is committed to continue to improve the refinery interface for all project participants. We believe that the review panel's suggestion for an advisory panel composed of refinery experts who would be available to advise all BETO projects is an ideal solution to facilitate seamless integration with the existing refinery infrastructure.

INNOVATION

- We appreciate the panel's input on the role of the national labs and universities in R&D, and we will work with them to ensure the projects we fund through the AOP process or at universities are both innovative and advance the commercial state of the art, ideally through collaboration with industry partners.

- We understand that there are technical approaches being funded that, while innovative, may face commercialization challenges. We will work with these projects to address these concerns and obtain industrially relevant data for a TEA/LCA analysis to either support continued funding or terminate the project.
- As recommended by the panel, we will continue to work on strengthening the FOA merit review process to ensure strong projects with credible, clear technical metrics are selected into the portfolio. We will continue to implement active project management that will be even more robust going forward in compliance the new Office of Energy Efficiency and Renewable Energy guidance.

GAPS

- We agree that separations technologies may be a significant R&D challenge (as also identified at Conversion Technologies for Advanced Biofuels workshop in December 2011). To address this, we recently released the Carbon, Hydrogen, and Separation Efficiencies in Bio-Oil Conversion Pathways (CHASE) funding opportunity in 2013, with a specific area for separations-efficiency improvements and selected projects in this area.
- We will also be addressing the recovery of the aqueous-phase organics to make higher value chemicals and fuels in some of the recently selected CHASE projects and lab core R&D.
- We agree that continuous catalyst-regeneration technology for low-temperature HDO is an important approach for the success of these bio-oil technology pathways. We will continue to invest in this approach.

SYNERGIES

- We recognize that some projects may be overly broad and may be trying to do everything, which can make optimization of unit operations difficult. We will examine the construction of future funding opportunity announcements (FOA) and lab core R&D to be specific in addressing challenges in focused areas, like CHASE or aqueous-phase reforming.
- We have worked diligently with national labs to ensure that overlaps or redundancies are reduced and to develop more strongly linked, coordinated projects. As an example, we have combined the bio-oil catalytic-upgrading lab core R&D efforts into one, multi-lab, linked project.
- We agree that industry involvement and collaboration with national labs and university projects is critical for guiding technology development and for moving new technologies into the marketplace. This is true even for more fundamental R&D, such as the BETO-funded Computational Modeling Consortia that is developing an industry advisory panel to guide the research priorities.

RECOMMENDATIONS

- We agree that additional funding will be required at higher TRLs to validate new technologies in integrated pilot and demonstration units. BETO's Demonstration and Deployment program focuses on pilot and demonstration units. We share the review panel's hopes that this activity will continue to be supported at the required level
- We will continue to strengthen refinery/fuel product connections. We are working with our BETO strategic analysis team to further develop a bio-oil refinery-integration analysis report, and investigate process and blending models for bio-oil in refineries.

We are also planning a workshop in 2014 to gather key stakeholders in the petroleum industry to provide R&D recommendations, and to inform a future FOA in this area.

- As stated above, we agree that a mechanism such as an advisory panel, committee, consortium, etc., for refinery utilization of bio-crudes/oils—comprised of petroleum industry experts working with bio-oil technology developers—would be ideal for providing consulting resources to our projects and potentially providing insight to the Office on portfolio balance
- We will investigate development of less-cost prohibitive mechanisms—or promoting existing mechanisms, such as cooperative research and development agreements (CRADA)—to allow industry and universities to collaborate with the national labs.

ADDITIONAL COMMENTS

- We agree that additional resources should be devoted to solving issues surrounding processing equipment (e.g., feeders, reactors, filters) in real world systems.
- We agree with the recommendation that DOE should conduct analysis to understand the potential market impacts associated with introducing different ratios of bio-oil-derived diesel versus gasoline in the petroleum fuel mix.
- We agree with the recommendation that DOE should analyze and communicate the relative merits of pyrolysis on a small-scale, distributed basis compared to a centralized conversion facility. Indeed, BETO is funding a GTI project that is conducting this type of analysis.

CONTENTS

NEW EBULLATED BED TECHNOLOGY FOR HYDRO-PROCESSING BIO-OILS TO PRODUCE GASOLINE, DIESEL, AND JET FUELS

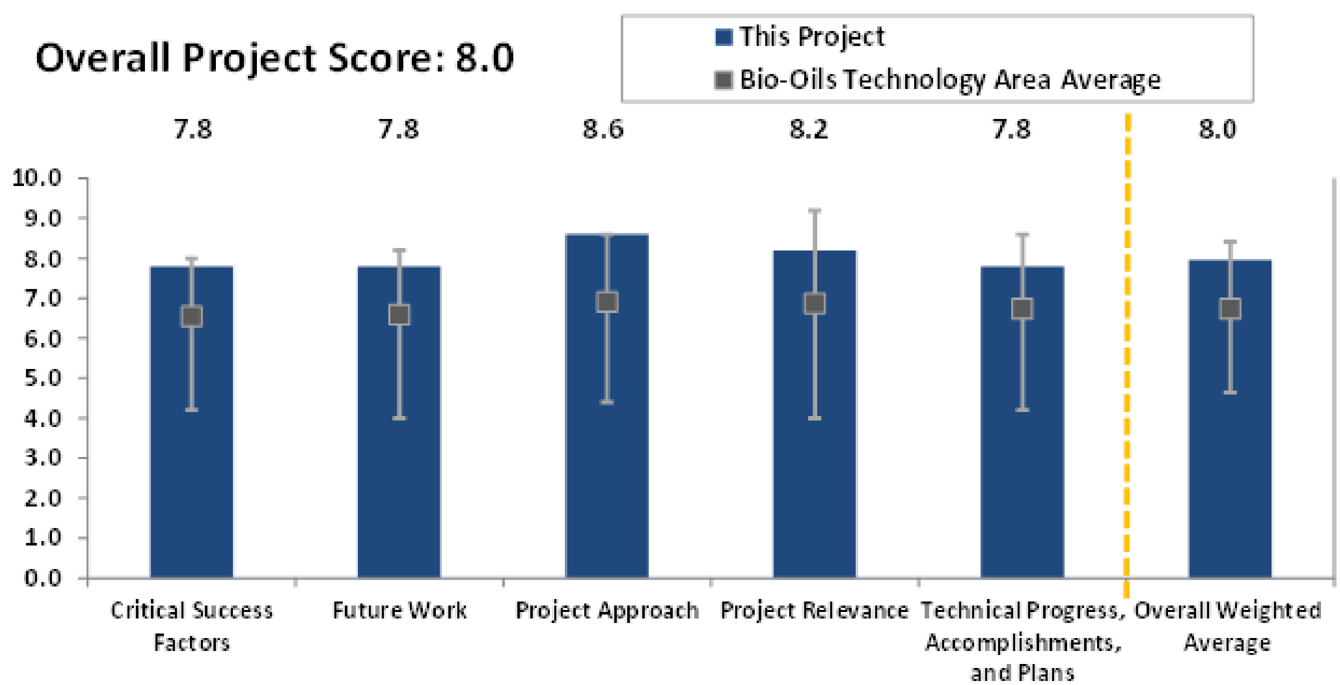
(WBS#: 3.2.2.21; 3.2.2.22; 3.2.2.23)

Recipient:	W.R. Grace & Co
Presenter:	Steve Schmidt
Total DOE Funding:	$4,000,000
DOE Funding FY13:	$1,500,000
DOE Funding FY12:	$1,400,000
DOE Funding FY11:	$1,100,000
Project Dates:	2011-2014

Project Description

Photo Courtesy of W.R. Grace & Co

This project's relevance is that it addresses known reactor and catalyst limitations involved in fuel production via hydrotreating of pyrolysis oils: short catalyst life, coking/fouling of fixed beds, and corrosion of reactor surfaces—each largely due to the feedstocks' high acid and oxygen contents. Our approach is the use of an ebullated bed reactor and non-standard (acid-resistant) catalyst supports, with a goal of making transportation fuels in a 1,000-hour feasibility test. The ebullated bed reactor improves on a fixed bed reactor for pyrolysis oils in avoiding local hot spots and bridging of foulants across stationary particles, as well as greater convenience in continuously adding and removing catalyst. Novel hydrotreating catalyst supports (more than 100 variations) have been lab-produced and screened in high throughput, micro-scale stability testing with model acid compounds (193 total samples tested, including existing standard types). The 10 most promising support candidates have been formed/extruded at pilot, 5 kilogram (kg) scale for ebullated bed testing. A 70% reduction in leachability of supports in acid has been shown. Real-world feeds from fast pyrolysis of wood and forest



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

residue have been made at 1,000-liter scale by the Technical Research Centre of Finland (VTT). A pilot ebullated bed reactor with approximately 0.5-liter catalyst bed volume, in a total of 9 runs to date, has yielded low-oxygen products from these oils. Two first candidates were selected for scaled-up reactor testing. Corrosion analysis is being performed by ORNL, both *in situ* and *ex situ*, to evaluate required materials of construction. Preliminary techno-economic and life-cycle analyses to measure improvement over petroleum and fixed bed hydrotreating have been performed by PNNL. The anticipated success factors and challenges pertain to stability (and thereby cost) of catalyst and reactor operation, as well as market readiness for pyrolysis oils in refineries. Existing Grace customers have expressed interest in projected outcomes of the project.

Overall Impressions

- Concerned about catalyst screening. It is not clear to me what criteria are being used because of proprietary concerns.
- Excellent combination of commercial and lab partners, going after a truly critical obstacle that must be overcome to integrate bio-oils into the refining and marketing system.
- Overall, this project seems to be a realistic approach to processing of pyrolysis oil and could become commercial.
- The ebullated bed technology seems to offer significant potential for improving the conversion of bio-oil. The project is well organized with an impressive team of partners. The research is on track, and the future efforts are well focused on the critical success issues identified by the project team.
- This appears to be a technically sound approach with a fair chance of success, although the hurdles of catalyst activity maintenance and corrosion remain.

PI Response to Reviewer Comments

- We are looking at similarity to traditional alumina supports in terms of strength and porosity, combined with greatly reduced rate of leaching in acidic environment.
- Thank you for that affirmation. We hope we have, in fact, defined the critical issue(s) and have started on a path that can resolve them.
- Again, thanks for the confidence in us. We know we (Grace) were chosen for our real-world connection to interested customers, and that PNNL and VTT respectively were chosen for their reactor/process know-how and credibility in making reliable, representative feedstocks. We hope the component pieces are all in place to maximize chances of commercialization.
- We appreciate the positive feedback and will do our best to stay on track and focus on the key deliverables.
- We agree that those are the ‘killer variables,’ along with stable operation of the reactor and its complex three- or four-phase dynamic mixture

UPGRADING OF BIOMASS FAST PYROLYSIS OIL (BIO-OIL)

(WBS#: 3.2.2.24)

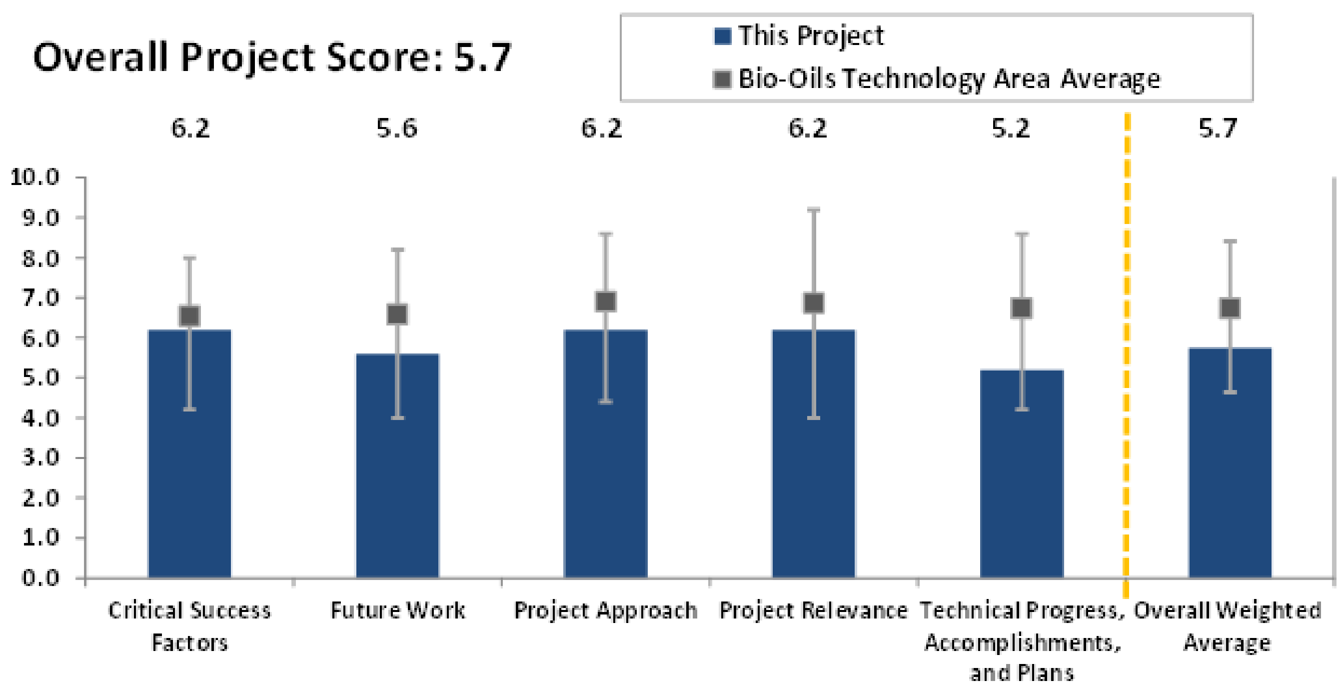
Recipient:	PNNL
Presenter:	Corinne Valkenburg
Total DOE Funding:	$2,988,000
DOE Funding FY13:	$797,000
DOE Funding FY12:	$891,000
DOE Funding FY11:	$1,300,000
Project Dates:	2010-2015

Project Description

Photo Courtesy of PNNL

The goal of this project is to develop a low-cost catalytic system for stable upgrading to produce gasoline-diesel range hydrocarbon. The products of partial processing will also be tested for compatibility with existing refining unit operations. The technology developed in the project is expected to contribute significantly to the successful commercialization of fast-pyrolysis-based biofuels. The project will use bio-oils from hardwoods, softwood (pine beetle kill), and corn stover. The primary feedstocks used in the project will be raw bio-oils, as well as fractionated bio-oils.

The specific objective of this project is to reduce the cost associated with the catalytic upgrading of pyrolysis oil by increasing liquid-fuel yield by improving carbon utilization; improving hydrogen (H_2) efficiency; and lowering operating temperatures and pressures. To meet this objective, the project will strive to understand the cascade of necessary reactions to develop catalysts and process parameters that reduce process performance over time. Catalyst and process conditions will be identified and optimized to enable extended operations, which will be demonstrated via 1,000 hours of operation in an integrated bench-scale reactor system. This project will leverage the long-established research partnerships



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

between PNNL, UOP, and W.R. Grace, as well as the Technische Universität Müchen, in developing catalyst systems. UOP will provide fast pyrolysis oils, as well as fractionated oils. Technische Universität Müchen will work closely with PNNL to measure and understand the reaction cascades. W.R. Grace will provide materials and technical support related to refinery integration.

Overall Impressions

- The project addresses an important issue, which is converting low-value organic by-products into more valuable fuels. After a slow start caused by changing interests of a partner, the project has been re-scoped and now appears to be on track for successful completion.
- The use of alumina seems to be a false start. Need to get more active input/support from their industry partners.
- There is a key potential advance here (small fragments --> alcohols and thence to fuels via alkylation of rings), but there is some ancillary work of less obvious value. It's not clear that the original partnership, which looked like a very good one, is still truly in place. Without that, it is really just more lab-directed work at PNNL on hydrotreating, which is useful but not terribly innovative or commercially promising.
- Think this is a good project. The slides were decently understandable.
- This appears to be a make-work project for the labs with little novelty and little chance of commercial realization.

PI Response to Reviewer Comments

- Thank you for the review and feedback on this competitively funded project. We agree that the industrial partnerships are valuable and will seek more active input from UOP and W.R. Grace as we move forward. It is unfortunate that the inherently low-value proposition of transportation fuels gives cause for industry to focus on developing higher-value products. However, we are fortunate to be working with world leaders in refinery technology and catalyst provision. We also believe that the novelty of this effort is the tying of fundamental reaction-kinetics studies of model compounds directly to bio-oil fractions, then whole bio-oils over the two year period of performance. As such, the knowledge developed is expected to bolster the field of catalytic HDO, thereby facilitating commercially viable catalyst development for catalytic fast pyrolysis, hydropyrolysis, and upgrading of catalytic fast pyrolysis, hydropyrolysis, conventional fast pyrolysis, and hydrothermal liquefaction bio-oils. We are excited about moving the work forward with our academic and industry partners and note that there are aspects of the catalyst development that industry identified as having specific value.

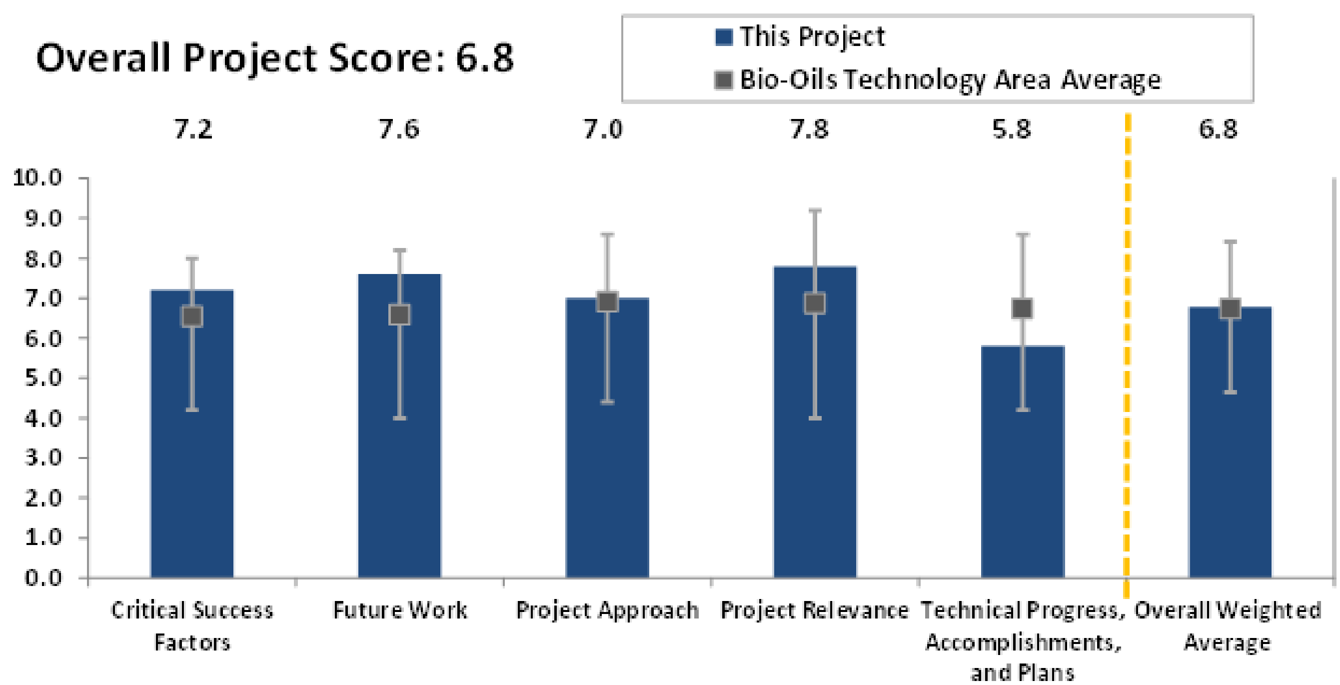
OPTIMIZING CO-PROCESSING OF BIO-OIL IN REFINERY UNIT OPERATIONS USING A DAVISON CIRCULATING RISER (DCR)

(WBS#: 3.3.1.1; 3.3.1.25; 3.3.1.26)

Recipient:	PNNL
Presenter:	Alan Zacher
Total DOE Funding:	$4,000,000
DOE Funding FY13:	$3,500,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012-2015

Project Description

The purpose is to insert biomass early into petroleum refinery infrastructure to produce liquid transportations fuels. This will be accomplished by determining the minimum amount of stabilization required to co-process bio-oil and petroleum into a fluid catalytic cracking (FCC) reactor using a Davison Circulating Riser (DCR) piloting tool. The project brings experts in bio-oil production, stabilization, and upgrading, the industry leader in FCC piloting, bio-fuel corrosion analysis, and carbon-14 analysis. The outcome will be a design package of optimal co-processing envelope, new FCC catalysts, corrosion and materials compatibility, life-cycle analysis, techno-economic analysis, and biogenic carbon accounting to demonstrate that the fuel generates Renewable Identification Number (RINs) credit, and qualifies toward EISA Renewable Fuel Standard advanced biofuels goals. The relevance to BETO milestones and targets include generating data that validate bench-scale processes in pyrolysis oil production, and upgrading routes and work toward the fiscal year 2017 conversion cost target of $1.83/gge by addressing the MYPP barriers of pyrolysis/stabilization and fuels synthesis and upgrading. This project is new for fiscal year 2013 and has not generated data for technical accomplishments. Key technical challenges include demonstrated bio-oil refinery incompatibility, current FCC catalysts are not tuned for biomass co-processing, a market reluctance for bio-oil use, and the lack of a RINs credit calculation for co-processing. This project will be successful upon identifying an optimal co-processing envelope, a trusted



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

method for RINs credit determination by biogenic carbon accounting, and a complete product analysis and demonstration package on an industrially trusted FCC piloting tool. This will result in a path for pre-commercial trials at refineries, commercialization, and implementation.

Overall Impressions

- This is more of a matter of establishing a baseline than of real innovation, but since most bio-oil work has focused on hydroprocessing, a baseline is needed for FCC. If this project can just get off the ground, it should be able to accomplish that, as well as some tuning of catalysts and process conditions.
- Seems like a good project, but too new to evaluate progress.
- The project focuses a strong team on the important issue of how to improve FCC of bio-oil. The project, which started very recently, should provide very key data on the suitability of this upgrading approach in a petroleum refinery. The work is very relevant to the DOE portfolio.
- These feeds will likely load up the main column of an FCC and back out feed, as well as adversely affect the unit heat balance. This is unlikely to be attractive unless these feedstocks are very cheap.
- This project has potential. It has good collaboration, but mostly likely will not be able to integrate with existing refining FCC capacity due to refinery resistance, refinery economics, and availability of spare FCC capacity; however, it will answer some questions. Please note that on slide seven of the presentation, kerosene is shown as going into the motor gasoline blendstock pool. This will not happen.

PI Response to Reviewer Comments

- Thank you for the comments. We appreciate the observations and understanding of the project's ability to answer current questions on bio-oil insertion into FCC reactors.
- We and our industrial partners, Grace and Tesoro, have received intense industrial interest in the outcome and potential for success. This is much more than baseline evaluation, as there is significant innovation in developing new functionality for fluid catalytic cracking catalysts specifically for co-processing bio-oil and demonstrating optimal processing envelopes. These tuned catalysts may also have broader applications in other pathways, such as catalytic pyrolysis. There is published research that demonstrates a positive heat balance for FCC when processing bio-oil.[3] However, there is limited data on co-processing at an industrially relevant scale, and this project will provide pilot-scale data for heat and mass balances, as well as quality of the co-processed fuel product. The preliminary design package, which will be the outcome of this project, will establish the envelope and conditions in which bio-oil co-processing inside a refinery can make sense and be successful as demonstrated on industry-trusted, pilot-scale tools. This project is well suited to provide valuable, pilot-scale data in co-processing pyrolysis oils for BETO and industrial stakeholders. This is a new project and at the time of the review, lab work had not yet begun. It is unfortunate that we were not able to go deeper into the plans of this project in an open review format that would better assist the reviewers' evaluation. As of the writing of this response, the project is fully underway and we have completed the first of multiple co-processing campaigns in the Davison Circulating Riser pilot equipment. We are excited about the next project review.

[3] Schiller, R.; Bryden, K.; Habib, Jr., E.T.; et al. *Catalagram*. (113), 2013. www.grace.com/About/Businesses/Documents/Catalagram113_Spring.pdf

PLATINUM-BASED, BI-METALLIC MONOLITH CATALYSTS FOR PARTIAL UPGRADING OF MICROALGAE OIL

(WBS#: 3.3.1.18)

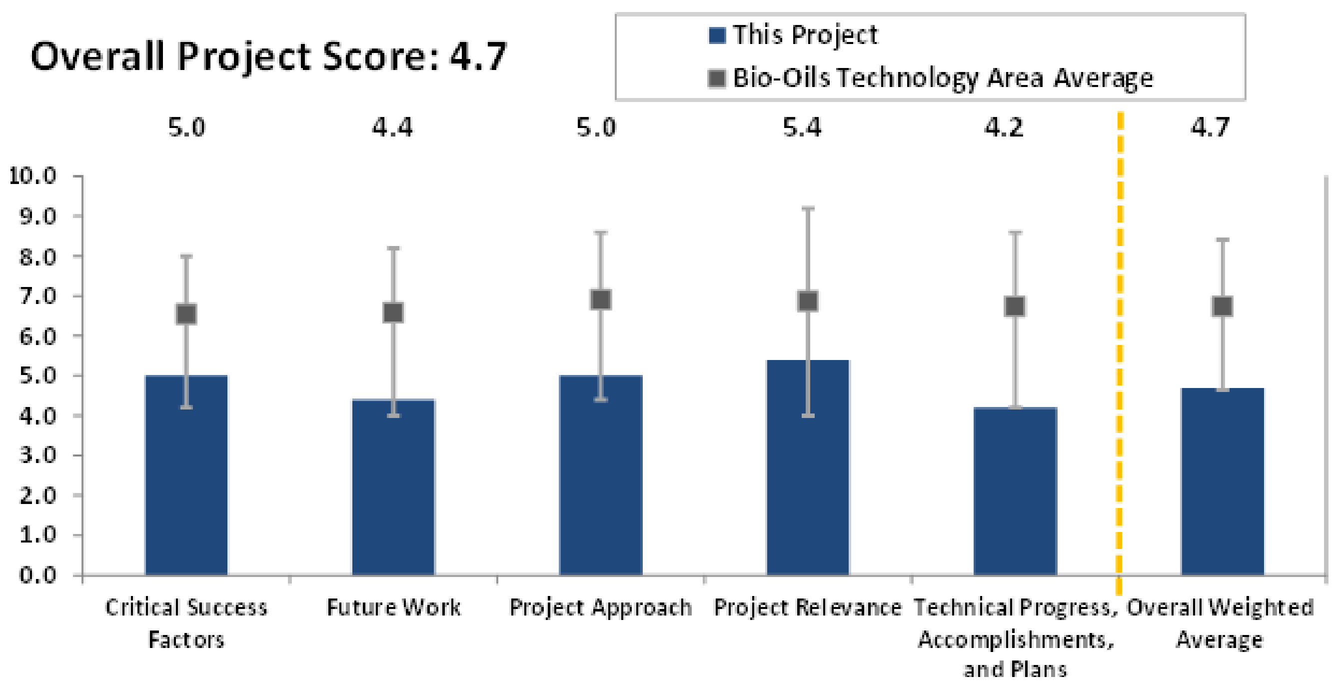
Recipient:	Stevens Institute of Technology
Presenter:	Adeniyi Lawal
Total DOE Funding:	$651,194
DOE Funding FY13:	$546,160
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013-2014

Project Description

Photo Courtesy of Stevens Institute of Technology

The proposed transformative technology converts microalgae to an algal oil feedstock suitable for insertion as a middle distillate feedstream into a petroleum refinery's hydrotreatment unit. This will produce green diesel by combining a proprietary, patent-pending, algal oil pre-processing platform with innovative reactor concepts and catalyst development for first-stage, partial upgrading of the pre-refined algal oils via HDO. Our approach comprises three key steps: extraction of algal oil from microalgae, followed by fractionation and purification of the algal oil to produce a cleaner *in-situ*, pre-refined algal oil, and—finally—HDO of the pre-refined algal oil in a monolith reactor wash-coated with platinum-based, bi-metallic catalysts supported on high surface area γ-Al_2O_3. Removal of residual oxygen and other heteroatoms from the partially upgraded feedstock in the petroleum refinery hydrotreater will produce a liquid fuel comprising mostly straight chain alkanes, which mimics diesel.

Overall Impressions



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

- Far too specific to a single algae species and extraction process; some work (HDO) is duplicative and being done better elsewhere, and some concepts (monolith) add little or no value.
- A problem can be in not having a refinery partner yet.
- Relatively farfetched claims for a bench-scale research project. Words lack credibility without more supporting technical substance.
- The catalyst work is progressing, but the nature of the algal oil is unclear. The catalyst expert needs to better understand the characteristics of the algal oil, how it was extracted, and whether that is representative of a larger set of possible oils. The project will have difficulty if the bio-oil feedstock is not well understood.
- This project takes a reasonable approach to algal oil processing. Better characterization of streams is required, as is input from a refinery partner.

PI Response to Reviewer Comments

- Considering the fact that we were only three months into the project at the time of the review, the results and data presented constituted accomplishments commensurate with project execution period.
- Catalyst activity and catalyst life constitute a critical factor in HDO of bio-oils. We identified two promising and high-activity, precious-metal-based catalysts. One of them was on-stream for 80 hours while the other was on-stream for 40 hours. We identified the mode of catalyst deactivation and developed an effective regeneration strategy that restored activity to close to its initial (fresh catalyst) activity each time. Although the levels of poisonous heteroatoms in our algal oil are quite low, the excellent resistance to coke formation and tolerance to poisons by precious-metal-based catalysts are also a contributory factor. We intend to further improve the extraction process to achieve even lower amounts of these heteroatoms.
- Except for oxygen content, our algal oil meets the requirements for major heteroatoms (e.g., nitrogen, phosphorous, sulfur).
- At oil extraction efficiency of approximately 90%, we exceeded the performance metric of 80% efficiency.
- Our proposal stated that we would be working with oils from 3–4 different strains of algae. It was not feasible to evaluate all the strains within three months of project start date.
- As a project awarded under Topic Area 1, we are required to have a petroleum refinery partner ***before the end of the projec***t. Discussions are at an advanced stage with a refiner, and we are quite optimistic about the outcome.
- Algal oils are more complex in composition than vegetable oils, which are predominantly neutral lipids, mostly triglycerides. In addition to neutral lipids, algal oils may also contain significant amounts of polar lipids and unsaponifiable matter depending on strain, cultivation, etc. Valicor has secured additional sources of algae known to have fatty acid methyl esters profiles perfect for fuel.

STABILIZATION OF BIO-OIL FRACTIONS FOR INSERTION INTO PETROLEUM REFINERIES

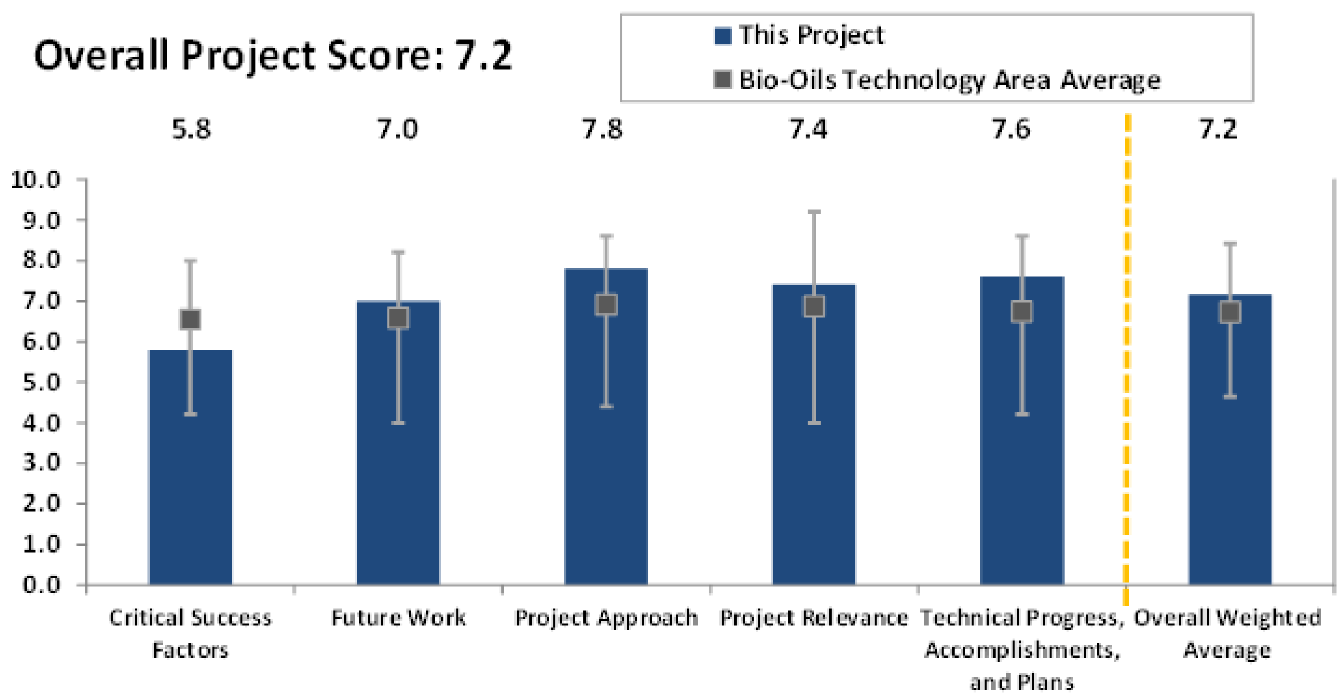
(WBS#: 3.3.1.21; 3.3.1.24)

Recipient:	Iowa State University
Presenter:	Robert Brown
Total DOE Funding:	$937,500
DOE Funding FY13:	$937,500
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013-2013

Project Description

Photo Courtesy of Iowa State University

The overall goal of this project is to recover bio-oil as four distinct fractions followed by stabilization through catalytic upgrading processes customized to the physical and chemical properties of each fraction. Specific objectives include: production of four fractions of bio-oil (soluble carbohydrate, clean phenolic oligomers, middle fraction, and light ends); stabilization of the soluble carbohydrate fraction (sugars and furans) through a combination of aldol condensation, ketonization, oxidation, and hydrogenation reactions; stabilization of the clean phenolic oligomers through hydrodeoxygenation reactions; stabilization of the middle fraction through alkylation and hydrodeoxygenation reactions; stabilization of the light ends through ketonization and hydrogenation reactions; and estimation of capital and operating costs for the production of refinery feedstocks via stabilization of pyrolysis intermediates. The approach consists of: pyrolyzing biomass and recovering bio-oil as stage fractions using pilot-scale pyrolyzer and bio-oil recovery system (half a ton per day of biomass and half a barrel per day of bio-oil); blending- and washing-stage fractions to produce upgrading fractions; stabilizing the upgrading fractions in bench-scale reactor systems; evaluating feasibility of inserting stabilized upgrading fractions in a refinery;



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

and performing a TEA of bio-oil production and stabilization. Progress to date includes: production of oak-derived, bio-oil fractions and upgrading fractions, and initiating upgrading experiments focused on carbohydrate-derived fractions. The project is relevant to DOE's goal of producing bio-oil with desirable qualities for making hydrocarbon transportation fuels in the gasoline, diesel, and jet range. Critical success factors include technical—for maximum carbon efficiency, all fractions must be satisfactorily stabilized; market—must be able to identify refinery insertion points for all stabilized fractions; and business—must identify a petroleum company interested in developing stabilized fractions.

Overall Impressions

- The project is running very well and is likely to meet its objectives on time. It is investigating a very interesting and potentially valuable concept (bio-oil fractionation). It does seem to be aimed at a concept that requires far too many units and far too much operations complexity to ever succeed at the scale at which it must operate.
- I like the project, but also see concern expressed about its ability to be economic.
- It is technically interesting to understand the molecules and conversion options, but realistically, this pathway is probably too complex to be practical.
- The potential for fractionation is interesting, and the project is proceeding as planned. The need for many processing steps potentially adds costs, and the economic issues need to be addressed. The project also produces long-chain alcohols in some fractions, and the compatibility of these products with the refinery needs to be addressed.
- This has the same issue as other projects regarding insertion into a refinery where spare capacity and/or proper metallurgy may not exist. This project also may be disadvantaged from the production of multiple streams, all of which require further processing. Although this may make refinery insertion more feasible for some of the product streams, it also raised logistical issues. If located near the biomass source, this process would then require transportation of multiple small streams to a refinery. If located near the refinery, biomass transport becomes an issue. Either way, transportation may be an issue with this process.

PI Response to Reviewer Comments

- We appreciate the reviewer's comments and find them helpful in completing our project. The major concern expressed was that moving multiple bio-oil fractions from distributed pyrolysis reactors to a central upgrading facility would be costly. We argue that shipping costs would be comparable to or even cheaper than moving whole bio-oil, since some of the fractions would be less corrosive and more stable than the whole bio-oil, allowing them to be contained in less expensive tanks while moving the same total volume of liquid.

Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

DEMONSTRATION OF PYROLYSIS-BASED BIOREFINERY CONCEPT FOR BIOPOWER, BIOMATERIALS, AND BIOCHAR

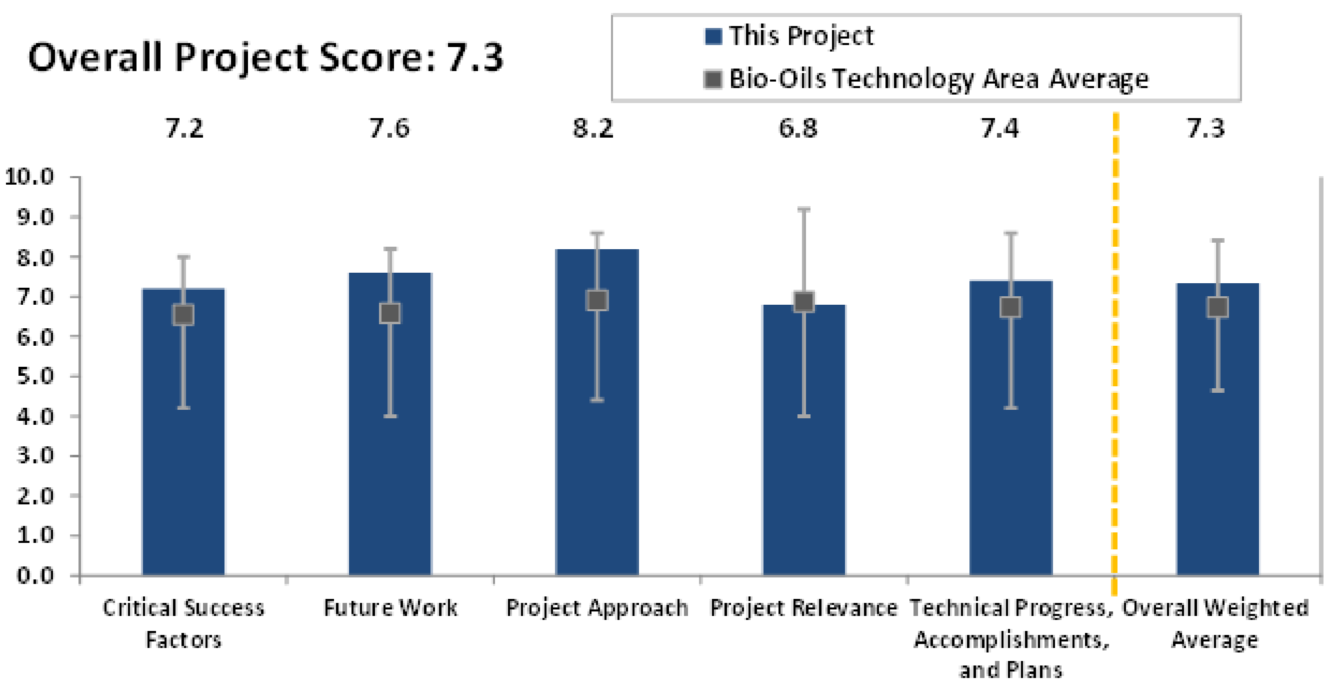
(WBS#: 3.2.2.25)

Recipient:	Avello Bioenergy
Presenter:	Dennis Banasiak
Total DOE Funding:	$2,500,000
DOE Funding FY13:	$1,917,000
DOE Funding FY12:	$583,000
DOE Funding FY11:	--
Project Dates:	2011-2014

Project Description

Photo Courtesy of Avello Bioenergy

The main objectives of this project are to design, build, and operate an integrated biomass thermochemical 2.5-ton-per-day pilot plant to produce large amounts of bioproducts, and test the bioproducts' performance for market acceptability. Expected outcomes include successful demonstration of Avello's proprietary, integrated, pyrolysis bio-oil-fractionation technology; continuous plant operation; and large-scale bioproducts testing. The presentation will focus on introducing the technology, the specific activities planned, project management goals, and critical success factors for the project. A successful project will demonstrate and advance the commercialization of this thermochemical technology platform to convert non-food agricultural and woody biomass resources into sustainable petroleum replacements for asphalt pavements and roofing shingles, biofuel blends for clean-power generation, renewable chemicals, and soil improvement products, providing bio-carbon sequestration opportunities.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- A novel approach to look at more homes for bio-oil molecules. A complex approach, but it may achieve some interesting results.
- Looks interesting. I look forward to seeing what comes from the project.
- One of the very best projects in the entire portfolio. Great commercial potential, but simultaneously innovative and novel. Please get the contracts done so these guys can get to work!
- Overall this seems like a good project with a good chance of success. That said, it nonetheless faces several daunting challenges. The production of multiple, small product streams reduce the volume of those streams and the scale of downstream processing/handling units. This lack of economies of scale could therefore reduce the overall project economics. This process may have to be quite large and centralized in order to increase the volume of product streams to an economic level. This, in turn, will limit the ability of this process to be distributed as small units throughout the biomass supply areas. A central processing scheme may be required. This will then necessitate potentially un-economic transportation of large amounts of biomass.
- The project has excellent cost sharing and could help establish the infrastructure for pyrolysis to products. The project will not make liquid transportation fuels, so it's relevance to DOE's current priorities is very weak.

PI Response to Reviewer Comments

- Although this project has purposely focused on the "rest-of-the-barrel" concept and not only on transportation fuels, Avello agrees with the reviewers that the project has high potential to contribute to the development of bio-oil utilization and DOE's pyrolysis goals.

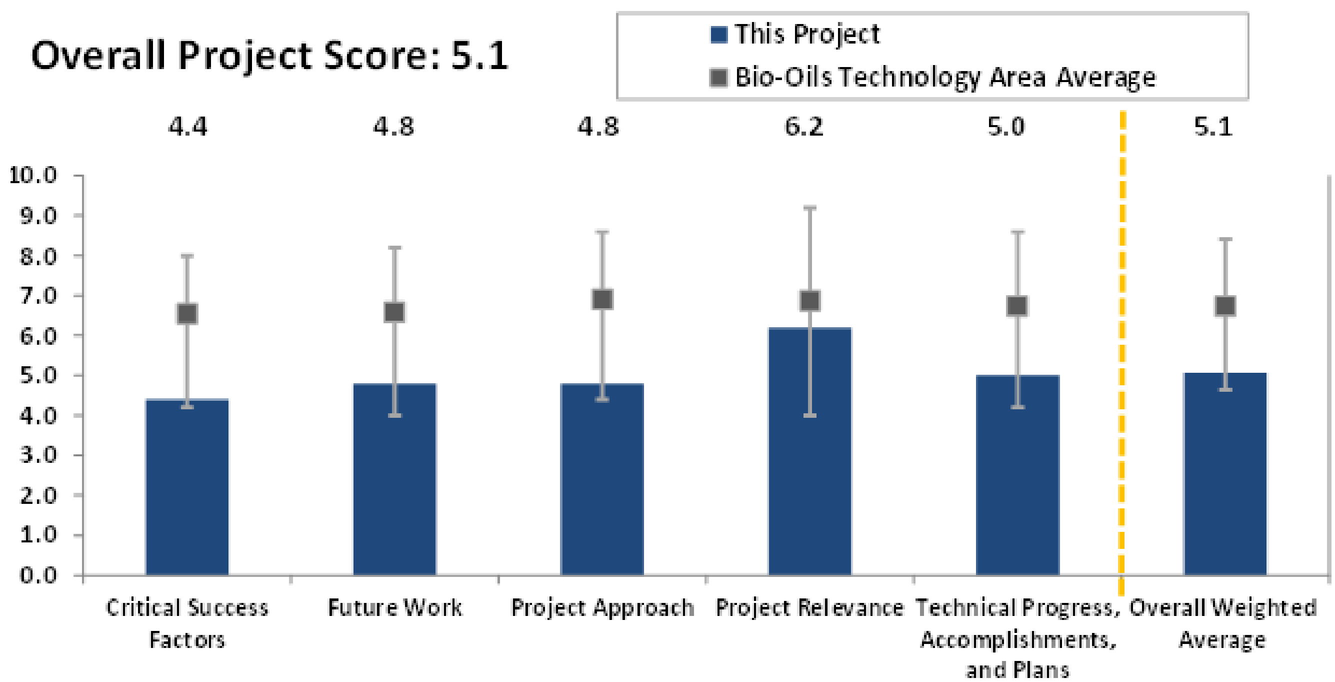
MISSISSIPPI STATE UNIVERSITY SUSTAINABLE ENERGY CENTER

(WBS#: 7.7.4.8)

Recipient:	Mississippi State University
Presenter:	Fei Yu
Total DOE Funding:	$15,587,449
DOE Funding FY13:	--
DOE Funding FY12:	$4,922,748
DOE Funding FY11:	$4,597,536
Project Dates:	2006-2014

Project Description

The Mississippi State University pyrolysis/syngas program goals support the development of technologies for conversion of forest and agricultural resources into cost-competitive liquid fuels, such as renewable gasoline, jet fuel, and diesel. The specific objectives of this program are to: develop hydrocarbon and biodiesel fuels from raw bio-oil produced from Southern pine and agricultural products and residues; develop auger reactor designs that can provide test quantities of raw bio-oil; and test designs at pilot plant scale; and develop technologies for biomass gasification and catalytic conversion of cleaned syngas to hydrocarbon biofuels. This is accomplished through the design and optimization of a syngas-to-hydrocarbons pilot plant, including biomass gasification, syngas cleanup, and syngas upgrading, as well as new catalyst material development. Projects underway at this time include design and construction of a pilot-scale hydrotreater and stirred reactor for 100% and low hydrogen methods, now nearly complete; development of a one-ton/day, pilot-scale pyrolysis reactor; design and testing of a bio-syngas purification system; optimization of the catalytic process conditions to account for the effects of impurities in the bio-syngas; and completion of the process design and economic analysis. Projects completed at this time include: a laboratory-scale (7 kg/hour) pyrolysis reactor; laboratory-scale packed bed reactor research (nearly complete); information utilized for pilot-plant application; laboratory-scale research on low-hydrogen method (nearly complete, patent pending); information gathering for utilizing pilot-plant application; and increase and utilization of anhydrosugars by spray method in the pyrolysis reactor. On several completed



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

projects, patents are pending: olefination/esterification of bio-oil to produce a high-energy boiler fuel; and production of hydroxymethyl furfural from maximized bio-oil anhydrosugars. Additional projects were completed: both pilot-scale bio-syngas purification system and pilot-scale catalytic conversion system were designed, fabricated, and installed; and several multi-functional catalysts were screened and chosen for bio-syngas conversion into wide-cut diesel and jet fuel hydrocarbons in lab-scale FT reactors.

Overall Impressions

- A great deal of money was allotted to this project for essentially two projects. There is concern about the PI understanding the required specifications for the fuels produced. Though it will be sent out to a petroleum testing facility, there is still a need to know what you need to have done in order to meet specifications.
- The work is not well-organized, well-focused, or competitive with the best competing work in the United States or abroad, and the progress to date does not seem commensurate with the time and money expended.
- Most likely, the gasification route will not be economical. Typically, these processes are very expensive even at large scale and have difficulty economically producing transportation fuels. The pyrolysis route may prove to be more economical and have better commercial potential. It seems unlikely, however, that a low hydrogen consumption route will be able to produce a fungible, drop-in transportation fuel given the chemistry of the pyrolysis process.
- The presentation lacked technical details or rational explanations for the claims made. It's almost impossible to assess any of the claims being made with no details given or explanations provided.
- The work at Mississippi State has significantly expanded the capabilities of the university, and they have successfully built and operated both a pyrolysis/upgrading unit and a gasification/synthesis facility. They have also successfully produced many publications and presentations. In going forward, the university needs to focus on continued science and engineering innovation that will advance the state of the art. The current facilities are good tools to do this, but the research needs to be focused on the innovation and less on operating the units. The university may want to consider selecting one of the two pathways for future emphasis and scale back on the other to achieve sharper focus.

PI Response to Reviewer Comments

- The goal of the Sustainable Energy Research Center at Mississippi State University is to develop liquid transportation fuels from southeastern feedstocks. The two projects reviewed were bio-oil production/upgrading and syngas-to-liquid-hydrocarbons.
- Diesel fuel has been produced with both technologies, with the fuel close to the American Society for Testing and Materials (ASTM) specifications. Internal and external analyses are being used to determine the additional steps necessary to bring the fuels to full ASTM compliance.
- Each of these technologies will soon be at a pilot-scale level of operation with the production of gallons of fuel per day. With scale-up, these fuels can be produced for about three to four dollars per gallon based on our techno-economic analyses.
- The gasification route is unique in that it is not a traditional Fischer-Tropsch process but instead, a one-step catalytic process that produces liquid hydrocarbons rich in diesel-range or jet-fuel-range fuels. Separate catalysts have been developed for the two ranges. The system is easily expanded by using multiple parallel reactor tubes.
- Through the 2012 fiscal year, the faculty had graduated 19 Ph.D. students and had published 197 articles in refereed journals. An additional 34 Ph.D. students are in the pipeline, with expected graduation in the next few years.
- Both the bio-oil and syngas fuel technologies have been licensed to outside developers who are working toward commercializing the processes. These developers are also providing additional support for the research related to taking these fuels to a full-scale level of production.

THERMOCHEMICAL PLATFORM ANALYSIS—FAST PYROLYSIS DESIGN CASE AND SUSTAINABILITY INTERFACE

(WBS#: 3.6.1.3; 3.6.1.1)

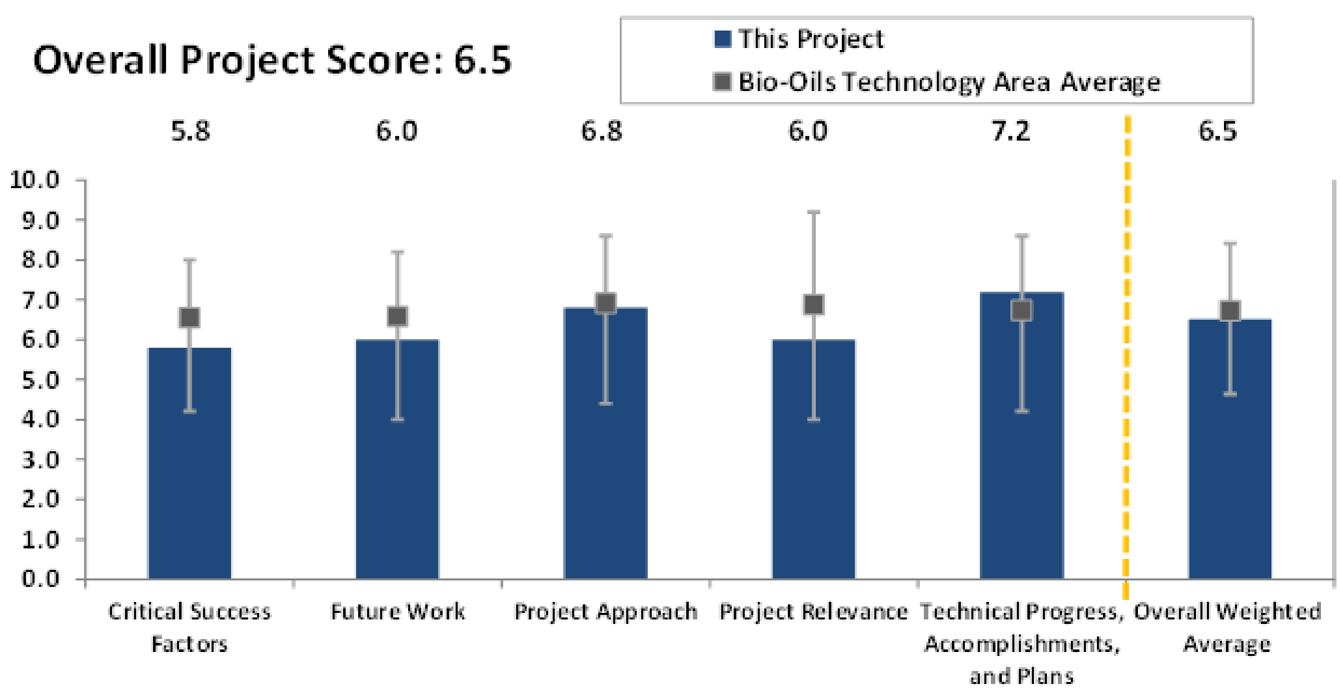
Recipient:	PNNL
Presenter:	Sue Jones
Total DOE Funding:	$1,582,000
DOE Funding FY13:	$425,000
DOE Funding FY12:	$315,000
DOE Funding FY11:	$250,000
Project Dates:	2007-Ongoing

Project Description

This project supports the DOE-BETO 2017 goal toward supplanting petroleum-based liquid transportation fuels with renewable resources by providing design cases for fast pyrolysis and upgrading. Specifically, this involves the development of the annual state-of-technology assessments to measure progress toward technical goals, and the integration of sustainability metrics into the overall analysis of bio-oil production and upgrading. The 2009 fast pyrolysis and upgrading design case was based on data up through 2008. In fiscal year 2013, PNNL and the National Renewable Energy Laboratory (NREL) are collaborating to update this case to incorporate new experimental data in order to provide focused technical and cost targets for BETO.

Overall Impressions

- This is a large project. It seems like later projects provide details on this. I like the overall project. It seems to be following plan and progressing well.
- On the surface, this project appears to be life support for the national labs. They are certainly important assets, but could be used more effectively. It is not clear at this time if this project, as currently structured, adds much value to the Bio-Oil Technology Area. Use of the national labs by commercial/academic organizations appears to be limited due to the high cost to outside parties to use the national lab assets. One possible improvement would be to utilize the money spent on projects like this one to



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

subsidize or lower the overall cost to third parties for using the national lab assets. This may make the work more relevant. Although some aspect of third party work may be proprietary, there certainly would be some non-proprietary aspects of this work that could be disclosed to others. Having this kind of input from outside the silo may greatly improve the ability of the national labs to lead the development of biomass technology and processes.

- The work in these projects could be skewed to increase funding, and validity in the results is therefore questionable.
- The work on the DOE design case is high in quality and proceeding as planned. The inclusion of sustainability is excellent, and it is good to see that the design case is being reevaluated to include new information that has become available in the last two to three years.
- While the goal of modeling the process concepts and assessing costs is laudable, the influence of government mandates might be producing results that lack the credibility that other nongovernmental analysis programs can provide. Concluding that most process paths are on pre-mandated schedules and on pre-mandated cost pathways is not credible for normal research programs. If the progress was as described, money would be flooding in to build demonstration and commercial plants. The money does not seem to be as optimistic as DOE projections.

PI Response to Reviewer Comments

- Thank you for your review. It is unfortunate that the presentation did not make clear the underlying purpose for this work. The Bioenergy Technologies Office uses national laboratory-directed research along a specific pathway as a means to set goals and measure progress towards those goals using data, methods, and assumptions that are public and well documented. We agree that this is not the only direct liquefaction pathway to fuels, but it does allow industry to use these data to develop their own systems. The more detailed techno-economic analyses (e.g., design cases) are reviewed by modeling experts and experimentalists at DOE national laboratories and by external reviewers such as industrial catalyst vendors, leaders in the field of direct liquefaction, refinery equipment vendors, and academics. The Office does support industrial research through solicitations, but because of intellectual property constraints, the details of such work are not usually made public. Each private entity has their own internal means to calculate costs, making comparison amongst competing technologies and against targets difficult on a fair basis.
- Small-scale plants converting biomass to finished fuels may not be an efficient means of using existing infrastructure and the production of bio-intermediates that are finished in a refinery may be preferable. However, the challenge of how to value that intermediate, how to estimate the processing costs within the refinery, and how to measure progress towards the BETO's programmatic goals has not yet been solved. Additionally, integration of bio-intermediates with a refinery may not be a national model, but rather, a niche opportunity; as such, the standalone model not integrated into a refinery has its merits for a transparent comparison of different technologies. Refinery integration is recognized as a significant gap and work to address this issue, with the assistance of refining experts, will commence in fiscal year 2014.

FEEDSTOCK INTERFACE & FEEDSTOCK-THERMOCHEMICAL INTERFACE EQUIPMENT

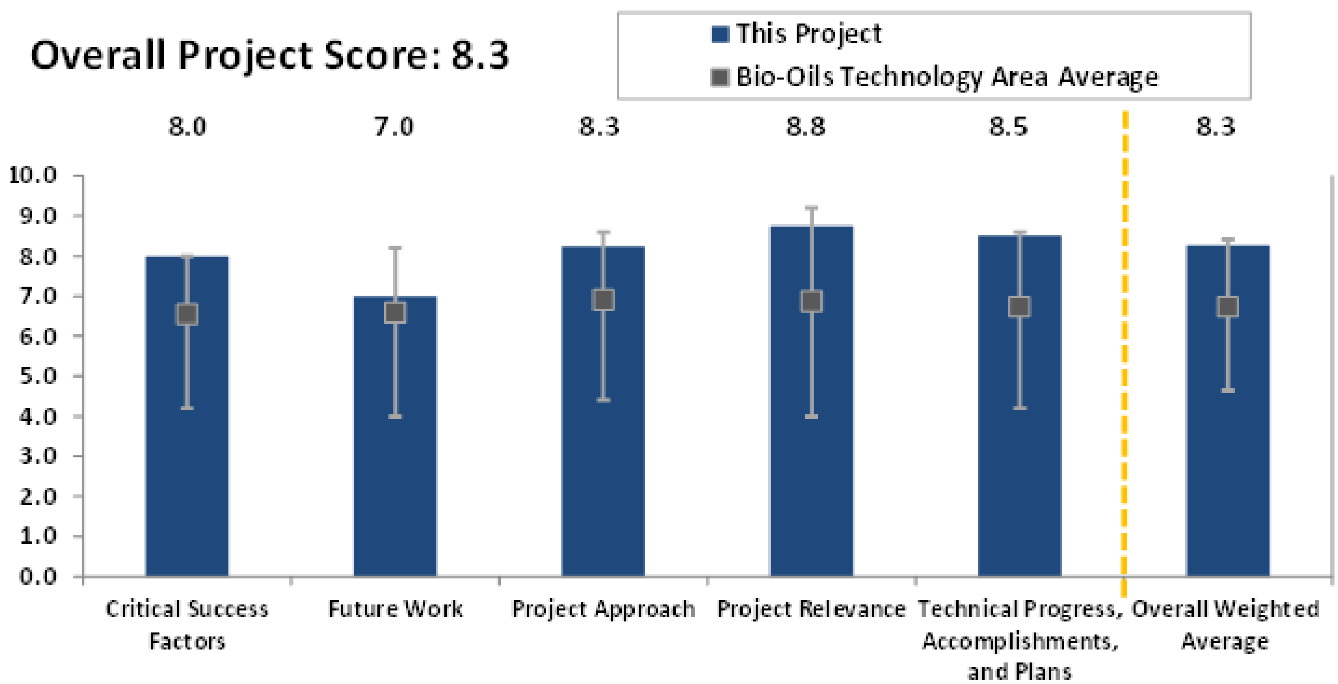
(WBS#: 3.1.2.3; 3.7.1.3; 3.1.2.1; 3.1.2.2)

Recipient:	INL; NREL; PNNL
Presenter:	Tyler L. Westover
Total DOE Funding:	$6,129,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2007-2022

Project Description

Photo Courtesy of INL, NREL, PNNL

The purpose of the Feedstock/Thermochemical Interface Project is to link supply chain expertise and capabilities at INL with corresponding conversion research at NREL and PNNL so that feedstock specifications and conversion sensitivities can be established. This work involves determining the range and variability of key feedstock properties, such as ash content/composition, moisture, heating value, and oxygen content, evaluating the effectiveness and cost of pretreatment options to control key properties and the impact of such properties on the yield and quality of conversion products. The ultimate goal is to develop predictive supply and conversion models that are needed to enable least-cost formulations to be determined in real time at a local level, depending upon available resources. Key aspects of the project include developing rapid analytical screening tools for parameters that affect conversion reactions; building a shared inventory of realistic, well-characterized, field-run samples; assessing preconversion technologies; performing conversion and upgrading tests to determine the impact of key feedstock properties; and developing predictive supply and conversion models. A laser-induced breakdown spectroscopy method has been developed



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

for rapid, onsite ash characterization. Molecular beam mass spectroscopy, high-speed thermogravimetry/differential scanning calorimetery, and two-dimensional gas chromatography techniques are being developed for rapid analysis of feedstock chemical and fuel properties. Many feedstock samples, including southern pine, white oak, hybrid poplar, corn stover, and switchgrass, have been prepared and shared among the labs for conversion experiments. Woody samples have been subjected to dry thermochemical preconversion processes at temperatures as hot as 270° Celsius (C), and then subjected to gasification and pyrolysis experiments to investigate potential advantages and costs. Near-term future work will focus on select feedstocks (clean pine, whole tree pine, hybrid poplar, switchgrass, and corn stover) and blends of these feedstocks to perform comprehensive conversion and upgrading experiments from which predictive, multivariate conversion models will be built.

Overall Impressions

- Determining the impacts of biomass characteristics on the resulting product is important, and the project has made good progress. In going forward, the project needs to focus more closely on the bio-oil pathway relevant to DOE and deemphasize others.
- Interesting project for fast testing of materials for processing. Modeling—not sure about background on doing fast pyrolysis modeling.
- Outstanding effort. Needs to reach out to a broader base of collaborators and keep a sharp eye on shifts in the MYPP and in the direction industry is going, but overall a fantastically valuable project for BETO.
- This project stands out as one of the best and most productive uses of our national lab resources. It addresses known issues regarding feedstock handling/pre-processing and should be of great value to virtually every biomass conversion project out there. In this regard, this project will help lead the industry to more economical and feasible biomass solutions.
- Very interesting, but breadth of scope may be too broad. However, a good probability of adding value to our knowledge base.

PI Response to Reviewer Comments

- We greatly appreciate the comments and suggestions from the reviewers. We are pleased the reviewers agree that we must evaluate a broad range of technologies and feedstocks while paying close attention to the MYPP to assist in guiding research efforts. As such, future efforts will focus on the fast pyrolysis and bio-oil upgrading via hydrotreatment pathway to more closely align with BETO's priorities while de-emphasizing gasification. Since a principal focus of this project is the development of tools and test methods that can be applied in the field in real time such as laser-induced breakdown spectroscopy, Fourier transform infrared spectroscopy, and thermogravimetry/differential scanning calorimetery. An important aspect of conducting the research is assuring that laboratory research materials are truly representative of feedstocks harvested at commercial scale. However, this task does not perform pyrolysis modeling. The objective is to develop reduced-order models or multivariate, linear-regression-type models to use rapid screening data to predict conversion performance. When conversion or cost models are necessary, this task seeks help from other tasks such as Core Conversion Platform or the Feedstock Logistics Project. Although industry partners are not explicitly listed as partners in the presentation, this project does work indirectly with industrial partners through the Core Feedstock and Conversion Platforms. The process is like a pipeline: Industry (feedstocks) → Feedstock Technology Area (DOE) → Interface Task (DOE) → Conversion Platform (DOE) → Industry (Conversion & Upgrading). If the Interface Tasks engage in substantial effort directly with industry, it runs the risk of cutting out the Feedstock and Conversion Platforms, which could cause confusion and duplicate effort. However, industrial collaborations can help guide the prioritization of relevant technologies and feedstocks. While the scope is necessarily broad, multivariate analysis of planned field-to-fuel experiments is believed to be capable of identifying the feedstock compositional characteristics necessary for further refinement of the research.

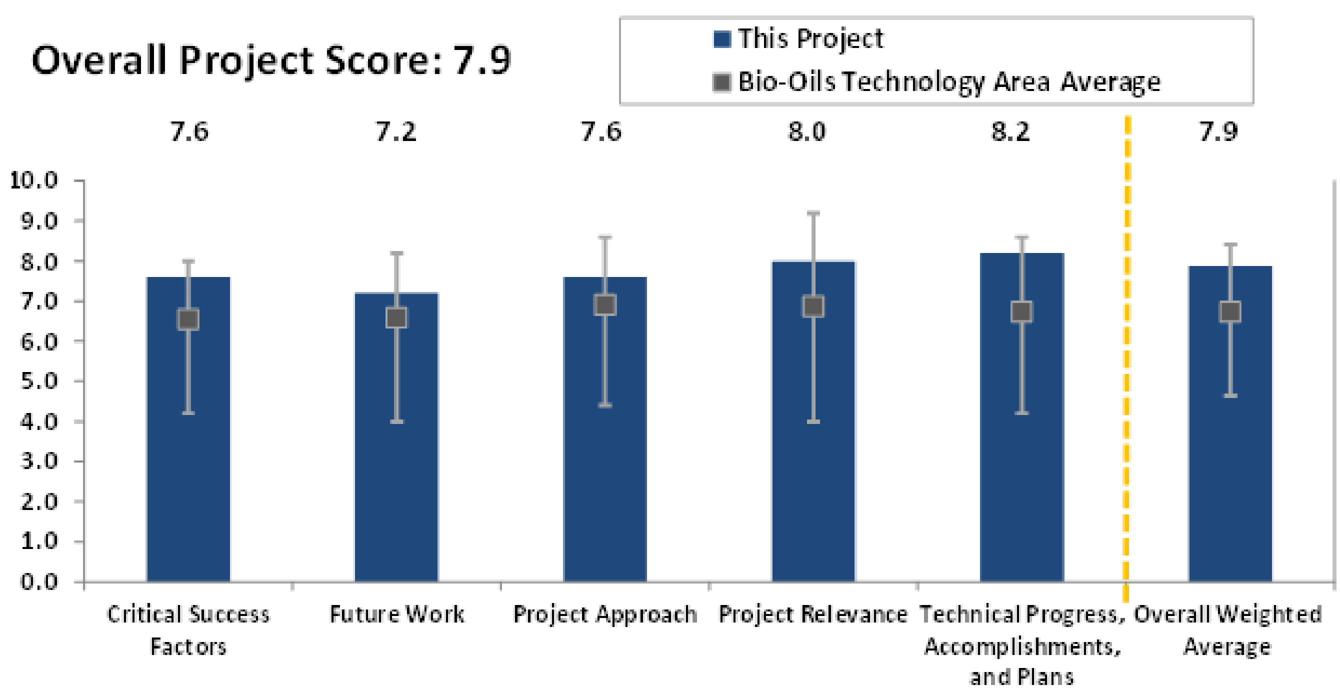
PYROLYSIS OIL R&D, HYDROTREATING OF PHYSICALLY STABILIZED PYROLYSIS OIL, & CAPEX

(WBS#: 3.2.2.4; 3.2.2.32; 3.7.1.2; 3.2.2.5)

Recipient:	PNNL; NREL
Presenter:	Alan Zacher
Total DOE Funding:	$10,800,000
DOE Funding FY13:	$1,000,000
DOE Funding FY12:	$2,000,000
DOE Funding FY11:	$2,000,000
Project Dates:	2006-2015

Project Description

The purpose of this project is to develop basic science and engineering for production of fuels from biomass by pyrolysis and upgrading. Historically, results from this project have provided data and identified barriers to inform DOE, such that they can create solicitations for further development of fuels from pyrolysis and scale-up of the technology. This is through broad research in pyrolysis and upgrading, advanced analysis techniques, integration of the pyrolysis conversion chain, and informing the pyrolysis design case. Technical accomplishments include breaking upgrading catalyst lifetime barriers; advancing traditional and catalytic pyrolysis; demonstrating impact of feed types, quality, and pre-treatment; developing analytical techniques for answering crucial questions; and constructing new equipment and processes for overcoming barriers. The relevance to BETO milestones and targets include achieving prior-year cost and technical targets, generating data to validate bench-scale processes, and working toward the fiscal year 2017 conversion cost target of $1.83/gge by addressing the MYPP barriers of pyrolysis/stabilization and fuels synthesis and upgrading. Key technical challenges include the fact that bio-oil is chemically dissimilar to traditional refinery feeds, bio-oil upgrading catalysts demonstrate short lifetimes, and there is a lack of data on quality and composition of fuels from this process and how they fit into existing refinery infrastructure. This project will be successful upon developing a sustainable process for bio-oil HDO to fungible fuels, demonstrating catalysts for upgraded fuel products at scale, and market understanding and acceptance of functional qualities of bio-derived fuels. This will result in meeting MYPP cost and technical targets, and improved market adoption of the technology.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- A valuable attempt to stabilize and characterize bio-oils. However, heteroatoms can have huge impacts on catalyst, corrosion, and sour water contaminants. There is more to insertion than getting a group of molecules in the right boiling range.
- Good project; very large. This project needed more presentation time because it covered a lot of material in a short time, mostly with national lab projects.
- The project is looking at highly relevant issues related to upgrading liquid bio-oil. The work is a very good example of the ways the labs can team up and perform high-quality research that advances the state of the art in an area, as well as show how the core research can be a valuable and effective part of the DOE portfolio.
- This is solid work at the interface between science and practical application—much more relevant that purely scientific work, but not likely to keep pace with industry in terms of commercial implementation. The work would be far more valuable in collaboration with industry, as well as universities and other labs.
- This project appears to be a relatively good use of the national lab assets. It supports other national lab projects and informs other pyrolysis researchers in universities and corporations, and fills a basic, core research gap that should advance the state of technology.

PI Response to Reviewer Comments

- Thank you for the comments and suggestions. We appreciate the review and fresh perspective. As the reviewers stated, the research effort balances science and practical application toward highly relevant issues facing bio-oil upgrading. The learning's have broad implications to bio-oils produced from a number of pyrolysis and liquefaction technologies. The results are being used to advance the technology in a number of areas consistent with the core program of the BETO portfolio.
- We agree there is a unique role that national laboratories provide for the benefit of public progress. We also agree that to stay relevant with industrial implementation, there is an increased need to continue to expand quality collaboration with industry and university partners (as well as sister laboratories), and we are working to broaden the current collaborations and industrial oversight.
- We are cognizant of the implications and potential pitfalls that new heteroatom containing species, even at low concentrations, may have on industrial application of the process as stated. An important thrust of the research is in fuel product characterization and specification to proactively identify challenges and potential barriers earlier in the research phase.
- Thank you again for the encouragement and suggestions identifying the most important elements of the research approach.

PNNL/VTT PRODUCTION AND UPGRADE OF INFRASTRUCTURE COMPATIBLE BIO-OIL

(WBS#: 3.2.2.26)

Recipient:	PNNL
Presenter:	Douglas Elliott
Total DOE Funding:	$1,200,000
DOE Funding FY13:	$100,000
DOE Funding FY12:	$549,000
DOE Funding FY11:	$351,000
Project Dates:	2012-2015

Project Description

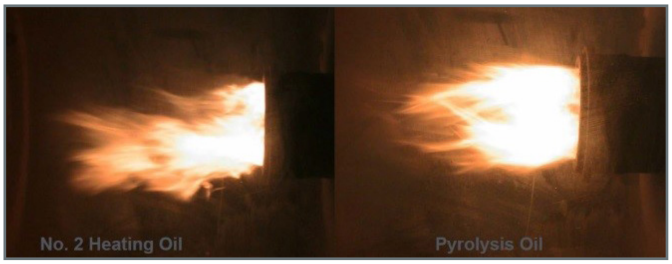
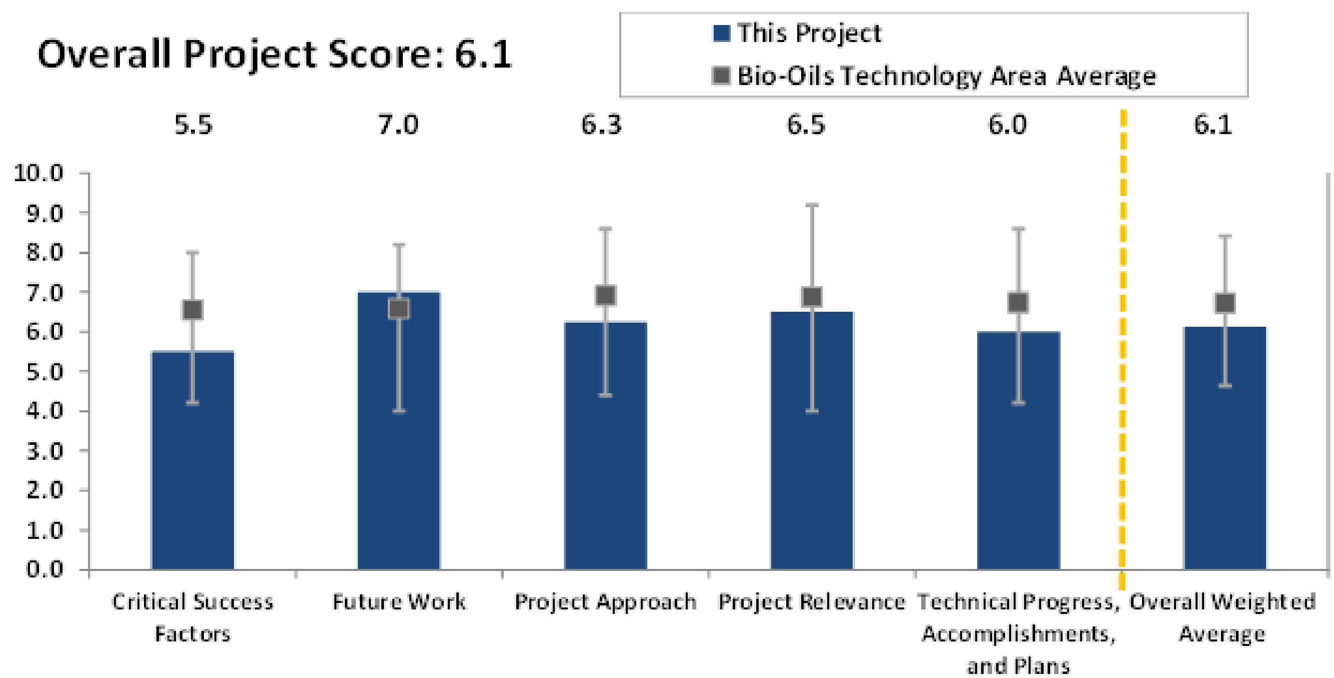


Photo Courtesy of PNNL

The goal of this project is to validate, in collaboration with an international process technology leader, an integrated conversion process for biomass to gasoline, diesel, or jet fuel by fast pyrolysis and hydrotreating. The major project objectives include processing fast pyrolysis bio-oil to infrastructure-compatible fuels using hydrotreating methods, analyzing the products and evaluating infrastructure compatibility, and performing a techno-economic assessment process modeling and evaluating the outputs based on input from process tests in the hydrotreated bio-oil. To do this, PNNL will partner with VTT in development of both the fuel production processes and the techno-economic assessment of those processes.

Overall Impressions

- Basic ongoing work on hydrotreating, this time with a European partner, but no domestic commercialization links.
- In this case, it appears the practical hurdles of long-distance collaborative research outweigh any significant value added.
- I like this project. The national labs are working well on making products.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

- Overall, the work done here is important and could provide some new insight into an economic pathway to transportation fuels via pyrolysis. However, the work done by this project seems to be nearly identical to work being done by other DOE-funded projects. In addition, this project could suffer from problems arising from degradation of the pyrolysis oil samples during transport from Finland to the United States.

PI Response to Reviewer Comments

- This collaboration provides bio-oil feedstock, useful on two levels. First, VTT provides large quantities of bio-oil feedstock for the upgrading research at PNNL; and second, they provide samples of "improved" bio-oils for upgrading comparisons. These "improved" bio-oils are not available elsewhere within the DOE portfolio, nor are the larger quantities of bio-oils, which will be needed for the large-scale hydrotreater start-up. This work is both different from other work and fundamentally important to BETO through both technology advancement and the pathway to increase scale. In addition, the collaboration provides access to the industrial consortium in Finland, which is building the first, commercial, fast pyrolysis plant in the world.
- The CORE pyrolysis project is developing improved hydrotreating configurations to enable long-term operation with a stable catalyst. In contrast, this project is evaluating alternative bio-oil products, which are more conducive to hydrotreating. VTT produces "improved" bio-oils based on selective collection and catalytic modification. The combination of modified pyrolysis and simplified upgrading can then be examined in the TEA effort to determine the size of the advantages of the combined process.
- The difficulties of long-distance collaborative research have been successfully addressed in this project. Good communications have been established and maintained. Exchange of process information has allowed coordinated development of process models at each site. The TEA work will provide the first direct comparison of fast pyrolysis and hydrothermal liquefaction since the 1980s. The issue of bio-oil stability arose only in the processing at low-severity conditions for bio-oil stabilization. As reported, minor changes in bio-oil quality were evaluated and the changes were overwhelmed by the changes during bio-oil transit. However, those minor changes during storage and transport (identified by this research) are inconsequential to the large changes being evaluated for the production of transportation fuels from bio-oil.

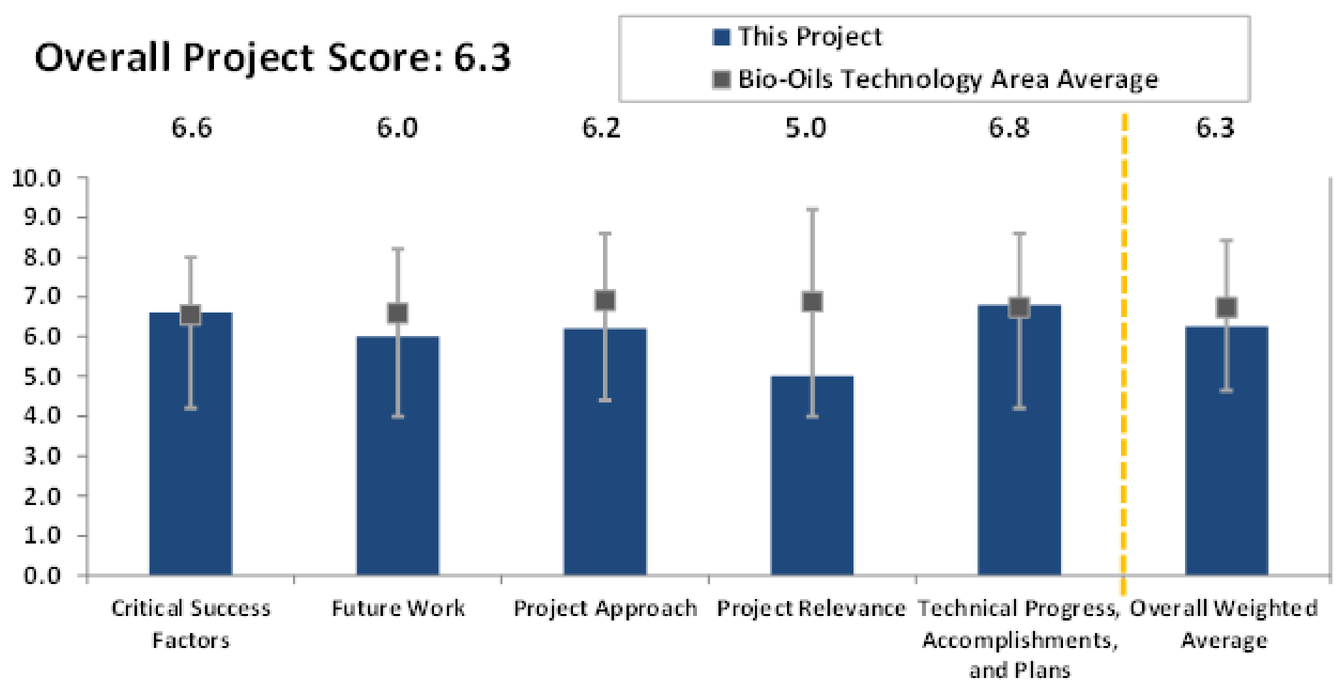
CA-02 PYROLYSIS AND UPGRADING COLLABORATION WITH CANADA

(WBS#: 6.5.9.1; 6.5.9.2)

Recipient:	NREL; PNNL
Presenter:	Kristiina Iisa
Total DOE Funding:	$600,000
DOE Funding FY13:	$100,000
DOE Funding FY12:	$100,000
DOE Funding FY11:	--
Project Dates:	2009-2017

Project Description

This project is part of the Clean Energy Dialogue between the United States and Canada and supports shared commitments in advancing clean energy. Both countries have identified pyrolysis as an important area for technical collaboration. The goal of this project is to advance pyrolysis of residue woody feedstocks for use in biofuels and biopower applications. This will include production and upgrading of bio-oil from woody residues to meet requirements for use as transportation and stationary power applications. The relevance to the Office of Energy Efficiency and Renewable Energy and BETO is in generating data to enable use of low-value, residue woody biomass to satisfy biofuels targets and meet national commitments to the Clean Energy Dialogue. The pyrolysis of hog fuels and pine beetle killed trees were compared to that of reference, clean woody feedstocks. The presence of ash impurities decreased oil yields, increased char yields, and impacted oil and gas composition. The impacts were highest for hog fuel from trees transported in the ocean, and water washing was tested as a means to reduce the salt content. Washing was effective in removing sodium and chlorine and restoring oil yields to values comparable to other hog fuels. Liquid transportation fuels were produced from mountain pine beetle-killed wood and reference hog fuels via fast pyrolysis, followed by fixed-bed catalytic upgrading, and were found to have similar impacts to catalyst lifetime as other non-stabilized bio-oils; no additional challenges to upgrading were identified. The final mass yields of hydrocarbon fuel from the feeds were both 25%.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- A small project, but seems to be useful for understanding low-value feedstocks.
- Beetle kill is a one-off opportunity. The biomass is widely dispersed in rugged terrain with little transportation infrastructure. The hurdles to economically access and convert this particular biomass would appear to be monumental.
- Ongoing technical collaboration with Canada is certainly worthwhile, and hopefully there is a lot more than this going on in other programs. The focus on pine beetle kill trees and hog fuel, however, probably should be reexamined—those feedstocks are not going to make much difference for either nation.
- The collaboration with Canada, a major source of biomass, is important. The work needs to go beyond the present focus on beetle-killed wood and deal with other bio-oil related issues. The major output to date has been information on feedstock influences on conversion, and this data needs to coordinate with the Feedstock Interface task.
- The main value of this project is in the determination of the value of residue woody products as pyrolysis feedstocks. The work done to date has determined that these residue feedstocks, indeed, have value. Any additional work along these lines does not appear to be necessary and may be of little value. The pyrolysis work done as part of this project does not appear to be adding much to the pyrolysis/upgrading knowledge base and replicates work being done by other DOE-funded projects.

PI Response to Reviewer Comments

- The focus on low-value feedstocks is enabling to pyrolysis technology in general because all biomass feedstocks have a range of quality below pristine feeds, and it is important to understand the impact of feedstock quality variations. Our work successfully demonstrated that even though low-quality feedstocks gave lower pyrolysis yields, this was compensated by higher upgrading yields, and similar overall carbon yields to final product could be achieved from the residue feedstocks and clean wood.
- We acknowledge the one-off nature of pine beetle-killed trees and the costs associated with harvesting it, and proposed no further work on this feedstock. For hog fuels, there is currently a surplus compared to the needs of the mills for heat and power generation. While the overall amount may not be large, hog fuel and other residues represent a potential low-cost supplemental feedstock for pioneer pyrolysis plants and could thus accelerate the adoption of pyrolysis technology.
- The researchers in this project work in close collaboration with the Feedstock Interface project and strive to ensure no duplication of work and effective sharing of data. This project is unique in that it links the entire conversion chain from biomass to end use. The work to date has shown that low-value feedstocks could be pyrolyzed and upgraded to oil with low oxygen content and good boiling point range as assessed by simulated distillation. However, larger quantities of oil would be needed to produce actual distillation cuts and determine their properties. Our collaboration with the Canadian partner would give us the capability to produce oil, upgrade, fractionate, and test in a stationary engine.

IEA TASK 34 FAST PYROLYSIS

(WBS#: 6.3.2.25)

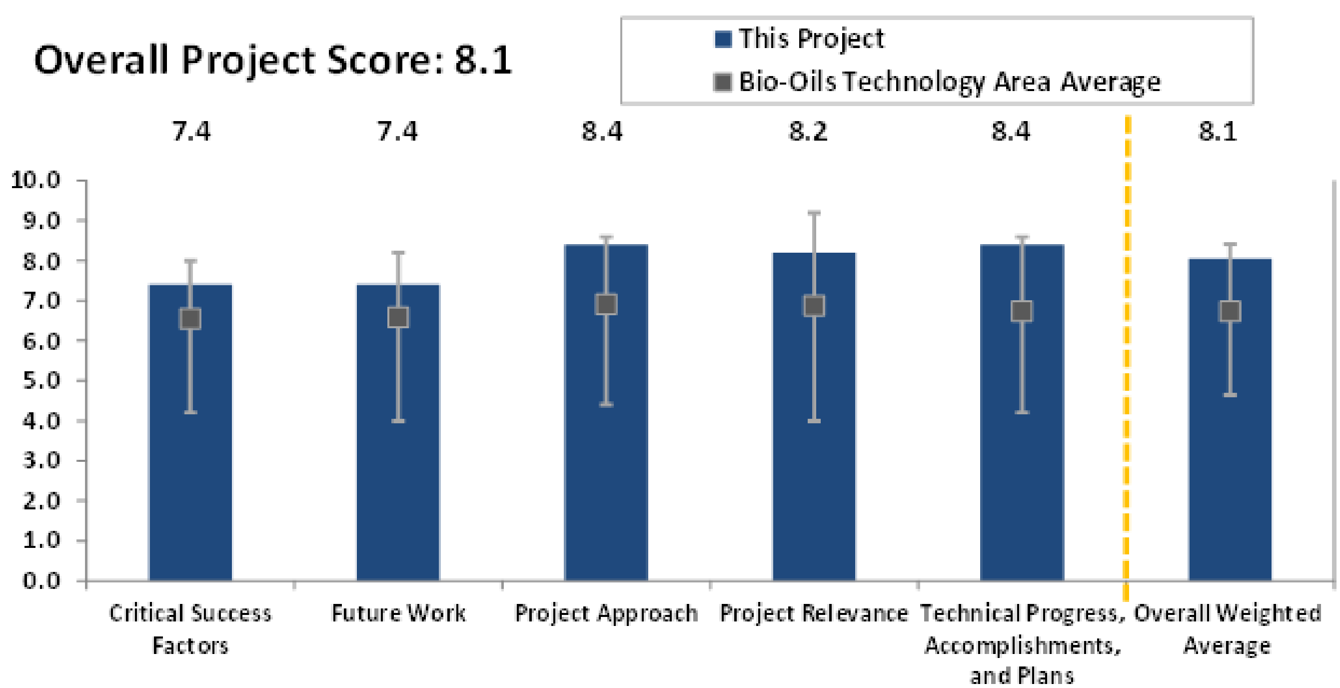
Recipient:	PNNL
Presenter:	Douglas Elliott
Total DOE Funding:	$295,000
DOE Funding FY13:	$25,000
DOE Funding FY12:	$20,000
DOE Funding FY11:	$20,000
Project Dates:	2008-2015

Project Description

The main task for PNNL in the International Energy Agency support is the participation in Task 34 of International Energy Agency Bioenergy, which deals with fast pyrolysis. The effort includes participation in the task activities, as defined by the members. Typically there are two meetings per year, with additional effort between meetings on the various task elements. DC Elliott of PNNL is the national team leader for the United States in Task 34. Task 34 provides key information on biomass pyrolysis developments from the international connections into the BETO Bio-Oil Technology Area. In addition, the task activities generate new data through round robin arrangements that facilitate commercialization of bio-oil. Through this task, the United States will be able to continue to access data and participate in the round robins organized by Task 34. The jointly authored technical articles for sulfur and nitrogen analysis in bio-oils and bio-oil storage, handling, and transportation issues should be completed. The task members have played a role in the establishment of the ASTM standard for bio-oil use as a burner fuel and also are involved in helping to establish standards for bio-oil in Europe by supporting the mandate to European Committee for Standardization to develop standards for a range of applications for bio-oil.

Overall Impressions

- A solid information-sharing effort at a reasonable cost. Well worth continuing.
- Limited scope appears appropriate with reasonable value added to establishing standards that would



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

be needed when bio-oils become internationally fungible.

- Small project, but valuable for connecting with other countries on fast pyrolysis and standardizing analytical methods.
- This is an excellent example of a highly successful international collaboration. The cost- and task-sharing by other international participants makes this a highly cost-effective way for DOE to understand and leverage what is going on in other parts of the world. The project is highly productive and relevant to industry in ways such as producing end-use standards for bio-oil.
- This is an important project that provides necessary international communication, standards, and analytical techniques that are required for the successful and widespread commercialization of fast pyrolysis bio-oil projects, both here in the United States and around the world. This is a great use of the national labs and should continue.

PI Response to Reviewer Comments

- Thank you for the positive feedback confirming the importance of this international collaboration and its relevance to industry.

BRAZIL BILATERAL: PETROBRAS-NREL CRADA

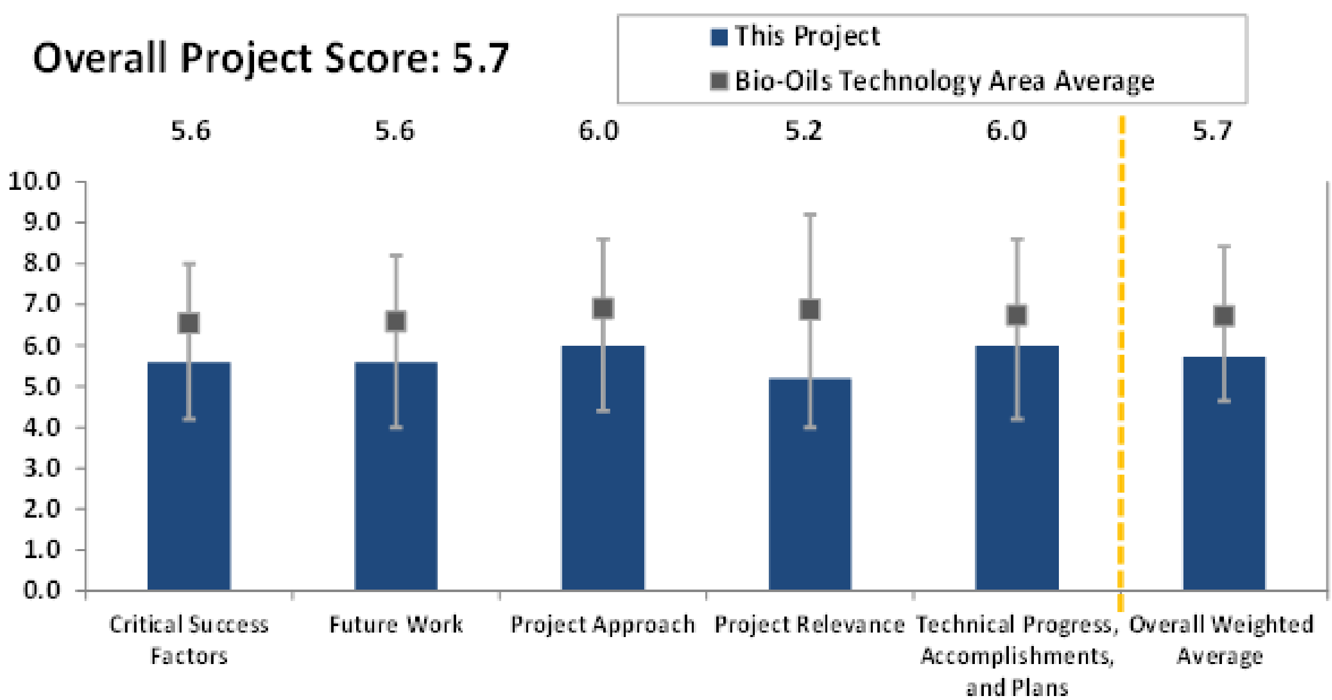
(WBS#: 6.5.1.1)

Recipient:	NREL
Presenter:	Helena Chum
Total DOE Funding:	$500,000
DOE Funding FY13:	$50,000
DOE Funding FY12:	--
DOE Funding FY11:	$250,000
Project Dates:	2012-2015

Project Description

Photo Courtesy of NREL

The project is part of the Strategic Energy Dialogue between the governments of the United States and Brazil. Significant expertise from Petrobras in heavy petroleum refining alone and with biomass pyrolysis oils will benefit BETO and international programs, the U.S. economy and the Brazilian economy, energy security, diversification of transportation fuels, and climate change mitigation. Petrobras and NREL investigate a two-step route to biofuels production that involves fast pyrolysis, followed by bio-oil upgrading to gasoline, diesel, fuel oil, and liquefied petroleum gas at pilot and demonstration scales, as well as syngas production at pilot scale. The joint work will facilitate assessment of traditional fast pyrolysis upgrading in the petroleum refinery context and provide significant cost share (four-to-one Petrobras to BETO international-funded work at NREL). Work will generate data on a U.S. feedstock and NREL-processed Brazilian bagasse and access to feasibility evaluation results. The assessment of this alternate (proprietary) route to hydrocarbon fuels supports BETO's bio-oil pathway R&D cost goals. Barriers addressed are fast pyrolysis technology and bio-oil characterization, stabilization, and upgrading. Joint research, development, and demonstration work started in February 2013. In fiscal year 2012, fast pyrolysis of American white oak (600 kg) generated bio-oils for comparative assessment at Petrobras. In 2013, 1,000 kg of bagasse will be pyrolyzed at NREL's facility and shipped to Petrobras for co-processing studies. Petrobras and NREL will exchange samples, analytical methodology, and results



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

to improve techniques. In calendar year 2014, Petrobras will co-process bagasse and oak oils. Petrobras and NREL will address syngas production with catalysts from both organizations. In the last quarter of 2014, the analyses of experimental results will lead to the preparation of the TEA/LCA/sustainability analysis under U.S. conditions (NREL) and Brazilian conditions (Petrobras proprietary). Expected completion is February 2015. Timing of milestones may be impacted by uncertainty in arrival of large and small samples both ways. The project contributes to the expansion of the biomass pyrolysis industry producing oils that can be upgraded in refineries by providing alternative processing.

Overall Impressions

- Given the lack of detail regarding the Petrobras process, it is impossible to properly assess the impact of this project. This project could be important, but application could be limited depending on how Petrobras chooses to license/sell the technology. Like other projects where the bio-oil source is distant from the upgrading process, this project may suffer from sample stability issues.
- Not an effective use of the funds expended. Active collaboration with Brazil makes a great deal of sense, but there are no obvious, compelling reasons to accomplish that through this particular project.
- The project is proceeding as planned and is successful. The project has significant opportunity for technology transfer to Brazil.
- This appears to be a relatively low-value-added exercise to use up space in national labs and show international cooperation and scope.
- Useful to collaborate with Brazil, but biomass sources tested are very different. Brazil will be testing fast pyrolysis bio-oil mixed with petroleum for processing.

PI Response to Reviewer Comments

- We thank the peer reviewers for their comments. We agree that, given the constraints of the presentation we gave, all reviewer impressions are valid. Had the peer review taken place three months later, a different presentation would have clarified questions the peer reviewers asked. The Petrobras intellectual property situation now enables them to publish results obtained prior to the CRADA. As described in the presentation, NREL and Petrobras will be preparing a joint TEA-LCA assessment for the route in the United States as a deliverable of the work. For this deliverable, Petrobras will process five tonnes of pyrolysis oils in the 150 kg/hour unit scale at Petrobras, from which mass and heat balances, together with the composition and characterization of products, will be obtained and enable the TEA-LCA assessment.

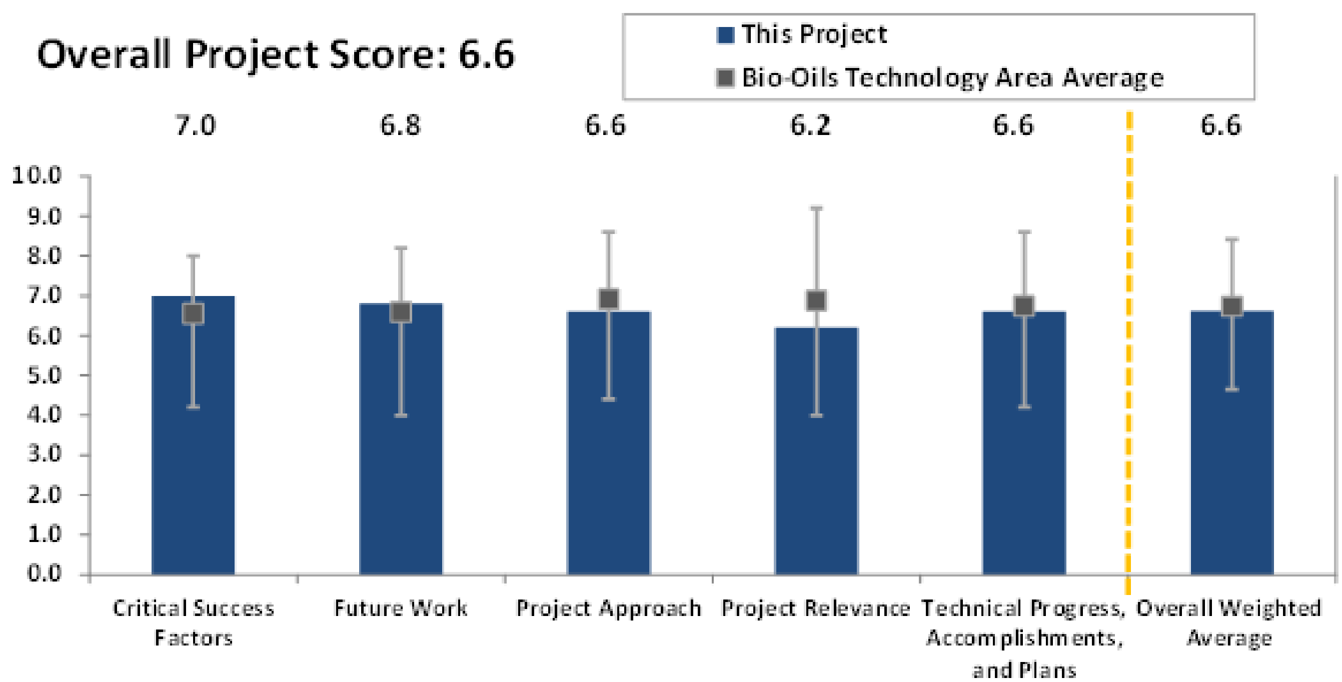
U.S.-CHINA COLLABORATION—THERMOCHEMICAL CONVERSION OF BIOMASS

(WBS#: 6.5.2.2)

Recipient:	PNNL
Presenter:	Jonathan Male
Total DOE Funding:	$1,100,000
DOE Funding FY13:	--
DOE Funding FY12:	$100,000
DOE Funding FY11:	$100,000
Project Dates:	2008-2013

Project Description

The goal of this project is to combine and leverage U.S. and Chinese biofuels expertise to evaluate, develop, and enable commercially viable processes in thermochemical conversion of biomass to advanced biofuels. In the project with the China National Offshore Oil Corporation and the Dalian Institute of Chemical Physics, the first objective is to use U.S. and Chinese technology and costing for techno-economic analysis to enable comparisons and guide decision making. The second objective is to develop a detailed understanding of a novel, fuel-synthesis catalyst to improve biofuels productivity. In the project with Quingdao Institute of Bioenergy and Bioprocess Technology and Tsinghua, the objective is to develop a detailed understanding of bio-oil hydrotreating catalysts, especially their deactivation modes. The relevance of these projects to BETO is through bringing together Chinese and U.S. expertise to support thermochemical conversion to drop-in biofuels for 2017 technical targets. This research addresses MYPP barriers Gt-G, Tt-G, and At-C, and helps support the goals of the U.S.-China Renewable Energy Partnership. There are several technical accomplishments in these projects. Three techno-economic analyses have been developed with Chinese and U.S. inputs. A detailed mechanistic understanding study, combining theoretical and experimental approaches, has been developed to investigate the effect of support and additives on the mixed higher alcohols synthesis from syngas over a unique cobalt catalyst developed in the Dalian Institute of Chemical Physics. A literature study focused on the recent advances in hydrotreating of pyrolysis bio-oil and its oxygen-containing model compounds was finished. A detailed understanding of bio-oil hydrotreating catalysts, especially their deactivation modes, was



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

developed by detailed characterization of catalysts and computational modeling. There are several success factors, including demonstrating a detailed understanding of catalysts for fuel synthesis and upgrading to enable a pathway to commercial viability. The key challenges are simultaneously meeting Chinese and U.S. technical goals and demonstration of robust catalysts for conversion of bio-intermediates to biofuels. Publications that are peer reviewed and presentations at conferences are the means of broad dissemination of results of the work done within this project.

Overall Impressions

- This is a good example of an R&D project undertaken to a large extent because we wish to establish a relationship with a particular partner. Not earth shaking, but for the HDO work at least, it looks to be solid work, producing useful results for an important biofuel processing pathway. As with a number of the international collaborations, this appears to be a low-productivity effort with many hurdles to success. The justification seems to be finding projects to keep the national labs busy and show international cooperation and collaboration, whether value is added or not.
- Collaboration with other groups to help with catalytic deactivation should be done. Mostly focus on one catalyst. The United States has shifted to drop-in fuels instead of ethanol.
- Interaction with China, one of the most rapidly growing technology developers, is important and the project appears to be making reasonable progress.
- This international project is an important collaborative effort between the United States and China, which should continue. Both parties bring significant knowledge and resources to the R&D effort and are motivated to make this technology succeed.

PI Response to Reviewer Comments

- There are several permutations on direct liquefaction (fast pyrolysis, catalytic pyrolysis, hydropyrolysis, and hydrothermal liquefaction). All produce a product that is on a continuum of bio-oil quality and needs catalytic upgrading before entry into a refinery or production of a fuel blendstock. Most of the current bio-oil hydrotreating uses the conventional catalysts, typically molybdenum-based sulfide catalysts, designed for hydrotreating of the refined petroleum products. However, these conventional catalysts have limits of stability with bio-oils, which has been identified as a bottleneck of the bio-oil upgrading process, and a barrier in the Bioenergy Technologies Office's MYPP. This project aims to fundamentally understand the deactivation mechanism of current sulfide-based, bio-oil hydrotreating catalysts, in order to develop regeneration methods for current catalysts and to develop new hydrotreating catalysts with improved stability. Additionally, new bio-oil upgrading catalysts specifically designed for bio-oil hydrotreating are being developed in China with model compounds, tested with whole bio-oil in the U.S., and measured against the U.S. benchmark catalyst in order to accelerate the technical progress.
- The fuel synthesis catalyst investigated in this project was initially designed by the Dalian Institute of Chemical Physics and makes higher alcohols than ethanol, which was seen as interesting and worthy of understanding in order to enable control of the production of alcohols. In China, the current biomass research and development focus is on ethanol production while the U.S. is looking to fulfill ethanol's promise and gain traction on future infrastructure-compatible fuels. Understanding the Dalian Institute's catalyst enables near-term goals on fundamental knowledge of catalysts, co-catalysts, and supports to be disseminated to help ethanol production. For the U.S., we are cognizant that molecules with more than one carbon-carbon bond already assembled have potential benefits as intermediates for infrastructure-compatible fuel blendstocks.

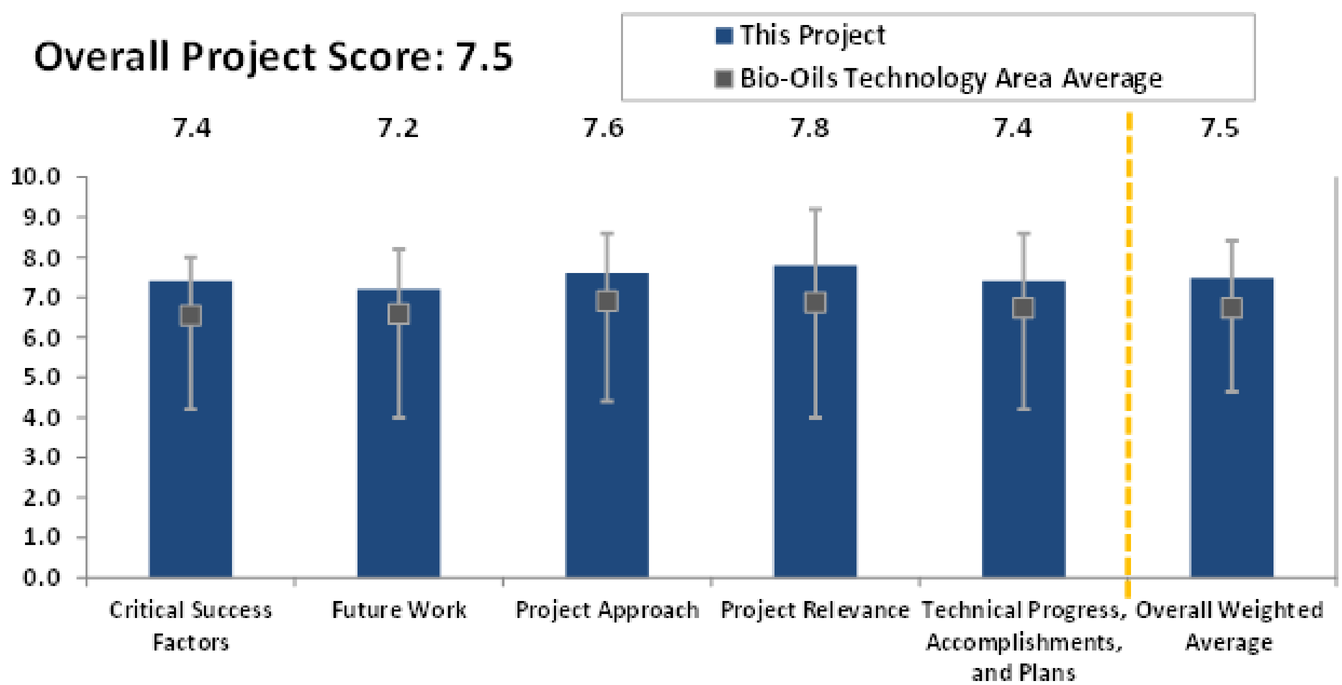
BIO-OIL UPGRADING WITH NOVEL, LOW-COST CATALYSTS AND THE SYNERGISTIC EVALUATION OF NOVEL CATALYTIC METALS FOR BIO-OIL UPGRADING

(WBS#: 3.2.2.2; 3.2.2.29)

Recipient:	ORNL; PNNL
Presenter:	Jae-Soon Choi
Total DOE Funding:	$600,000
DOE Funding FY13:	$600,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012-2015

Project Description

In this effort, ORNL and PNNL collaborate to develop novel, low-cost catalysts that are durable under real bio-oil upgrading conditions. At present, the limited stability of catalysts is a critical technical barrier to the commercial development of bio-oil for transportation fuel technologies. For instance, sulfided cobalt molybdenum or nickel molybdenum/aluminum oxide catalysts—the current reference in petroleum hydroprocessing—deactivate quickly due to the low sulfur content of bio-oils. Precious metal catalysts, such as carbon-supported ruthenium and palladium, are more robust but expensive. Our approach is to engineer catalysts based on transition-metal carbides, which do not require sulfiding agents in the feed to remain active and are low-cost materials. The catalyst development is guided by fundamental understanding of catalyst structure-reactivity relationships and continuous pilot-reactor evaluation of performance with real bio-oils. During this first project year, activities focused on the synthesis, characterization, and evaluation of a range of bulk molybdenum and tungsten carbides in hydroprocessing model bio-oils to generate initial structure-performance correlation data. Results showed promising performance of bulk molybdenum carbides with respect to activity, selectivity, and coking resistance, with some formulations comparing favorably with reference ruthenium/carbon



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

catalysts. Two molybdenum carbide formulations were down-selected for more detailed characterization and performance evaluation with both model and real bio-oils. Furthermore, a method of bulk oxide shaping was developed, enabling a large-scale synthesis of carbides necessary for the continuous pilot-reactor testing with real bio-oils. Future work includes continued formulation, characterization, and reactivity study of carbides to obtain fundamental insights and data necessary for the optimization of catalytic performance, pilot-reactor testing with real bio-oils, with in-depth analysis of upgraded products and reaction pathways, long-term stability assessment, and deactivation mitigation.

Overall Impressions

- This is a novel approach that may identify significant opportunities.
- Decent project.
- This is important work that seems to be well-planned, organized, and implemented. It is a good use of the national lab assets and of fundamental importance to the bio-oil industry.
- The work seems to be going well, but many issues around carbide catalysts remain open, as does the question of broad-spectrum hydrotreating of light organics as a bio-oil stabilization strategy.
- This is quality, basic research attempting to identify better catalysts for upgrading. The work will benefit DOE even more if the research quickly gets to upgrading whole bio-oil instead of model compounds, and if an industry partner or advisor can be obtained.

PI Response to Reviewer Comments

- We appreciate the very useful, constructive comments and suggestions given by the reviewers. Since the last peer review, we have begun reactor testing with real bio-oils, complementing data obtained with model bio-oils for more meaningful assessment of carbides' potential as durable, low-cost catalysts for bio-oil upgrading. Detailed analysis of results will guide our future research. In addition to understanding catalyst structure-performance relationships and designing carbide-based catalyst formulations with enhanced performance and tailored to bio-oil hydroprocessing, we will proactively consider other important technical and economic issues relevant to commercial applications of carbide catalysts and strive to expand and enhance collaborations, particularly with industry.

SELECTIVE DEOXYGENATION CATALYSTS / PREVENTION OF DEACTIVATION OF SUPPORTIVE METAL CATALYSTS

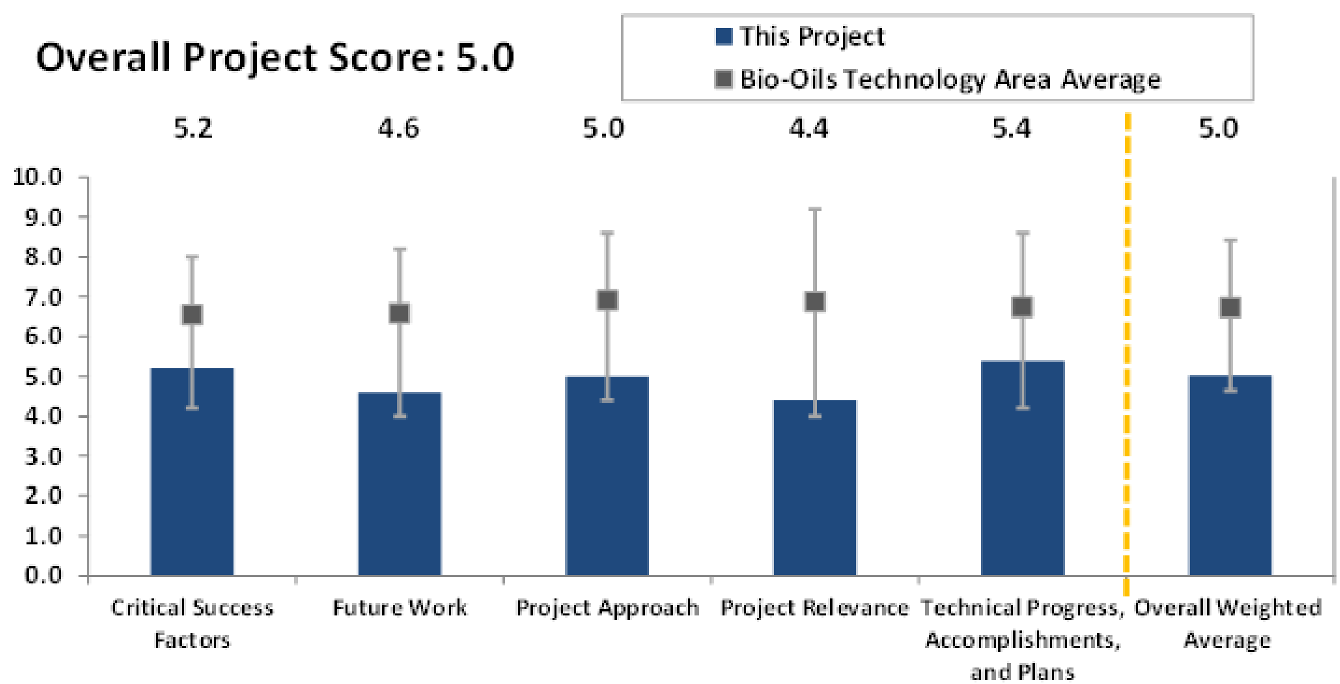
(WBS#: 3.3.1.11)

Recipient:	ANL
Presenter:	Joseph Libera
Total DOE Funding:	$500,000
DOE Funding FY13:	$260,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012-2014

Project Description

Photo Courtesy of ANL

A predominant attribute of the chemicals comprising pyrolysis oil is oxygenate functional groups that protrude from the main hydrocarbon backbone or ring, or are located and the head or tail of the molecules. These functional groups are responsible for polymerization tendency of pyrolysis oils. Atomic-layer deposition is used to deposit catalytically inactive, semi-permeable overlayers on active, metal-coated catalyst supports that produce restricted—and thereby selective—access of the target functional group to the active atoms buried below the overlayer. The strategy will be used on both conventional catalysts and those prepared entirely by ALD. For rapid catalyst development, a new trickle bed reactor was built for rapid screening of aqueous-phase reactants or pyrolysis oil with hydrogen pressures to 3,000 pounds per square-inch gage. The new system takes a 0.25–2.00 gram catalyst charge and can screen two to three catalysts per week. Product analysis by gas chromatography-mass spectrometry for liquid-phase products and by gas chromatography for gas-phase products is installed next to the reactor for immediate analysis. Liquid chromatography-mass spectrometry and nuclear magnetic resonance for analyses of pyrolysis oil



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

is also available. Synthesis of the ALD catalysts takes place in existing ALD facilities in the same lab, allowing a turnaround time of synthesis and testing of two to three days. ALD catalyst synthesis and testing commenced in April 2013. The work began by exploring the acetic acid, furfural, and guaiacol model systems, and building on our previous findings of niobia stabilization of silica in hydrothermal environments and our observations that alumina overcoats reduce sintering and coking in palladium catalysts. These models system provide a wealth of published results for comparison and evaluation of selectivity benefits of the synthetic strategies described above.

Overall Impressions

- Currently, ALD does not seem to be the most viable pathway to improved catalysts.
- The ALD technique studied by this project has the potential to finely tailor catalyst to meet specific processing needs. However, it is a very expensive technique that will most likely not be of commercial value at any time in the near future. This project appears to be more of a demonstration of capabilities of the ALD process rather than an integrated catalyst R&D project, and may lack sufficient fundamental catalyst science input to advance the state of technology. There does not seem to be enough time left in this project to accomplish the stated future work items.
- The PI is doing good research, and the lab has interesting capabilities; however, if the concept must use a very expensive, rare-earth metal on a non-commercial deposition process, the likelihood of this approach having impact is very small. It is not clear why BETO is pursuing development of a catalyst deposition process without a catalyst industry partner.
- Very interesting method of catalysis. Looking to see how catalyst preparation will affect catalysts for bio-oil.
- Very sophisticated scientifically, but too exotic to seriously impact real biomass conversion technologies.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

CHARACTERIZATION AND TREATMENT OF AQUEOUS PRODUCTS FROM DIRECT LIQUEFACTION PROCESSES; CONVERSION OF DIRECT LIQUEFACTION PROCESS, AQUEOUS-PHASE ORGANIC PRODUCTS INTO LIQUID HYDROCARBON FUELS AND HYDROGEN

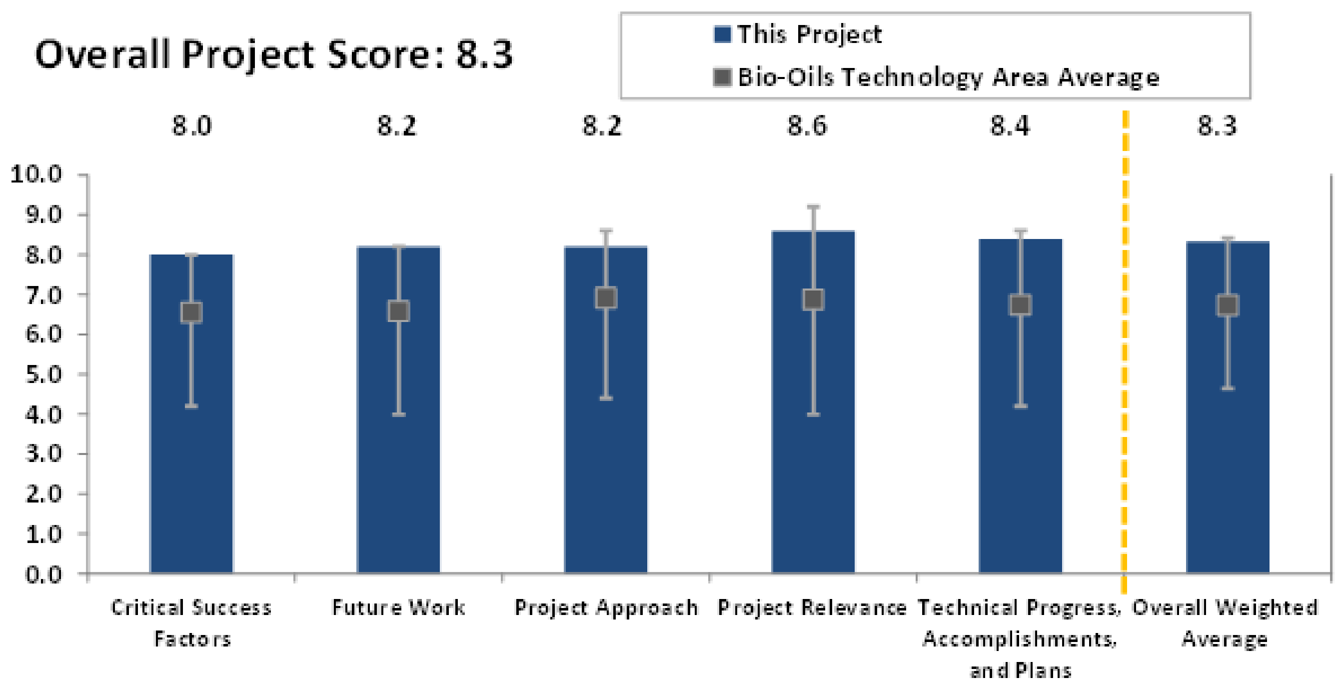
(WBS#: 3.2.2.34; 3.2.2.30; 3.2.2.33)

Recipient:	PNNL
Presenter:	Karl Albrecht
Total DOE Funding:	$2,400,000
DOE Funding FY13:	$2,400,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012-2015

Project Description

The three projects listed above will be presented during a single presentation entitled Direct Liquefaction Aqueous-Phase Utilization: Characterization, Upgrading, and Steam Reforming at the BETO 2013 Project Peer Review. The overall goal of the three projects is to increase the carbon yield to liquid fuels and diminish hydrogen upgrading requirements by utilizing the organics in the aqueous phase produced from a variety of direct liquefaction approaches (e.g., fast pyrolysis, catalytic fast pyrolysis, hydrothermal liquefaction). One project (WBS 3.2.2.34) is working to characterize the aqueous streams from various PNNL legacy and newly produced direct liquefaction processes. The second project (WBS 3.2.2.30) is investigating the feasibility of upgrading aqueous-phase organic compounds to liquid fuel-range hydrocarbons. The third project (WBS 3.2.2.33) is

Photo Courtesy of PNNL



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

investigating the steam reforming of the aqueous-phase organic compounds to provide a portion of the hydrogen required for bio-oil upgrading. Challenges shared by each of the projects include developing characterization and catalytic processes to accommodate a variety of functional groups (i.e., acids, aldehydes, alcohols, nitrogen containing groups, etc.), the relatively low concentration of the compounds in water, and the presence of water-soluble inorganics. All of the projects started in fiscal year 2013 and have initiated activities pertaining to aqueous-stream characterization and treatment. The relevance of these projects is directly correlated with goals and activities in the 2012 MYPP; for example: "For these (conversion) technologies, processes for recovering carbon and/or hydrogen from aqueous- and/or gas-phase streams are being developed to maximize energy efficiency." The successful projects will produce data that can be implemented into TEAs to determine the financial benefits of implementing an aqueous-phase organics upgrading and/or steam reforming process. Furthermore, data produced by the characterization effort may be implemented into existing TEAs to supplement data required for modeling wastewater treatment, or other aqueous-phase processing outside of upgrading or reforming.

Overall Impressions

- This is extraordinarily valuable work, with excellent progress so far and plans going forward. Lack of linkage to commercial players is the only significant weakness.
- Interesting for aqueous-phase characterization. Important.
- This appears to be an exercise in repurposing a pilot plant for which there was no longer a use.
- This is excellent work focusing on the highly important issue of effectively dealing with aqueous organics from a variety of bio-oil processing steps.
- This is important work and a good use of the national labs. Improving carbon recovery from the aqueous phase should improve the economics of bio-oil processes in general and reduce the load of any wastewater treatment processes. These improvements will be of great importance to a wide range of biomass projects.

PI Response to Reviewer Comments

- We greatly appreciate the comments and suggestions from the reviewers. We are pleased the reviewers agree that there is a high degree of value to be obtained from understanding (e.g., characterizing) and utilizing (e.g., reforming or upgrading) the organics in the aqueous phases produced by the various direct liquefaction processes. Our aim is to work with industrial partnerships as we move forward. This will help better define the value proposition of the technologies that can gain value from the use of organic compounds otherwise lost in the aqueous phase. It will also insure that we are addressing the most relevant issues. Additionally, we look forward to working with other institutions like NREL to characterize and utilize aqueous streams such as those produced by catalytic fast pyrolysis.
- The materials of construction of the gasifier, as well as the fluidized bed configuration, broaden our capabilities and enable us to perform high-temperature bio-oil production, which is a cost-effective use of DOE capabilities. A central goal of our overall program is to produce a bio-oil that requires less upgrading. This cost-effective solution not only allows for generation of streams for analysis from processes such as high temperature fast pyrolysis, but also catalytic fast pyrolysis and vapor-phase upgrading of pyrolysis oils.

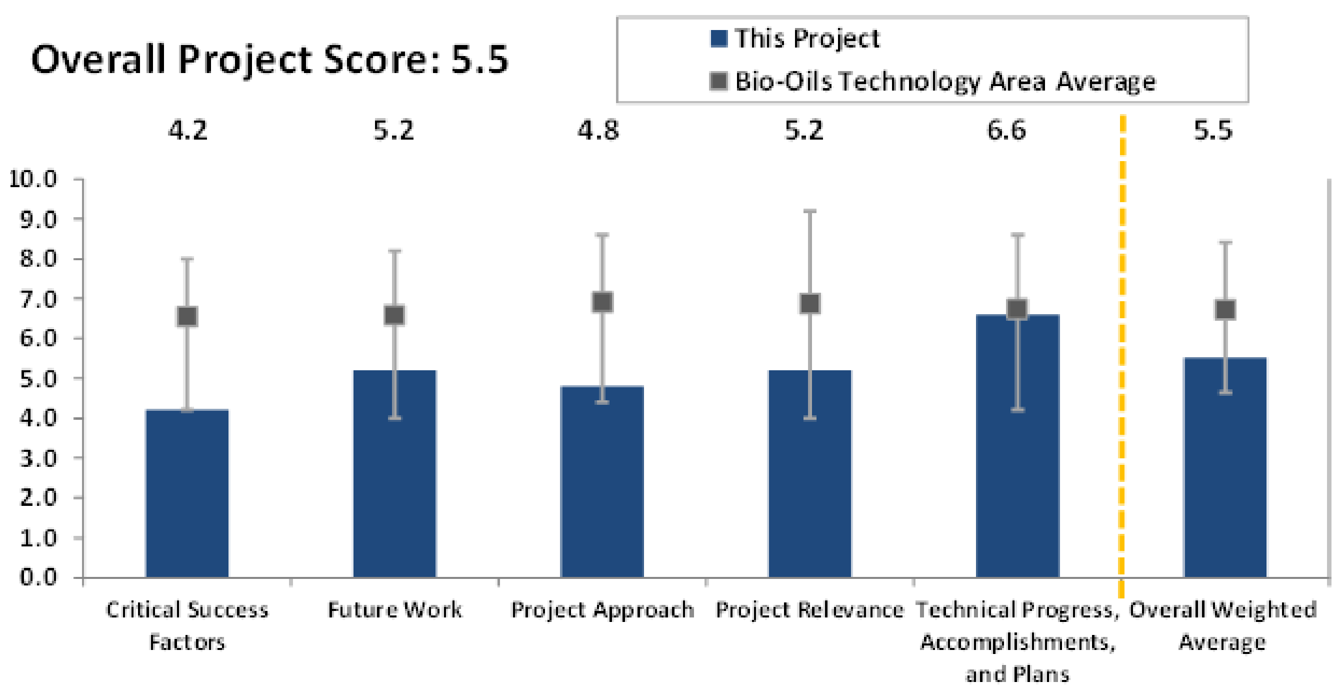
RENEWABLE HOME HEATING OIL IN THE NORTHEAST

(WBS#: 3.6.1.5, 3.2.5.16, 3.2.2.16, 3.2.2.26)

Recipient:	PNNL; BNL; INL; ORNL
Presenter:	Jonathan Male
Total DOE Funding:	$1,500,000
DOE Funding FY13:	--
DOE Funding FY12:	$1,500,000
DOE Funding FY11:	--
Project Dates:	2012-2014

Project Description

The purpose of this collaborative project is to evaluate the options of replacing up to 20 weight percent (wt%) petroleum-derived fuel oil in the Northeast with infrastructure-compatible bio-oil by 2022, thereby stabilizing the supply and cost spikes for heating oil. The Northeast is the location of more than 80% of the 7.2 million homes that used heating oil in 2009. The average household consumes approximately 850 gallons of heating oil per season. Minimally upgraded bio-oils as heating oil substitute may present a significant opportunity to reduce heating oil price volatility and reduce greenhouse gas emissions. The approach is to leverage related Bioenergy Technologies Office research in feedstock interface, fast pyrolysis, bio-oil upgrading, corrosion studies, and logistics modeling in order apply to it across the entire supply chain for renewable home heating oil. This work is part of a coordinated effort involving Idaho National Laboratory (feedstock and logistics), Pacific Northwest National Laboratory (bio-oils and upgrading), Oak Ridge National Laboratory (materials), and Brookhaven National Laboratory (combustion and market entry) to develop this application and market as an early point of entry for this renewable fuel. Technical accomplishments include assessing the optimal feedstocks and the quantities required in the Northeast, and characterization of feedstocks and bio-oils has begun. This project is aligned with the overall Bioenergy Technologies Office mission to "develop and transform renewable biomass resources into commercially viable,



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

high-performance biofuels, bioproducts and biopower through targeted research…" The key technical challenges include developing economic feedstocks in the Northeast, development of minimally upgraded bio-oil, and infrastructure-compatible, renewable heating oil that is miscible with No.2 fuel. The project examines the entire supply chain, and as such, is uniquely positioned to identify beneficial trade-offs.

Overall Impressions

- Although this project seemed like a good idea on the surface, there are many obstacles to overcome in order for it to be successfully implemented on the ground. This includes use of the home heating oil production plants during the summer, long-term stability of the mixed bio-oil home heating oil in tanks over the summer, and perhaps even for years in some homes. With corrosion a very real possibility of this fuel, leakage of home heating oil tanks and subsequent contamination of ground water could be a very serious game-ending problem, which could have severe negative consequences for the entire bio-oil industry, similar to what happened with methyl tertiary butyl ether in the United States.
- Interesting perspective for using lower-quality bio-oil with minimal upgrading, but it must meet specifications for heating oil. Is this better than complete upgrading for better fuels?
- The relevance of this work to BETO is unclear. Unless the upgraded bio-oil is essentially identical to home heating oil, it will almost certainly not be accepted by heating oil suppliers or customers. Any blend that makes home heating systems fail (such as seals) and creates spills would be both an environmental and economic disaster. It is critical to get the bioheating oil to essentially the same specifications as petroleum home heating oil. Hence, the various studies on bio-oil that can be blended with more than a percent or two oxygen content are probably unrealistic. If the program can successfully make gasoline/diesel, it will by default make home heating oil. If not, then the probability of commercial impact for home heating oil applications is very low. There is little involvement of furnace manufacturers or oil suppliers, and factors that industry defines as critical have not been identified. It is not clear why extensive additional effort in this area is needed.
- This is a nice project, but currently aimed at a market that will come under pressure both for the intended feedstock (wood) and the intended product (home heating). It would make much more sense to direct this at the use of fuel oil for electricity production in Hawaii, and to base it on urban and agricultural waste rather than wood as a feedstock.
- Too many hurdles are being overlooked or ignored to justify viability. This undermines the credibility of this work.

PI Response to Reviewer Comments

- The heating oil market is under pressure from other energy sources; however, each of these has serious constraints that limit their growth. For natural gas, there is a lack of infrastructure and the capital cost for widespread conversion to this fuel is a major barrier. Residential use of solid biomass has started to increase in the Northeast and this has been driven by low-cost fuel and low-cost conversion appliances. However, this technology has high air pollutant emissions. Electricity prices in the Northeast are relatively high, making heat pumps a less attractive alternative. Energy Information Administration projections show continued use of home heating oil, although with a slow decline for many years.

- We agree with the reviewers that any fuel that displaces home heating oil will need to pass through a very rigorous qualification process. No fuel that has stability issues or that presents a corrosion/leak potential will be legally accepted. This project recognizes the need to produce a fuel that will meet all of these requirements, and project plans have been developed specifically to address these concerns.
- The fuel proposed to be produced for the home heating oil application in this project will be functionally acceptable; however, not necessarily identical to the petroleum-derived heating oil. For example, bio-oils with an oxygen content of 1.8, 2.4, and 13 wt% oxygen have been prepared where the TAN are between 1 and 2.8 milligrams of potassium hydroxide per gram, which suggests corrosion may not be so problematic. Additionally, PNNL hydrotreated a bio-oil to an oxygen content of 3.3 wt% oxygen and ORNL demonstrated this was not corrosive to carbon steel after 1,000 hours. Ultimately, until renewable home heating oils are made and tested, the opportunity for an early market introduction into a less-rigorous application than transportation cannot be supported or rejected.

NATIONAL ADVANCED BIOFUELS CONSORTIUM (PRESENTED IN CONJUNCTION WITH THE BIOCHEMICAL CONVERSION TECHNOLOGY AREA)

(WBS#: 3.3.1.1)

Recipient:	Alliance for Sustainable Energy, LLC
Presenter:	Tom Foust
Total DOE Funding:	$34,949,784
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010-2013

Project Description

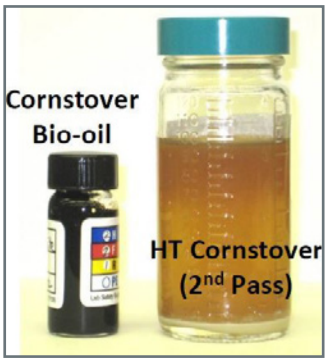
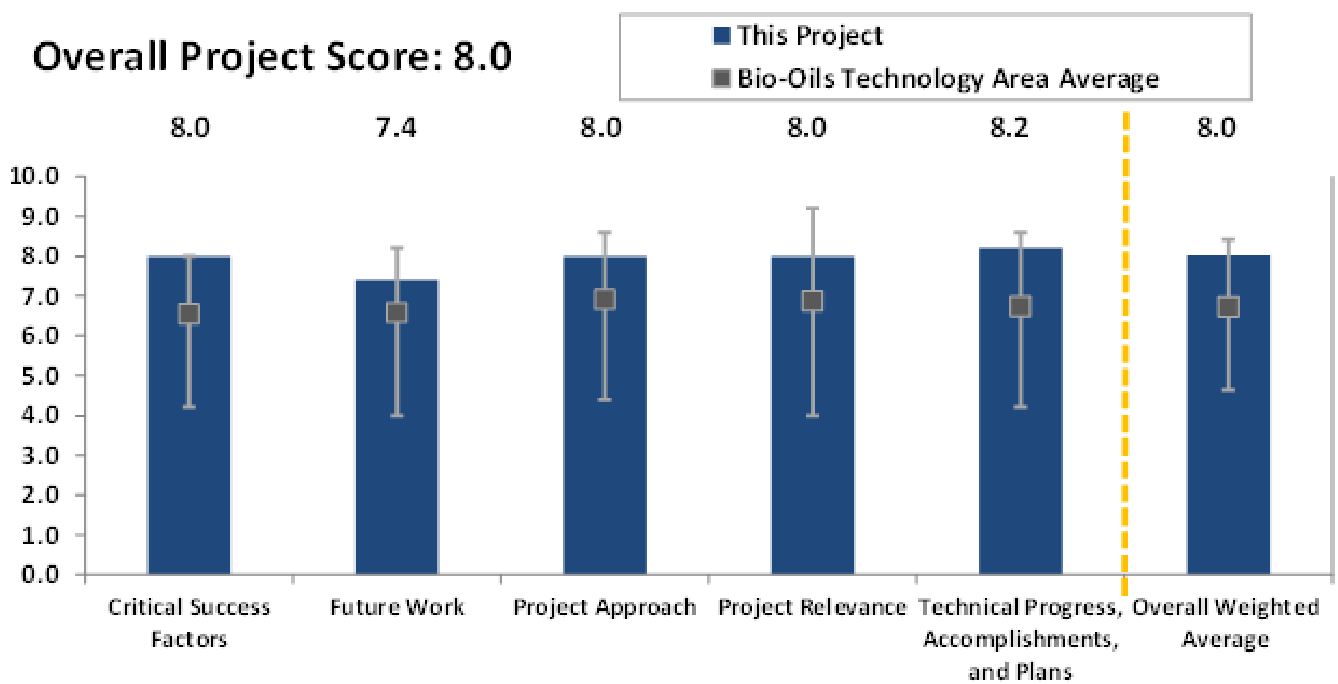


Photo Courtesy of Alliance for Sustainable Energy

The National Advanced Biofuels Consortium is a collaborative effort among DOE national laboratories, universities, and private industry that is developing technologies to produce infrastructure-compatible, biomass-based hydrocarbon fuels. The consortium, led by NREL and PNNL, is funded by DOE under the American Recovery and Reinvestment Act of 2009 and by NABC partners. NABC is in the third year of a three-year program. The goal of NABC is to accelerate development of technologies for sustainable, cost-competitive, drop-in, fungible hydrocarbon fuels from lignocellulosic biomass to a pilot-ready state. Displacing oil at the refinery gate avoids cost in new infrastructure and increases the rate of broad deployment into the existing fleet. This approach provides a cost-effective way to supplement the existing market with drop-in fuels made from biomass and achieve the DOE goals of U.S. energy security, reduced greenhouse gas emissions, and creating economic opportunities across the nation. NABC is developing technologies from both thermochemical and biochemical platforms to produce the best processes for hydrocarbon fuels. Stage one, the first year of NABC,



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

focused on a rigorous evaluation of advanced biofuel conversion technologies culminating in a down-select to those that met the criteria to be pilot-ready by end of NABC. Stage two of NABC is focusing on developing the two selected technologies to a pilot-ready state, while also working on two other promising technologies to address major technical challenges. In addition, cross-cutting activities focus on refinery integration sustainability and the fundamentals associated with each technology.

Overall Impressions

- Catalytic fast pyrolysis, of the most promising technologies, was withdrawn due to issue from UOP and did not move forward with the other partners. This apparently was an intellectual property/commercialization issue. This was a large and disappointing loss. Overall, some good work has come out of this effort, including many peer-reviewed papers, but it is not clear if the large costs justified the benefits obtained.
- Setting arbitrary goals, such as 36 billion gallons per year biofuel production by 2022 when most technologies are in kg/day pilot scale in 2013, undermines the credibility of the entire program.
- Successful approach in improving technologies, drilling down to refinery integration.
- The NABC project made very good progress in bringing multiple concepts to pilot-ready states, and the Consortium is successfully nearing completion. While the Consortium fully met or exceeded the requirements of its FOA, the overall impact of this large effort is unclear because no specific follow-on is planned.
- This is the poster child for an ideal multiperformer project. The ONLY meaningful weakness is that a few top potential partners could not be enticed to join, but that was not entirely within the control of the organizers. Extremely strong in every other respect.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

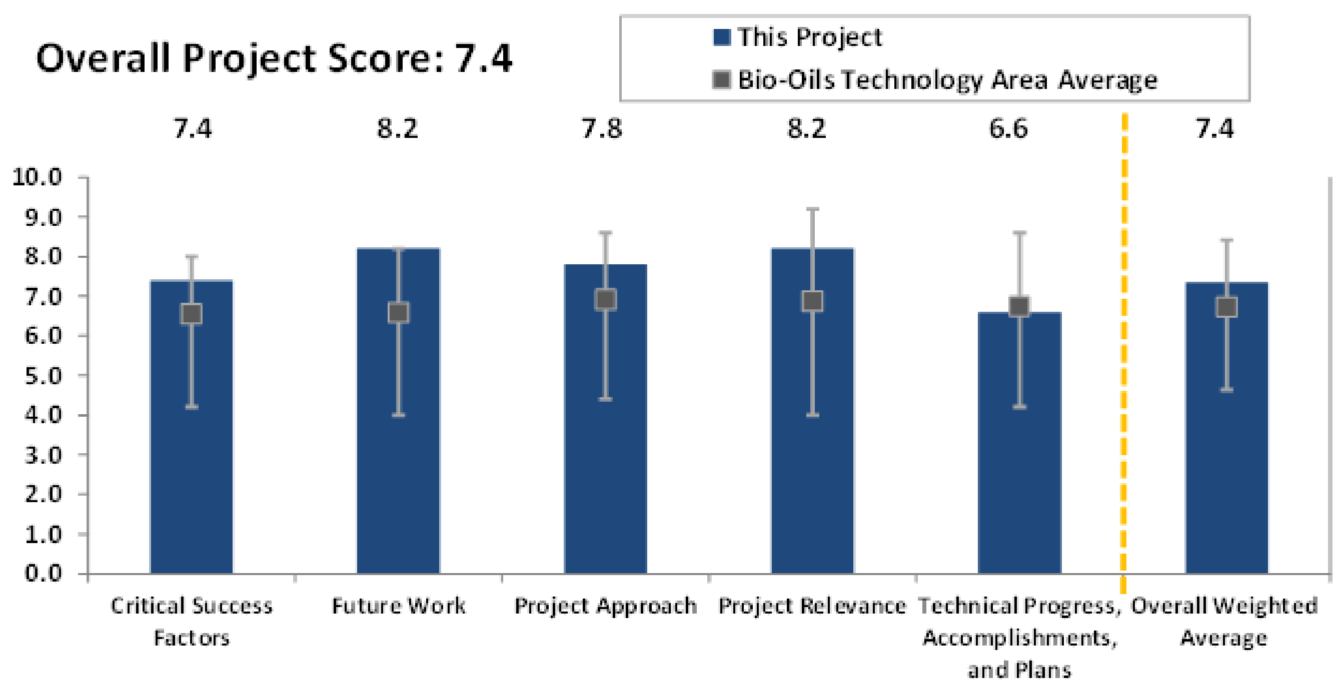
COMPUTATIONAL PYROLYSIS CONSORTIUM

(WBS#: 3.6.1.7; 3.6.1.8; 3.6.1.9; 3.6.1.10; 3.6.1.11)

Recipient:	ORNL; ANL; NREL; PNNL; and INL
Presenter:	Stuart Daw
Total DOE Funding:	$2,200,000
DOE Funding FY13:	$2,200,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013-2017

Project Description

This is a new multi-national-lab activity that was just initiated in April 2013. The objective is to collectively leverage the computational modeling capabilities of five national laboratories to accelerate pre-competitive development of improved catalytic process technologies for converting biomass-generated pyrolysis oil to infrastructure-compatible liquid fuels. The collaborative research team includes ORNL, NREL, PNNL, INL, and ANL. ORNL acts as team leader, and each partner lab contributes unique expertise and experimental facilities required to generate critical data (e.g., biomass feed composition, transport properties, and kinetic rate constants) and construct efficient, accurate computational models (e.g., multiphase flow reaction simulators) of candidate catalytic-process components. The project scope is directed at conventional fast pyrolysis with catalytic bio-oil upgrading, *in-situ* catalytic vapor-phase pyrolysis, and *ex-situ* catalytic vapor-phase pyrolysis. Process model development is targeted at technical barriers and risk factors identified in BETO's MYPP and the most recent BETO technology design cases for fast- and vapor-phase catalytic pyrolysis. Close two-way coupling between experiments and model building is heavily emphasized in the technical approach. The project plan also includes identification of a panel of industry experts who will review progress at regular intervals and provide guidance concerning technical details and industry priorities. A project progress assessment and go/no-go decision to continue are currently scheduled for the end of March 2014.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Appears to be valuable work, but the large scope also appears to base load the national labs and justify their existence as much as feeding pre-commercial development.
- Looks promising, but too early to tell for sure. Involve industry, and focus on tools more than individual process technologies.
- Organization seems to be in place to make this project a success
- The use of a consortium to provide fundamental information that will educate and guide applied efforts is important. In future years, DOE will want to ensure that the consortium continues to fine tune its efforts to maintain focus on the highest priority issues relevant to BETO and avoid wandering into academically interesting, but secondary, topics.
- This is important/required work that will add value to the BETO effort. This is a good use of our national lab assets. It leverages existing knowledge and should remain grounded by the inclusion of a panel of industry advisors.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

CATALYTIC PYROLYSIS SCIENCE

(WBS#: 3.6.1.6)

Recipient:	NREL
Presenter:	Mark Nimlos
Total DOE Funding:	$4,000,000
DOE Funding FY13:	$2,000,000
DOE Funding FY12:	$2,000,000
DOE Funding FY11:	--
Project Dates:	2012-2017

Project Description

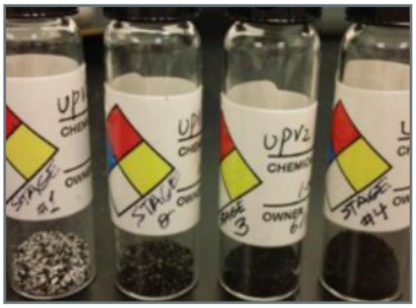
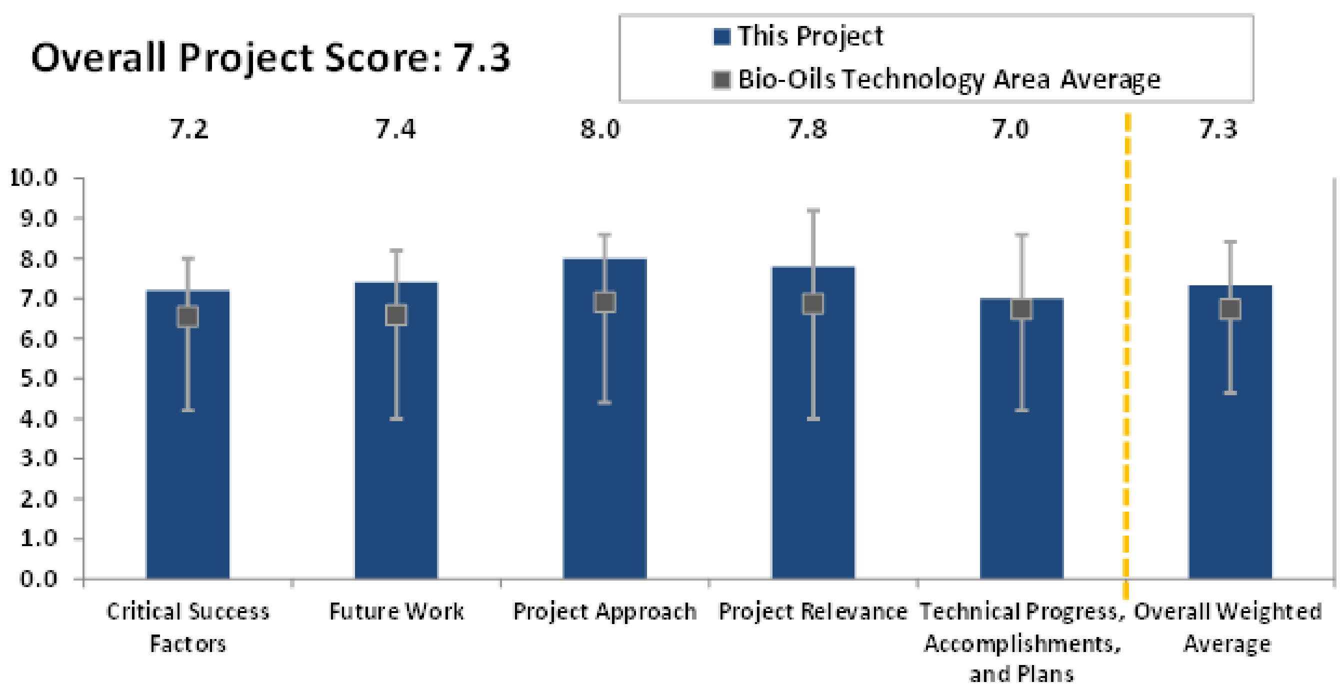


Photo Courtesy of NREL

This project started on October 1, 2012, with the goal of helping reach the BETO cost target of $3/gge for renewable hydrocarbon fuels from biomass. The focus is on catalytic fast pyrolysis (*in situ* and *ex situ*). We use laboratory experimentation and computational modeling (which will be shifted to the new Computational Pyrolysis Consortium) to investigate biomass pyrolysis, the catalytic upgrading of the pyrolysis vapors, and the properties of the resulting oil. The pyrolysis work has focused on understanding product formation, reducing char, and the effects of pretreatment. Catalyst development and testing is being conducted in collaboration with the Colorado School of Mines (Richards) and Johnson Matthey through a CRADA. This centers on the development of catalysts to reduce the amount of oxygen in pyrolysis vapors and thereby improve the properties of the condensed oil. Maintaining high carbon efficiencies is also important, as is producing hydrocarbons in the middle-distillate range, since markets are growing for diesel and jet fuel. In addition to developing new catalysts, we are also investigating the use of hot gas filtration and hydrogen-donor molecules to improve carbon yields. In the first seven months of catalyst work, we have screened a number of materials to determine the types of gas-phase compounds that are produced by upgrading. Future work will continue this effort and will study the chem-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

ical and physical properties of the condensed product. The results will help build more accurate engineering and techno-economic models for catalytic fast pyrolysis.

Overall Impressions

- I like the project. It is well organized. I like the approach to catalyst development.
- Long-term project with goals common to many other projects. Redundancy seems to be a theme.
- Looks promising at this early stage. Could benefit from more internal (lab) and external (industry) links.
- Overall, this appears to be a useful project and a good use of the national labs; it should provide knowledge that advances the state of technology.
- The project is conducting high-quality, basic research with a very good industry partner.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

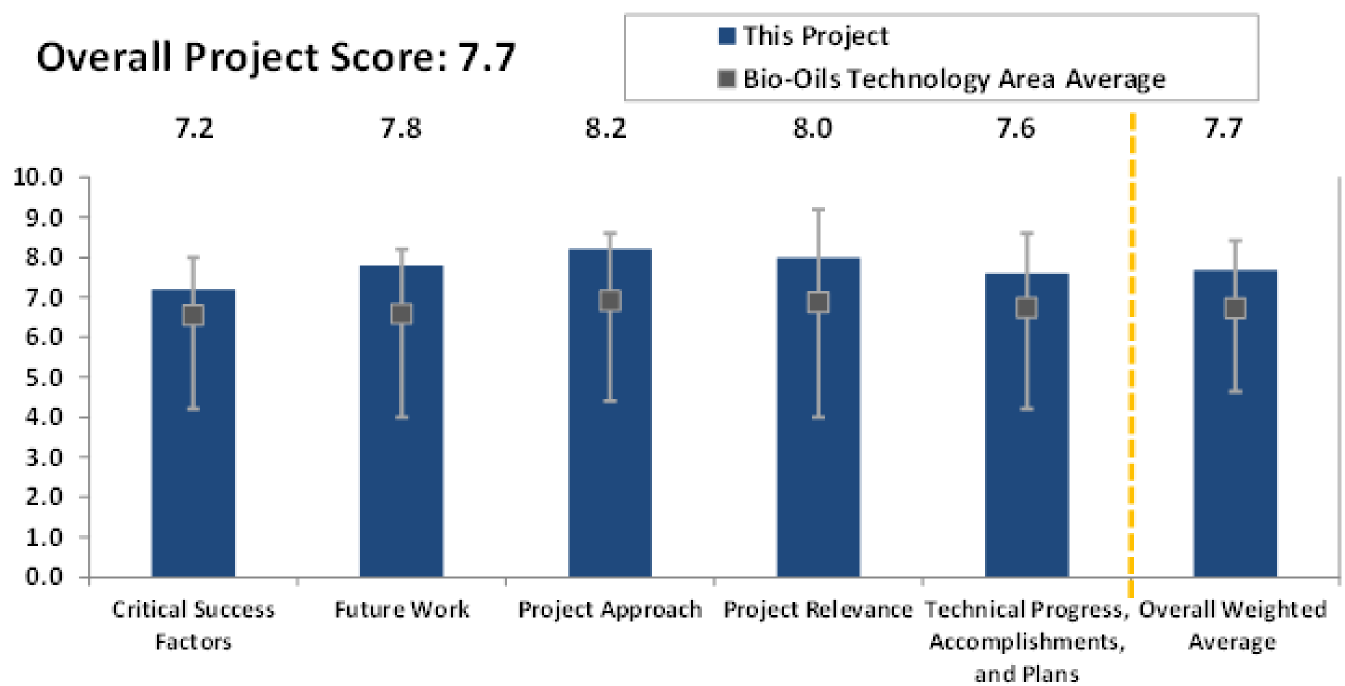
CATALYST DEVELOPMENT/ TESTING: DECONSTRUCTION

(WBS#: 3.3.1.14)

Recipient:	NREL
Presenter:	Kim Magrini
Total DOE Funding:	$2,000,000
DOE Funding FY13:	$2,000,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012-2022

Project Description

This project seeks, develops, evaluates, and characterizes catalysts for economical, efficient deconstruction of biomass into stable intermediates suitable for further upgrading or blending into petroleum feedstock. Inherent in the proposed work is the ability to develop catalysts and feedstocks to quantify both the intermediate and final products with online, real-time measurements at laboratory through pilot scales. Also included is the identification, procurement, and commissioning of pyrolysis-capable reactors spanning laboratory through small pilot scales to evaluate long-term catalyst performance and regeneration—information that is critical for developing correlations for use in the 2017 pilot-scale demonstration. The objective of this task is to design catalysts, understand their impact on the catalytic deconstruction of biomass, and ultimately tailor their activity to produce fungible, hydrocarbon fuel intermediates at the pilot scale. Diesel and jet-fuel are hydrogen-rich fuels compared to gasoline. The approximate average formula for diesel is $C_{12}H_{23}$ (a mixture of approximately 75% saturated hydrocarbon and 25% aromatic hydrocarbon). The approximate formula for biomass is $C_4H_6O_3$. Due to the difference in the hydrogen-to-carbon ratio between the final products and biomass pyrolysis intermediates, some hydrogen needs to be introduced in the deconstruction stage to produce stable and refinable products. Ideally these stable intermediates will take the forms (i.e., functionality, chain length, etc.) that will allow them to be upgraded to desirable products, such as diesel and jet fuel at a 2017 cost target of $3/gallon. In order to achieve these goals, a combination of approaches is used that span laboratory to pilot scales.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

These include catalyst design, synthesis, and testing to understand structure/activity relationships, and to impart functionality to deconstruction catalysts; evaluating unmodified and modified feedstocks to assess impact on intermediate product suites; catalyst evaluation at both scales with model and actual deconstructed biomass species; catalyst evaluation at steady-state conditions to predict potential catalyst lifetimes and develop efficient regeneration processes; and the development of characterization methods to understand the composition and destabilizing components of pyrolysis intermediates. A first-year component of this work is a comprehensive review of the literature on pyrolysis catalysis that will be documented in a journal article. A related activity will explore the impact of pressure on biomass hydropyrolysis with hydrogen-donor molecules to determine if this pathway can be efficient.

Overall Impressions

- A good fundamental project, but the model compound approach creates vulnerabilities relative to commercial realities.
- Overall good impression when looking at all three projects together.
- Overall, this appears to be a good project and a good use of the national lab assets.
- This is a promising project. It's in early days yet, and it needs careful management and a willingness to narrow or redirect focus as needed down the road.
- The PI has high-level expertise and is conducting research directly relevant to the catalytic upgrading of the pyrolysis vapors pathway. The project has just started, but appears to be well organized and making excellent progress.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

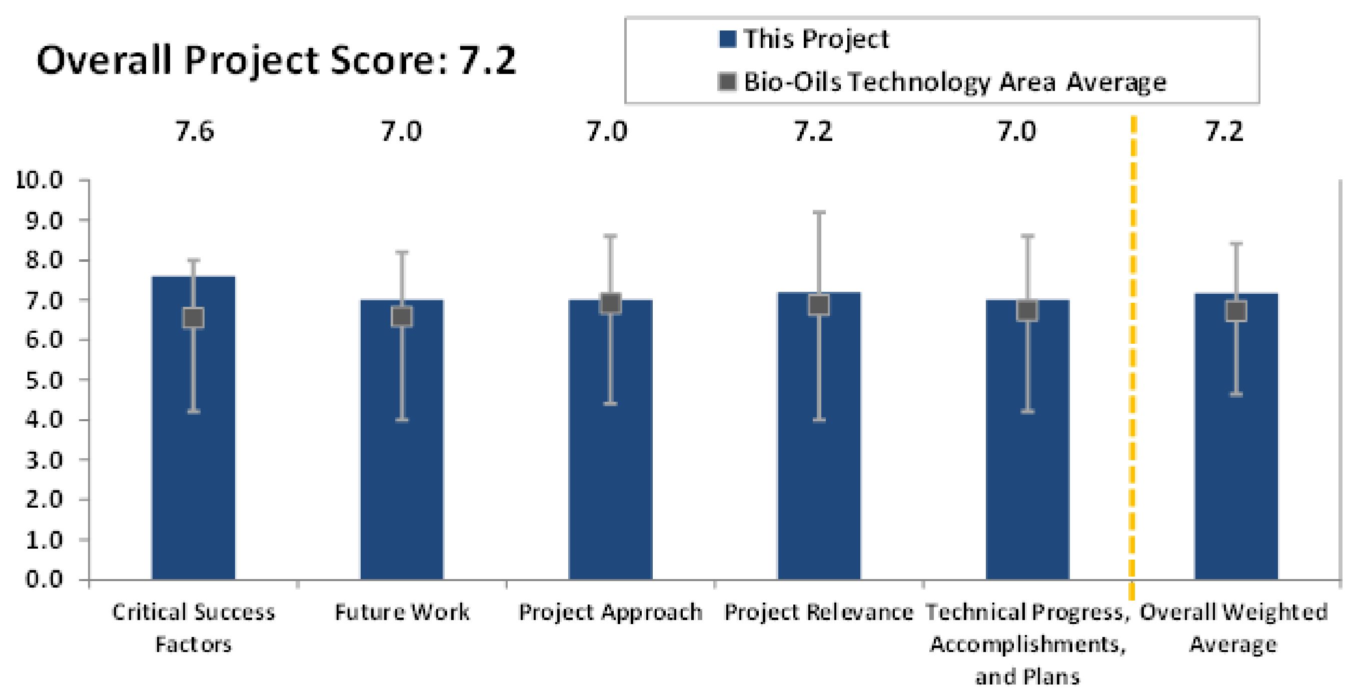
CATALYTIC UPGRADING OF PYROLYSIS PRODUCTS

(WBS#: 3.3.1.12)

Recipient:	NREL
Presenter:	Jesse Hensley
Total DOE Funding:	$2,000,000
DOE Funding FY13:	$2,000,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012-2022

Project Description

The Catalytic Upgrading of Pyrolysis Products task is a new project at NREL, beginning in fiscal year 2013. This task focuses on the development of catalyst materials for efficient and effective deoxygenation and stabilization of raw fast-pyrolysis vapors before they are condensed into liquid oil. In conjunction with other core tasks at NREL and other national labs, this task was developed to address a barrier to cost-effective hydrocarbon fuel production by thermochemical means, namely, the inherently low yields and high oxygen content of fast pyrolysis oil. The overall cost target for this process is a minimum fuel selling price of $3/gallon by 2022. Research and development in 2013 has focused on rigorous identification of technical barriers and research opportunities, as well as review of known art and experience in fast pyrolysis and oil upgrading. A pyrolysis pathways exercise, conducted by a separate task, was used to identify major needs for process cost reduction: improvements to bio-oil yield and reasonable upgrading catalyst lifetime. With this information, an approach to catalyst improvements was developed, along with short-, medium-, and long-term goals. These will be supplemented in fiscal year 2014 by a rigorous process design, which will provide quantified technical targets that lead to the minimum fuel selling price target. In general, this task has identified low-pressure hydrodeoxygenation as an impactful research thrust, and efforts are underway to design catalysts for this purpose.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- This appears to be a good project with a worthwhile objective and a reasonable chance of success.
- Continued on other projects; reasonably good.
- Fairly narrow, largely duplicative of other ongoing work in labs, academia, and industry. Non-collaborative and mostly just theoretical to date.
- The presenter is doing good work, but the presentation did not make clear the project's scope. The introduction suggested the project is aimed at larger-scale experimental work, but the presentation was almost exclusively on analysis, and no clear plan to transition from one to the other was presented. The presentation also did not make clear how well the analysis efforts are coordinated with other BETO analysis tasks. A sharper focus would help this project.
- This project seems to be another good use of the national labs. There are a plethora of national lab projects that relate to and possible overlap with this project. An overall flow diagram or Venn diagram that graphically depicts the interaction of these multiple, related national lab projects would have been useful. Without such a roadmap, it is virtually impossible for an outsider to understand and rate the importance of the individual projects or the overall larger, integrated effort. Along these same lines, it is critical that knowledge transfer between this project and the other, related national lab catalytic fast pyrolysis projects occurs smoothly and completely. A central, active oversight function is also critical.

PI Response to Reviewer Comments

- As a new project, we are aware of the need to provide the best value possible. Part of this includes avoiding duplicative work, pursuing mission-relevant research, and integrating with other BETO tasks. Since many of the BETO projects prior to fiscal year 2013 were focused on gasification technology, it is natural to have some overlap when making a large program shift. We feel that we've carved out an impactful and necessary element of cost-competitive, pyrolysis-derived biofuels, and as the projects mature and the Analysis tasks provide more input, we will work diligently to ensure that we're providing as much novelty and collaboration as we can. We're actively pursuing partnerships with industry and academia, and have a goal of at least one partnership by the next review. Finally, to clarify scope, we note that we are addressing small- to medium-scale catalyst development, and the results of our studies will feed into other tasks performing demonstration-type work. We work closely with the Analysis tasks to validate potential technologies, provide data sets for validation, and assist in process integration strategies.

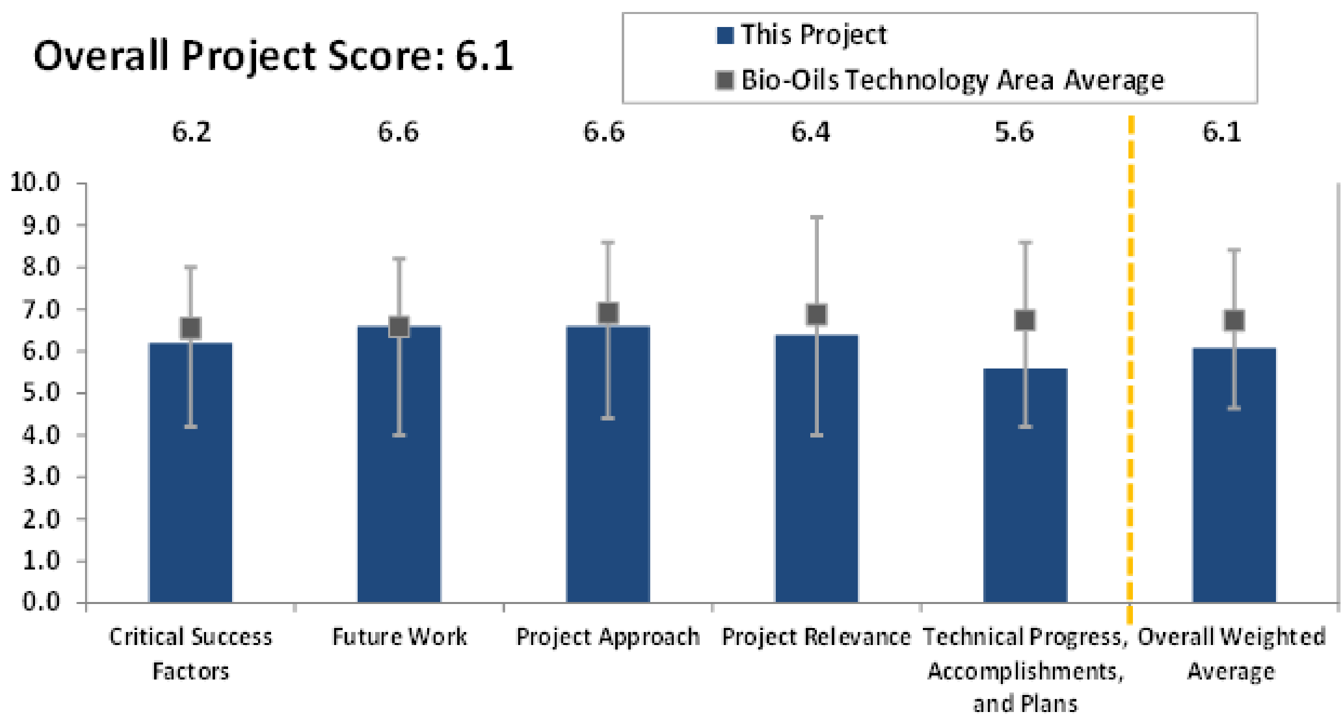
INTEGRATION AND SCALE-UP

(WBS#: 3.3.1.13; 3.7.1.1)

Recipient:	NREL
Presenter:	Mark Davis
Total DOE Funding:	$2,100,000
DOE Funding FY13:	$2,100,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010-2022

Project Description

The goal of this project is to demonstrate/validate the individual unit operations, as well as demonstrate the integrated production, of cost-competitive hydrocarbons at the pilot scale. The objectives of the project are to construct a flexible, integrated pilot plant capable of *in-situ* fast pyrolysis, and *ex-situ* catalytic fast pyrolysis, evaluate the performance of all unit operations, and validate techno-economic analysis and projections. Our technical approach will be to mimic a commercial-process model based on a conceptual design to demonstrate integrated process performance of key unit operations. The integrated design that will be constructed is based on pending fiscal year 2015 down-select to identify to most promising technology pathway and the formulated feedstock choice. This project will work closely with the catalyst design tasks to ensure proper reactor designs and integration. The project addresses the Thermochemical Conversion R&D Strategic Goal: "develop technologies for converting feedstocks into cost-competitive commodity liquid fuels such as renewable gasoline, jet fuel, and diesel and achieve a minimum fuel selling price of $3/gallon of gasoline equivalent" by validating unit operations, integrating processes, and demonstrating technologies required to convert biomass to stable intermediates or hydrocarbon fuels. The project addresses biomass conversion pathways in the MYPP to "demonstrate and validate bio-oil production to a stable intermediate" and contributes to BETO's portfolio of biomass conversion pathways by demonstrating/validating unit operations for fast *in-situ* pyrolysis, and *ex-situ* catalytic pyrolysis. This presentation will focus predominately on the future reconfiguration of the NREL pilot-scale facilities, future experiments, and the anticipated challenges the project may have to overcome.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Effort seems a bit premature and also appears to be the justification for continuing to modify and operate an existing pilot plant. Experience suggests that this is costly and inefficient.
- I liked that the group is aware of the issues with scale–up; they have experience that will be very beneficial to success.
- NREL appears to be effectively dealing with safety issues that have caused delays. The uncertainty about the final pyrolysis pathway makes it unclear what the present facility should include. BETO may want to focus the effort on present needs, such as providing reasonable quantities of liquid bio-oil, and postponing other decisions until later.
- There is some learning potential from scale-up, and some benefit from capability to produce larger quantities of pyrolysis oil, but not very innovative, and the value for the cost is questionable.
- This is difficult work with many impediments to success, but it needs to be done. Due to the immature nature of the supporting R&D work, it may be too early in the technology development cycle to implement a pilot plant of this scale.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

BIOMASS-DERIVED PYROLYSIS OILS CORROSION STUDIES

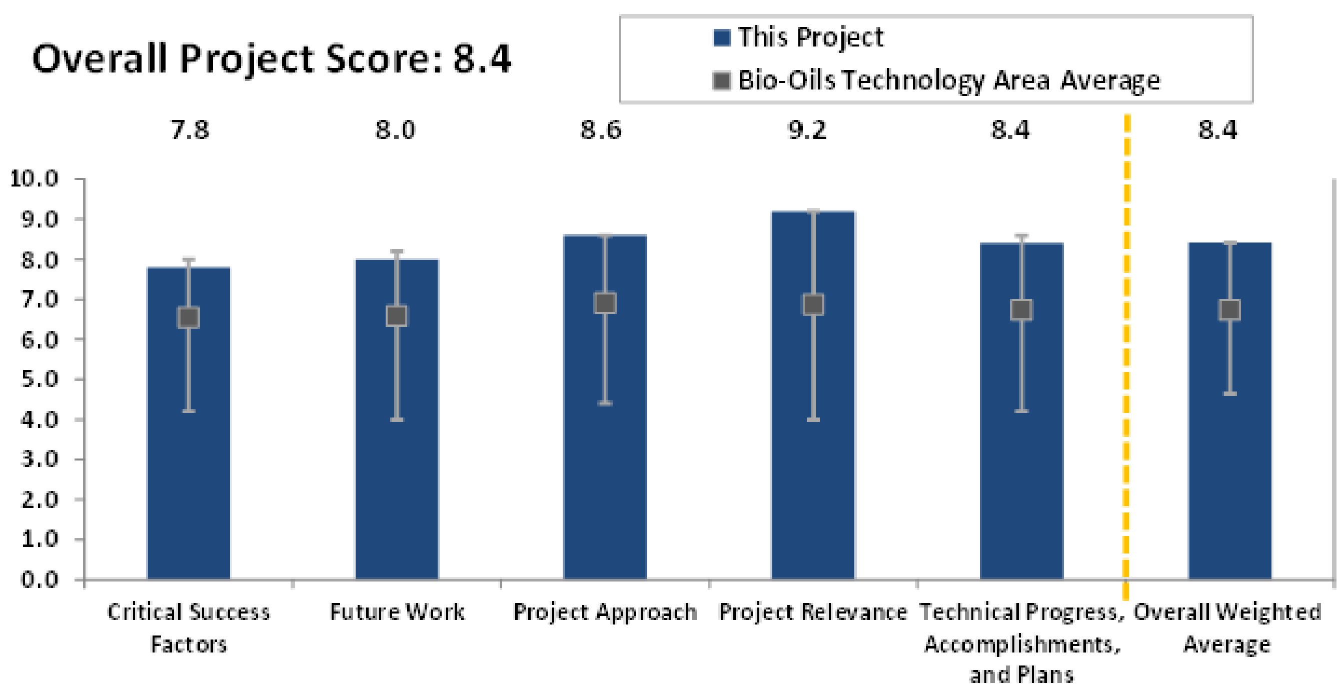
(WBS#: 3.2.2.16)

Recipient:	ORNL
Presenter:	James Keiser
Total DOE Funding:	$1,370,000
DOE Funding FY13:	$1,050,000
DOE Funding FY12:	$160,000
DOE Funding FY11:	$160,000
Project Dates:	2010-2016

Project Description

Photo Courtesy of ORNL

Biomass-derived pyrolysis oil offers a potential for replacement of fossil-derived liquid fuels. However—as produced pyrolysis oil contains significant amounts of carboxylic acids—this product presents serious corrosion issues for containment materials for production, processing, storage, and transport of bio-oil. This project has four tasks: assess the extent of corrosion of potential metallic containment materials caused by bio-oil, both as-produced oil and oil at various stages of further processing; identify or develop alloys that are resistant to bio-oil degradation; use conventional or developmental analysis techniques to characterize bio-oil intermediates and products; and assess the compatibility of elastomers, plastics, and sealants with bio-oils. As-produced pyrolysis oil from many sources has been studied both to characterize the acidity and concentration of acidic components, and to determine the corrosion rate of potential containment materials. Laboratory corrosion studies with untreated oil showed reactions with carbon steel and 2¼Cr-1Mo steel were so extensive that those alloys are unsuitable for handling bio-oil even at 50°C. Analysis showed untreated bio-oil had TANs that ranged from 40 to values over 100. A chemical separation technique identified formic and acetic acid as the acids present in greatest concen-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

tration. Studies showed 300-series stainless steels are resistant to bio-oil corrosion under these test conditions. Studies with stabilized and hydrotreated bio-oil showed carbon steel and 2¼Cr-1Mo steel were not corroded by the hydrotreated oil. Other studies include exposing corrosion samples in operating pyrolysis systems, and these samples, as well as components of operating systems, are being examined. Compatibility studies of elastomers, plastics, and sealants are planned using treated pyrolysis oil like that planned for blending with home heating oil. This project will be successful if materials with sufficient corrosion resistance can be identified so that materials-degradation issues do not prevent commercialization of any bio-oil technologies.

Overall Impressions

- A very critical area of emphasis that must be addressed for these biomass-derived materials to be commercially produced and used.
- This project is essential.
- This is high-quality research focused on an issue that is very important to BETO. Determining both the rates and the mechanisms of corrosion are important, and the project is doing a good job in this area.
- This is important work that is required to move the bio-oil process/handling technology forward.
- This is a very valuable study that will become even more so if, and as, industrial partners are added and a broader range of bio-oils are studied.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

TAN CONTROL OF BIO-OIL

(WBS#: 3.2.2.27)

Recipient:	ANL
Presenter:	Yupo Lin
Total DOE Funding:	$200,000
DOE Funding FY13:	$200,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012-2014

Project Description

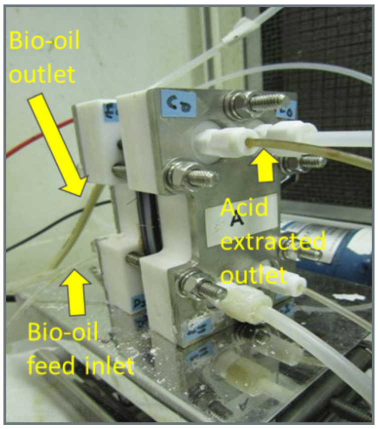
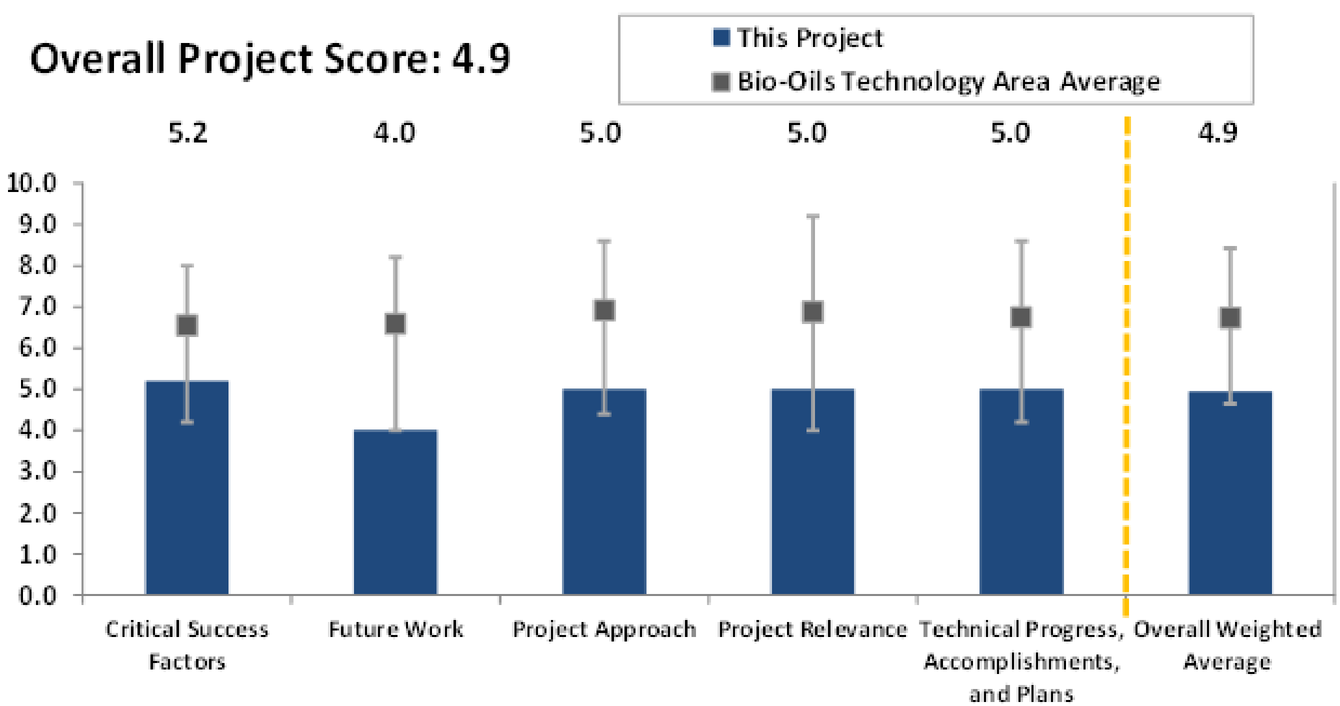


Photo Courtesy of ANL

Problems with stability due to the presence of organic acids have created major technology hurdles for bio-oil that cause problems in storage and transportation. Removing carboxylic acids will reduce acidity and oxygen of the bio-oil, and thereby increase stability. This addresses the MYPP barrier Tt-E, pyrolysis of biomass, and bio-oil stabilization. This project will evaluate the application of ANL's proprietary resin wafer electrodeionization technology for the removal of organic acids and inorganic salts from pyrolysis bio-oil. The effects of organic acid and salt removal on bio-oil stability and acidity will be studied. We will also evaluate pulse-flow microfiltration for char removal to overcome problems related to high viscosity and particulate fouling on the membrane surface. Because char also contains alkali metals, its removal can also enhance stability of bio-oil. Since the project started in October 2012, we have completed Task A and fabricated several resin wafers with different physical and chemical properties. Initial compatibility evaluation of commercial ion-exchange membranes in bio-oil has been carried out. The ionic conductivity of cation-exchange membranes and selected anion-exchange membranes were found to be unaffected by bio-oil. The small volume of bio-oil samples available from NREL precluded comprehensive testing for char removal by microfiltration in Task B. Instead, Task C was carried out. Preliminary evaluation of acid removal



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

using resin wafer electrodeionization was performed in an exploratory-scale unit. Thirty percent to fifty percent removal of acids was observed, and the results were confirmed by analysis for TAN. Several operating issues were identified. Among them, the pressure drop caused by the high viscosity of bio-oil was the most notable. A strategy to address this challenge will be discussed in the presentation.

Overall Impressions

- An interesting approach, but membrane fouling and long-term reliability remain as major hurdles.
- Electrodeionization for bio-oil looks like one of those cases of a hammer in search of a nail. Sometimes that can result in a major improvement that experts in the target application area would never have found on their own, but the chances of this are unlikely.
- Good idea, but seems to have needed better planning.
- Overall, this project is evaluating potentially useful technology and should continue until a go/no-go decision is reached.
- Separations are important, but this approach does not appear to be highly compatible with bio-oil. The characteristics of bio-oil will cause fouling, the rates of separation are very slow, and electricity costs have not been calculated. As an incubator type of project, this effort needs to be more sharply focused on rapidly obtaining key performance data and then providing a quick TEA to see if there is really an opportunity that this approach can be economically feasible.

PI Response to Reviewer Comments

- Electrodeionization is an electrochemical ion-exchange system that shows enhanced ion-exchange capacity and higher ion-removal rates than conventional ion-exchange column technology. Using electric water-splitting reaction, it also avoids the needs of chemicals to regenerate the ion-exchange beads as ion-exchange column does. Therefore, no chemical regeneration waste was produced. It has been successfully applied in high-fructose corn syrup desalination to replace ion-exchange column. Due to the synergy between high-fructose corn syrup and bio-oil in high hydrocarbon contents and liquid viscosities, it was thought to be a good fit for the application of electrodionization to control TAN.
- During the first half of fiscal year 2013, the new project was focused on developing sample characterization methods, bio-oil liquid handling and cleaning procedures, and material compatibility tests in an electrodeionization system. At the time of project review, there were not enough results to conclude the process performance except the demonstration of organic-acids removal capability using electrodeionization. In material compatibility evaluation, it was found that bio-oil did not alter the cations transport capability of any cation-exchange membranes under testing. While anion-exchange capacity was reduced greatly in some types of anion-exchange membranes, selected anion-exchange membranes showed minor effects on their anion transport property in bio-oil. The preliminary process performance, obtained right after the project review, showed the electricity cost to remove 57% acids from the bio-oil was around 0.3 cents/kg of bio-oil treated. It is encouraging. We also found that the decrease of acid removal rates in the end of each electrodeionization operation could be revived by applying a simple clean-in-place procedure. Currently, we are continuing to improve the operation conditions of electrodeionization to get consistent process performance of acid-removal rates. It would be used in conjunction with the electricity consumption (e.g., 0.3 cent/kg bio-oil) information to estimate preliminary TEA to determine technology viability.

A LOW-COST, HIGH-YIELD PROCESS FOR THE DIRECT PRODUCTION OF HIGH-ENERGY-DENSITY LIQUID FUEL FROM BIOMASS

(WBS#: 3.2.2.7)

Recipient:	Purdue University
Presenter:	Fabio Ribeiro
Total DOE Funding:	$1,000,000
DOE Funding FY13:	--
DOE Funding FY12:	$131,798
DOE Funding FY11:	$174,329
Project Dates:	2008-2013

Project Description

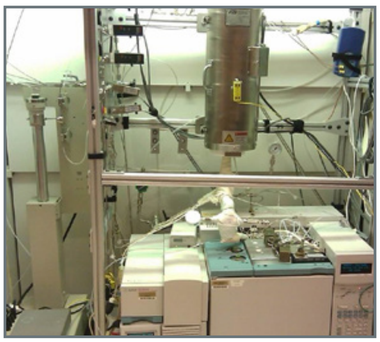
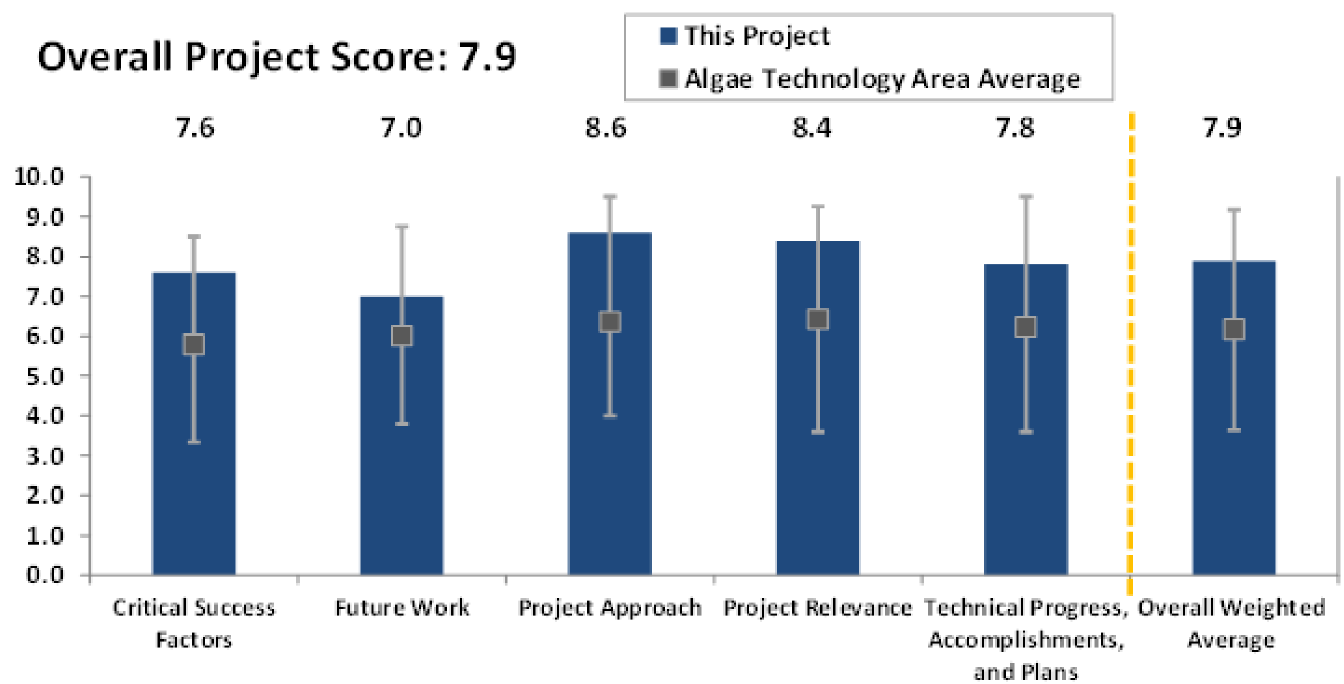


Photo Courtesy of Purdue University

The goal of this project is to generate proof-of-concept experimental data for our proposed, low-cost process for high yield of liquid fuel from biomass, called H2Bioil.[4] The novelty of the H2Bioil process is the utilization of hydrogen generated from an external energy source, such as coal, natural gas, nuclear, or solar energy, as an additional energy input to the process in order to minimize loss of carbon as carbon dioxide during the conversion to high-energy-density fuels. In addition to an increased fuel yield, oil obtained from this process will likely be more stable and compatible for input into existing oil refineries compared to traditional pyrolysis oil due to the reduction of reactive, oxygen-containing functional groups and decreased water solubility. Two lab-scale, continuous-flow, experimental apparatuses were constructed: a cyclone-type, high-pressure, fast-hydropyrolysis reactor system complete with a screw-feeder, secondary fixed-bed reactor, and oil condensation/collection system; and a stand-alone fixed-bed reactor for catalytic, vapor-phase oil upgrading studies. This equipment enabled us to explore the effect of hydrogen partial pressure during fast-hydropyrolysis and to develop new catalytic routes to upgrade these oils



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

[4] Agrawal, R.; and Singh, N.R. "Synergistic Routes to Liquid Fuel for a Petroleum Deprived Future," *AIChE Journal* (55:7), 2009; pp. 1898–1905.

to high-quality liquid fuels via hydrodeoxygenation and carbon-carbon coupling reactions. To reduce the inherent chemical complexity in bio-oils, we utilized model compounds representative of biomass, lignin, and cellulose as a starting point for work on real biomass feedstocks and biomass-derived oils. We achieved oxygen-reduction milestones using model compounds for both hydropyrolysis and catalytic hydrodeoxygenation using ruthenium- and platinum-based catalysts. Applying the knowledge gained from model compounds, we successfully overcame challenges of high-pressure operation, feeding solid biomass, catalyst development, and analytical method development to meet biomass-conversion and oxygen-reduction milestones using real biomass. In addition to experimental work on H2Bioil, we also investigated other augmented biomass-to-liquid fuel processes using an energy systems approach.

Overall Impressions

- Based on the information presented, this project does not appear to have significantly advanced the state of the art in catalytic upgrading, and it has no significant impact in furthering BETO's goals.
- Seems like they spent most of the time on building and shakedown of reactors without testing reactors using samples. Didn't get to see the best results.
- This is a study mainly of academic interest. Simplistic analysis and model-compound work are not likely to have much practical applicability.
- The contributions of this project are not clear. Most likely, the high-pressure reactor route is not economical, but no TEA and LCA figures were presented to make this determination one way or another based on this project. Overall, the lack of data presented calls into question the value of this project. Since this project is complete, more data and conclusions should have been provided. Based on this lack of information, it is logical to conclude that this process did not live up to its expectations.
- This stands out as one of the weakest research projects in the portfolio. A lot of claims and goals with little content.

PI Response to Reviewer Comments

- We are the first to experimentally demonstrate a scalable, biomass-thermochemical-conversion process (H2Bioil) to produce 100% deoxygenated four-carbon or more hydrocarbon fuel with a carbon recovery of 36–40%. We have advanced the state of the art in catalytic upgrading by identifying a bi-functional catalyst system resistant to coking that produces hydrocarbons from lignin model compounds, cellulose, and real biomass.
- The success above has validated our assumptions that high-hydrogen pressure and direct reaction of fast hydropyrolysis vapors would lead to simplification and control of the product distribution. Since the tools necessary to test this new concept were not available, we spent considerable effort designing a high-pressure, low-residence time reactor, a novel feeder for solids at high pressure, and downstream product analysis. While overcoming the design challenges took longer than we anticipated, we have been able to test not only model compounds and pure cellulose, but also whole biomass. It was the combination of these results that has led us to the new bi-functional catalyst.
- The judicious choice of model compounds has allowed us to rapidly screen catalysts and identify catalyst descriptors for desirable reaction pathways. The end result is a system that has validated the high-carbon recovery of the H2Bioil.
- Despite requiring the use of 25–50 bar hydrogen to obtain higher carbon and energy efficiency versus traditional processes, techno-economic analysis reveals the H2Bioil process can be economically competitive with the break-even crude oil price of $103–116 per barrel using H_2 from coal, natural gas, and nuclear sources. We note that high pressure is common in petroleum processing.
- In summary, our work has successfully identified and demonstrated a unique, high-yield processing route for liquid fuel production from biomass. Our tandem reactor design and catalyst performance will have direct impact on biomass conversion technologies.

UPGRADING OF INTERMEDIATE BIO-OIL PRODUCED BY CATALYTIC PYROLYSIS

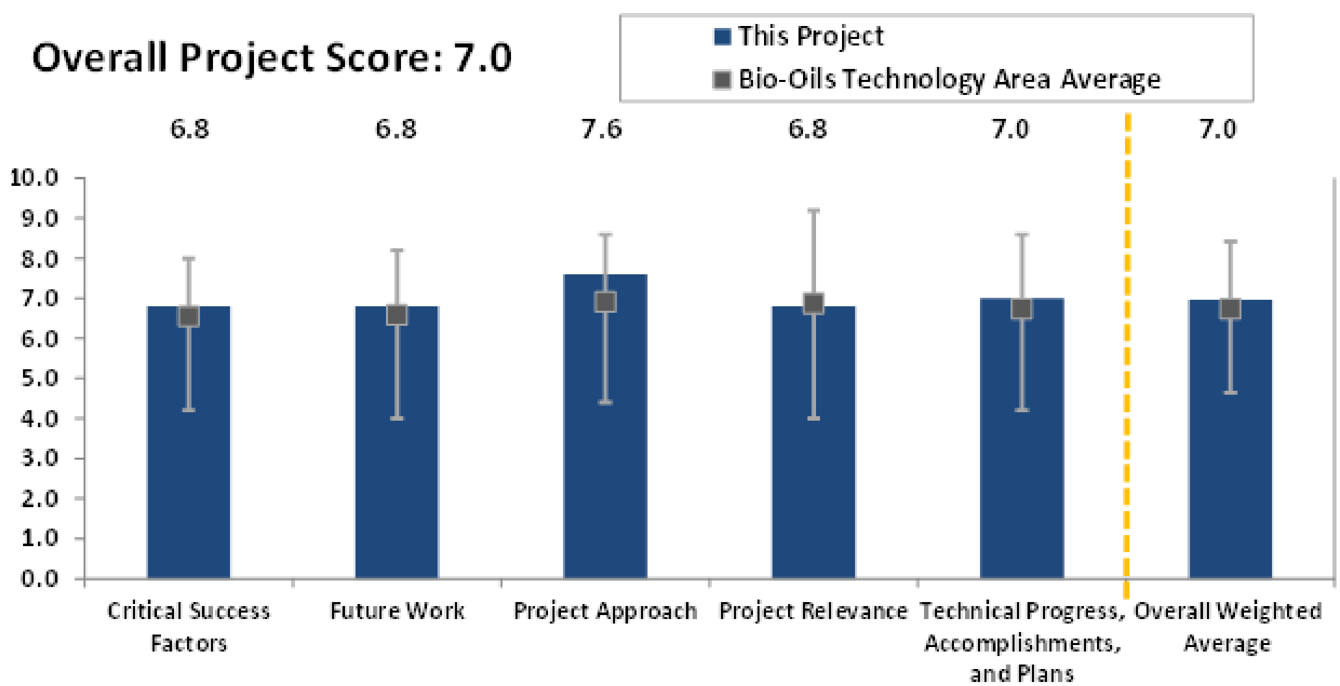
(WBS#: 3.2.2.19; 3.2.2.20)

Recipient:	Battelle Memorial Institute
Presenter:	Zia Abdullah
Total DOE Funding:	$1,053,307
DOE Funding FY13:	$181,058
DOE Funding FY12:	$811,432
DOE Funding FY11:	$60,817
Project Dates:	2010-2013

Project Description

Photo Courtesy of Battelle Memorial Institute

The objectives of the research are to develop a hydroprocessing system and hydrotreatment catalysts tailored for the catalytic bio-oil produced by Battelle's *ex-situ* fast pyrolysis and vapor-phase upgrading system. This project meets all of the objectives of FOA-0000342, supports one of BETO's thermochemical pathways and meets bioenergy industry needs. Battelle Memorial Institute is the prime contractor, and PNNL is subcontractor to Battelle. Industrial partners include Marathon Petroleum Company, Domtar, Praxair, and Sud Chemie. The project is on schedule and on budget. The key technical barriers addressed by this project include hydrotreatment catalyst deactivation by coking, corrosion of materials of construction, and catalyst deactivation occurring during long-term operation of the hydrotreatment system. The technical achievements to date include: building and commissioning of a lab-scale hydrotreater for catalyst screening, and a pilot-scale hydrotreater with capabilities for catalyst regeneration and hydrogen recycle for long-term hydrotreatment trials; development of non-carbon-supported and non-sulfided catalysts for hydrotreatment; testing of these catalysts for 275 hours on stream at lab scale and 200 hours on stream at pilot scale; and generating data on corrosion of construction materials. These technical achievements all contribute to the Technology Area's goals because they have built hardware capabilities and catalysts for conversion R&D,



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

demonstrated conversion catalyst performance, and generated data for conversion processes. Battelle plans to apply the project outputs in its small-scale *ex-situ* catalytic pyrolysis–hydrotreatment technology. This technology is expected to be spun off in fiscal year 2013 and will target distributed deployment of a large number of these systems to contribute toward meeting BETO's goals. Critical success factors and challenges include the ability to regenerate the catalyst and achieve long-term operation with lower coke production rates.

Overall Impressions

- This reviewer's main complaint is that the results to explain the process were not presented in full. I realize this may be due to proprietary issues, but I really couldn't evaluate how well the project was progressing.
- This is a solid project with an unusually strong group of collaborators, including a good spectrum of industrial partners. It may not be innovative enough to make significant impact, though.
- The project appears to be on track and has a reasonable probability of meeting its 1,000-hour goal.
- This appears to be a well-managed effort with good progress.
- This project is generating product and has the potential to stand alone near the biomass source. It does not require refinery integration, which gives it more geographic flexibility.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

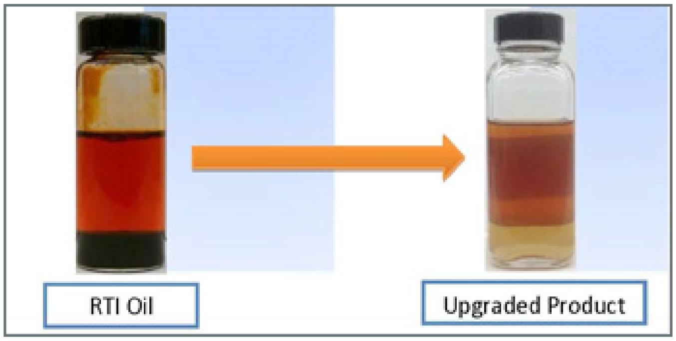
CATALYTIC UPGRADING OF THERMOCHEMICAL INTERMEDIATES TO HYDROCARBONS

(WBS#: 3.3.1.10)

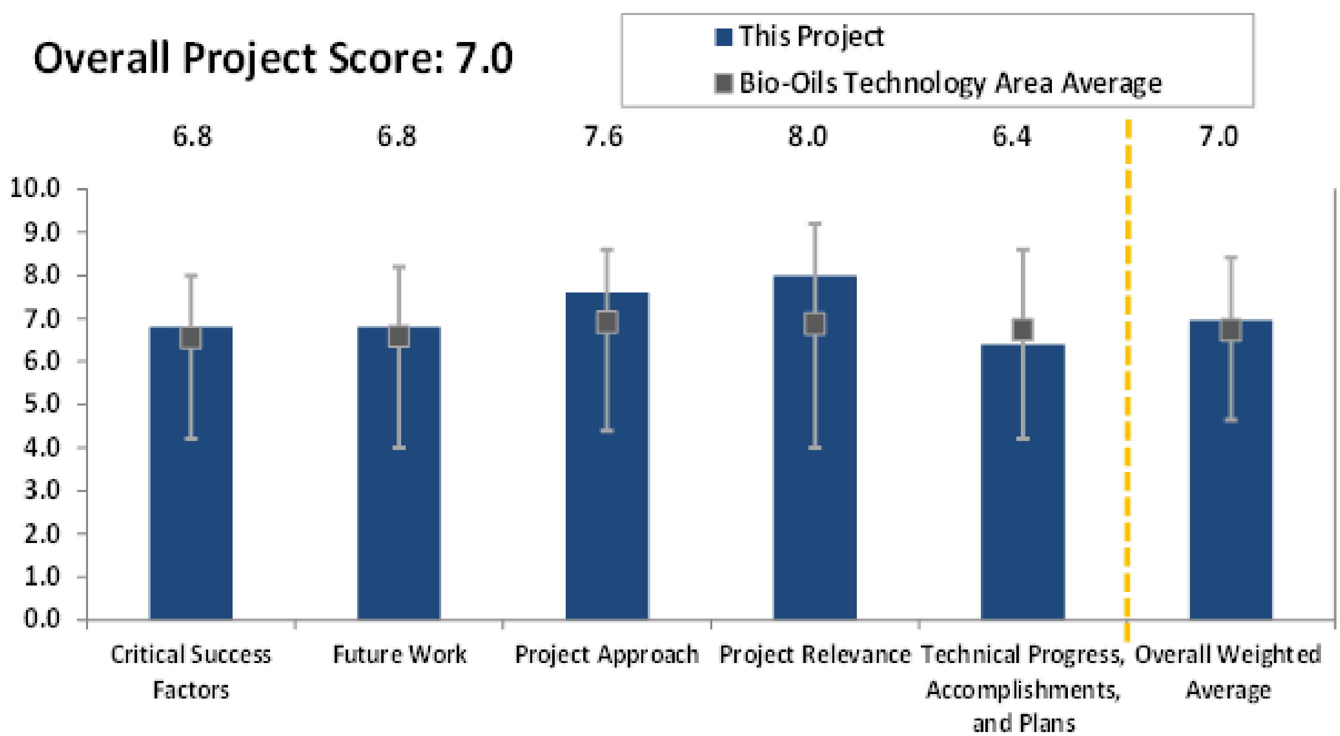
Recipient:	Research Triangle Institute
Presenter:	David Dayton
Total DOE Funding:	$4,000,000
DOE Funding FY13:	$1,256,000
DOE Funding FY12:	$1,808,380
DOE Funding FY11:	--
Project Dates:	2011-2015

Project Description

Photo Courtesy of Research Triangle Institute



The goal of the project is to demonstrate an advanced biofuels technology that integrates a catalytic biomass pyrolysis step and a hydroprocessing step to produce infrastructure-compatible biofuels. Research Triangle Institute (RTI) International is developing a novel single-step catalytic biomass pyrolysis process to produce a hydrocarbon-rich, bio-crude intermediate. Our partner, Haldor Topsoe, has developed a strategy for upgrading bio-crude intermediates based on extensive hydroprocessing-catalyst and process-development expertise. At this stage in the development process, the proof of concept has been demonstrated for the individual components. The next step along the technology commercialization pathway is to scale-up the catalytic biomass pyrolysis process, integrate this technology with a hydroprocessing unit, and demonstrate the long-term operation and performance of the integrated process. The technical goals are to optimize the catalytic biomass pyrolysis process at the bench scale (one ton/day) to achieve a high degree of deoxygenation, while maximizing the bio-crude production; improve bio-crude thermal stability; evaluate the impact of bio-crude quality in the hydroprocessing step; minimize hydrogen demand of the integrated process;



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

and maximize biofuels yields. A detailed plan has been developed to address these technical challenges and collect required processing and engineering data to support the development of a commercial-scale design package for a proposed, integrated, catalytic-biomass-pyrolysis process with bio-crude hydroprocessing. Technical data will be used to modify technical and economic inputs to the pro forma analysis to evaluate the economic potential of the technology. Sufficient bench-scale engineering data will be collected to guide the development of a technically viable, integrated catalytic-biomass-pyrolysis process with bio-crude hydroprocessing.

Overall Impressions

- This appears to be a well-thought-out and well-executed process and catalyst development effort.
- Had some issues with glossing over getting certain things done before scaling–up. It is problematic that RTI does not yet have a contract with Topsoe.
- Solid project with real commercial potential. Delayed start means that work has only begun, so much of the potential remains just that for now.
- This is a project that may provide some good results/data. There is nothing novel in the configuration, but if successful, it could be commercialized as multiple small units located near the biomass source producing either drop-in fuels, or a stable, low-oxygen, low-TAN bio-oil that can be pipelined to a central processing facility. This makes the process more flexible and improves the probability of commercial success.
- While the significant delay in project start-up is troubling, the project may ultimately benefit since larger-scale equipment will now be in place. The larger-scale equipment will provide more realistic data for the proposed effort.

PI Response to Reviewer Comments

- Comprehensive catalyst development and laboratory-scale (one-foot-diameter fluid bed reactor) catalytic-biomass-fast-pyrolysis experiments with greater than 95% mass balance and product-stream analyses were completed in a project funded by DOE and the Advanced Research Projects Agency-Energy. The results from this previous work provided the basis for the design of a one-ton-per-day pilot unit that has been commissioned and is now operational. The first bio-crude sample was produced in the one-ton-per-day pilot plant in August 2013 and—now that negotiations with our partner are complete and we have a fully executed subcontract with Haldor Topsoe—we will be generating numerous samples for upgrading studies and executing the project plan.
- The design of the catalytic-biomass-pyrolysis reactor system may be quite familiar; however, the novel catalyst developed for this process has the potential to improve the yield of low-oxygen content bio-crude that is more easily upgraded than other bio-oil intermediates. We intend to optimize process conditions in the catalytic fast pyrolysis step to maximize bio-crude yields, while also investigating the impact of the bio-crude composition in the hydrotreating step to maximize biofuel yield. The integration of the biomass conversion and upgrading steps in a single experimental facility allows us to validate process conditions that maximize process yields and carbon efficiency while minimizing hydrogen demand.
- A preliminary techno-economic analysis suggests that our catalytic fast pyrolysis process is cost competitive and could achieve the $3/gge BETO target, but this includes generic assumptions about the upgrading step. These assumptions will be updated based on the hydrotreating studies in this project and a revised TEA will be developed. Technical barriers and metrics not already identified will be addressed as the project progresses. The results from this project will provide the technical and economic data required for scale-up and commercialization to produce cost-competitive advanced biofuels.

SOUTHERN PINE-BASED BIOREFINERY CENTER

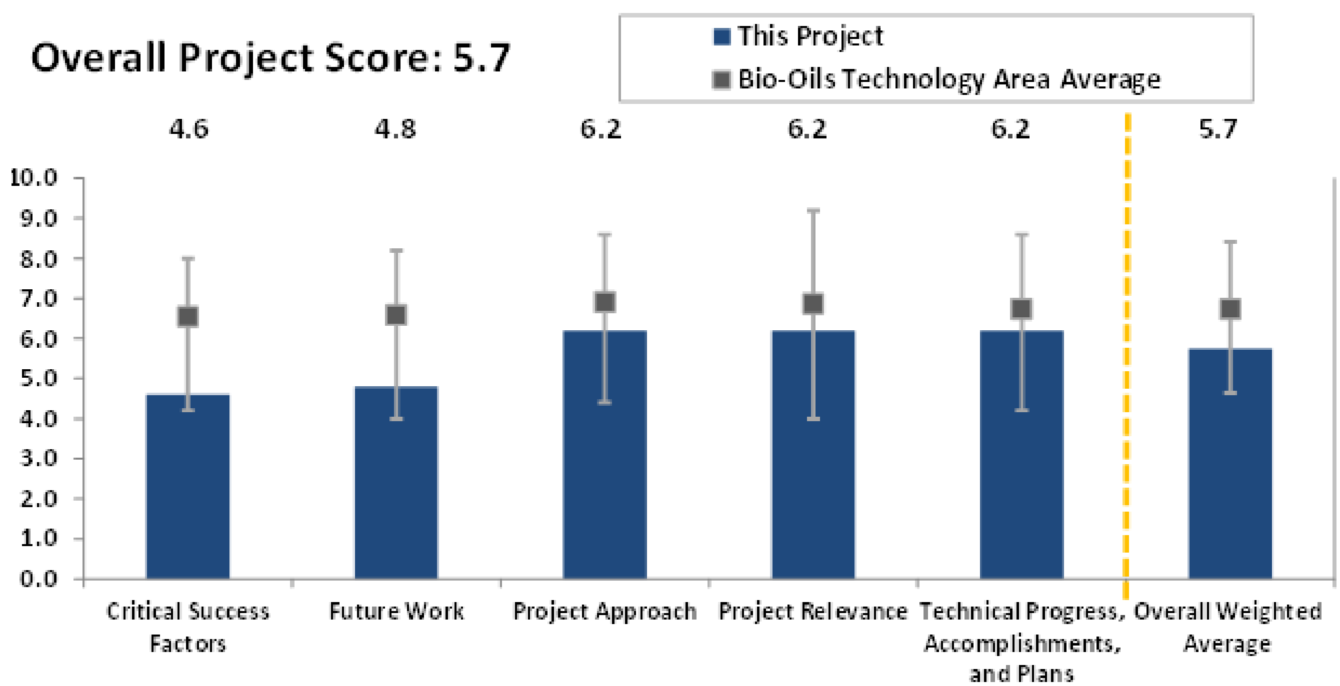
(WBS#: 7.5.7.3)

Recipient:	Georgia Tech
Presenter:	Arthur Ragauskas
Total DOE Funding:	$333,333
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010-2013

Project Description

Photo Courtesy of Georgia Tech

In Georgia and the Southeast, the forest products industry is destined to take a lead role in the conversion of pine to value-added green materials, fuels, and energy. This key regional industry has a deep technical history of converting Southern pine to value-added, paper-based materials in a sustainable manner. The challenge for the near future is to accelerate technological developments that will facilitate the conversion of Southern softwoods into pulp, paper, bioenergy, and biofuels. A key challenge for the implementation of these technologies is the need to demonstrate that these benefits can be achieved with ongoing forest-products unit operations and will generate current and future product streams. In this program, the researchers have developed the necessary laboratory data to identify how these new biofuel operations could be integrated into a modern, kraft-lignin biorefinery operation, generating both second- and third-generation biofuels and value-added green materials. This presentation will focus on our research accomplishments in the catalytic pyrolysis of pine residues, bark, and kraft lignin to bio-oils and the subsequent upgrading to a fungible fuel.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- It is unclear that the testing of individual components from biomass will lead to a substantially greater understanding of how whole biomass pyrolyzes. The information about the individual components is interesting, but the real-world pyrolysis is much more complex than the summation of individual parts. The presentation did not make clear how or if the correlation between parts and the whole biomass will be made, and did not address requested issues, including success factors or future work.
- Nearly complete. Fundamental and fairly comprehensive, but far from a complete analysis with practical implications.
- The project is okay. It seemed to complete expected deliverables.
- Strong analytical chemistry; weak and disorganized otherwise. Maybe it's the structure of the grants, but this work would have been much more valuable if the strong analysis done here had been linked to other performers with more expertise and a more realistic experimental set-up on the processing side. By applying strong analysis to weak process chemistry and engineering, the strength is largely wasted.
- The objective of pulp-mill integration is a great one. However, this project suffers from too broad of a focus and lack of any pulp-mill partners.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

UNIVERSITY OF OKLAHOMA BIOFUELS REFINING

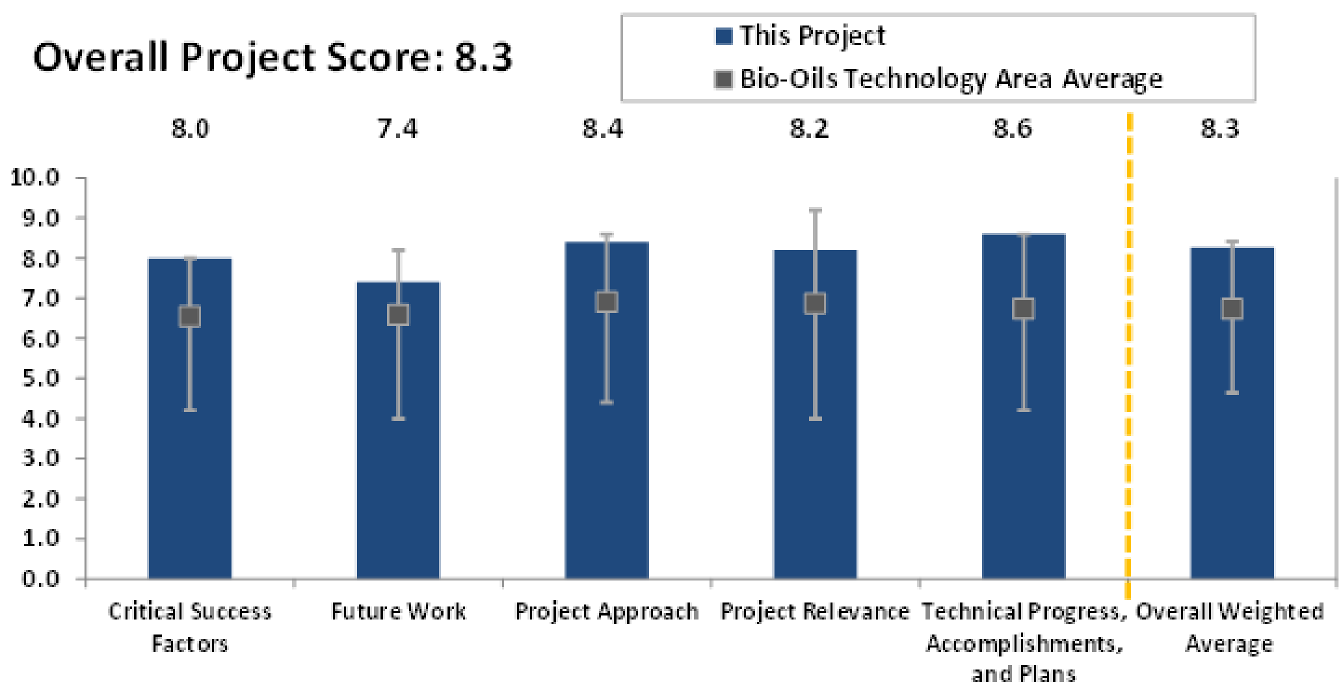
(WBS#: 7.3.4.1)

Recipient:	University of Oklahoma
Presenter:	Steve Crossley
Total DOE Funding:	$1,951,625
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2009-2013

Project Description

Photo Courtesy of University of Oklahoma

The research in this project develops the knowledge needed to develop catalysts and processes to upgrade pyrolysis bio-oil. Research goals include maximizing carbon retention in the upgraded products, minimizing hydrogen consumption in the upgrading processes, and optimizing product fuel properties. These goals relate directly to BETO's goals of cost competitiveness, sustainability, and ease of integration of pyrolysis-based biofuels. Initial studies have used model compounds to identify catalysts and reaction conditions that are active and selective for several classes of reactions. Condensation, ketonization, and etherization reactions have been investigated to build longer (fuel-range molecules) carbon chains from small oxygenates (i.e., aldehydes, ketones, acids, etc.). Metal alloys were investigated with furanic model compounds to control the selectivity of carbon-carbon versus carbon-oxygen cleavage of carbonyl groups. Metal oxides and zeolites were found to be active and selective in model compound studies, and reaction pathways were determined. The incorporation of metals with acid catalysts has been investigated to preserve carbon in the liquid phase. Alkylation and transalkylation pathways prior to deoxygenation improve carbon retention. These catalysts have also been used in preliminary studies upgrading pyrolysis vapors (i.e., prior to condensation), with significant conversion of oxygen-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

ates, some deoxygenation, decreased TAN, and oil-water phase separation. These model compound studies and theoretical (density functional theory) calculations have been used to identify active catalysts and reaction conditions, and to elucidate deoxygenation, alkylation, and deactivation pathways. Results from these model compound studies allow the proposition of catalytic strategies that maximize fuel-range liquid production dependent on the chemical species present in bio-oil fractions. This project has led to several follow-up projects aiming to implement these strategies with real bio-oil streams while emphasizing the practical limitations, such as catalyst deactivation and techno-economics that govern the ultimate successful implementation of this knowledge.

Overall Impressions

- Good fundamental work, but probably not on the critical path for commercialization. Model compound studies are fraught with unrealistic expectations when trying to generate commercial applications.
- Overall, this appears to be a well-organized, well-executed project that will provide insight and understanding into fundamental pyrolysis oil upgrading chemistry and catalysts.
- Really good project for catalyst removal of oxygen and retaining carbon low-pressure reactors for farm use.
- This is high-quality academic work to build a knowledge base on catalysis. The various lab programs will benefit from closer coordination with this project.
- Truly excellent fundamental study; suffers only from absence of a clear path forward toward application.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

LONG-TERM PROCESSING IN THE PRODUCTION OF GASOLINE AND DIESEL FROM BIOMASS USING INTEGRATED HYDROPYROLYSIS PLUS HYDROCONVERSION PROCESS (IH2 PROCESS)

(WBS#: 3.2.2.18)

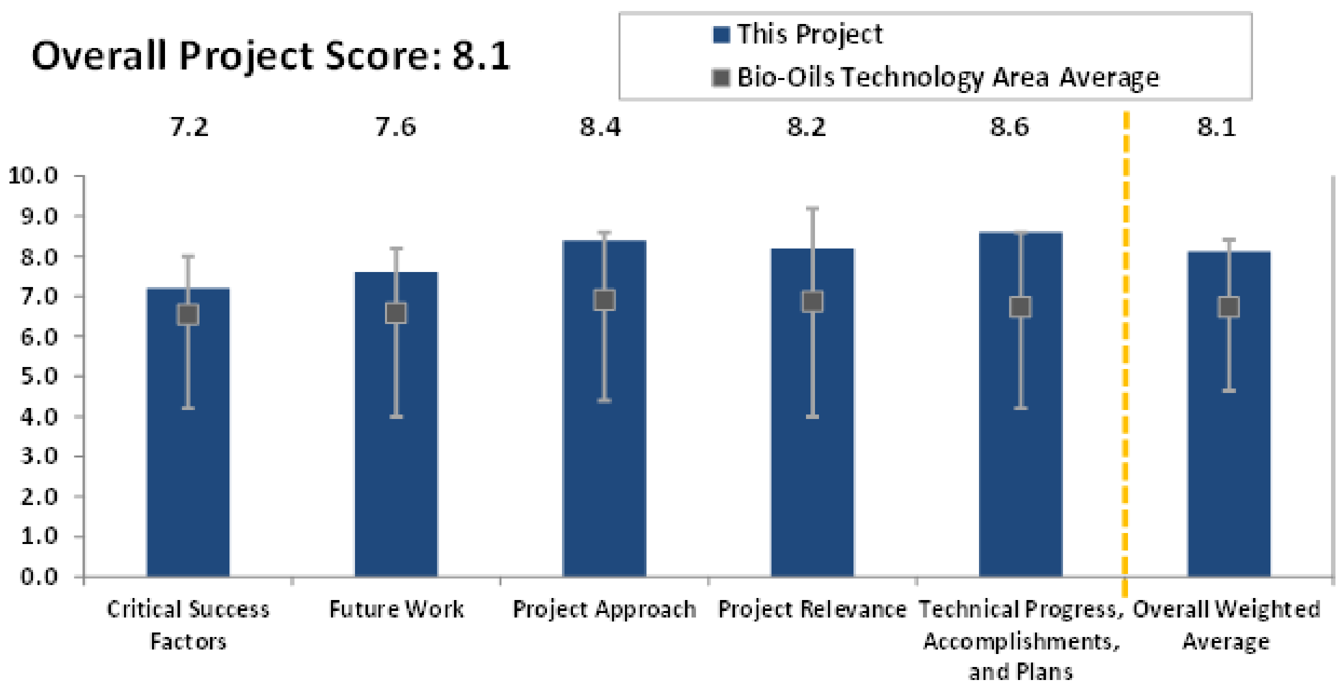
Project Description

Cellulosic and woody biomass can be directly converted to hydrocarbon gasoline and diesel blending components through the use of a new, economical technology named integrated hydropyrolysis plus hydroconversion (IH2). The IH2 gasoline- and diesel-blending components are fully compatible with petroleum-based gasoline and diesel, contain less than 1% oxygen, and have less than one TAN. The IH2 gasoline is high quality and very close to a drop-in fuel. The LCA shows that the use of the IH2 process to convert wood to gasoline and diesel results in a greater than 90% reduction in greenhouse gas emissions compared to that found with fossil-derived fuels.

Recipient:	Gas Technology Institute
Presenter:	Terry Marker
Total DOE Funding:	$2,900,000
DOE Funding FY13:	$63,000
DOE Funding FY12:	$1,660,000
DOE Funding FY11:	$1,160,000
Project Dates:	2011-2013

The techno-economic analysis showed the conversion of wood using the IH2 process can produce gasoline and diesel at less than $2/gallon. In this project, the previously reported, semi-continuous, small-scale IH2 test results were confirmed in a continually operating 50 kg/day pilot plant. The continuous IH2 pilot plant used in this project

Photo Courtesy of Gas Technology Institute



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

was operated around the clock for more than 750 hours and showed good pilot plant operability while consistently producing 26–28 wt% yields of high-quality gasoline and diesel product. The IH2 catalyst showed good stability, although more work on catalyst stability would be recommended. The IH2 process is a true game-changing technology, utilizing our domestic renewable biomass resources to create transportation fuels that are sufficient in quantity and quality to substantially reduce our reliance on foreign crude oil and reduce our greenhouse gas emissions.

Overall Impressions

- Impressive work with good results. Hopefully this can be built upon and scaled.
- Outstanding example of innovative technology development with strong commercial potential.
- Overall, this process appears to be a game changer and, if implemented on a commercial scale soon, could significantly and permanently change the biomass-to-liquid transportation fuels landscape. It is perhaps the best project currently in the bio-oil pathway.
- Really good-sounding project. However, some issues are not addressed—corrosion of materials, product toxicity, and low diesel quality. Economics are not really complete.
- This project has made exceptional progress in piloting a technology with excellent breakthrough potential. If the technology can successfully be scaled up, the basic problems with pyrolysis to hydrocarbons would be solved. Success would also likely make much of the remaining BETO research redundant.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

REFINERY UPGRADING OF HYDROPYROLYSIS OIL FROM BIOMASS

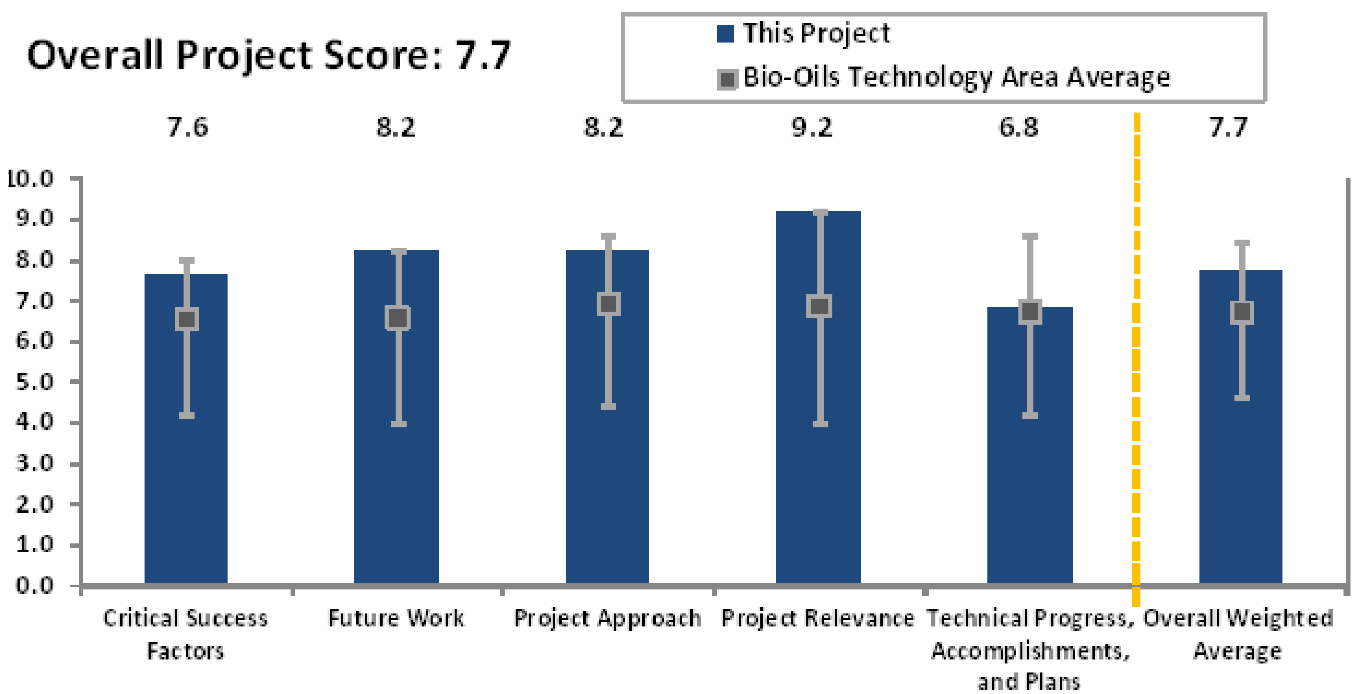
(WBS#: 3.3.1.16)

Recipient:	Gas Technology Institute
Presenter:	Terry Marker
Total DOE Funding:	$3,200,000
DOE Funding FY13:	$280,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013-2016

Project Description

This is a new project that has just been awarded. The goal of this project is to develop a cost-effective route for converting biomass to transportation fuels by first converting biomass to hydropyrolysis oil, and then upgrading the hydropyrolysis oil in a petroleum oil refinery using existing refinery equipment. This will be accomplished by working closely with Valero, a major U.S. petroleum refiner. A secondary goal is to produce a preliminary engineering design package for a hydropyrolysis demonstration-scale facility and commercial-scale facility to be located adjacent to a refinery. A third goal will be to develop an engineering design package for locating a hydropyrolysis unit converting corn stover at a corn ethanol plant and shipping the hydropyrolysis oil to a nearby refinery for further upgrading. GTI's hydropyrolysis technology is a newly developed technology that converts biomass directly to gasoline- and diesel-blending components. GTI will produce the hydropyrolysis oil using an existing pilot plant, and partner CRI Catalyst will then do upgrading studies of the hydropyrolysis oil in its hydrotreating test facilities. Valero will study insertion of hydropyrolysis oil at several of its specific refineries and into various refinery processing units, and describe the required feed

Photo Courtesy of Gas Technology Institute



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

properties for insertion. The company will also complete a risk analysis and TEA. Hydropyrolysis with refinery upgrading of hydropyrolysis oil to transportation fuels is expected to produce gasoline and diesel fuels from biomass at less than $1.80/gallon while reducing greenhouse gas emissions by more than 90%. This technology works well with a variety of biomass feeds, including wood, corn stover, and algae.

Overall Impressions

- This is among the most promising projects in the portfolio; there are promising initial results and a solid plan for development/improvement.
- I like project, but am frustrated with the lack of information from companies.
- Overall, this project appears to be an intelligent and potentially successful approach to the difficult task of integrating pyrolysis oils into existing crude-oil-refining infrastructure. There are many obstacles to this integration, and this project seems to be aware of them and have a plan to overcome them. This project should help determine if refinery integration of bio-oils is both feasible and economical.
- The project represents an excellent way to examine and answer the highly relevant questions of distributed versus centralized pyrolysis. The results should provide good data to clarify where and at what scale biomass conversion should be, and where the hydrotreating should occur. The leverage that this project gets from another closely related GTI project is excellent.
- This has real potential working with an interested and viable refinery partner to generate some real-world results.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

ADVANCED BIOMASS -TO-GASOLINE PROCESS

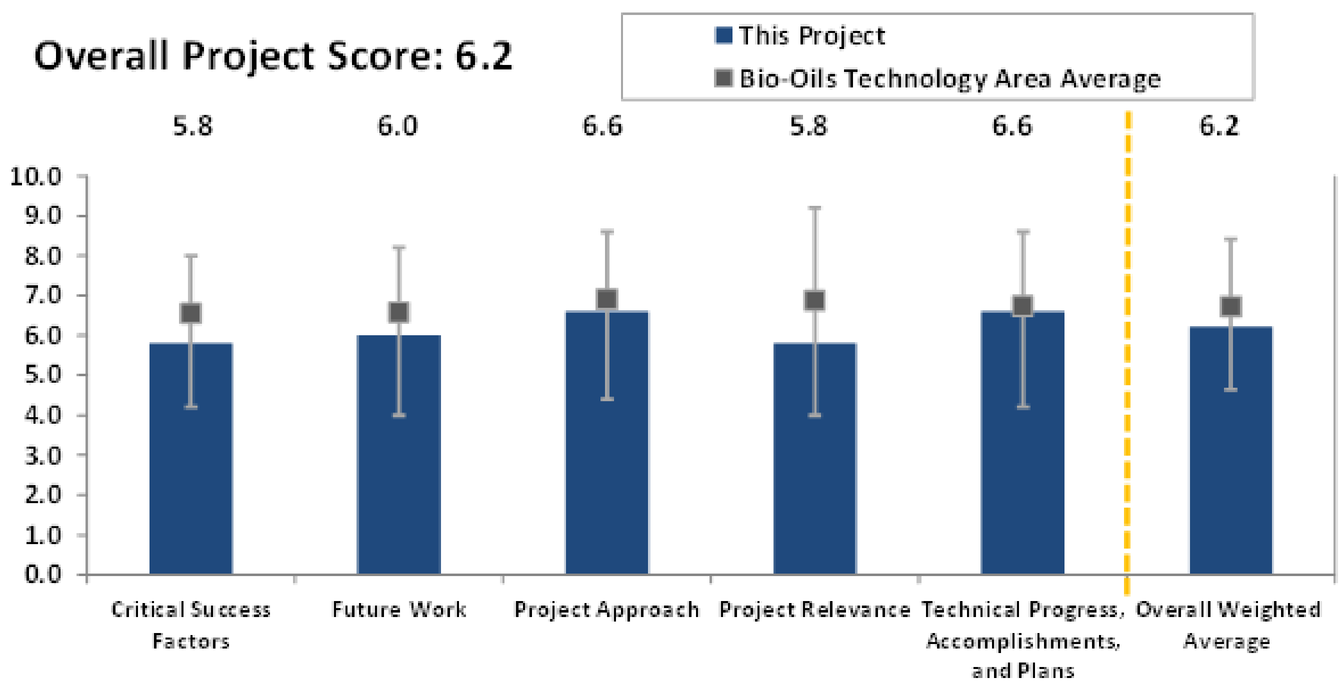
(WBS#: 3.2.2.17)

Project Description

Photo Courtesy of Exelus, Inc.

Recipient:	Exelus, Inc.
Presenter:	Mitrajit Mukherjee
Total DOE Funding:	$1,000,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010-2013

The United States has abundant biomass resources and, with the right technology, has the potential to convert these renewable resources into valuable industrial products and bio-fuels. However, current high-temperature thermochemical processes to convert renewable feedstocks to fuels or chemicals—such as pyrolysis and gasification or low-temperature enzymatic processes—are simply not cost competitive with conventional fossil-fuel based processes. Exelus has developed a first-of-a-kind process to deconstruct biomass into a stable liquid feedstock and convert it to liquid transportation fuels. The final product is a mixture of alcohols that serve as a direct replacement for gasoline. This process finds the middle ground between the slow, low-temperature reactions catalyzed by enzymes and the fast, high-temperature, and non-selective reactions occurring in pyrolysis or gasification. The Exelus concept overcomes the issue of highly reactive intermediates (sugars) reacting to form non-selective products like polymers and acids through the use of environmentally benign chemistry and innovative reactor designs. Liquid-phase aqueous processing is used to minimize the need to dry biomass and to provide both a solvent and reactant in the hydrolysis of biomass. A combination of low-capital investment, high biomass utilization, and lower processing costs translates into a cost of fuel produced via the new route of about $2/gallon. The



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

transformational potential of the Exelus biomass-to-gasoline technology will enable construction of small-scale plants close to the biomass source at significantly lower costs, allowing widespread deployment of the technology worldwide. This is achieved by removing the thermodynamic barriers encountered in conventional thermochemical technologies and allowing for pseudo-isothermal operation, which leads to better exergy utilization of the raw materials and a significant reduction in capital costs.

Overall Impressions

- A non-drop-in, non-ethanol fuel product that will face serious obstacles to commercial acceptance. Economics don't seem promising.
- It is not clear from the presentation just how successful this project has been. If this is a real, viable process with commercial potential, the need for this obfuscation is obvious. However, as a reviewer, it is difficult to determine the actual state of this particular technology. If it does everything the presentation says it does, it could be a real game changer. At this time, however, sufficient information has not been made available to this reviewer to accurately assess the situation. This reviewer is inclined, however, to believe that this process has great potential.
- It's very hard to verify claims made with little or no factual information provided.
- Seems decent. Multiple catalysts overall yield lignin free basis, but most information is proprietary.
- The presentation was very general in nature. As a result, it is difficult to determine whether substantial technical progress was made.

PI Response to Reviewer Comments

- This is a game-changing technology that steps beyond the usual thermochemical routes, such as pyrolysis or gasification, to produce high-value gasoline blendstock. We are not aware of any other organization that has been able to produce higher alcohols like ethanol and propanol from lignocellulosic feedstocks using heterogeneous catalysts under mild reaction conditions. Propanol was blended in gasoline in the U.S. for many, many years until it became too expensive to do so.
- A push to move beyond ethanol-based renewable fuels with higher alcohols (e.g., bio-butanol) that have better fuel-blending properties will accelerate once companies try to figure out how to produce them under commercially viable conditions. The total cost of producing higher alcohols via our process (assuming selectivities lower than what we have achieved in the labs) pegs the price at $2/gallon—way below current gas prices
- Details of the innovative process chemistry along with reaction conditions were presented. Results obtained for each step using multiple catalysts were presented. Data from a 300-hour stability run was also shown. Short of revealing the catalyst composition, there is not much else to show
- We have presented a concise summary of the entire process, types of reactors used, reaction conditions, types of feedstock used, and a clear description of the product slate. We have also presented a clear methodology used to calculate product pricing.

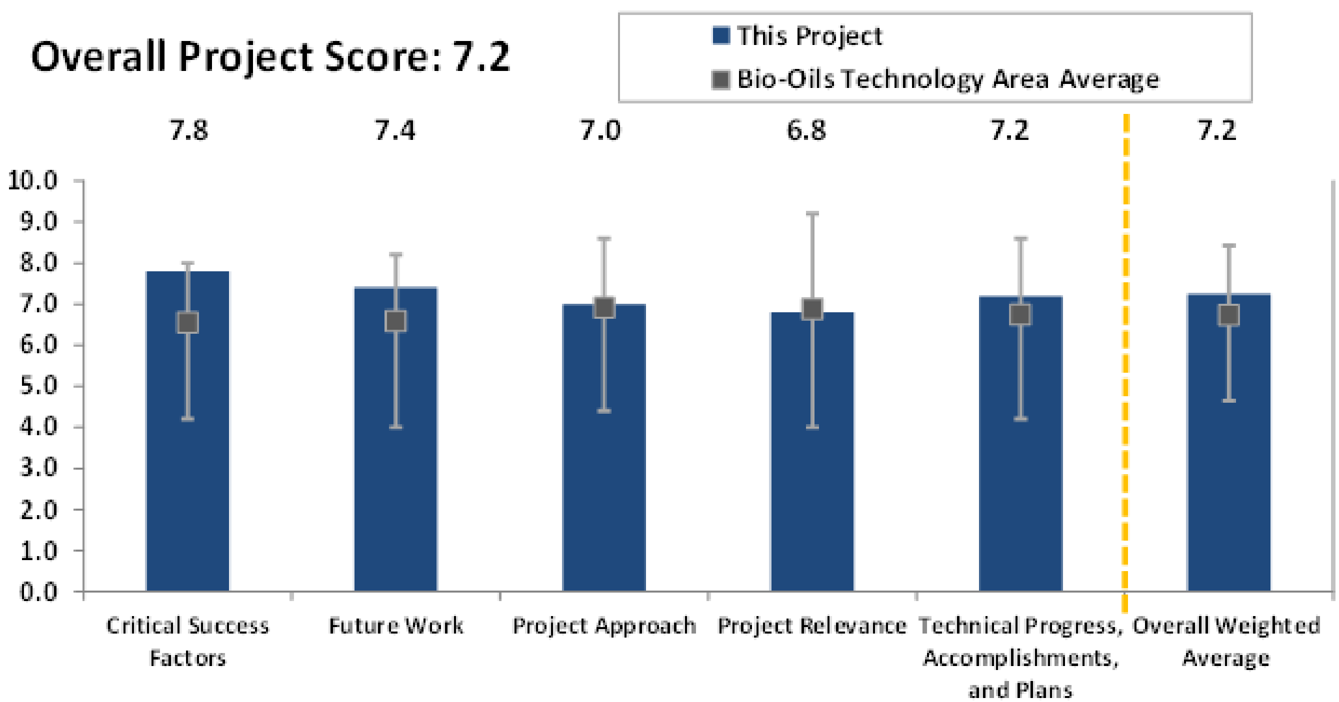
IMPROVED HYDROTHERMAL LIQUEFACTION BIO-OIL PRODUCTION

(WBS#: 3.2.2.31)

Recipient:	PNNL
Presenter:	Richard Hallen
Total DOE Funding:	$200,000
DOE Funding FY13:	$200,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012-2015

Project Description

Hydrothermal liquefaction of biomass produces a bio-oil product that is more stable and easier to upgrade compared to conventional pyrolysis-generated bio-oils. However, the quality of the bio-oil has been found to vary depending on feedstock, process conditions, and reactor configuration. This project is a new start in fiscal year 2013 to use state-of-the-art, advanced characterization techniques, such as Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR-MS), to investigate the difference in composition and molecular weight distribution of hydrothermal liquefaction bio-oils as a function of the feedstock, process conditions, and reactor configuration. The analytical results will be correlated to resulting bio-oil chemical and physical properties, including the impact on upgrading of the bio-oil to hydrocarbon product for fuel blendstock or refinery integration. PNNL has provided New Mexico State University with a variety of hydrothermal liquefaction bio-oil samples. The university has conducted initial FT-ICR-MS analysis of a small subset of the samples prepared from forest product residues (pine) and corn stover. The bio-oils were prepared as part of the NABC hydrothermal liquefaction development effort, and most of these bio-oils samples were used as feedstocks for upgrading tests. Future studies will include use of this powerful analytical technique to better define and understand the residue oxygen- and nitrogen-containing species in hydrotreated hydrothermal-liquefaction bio-oils, a key unknown identified by NABC refinery integration partners. An initial screening of one mild hydrotreated sample will be presented as an example of the application of this analytical technique to bio-oil upgrading for refinery insertion.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- A comprehensive and valuable study to understand qualities and compositions versus feed and operating conditions for bio-oils generation.
- Characterization of hydrothermal liquefaction bio-oil samples is a worthy exercise that should add to the knowledge base. On the other hand, this project is tainted somewhat by the use of old, potentially degraded samples that are representative of limited operating conditions and feedstocks.
- This project shares the strengths and weaknesses of most of the lab projects—sound scientific work, utilizing new techniques and investigating the fundamentals in far greater depth than is likely in the commercial world, but little or no link to the commercial world, so limited chance for impact and virtually no chance for feedback.
- The project provides useful information about hydrothermal liquefaction systems that can convert wet biomass such as algae. The project serves the same useful purpose of developing basic and applied information, as do the various catalytic studies for the pyrolytic processing pathways.
- A well-organized analytical project; difficult materials to analyze.

PI Response to Reviewer Comments

- We appreciate the insights provided in the reviewer comments. The PNNL research team has found hydrothermal liquefaction bio-oils to be significantly more stable for long-term storage than corresponding pyrolysis bio-oils. The NABC team sub-sampled and archived bio-oil samples for cold storage and in the dark of all feed shipped off to UOP for upgrading. Both the hydrothermal liquefaction bio-oil feed and hydrotreated product are available for examination. Preliminary characterization data of upgraded bio-oil samples has been shared with the NABC refinery integration team, and the ability to characterize low levels of nitrogen compounds was viewed as valuable for resolving issues associated with refinery integration of biomass-derived oils.
- The link to the commercial world is important to the project team and we are working with industry to move hydrothermal liquefaction toward commercialization in projects that have grown from this relatively small, core-funded effort. Bringing in industrial oversight for this and other work is something that we will further explore to ensure the relevance of the research and the application to industry.

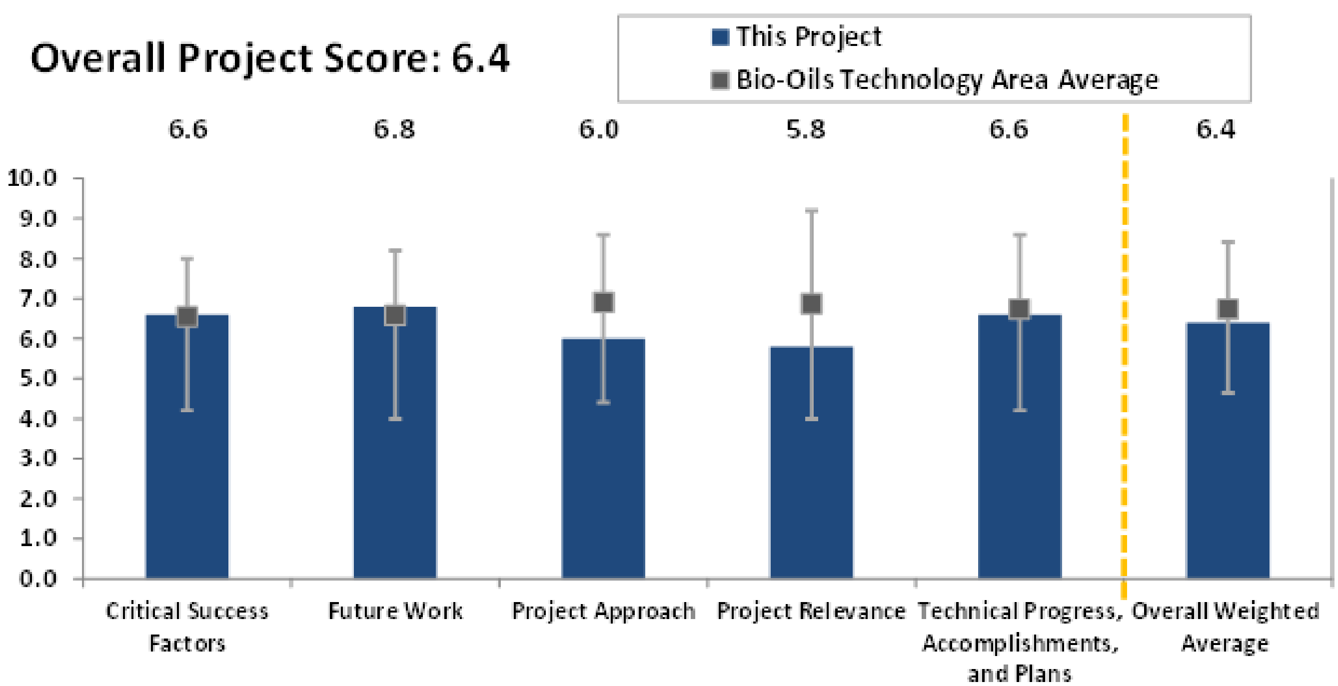
OPTIMIZED CO-PROCESSING OF ALGAL BIO-CRUDE THROUGH A PETROLEUM REFINERY

(WBS#: 3.3.1.20)

Recipient:	Sapphire Energy
Presenter:	Benjamin Saydah
Total DOE Funding:	$500,920
DOE Funding FY13:	$456,356
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013-2014

Project Description

Sapphire's strategy is to produce a drop-in, refinery-intermediate stream from open-pond algae cultivation. This drop-in replacement strategy provides a quicker and lower-capital path to market, as it takes advantage of the billions of dollars of capital already deployed in the existing petroleum-refining industry. However, without data to support this route to market, refiners are unlikely to purchase algal bio-crude because of the unknowns associated with new feedstocks, like lower yield and damage to refinery equipment from contaminants, such as nitrogen and metals. Sapphire has completed proof-of-concept studies to demonstrate the viability of this strategy. The testing and analysis will provide detailed yield, quality, and economic metrics for upgrading Sapphire-produced bio-crude at various stages and insertion points of a petroleum-refinery process stream, and will be used to identify the optimal insertion point for Sapphire's bio-crude in a petroleum refinery. These potential insertion points in a refinery include the distillate hydrotreating, cat-feed hydrotreating, followed by FCC, coking, and hydrocracking process units. The metrics produced from these various studies will further demonstrate commercial viability as a drop-in refinery feedstock by providing a basis for assigning an economic value to Sapphire bio-crude, determining relative energy content for calculating RIN values, and updating a Sapphire bio-crude LCA, as well as providing sufficient finished fuel product for initial ASTM product-specification testing. The final objective of this project is to have all of the standard industry data necessary to assign an economic value to Sapphire bio-crude and ultimately negotiate and enter into a contractual arrangement with a refinery partner.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Algae are economically challenged as feedstocks at this point, and it is a concern when the intermediate they produce is an oil that may be suitable only for FCC of coking feed. A clean triacylglycerides oil at least could undergo mild hydrotreating and isomerization with a very high yield of diesel and/or jet fuel. Also, the distribution of bio-based fuels into end products could be more closely controlled than when the FCC or coker are used, easing the path to regulatory acceptance in the marketplace. In some ways, this project seems to combine the economic challenges of algal oil with the processing challenges of pyrolysis oil—either set of challenges on its own is formidable, but both at the same time would seem fatal.
- Decent project. Do they have enough time to accomplish what they want? How will they get this into the market?
- Refinery integration of raw hydrothermal liquefaction bio-oil is a very difficult challenge with a low probability of success. Some additional upgrading beyond the hydrothermal liquefaction process will most likely be required. The PI is well aware of the challenges. He is also an experienced refiner, and is in a good position to make this work. The data produced by this work may be somewhat limited due to the fact that it is really only applicable to hydrothermal liquefaction bio-oil produced in a proprietary process. Despite these limitations and challenges, I believe this to be a worthwhile project.
- There seems to be a gap between what's being done in the lab and what a refiner would need to understand with regard to risks and economics. This is far from commercialization.
- This is an interesting algae project, but the PI did not present a compelling case that the raw bio-oil, with high oxygen, nitrogen, and possibly phosphorous content, would actually be accepted and processed by a refinery. A more robust connection with the petroleum industry is needed.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

DEVELOPMENT OF BIO-OIL COMMODITY FUEL AS A REFINERY FEEDSTOCK FROM HIGH-IMPACT ALGAL BIOMASS

(WBS#: 3.3.1.22)

Recipient:	University of Georgia Research Foundation
Presenter:	James Kastner
Total DOE Funding:	$698,000
DOE Funding FY13:	$698,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013-2014

Project Description

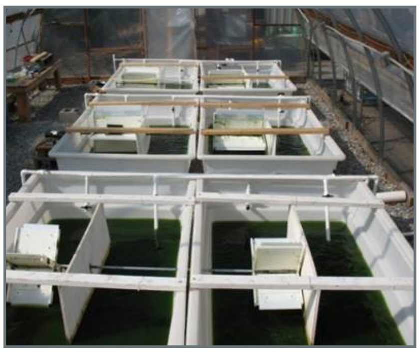
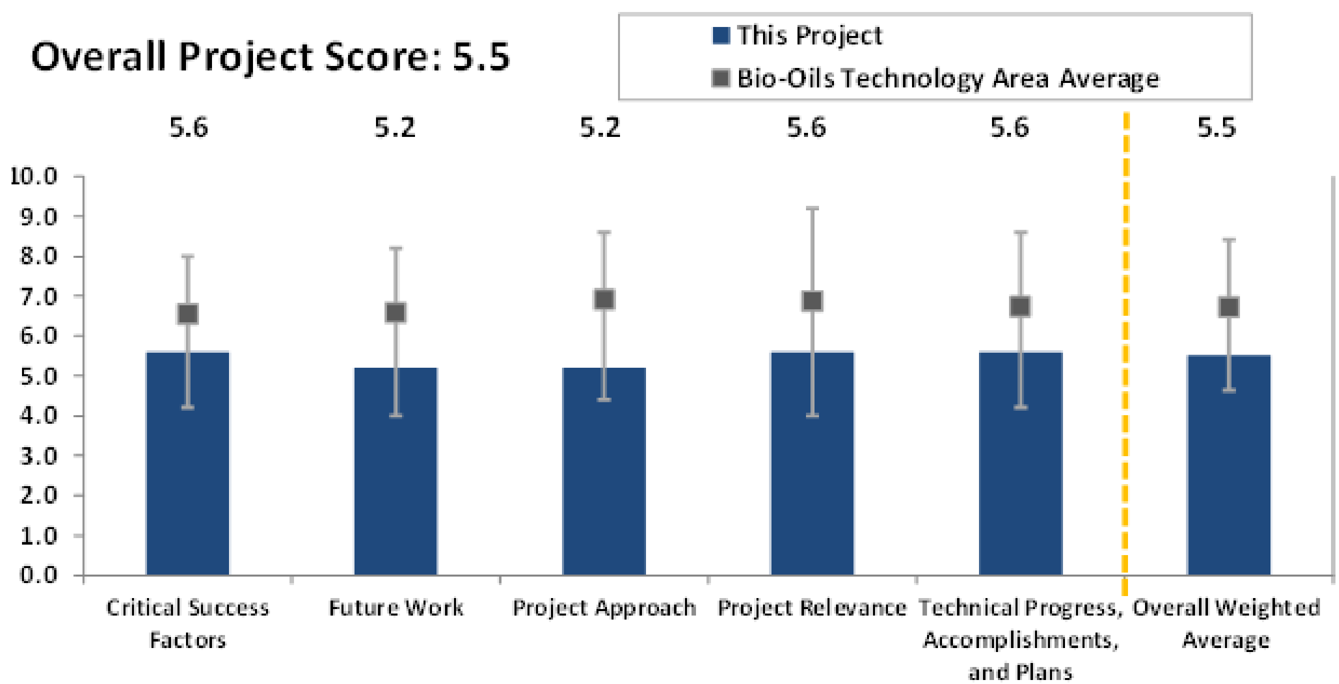


Photo Courtesy of University of Georgia

The objective of this project is to produce a refinery-grade bio-oil feedstock from algal biomass. A two-stage, catalytic thermochemical liquefaction process will be developed to convert algae to a refinery intermediate. Mixed algal consortia (*Chlorella sorokiniana, Chlorella minutissima, and Scenedesmus bijuga*) will be grown in algal flo-way systems developed at the University of Georgia Microalgae Laboratory, and used as the feedstock for fuel synthesis (preliminary work utilizes *Spirulina*, until microreactors are ready). Thermochemical liquefaction will be performed in a two-stage, batch process to produce a thermochemical-liquefaction oil, which will be upgraded to a refined product by catalytic HDO to reduce the oxygen and nitrogen content and increase levels of gasoline- and diesel-range hydrocarbons. Product properties and a mass and energy balance on the thermochemical liquefaction and HDO process will be evaluated. The upgraded bio-oil product will be analyzed by a commercial microcrude assay for its suitability as an intermediate feed for gasoline/diesel production at an insertion point (hydrotreating or catalytic cracking) in a petroleum refinery process, and will be compared with the petroleum naphtha and gas oil. Catalytic cracking of the upgraded bio-oil and commercially available gas oil



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

will be performed in a batch-type reactor simulating the petro-refinery process to evaluate the product as a potential refinery feedstock. Unit operation integration and cost modeling will be performed using process simulation software. LCA of the integrated process (for producing algae-based, refinery-graded bio-oil product) will be evaluated using the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model. Finally, talks will be initiated with a refinery company to evaluate the upgraded algal bio-oil as a feedstock at suitable insertion points in the refinery process.

Overall Impressions

- An interesting one-year project to see if the sequential processing steps can remove nitrogen from the algal bio-oil.
- Another project that probably will not provide nearly enough information to address refinery-insertion risk analyses. The gap between what's generated in a research lab and even a small commercial trial can be huge.
- Not sure about this one. Schedule seems tight.
- Overall, this project does not appear to be well focused and seems to lack a solid direction. This is due largely to the lack of refining experience on the project team and lack of input from a refining partner.
- The two-stage thermochemical liquefaction is an interesting concept, but there has been little useful work done to date, and the clock is ticking on a relatively short project.

PI Response to Reviewer Comments

- This project focuses on a critical barrier in algae-to-liquid fuel processing—nitrogen reduction in algal oil generated via hydrothermal liquefaction to improve catalytic HDO and denitrogenation of the oil. LCA and literature analysis indicates that to achieve sustainable, economical algal oil production (i.e., limited water, nitrogen, and phosphorous inputs, and high productivity), open raceways systems using locally adapted algae strains will be required. These conditions will generate algae high in protein, yet there has been little to no work developing methods to economically reduce protein or nitrogen levels. The typically high nitrogen levels in algal bio-oil generated via hydrothermal liquefaction (5–10%) limits catalytic decarboxylation, HDO, and denitrogenation of the oil, since many of the nitrogenated compounds act as catalyst poisons, increase hydrogen demand in HDO, and generate nitric oxide upon fuel combustion.
- As noted by one of the reviewers, "Progress is good, particularly considering the recent start. Algae have been grown, initial thermochemical tests underway, some TEA. Results show some nitrogen removal, which is good at this early stage."
- As noted in the FOA, Topic Area One applicants are not required to have a petroleum refinery partner at the time of application, but must describe their plans to overcome R&D barriers for making bio-oil feedstock acceptable in a petroleum refinery and engage with the intent to secure a refinery partner by the end of the project.

BIO-OIL SEPARATION AND STABILIZATION BY SUPERCRITICAL FLUID FRACTION

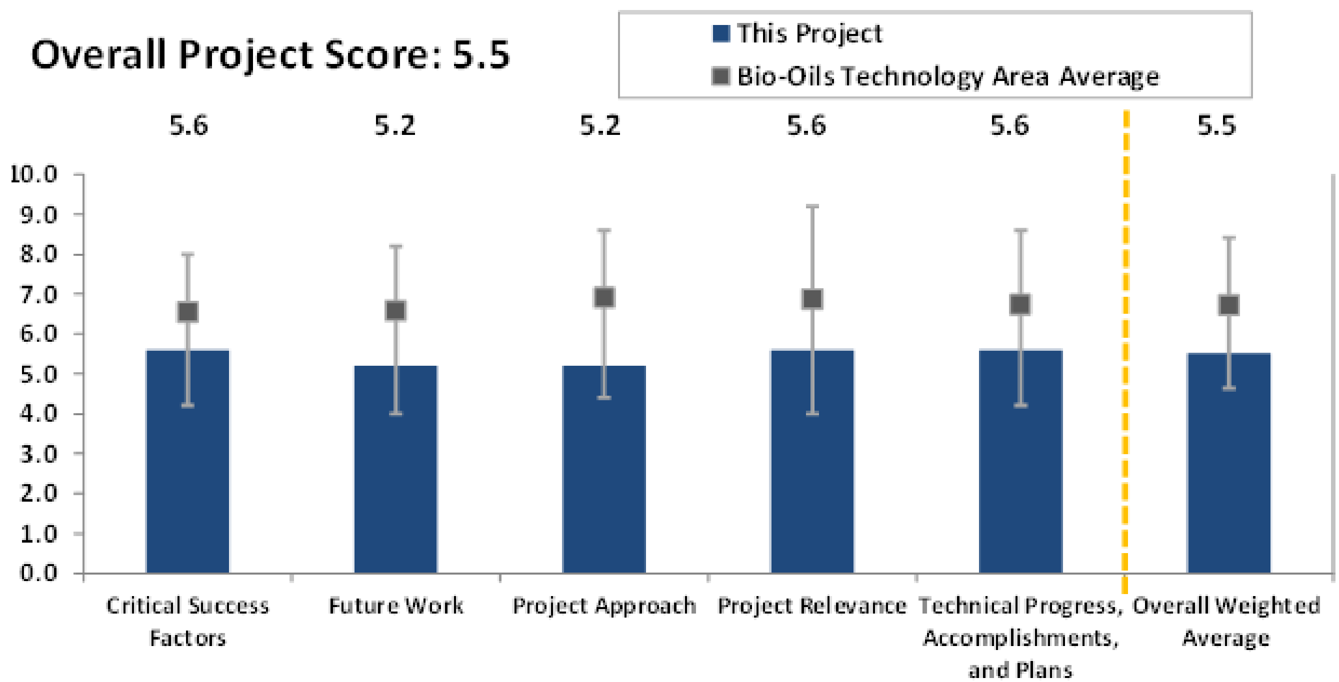
(WBS#: 3.3.1.22)

Recipient:	INL
Presenter:	Daniel Ginosar
Total DOE Funding:	$750,000
DOE Funding FY13:	$750,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012-2013

Project Description

Photo Courtesy of INL

Bio-oils produced by thermal processes—such as fast pyrolysis, catalytic pyrolysis, or hydrothermolysis—are a promising source of sustainable, low greenhouse-gas-emitting, alternative fuels. These thermal treatment processes are also well suited to decentralized energy production due to low capital and operating costs. However, pyrolysis bio-oils from algae have complex chemical compositions, including large concentrations of water, carboxylic acids, carbohydrates, and protein-derived substances. The oils are acidic, viscous, reactive, and thermally unstable. Due to the occurrence of decomposition products together with water and an abundance of compounds of many classes, range of polarities, and the large fraction of oxygenated compounds, the mixture is difficult to fractionate by distillation, chromatography, or membrane-based processes. Several methods have been explored to separate bio-oils into stable fractions. By far, the most effective separation and stabilization method has been solvent extraction. Although effective, solvent extraction poses two main obstacles to commercialization: the significant amounts of energy required to remove the solvent from the product, and the propensity of the solvent to be contaminated with minerals from the char or ash. Separation of thermally produced bio-oils using supercritical fluids offers the advantages of liquid solvent extraction while drastically reducing energy de-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

mands and the predisposition to carry over solids into the extracted phase. *Scenedesmus dimorphus* was pyrolized at 350°C, 400°C, and 450°C with and without a catalyst. Supercritical carbon dioxide and propane were evaluated for the extraction and fractionation of algal pyrolysis oils into stable fractions. Extractions were carried out at 25°C, 40°C, 65°C, and 110°C at a reduced pressure of 2.0. The effect of extraction conditions on product composition and stability will be discussed.

Overall Impressions

- Separations in pyrolysis are an important topic, and supercritical fluid fractionation could potentially have some benefits. However, the project as presented does not focus on developing an understanding of what needs to be removed from the oil to stabilize it, or how those extractions will impact the refinery performance of the product (for example, a solid extract). As presented, the project is unlikely to have a meaningful TEA by the end of the one year of work, which is crucial to estimating whether the economics could be reasonable. Supercritical fluid fractionation is typically used for higher-value products rather than low-value fuels, so there is a major question about the economics that must be at least tentatively answered. It is not sufficient just to apply a tool to a problem—a much sharper focus is needed.
- Separations technologies in general are likely to be key to producing decent-quality bio-oils economically. This appears to be good value-added research.
- This project has potential, but it would have been improved without the complication of multiple thermochemical conversion pathways, and if an experienced supercritical fluid technology provider were onboard.
- It is unclear how the project got to this point; failure of merit review process perhaps. The project should be terminated with funds redirected to more promising work.

PI Response to Reviewer Comments

- One reviewer had a strong opinion against the economic viability of supercritical fluid processes for energy applications. Although we appreciate the reviewer's opinion, we would also like to point out that supercritical fluid processes are being used commercially and economically in the processing of low-value energy feedstocks. Examples are the residuum oil supercritical extraction process and the propane deasphalting process. These processes have been used in the petroleum refining industry for more than 50 years, and were developed at a time when crude oil prices were a fraction of what they are today.
- Additionally, our team member, CF Technologies, Inc., has developed small-scale supercritical fluid processes that are economical with low-value products. Processes they developed provide examples of two different types of critical fluid processes being economical with low-value products. These plants are both owned and operated by for-profit corporations; both process industrial wastes and produce products with very low value. They have both operated without interruption for many years, demonstrating the potential of critical fluid processes to operate economically with low-value products.
- The first example is an industrial wastewater plant processing water contaminated with organic chemicals in a continuous, countercurrent, carbon dioxide extraction, nominally processing 20 gallons of wastewater per minute; this plant has been operating continuously for more than 20 years.
- The second example uses hydrocarbon critical fluid solvents to recycle industrial oil adsorbents—granular clay type and polypropylene pad type—and similar waste products such as oil filters. They developed this semi-batch process in the mid-90s; the first plant was built in 1998 and continues to operate. The major operating expense is labor for material handling of the solids before and after processing; yet because the process has such low processing costs, this plant continues to operate profitably after 15 years of operation.

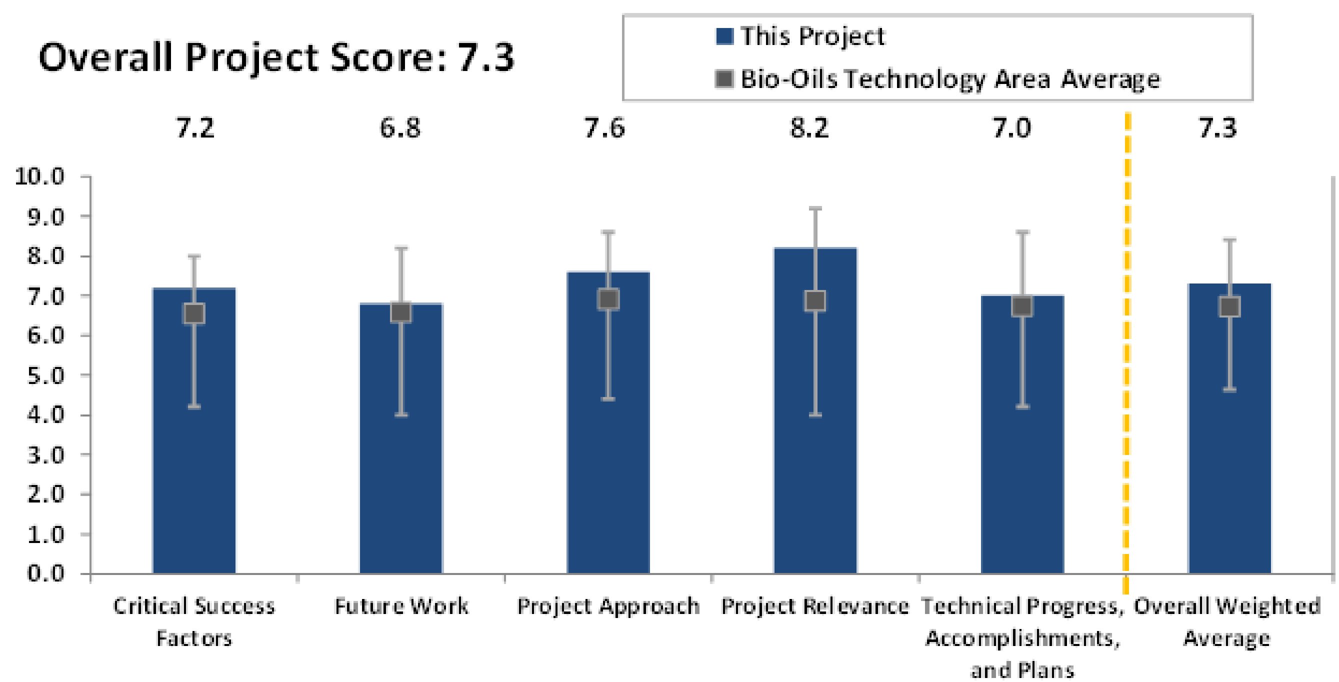
LIQUEFACTION OF AGRICULTURAL AND FOREST BIOMASS TO DROP-IN HYDROCARBON BIOFUELS

(WBS#: 3.3.1.23)

Recipient:	Iowa State University
Presenter:	Robert Brown
Total DOE Funding:	$4,375,000
DOE Funding FY13:	$1,600,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013-2015

Project Description

The overall goal of this project is to demonstrate the viability of solvent liquefaction as a pathway to stable intermediates that can be upgraded to fuel blendstocks. Specific objectives include improvements to separation of product liquid from solvent; continuous recycling of solvent to the reactor; continuous solids (char) removal from the liquid stream; and identification of hydroprocessing conditions appropriate to upgrading the bio-oil. The approach consists of proof-of-concept testing using a small (one kg/hour) pilot solvent liquefaction unit and a continuous product separation and solvent recycling system. Catalysts and operating conditions for hydroprocessing solvent liquefaction bio-oil will be determined using bench-scale, fixed bed microreactors. Targets to be met before advancing to next tasks include: eight hours of continuous solvent liquefaction operation; production of bio-oil with oxygen content less than 25%; and five-day hydroprocessing operation with production of bio-crude with oxygen content less than 2%. Progress to date includes: the solvent liquefaction unit has been disassembled and packaged for shipment to Iowa State University; all new major components have been identified and specification has commenced; and process and instrumentation diagrams have been updated to incorporate continuous liquid and solid separation and solvent recycle. The project is relevant to DOE's goal of producing bio-oil with desirable qualities for making hydrocarbon transportation fuels in the gasoline, diesel, and jet range at less than $3/gallon. Critical success factors include: production of thermally stable, low-oxygen-content bio-oil; demonstration of continuous operation of key unit processes—liquid fractionation, solids separation, and solvent recycle;



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

and cost-effective catalysts and process configurations and conditions for hydroprocessing of bio-oil to refinery-compatible biocrude.

Overall Impressions:

- A work in progress. Hard to evaluate given the current status of the effort.
- Designed for low-moisture project.
- Overall, the technical process aspects of this project seem worthwhile and potentially successful. It is not clear why a forest sustainability element is included, or how much of the $4 million budget is allocated to this sustainability effort. This is really two projects in one, and they are not tightly coupled or related. No information was provided about this sustainability effort (i.e., who's doing it, how extensive will it be, how much of the budget does it consume, etc.). Including unnecessary items like this in an otherwise process-engineering project can cause it to lose focus. It can also cast doubts on the overall project and the associated funding process.
- Solid technology; nice to have a commissioned pilot rig donated by Catchlight. It is unclear whether there is any actual commitment from Chevron or Weyerhaeuser to move this forward, however, so moving toward commercialization may be problematic.
- This is an interesting project with an exceptional group of partners. The work has just started, but it should provide very useful results.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

CATALYTIC UPGRADING OF THERMOCHEMICAL INTERMEDIATES TO HYDROCARBONS: CONVERSION OF LIGNOCELLULOSIC FEEDSTOCKS TO AROMATIC FUELS AND HIGH-VALUE CHEMICALS

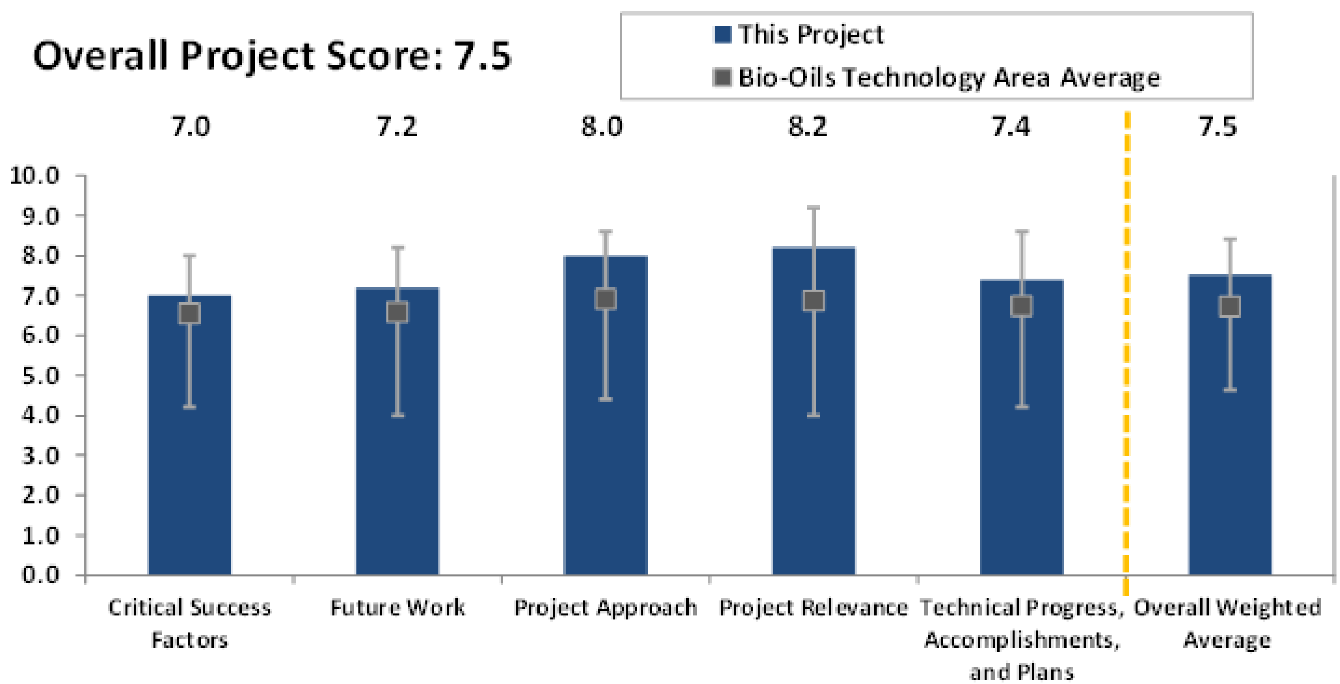
(WBS#: 3.3.1.10)

Recipient:	Virent Energy Systems, Inc.
Presenter:	Randy Cortright
Total DOE Funding:	$4,000,000
DOE Funding FY13:	$827,000
DOE Funding FY12:	$1,250,000
DOE Funding FY11:	$1,920,000
Project Dates:	2011-2014

Project Description

Photo Courtesy of Virent Energy Systems, Inc.

The goal of the project is to couple Virent's biomass liquefaction process (Solvolysis) with the BioForming® process to convert bagasse, corn stover, and loblolly pine into aromatic-rich fuels and chemicals. The unique ability to effectively solubilize not only the hemicelluloses and cellulose, but also the lignin components of biomass into convertible intermediates, sets this process apart from other approaches. Solvolysis involves solvent-assisted liquefaction of biomass coupled with stabilization of the reactive species through the use of an HDO catalyst. After stabilization, the intermediates can be fed into a condensation reactor producing a stream of aromatic-rich hydrocarbons for use as fuels and high-value chemicals. Since inception in the fourth quarter of 2011, several project milestones have been reached, including biomass liquefaction in excess of 95% and soluble oxygenates yields exceeding 80%, both of which illustrate an improvement over traditional biochemical and thermochemical deconstruction methods. Additionally, process optimization efforts are improving Virent's understanding of the impact of reaction variables (such as temperature and reaction time) on solvolysis process performance. Future work under



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

this project will focus on improving stabilization catalyst stability through catalyst development and biomass pre-treatment, optimization of the condensation process for solvolysis intermediates, and construction of a continuous deconstruction unit to improve system operability and allow for integration with the condensation process.

Overall Impressions

- Decent project, but limited information.
- Solid project with real innovation and excellent progress to date, plus a good team of collaborators.
- Some very useful and interesting results; however, major hurdles appear to exist between feedstocks, severe catalyst poisoning, ash, and carbon retention.
- The project goals are noteworthy. However, the progress seems slow and even behind schedule, and the obstacles to successful completion of this project are formidable.
- The project is proceeding well.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

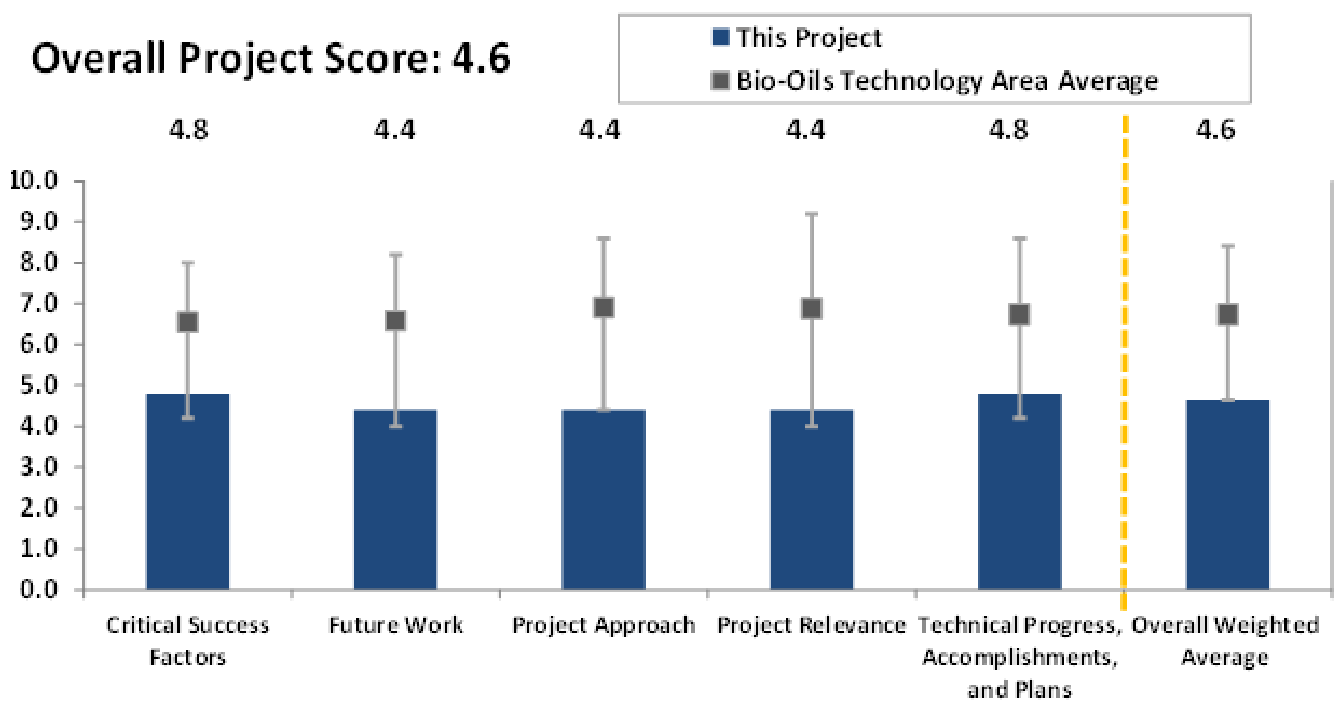
MILD BIOMASS LIQUEFACTION PROCESS FOR ECONOMIC PRODUCTION OF STABILIZED REFINERY-READY BIO-OILS

(WBS#: 3.3.1.17)

Recipient:	Southern Research Institute
Presenter:	Santosh Gangwal
Total DOE Funding:	$654,330
DOE Funding FY13:	$654,330
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2013-2014

Project Description

The goal of this project is to commercialize a cost-effective, low-severity thermal liquefaction process to convert woody biomass to stabilized bio-oils that can be directly blended with petroleum refinery streams for production of gasoline- and diesel-range hydrocarbons. The specific objectives of this 12-month project are to demonstrate the process at laboratory scale and develop a plan in partnership with a refinery to move the technology toward commercialization. The project addresses BETO's objectives to accelerate the production of transportation fuels from high-impact biomass feedstock, and to support industry's capacity and need to meet the EISA volume requirements. Several laboratory-scale tests of the process have been conducted over a range of statistically designed test conditions. The results of these tests show that there is a significant impact of reaction conditions on biomass conversion and bio-oil yield. At optimum reaction and separation conditions, 98% of the biomass was converted; 60% of the biomass was converted to stabilized bio-oil, with the remaining 38% converted to by-products. Bio-oil samples in sufficient quantities will be produced and sent to the refinery partner for characterization, and for evaluating the potential of direct blending of the bio-oils with their hydrotreater/cracker input streams. A preliminary TEA and LCA of the process will be carried out.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Claims appear to be unsupported. Goals appear to be unrealistic and general.
- Not even close to enough information presented to allow anyone to form a valid overall impression, but what was presented looked extremely weak.
- This reviewer is unsure that the panel understands conversions correctly. The PI needs to aggressively pursue refiner to work with the project. The timeframe is short, and work has not started on continuous reactor yet. This reviewer is concerned with the short timeframe to get all of the work completed.
- Overall, this project has worthy and practical goals, and it may have already made some significant progress, although this apparent progress is somewhat incredible and needs to be validated. If the prior results are confirmed, this project could advance the state of technology. The project timeframe is short at only 12 months, and progress appears to be somewhat behind schedule.
- The presenter provided so little information about the concept that a reasonable evaluation is very difficult. Even simple factors such as approximate temperature ranges were omitted on the basis of being key intellectual property, and meaningful explanations about why the system was a potential improvement over existing ones was absent. Other presenters did a good job of both protecting intellectual property and providing relevant information, but in this case, the presenter claimed most parameters as being proprietary without providing even rough ranges or any other justification for the work. Based on the information provided to reviewers, the probability of success in this project seems minimal.

PI Response to Reviewer Comments:

- The reaction conditions are a part of the process integration and related to potential intellectual property; that is why so little information was presented on the conditions. We presented the reasons why processes in the past were not commercialized. By paying attention to both the process and the product, we hope to do so. It is difficult to disclose conditions since the process integration involves them and could be part of the intellectual property. This was the advice of our intellectual property department and our management who have invested significantly in this project. We respectfully disagree that based on the information provided, the probability of success seems minimal. It is not clear why the reviewers state this. However, we do agree that based on the information provided, it may not be possible to determine the probability of success.
- The results we obtained were excellent. We defined conversion as conversion of the moisture- and ash-free solid to gas or liquid. We achieved up to 98% conversion rate. Of this, conversion to oil was up to 60%. We completely agree that we need to aggressively pursue refinery partnership. The project is for proof of concept at lab scale and we agree that the timeframe is short. It was in its fourth month when the presentation was prepared. We agree the schedule may slip by a couple of months. We agree that the batch reactor results need to be validated in continuous reactor.

FEEDSTOCK SUPPLY AND LOGISTICS

TECHNOLOGY AREA

INTRODUCTION

The Feedstock Supply and Logistics Technology Area is one of nine key technology areas that were reviewed during the 2013 Bioenergy Technologies Office (BETO or the Office) Project Peer Review, which took place on May 20–23, 2013, at the Hilton Mark Center in Alexandria, Virginia. A total of 28 projects were reviewed by six external experts from industry, academia, and other government agencies. This review addressed a total U.S. Department of Energy (DOE) investment of approximately $138 million, which represents approximately 9% of the BETO portfolio reviewed during the 2013 Peer Review. The principal investigator (PI) for each project was given approximately 20–40 minutes (depending primarily on the funding level and relative importance to achieving BETO goals) to deliver a presentation and respond to questions from the review panel. Projects were evaluated and scored for their project approach, technical progress over two federal fiscal years (2011–2012), relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Project Peer Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI. Overview information on the Feedstock Supply and Logistics Technology Area, full scoring results and analysis, the Review Panel Summary Report, and the BETO Programmatic Response are also included in this section. BETO designated Steve Thomas as the Feedstock Supply and Logistics Technology Area review lead. In this capacity, Dr. Thomas was responsible for all aspects of review planning and implementation.

FEEDSTOCK TECHNOLOGY AREA

OVERVIEW

As the starting material for biomass-to-biofuels, bioproducts, and biopower value chains, a sufficient and secure supply of affordable, high-quality feedstocks is a critical necessity in order to accomplish Office goals and enable a biomass conversion industry. Feedstock Supply and Logistics research and development (R&D) relates directly to, and strongly influences, all of the downstream elements of the Office's portfolio and their respective goals and objectives.

The scope of the Feedstock Supply and Logistics Technology Area includes terrestrial, lignocellulosic feedstocks (i.e. agricultural residues, forest resources, and dedicated energy crops) and excludes algae, which was reviewed separately. Feedstock Supply and Logistics encompasses sustainable feedstock production, resource assessment, and feedstock logistics. These activities are directed at reducing the delivered cost of feedstock, improving and preserving the quality of harvested feedstock, improving environmental performance of feedstock production, and expanding the volume of feedstock materials accessible to the bioenergy industry.

Sustainable production R&D activities are focused on getting affordable, abundant, and high-quality biomass materials into the feedstock supply chain. There are three primary activities associated with sustainable production: resource assessment, feedstock production, and feedstock characterization.

Feedstock logistics refers to the supply chain operations that occur between feedstock production sites and the biomass conversion reactor inlet. Activities in this area are primarily focused on how to most

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

efficiently, inexpensively, and sustainably harvest and deliver high-quality biomass from a variety of crops to biorefinery end users. These operations include feedstock harvest and collection, storage, handling, preprocessing, and transport to the biorefinery.

Biomass may be transported between field or forest and conversion facility by truck, train, or barge using existing transportation infrastructure. By optimizing container volumes and dimensions designed for moving biomass feedstocks to simultaneously reach both weight and volume limits would increase efficiencies in the feedstock supply chain and therefore decrease delivered feedstock cost. Existing transportation infrastructure demonstrates these efficiencies for many commodities. Preprocessing raw biomass to feedstocks with infrastructure-compatible material characteristics can leverage key components of the existing infrastructure.

FEEDSTOCK SUPPORT OF OFFICE STRATEGIC GOALS

Feedstock Supply and Logistics projects are part of BETO's mechanism to demonstrate and validate its overall technology goal: to develop and deploy sustainable, commercially viable biomass conversion technologies that produce biofuels. These biofuels will support meeting the Energy Independence and Security Act Renewable Fuel Standard (RFS) targets. This goal is best accomplished through public-private partnerships.

The Feedstock Supply and Logistics Technology Area's strategic goal is to:

> *Develop sustainable technologies to provide a secure, reliable, and affordable biomass feedstock supply for the U.S. bioenergy industry, in partnership with the U.S. Department of Agriculture (USDA) and other key stakeholders.*

FEEDSTOCK SUPPORT OF OFFICE PERFORMANCE GOALS

The Feedstock Supply and Logistics Technology Area currently has two performance goals.

- The feedstock resource assessment goal is to establish geographic, economic, quality, and environmental criteria under which the availability of 155 million dry tons (DT) per year would be feasible by 2017.
- The feedstock logistics goal is to develop and demonstrate feedstock supply and logistics systems that can deliver feedstock to the conversion reactor throat at required conversion in-feed specifications at or below $80/DT (2011 dollars) by 2017. Cost-saving and process-improving technologies will be developed within each stage of the feedstock supply chain in order to achieve this goal.

The specific **resource assessment milestones** under investigation are:

- By 2013, identify environmental criteria (soil health and air quality) and establish a methodology for their incorporation into biomass supply assessments for agricultural residues, energy crops, and forest resources pathways.
- By 2014, integrate environmental and feedstock quality criteria into biomass supply assessments for agricultural residues, energy crops, and forest resources pathways.
- By 2016, produce a fully integrated assessment of potentially available feedstock supplies under specified criteria and conditions.

The specific **feedstock logistics milestones** under investigation are:

- By 2013, deliver feedstock supply and logistics design cases achieving the 2017 goal of delivering feedstock to the conversion reactor throat at required specifications at or below $80/DT (2011 dollars).
- By 2015, evaluate advanced herbaceous and woody biomass preprocessing systems against conversion performance criteria.
- By 2017, validate a fully integrated advanced feedstock logistics system that accepts a broad range of herbaceous and woody biomass resources at field scale.

APPROACH FOR OVERCOMING CHALLENGES

The R&D approach for overcoming feedstock supply challenges and barriers is organized around five key activities: assessing current and potential sustainable biomass feedstock supplies in all U.S. counties and their corresponding costs; establishing a baseline for lignocellulosic feedstock productivity and environmental sustainability across all regions of the United States; improving the capacity and efficiency of feedstock harvesting, handling, collection, preprocessing, storage, and transportation; conserving harvested biomass during handling and storage operations; and controlling stability and maintaining feedstock quality throughout the logistics system operations with conversion input specifications clearly in mind.

For more information on the Feedstock Supply and Logistics Technology Area, please review BETO's Multi-Year Program Plan (MYPP) at bioenergy.energy.gov/pdfs/mypp_may_2013.pdf.

REVIEW PANEL

The following external experts served as reviewers for the Feedstock Supply and Logistics Technology Area during the 2013 Project Peer Review:

Feedstock Supply and Logistics Reviewers	
Lyle Stephens (Lead Reviewer)	Deere & Company, retired
Marilyn Buford	U.S. Forest Service
Jami Nettles	Weyerhaeuser Company
Tom Richard	Pennsylvania State University
Steve Searcy	Texas A&M University
Michael Tumbleson	University of Illinois, Emeritus

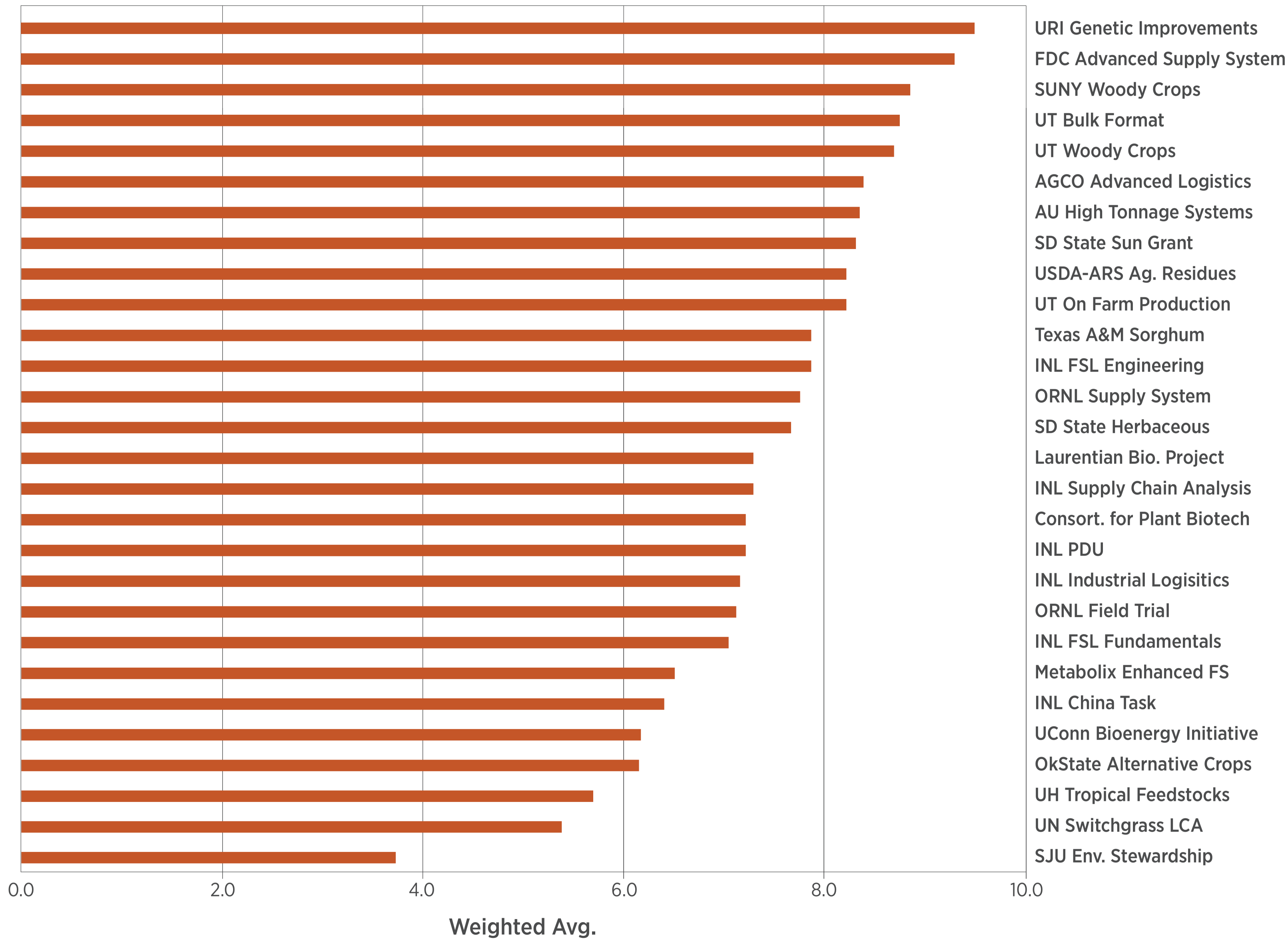
FORMAT OF THE REPORT

Information in this report has been compiled as follows:

- **Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.
- **Project Scoring Information and Short Names Key**: The final score charts depict the overall weighted score for each project in each technology area. Short names for each project were developed for ease of use in the scoring charts, the table of contents, and other locations. Full project names, along with their designated short names and their work breakdown structure (WBS#), are provided in the Short Names Key.
- **Review Panel Summary Report**: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.
- **BETO Programmatic Response**: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.
- **Project Reports**:
  - **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space constraints allotted.
  - **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
  - **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and the whiskers depict the range of scores for each category within each technology area.
  - **Reviewer comments** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant by BETO's director were excluded from the final report.
  - **PI Responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the

TECHNOLOGY AREA SCORE RESULTS



SHORT NAMES KEY

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
7.1.2.5	Research and Technology Development for Genetic Improvement of Switchgrass	University of Rhode Island	URI Genetic Improvements
1.2.1.6z; 1.2.1.7	Design and Demonstration of an Advanced Agricultural Feedstock Supply System for Lignocellulosic Bioenergy Production	FDC Enterprises Inc.	FDC Advanced Supply System
1.2.1.2	Development and Deployment of a Short Rotation Woody Crops Harvesting System Based on a Case New Holland Forage Harvester and SRC Woody Crop Header	State University of New York College of Environmental Science	SUNY Woody Crops
1.2.1.5z; 1.2.1.9	Development of a Bulk-Format System to Harvest, Handle, Store, and Deliver High-Tonnage Low-Moisture Switchgrass Feedstock	University of Tennessee	UT Bulk Format
1.1.1.1d	Regional Feedstock Partnership: Woody Energy Crops	University of Tennessee	UT Woody Crops
1.2.1.4z; 1.2.1.8	Integration of Advanced Logistical Systems and Focused Bioenergy Harvesting Technologies to Supply Crop Residues and Energy Crops in a Densified Large Square Bale Format	AGCO	AGCO Advanced Logistics
1.2.1.3	High Tonnage Forest Biomass Production Systems from Southern Pine Energy Plantations	Auburn University	AU High Tonnage Systems
7.6.2.6	South Dakota State University, Sun Grant Initiative, Regional Biomass Feedstock Development Partnership	South Dakota State	SD State Sun Grant
1.1.1.1az	Regional Feedstock Partnership: Agricultural Residues, Stover Removal Tool	USDA ARS	USDA-ARS Ag. Residues
1.3.1.5	Demonstration of On-Farm Production of a Dedicated Energy Crop incorporating Multiple Varieties of Switchgrass Seed (Switchgrass Production)	University of Tennessee	UT On Farm Production
1.1.1.1b	Regional Feedstock Partnership: Sorghum	Texas A&M U	Texas A&M Sorghum
1.3.1.4	Feedstock Logistics Engineering	Idaho National Laboratory (INL)	INL FSL Engineering
1.6.1.1	Supply System Logistics Task	Oak Ridge National Laboratory (ORNL)	ORNL Supply System
1.1.1.1c	Regional Feedstock Partnership: Herbaceous Energy Crops	South Dakota State University	SD State Herbaceous
7.1.5.4	Laurentian Bio-Energy Project (MN)	Laurentian Energy Authority	Laurentian Bio. Project
1.6.1.2	Feedstock Supply Chain Analysis	INL	INL Supply Chain Analysis
7.6.2.1	Energy from Biomass Research and Technology Transfer Program	Consortium for Plant Biotechnology Research	Consort. for Plant Biotech
1.3.1.2	Deployable PDU (Deployable Process Demonstration Unit)	INL	INL PDU
1.6.1.9	Industrial Logistics (Supply System Integration)	INL	INL Industrial Logistics
1.1.1.3	Regional Feedstock Partnership: ORNL Field Trial Data Management and Analysis	ORNL	ORNL Field Trial

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
1.3.1.3	Feedstock Logistics Fundamentals	INL	INL FSL Fundamentals
1.2.3.1	Renewable Enhanced Feedstocks for Advanced Biofuels and Bioproducts (REFABB)- Development Program	Metabolix	Metabolix Enhanced FS
6.5.2.5	China Task (In 2011, China - Biomass supply logistics)	INL	INL China Task
7.6.2.12	Bio Energy Initiative for Connecticut	University of Connecticut	UConn Bioenergy Initiative
7.1.5.11	Alternative Crops and Biofuels Production	Oklahoma State University	OkState Alternative Crops
7.1.2.6	University of Hawaii, College of Tropical Agriculture and Human Resources, Development of High Yield Tropical Feedstock	University of Hawaii	UH Tropical Feedstocks
7.1.2.9	Switchgrass Biofuel Research: Carbon Sequestration and Life Cycle Analysis	University of Nebraska-Lincoln	UN Switchgrass LCA
7.1.2.10	Saint Joseph's University Institute for Environmental Stewardship	Saint Joseph's University	SJU Env. Stewardship

REVIEW PANEL SUMMARY REPORT

INTRODUCTION

Peer Review presenters, BETO personnel, other DOE researchers, and the interested public constitute a community of interest who share a common goal: sustainably delivering a reliable supply of biomass feedstocks to a network of biorefineries. Each member of this community who participated in the Peer Review seemed to take pride in making a contribution toward that goal, without seeking to minimize the contributions of others.

Based on the Peer Review presentations, as well as the discussions that followed each, the review team offers the following observations and recommendations.

IMPACTS

1 What are the key strengths and weaknesses of the projects in this technology area? Do any of the projects stand out on either end of the spectrum?

2 Is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry in this technology area? Is the government's focus appropriate in light of private-sector investments? Are there any projects that stand out as meeting (or not meeting) this criterion?

The Feedstock Production and Logistics Technology Area made substantial progress in obtaining valid data concerning the production, harvesting, preprocessing, storage, and transportation of both woody and herbaceous feedstocks. Assumptions are being replaced with observations, overall systems are being synthesized from existing and new components, and operations are being demonstrated at scale.

1. The most impactful projects involved a range of stakeholders—DOE and university researchers, original equipment manufacturers (OEMs), processors, and agricultural and forest biomass producers—and had clearly defined goals and deliverables.

Leading the list was a group of five projects—referred to as "high-tonnage logistics"—that developed and demonstrated systems to harvest dedicated crops and deliver them to a biorefinery. While they attained a range of success in reaching their goals, each delivered tremendous value to BETO.

A second group, known as the Regional Feedstock Partnership (RFP), made major contributions to the production and management of both dedicated crops and crop residues in a wide range of climates and soils in the central United States. The management of these projects—from competition for project selection and award, to their final reports—was similar to that of BETO, even though they were managed by a regional group.

2. Past biomass programs provided data and experience that aided current programs.

The corporate knowledge gained in past biomass projects remains valuable today, and it should be readily available to all through vehicles such as the Bioenergy Knowledge Discovery Framework (KDF) and the Biomass R&D Resource Library. Not only should these libraries include data and models, but they should also contain final project reports. One example that displayed the value of this historical knowledge was the experience gained through the Chariton Valley Switchgrass Project (roughly one decade ago) being invaluable to one of the current high-tonnage projects, which leveraged that knowledge to demonstrate a high degree of success.

- Advancing sustainable production and logistics systems for a variety of feedstocks is a strength.

The bioenergy industry is too young to exclude very many candidate crops and management systems. Assumptions about several crops are being examined, and it was found that some were inaccurate, notably the potential role of Conservation Reserve Program (CRP) land.

- Projects such as the RFP appropriately used federal funds to convene and leverage resources from many sources (universities, industries, etc.) to address feedstock development, testing, and deployment.

The regional nature of these projects can encourage participation by entities that are reluctant to deal with a federal bureaucracy. These entities can bring local knowledge and experience that enhances the probability of success.

INNOVATION

3 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach these barriers? Do any projects stand out as meeting (or not meeting) this criterion? Can you recommend new ways to approach these barriers?

The projects covered in this review described a number of innovative solutions to production and logistics challenges, as well as innovative management approaches to regional and global projects.

- Feedstocks projects addressed a wide range of barriers from a variety of approaches: competitive, consortium, congressional. (high tonnage, RFP, Rhode Island plant breeding).

The success of the projects reported on in this Peer Review reflected the competence and dedication of their performers and managers more than the genesis of their inspiration. BETO management recognized the contribution of several projects that started outside of DOE and have melded them into the BETO portfolio.

- The projects addressed broad problems that BETO is charged with. Examples include sub-parcel optimization and feedstock analysis efforts producing a useful accessible model of feedstock supply systems.

The idea of specifying biomass feedstocks by their functional characteristics rather than by plant species was a major step toward creating a biomass commodity market. The concept needs to be vetted throughout the supply chain to confirm that biomass is truly fungible.

- The success and breadth of ideas that came out of high-tonnage projects was a result of marrying projects.

Two bale-picking vehicles, a bale trailer employing cotton module handling concepts, and an automatic load securement system add to the versatility of future logistics systems.

- The projects demonstrated novel preprocessing (i.e., blending, ash avoidance, and removal).

Blending components and pelleting at higher moisture enhanced the durability and chemical quality of pellets while lowering their cost.

- Feedstock logistics is critical and expensive. Success has been demonstrated. There are numerous untested ideas, and big opportunities remain; more investment is required.

The impact of ash—both naturally occurring mineral content in plant tissue and soil entrained by the harvesting process—deserves further study. Review team members voiced various levels of concern about the effect of soil bacteria and fungi on biochemical processes, conflicts between soil minerals and chemical pretreatments, and potential fouling of thermochemical processes. Addressing these concerns will impact the design and selection of crop and residue harvest systems.

GAPS

4 Are there any other gaps in the portfolio for this technology area? Are there topics that are not being adequately addressed? Are there other areas that BETO should consider funding to meet overall programmatic goals?

The review team identified a number of issues that deserve additional examination:

- Techniques for densification and ash removal or mitigation.
- Need a more concerted effort to reduce storage losses, as long storage will be required in most scenarios involving herbaceous material.
- Work to add uncertainty measures to modeling and costing efforts.
- Actual, real-world, cost information, in addition to engineering cost information (e.g., acceptable level of return on investment, profit, opportunity cost).
- Continuing and extending feedstock production and management projects.
- Workforce development: safety in field and plant setting, operational development/training. Utilize process demonstration unit (PDU) for training?
- Model of the "depot" concept—techno-economic analysis (TEA) needed.
    - Blending strategy—regional variation?
    - Information about how we can recover valuable co-products during biomass preprocessing.
- Supply chain needed to handle wet biomass/dry matter loss. Economic analysis needed.
    - What are the specifications of the end user needs?
    - Education needed between supplier and purchaser to come to uniform units/understanding. Equitable way to do this?
    - Publicly available, high throughput, affordable characterization tools are critical, but rare (e.g., sensor from Auburn; near infrared (NIR) calibrations for only a few crops and narrow range of moisture). These tools need two-way linkages to data libraries.
        - Set standards?
            - The International Organization for Standardization (ISO) is developing a labeling requirement standard.

SYNERGIES

5 What synergies exist between the projects within this technology area? Is there more that BETO could do to take advantage of these synergies and better enable projects to meet their objectives?

As the bioenergy portfolio develops, the panel noted that certain synergies became apparent and deserved recognition:

- Projects build on the legacy of earlier projects. Consider an organized search for relationships hidden in accumulated project data (i.e., data mining).
- Significant synergies exist within and across portfolio and project components and cooperators. Examples include RFP, sub-field level optimization modeling, and high-tonnage projects. Information feeds into the KDF and Biomass R&D Resource Library,

which are used to build and test model behavior and output and provide useful support tools.

- Working with USDA will continue to be important, leveraging experimental systems and expertise that are highly relevant to feedstock production, management, and logistics.
- Templates on the KDF and Biomass R&D Resource Library should routinely request sustainability information.

RECOMMENDATIONS

6 Is BETO funding projects at the optimal stage of the technology pipeline? Is there more that BETO could do to orient technologies toward successful commercialization? Are there any projects that stand out as positive or negative examples of this orientation?

7 What are the top three most important recommendations that would strengthen the portfolio in the near to medium term?

Based on the observations noted above, the review team offered the following recommendations and comments:

3. BETO is funding at appropriate stages of the technology pipeline. Examples include RFP (feeding into the KDF and Biomass R&D Resource Library), high-tonnage projects, linking feedstock analysis, and sub-field optimizations efforts.

The review team encouraged the funding of a wide range of project maturities, ranging from concept discovery to system integration. A very low failure rate would indicate a very low breakthrough rate and slow development of this new industry. Even unsuccessful projects can yield valuable data, so project request for proposals should include every possible inducement to submit every observation to the KDF and Biomass R&D Resource Library.

4. TEA is needed to justify the "depot" concept.

The depot concept has evolved from a simple distributed storage concept to include distributed pre-refinery processing. Such processing may increase the energy density of the feedstock, or improve other beneficial characteristics; however, it requires multiple sets of machinery. Storage costs may increase compared to a single, large storage, but the risk of catastrophic supply interruption, and the cost of insuring against it, may be reduced. A comprehensive optimization is appropriate.

5. The high cost in time and money for deployment of the PDU may argue for regional, stationary PDUs, which would also enhance their value for workforce development.

The goal statement given for this project did not inherently depend on deployability. Designating this unit as a user facility should help verify its value to the future bioenergy industry. That industry will require a workforce that is trained to safely carry out the processing steps required. Such training would be a valuable adjunct to other DOE efforts to encourage the creation of a bioenergy industry.

6. Support innovative/under-researched regional feedstock crop production and logistics systems.

The experience gained in actively managing CRP land has started documenting its potential contribution to bioenergy supplies and has illustrated the use of harvest date to manage grassland species.

7. Ensure ongoing data collection from critical, regionally relevant field/plot studies.

A critical component of any biorefinery plan is the stability of its supply of raw materials. These studies will help document the variability of both yield and quality, and contribute toward best management practices for producing the feedstock.

8. Give a serious look at data analytics.

Every correctly recorded observation has value. Over its history, BETO has fostered the creation of millions of observations of myriad aspects of bioprocessing—from the physical chemistry of enzyme production to the effect of hammermill shape on *Miscanthus fines* production—which were entered into the KDF, Biomass R&D Resource Library, and numerous scientific journals. The emerging science of data analytics may allow the extraction of relationships not visible within the scope of a single project.

9. Continue/encourage public-private partnerships with a regional focus.

The success of the RFP projects should encourage the continued use of that model.

10. Emphasize best management practices that achieve sustainability metrics.

"Achieving metrics" assumes that metrics have been created. The creation of sustainability criteria and indicators should be a goal of BETO and should involve all stakeholders. Once these criteria and indicators have been established, future projects should include sufficient time to develop and test best management practices, which may require several years.

11. Emphasize human dimensions of feedstock supply and logistics, including social factors, risk management, and decision science.

Future potential providers of biomass feedstocks may decide not to participate in the industry, based on factors that have not been included in current supply estimates. This reduction in potential feedstock may be fatal to a proposed biorefinery, even in a locality with abundant potential supplies.

12. Clear need for optimization of feedstock supply chains; restructuring the China project may offer an opportunity to meet this need.

The depot concept mentioned above is just one of many possible configurations of a bioenergy industry. The "best" configuration for a given end product requires evaluation against multiple criteria. The development of a supply chain evaluation tool that can weight these criteria properly for both the Chinese and American economic and social systems will be a challenging effort; however, it might enhance the value of this project for both nations.

13. Biomass quality assessment to support and enable trade.
    - Actively participate in ISO/international standard development.
    - Develop mechanisms to allow market to adopt standards.

The establishment of standards-based trade requires the creation of criteria around which standards can be developed; these standards should be easy and affordable to measure. Kernel moisture and test weight (bulk density) can be measured in a few seconds and form the basis of commodity grain trade in the United States. Similar important properties need to be defined and rapid evaluation techniques developed if a similar commodity biomass market is to develop. Low-cost, real-time biomass characterization methods are needed for a wide variety of feedstocks and a range of moisture and storage/preprocessing conditions. Enabling data and methods that are developed with public funds (such as NIR calibrations) should be freely accessible through mechanisms like the Biomass R&D Resource Library.

CONCLUSION

The evaluated Feedstock Production and Logistics Technology Area's activities continued to move the nascent bioenergy industry forward. Experience and knowledge gained from the many and varied programs are refining estimates of available supplies, reducing the cost of feedstock delivery, and developing tools for managing these valuable resources.

BETO PROGRAMMATIC RESPONSE

INTRODUCTORY COMMENTS

I would first like to thank our entire review team for their patience, diligence, and thoughtful, constructive input during the Peer Review process. BETO will benefit significantly from the insights and wisdom shared by the review team, and I hope that the process was not too onerous for them. I would also especially like to acknowledge Lyle Stephens for his many years of sustained interest, active involvement, and devotion to the goals and objectives of the Office.

Many thanks to:

- Lyle Stephens, John Deere (retired)
- Jami Nettles, Weyerhaeuser
- Marilyn Buford, U.S. Forest Service
- Mike Tumbleson, University of Illinois, Emeritus
- Steve Searcy, Texas AgriLife
- Tom Richard, Pennsylvania State University

IMPACTS

1. The review team highlighted the five competitively awarded high-tonnage logistics projects and the Sun Grant Initiative Regional Feedstock Partnership as the most impactful projects in the Feedstocks Supply and Logistics portfolio. They credit the range of stakeholders involved in these projects, as well as the clearly defined goals and deliverables for this success.

Each of the multi-institutional high-tonnage projects have developed and demonstrated strategies and technologies at commercial scale that have shown significant economic benefit to the supply chain system; these projects should help make biorefineries economically competitive and sustainable. Over the past three years, the approach of designing, building, and demonstrating purpose-designed feedstock logistics equipment has clearly shown that private-public partnerships can produce substantial and meaningful results using a variety of biomass feedstocks. However, this remains an area where additional progress is essential for BETO to achieve its 2017 and 2022 goals. The potential benefit from the follow-on fiscal year 2013 Logistics funding opportunity announcement (FOA)—$5.7 million for one project—would be significantly increased if the fiscal year 2014 budget accommodated funding for more than one selection from this FOA.

The Regional Feedstock Partnership has enjoyed a relatively long history and DOE has worked hard to organize and manage this effort. Given the regional nature of biomass feedstocks, the effort began with a series of workshops hosted by the five Regional Sun Grant Centers. The first of these was held May 10–12, 2006, in Knoxville, Tennessee. The goal of the RFP was to facilitate the development of biomass resources in each Sun Grant Center region in order to fulfill the region's potential contribution toward meeting the goal of 1.3 billion tons of biomass, as defined by the joint USDA/DOE study *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*.[2] USDA agencies, DOE, and land grant universities were involved in many of the workshops, jointly chairing many of the working groups that helped identify the crops and/or biomass feedstock materials that would be studied. DOE national laboratory representatives from Oak Ridge National Laboratory and Idaho National Laboratory also participated in the process. The data from the partnership trials were received in Oak Ridge National Laboratory's Bioenergy Knowledge Discovery Framework. Biomass samples collected from the field trials were stored at the Idaho National Laboratory's Feedstock Library. These samples are invaluable to BETO from both a feedstock production and logistics point of view, and also as diverse materials for testing in conversion processes.

The Regional Feedstock Partnership DOE award is an extensive, multi-year project that includes several dozen subcontractors at (mostly land grant) universities and the USDA's Agricultural Research Service (USDA-ARS). South Dakota State University manages the project for BETO. Vance Owens, Jim Doolittle, and their staff deserve a lot of credit for keeping this project on an organized path forward. The annual crop (corn stover, wheat straw, and sorghum) and mixed native grasses (CRP) teams will have each ended their field work by the end of the 2013 crop year, and are in the process of preparing their final reports. The remaining perennial crop teams (switchgrass, *miscanthus*, energy cane, willow, and poplar) are currently in their sixth cropping year, with definite plans for a seventh—and final—year in 2014. Participants in the RFP universally maintain that at least five years of mature crop data are essential to properly evaluate the performance of these perennial crops across wide geographical and environmental conditions. A longer period of study would be even better, as this would provide real world data regarding stand longevity and performance over time, space, soil types and weather conditions (e.g., drought). The RFP and BETO are investigating ways that some of this work might be continued.

The point about making data, information, and accomplishments from federally funded projects readily available to the public is well taken, though somewhat difficult to achieve. BETO management believes that the ultimate value of the RFP efforts is the collaborative results of individual institutions vis-à-vis replicated field trials. DOE is working directly with the partnership managers, researchers, and national laboratories to support a number of products, including national energy crops yield maps and crop synthesis reports, as well as efforts to publish raw data sets through publically accessible data bases.

2. DOE commends the review panel for their attention to detail regarding the usefulness of the Chariton Valley project to one of the high-tonnage projects. The Chariton Valley project was seminal in the development of the logistics strategies and equipment designs for the FDC logistics project.

3. The regional nature of the RFP is absolutely critical to its value. Data gathered from widely separated sites will provide several years of crop performance data at the same sites and permit the assembly of preliminary national/regional yield maps for a variety of crops. This will be extremely valuable to the developing bioenergy industry, as well as to growers and policymakers.

[2] *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*. DOE/GO-102005-2135. Oak Ridge, TN: Oak Ridge National Laboratory, U.S. Department of Energy, U.S. Department of Agriculture. April 2005. Bioenergy.energy.gov//pdfs/final_billionton_vision_report2.pdf

INNOVATION

1. The reviewers rightly observe that excellent value has been obtained from projects funded via several different mechanisms. While this is not necessarily true for each and every project, it shows that a motivated and well-informed PI can produce valuable results that can positively impact Office goals.
2. The reviewers have concisely summarized the concept of classifying feedstocks according to "functional characteristics," rather than simply by species. This terminology is very appealing, and the observation that this evolution could facilitate the creation of a biomass commodity market is very much appreciated. Fiscal year 2014 plans include efforts to assess the conversion characteristics of various biomass blends to validate the concept in the context of conversion processing in both biochemical and thermochemical processes.
3. It was a distinct pleasure to witness the instant at the Peer Review when two of the logistics projects realized that the combination of their technologies would actually advance things further than either would have achieved separately. That one moment made the entire Peer Review experience extremely worthwhile and rewarding.
4. The novel preprocessing strategy of pelletizing at high moisture content is a potentially useful strategy when biomass cannot easily be dried prior to harvest and collection. Ash avoidance is absolutely critical for biomass processing, as nobody wants to purchase inert or potentially detrimental material packaged with their feedstock, and all conversion processes are expected to establish a maximum ash specification for their feedstock(s). Since thermochemical processes are particularly sensitive to ash content, it is extremely important to learn how to effectively minimize ash content in feedstock materials at the lowest cost possible. Ash removal is an additional and potentially necessary strategy that will be explored. Ash avoidance and removal strategies for both woody and herbaceous materials will also be pursued going forward.

GAPS

The review panel identified a number of issues that deserve additional examination:

1. **Techniques for densification and ash removal or mitigation.**
   Traditional pelletization and briquetting technologies can increase bulk densities to as high as 40–50 pounds per cubic foot. Other than pyrolysis as a process to convert solid biomass into a liquid bio-oil, BETO is not currently aware of any technology that can provide herbaceous or woody biomass at densities above that point. The conversion performance of such super-dense materials would need to be investigated, as the literature in the field contains information indicating that very dense pellets do not perform well in combustion applications.
2. **Need more concerted effort on reducing storage losses, since long storage will be required in most scenarios involving herbaceous material.**
   Moisture content (more precisely, water activity) is clearly the biggest challenge in terms of stabilizing biomass during storage. If moisture content can be brought down to 20% by weight or less—and kept there—then it will be quite stable over time (unless animals start eating it). This means that biomass, once dried to below 20% moisture content, must be stored in ways that prevent it from taking up moisture from the environment (humidity, precipitation, wicking through contact with the earth, etc.), which can be difficult in moist environments. To do so, it must be stored covered (tarps, roof, etc.) but not entirely wrapped, and protected from contact with the ground. If moisture content cannot be easily reduced to below 20% and maintained at those levels, several other options are available; it

is not clear how affordable these strategies would be. These strategies include ensilation (low pH, low O_2); storage at very low temperatures (less than 0° Celsius); densification to reduce volume and make the pellets/briquettes impermeable to water; and perhaps others.

3. **Work to add uncertainty measures to modeling and costing efforts.**
   BETO agrees with this statement. Real data are always preferred to assumptions regarding variables. Uncertainty measures are a function of the range and relative frequency of occurrence of values measured for parameters use in a model, as well as the less-easy-to-quantify uncertainty that accompanies estimated values.

4. **Actual real-world cost information in addition to engineering cost information (e.g. acceptable level of return on investment, profit, opportunity cost**)
   These will be essential elements to include in BETO's drive to develop technologies that can deliver acceptable quality feedstocks to the reactor throat at less than $80/dry ton. These real-world costs must be factored into these modeling and demonstration efforts.

5. **Continuing and extending feedstock production and management projects.**
   BETO thanks the review team for recognizing the importance of DOE feedstock production and management work. Future considerations for feedstock production and management will be included in BETO's MYPP.

6. **Work force development: safety in field and plant setting, operational development/training. Utilize PDU for training?**
   BETO will take this concept into consideration, but is concerned about potential liability and safety issues.

7. **Model of the "depot" concept—TEA needed**
   BETO will conduct an analysis that can tell us whether the depot concept is useful, and in what particular situations. Does the depot concept add costs to the system, or reduce them? Under what conditions can it be counted on to reduce costs? Those are the cases where it makes sense to utilize the depot concept.

   a. **Blending strategy—regional variation?**
      Nearly all feedstocks are expected to be variable in their chemical composition and physical characteristics, depending on genetics, where they are grown, how they are produced and harvested, how they are preprocessed, and so on. The only exceptions might be cloned crops (e.g., hybrid poplars, shrub willows, and *Miscanthus x giganteus*), but environment has been shown to affect wood composition in the same clone of hybrid poplar when it is grown in widely different geographies. As a result, it will always be necessary to have the capability to rapidly and inexpensively assess the pertinent physical and chemical characteristics of the entire variety of relevant feedstock materials in order to be able to create a blend that both meets conversion process in-feed specifications and performs acceptably in the conversion process. Regional variation is not anticipated to be much different than variation that will be experienced more locally.

   b. **Information about how we can recover valuable co-products during biomass preprocessing**
      The possibility of co-products that could be split off from the feedstock supply chain is a strategy that could significantly change the way the industry and BETO think about the economics and engineering around biomass feedstocks. Obvious possibilities include ash and lignin, which could both be used as soil amendments. The tantalizing possibility of making something more

valuable from lignin has been investigated for many years. A possibility is taking the nitrogen or protein content of herbaceous biomass and using it as a soil amendment or fermentation nutrient. The ability to recover the nitrogen content of herbaceous materials prior to conversion in a thermochemical process would also solve the problem of gaseous nitrogen emissions from such a process.

8. **Supply chain needed to handle wet biomass/dry matter loss. Economic analysis needed.**
   Certain candidate bioenergy crops (e.g., energy cane, sweet sorghum, biomass sorghum) will require harvesting at high-moisture content (60–70% moisture), as they do not undergo a senescence phase. These crops are and will continue to be extremely difficult to reliably dry down to a moisture content that will permit storage in baled or loose chop form for any longer than a day or two. Similarly, in recent years we have seen examples where corn stover does not dry down very well in the United States' Corn Belt region. Assuming that dry down to less than 20% moisture content is impractical for these crops, there are at least three alternatives that can still get these materials into the supply chain: just-in-time delivery, much like the way a sugarcane processing facility works (this should be perfectly adequate for sweet sorghum in a sugarcane producing region); ensilation; or conversion to some sort of more stable intermediate, such as a bio-oil, which could be transported and stored more easily. An economic analysis of these alternatives needs to be done to understand the potential tradeoffs, and whether or not any of the possibilities is potentially viable.

   a. **What are the specifications the end user needs?**
      BETO agrees that it is important to link feedstocks with the different conversion pathways and specifications for end use.

   b. **Education needed between supplier and purchaser to come to uniform units/understanding. Equitable way to do this?**
      It will eventually be necessary for the industry to come to agreement on standard units to describe feedstock materials (e.g., U.S. tons or metric tons).

   c. **Publicly available, high throughput, affordable characterization tools are critical, but rare (e.g., sensor from Auburn, NIR calibrations for only a few crops and narrow range of moisture). These tools need two-way linkages to data libraries.**
      Widely available and affordable, rapid analytical methods to assess a wide variety of feedstocks' relevant characteristics are not currently available. However, using the model presented by the forage industry, we know that it is possible to produce commercially available methods. In fact, the commercial, analytical laboratories that perform forage analysis cooperate as a network and share information and data with each other all the time. Calibrated and validated NIR methods exist today for corn stover, sorghum, and switchgrass, at a minimum. Other methods to estimate chemical composition (e.g., pyrolysis-mass specification, thermogravimetric, etc.) are available for woody species, such as hybrid poplar and willow. None of these are yet commercially available, however, so far as BETO knows. The recently concluded fiscal year 2013 Advanced Feedstock Logistics FOA includes a mandatory task for the development of mobile, rapid, analytical methods to assess feedstock quality at any stage of the supply chain, from field to biorefinery.

d. **Set standards?**
BETO would need to work with an established standards-setting organization. BETO would not presume to set standards itself, but could propose potential standards and assist in producing the data and information that could help others make determinations regarding industry standards. ISO is developing labeling requirements standards.

SYNERGIES

As the bioenergy industry develops, certain synergies become apparent and deserve recognition:

1. **Projects build on the legacy of earlier projects. Consider an organized search for relationships hidden in accumulated project data, i.e. data mining.**
The Bioenergy Feedstock Information Network has more than 1,500 DOE feedstock-related references, and may be of use. The KDF and the Biomass R&D Feedstock Library at Idaho National Laboratory (INL) are publically available, researchable repositories of information. Efforts to gather information may also be improved in the future.

2. **The investment required to produce such a data mining tool would be large, but the value could be equally great.**
Significant synergies exist within and across portfolio and project components and cooperators. Examples include RFP, sub-field level optimization modeling, and high-tonnage projects. Information feeds into the KDF and Biomass Resource Library, which are used to build and test model behavior and output and provide useful support tools. There are several strong synergies and interactions between Feedstock Supply and Logistics and Analysis and Sustainability, Biochemical Conversion, and Thermochemical Conversion, and we are working on forging a stronger interaction with the Integrated Biorefineries Technology Area. We all need to continue to work harder to include others on the BETO staff when these opportunities for interaction appear.

3. **Working with USDA will continue to be important, leveraging experimental systems and expertise that are highly relevant to feedstock production, management, and logistics.**
BETO intends to continue work with USDA at whatever level is practical to leverage each other's resources to the maximum extent possible. In this regard, we hope to be able to attend coordinated agricultural project meetings, and similar bioenergy-related events.

4. **Templates on KDF/Biomass Resource Library should routinely request sustainability information.**
This is a good idea, but it presumes that all/most projects are collecting sustainability data when they mostly are not at the present time. This could be uniformly instituted in future awards, however.

RECOMMENDATIONS

1. **BETO is funding at appropriate stages of the technology pipeline. Examples include RFP (feeding into KDF and Biomass R&D Library), high-tonnage projects, linking feedstock analysis and sub-field optimizations efforts.**
The review team encouraged the funding of a wide range of project maturities, ranging from concept discovery to system integration. A very low failure rate would indicate a very low breakthrough rate and slow development of this new industry. Even unsuccessful projects can yield valuable data, so project request for proposals should include every possible inducement to submit every observation to the KDF and Biomass R&D Resource Library.

   The Feedstock Technology Area funds projects spanning from basic research and engineering, to commercial-scale demonstration projects, ranging from TRL 1–2 to 6–7. BETO intends to keep a balance among this range of activities in the future.

2. **A TEA is needed to justify the "depot" concept.** The depot concept has evolved from a simple distributed storage concept to include distributed pre-refinery processing. Such processing may increase the energy density of the feedstock, or improve other beneficial characteristics; however, it requires multiple sets of machinery. Storage costs may increase compared to a single, large storage, but the risk of catastrophic supply interruption, and the cost of insuring against it, may be reduced. A comprehensive optimization is appropriate.

   This has already been discussed earlier in this response. BETO is in complete agreement with the review panel here.

3. **The high cost in time and money for deployment of the PDU may argue for regional, stationary PDUs, which would also enhance their value for workforce development.** The goal statement given for this project did not inherently depend on deployability. Designating this unit as a user facility should help verify its value to the future bioenergy industry. That industry will require a workforce that is trained to safely carry out the processing steps required. Such training would be a valuable adjunct to other DOE efforts to encourage the creation of a bioenergy industry.

   The training issue using the PDU has been discussed in an earlier response. Regardless of whether the PDU can be used as a training facility, BETO agrees with the assertion that a trained workforce will be required to staff a developing biomass industry. To this end, the Office may consider sponsoring the development of training curricula at appropriate land grant institutions and engineering schools around the country. This could be accomplished via a competitive FOA.

4. **Support innovative and under-researched regional feedstock crop production and logistics systems.** The experience gained in actively managing CRP land has started documenting its potential contribution to bioenergy supplies and has illustrated the use of harvest date to manage grassland species.

   Perhaps this is an area for consideration as a small business innovation research topic. Our CRP trials showed yield at about 1–3 dry tons per acre, and therefore not sufficient to be a major contributor to the billion-ton vision.

5. **Ensure ongoing data collection from critical, regionally relevant field/plot studies.** A critical component of any biorefinery plan is the stability of its supply of raw materials. These studies will help document the variability of both yield and quality, and contribute toward best management practices for producing the feedstock.

   Again, BETO thanks the review team for the recommendation.

6. **Give a serious look at data analytics**. Every correctly recorded observation has value. Over its history, BETO has fostered the creation of millions of observations of myriad aspects of bioprocessing—from the physical chemistry of enzyme production to the effect of hammermill shape on *Miscanthus fines* production—which were entered into the KDF, Biomass R&D Resource Library, and numerous scientific journals. The emerging science of data analytics may allow the extraction of relationships not visible within the scope of a single project.

   Good idea, and BETO hopes to realize the full capabilities of the KDF and the Resource Library.

7. **Continue/encourage public-private partnerships with a regional focus.** The success of the RFP projects should encourage the continued use of that model.

   This comment has already been addressed.

8. **Emphasize best management practices that achieve sustainability metrics.**
   "Achieving metrics" assumes that metrics have been created. The creation of sustainability criteria and indicators should be a goal of BETO and should involve all stakeholders. Once these criteria and indicators have been established, future projects should include sufficient time to develop and test best management practices, which may require several years.

   This is progressing in the Sustainability and Analysis Technology Area. The Feedstocks Technology Area and Sustainability and Analysis Technology Area teams plan to interact more regularly on this topic.

9. **Emphasize human dimensions of feedstock supply and logistics including social factors, risk management, and decision science.**
   Future potential providers of biomass feedstocks may decide not to participate in the industry, based on factors that have not been included in current supply estimates. This reduction in potential feedstock may be fatal to a proposed biorefinery, even in a locality with abundant potential supplies.

   This is part of the whole sustainability picture, and is currently being pursued. BETO reiterates the comment in response to the previous recommendation.

10. **Clear need for optimization of feedstock supply chains; restructuring the China project may offer an opportunity to meet this need.**
    The depot concept mentioned above is just one of many possible configurations of a bioenergy industry. The "best" configuration for a given end product requires evaluation against multiple criteria. The development of a supply chain evaluation tool that can weight these criteria properly for both the Chinese and American economic and social systems will be a challenging effort; however, it might enhance the value of this project for both nations.

    BETO needs to consider the investment in the China project. The idea presented by the review panel is interesting.

11. **Biomass quality assessment to support and enable trade**

    - Actively participate in ISO/international standard development.
    - Develop mechanisms to allow market to adopt standards.

The establishment of standards-based trade requires the creation of criteria around which standards can be developed; these standards should have easy and affordable measures. Kernel moisture and test weight (bulk density) can be measured in a few seconds and form the basis of commodity grain trade in the United States. Similar important properties need to be defined and rapid evaluation techniques developed if a similar commodity biomass market is to develop. Low-cost, real-time biomass characterization methods are needed for a wide variety of feedstocks and a range of moisture and storage/preprocessing conditions. Enabling data and methods that are developed with public funds (such as NIR calibrations) should be freely accessible through mechanisms like the Biomass R&D Resource Library.

We agree that BETO should actively participate in the formulation of standards for the bioenergy industry. This includes everything from feedstocks to sustainability, to fuel quality parameters.

CONCLUSION

The Feedstock Production and Logistics activities in the Bioenergy Technology Office continue to move the nascent bioenergy industry forward. Experience and knowledge gained from the many and varied programs are refining estimates of available supplies, reducing the cost of feedstock delivery, and developing tools for managing these valuable resources.

BETO appreciates the work of this peer review committee.

CONTENTS

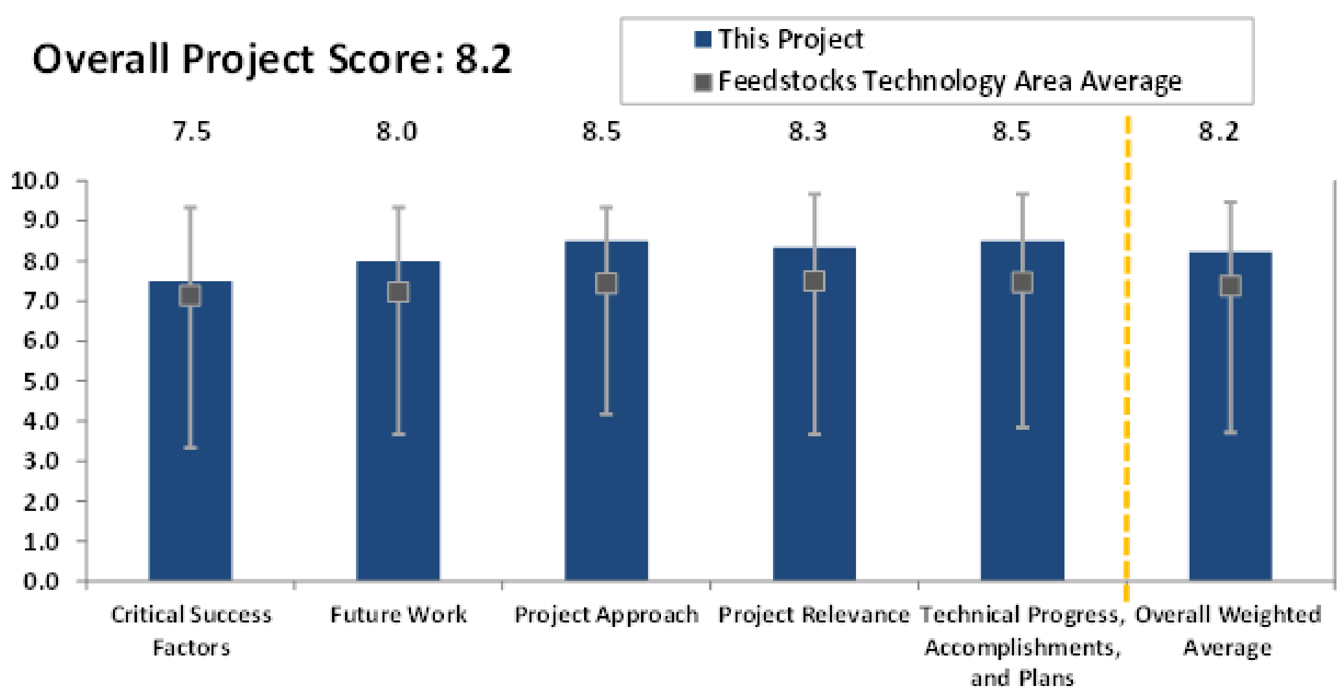
REGIONAL FEEDSTOCK PARTNERSHIP: AGRICULTURAL RESIDUES, STOVER REMOVAL TOOL

(WBS#: 1.1.1.1AZ)

Recipient:	USDA ARS
Presenter:	Doug Karlen
Total DOE Funding:	$1,020,493
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$1,020,493
Project Dates:	2007-2013

Project Description

The Regional Feedstock Partnership program in collaboration with the USDA-ARS Resilient Energy Agricultural Practices (REAP) team established coordinated field trials to develop sustainability guidelines for harvesting corn stover as a bioenergy feedstock. ARS-REAP was formerly called the Renewable Energy Assessment Project; the change in name better communicates relationships between soil health and practices, including agricultural residue harvest and management. ARS-REAP provided leadership for studies at various locations in Iowa, Illinois, Minnesota, Nebraska, Pennsylvania, South Carolina, and South Dakota. The studies used no-tillage or the least amount of pre-plant tillage possible and evaluated three corn stover harvest strategies—none, approximately 50%, and maximum collectable (approximately 90 to 100%). Additional soil and crop management treatments, appropriate and important for each location, were incorporated into the studies. The partnership also provided access to additional long-term ARS-initiated and university partner-initiated field experiments and soil resource response data that were used to help interpret the short-term Regional Partnership results. Five-year crop yields, nutrient balances, soil-test changes, and greenhouse gas and nitrogen leaching metrics are being quantified and summarized for publication in a special issue of Bioenergy Research. Key findings are that sustainable stover harvest rates are determined by grain yield and must be site specific; excessive crop residue harvest can have negative effects on soil organic matter fractions, soil aggregate size, and soil microbial communities; continuous greenhouse gas



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

emission monitoring provides more accurate cumulative information than periodic measurements using static chambers, but at a much higher cost; and continuing long-term monitoring of field sites is crucial for development of sustainable bioenergy feedstock supplies. Finally, data from these field trials have been used to develop a residue management tool that is currently being vetted by commercial partners as they develop sustainable bioenergy feedstock supplies in Iowa and other states.

Overall Impressions

- The project has made significant contributions to documentation and understanding of corn stover as a feedstock for bioenergy applications. Continued efforts by USDA-ARS should enhance the available data in the future. At the end of this project, a significant emphasis must be placed on the collection, synthesis, and delivery of the knowledge gained through the KDF.
- This project really optimizes resources by collecting sustainability data in a broad, production-based framework. Given the high cost of greenhouse gas data collection, as well as the other factors considered, I'm very impressed with the research strategy. It seems very balanced and likely to produce high-quality, useful results.
- A more focused design with comparable data would be helpful. Variables must be controlled and included in overall interpretation of findings for application to end users. The area in the corn cob that was attached to the stalk does not grind and plugs the mill screens and augers.
- Corn stover is widely recognized as a major feedstock opportunity, but carries major environmental risks. This project provided a broad assessment of yield potential, feedstock characteristics, and some sustainability metrics (soil characteristics, limited greenhouse gas, and water quality indicators). Landscape environmental assessment residue removal tool provides an analytical framework to explore the balance between economic drivers and sustainability constraints. This was a good example of a partnership between USDA and DOE national labs, as well as university-industry activity, and there was massive leveraging of relatively modest federal funds. Of particular note was the effort to harmonize and aggregate datasets so that meta-analysis could be coordinated across the team. The process of addressing concerns about such collaboration, the successful demonstration of cross-institutional collaboration, and eventual public access to this data will be a major long-term benefit of this research. Given the vast acreages of corn production in the U.S., and the high volumes of stover that are potentially available, additional research on this feedstock will be important. Cropping systems that incorporate cover crops and perennial segments as well as manure in dynamic crop rotations could readily address this, but were not studied in a comprehensive way. Future work should specifically address development of best management practices for stover harvest that retains or improves soil and water quality relative to conventional production practices.
- Excellent work that impacts the evaluation of corn stover availability, as in the *Billion-Ton Update* supply curves.
- Useful and effectively done. Guidelines were developed for how sampling should be done to reflect actual removal affect for future studies. Residue management tool was developed by synthesizing/linking existing models and databases and applying the concept of limiting factors as quantified by the data collected/accessed for the study. The product is useful and an innovative path for extending the research is presented.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

REGIONAL FEEDSTOCK PARTNERSHIP: SORGHUM

(WBS#: 1.1.1.1B)

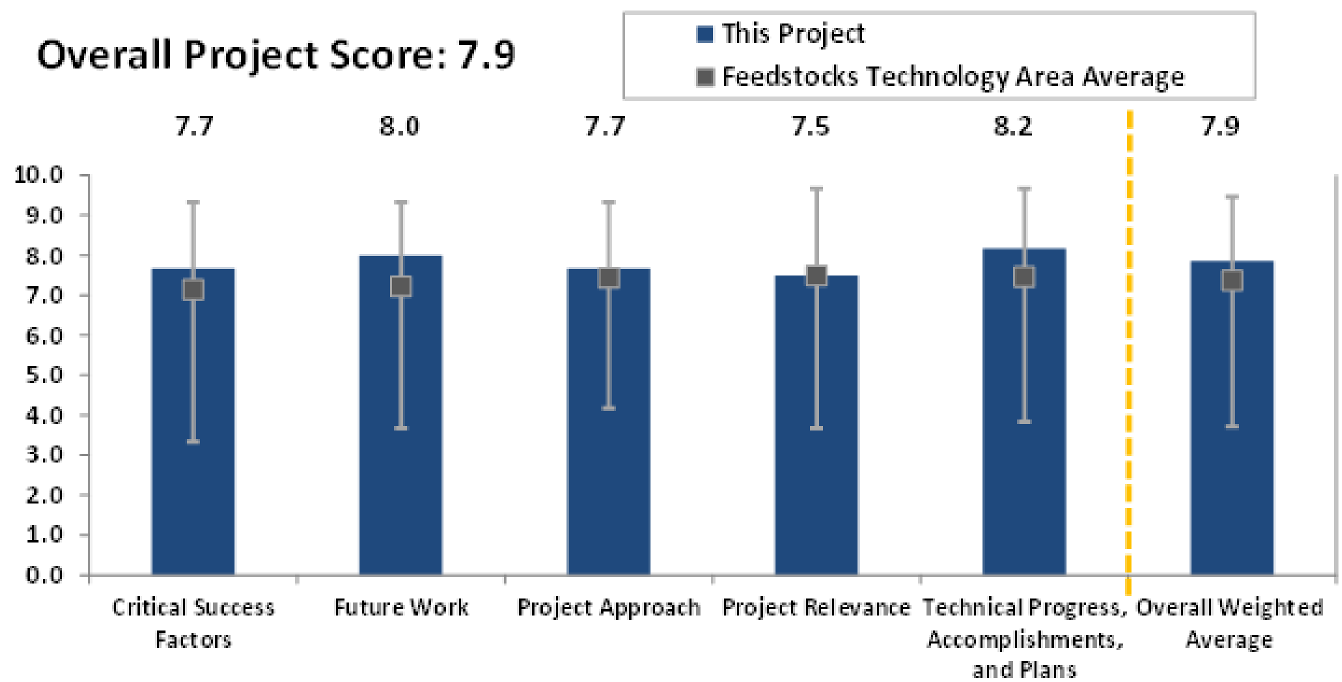
Recipient:	Texas A&M U
Presenter:	William Rooney
Total DOE Funding:	$1,287,348
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$386,370
Project Dates:	2007-2013

Project Description


Photo Courtesy of Texas A&M U.

Sorghum (*Sorghum bicolor L. Moench*) is one of four herbaceous, dedicated bioenergy crops identified by the U.S. Department of Energy due to its high-yield potential and stress tolerance. Of this group, it is the only annual crop and it is tractable to breeding and improvement. Recent breeding efforts are now producing dedicated energy sorghums. The purpose of the study is to assess the biomass yield potential and composition of existing sorghum genotypes across different production sites in the U.S. Five sorghum hybrids and one variety were evaluated across eight locations in seven states over four years. For most agronomic and compositional traits, significant variation was detected for genotypes while the significance of environments and genotype by environment interactions depended on the particular trait. The results indicate that sorghum has excellent potential as a biomass crop and that certain environments are especially conducive to energy sorghum production. The extensive resources available to sorghum breeders and geneticists should allow future improvements to the yield and quality traits in bioenergy sorghum to meet the needs of multiple end users.

Overall Impressions



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

- Perhaps continued work should be funded by appropriate commercial units. Many of the findings are those provided by seed companies for sale of commodities.
- Project was effective in examining sorghum growth patterns across a range of environments. As newer varieties are introduced, the improved performance of those will need to be entered into the KDF.
- Sorghum, as the only dedicated energy crop in the regional partnership that is also an annual, provides a rapid response feedstock for anticipated exponential growth in biorefinery demand. The research thus far has been primarily on breeding and variation associated with genetics and different environments. The focus was on biomass sorghum (including forage sorghum and sweet sorghum), which is distinct from grain sorghum and has had had much less agronomic research than grain sorghum. There was no research on sustainability criteria such as impacts on soil health, water quality, or greenhouse gas emissions, which are important for biofuel life-cycle analyses. While funding was limited, the exclusive focus on breeding represents a shortsighted decision about priorities for the use of public funds. Seed companies regularly invest in variety trials and breeding programs for annuals, and, in fact, this private sector investment is being made for sorghum and is already resulting in new varieties. If sorghum is going to be used for biofuels, there is a critical need for data on environmental impacts and development of agronomic practices that will address those impacts. Sorghum was moist at harvest— 50 to 90% (average 70%)—and had high sugar content, so there is a clear need for research on storage and logistics on this wet, sugar-rich material. Harvest is possible in Texas from July through November, but that will not keep a refinery running year round. In what regions is field drying possible, and how does that affect sugar content and potential biofuel yield? How can this crop's harvest season be extended to complement sugarcane and energy cane in the Deep South, and what are the options further north? This team did a nice job exploring the primary research questions around the interactions between genotype and environment. Through the course of this project, they identified a range of other concerns, including several sustainability issues and economic needs. Sustainability issues include soil and water effects, greenhouse gas emissions, nutrient cycling, and crop rotations. Economic needs include varieties that extend the harvest season, storage strategies for high moisture materials, and refining systems that can alternate with sugarcane or another crop with a complementary harvest season. Both sets of factors should be addressed in future research.
- The project developed a seasonal deployment strategy to provide a longer harvest window with yield potentials for sorghum that includes guidelines for hybrid, planting date, harvest date, and probable yield; and supply plan for a hypothetical mill. Breeding has improved issues related to lodging. Project seems to have a reasonable approach, and provides useful preliminary results. Options for reducing delivered costs are areas of needed research. It isn't clear how large a part sorghum will play as a regional feedstock, even in rotations with sugarcane or energy cane.
- This is a well-done, nicely implemented study. The range of environments and genotypes evaluated gives broad guidance to potential sorghum producers.
- This, and similar, project(s) provides data and best management information for a variety of crops in a range of environments. These results will improve the accuracy of supply estimates and provide management guidance for potential biomass producers.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

REGIONAL FEEDSTOCK PARTNERSHIP: HERBACEOUS ENERGY CROPS

(WBS#: 1.1.1.1C)

Recipient:	South Dakota State University
Presenter:	Vance Owens
Total DOE Funding:	$4,533,072
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$1,150,637
Project Dates:	2007-2013

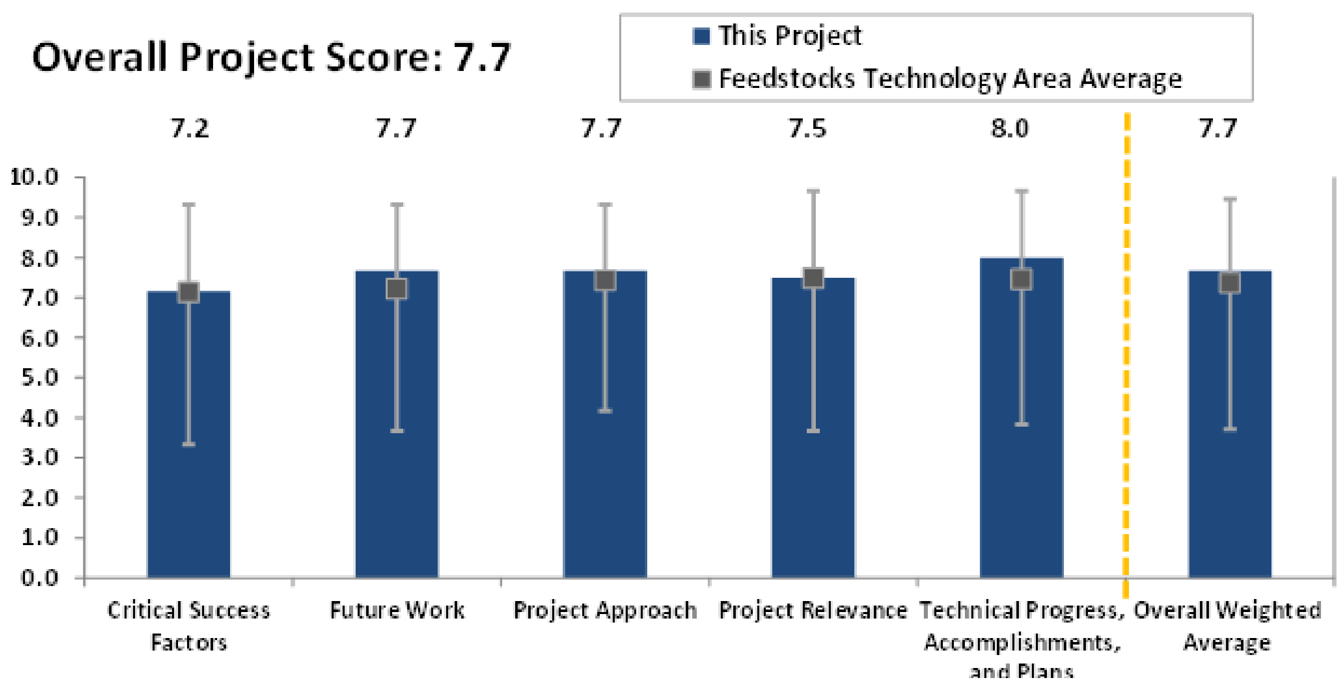
Project Description

Photo Courtesy of South Dakota State University

The purpose of this project is to help develop more accurate feedstock supply information using replicated field trials of select species across the U.S. Field trials of switchgrass (six sites), *miscanthus* (five sites), energy cane (eight sites), and CRP mixtures (six sites) were initiated primarily in 2008, with some sites coming online one or two years later depending on establishment success in the first year. Therefore, up to five years of biomass yield data have been collected to date. However, we hope to continue beyond 2012 since long-term yield data is critical with perennial species. Sustainability data, including water quality and greenhouse gas emissions, have been collected at one switchgrass site in South Dakota, and one *miscanthus* site in Illinois since 2010. All of the data collected in this project are highly relevant to industry as biorefineries are sited and to policy makers as they evaluate bioenergy practices.

Overall Impressions

- Good information on potential yields; preliminary information on management treatments, clear state-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

ment of areas needing more work; motivated teams; not really clear how significant these crops can be in the overall scheme of the problem.

- The project has made significant contributions to documentation and understanding of perennial grasses as feedstocks for bioenergy applications. At the end of this project, a significant emphasis must be placed on the collection, synthesis, and delivery of the knowledge gained through the KDF.
- The Regional Feedstock Partnership, in spite of the large size of the undertaking, has been well managed and productive. Many of the components involved new systems and challenges due to weather, but barriers have been handled and excellent progress made. This work will provide foundational data for feedstock growth across the U.S.
- This overview of herbaceous energy crops included energy cane, *miscanthus*, switchgrass, and mixtures on CRP ground. This is a significant and ongoing need for public investment in these perennial crops, in contrast to annual crops where agribusiness has a recurring profit opportunity. This is true for variety development, fertilizer management, and pest and weed control. For future research, it will also be important to consider emerging energy feedstocks that may have been overlooked a few years ago, including herbaceous winter annuals such as winter rye, and how these crops might be integrated in food crop systems in time (rotations) and space (landscapes). The team was well distributed across the U.S., and included many of the leading researchers in the field. This type of team research is incredibly valuable, and needs additional and ongoing support. These teams have faced (and overcome) considerable challenges associate with large-scale, multi-institutional team science, including serving as guinea pigs for new strategies for data management (KDF). This would be an appropriate time to reset these teams, with a more open competitive process for team selection and a reset on experimental design to feature (and fund) more intensive research on a range of sustainability metrics.
- This, and other, project(s) provides data and best management information for a variety of crops in a range of environments. These results will improve the accuracy of supply estimates and provide management guidance for potential biomass producers.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

UNIVERSITY OF HAWAII, COLLEGE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES, DEVELOPMENT OF HIGH YIELD TROPICAL FEEDSTOCK

Recipient:	University of Hawaii
Presenter:	Andrew Hashimoto
Total DOE Funding:	$7,919,250
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2008-2016

(WBS#: 7.1.2.6)

Project Description

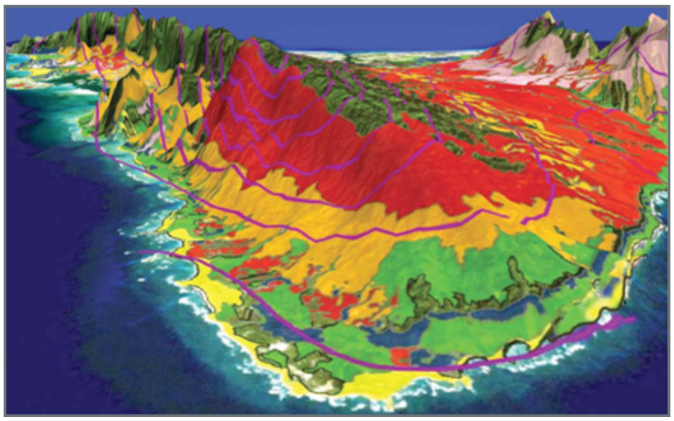
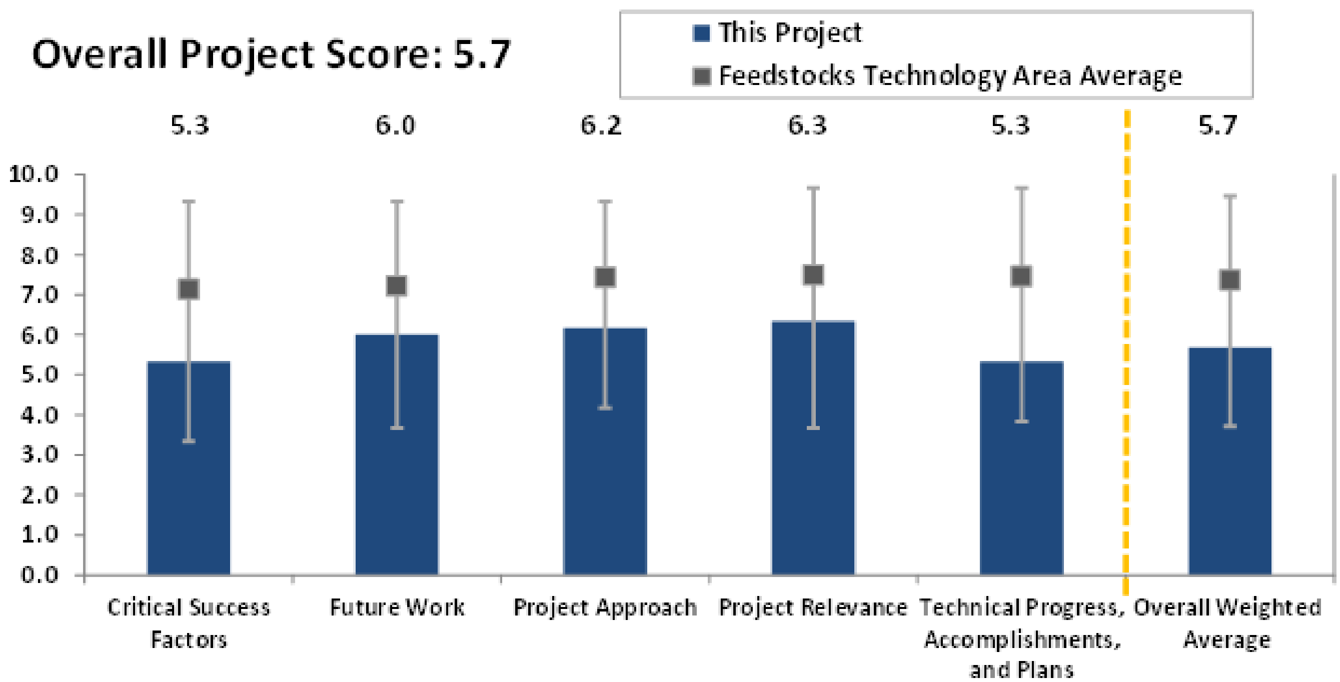


Photo Courtesy of University of Hawaii

The goal of this project is to determine the economic feasibility, community impact, and environmental sustainability of biomass-based renewable energy production in Hawaii and the tropics by addressing the following critical questions: What energy crops will produce the most biomass for various climates in Hawaii, and what are the required inputs? How will feedstock properties affect biochemical and thermochemical conversion efficiencies? What are the carbon sequestration profiles of these feedstocks and management techniques? How do renewable energy systems impact communities in economic, carbon-savings, and quality-of-life terms? How can we describe all of the above in an integrated model that allows producers and communities in similar climates to produce sustainable, biomass-based energy? The results from this project will be directly applicable to a vertically integrated, 35,000-acre agribusiness, and other businesses in Hawaii, like the electrical utilities on



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

each island that are currently seeking local biofuel for their generators. The results will also be applicable to regional allies in the Asia-Pacific region. Discussions are underway with the University of Queensland in Australia to collaborate on developing feedstocks for biofuels, specifically aviation biofuels. Discussions are also underway with a company developing a biomass-to-electricity plant in Papua New Guinea. Finally, the results of this project are applicable to the Department of the Navy's Great Green Fleet Initiative and their interest in locally sourced biofuels for their aircraft, ships, and vehicles.

Overall Impressions

- Much work yet to be done. Providing outcomes and impacts must be encouraged. Long-term involvement of commercial concerns is paramount to success of the proposed project.
- The approach and results seem somewhat scattered and not as focused as they could be on BETO goals. Project is pursuing a number of goals and has pulled in additional funding that is strongly energy-related.
- The project components all appear valuable, but there are challenges in the wide range of completion stages, changes in technology, and reduction in funding. A comprehensive look at the most important barriers to technology transfer, feedstock growth, and other BETO goals would help maximize the outcome of this project. The risk is ending up with many small pieces of important information, but no overall roadmap for future biofuel research and commercialization in Hawaii.
- The team has leveraged Hawaii's geographical, climate, and strategic advantages to strong effect, with applications to aviation and ocean transportation fuels as well as a range of local renewable energy strategies. Feedstock research includes four energy crops at three elevations (climates) and three irrigation levels. Preliminary results are available on napier grass, sweet sorghum and energy cane (with sugarcane as a control), including elevation and irrigation impacts on yield. Some crops are harvested annually, and some—like sweet sorghum and napier grass—can be harvested in several cuttings per year (similar to hay). Research is continuing on protein separation and co-product recovery, as well as downstream conversion. This team has good collaborations with Hawaii Electric Company and other utilities, the U.S. Navy, and international groups. Publications have been limited to date, especially relative to the large federal investment. There is an international need for research on tropical energy crops, especially some of the sustainability impacts that may not get immediate attention in other parts of the tropics. Future plans for this team include additional agronomic and environmental research, as well as integration with conversion processes. Sustainability metrics will be expanded to include comprehensive life-cycle assessment (LCA) of integrated systems. One interesting component is the indirect greenhouse gas reduction benefit associated with more decentralized workforce opportunities and reduced commuting requirements. Work in progress and planned for the Biomass Research and Development Initiative project is relevant and needed, and with new competitive funding, the team is well resourced to complete it.
- What is unique about Hawaii among the United States? Location. It is the only state in the tropics, but its latitude and its range of microclimates and soil types make it an ideal location to develop biomass crops for export to a wide range of tropical countries, along with any specialized processing required for these crops. Its limited land area makes it

unlikely to contribute a meaningful quantity of fuel to the Great Green Fleet, but it is sufficient to develop and propagate new crops and provide substantial employment for those who learn the technician-level skills needed in the industry. An advanced plant breeding technique, such as the one reported by Dr. Albert Kausch of the University of Rhode Island, might enhance the development of this industry.

- Whole thing is very general. Limited data presented.

PI Response to Reviewer Comments

- The review team expressed concerns that this congressionally-directed project exceeded the scope of the Bioenergy Technologies Office's programs, and that "publications have been limited to date, especially relative to the large federal investment." There are several extenuating circumstances that delayed the start of the project. First, the subcontract with our collaborating commercial sugar company (host site for the energy crop trials) was not approved until April 2011, which delayed the establishment of the trials and resulted in only one full year of crop-yield data to date. Also, the subcontract with our collaborating produce farmer was delayed until November 2011, resulting in most of the equipment and installation having to be rebid. Thus, the micro-hydro system just recently became operational. Finally, 36% of the $7.9 million in DOE funds for the project was allocated to the two collaborating companies (they also provided 73% of the cost-share funds for the project); technical project reports, rather than peer-reviewed publications, are the primary outcomes of interest to these companies.

REGIONAL FEEDSTOCK PARTNERSHIP: WOODY ENERGY CROPS

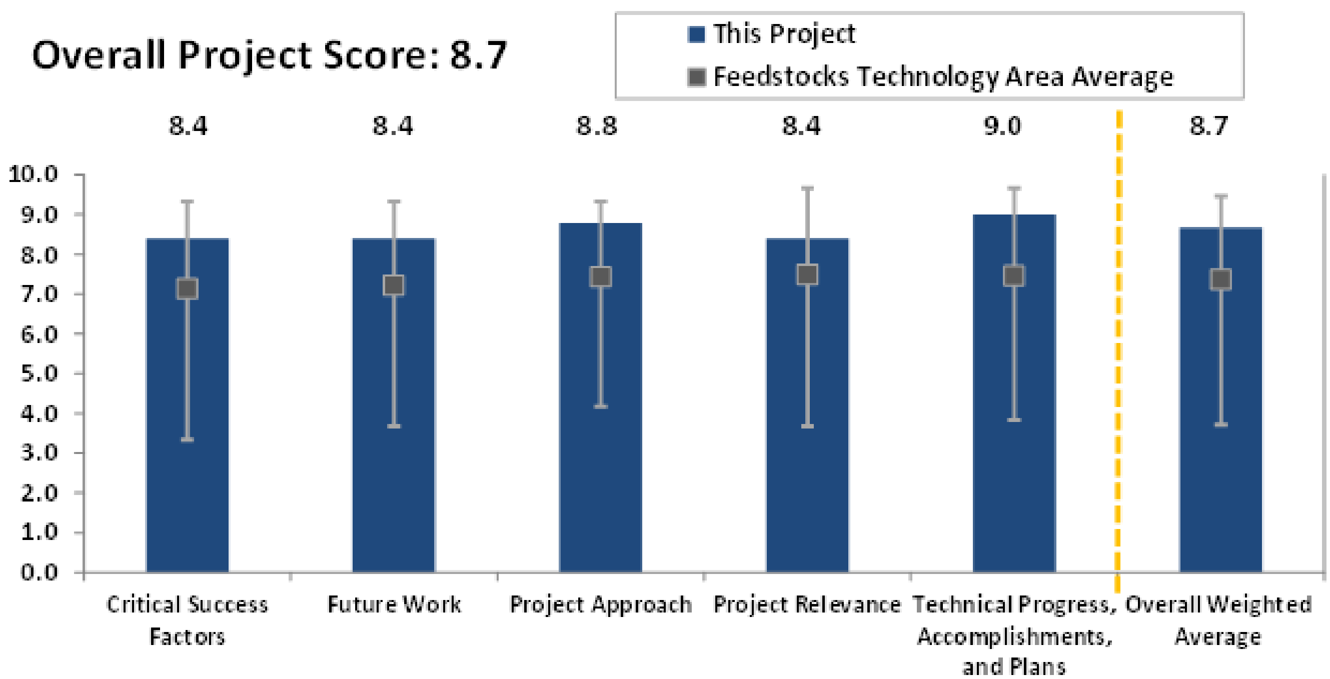
(WBS#: 1.1.1.1D)

Recipient:	University of Tennessee
Presenter:	Tim Rials
Total DOE Funding:	$2,526,316
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$928,596
Project Dates:	2007-2013

Project Description

Photo Courtesy of University of Tennessee

A portfolio of bioenergy crops is vital to the successful broad-scale deployment of biorefineries in the United States. Providing optimal performance in both biochemical and thermochemical conversion platforms, these dedicated biomass production systems also address other important considerations, including enhanced ecological and environmental benefits, improved economic performance, flexibility in meeting landowner objectives, and minimization of supply chain uncertainty and risk. Short-rotation woody crops (SWRC) have a key role to play in fulfilling these potential benefits while maximizing productivity over diverse sites. Realization of SWRC's potential across the nation requires a structured program of breeding and field testing, as well as the development of cultural practices to optimally manage these crops. The Sun Grant Initiative, in partnership with the Department of Energy's Bioenergy Technology Office, is working to advance SRWC as a source of high-quality biomass. The Feedstock Development Partnership's program currently targets two, woody-crop production systems: hybrid poplar (led by the University of Minnesota) and willow (led by the State University



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

of New York). Both teams have taken a similar approach in that, along with the installation of new trials of elite varieties and clones, a number of existing trials have been incorporated into the effort to further the value of the new studies. The 22-site willow trial network is concentrated in the Northeast and Midwest, and includes 20 improved variety studies in eight new states. Substantially larger in scope and coverage, the poplar trial network consists of 74 plantings (yield, genetic screen, and nursery) across the U.S. The presentation will highlight recent performance improvements for both poplar and willow systems, and will discuss the significance of yield increases on economic sustainability.

Overall Impressions

- Building on existing woody crops work at the start of the project was very appropriate and has resulted in rapid development of significant results. Ability to incorporate existing field trials and genetics development was helpful. Comparison of the project results against the *Billion-Ton Update* estimates is valuable. The linkage of this program's results to the Biomass Crop Assistance Program's investments is exactly what was desired from these regional feedstock projects. In that sense, this subproject is contributing at a greater level than the other feedstock projects.
- Pertinent, useful data collection and dissemination of information. This multi-location, interdisciplinary work should be continued.
- This project encompasses the woody crops component of the Sun Grant RFP. The primary focus has been on poplar and willow. These crops are likely to play a very large role in biofuels, and have valuable co-products and alternative markets that strengthen demand for this material. Approach includes genetics and breeding, replicated variety trials (64 total sites), and strong integration of yield results in the KDF. Poplar research focused on clone tests. Careful propagation strategy and high survival rates (80%) allowed for useful results. Not surprisingly, different varieties performed better in different regions. Extensive data demonstrated high yields (50% to 100% increases from standard clones for some regions), which should translate into lower-cost feedstocks. For willow, trials pushed the limits of the ranges for this crop and coppice system. Results demonstrated 14% increase in yield from baseline (top five varieties, 20% for top variety), with ongoing increases for coppice cycles. The project improved internal rate-of-return economics to reduce debt period to cash flow from 15 years to less than 10 years. Weed control is a significant part of this challenge, affecting both yield and survival rates in the early years, and thus reducing profit. Disease can also be a major issue, especially in poplar. Regional breeding programs are necessary to address this concern. Continued research on woody energy crops will be important for long-term bioenergy industry success. This project demonstrated the kind of close collaboration between government, industry, and universities that is a model for feedstock development. There are strong collaborations with both industry and universities for genetic material, and commercial nurseries are already using the results to select varieties for propagation. For future feedstock development efforts, it would be good to more effectively engage downstream users (fuel, chemicals, and, in this case, materials) to provide feedback for crop development.
- This project maximizes resources by incorporating existing plots and having very focused goals. The overall work is well managed, has a high level of output, and will lead the way for successful implementation of hybrid poplar and willow development as biofuel feedstocks.
- This project mobilized a good range of resources that were applied to a focused task, a combination that enhances the probability of success.

PI Response to Reviewer Comments

- Regarding the work continuing beyond the project, the woody crop experiments will not be maintained and will ultimately be lost unless funded. While some experiments may remain, they will only do so on land that is managed by commercial entities (ArborGen, GreenWood) or on university-owned lands. There is a real risk that a portion of the field trial network will be dismantled at a stage when the woody project team begins to yield the most useful data. This would include propagation of superior clones in sufficient numbers to accommodate closed-canopy yield blocks of sufficient size that allow long-term measurements of absolute yields (tons/acre/year) versus relative yield (percent over test mean), as is the case in clone tests. Also, the issue of coppice production on short rotations using the best clones for each of the regions is an open question that could be answered if the project continued. Due to the vulnerability of these tests, and if the DOE-supported program is eliminated, there are no guarantees that the data will be available in the future.
- The woody project team, with members from Oregon State University's PRISM Climate Group and Oak Ridge National Laboratory, will be meeting in the fall of 2013 to prepare a map of the potential relative yield distribution of woody species (poplar, willow, and pine) across the U.S. under long-term, average climate conditions, using the PRISM-EM environmental suitability model. The map will be of relative yield, ranging from 0 to 100% of maximum. After the meeting, PRISM Climate Group members will incorporate estimates of long-term farm yield at field trial points to transform the best-guess relative yield map into an actual yield map that reflects the knowledge of the team. This is a demonstration that the woody project team is taking the project to the next step, defining today's state of the art with an eye on tomorrow's targets.

REGIONAL FEEDSTOCK PARTNERSHIP: ORNL FIELD TRIAL DATA MANAGEMENT AND ANALYSIS

(WBS#: 1.1.1.3)

Recipient:	ORNL
Presenter:	Laurence Eaton
Total DOE Funding:	$300,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$300,000
Project Dates:	2008-2014

Project Description

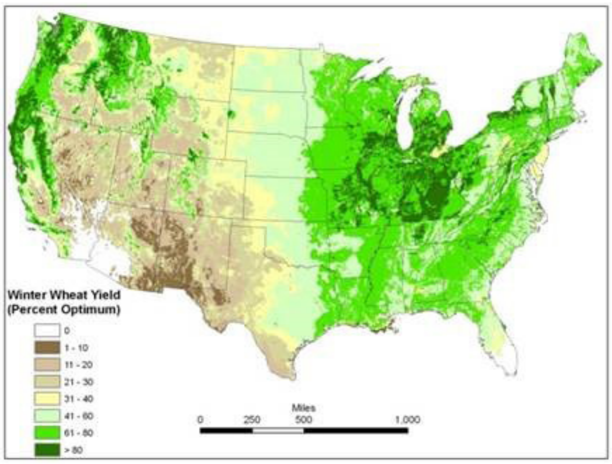
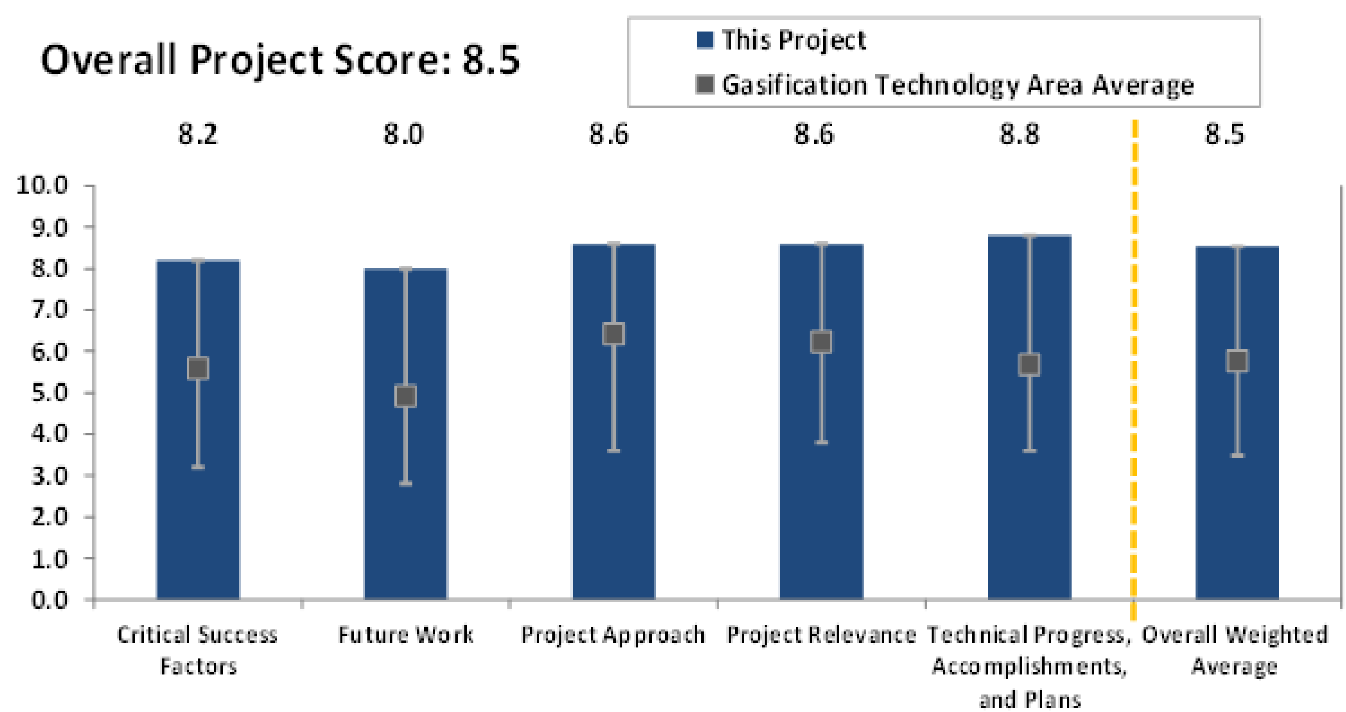


Photo Courtesy of ORNL

Realistic projections of potential yields of biomass crops are critical to the commercialization of biotechnology. This project creates technological tools, provides support, and analyzes data generated by the Sun Grant Regional Feedstock Partnership. As the central hub of field-trial data collection, Oak Ridge National Laboratory (ORNL) verifies and archives data from more than 40 trial locations for seven key crops (switchgrass, *Miscanthus x giganteus*, biomass sorghum, energy cane, CRP grasses, willow, and poplar) and agricultural residues (corn stover and wheat straw) within the Bioenergy Knowledge Discovery Framework. The Sun Grant Initiative online community provides a forum for collaboration and data verification to ensure uniformity and quality control. Future activities (fiscal year 2013–2014) include organization and leadership of separate expert yield workshops between the field trial teams and the resource assessment teams to synthesize individual-site yield potential within a national crop productivity model. The project will



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

provide the bioenergy community the first set of uniformly generated yield-potential maps using state-of-the-art modeling tools calibrated to replicated field trials and, most importantly, reviewed by crop experts. These maps and supporting documentation provide important data for research across the bioenergy supply chain.

Overall Impressions

- ORNL's KDF provides a central clearinghouse for data from Sun Grant feedstock projects, including both archiving and integration with resource assessment and feedstock models for analysis and visualization. This effort currently facilitates interaction within the Sun Grant research community among energy crop researchers and resources assessment modelers. This is currently a closed, collaboration community, with hopes of a public release at some point in the future. Over time, the data should become accessible to the broader community as primary field trial researchers publish their results. Through this project, the DOE Feedstock Technology Area provided a testbed for development of national data management and analysis tools. The effort started very slowly, which is not surprising given challenges of data interoperability, multiple agency research cultures, and concerns about data security, privacy before publication, and trust among researchers. There is increased cooperation from experimentalists, although missing data continues to be a challenge. Data are being used to assess local and regional variability, and to develop and improve national and regional models for different crops. The KDF should continue to serve as a central clearinghouse of the Technology Area, along with the INL Biomass Resource Library. Increasingly, important components are in place, but participation needs to improve, which may imply more work on user needs assessment to make sure that the KDF is adding value to the researchers. There is also a substantial—but largely untapped—external user community that should also be engaged in the development of data protocols, access to tools (including those external to ORNL and DOE), and user interfaces. The current system provides good access to certain limited data (e.g., county-level price supply curves), but does not tap the full richness of modeling and analysis capabilities. If this knowledge system is to function to its full potential, it should not be staffed by scientists and modelers, but needs a staff of curators and librarians trained in information science whose primary focus is on external user communities and public access. This recommendation was raised in the previous review, and progress on these aspects is not yet sufficient. With broader access and information science expertise, the KDF can serve as a platform for serious data mining. This vast storehouse of data will allow us to understand patterns that we do not currently know exist. A much broader community should be engaged in this effort, including information scientists and statisticians at universities. Innovative incentive programs such as competitions and prizes, as well as external grants, should be offered to engage that broader community to both ask and answer new questions that can only be answered by data mining and data synthesis.
- The desire for validation and consistency should not overshadow the importance of measures of variation, even unexplained variation, in the data. Relationships not now evident may be uncovered by advances analysis.
- The project should be congratulated for organizing the data from a wide range of PIs, no small task. However, I am troubled that there was no information provided about the efforts to include potential users of the data as it was being organized. The value of the KDF will be limited if a broad cross-section of the user community is not incorporated into the process early on.
- The up-front planning involved in this effort is an example for other collaborative projects. Resources need to be made available to keep this work on task, and eventually enable broad access to field data.
- Useful product for collaboration and ultimate information delivery to the public.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

SWITCHGRASS BIOFUEL RESEARCH: CARBON SEQUESTRATION AND LIFE CYCLE ANALYSIS

(WBS#: 7.1.2.9)

Recipient:	University of Nebraska-Lincoln
Presenter:	Adam Liska
Total DOE Funding:	$473,800
DOE Funding FY13:	$154,000
DOE Funding FY12:	$154,000
DOE Funding FY11:	$154,000
Project Dates:	2010-2013

Project Description

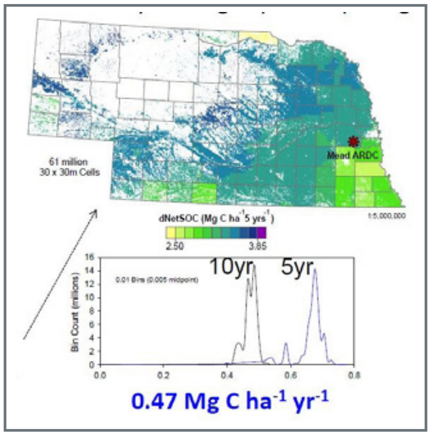
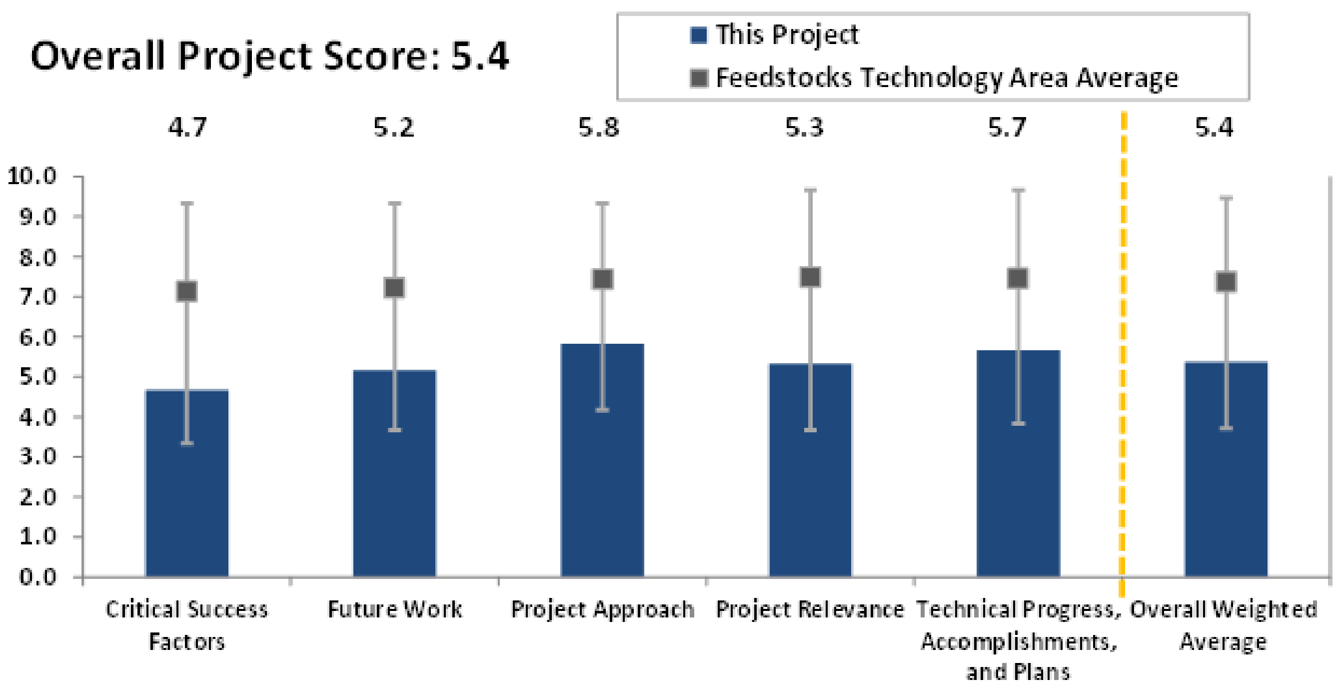


Photo Courtesy of University of Nebraska-Lincoln

This project measures the net differences in field-level greenhouse gas emissions—carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4)—due to corn residue removal for cellulosic ethanol production. Gas measurements are then incorporated into life-cycle assessment of the final biofuel product to determine whether it is in compliance with federal greenhouse gas emissions standards for biofuels (Renewable Fuel Standard-2, or RFS2). The field measurements have been conducted over three years on two, quarter-section, production-scale irrigated corn fields (both roughly 50 hectares, as this size of field is necessary for reproducible eddy covariance flux measurements of CO_2; chamber measurements are used to determine N_2O and CH_4 emissions). Due to a large hail storm in 2011, accurate measurements of CO_2 flux could not be determined for that year, which led us to develop soil organic carbon modeling techniques to estimate changes in CO_2 emissions from residue removal. Modeling has predicted emissions of CO_2 from oxidation of soil organic carbon that are consistent (less than 7%) with nine years



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

of CO_2 flux measurements at the two production field sites, and modeling is also consistent with other field measurements. The model was then used to estimate the average change in soil organic carbon and CO_2 emissions from nine years of simulated residue removal (six megagrams of biomass per hectare per year) at the sites; loss of 0.43 megagrams of carbon per hectare per year resulted. Supercomputing with the model was then used to estimate soil organic carbon changes over 10 years across Nebraska, based on 61 million, 30 by 30 meter grid cells to account for regional variability in initial soil organic carbon, crop yield, and temperature; average loss of 0.47 megagrams of carbon per hectare per year resulted. When these CO_2 emissions are included in simple life-cycle assessment calculations, emissions from cellulosic ethanol from crop residue are above mandated levels of 60% reduction compared to gasoline. This work has been extensively peer reviewed.

Overall Impressions

- Initial outline for collection on pertinent data was good; however, little definitive information was presented. Perhaps a focused orientation with specific bits of data for incorporation into outcomes that would enhance usefulness for producers could be pursued.
- Results from two fields are extending state-wide with modeling. The problem of extending the data from a limited source still exists. The author made the point that the soil chemistry he is using has been supported by others in published work. I can't judge that, but further confirmation of this work with observations in other locations would be needed.
- The goal of this project is to understand the impact of corn stover removal on soil carbon, nitrogen, greenhouse gases, and other environmental impacts through a comprehensive LCA. The specific focus is on irrigated acres of corn grain production in Nebraska. While this project is addressing important sustainability questions, the target (irrigated corn) has long been known to have serious sustainability challenges associated with both irrigation water and soil carbon impacts. This project has documented that those soil carbon losses translate through LCA into biofuel products that fail to meet the advanced biofuel target of a 60% greenhouse gas reduction relative to gasoline equivalents. The results of this study are not a surprise, although hopefully widespread publicity will reduce future interest in this problematic bioenergy feedstock. Hail storms in September 2010 limited the value of field-site data in 2011. The continuous corn cropping system had been losing carbon on these sites even without residue removal. Model validation was good (7% difference) for 10 years of data on that site. Model was then run across Nebraska to simulate the impacts of stover removal. LCA indicates the soil carbon losses will exceed Environmental Protection Agency (EPA) greenhouse gas reduction thresholds without mitigation options. Planned additional field work is limited in value due to the small number of replicates (only two fields). However, given the modeling results, it is not clear what benefit will accrue from continuing this line of research. Closure of the project this year is appropriate. Although alluded to in the presentation, the real challenge is to develop, evaluate, and implement sets of practices that can produce sustainable biofuels in this region. For example, the title of this presentation indicated switchgrass was the subject feedstock. That was presumably a typographic mistake, but is clearly a more logical subject of study.
- There are concerns about LCA boundaries and assumptions in the analysis; presenter did not provide a useful answer to the questions asked.
- Very interesting work and a topic that is critical to the long-term success of the biofuel industry. The modeling/extrapolation methodology needs close scrutiny as the PIs open it to peer review, but the field data collection appears sound.

- Were crops successfully grown in 2011 and 2012? If so, where are the results? Where is a carbon budget?

PI Response to Reviewer Comments

- The useful focused data provided for biofuel producers is the relative change in soil organic carbon and CO_2 emission rates that can be incorporated into LCA models, with the unit of gallons of CO_2-equivalent per megajoule of biofuel; this information can be used directly by the EPA in RFS2 standards. All ecosystem models are based on limited selected data; the model that we use is supported by the research at our field sites (these large production-scale field sites, covering nearly a square mile, have also resulted in nearly 60 research publications over the last 10 years). To extend the model across the larger region, direct field measurements of soil, crop yields (annually), and temperature (monthly average) are used based on geospatial databases. Such dedicated field sites are the basis of advanced scientific understanding of greenhouse gas fluxes in modern agriculture, which is why they have been extensively supported by the USDA, the National Aeronautics and Space Administration, and many other government agencies (our field sites have been supported with nearly $10 million in research support over the last 12 years). We plan to further validate the model with data from other regional field sites, contingent on funding. Continuation of this research would increase the confidence in the understanding of residue removal and net CO_2 emissions by quantifying these changes for building accurate models (more information can reduce the uncertainty in these processes). We believe these are unique experiments. This work quantifies primarily one factor in the lifecycle (CO_2 emissions from soil carbon) and it does not extensively address other factors, as they have been shown to be less significant in the life cycle (LCA results included in our final report will show this). Three related publications describing our measurements and related models are being prepared for submission.

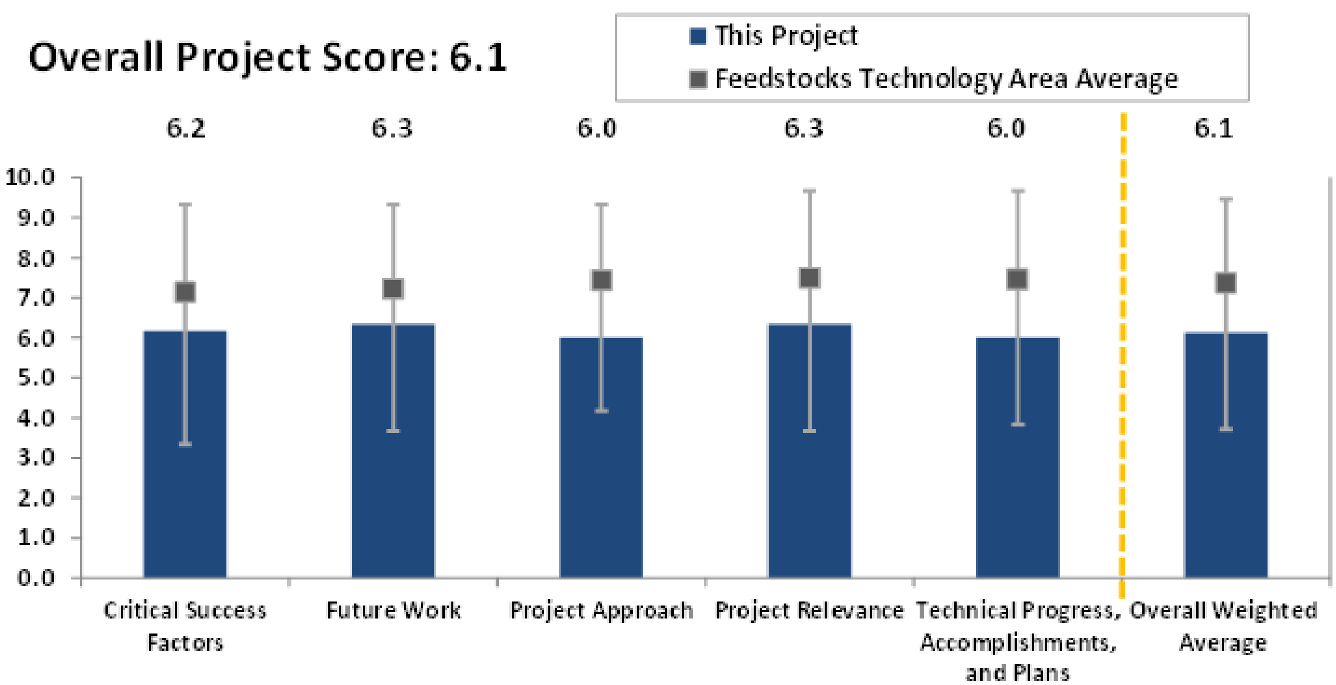
ALTERNATIVE CROPS AND BIOFUELS PRODUCTION

(WBS#: 3.2.1.1; 3.2.1.3)

Recipient:	Oklahoma State University
Presenter:	Philip Kenkel
Total DOE Funding:	$422,624
DOE Funding FY13:	$181,667
DOE Funding FY12:	$146,425
DOE Funding FY11:	$75,300
Project Dates:	2009-2012

Project Description

The research focused on four critical areas of the biofuel supply chain. A composite ratio approach was used to project switchgrass yield for every major soil type and county. This identifies potential supply and paves the way to model yield variability. The potential supply for the top five most abundant soil types in Oklahoma was 49 million tons per year. Similar estimates were prepared for seven other states in the southern plains. An economic engineering approach was used to analyze the costs of harvest, transportation, and storing switchgrass. The analysis also examined a producer-owned cooperative structure. Harvesting and transportation costs were projected at $18 per ton, with the harvesting cooperative achieving a 29% cost savings over individual operations. The model indicated that the majority of the economies of scale in harvesting can be achieved with 5,000 acres of coordinated harvesting. Feasibility templates were developed for lignocellulosic ethanol, sweet sorghum ethanol, and biodiesel production. A mixed integer optimizing model was used to identify the optimal number, size, and location of biorefineries. The model determined the least-cost locations and industry expansion path. The break-even price of cellulosic ethanol was estimated at approximately $0.74 per liter with cost increasing to approximately $0.77 per liter for a nine-plant industry. A community economic impact model examined the direct, indirect, and induced economic impacts of a 50-million-gallons-per-year biofuel plant under alternative ownership structures. The combined industry impact for a 50-million-gallons-per-year biorefinery was $70 million and 556 employees for a privately owned firm, and $86.1 million and 726 employees for a locally owned cooperative. These four



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

integrated components addressed the economic barriers to commercialization.

Overall Impressions

- A more focused project design with achievable outcomes may be warranted. Need connections between various parts of the study.
- Clear, effective, well-presented.
- The project has identified several critical points in harvesting, economies of scale, and sensitivities that will have utility across feedstocks and geographies.
- This project may contain more value than was apparent in the presentation. Peer review of proposed publications may determine whether that is so. Most results are simply stated, but not supported with adequate model detail.
- This project modeled a switchgrass bioenergy supply chain, including feedstocks, harvest and logistics, conversion processes, and economic impact. In addition to switchgrass, the team developed templates for sweet sorghum ethanol and biodiesel feedstocks. The supply chain model identified optimal size and location of biorefineries. Results indicate large volumes can be available in Oklahoma at modest costs. Economies of scale can be achieved with 5,000 acres of coordinated harvesting, and harvesting cooperatives can reduce harvesting costs by nearly 30%. The transparent platform allows entrepreneurs and planners to evaluate potential projects in a useful and flexible format that businesses can use. This approach could serve as a model for other regions in the U.S. Consideration of business models for different economies of scale is critical as this industry scales up. Standardization of approaches is important and they have made important strides, but the process and produce are not well integrated into other national programs. This is a role that the Bioenergy Technologies Office should play.
- This project provided no data on the results of their work, only summary figures. While 100 individuals may have downloaded the model, what has been result of those efforts? With no significant data reported, it is difficult to assess the impact of this work.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

LAURENTIAN BIO-ENERGY PROJECT (MN)

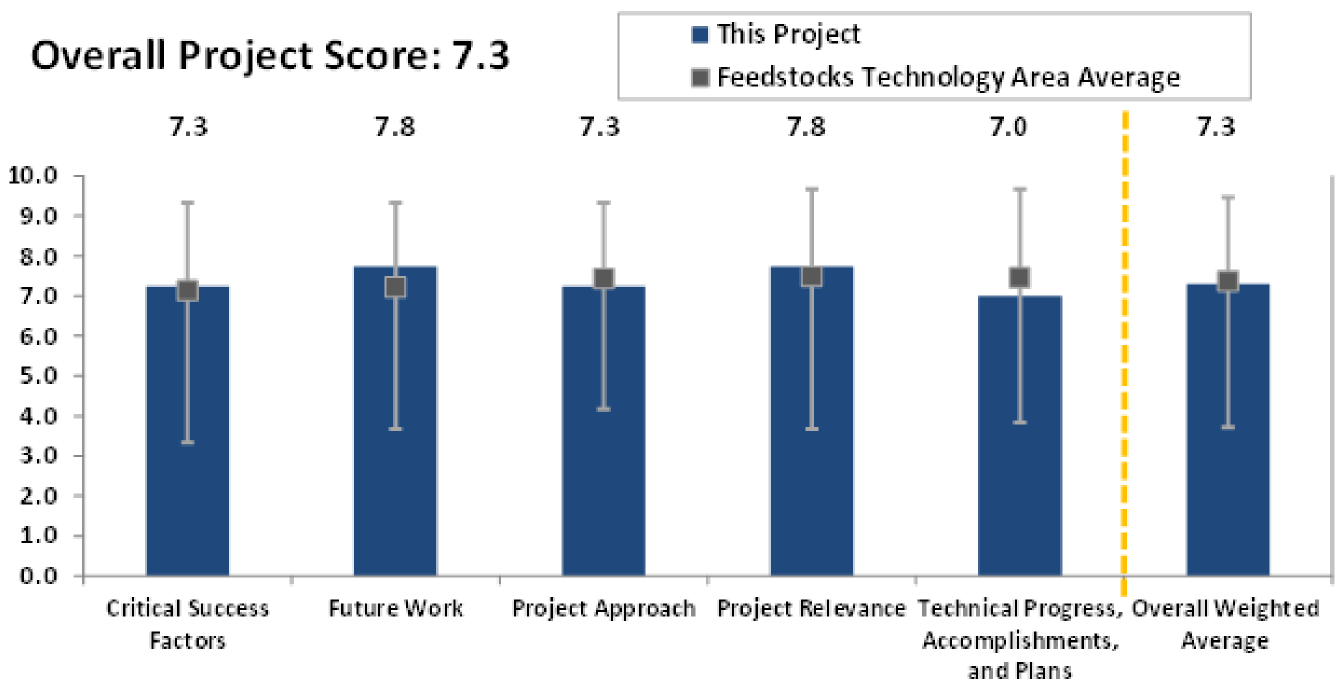
(WBS#: 7.1.5.4)

Project Description

Photo Courtesy of Laurentian Energy Authority

Recipient:	Laurentian Energy Authority
Presenter:	Bill Berguson
Total DOE Funding:	$2,221,500
DOE Funding FY13:	$350,000
DOE Funding FY12:	--
DOE Funding FY11:	$148,180
Project Dates:	2007-2014

This overall project's purpose is to assess the feasibility of producing woody biomass for the Laurentian Energy Authority facilities in Virginia and Hibbing, two biomass-fired district heating systems located in northern Minnesota. The project evaluates the economic and operational feasibility of various biomass sources in Minnesota. The project tasks include development of best management practices for harvest of brushland biomass and forest harvest residues; analysis of best available technology for harvesting brushlands; biomass availability and collection technology for forest harvest residues and rights of way; and evaluation of available soils and variation in productivity of poplar plantations. Since the original appropriation, the project has been modified to add tasks of assessment of biomass availability through thinning of aspen and red pine, as well as enhanced poplar research through genetic improvement and productivity research in association with the DOE-Sun Grant Regional Biomass Feedstock Partnership. Accomplishments to date include completion and adoption of first-of-a-kind statewide recommendations



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

for biomass removal in forested and brushland environments, development of a method to assess brushland biomass density resulting in improved evaluation of harvest logistics and costs, and estimation of the economics and logistics of collection of forest harvest residues. Additional project results are establishment of the largest network of red pine and aspen thinning research in the U.S., and establishment of one of the largest poplar breeding and field-testing programs in the U.S. Current work includes analysis of biomass production in thinning trials, and poplar breeding and genetics field trials in association with the DOE-Sun Grant Partnership. An anticipated modification of this project will allow continued national leadership in development of poplar as a dedicated energy crop, in addition to assessment of opportunities to procure woody biomass through thinning operations in existing forests in Minnesota.

Overall Impressions

- Although this was conceived as a localized project, it has been managed in a way that contributes results that can be used in a wider realm.
- Apparently provided a positive situation for industry, government, and academia working in concert. Involvement of community, commercial interests, and environmental concerns during project design and development was good. Hopefully this type of approach could be used as an example for other needs.
- Project appears to have been successful in increasing genetic material available and making guidelines available for others.
- Project is making good progress toward the demonstration of a bioenergy combined heat and power plant

PI Response to Reviewer Comments

- No official response provided at time of report publication.

FEEDSTOCK LOGISTICS ENGINEERING

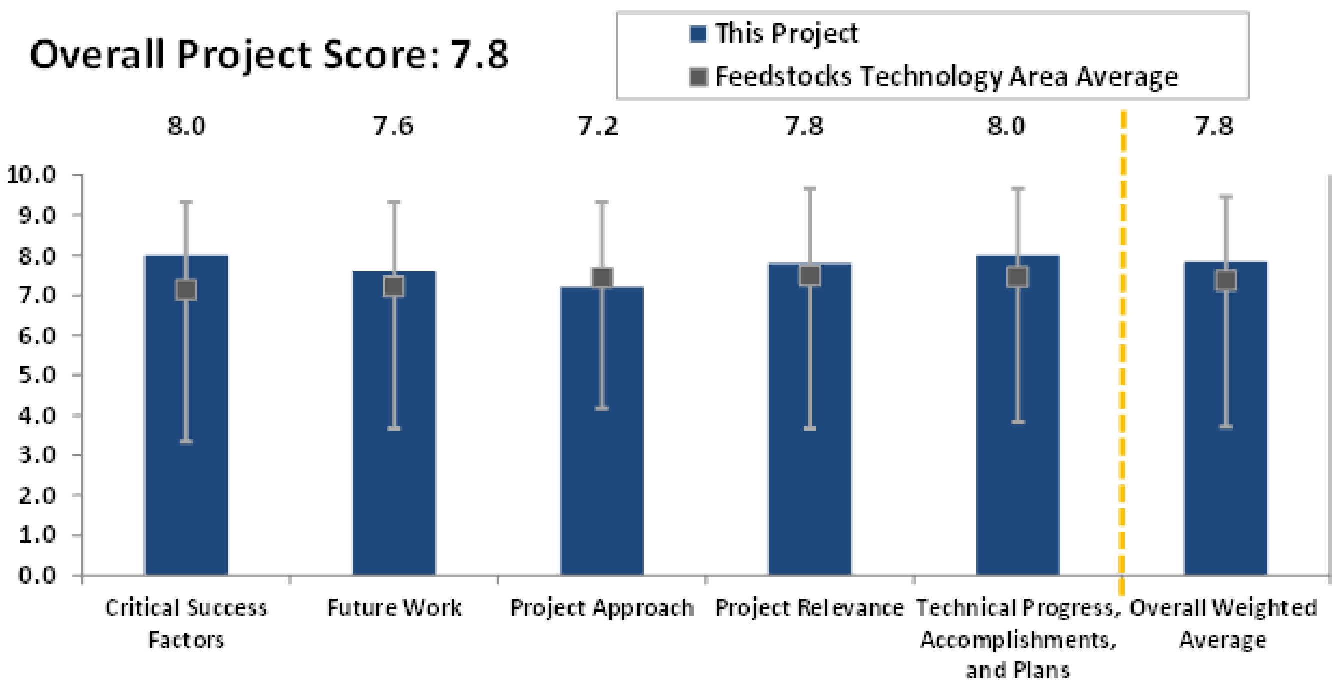
(WBS#: 1.3.1.4)

Recipient:	INL
Presenter:	Kevin Kenney
Total DOE Funding:	$21,000,000
DOE Funding FY13:	$1,850,000
DOE Funding FY12:	$2,200,000
DOE Funding FY11:	$2,600,000
Project Dates:	2006-2017

Project Description

Photo Courtesy of INL

Lignocellulosic biomass feedstock supply system designs are generally adapted from agricultural forage system models that supply hay and forage to dairies, feedlots, and farms. Through DOE investments in feedstock logistics, much has been learned to differentiate the attributes of a national-scale biomass market from hay and forage markets. Attributes of versatility, sustainability, and stability (i.e., preservation of biomass quality) have necessitated fundamental changes to equipment, processes, and best management practices to support the sustainable supply of low-cost feedstocks to a national biofuels market. The development of biomass-specific machinery and research-based best management practices for harvesting, storing, and processing biomass crops has helped overcome sustainability, quality, and loss challenges, and enables feedstock cost reductions that achieve DOE's target for herbaceous feedstock logistics. This presentation will highlight specific feedstock R&D accomplishments associated with achieving the 2012 cellulosic ethanol cost target. These include field research, analytical characterization of harvested material, and statistical analysis of field efficiency and sample quality data to develop best management practices for minimizing soil contamination in harvest crop residues. Further, biomass storage research will be presented to show how a better understanding of moisture behavior



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

in biomass storage systems has resulted in the development of biomass storage best management practices, which can limit dry matter losses to less than 10%. Finally, biomass preprocessing research will be presented to show how understanding the mechanics of biomass deconstruction has enabled exploitation of impact and shear forces in biomass grinder design to reduce energy consumption, increase grinder throughput, and produce more consistent feedstock products.

Overall Impressions

- Excellent job of systematically targeting issues and implementing appropriate research.
- Methodical approach, but not clear how widely the technology improvements have been communicated or deployed in industry.
- Problems are being solved by the diligent application of engineering principles.
- This project shows the evolution of the logistics system over the five-year period and an achievement of the stated goal for delivered biomass cost. The project has been effectively managed to make the advancements hoped for. This project has moved forward in an expected manner. Future work to extend these results to additional feedstocks is desirable and appropriate.
- To ascertain relevant costs for delivery of material to converter throat, need to utilize actual numbers based on findings published in peer reviewed journals rather than models based on assumptions and attempts to meet set target numbers. With respect to utilization of corn stover as a biomass source, various items of interest must be considered:
    - The material must not touch the ground, as soil bacteria will be incorporated.
    - Corn leaves do not grind with conventional particle size reduction equipment; therefore, corn stover cannot be transported with air.
    - For biological conversion technologies, ash content should be less than 5%; however, when harvesting second pass corn stover, mineral content is 15 to 30%.
    - For thermochemical conversion technologies, ash content must be less than 1%, preferably less than 0.1%.
    - Except for producers who artificially enhance water available in sand, one pass over a field at harvest time is all that is acceptable.
    - Locations for storage of corn stover have not been established. Stacking on a farm field is not acceptable due to field conditions at the time of removal.
    - Many true environmentalists (landowners) provide tender, loving care to their land. As such, they would not allow a second pass by a custom operator with a driver not cognizant of soil compaction, ruts in the field, and interference with other operations like manure handling and fertilization.

PI Response to Reviewer Comments

- We communicate our research through high-quality, peer-reviewed journals, but we recognize that prospective operators do not likely read these journals. Therefore, we also communicate in the form of best management practices that are disseminated through our industrial collaborators.
- The data underpinning the achievement of the $35 target is solidly rooted in INL R&D, involving improvements in feedstock harvest, storage, and preprocessing. These improvements were detailed in the peer review presentation; some have already

been published in peer reviewed journals and other manuscripts are in various stages of publication. A final demonstration of this accomplishment was conducted at-scale with data supporting estimation of relevant feedstock costs typical of conventional feedstock supply system designs.

- Many factors must be considered in developing a sustainable and economical feedstock supply chain. The reality is that there is not a one-size fits all solution. Factors that may be limiting for one crop, grower, or refinery may not be limiting for others; operations and processes that may work in one scenario may not work in others. We have tried to address this by first initiating our research with intensive modeling and simulations that cover a broad range of inputs and outputs to identify broadly applicable barriers and uncertainties. Our research—and ultimately, our solutions—then have the best chance to be broadly applicable to the emerging industry rather than point-source solutions that are applicable only to niche resources or specific scenarios.

FEEDSTOCK LOGISTICS FUNDAMENTALS

(WBS#: 1.3.1.3)

Project Description

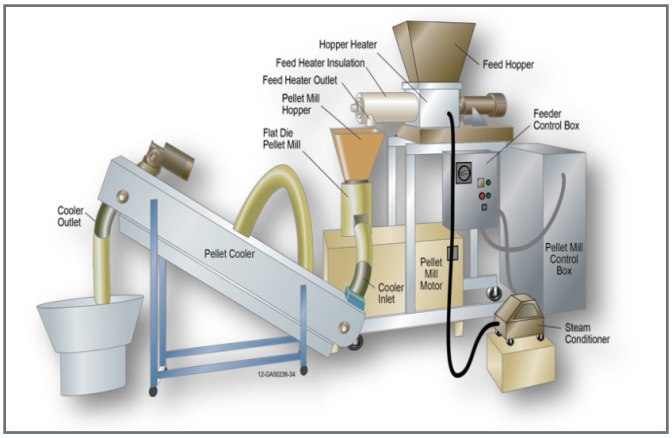
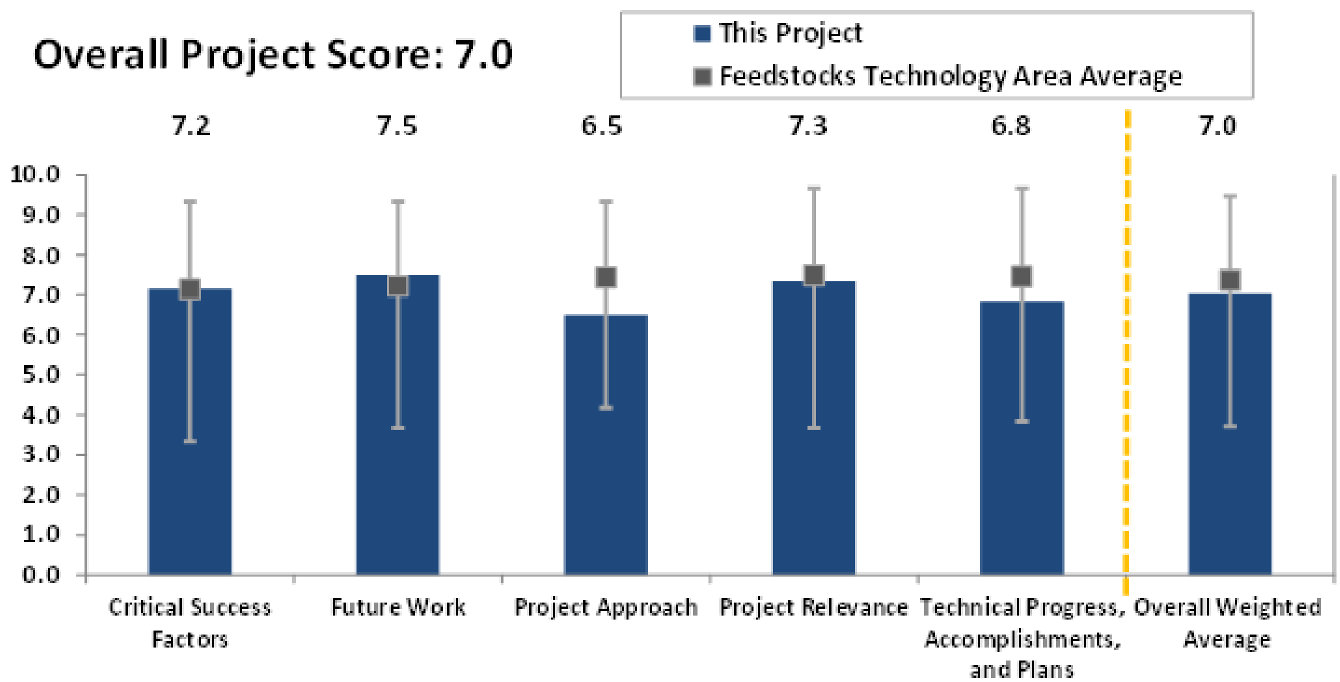


Photo Courtesy of INL

Recipient:	INL
Presenter:	Jaya Shankar Tumuluru
Total DOE Funding:	$6,000,000
DOE Funding FY13:	$1,850,000
DOE Funding FY12:	$1,200,000
DOE Funding FY11:	$1,500,000
Project Dates:	2009-2017

Biomass pre-conversion fundamentals is focused on systematically identifying, developing, and testing advanced preprocessing operations and systems that will be necessary to solve barriers associated with out-year (three to five years) BETO cost and technical goals. The DOE Biomass Densification Workshop held at INL in August 2011, introduced advanced preprocessing technologies that included mechanical separations, chemical pre-conversion, formulation, and densification. Workshop participant feedback was used to identify opportunities and barriers facing the development and deployment of these technologies. These barriers were identified and introduced in the R&D plans of the Feedstock Logistics Fundamentals project (WBS 1.3.1.3). Improved cost-value relationship was identified as a common barrier for these advanced preprocessing technologies to be viable for insertion into the feedstock supply chain. The 2013 Peer Review will present progress and accomplishments in defining and improving the cost-value relationships of these technologies.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Probably good work, but presentation and answers to questions not usefully clear about methods and outcomes.
- The project is ambitiously looking to solve critical problems in commercialization of biomass, and has the potential to deliver high returns over the remaining years of the project.
- These results highlight the value of challenging assumptions and "things everybody knows."
- This is important work and should be continued, providing it continues to show progress.
- This project has demonstrated low-severity chemical "pre-conversion" that homogenizes and reformulates diverse feedstocks to achieve predictable and uniform biomass characteristics. There is a substantial opportunity to aggregate diverse, low-value feedstocks and use low-cost pre-conversion strategies to upgrade the feedstocks' value to meet industrial specifications. This project demonstrated that blending and reformulation of feedstocks through low-severity chemical pre-conversion can help achieve important cost reductions, as well as economies of scale. These low-cost strategies can both enhance biomass value (cleaning, etc.) and reduce downstream costs. Plans for future work will address fundamentals to enable lower-cost, large-scale feedstock formatting. Although there appear to be significant commercial benefits to this approach, this project has no industrial collaborations at present. While such collaborations are planned for the future, there is a missed opportunity to leverage industrial knowledge and tune the feedstock formulations and preprocessing conditions to meet specific technology requirements, and to develop feedstock independent specifications that will apply to a variety of major conversion technologies.

PI Response to Reviewer Comments

- It was a challenge to provide all the details about methods and outcomes of four different tasks — densification, formulation, mechanical separation, and chemical pre-conversion—in the allotted 20 minutes of the total presentation time. Rather than spending only five minutes for each task, we chose to focus more on the densification task because it has received the bulk of the funding in the last two years. Based on the reviewer's comments, the approach and outcome of densification is well understood. We have methods and outcomes for all of the tasks; however, time was limited to provide all the details. We expect that the additional details provided in our responses to the reviewer comments will provide more clarity. The experimental data generated from these tasks will be presented in national and international conferences, and published in peer-reviewed journals, to show progress.
- Regarding industrial collaborations, we initially started the advanced pre-processing tasks with industry and stakeholders' input through the DOE Densification Workshop conducted at Idaho National Laboratory to identify the barriers/ challenges. We have since focused on TEA to identify the goals and feasibility of technologies in these tasks. Following completion of TEA, we will re-engage with industry in development and scale-up of these technologies. Presently, we are collaborating with equipment manufacturers to assess the suitability of existing equipment for these tasks. Having said this, the challenges with the advanced technologies mentioned in the presentation are acceptability of new feedstocks and unproven processes. Our plan is to continue leveraging both biochemical and thermochemical interface tasks to test the product performance, and use engineering tasks for scale-up of new technologies based on the fundamental knowledge developed in this task. This approach will help us attract industrial partners for commercial deployment.

INDUSTRIAL LOGISTICS (SUPPLY SYSTEM INTEGRATION)

(WBS#: 1.6.1.9)

Recipient:	INL
Presenter:	Robert Jeffers
Total DOE Funding:	$1,900,000
DOE Funding FY13:	$750,000
DOE Funding FY12:	$250,000
DOE Funding FY11:	$285,000
Project Dates:	2009-2022

Project Description

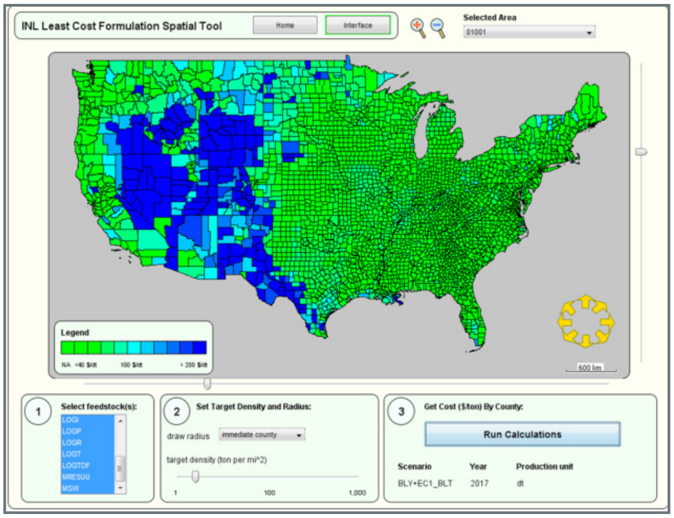
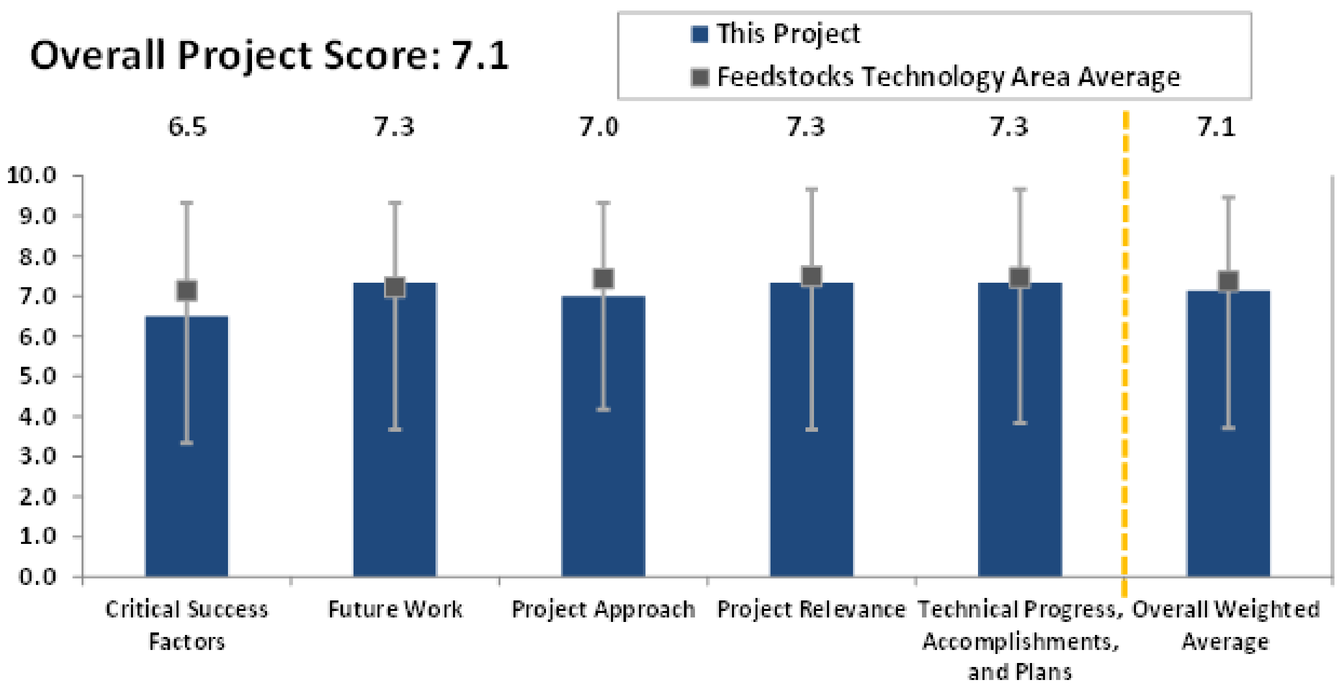


Photo Courtesy of INL

This project is titled Feedstock Supply System Integration and is focused on developing the tools and databases necessary to support the Feedstock Technology Area. The goal of this work is to facilitate integrated, rigorous engineering assessments of supply system configurations to develop the relationships between delivered feedstock cost, accessible volumes, and delivered feedstock specifications. Supply system analyses have typically focused on understanding how a collection of equipment and processes function within certain constraints, such as cost and throughput. The development of a national-scale biomass industry requires analyzing supply-system designs as more tightly integrated components of the larger bioenergy system. This requires explicitly coupling the supply-system design analysis with the biomass-resource production and conversion interfaces. For the resource production interface, a supply system design analysis must be properly informed as to the location, distribution, and environmental conditions for the resources it utilizes; the physical and



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

chemical composition characteristics of the resource; and the suite of sensitivities associated with access to that resource. Through the conversion interface, the processes within the supply system will create a commodity biomass material that must provide a high-value feedstock for conversion processes. This project is establishing the relationships across these interfaces and within supply system operations through integrated utilization of data and modeling resources.

Overall Impressions

- Approach appears to be multi-objective coupling of system-level models linked for optimization. An interesting and hopefully useful tool. Should work on how to display uncertainty in the outcome in easily displayed/understood terms (sooner rather than later), and include frontline users in the development (e.g., businesses, communities).
- The access to data provided by these and similar tools is invaluable to the research community and encourages public support for bioenergy research.
- There are many questions as to model implementation over this long of a project time. Are the output simplifications based on outdated technology? Will they be updated through time as our knowledge of optimum conditions change? The Biomass Library is certainly very worthwhile, but the graphic model output may not be appropriate on a county level. I think it is too simple for industry, and too suggestive for individual investors. It is supposed to inform the most promising areas for research, but I don't see that this will be the most common use.
- This is a potentially valuable effort, but it will be a complex task, and one that will likely have difficulties capturing the complexities of interactions between unit operations in the modeling effort. Coordination with the similar efforts toward the KDF at ORNL is needed.
- This project includes the development of the INL Biomass Resource Library, as well as a biomass logistics model that evaluates cost and volume data to project least-cost formulations at a county level, and simulates logistic pathways that couple feedstock resources to conversion facilities. Of particular importance, the project provides a public interface for external stakeholders to access biomass feedstock characteristics and logistics modeling tools. This project has multiple, very high-profile products. The Biomass Resource Library allows users to assess the means and statistical variation of biomass characteristics as a function of feedstock source (for specified geographical locations and growing conditions, varieties, and anatomical components), and how they are impacted by various harvest, preprocessing, and storage unit operations and coupled systems. The web-based biomass logistics model is providing county-level logistics costs to inform both national resource cost assessments, as well as screening regional opportunities for site selection. The library and logistics tools also allow users to input their own data and explore alternatives. The project has demonstrated that formulations that blend feedstocks of different costs and qualities to meet conversion technology specifications can reduce costs and increase the range of regions where biofuels will be cost effective. Collaboration at present is entirely within the research community. There is a need to get the consultants and industry analysts involved early so that system design and user interfaces are responsive to their needs, and to demonstrate value to the Biomass Library's contributors. That can be accomplished by engaging the potential user community in focus groups and beta-testing evaluations, and by employing library scientists and information scientists to apply their expertise in data access, user interfaces, and data visualization. One important need for the logistics model is to allow external users to "plug and play" with new technologies without having to wait in line or become a priority for DOE's internal workflow. We are seeing the beginnings of an explosion of logistics technologies, from new harvesting equipment, to preprocessing and storage technologies, and it would benefit this nascent industry to allow others to quantify their technologies and assess their

feasibility and impact on the entire value chain, including both feedstock quality and logistics cost. This library and toolset are well poised to meet that challenge, but again, issues of access and interfaces are key. The Biomass Resource Library, logistics modeling framework, and user interfaces will be extremely valuable over time. Given the focus and relevance of this effort for critical business decisions, a strong and active industrial advisory board should be an integral part of this project.

PI Response to Reviewer Comments

- This project develops three separate but coupled components: the Biomass Resource Library, which includes characteristic and pedigree data for biomass throughout supply chains; the Biomass Logistics Model, which takes volume and characteristic data and returns a cost of logistics pathways; and the Least-Cost Formulation Toolset, which couples cost versus volume data at the county level from POLYSYS, characteristic data from the Library, and cost versus characteristic runs from the Biomass Logistics Model. Therefore, this has a complementary relationship to the KDF, in that an interface to the Biomass Resource Library will be accessible through the KDF. This allows researchers to upload, view, download, and run preliminary analysis on data being generated throughout the Partnership. The Least-Cost Formulation Toolset will sit atop the Library as the integrative component, run through the web and accessible through the KDF. This does not mean the actual internals of the modeling is shared; rather, that the interface is accessible.
- The Least-Cost Formulation tool will provide some "predictive" elements. It will inform researchers about cost, quality, and volume interdependencies, and progress to a more risk-based approach. The Library, along with the POLYSYS results, will be responsible for descriptions, while the Least-Cost Formulation tool is responsible for predictions. These will be combined to help BETO and others understand more about biomass supply chains.
- We recognize that increased industrial collaboration is needed, but that industry has risks being involved in the development cycle. The Library—along with the Least-Cost Formulation toolset—is part of our strategy to better communicate research with industry and help reduce risk. Part of this development is demonstrated firewalls to protect data in the Biomass R&D Library when cooperating with industry partners.

FEEDSTOCK SUPPLY CHAIN ANALYSIS

(WBS#: 1.6.1.2)

Recipient:	INL
Presenter:	Jacob Jacobson
Total DOE Funding:	$1,966,608
DOE Funding FY13:	$450,000
DOE Funding FY12:	$466,000
DOE Funding FY11:	$475,000
Project Dates:	2005-2022

Project Description

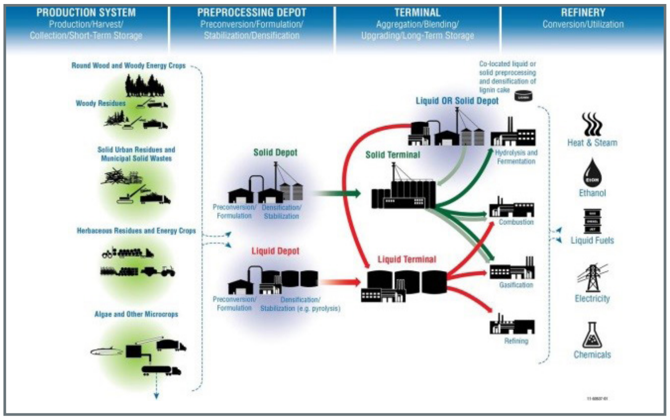
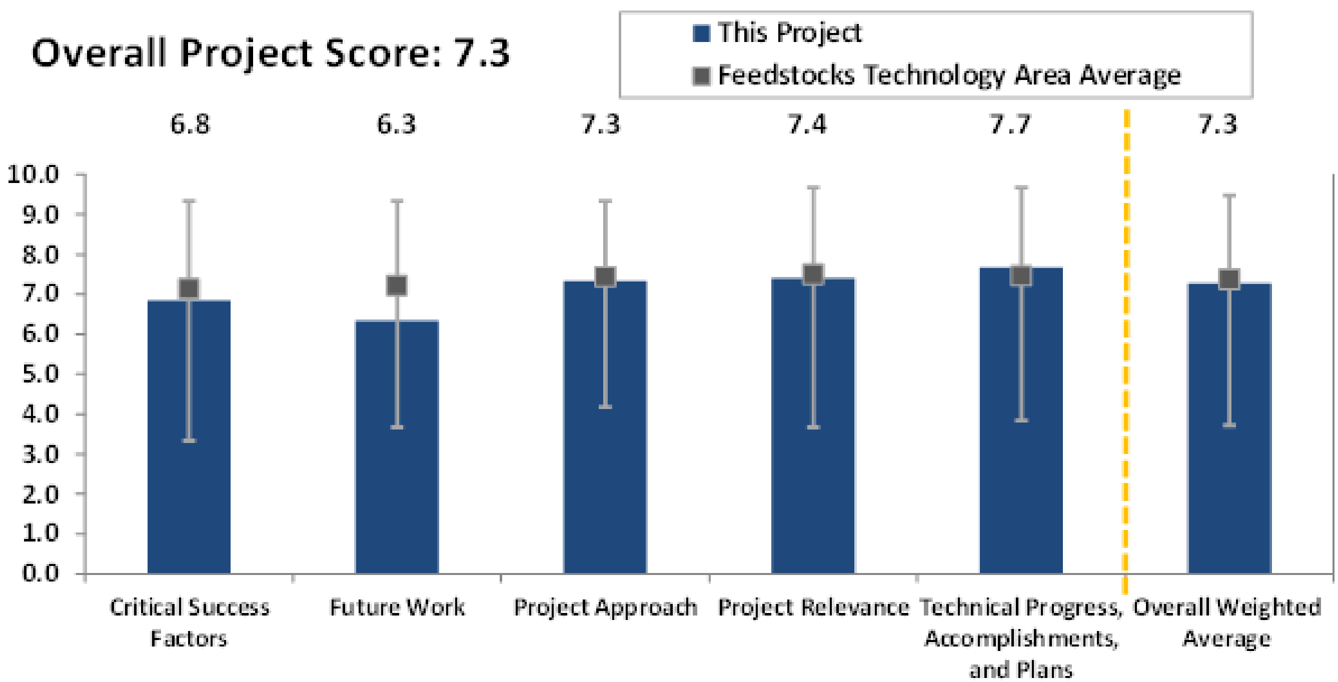


Photo Courtesy of INL

This project is titled Feedstock Supply Chain Analysis and is focused on analyzing biomass feedstock supply system designs. The main deliverables from this project are the annual state-of-technology reports for each of the logistic supply systems that apply to the eight DOE R&D conversion pathways. The state-of-technology reports are the yardsticks that we use to mark the annual progress that the Technology Area has made toward the 2017 and 2022 biofuel targets for both BETO and the RFS2. This task also has helped develop the proposed goals and yearly targets that are outlined in BETO's MYPP, which is the guiding document for the entire Bioenergy Technologies Office. Additionally, the analysis from this project identifies current cost, volume, or quality barriers to making biofuel competitive with fossil fuel while reducing greenhouse gas emissions and meeting sustainability requirements. Identifying barriers is also useful for directing research into areas that are most impactful. This project entails close collaborations with the INL engineering and science teams performing projects on the various processes



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

within the supply systems, such as feedstock storage, densification, grinding, transportation, and pretreatment. Each of these other projects supply their research data and models to the analysis task to compile the impacts to the logistic supply systems. Finally, the emerging idea of blending low-quality, low-cost feedstocks with high-quality, high-cost biomass material is imperative to reaching the volumes required under the Renewable Fuel Standard while also meeting the cost targets. This analysis requires integrating the *Billion-Ton Update* data from ORNL and the Biomass Library data on biomass characteristics into a single analysis framework that matches biomass types with the in-feed specifications for conversion technologies. This least-cost formulation analysis is a great example of adapting this analysis project to meet BETO requirements.

Overall Impressions

- Important part of the overall BETO portfolio.
- Not sure what this project is other than communications and report writing.
- This is an important project that supports most of BETO's activities with background information. In this presentation, it was not made clear how this effort is integrated with or utilizes either the KDF or the Biomass Library described in previous presentations.
- This project is providing the analytical basis for BETO's goals and progress across many dimensions of supply chain logistics, using system-level analysis to identify strategic and tactical opportunities to advance research on biomass feedstock supply chains. Goals include the identification of technology and financial barriers and opportunities, advanced technology and logistics design, and public information. Given these goals, it is imperative that this system be fully transparent and also be responsive to important innovations across the value chain. This is clearly a core responsibility for BETO, and should help drive other research investments across this Technology Area. This is an essential, high-productivity program. Synthesis of multiple research projects and data sources has resulted in major advances in the conceptualization and implementation of low-cost, high-volume feedstock supply chains. Recent progress has been substantial, but near-term opportunities have the potential to be even more dramatic. Of particular importance to achieving this potential is a focus on research gaps, unexploited technology opportunities, and a diversity of scale-up trajectories. For example, there appear to be several areas of path dependence that make it difficult for the Technology Area to shift course. Project results show the need and benefits of blending diverse feedstocks, but that requires understanding the behavior of a much broader range of materials under different moisture regimes during harvest, storage, and preprocessing. A well-articulated evaluation and presentation of these data gaps should be prepared to inform priorities for future research. It is not clear how stakeholders are involved with this systems analysis effort other than as subjects of study. At a minimum, there should be an industrial advisory group engaged more often than in annual reviews. There is also a great need for a consensus-building effort to develop common metrics for analysis, especially for DOE-funded projects whose data should be available for "apples to apples" comparisons. This project and, indeed, the entire Technology Area, have done an outstanding job of focusing a large number of research projects on a critical need for the biomass industry. Several low-cost, practical strategies have been demonstrated and progress has been rapid and significant. Substantial continued support for this effort is strongly recommended.
- This project provides important analyses that are valuable to program management and outside users. They should not, however, try to shape the future of the industry by the structure of their analyses.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

CHINA TASK (IN 2011, CHINA - BIOMASS SUPPLY LOGISTICS)

(WBS#: 6.5.2.5)

Recipient:	INL
Presenter:	Christopher Wright
Total DOE Funding:	$835,000
DOE Funding FY13:	$235,000
DOE Funding FY12:	$100,000
DOE Funding FY11:	--
Project Dates:	2010-2015

Project Description

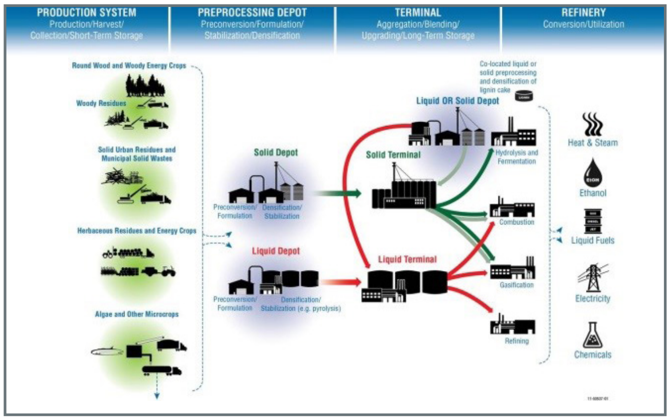
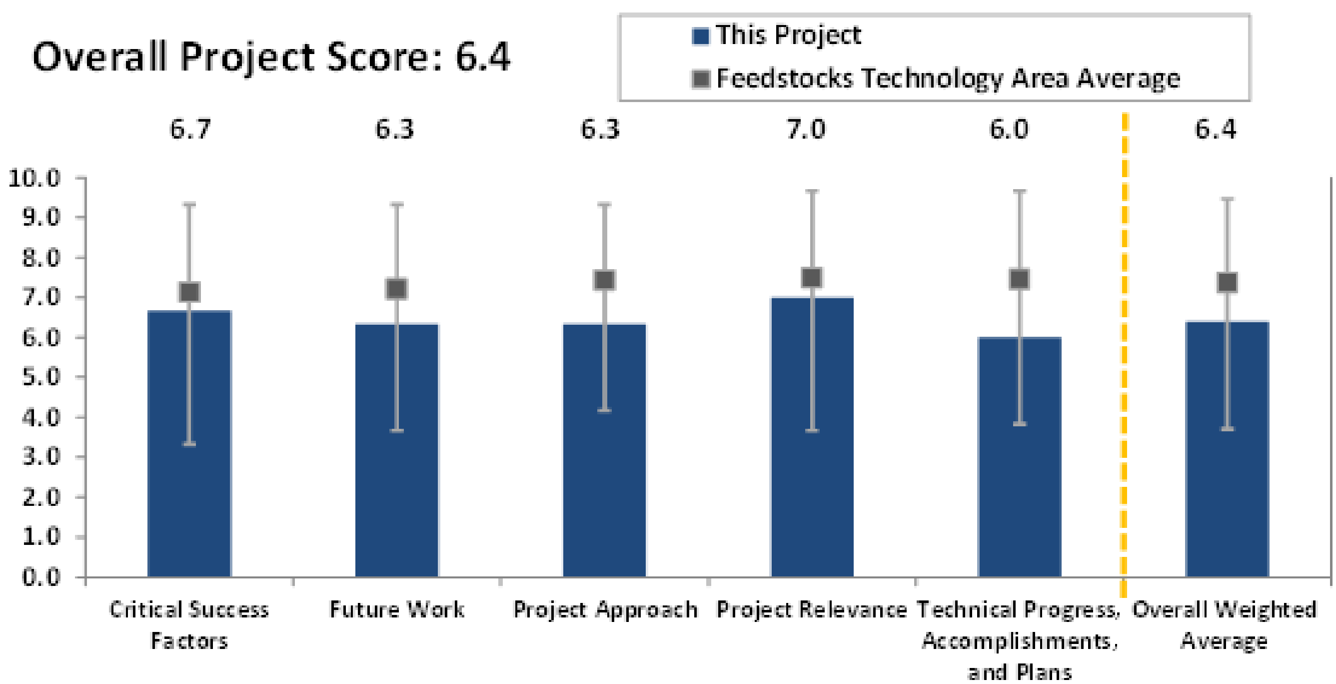


Photo Courtesy of INL

This project is titled China-Biomass Production and Supply Logistics and is focused on establishing a bi-national working group between the U.S. and China in order to identify and research barriers in biomass logistics and feedstock quality at large-scale, high-volume utilization; this will encourage U.S. industry to target technologies that can be implemented in the immature Chinese feedstock supply system. The main deliverables from this project are to establish collaborative relationships with Chinese-identified research institutes, exchange feedstock production and logistics methods, develop and populate databases of key production/logistics data, enhance the U.S. models, and expand the current models to capture international trade. DOE has a vested interest to expand the current biofuels program across international boundaries to promote industrial trade between the U.S. and international partners. China is of particular interest due to their current inefficient, highly secular, man-power-based biomass supply systems and their immature biopower and biofuel industries. There are opportunities for the U.S. to help support China as they expand their biopower and biofuel industry from a technical perspective, as well as an equipment and industrial perspective. This project will expand on some earlier international modeling of biomass transportation that was done in Western Europe.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

The vision is to allow China to expand their biofuel and biopower industry much quicker with help from the U.S., which will help China meet their growing demand for energy while minimizing greenhouse gas emissions. From the U.S.' perspective, it is a chance for the U.S. to expand their industrial ties with China and open up markets for agricultural equipment and biomass exports.

Overall Impressions

- Employs a rational approach and appears to effectively use internal and partner expertise. Useful tools adapted for Chinese conditions allow testing of the U.S. model's structure for robust applicability. Relevant because it addresses means to assist China in developing domestic resources and reducing pressure on global energy resources; this is a benefit to U.S. energy security and an opportunity to gain new information, as well as a means of enhancing U.S. energy and economic options. Success factors and critical challenges seem well understood and articulated. Apparent strong sensitivity to Chinese needs in this and opening systems to international participation so that the U.S. can create more-robust, domestic answers.
- International collaboration, especially with major energy and especially biofuel producers and consumers (e.g. China, Brazil, and Europe), is critical not just for global sustainability, but also to inform and assure best practices to leverage research advances around the world. The team has established effective collaborative relationships with key organizations; is actively exchanging data, methods, and models; and is expanding and enhancing models to address similarities, differences, and emergent properties of biomass feedstock production and supply chains. DOE representation on the International Technical Feedstock Working Group and its associated programs provides a platform for investigating both intra-national and international biomass supply chains. One particular area of collaboration that deserves greater emphasis is in sustainability analysis, and the integration and explicit inclusion of those metrics in feedstock production and supply chain analysis. Although the initial iteration of this China Task has been only of modest impact, if restructured, this project can provide an excellent example of leveraging U.S. research investments for international development and global sustainability. Feedstock and supply chain research is central to this effort, and there is considerable benefit from sharing knowledge about these systems in both directions, validating assumptions and advancing approaches.
- This project does not seem to be funded at the right level for interaction with the Chinese biofuel market. The current technical outcomes, such as the model and analysis of the Chinese system, don't have the broad audience they need; this audience just cannot be developed one scientist at a time. If this goal is truly important, it needs more resources and a more thoughtful work plan with key Chinese scientists identified, conferences planned, and leadership roles taken.
- This project is primarily an outreach effort that may provide some value in extending the range of evaluation of INL products, but is unlikely to have any direct positive influence on the U.S. effort to establish a biofuels industry.
- This project provides an opportunity to develop system optimization tools for both the U.S. and Chinese bioenergy industries, though it would require some restructuring of the project. The Chinese partners might bring a new approach to the table.

PI Response to Reviewer Comments:

- This project's focus is the establishment of strong, sustainable, researcher-to-researcher and institution-to-institution relationships that will enhance U.S. capabilities, promote U.S. industry, expose Chinese markets, and relieve pressure on U.S.

energy needs. A key success is the International Feedstock Working Group that resulted in data and information flow from China to the U.S., and enabled the expansion of in-country logistics models and country-to-country intermodal transport models (leveraged work done with the European Union and Utrecht University). Through the working group and modeling successes, the U.S. is positioned to become a world provider of biofuels technologies, leveraging the best research in China, and ensuring global sustainability of the biofuels industry.

- Future work within this project has three thrusts: develop an international branch of the Biomass Resource Library to enhance the existing U.S.-based version; perform and publish the results of site-specific analyses using a Chinese logistics model; and perform an industry-led, feedstock-supply-system field demonstration in China. INL strongly feels that this approach will strengthen DOE as international leaders in biomass feedstock research, development, and deployment and will provide a competitive advantage to U.S. industries. However, INL also realizes that these thrusts may be resource-limited if left only to DOE support. Thus, it is INL's strategy to heavily leverage the knowledge base within China and allow them to do some of the funding "heavy lifting." Current successes and future work test the robustness of U.S. models and pathways, identify other options for biomass utilization, and share research costs for bioenergy advancements

DEVELOPMENT AND DEPLOYMENT OF A SHORT ROTATION WOODY CROPS HARVESTING SYSTEM BASED ON A CASE NEW HOLLAND FORAGE HARVESTER AND SRC WOODY CROP HEADER

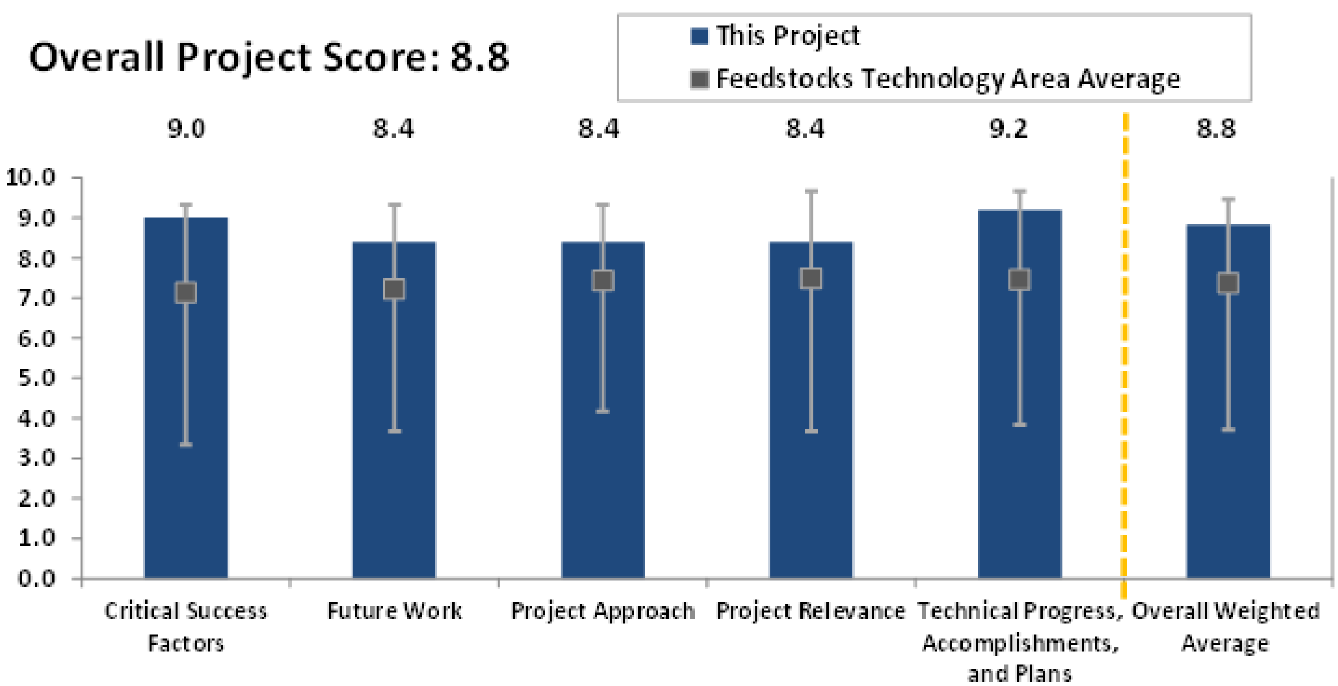
(WBS#: 1.2.1.2)

Photo Courtesy of SUNY

Recipient:	SUNY College of Environmental Science
Presenter:	Timothy Volk
Total DOE Funding:	$823,911
DOE Funding FY13:	$64,316
DOE Funding FY12:	$405,894
DOE Funding FY11:	$353,701
Project Dates:	2010-2013

Project Description

While demand for bioenergy sourced from woody biomass is projected to increase, the expansion and rapid deployment of short-rotation woody crops systems has been constrained by high production costs and limited market acceptance of chips from first-generation harvesting systems. This is a result of problems with quality and consistency. For willow and hybrid poplar SRWC systems, harvesting accounts for about one third of the delivered cost. Harvesting and transporting combined can account for 45–60% of delivered costs. The goal of this project is to build on existing collaborative efforts among the project partners to develop, test, and deploy a single-pass cut and chip harvester combined



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

with a handling, transportation, and storage system that are effective and efficient in a range of different SRWC production systems, environments, and operating conditions across North America. New Holland has developed a specialty cutting head (New Holland 130 FB Coppice Header) for its line of forage harvesters that allows the system to cut and chip woody crops in a single pass and produce a consistent quality chip that meets the specifications of biorefinery partners. Using an iterative process of field testing and optimization, harvester production rates and reliability have increased dramatically since the beginning of the project. Average production rates have increased from 9 megagrams per hour-1 to 35–41 megagrams per hour^{-1}, with maximums that have exceeded 50 megagrams per hour-1. Concurrently, downtime due to harvester equipment issues has dropped from 74% to just a few percentage points. Numerous collection systems have been tested, resulting in an informative matrix of available equipment and performance information that can be used for optimization modeling, which is an area where significant additional gains can be made. Harvesting costs have been reduced by 40–50% from the baseline of $40–50 per oven dry ton, and New Holland is now marketing the 130 FB Coppice Header worldwide.

Overall Impressions

- Provided data and findings based on actual field work. With continued efforts in this orientation, meaningful outcomes and impacts should be realized.
- The most impactful projects involve a range of stakeholders: BETO researchers, OEMs, processors, and biomass producers (agriculture and forest).
- This project has made significant advances for harvesting woody crops. The emphasis has been on the development of the harvester, appropriately so. The remaining tasks of optimizing the support and transport system can be done using existing or minimally modified equipment and techniques. The described transition of data into simulation elements of Integrated Biomass Supply Analysis and Logistics (IBSAL) should be emphasized.
- This project is developing a robust and effective harvest and logistics system for willow, which has substantial potential as a low-cost, high-volume feedstock. Prior research and demonstration projects identified challenges with willow harvest and logistics, which are being addressed in the current project. Early work demonstrated that a key bottleneck was the harvester, both harvest rates and especially reliability. These issues have been successfully addressed, and more recent emphasis has been on other system components, including scheduling, transport, and system optimization. Multiple strategies have been field tested, with key operational parameters (both technical and economic) documented and improved through industrial collaborations. Progress toward targets for efficiency and cost has been substantial and ongoing, with approximately 50% reduction in harvest costs from prior baseline. The team is very well-integrated with core DOE programs, including data management (ORNL KDF), models (IBSAL), etc. This university-led team is addressing key commercialization questions with excellent stakeholder collaboration. Partner organizations have been working effectively as a team, especially Case New Holland, which has embraced commercialization. The USDA-funded Biomass Crop Assistance Program is providing important financial incentives for scale-up and partnerships with end users. The willow system is an important target for near-term biomass feedstock. This project illustrates a comprehensive and complementary effort among stakeholders, each with an ongoing interest in overall system success. The track record in innovative R&D, practical cost reduction, and commercialization of new products is impressive.

- Very nice project with early payback in cost and greenhouse gas emission-reduction by improved logistics. Single-pass equipment is very important to the life-cycle sustainability and cost analysis.

PI Response to Reviewer Comments

- Over 80 hectares (200 acres) of willow and poplar biomass crops were harvested from late fall 2012 through the spring of 2013 as part of this project. At the time of the Peer Review, this data (more than 1,000,000 data points) was still being processed, but about 65% of it has been processed since May. Analyses indicate that throughput for the harvester (also referred to as effective material capacity) is consistently in the range of 60– 80 wet megagrams per hour $^{-1}$ across a wide range of willow yields (40–95 megagrams per hectare $^{-1}$), and is not driven by harvester speeds. These data reflect a dramatically improved harvester, but illustrate a need to enhance its capabilities on challenging ground conditions. These data also show that a harvesting operation built around this system is capable of producing a large, consistent, and relatively predictable material stream regardless of land productivity, which is a valuable insight for producers, operators, and end users alike. The results of these efforts should provide many opportunities to further lower harvesting and other costs improving and optimizing the logistics of material transport, supply, and storage.

HIGH-TONNAGE FOREST BIOMASS PRODUCTION SYSTEMS FROM SOUTHERN PINE ENERGY PLANTATIONS

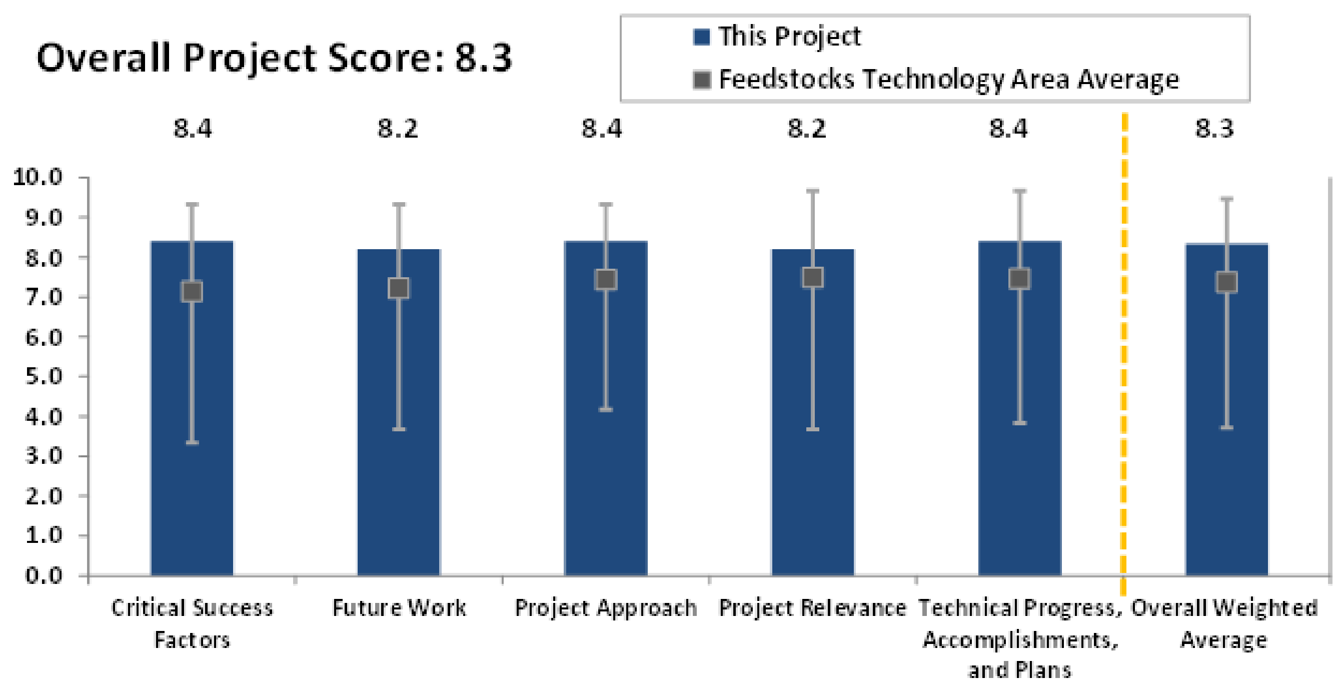
(WBS#: 1.2.1.3)

Recipient:	Auburn University
Presenter:	Steven Taylor
Total DOE Funding:	$4,990,000
DOE Funding FY13:	$3,400,000
DOE Funding FY12:	$795,000
DOE Funding FY11:	$795,000
Project Dates:	2010-2013

Project Description

Photo Courtesy of Auburn University

Short-rotation southern pine plantations in the U.S. hold great potential for producing more than 100 million dry tons of woody biomass per year in an economically feasible manner. This project has designed a high-productivity system to harvest, process, and transport woody biomass from southern pine plantations. The system, which consists of a track-type feller buncher, wheeled skidder, knuckleboom loader, whole-tree in-woods disk chipper, and high-capacity chip trailers, has been designed to harvest 10 to 15 year-old pine plantations. The Tigercat 845D track-type feller buncher incorporates a fuel-efficient, high-speed, shear-felling head, energy saving ER boom, and energy recovery swing system. The feller buncher meets EPA Tier 4i emissions requirements. The Tigercat 630D wheeled skidder is equipped with the industry's largest grapple with an opening area of 25 square feet. Field tests of transpirational drying in summer months resulted in reductions from 56% moisture content down to 35% in whole trees. After felling and skidding, trees are processed through a flail debarker and Precision WTC2675 whole-tree disk chipper, and then loaded into chip trailers for transport. To accommodate wood with lower moisture contents, high-capacity chip trailers



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

were designed and fabricated. For one-way hauls of 50 miles at costs of $4.00 per one-way mile, transport costs can be reduced by more than $5.00 per dry ton by reducing moisture content from 56% to 35%. Total harvest and transport costs have been reduced by 45% when the new system is compared to traditional-wheeled feller buncher and skidder systems. Additional research developed mass flow sensors for the chipper, as well as global positioning system (GPS)-based information systems that provide productivity feedback to the operator and machine managers. Biomass quality also is being measured through felling, skidding, and processing operations. Focus groups of loggers and landowners have been interviewed to quantify acceptance of the new harvest and transport systems.

Overall Impressions

- Nice project that found key cost improvements in ways that can be easily implemented. Well-managed and -implemented research.
- Project addressed a full range of issues related to harvest and delivery of pine for conversion. Included some sustainability aspects in terms of acceptability to landowners and loggers. The project was an effective collaboration between all parts of the team: researchers, equipment manufacturers, conversion companies, etc. This is a project that definitely seemed to meet the goals of providing higher-capacity, lower-cost systems. There is still a good bit of work to be done to complete the project. The results of this project should be captured for the KDF or the other modeling tools being developed by DOE.
- The focus of this project is on harvest and logistics options for southern pine. These systems are well established at commercial scale, but this project is focused on shorter rotations (10–12 years) and higher-stand densities than current systems. Dedicated energy plantations would require some modifications of existing in-woods chipping systems, with a somewhat different feller buncher and advanced management information systems. This project seems like an incremental advance in a relatively mature industry, so the magnitude of improvements in productivity and cost are surprising. Machinery advances had a modest impact on productivity and cost (approximately 10% in operating cost for feller buncher, but a 65% reduction in skidder cost per ton, 40% cost reduction for chipping). Major cost is in transport, so the key innovation was transportation drying to reduce weight and cost. The social science component is intriguing, although additional data analysis will be important. Baseline equipment was designed for longer rotations, and was thus optimized for larger trees with several different characteristics. Among the various improvements, transportation drying had the biggest impact. This may be a significant advantage of shorter rotations, where evaporation is more rapid because of the higher surface-volume ratio of smaller trees. While shorter rotations appear to have lower harvest/logistics costs per ton, they also require more frequent establishment so regeneration costs will be significant. From a landowner perspective, overall system analysis should consider comparisons over long time periods, and the tradeoffs between higher regeneration costs per ton and lower harvest/logistics costs per ton. Other human dimensions including perceptions and practices will be important factors in adoption of this alternative system.
- The most impactful projects involve a range of stakeholders: BETO researchers, OEMs, processors, and biomass producers.
- There is a need to provide more in-depth, detailed information to have useful outcomes and impacts.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

INTEGRATION OF ADVANCED LOGISTICAL SYSTEMS AND FOCUSED BIOENERGY HARVESTING TECHNOLOGIES TO SUPPLY CROP RESIDUES AND ENERGY CROPS IN A DENSIFIED LARGE SQUARE BALE FORMAT

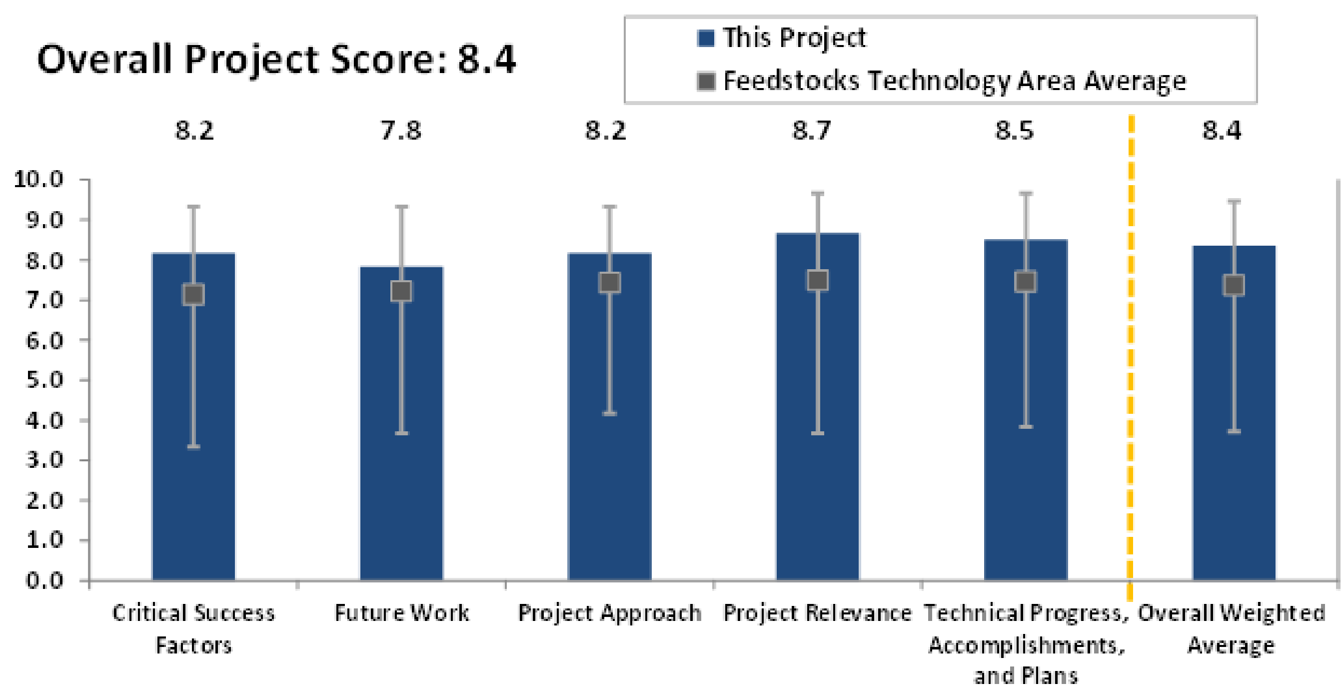
(WBS#: 1.2.1.4Z; 1.2.1.8)

Recipient:	AGCO
Presenter:	Maynard Herron
Total DOE Funding:	$5,000,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$1,367,490
Project Dates:	2009-2012

Project Description

Photo Courtesy of AGCO

Project objectives support BETO's adoption and production goals for feedstock adoption and cost minimization in a "stump-to-throat" harvest, storage, and transportation demonstration. Use of a common set of equipment, where possible, was emphasized as a key factor required for rapid adoption and cost minimization. Modifications to the equipment set, where required, were identified and have been implemented and demonstrated as first steps. Some equipment improvements have moved to full commercialization where market demands existed. The project demonstrates the use and suitability of commercially available or commercially ready equipment to supply the feedstock needs of a production-scale conversion facility. The equipment set, characterized by a high degree of commonality, was utilized to harvest crop residues of corn, wheat, and dedicated energy



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

crops, including switchgrass, energy sorghum, mixed grasses, *miscanthus*, and energy cane.

Overall Impressions

- Project gained experiences in harvesting multiple energy crops, and identified equipment modifications that allow AGCO to have harvest equipment commercially available when the market is present. The innovation demonstrated in this project is modest, but appears to match the initial expectations of the project.
- Project management plan was developed and appropriately modified as weather and other conditions dictated. Progress was made and milestones were generally met, although some problems occurred and not as much information was generated as planned. Because of higher-than-expected transport costs (drought-related), data acquisition and analysis were limited to a small portion of the total planned/expected; analyses targeted to cover the range of conditions. Equipment components in design and production—appears to be market ready, should a market develop.
- The approach was relevant to biomass work. Additional work, such as incorporating other sites and cooperators, will be beneficial. Focused direction working with onsite conditions was good.
- The focus of this project was on energy crops (energy sorghum, switchgrass, mixed grass) and residues (corn stover and wheat straw). The approach was to utilize and adapt existing technologies that were compatible with local infrastructures, labor, and agronomic practices. The first season was validation of equipment function. Systems were modified and tested in the second year, validated in the third year, and tested again in year four. The primary advances included single-pass crop residue harvesting equipment, validated two-pass systems on high-volume energy crops, improved corn head for corn residue collection, storage studies, and logistics. The diversity of crops and systems tested provided a wealth of real-world data for modeling and analysis. Single-pass systems had reduced fuel per dry ton, reduced machine time per dry ton, and demonstrated reduced ash content by a factor of two. Dry matter losses in dry storage ranged from 5% to 10%, and all samples accumulated moisture. In field tests, dry matter losses could exceed 20%. Among the systems tested—which were all based on dry storage—the best-practice storage method was a tarped bale, stacked up to four large bales high. The project successfully completed field-scale testing of harvest, baling, and storage systems for a diversity of energy crops and residues. Single-pass systems showed significant advantages, but will require new equipment and harvest paradigms. Dry storage showed significant dry matter loss, which will affect product quantity and quality. One useful (though not surprising) finding is that energy crops would benefit from drying on the stem, and then being harvested by single-pass cut and baling systems. This was a strong industrial partnership among AGCO, Stinger, three conversion companies (Terrabon dropped out), several universities, national laboratories, many farmers, and producers. The high-density baler was commercialized and is in production now. This project has largely achieved its goals and this technology pathway has been successfully transferred to the private sector.
- The most impactful projects involve a range of stakeholders: BETO researchers, OEMs, processors, and biomass producers.
- Very nice study with both important individual results, such as storage, put into a well-integrated, to-scale, commercial framework.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

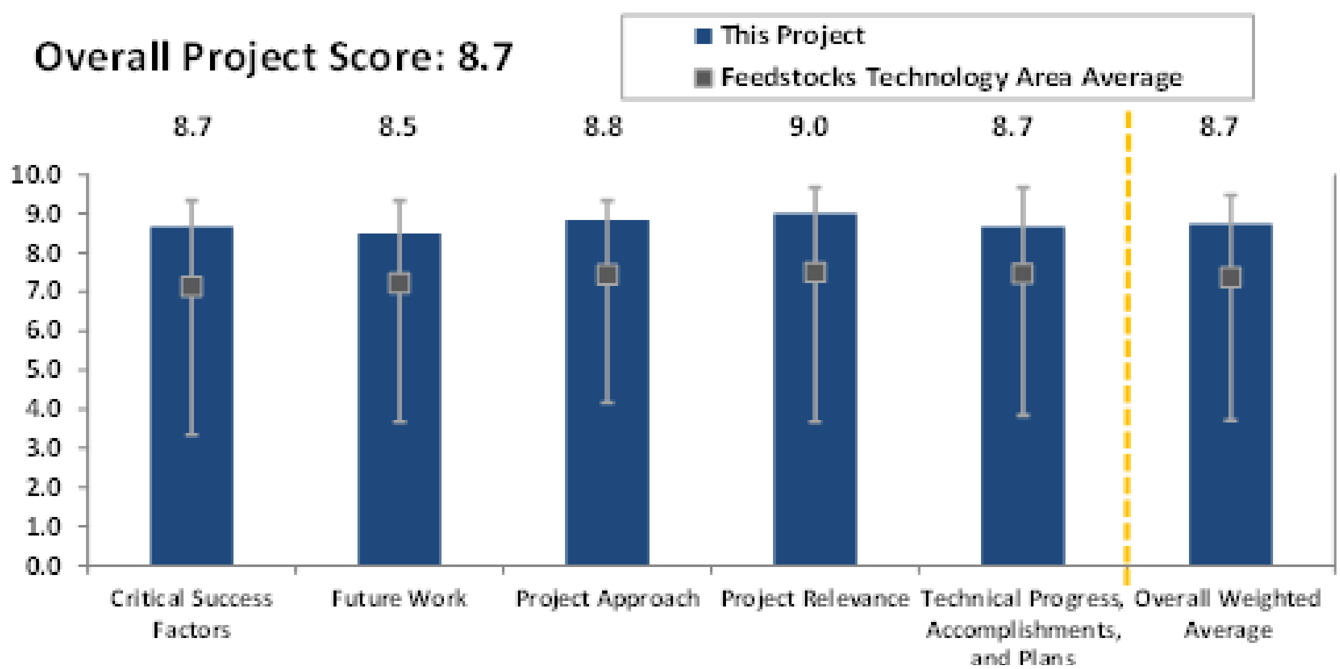
DEVELOPMENT OF A BULK-FORMAT SYSTEM TO HARVEST, HANDLE, STORE, AND DELIVER HIGH-TONNAGE LOW-MOISTURE SWITCHGRASS FEEDSTOCK

(WBS#: 1.2.1.5Z; 1.2.1.9)

Recipient:	University of Tennessee
Presenter:	Alvin Womac
Total DOE Funding:	$4,800,000
DOE Funding FY13:	$316,000
DOE Funding FY12:	$2,040,000
DOE Funding FY11:	$2,440,000
Project Dates:	2010-2013

Project Description

This project evaluates and compares comprehensive feedstock logistics systems (FLS), where a FLS is defined to comprehensively span from biomass material standing in a field, to conveyance of a uniform, industrial-milled product into the throat of a biomass conversion facility. Elements of the bulk-format FLS evaluated in this project include: field-standing switchgrass, dry chopped into bulk format on the farm, hauled (either loose or bulk compacted) to storage, stored with confining overburden in a protective facility, reclaimed and conveyed to bulk-format discharge, bulk compacted into an ejector trailer, and conveyed as bulk flow into the biorefinery. In this FLS evaluation, bulk storage bins served as a controlled and sensored proxy for large commercial stacks protected from moisture with a membrane cover. Bin bulk densities and reclaim of bulk switchgrass were monitored to establish baseline data. Deliberate engineering and testing of the constructed bulk-handling FLS advanced the state of knowledge useful for many feedstock supply systems. Logistics evaluation was conducted for the entire system, including GPS-tracked field and over-the-road equipment, operational conditions, load weights, bulk densities, moisture contents, particle sizes, reclaim and handling throughputs (ton per hour), power and energy use (kilowatt-hour per ton), unit costs (dollars per ton), switchgrass composition and ethanol potential, and assessment of efficiencies and utilization values (percentage). Two storage bins allowed for simultaneous testing of changes



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

in characteristics, handling, reclaim, and compaction of field-chopped, bulk-stored material over time (12 months in storage), and reclaim, handling, and compaction engineering performance of multiple specifications of bulk material, including field-chopped, coarse-tub grind and fine-tub grind. The discovery was that field-chopped, low-moisture (13% moisture content wet basis) switchgrass exhibited desired traits of increased loose bulk density (6.2 pounds per cubic foot), increased compacted bulk density (10.64 pounds per cubic foot, comparable to bale FLS), and a significant finding of propensity for free-flow compared to tub-grind switchgrass. While fine-tub-grind switchgrass flowed at rates more than double that for coarse-tub-grind switchgrass, the field-chopped, low-moisture switchgrass flowed at rates that were three to four times the rate of any tub-grind material, up to 40 tons per hour. The composition analysis for material in bulk format was similar to that in bale format, including composition over time. Costs for bulk format were highly competitive, with potential cost and performance benefits identified for downstream biorefinery processors. Technology transfer is active, as commercial project developers are increasingly interested in maximizing just-in-time delivery of feedstock and minimizing variability in feedstock characteristics. Project addressed a more complete FLS for delivery of feedstock specification to a biorefinery.

Overall Impressions

- Methodical approach resulted in relevant findings. Working with producers and equipment manufacturers and providing the information to the public was excellent. More DOE-funded work to advance the industry is critical.
- Moving from a harvest/delivery scenario to a harvest/depot, preprocessing/compaction/delivery scenario. Flow rate problems were well documented, but economic impact was not calculated. Flow rate problems aren't solved, and so using a depot process for this situation is questionable. Since bins were used instead of piles (which are expected to be the commercial practice) for storage, what is the impact on the analysis outcome/results if storage piles are the likely way things would be done in a commercial-scale operation? Provided potentially useful negative results about the depot concept and bin storage, but no indication it was recognized as such.
- This project addressed the complete logistics system from the field to the conversion plant. This is a wider scope than the high-tonnage logistics projects, and it seems to have a broader set of lessons learned. The project group should be complimented for taking on such a large scope of study. The study on handling of the chopped biomass is a significant addition to the knowledge base. Differences identified between the size-reduction techniques are a unique addition to the knowledge base. This project added great value in terms of experiences with material handling systems. BETO needs to continue this type of project.
- This project evaluated loose bulk handling of switchgrass. Trials were held in the Vonore facility in Tennessee, with hauling distances of 5.5 to 8.5 miles. GPS tracking was used to quantify the productivity of each harvest machine. Size reduction occurred early in the supply chain during forage harvest, which allowed a combination of mechanical and pneumatic conveyance downstream. Field-scale trials of bulk material evaluated flowability and feeding tradeoffs relative to an industrial-milled product. Downstream materials storage and handling was done at demonstration-scale to commercial-scale specifications, including full permitting and operational details (e.g. dust collection). The forage harvester was the limiting factor roughly 90% of the time. Tub-ground material had a wider particle size distribution than the field-chopped material, which dramatically reduced flowability. The field-chopped material flowed well and exceeded design specifications, allowing for low-cost, high-volume materials handling. Storage systems

appeared effective with little self-heating at approximately11% to 13% moisture. The critical barrier to commercialization of this uniform-format system appears to be a mobile stacker/reclaimer system with a low-cost, but durable, membrane cover for moisture protection. Developing strategies to engage commercial partners with that challenge is an essential next step. This was a first-of-kind demonstration of the depot concept with uniform formatting and loose handling of biomass. Such systems have been recommended by theoretical analysis at INL, but had not previously been demonstrated at field scale. It is very encouraging to see the potential, as well as to advance the practical understanding of the challenges. A clear understanding of the challenges and barriers to this approach now sets the stage for further scale-up and commercialization.

- This project mobilized a wide range of resources to apply to the problem. It generated some novel solutions and evaluated them with the resources available.
- Very nice project that should be an example to other feedstock/logistics systems.

PI Response to Reviewer Comments

- Thank you. All reviewer efforts and comments are highly appreciated.
- Economic analyses for bulk-format logistics was compared to bale-format logistics system. Bulk-format logistics used forage harvester-created particles to supply bulk format from field to biomass conversion facility. An additional reason for examining the tub-ground particles was to evaluate the impact of supply bales being ground and fed into the conversion facility. The bale-format economic analysis used the reduced flowability values. The forage harvester was the most logical, energy-efficient method for creating the bulk format early in the bulk-format logistics. It is possible to perform an economic analysis using the reduced flowability of tub-ground material in the bulk system, though it is not recommended. Essentially, reduced flowability of the wider particle size distributions would add costs per dry ton. The bins were proxies for bulk piles to evaluate storage bulk densities due to overburden, the reclaim process of stored material, and the suitability of storing large bulk quantities and the associated thermal dynamics and product stability. Bins were not recommended for commercial scale due to required numbers and costs.
- Thank you. The broad supply chain was prioritized to best reflect the actual supply chain from field to conversion facility. Examining and testing the complete supply chain, especially as it nears the facility by considering biomass processing (such as size reduction), was found to be important.
- Further scale-up and commercialization with a mobile stacker reclaimer is the next logical step in developing a system that can be scaled to the high tonnage requirements of a facility. The impact of a simple parameter such as particle size distribution impacts selection of harvesters and handling capacity

DESIGN AND DEMONSTRATION OF AN ADVANCED AGRICULTURAL FEEDSTOCK SUPPLY SYSTEM FOR LIGNOCELLULOSIC BIOENERGY PRODUCTION

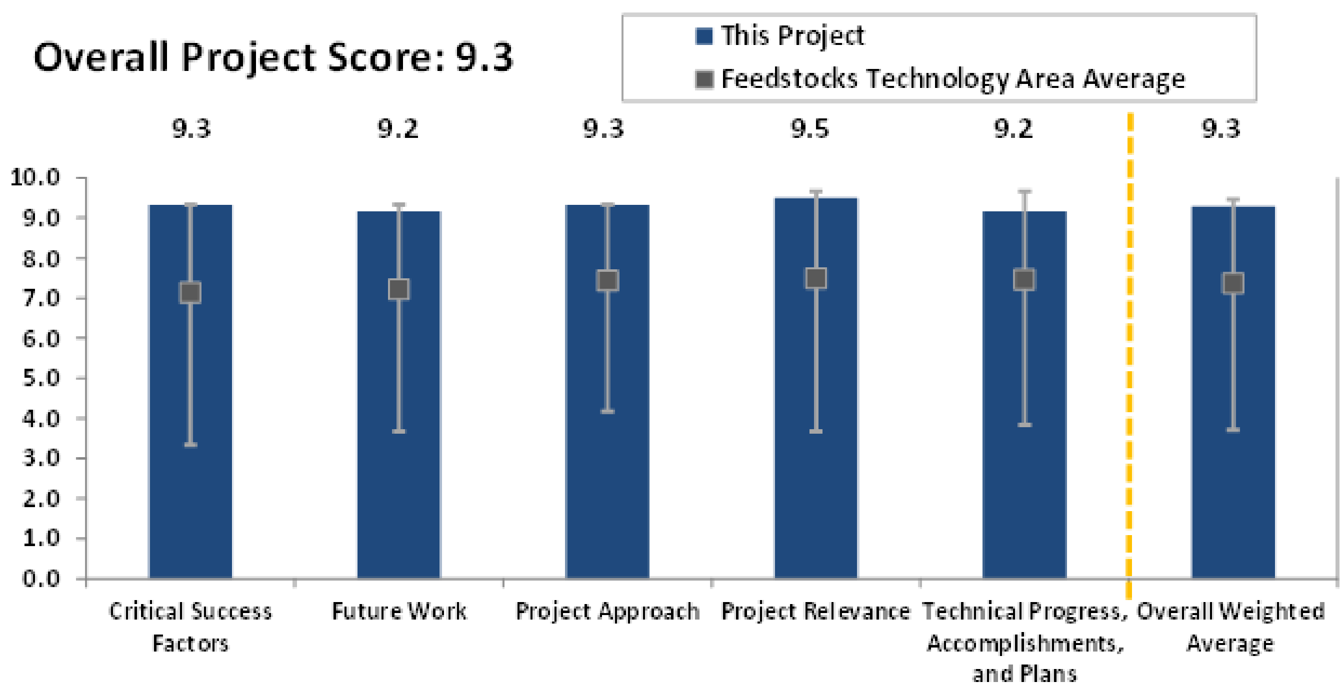
Recipient:	FDC Enterprises, Inc.
Presenter:	Fred Circle
Total DOE Funding:	$7,270,608
DOE Funding FY13:	$701,118
DOE Funding FY12:	$1,437,544
DOE Funding FY11:	$1,788,139
Project Dates:	2010-2013

(WBS#: 1.2.1.6Z; 1.2.1.7)

Project Description

Photo Courtesy of FDC Enterprises

This nearly completed, three-year project developed and demonstrated four innovative, first-of-a-kind pieces of equipment that are aimed at significantly reducing the cost of delivered herbaceous biomass. This equipment included a self-propelled baler (SPB), a bale-picking truck (BPT), a self-loading trailer (SLT), and a heavy crop header for harvesting high-yielding energy crops. This equipment was designed and fabricated during the first two years of the project and demonstrated on available crops (corn stover, wheat straw, and warm season grasses) across the nation, as available. Operational performance and cost data was collected and analyzed throughout the project to measure the costs of baseline harvesting (using conventional harvesting equipment) and advanced harvesting with the newly developed equipment. This data revealed that the project met its original goal of developing equipment that is realistically capable of reducing the cost of delivered biomass by $13 per dry ton. Each piece of equipment



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

was commission-tested after fabrication and then put to the test in one or more commercial harvesting seasons. During these tests, operational flaws were identified and addressed through upgrades and improvements. The first new SPB and BPT, and two new SLTs, have been purchased for use in the 2013 harvest season. All of the equipment will be commercially available to the industry as performance is more widely demonstrated and demand occurs.

Overall Impressions

- Clear implementation, monitoring, and analysis plan. Equipment design and fabrication apparently completed; testing and analysis underway.
- Project resulted in several new innovations in biomass handling equipment. The group utilized appropriate design strategies to gain system efficiencies and time savings. They were able to demonstrate the functionality of the new equipment designs that would reduce the time required for handling. Cost information giving a reduction was incomplete. Those data should have been more complete and shown the total cost estimates. Given the emphasis on the improved handling speed and efficiency, data comparing this system to the conventional systems should have been shared. The project did gain three years of operational data, but with the recent development of the equipment models, those models have only one year of testing. A second generation of the bale module loading truck shows a continuation of the benefit of this project toward the development of the needed optimized biomass logistics systems. This project has provided significant value, and continued efforts by this group should be encouraged.
- Solid, well-done project that delivered results.
- The goal of this project is to demonstrate industrial-scale feedstock supply system with cost reductions of $13 per ton, identifying and measuring all supply chain costs, quality, and sustainability metrics. A capable team of equipment manufacturers and operators evolved from the Ottumwa, Iowa, switchgrass co-firing project in 2000–2006, so they had extensive experience with switchgrass at industrial scale and a solid, practical understanding of the challenges. The new strategy is based on a cotton supply chain analog with large bale modules that require little individual handling, minimize individual units and modularize in a truckload package, and eliminate most separate operations. The team implemented an annual cycle of planning, deployment, data collection, analysis, and upgrading based on lessons learned. The feedstocks in this demonstration include both corn stover and switchgrass. Several new or modified pieces of equipment were designed, built, tested, modified, and validated for switchgrass, corn stover, and *miscanthus*. New equipment included an improved baler, self-loading trailer, a bale picking truck, single-pass harvest systems, and an improved header for heavy crops. Formation and transport of modules was demonstrated, including depot storage (dry). This strategy achieved bale densities of 11 and 12 pounds per cubic foot, and bales were transferred directly from the bale-picking truck to a transport truck with no individual bale handling. Performance/cost/quality data was collected on all operations. The project harvested more than 15,000 acres during the project, demonstrating industry-scale capability and durability. It would be very valuable to monitor storage losses at the various end-use locations, which would help BETO in understanding the feedstock moisture and management variables that influence this factor. Second-generation equipment is currently under development. The team is still working to improve bale density, which remains a significant cost factor. Final milestones include data analysis and cost estimation, which is currently underway.

- This project mobilized a good range of resources that were applied to a focused task, a combination that enhances the probability of success. The result is a deployable system now awaiting the development of an industry. The experience gained in a previous biomass supply project contributed to the success of this project.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

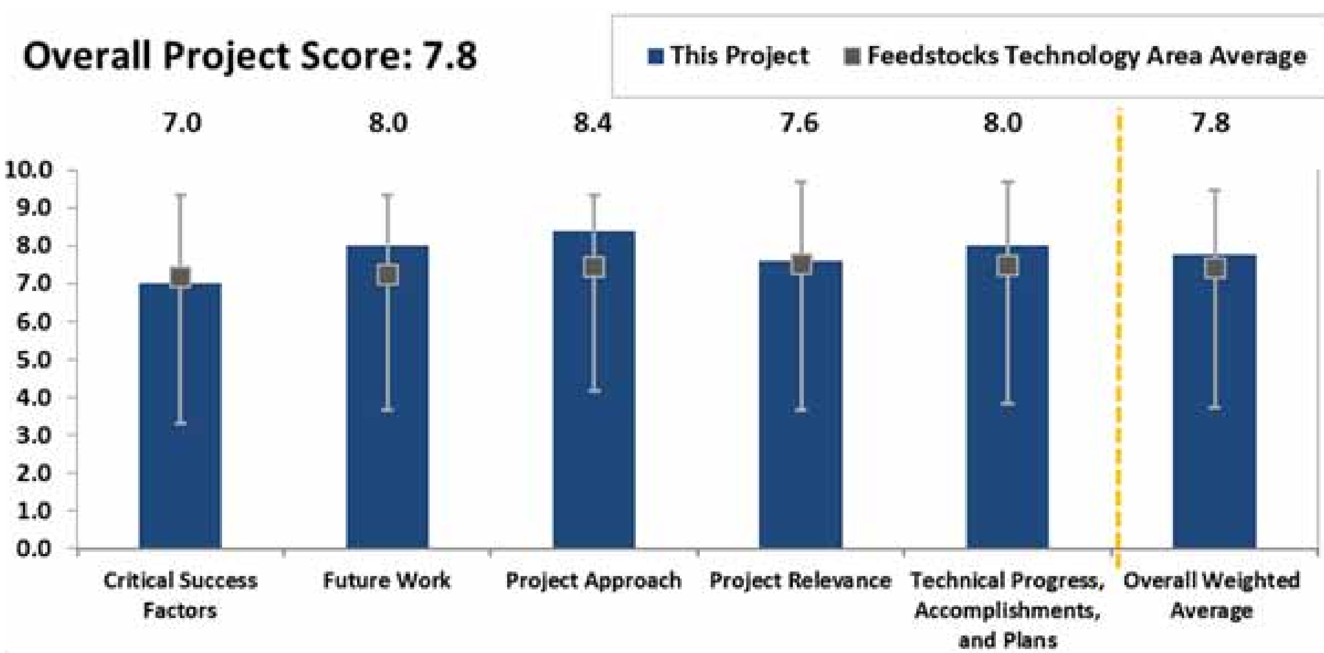
SUPPLY SYSTEM LOGISTICS TASK

(WBS#: 1.2.1.6Z; 1.2.1.7)

Recipient:	ORNL
Presenter:	Shahab Sokhansanj
Total DOE Funding:	$3,515,000
DOE Funding FY13:	$450,000
DOE Funding FY12:	$450,000
DOE Funding FY11:	$329,000
Project Dates:	2007-2015

Project Description

The ORNL feedstock logistics project supports national biofuels goals with research aimed at minimizing feedstock cost and addressing the risks associated with securing an industrial-scale feedstock supply for a biorefinery. In fiscal year 2011, a collaborative effort was initiated to develop simulations of the five DOE-funded, high-tonnage logistics demonstration projects: AGCO, FDCE, TennEra, the State University of New York, and Auburn. The projects vary in their feedstock focus, geographic region, and technology selections, with a common goal: to significantly reduce the delivered cost of commercial volumes of sustainably produced biomass in appropriate formats for conversion to bioenergy and bioproducts. In order to accurately assess the progress and benefits achieved by these projects, and to evaluate the impacts of these system designs on the biofuels industry, a common modeling strategy was needed. ORNL and INL were tasked to develop a framework for simulation and analysis of the large-scale biomass supply systems. In fiscal year 2012 and fiscal year 2013, the team visited the farms and plantations where each of the projects were testing and demonstrating their new equipment and operations. Using the initial observation and discussion with project engineers, the ORNL team developed the initial framework for modeling of each operation separately. In fiscal year 2013, the task is collecting operational input data from the demonstration projects and conducting analysis. Simulations of the high-tonnage logistics projects demonstrated the logistics cost of feedstock supply for stover residue and switchgrass decreased $8 to $13, from a base case of almost $47 per dry ton. The ORNL modeling effort addresses at least 10 technical barriers to the development of integrated biorefinery and feedstock logistics. A continued exchange of technical data between the modeling team and logistics projects' personnel has been a critical success factor. The projects have been described to the equipment manufacturers in several American Society



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

of Agricultural and Biological Engineers and Alternative Energy Technology Center venues. Future plans include sensitivity analysis, simulations for scale-up, and the related sustainability analysis.

Overall Impressions:

- Good optimization of resources in taking existing studies, compiling data, and building models.
- Participation with the high-tonnage projects has provided updated equipment costs for the various IBSAL simulation elements. This project provides value to future logistics system managers who may wish to use IBSAL in evaluating potential systems. It also provided value to the five logistics projects. I would have liked to hear a bit more on how the availability of the data from these logistics projects were used to enhance and update the capabilities of IBSAL. However, this project is a great example of gaining additional value from funded projects. This advantage is similar to the value of capturing project data into the KDF. Since Sokhansanj has been working on IBSAL for several years, I can assume work with this model will continue. However, the future of IBSAL was not sufficiently discussed.
- Simulation appears to be a rational way to bring this data together to deliver modeled engineering outputs (costs, energy, recovery, etc.) methodology and cost information uploaded to the KDF; plans include next steps and products for additional feedstocks and equipment.
- The analysis of the five high-tonnage projects helps establish their value to the Technology Area. The consistency of approach provides a level playing field for all bioenergy projects.
- This project developed and applied the IBSAL model to the five high-tonnage biomass feedstock supply chain projects. IBSAL has been developed for over a decade, with many previous applications, so it is well suited to this effort. The IBSAL simulation model requires a variety of inputs, including weather, field, and crop data; equipment data and storage systems; and scheduling impacts (crop moisture, etc.). Outputs include economic, energetic, and environmental impacts; dry matter loss; and equipment and labor requirements. Economic outputs are engineering costs, not feedstock prices, as the model does not account for management and business costs or profits. This project included multiple visits to each site, model modification to reflect specifics of each project, cooperative data collection, scenario development, and independent internal and collaborator review of assumptions and results. For each herbaceous system, costs have been projected for baseline and advanced scenarios in independent "apples-to-apples" comparisons. Cost reductions were estimated at roughly 30% from baseline for the AGCO and FDCE systems at highest density bales. TennEra cost reductions were lower relative to baseline (about 8%), but had a similar final cost. The methods and algorithms used in this modeling effort are available from the KDF. Data is now available for additional high-impact crops. Cost breakdowns of different components are available as well. The two woody crop projects will be assessed in the next phase of this project. With this high-tonnage validation of IBSAL, the model will now be more easily adapted to other logistic systems, including blended systems that include components of several of the current studies. There is also a need to consider systems that become economic at even larger volumes, such as will be required to supply a national infrastructure of full-scale biorefineries. This project was set up as a tightly coupled effort with the five high-tonnage supply chain projects. Cooperation among those projects with the IBSAL team worked well. Broader communication with other non-funded companies and universities will be important to leverage this federal investment for public benefit. BETO should be more actively developing industry advisory groups and other feedback mechanisms to drive analysis toward critical industry needs. Such an effort would benefit this project, as well as all others in the Feedstock Production and Logistics portfolio.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

DEPLOYABLE PDU (DEPLOYABLE PROCESS DEMONSTRATION UNIT)

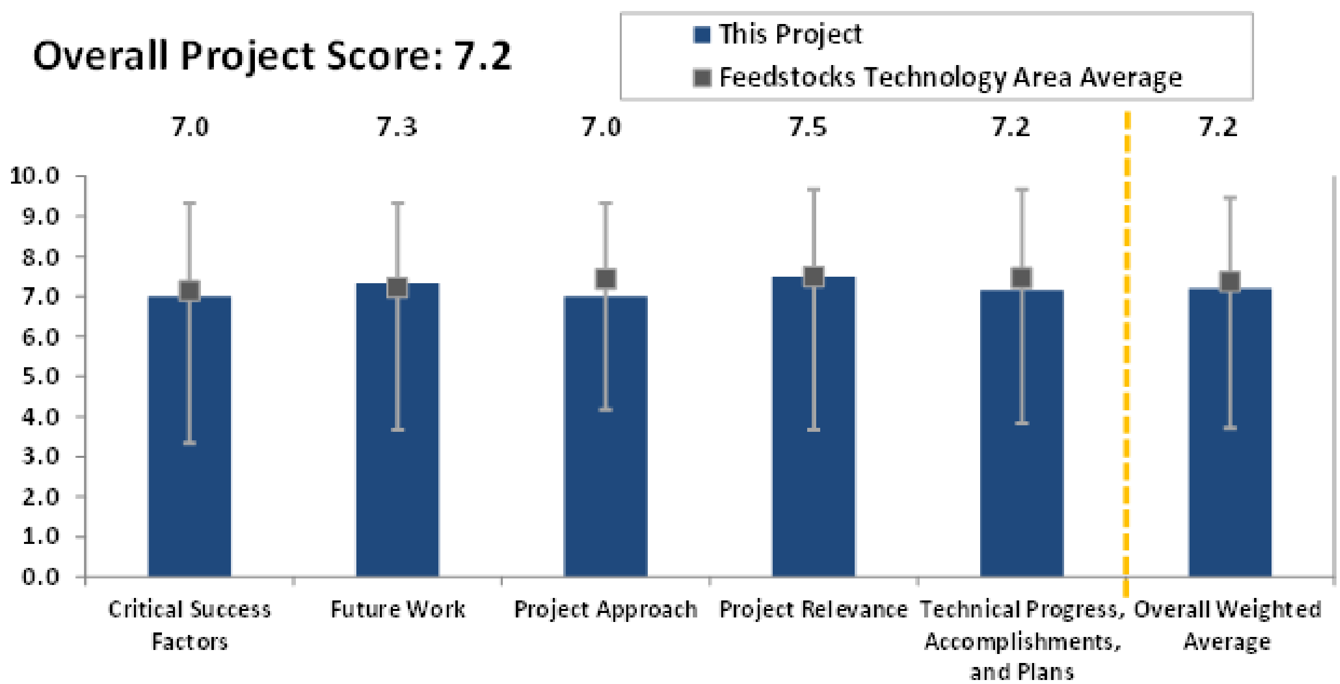
(WBS#: 1.3.1.2)

Recipient:	INL
Presenter:	Neal Yancey
Total DOE Funding:	$10,920,000
DOE Funding FY13:	$1,200,000
DOE Funding FY12:	$450,000
DOE Funding FY11:	$3,650,000
Project Dates:	2008-2017

Project Description

Photo Courtesy of INL

The underlying goal of the Feedstock Technology Area core research and development effort is to identify and overcome significant feedstock supply system barriers that prevent industry from sustainably procuring and using lignocellulosic material for the next generation of biorefineries. One of the ways this goal is achieved is by evaluating, and in many cases, by directly testing, different supply system technologies to determine current viable options and their potential for improvement. The feedstock deployable PDU is essential to achieving these objectives. PDU construction was completed in fiscal year 2010. Since then, 246 tons of biomass have been processed through the PDU in 96 separate tests involving 16 different biomass types. PDU data from these tests have been extensively analyzed to identify relationships between biomass input properties and machinery performance. For example, the relationship between biomass moisture content and energy requirements for size reduction has been studied. PDU tests have also been conducted to identify optimal configurations that reduce energy consumption and cost while improving feedstock quality specifications, such as particle size distribution. The 2013 Peer Review will discuss these accomplishments associated with PDU projects.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Based on information provided, this unit may be beneficial for various applications. Hopefully, further studies can be conducted.
- Continued development and use of the PDU is important for BETO goals. Extension of these functions should be encouraged.
- The process demonstration unit has been under development since 2009, and now has several years of testing and enhancement. The focus is on cost reduction, process enhancement, material upgrading, and material performance. The system is set up for both internal BETO R&D and will soon be designated a national user facility by DOE. It is a unique collection and configuration of equipment. Most of the work has been to produce a product for a customer—internal DOE BETO projects, other BETO-funded projects led by external organizations, or external clients. Extensive analysis has been completed on material characteristics and transformations and has been logged into the Biomass Resource Library. Some of these advances have been novel and unique, while others have been mundane. For example, the switch from a tub grinder to a horizontal grinder is following a technology "innovation" that the construction and demolition, mulch, and composting industries have been using for 20 years. There is substantial published literature on many of these processes for both woody and herbaceous biomass. It is a challenge to manage large-scale systems of this type, and to develop a customer base that will adequately use the excess capacity. While there has been some progress in this respect, ongoing intensive engagement with industrial collaborators will be essential for long-term success. Focus groups with current and potential customers will be critical for future success. The densification workshop was a good example of this, and additional workshops that engage stakeholders will be essential for future success. It is an open question whether the concept of moving the PDU to remote locations makes financial or logistical sense. A stronger case will need to be made than is currently evident.
- The high cost in time and money for deployment of the process development unit may argue for regional, stationary PDUs, which would also enhance their value for workforce development.
- This is a very important scale for a demonstration unit, and will ultimately lead to a greater range of feedstock sources.
- What are the real costs of doing this in terms of time, energy, and money across the feedstocks logistics supply chain? Does it consider the costs of deploying/re-deploying these things across a dynamic harvesting landscape on a scale necessary to develop useful information on operations at scale? This is not clear. Cost analyses all seem to be within-concept comparisons rather than providing a cost-benefit analysis of deploying this. Appears to define challenges and success in terms of the use of the PDU as keeping the PDU funded, rather than analyzing as a rational part of informing and developing the commercial supply chain.

PI Response to Reviewer Comments

- The reviewers generally recognize the usefulness of the PDU as a research tool, and they have provided good suggestions for further expanding the use model, including a platform for workforce training. One misconception that the PI would like to clear up is that the mobility and deployment of the PDU is to demonstrate the concept of mobile biomass processing systems that operate within the feedstock supply chain. The mobility design feature is intended to enable broader access to the PDU as a feedstock preprocessing R&D tool, and to enable partnerships that advance DOE-BETO programmatic goals. It is recognized by the reviewers that deployment remains a challenge, but it is also clear that our views and plans for deployment could have been better articulated. Certainly our experience to date has shown that in most cases, it is more economical for projects to ship biomass to INL for processing and then ship the processed feedstock back to the customer. We plan to continue to expand our user base under this model, and we also continue to invest in improvements to further reduce operational costs to expand this model. Nonetheless, deployment is also a viable option under the right conditions. Deployment of the entire system is unlikely and even undesirable, in that it leaves us without the capability to conduct our own DOE-funded work. Rather, partial deployment of one or two modules (the dryer and/or pellet mill, for example) to a partner's site where infrastructure, other complementary modules, operating expertise, and appropriate safety-related work control already exists. We are pursuing such deployment opportunities.

RESEARCH AND TECHNOLOGY DEVELOPMENT FOR GENETIC IMPROVEMENT OF SWITCHGRASS

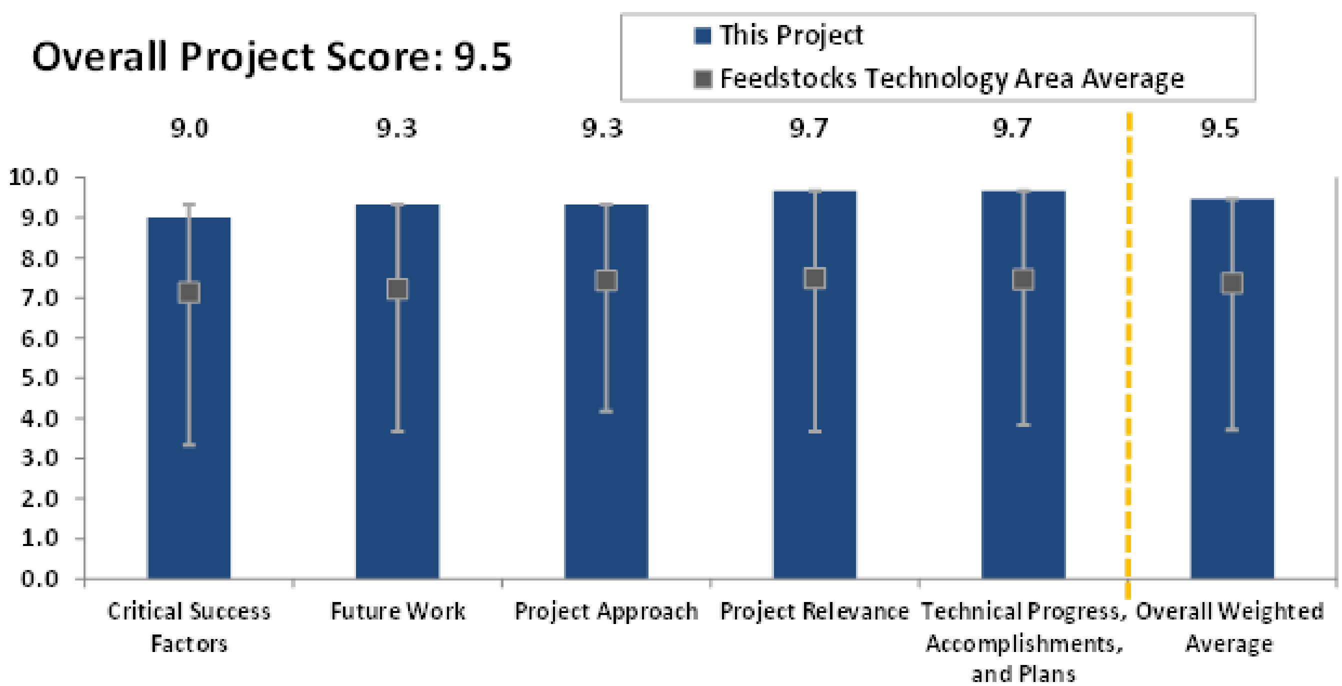
(WBS#: 7.1.2.5)

Recipient:	University of Rhode Island
Presenter:	Albert Kausch
Total DOE Funding:	$4,500,000
DOE Funding FY13:	--
DOE Funding FY12:	$1,500,000
DOE Funding FY11:	$967,750
Project Dates:	2008-2013

Project Description

Photo Courtesy of University of Rhode Island

The overarching goal of this project is the development of technology leading to commercial bioenergy crop hybrid varieties improved for production of cellulosic biomass used for biofuels, and the development of widely applicable intellectual property (IP) for bioenergy and agricultural crops generally. The need for the U.S. to increase its efforts on production of renewable biofuels and the role that switchgrass as a bioenergy crop will play are well understood and widely known. To reach the full potential of bioenergy, the power of advanced genetic and biotechnology tools needs to be brought to bear on the improvement of biofuels crops. Rapid genetic improvement of the most promising perennial grass feedstocks are anticipated as the key aspects of this project, including genetic modification, hybrid plant and genomics assisted breeding platforms, and conventional genetics, as well as other non-genetic modification approaches. While transgenics offer access to traits outside the conventional breeding pool, they are costly and involve unresolved issues regarding gene confinement, USDA deregulation, and commercial release. The specific relevance of this work is toward advances in key platform technologies used for hybrid



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

plant systems, genomics, breeding, and gene confinement purposes to facilitate switchgrass improvement as a key bioenergy crop. This project has accomplished the production of several new technologies, including the development of hybrid plant systems using synthetic lethality to produce male (pollen) and female (seed) sterility; advanced breeding strategies utilizing wide crosses by novel advanced tissue culture and genomics to produce new hybrids that are non-genetic modifications; and robust transgenic and gene confinement strategies for genetic modification applications. Among the key challenges remaining are the implementation, adoption, and widespread use of bioenergy cellulosic feedstocks for liquid fuel production, which will determine the future commercial success of the technologies achieved by this project.

Overall Impressions

- Excellent work with relevant species for providing field-trial material. For future of utilizing switchgrass, and other energy crops, this work is on the forefront. Further funding to enable field studies (with a few thousand acres) is paramount.
- Seems to have made major breakthrough in means of developing non-genetically modified hybrids.
- Synchronizing genetics with growth and processing has been a key problem. This rapid method of developing non-genetically modified crops could be a key to commercialization of feedstock planting.
- The focus of this project is on hybrid sterility systems to enable production of non-genetically modified hybrids. The basic strategy is to eliminate transgenes by a synthetic biology, toxicity circuit that relies on herbicide resistance as the selection strategy to identify the non-genetically modified hybrids. The project demonstrated the system by developing new switchgrass/panic grass hybrids. This system now allows rapid selection of non-genetically modified hybrids for rapid breeding of perennials. Other future approaches include zinc finger mutagenases for the control structure, anthrocyanin or other colors for the indicator (as opposed to herbicide resistance), and other synthetic biology approaches that can implement this basic strategy in other plant families. The system is elegant, has widespread applicability, and will reduce the time involved in breeding from many generations to two. The research team is actively collaborating with Ernst Conservation Seeds, and commercialization is well underway.
- This project has the potential, now nearing realization, to revise the bioenergy industry—and many others—by incorporating new traits into biomass crops. It represents a good investment into knowledge discovery.
- This technique will have implications far beyond the bioenergy fields, but should have great potential for energy crops.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

BIO ENERGY INITIATIVE FOR CONNECTICUT

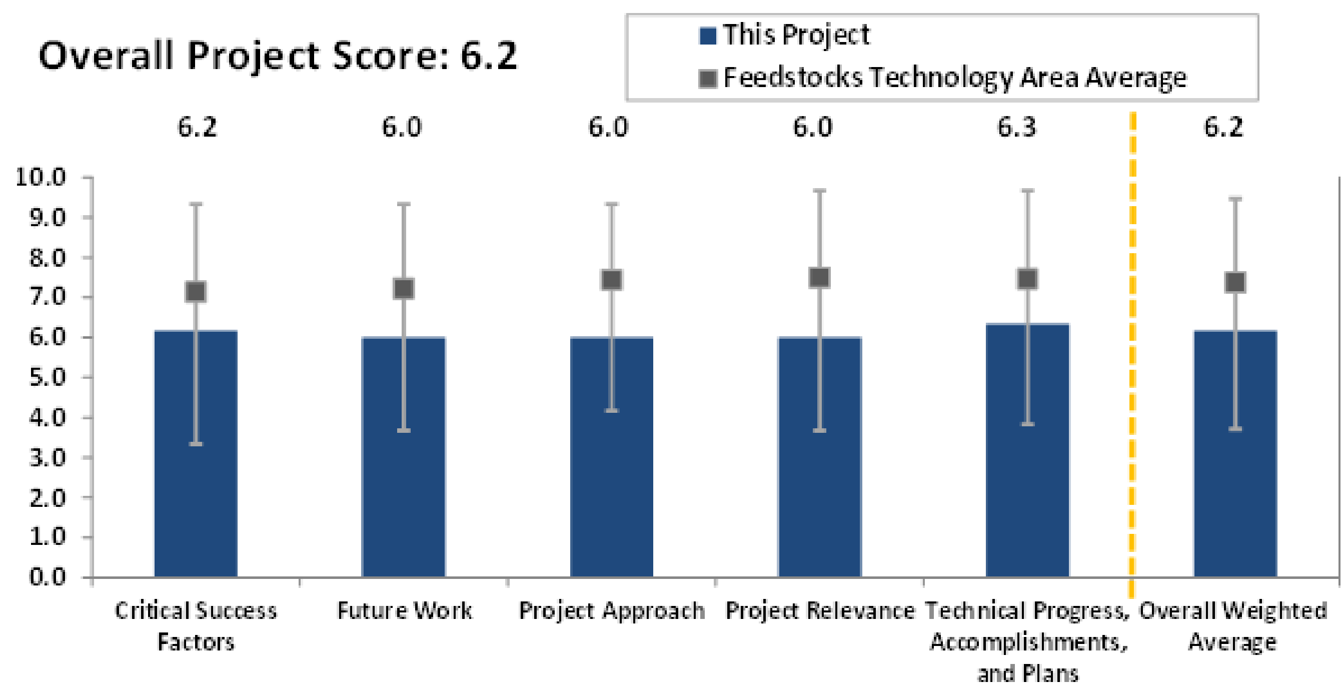
(WBS#: 7.6.2.12)

Project Description

Photo Courtesy of University of Connecticut

Recipient:	University of Connecticut
Presenter:	Steven Suib
Total DOE Funding:	$1,750,000
DOE Funding FY13:	$70,539
DOE Funding FY12:	$595,514
DOE Funding FY11:	$831,056
Project Dates:	2010-2013

The goals of this project are to study poplar as one of the best bioenergy crops for the Northeastern part of the United States; to make field evaluations and genetic improvement of poplar trees; to synthesize new heterogeneous catalysts and develop these for biomass conversion; to screen these catalysts in several biomass catalytic small-scale reactions; to build biofuels processing systems for economic evaluation of the University of Connecticut technology; to carry out outreach activities for commercial agricultural producers for production of biomass feedstocks with emphasis on direct-burn technologies; to produce a comprehensive inventory of feedstocks (total and available biomass of forest and agricultural residues, idle and marginal farmlands); and to use the Connecticut Center for Economic Analysis to develop analyses to measure current and potential net economic impact for the Connecticut biofuels industry. The key aspects of this research effort include genetic alteration to rapidly grow poplar trees; to make active, selective, and stable heterogeneous catalysts; to study these catalysts in a variety of biomass conversion reactions; to scale-up catalysts; to scale-up reactors used for catalytic reactions; to make an inventory of all biomass



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

sources in Connecticut; and to put together an economic strategy for use of biomass in Connecticut. This program is directly related to BETO's goals. Technical accomplishments were made in all areas of this project, most notably development of new catalysts and processes for commercialization of biomass conversion in Connecticut industry. Challenges and successes have been found in the scale-up of these systems and implementation in industrial environments.

Overall Impressions

- This is a small project with a variety of moving pieces that don't appear to be well integrated. It produced apparently useful catalysts for conversion.
- This project has contributed to improving the performance of several segments of the bioenergy chain, as well as a potential solution to a waste disposal problem. Successful commercialization of these developments will encourage future research and venture capital.
- This project is likely to have minimal impact on BETO's goals.
- This project was a coordinated effort among a few of the bioenergy researchers in southern New England. Cross-institutional collaboration was limited, as many top quality bioenergy researchers in Massachusetts were not involved. Heterogeneous catalysts and reactors have been developed and are being commercialized for glycerol to biodiesel using yellow grease as a waste feedstock. RPM is now using this approach for brown grease to biodiesel, and both the biodiesel catalyst and reactor design are in the process of commercialization. These waste greases are relatively low-volume feedstocks that can already be processed with existing available technologies, and cost savings were not documented. Other projects appeared to be an assortment of feedstock projects, ranging from genetically modified poplar to algae, with limited coherence.
- While there were a great many components of the project, the principal investigators focused on the important goals and made contributions to genetically improving poplar and catalysts that will advance the commercialization of biofuels.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

SAINT JOSEPH'S UNIVERSITY INSTITUTE FOR ENVIRONMENTAL STEWARDSHIP

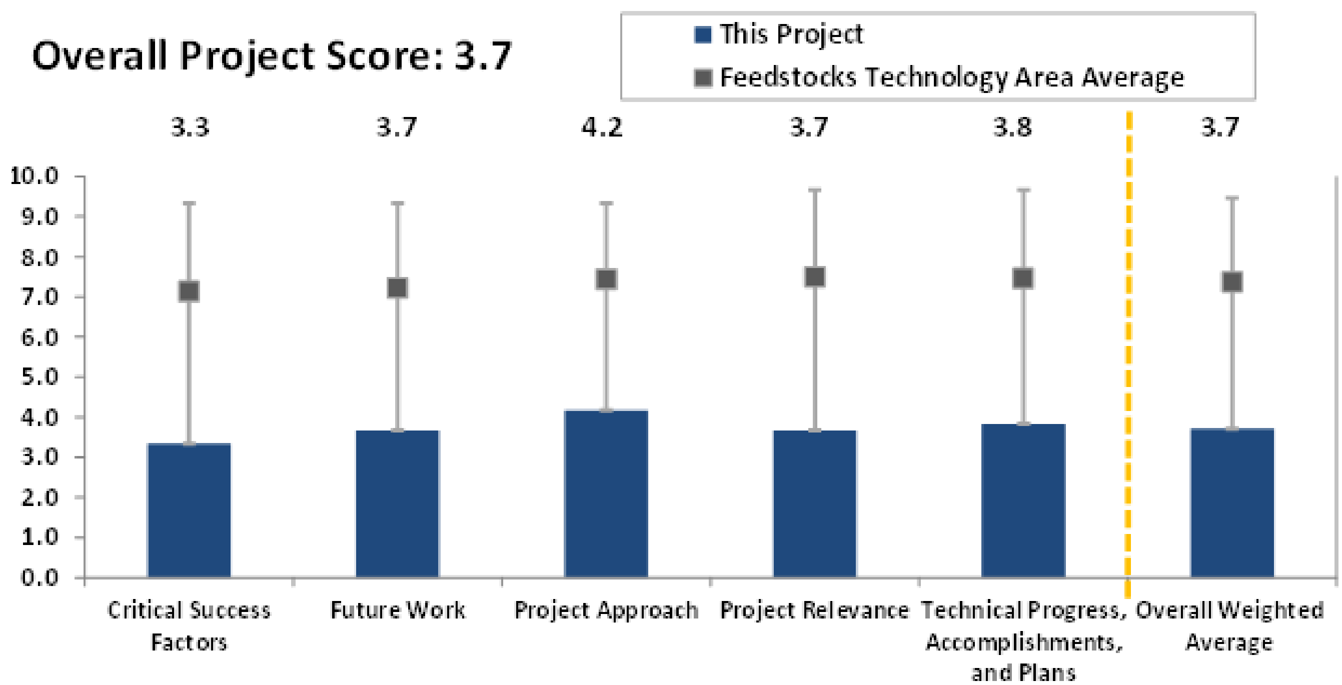
(WBS#: 7.1.2.10)

Recipient:	Saint Joseph's University
Presenter:	Clint Springer
Total DOE Funding:	$1,000,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010-2013

Project Description


Photo Courtesy of Saint Joseph's University

Saint Joseph's University has used the awarded funds from the U.S. Department of Energy to establish an Institute for Environmental Stewardship (IES) that has the three-fold mission of sustainability education, research, and outreach. The education component of this project involved building a variable-depth extensive green roof system for research, research training, and educational use. The research component of the project is funding an examination of the physiological, morphological, and growth responses of *Panicum virgatum* (switchgrass) to simulated climate change using a field and controlled-environment approach. To date, the IES has installed the green roof system, completed most of the switchgrass experiments, and held three stormwater management symposia.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- A focused approach with specific outcomes and impacts must be incorporated into design of the project.
- A substantial part of this project did not deal with feedstocks, but may be considered "citizen involvement" in national energy issues.
- Output products of this project seem to have limited value. The green roof objective was unrelated to DOE concerns. The switchgrass-related objectives have not generated significant value.
- Results from mesocosms and chambers do not always (or even often) correlate with actual field experiment results, so perhaps scalable, perhaps not; issues not addressed, so usefulness not clear.
- The disparate components of this make it difficult to extract meaningful results that advance BETO's objectives. There are certainly lessons learned, but they are limited in applicability.
- This project includes both green roof installation and instrumentation, and switchgrass variety trials. The green roof system has been installed and instrumented with various complementary research projects on system performance, microbial dynamics, etc. Data are being collected and are apparently available for classes to use for educational purposes. Research on the impact of climate change on switchgrass performance is being investigated, with an emphasis on genome size versus adaptation relationships. This project appears to be a continuation of the PI's postdoctoral research at the University of Kansas, and the relevance to St. Joseph's University or more broadly the mid-Atlantic region. Results indicate switchgrass appears highly resistant to rainfall variability based on climate projections for Kansas, Oklahoma, and Texas. There was no significant relationship between genome size (ploidy) and performance under ambient and projected climate conditions. Adaptation of switchgrass to climate change will be an important factor in long-term biomass resource projections. The goals of this project only partially connected with BETO's mission, and it was not clear how this project nests within the many research programs on this topic by other university and government research organizations.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

ENERGY FROM BIOMASS RESEARCH AND TECHNOLOGY TRANSFER PROGRAM

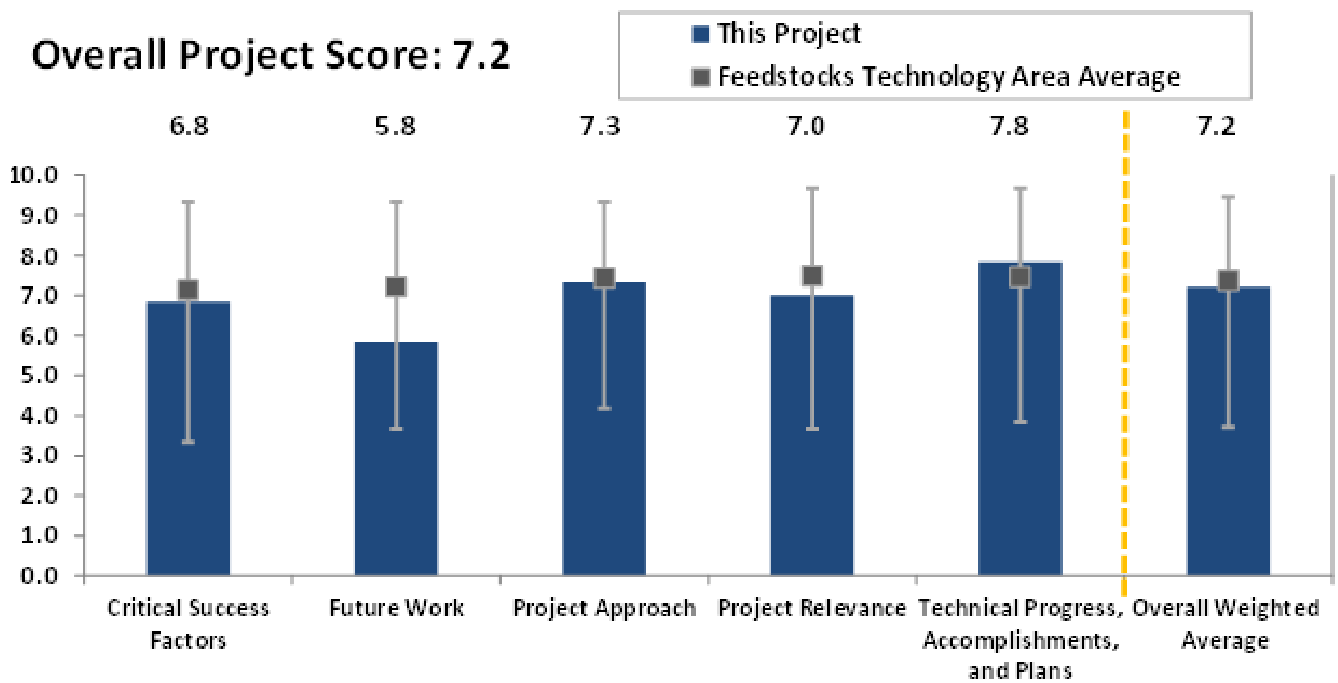
(WBS#: 7.6.2.1)

Recipient:	Consortium for Plant Biotechnology Research
Presenter:	Dorin Schumacher
Total DOE Funding:	$22,500,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2001-2013

Project Description

The Consortium for Plant Biotechnology Research, Inc., (CPBR) is a non-profit membership organization of more than 90 U.S. universities and private companies that are active in domestic and global renewable energy, agricultural, and environmental technology markets. Since 1989, congressional appropriations and federal agencies have provided more than $64 million in USDA, DOE, and Environmental Protection Agency funds—which have been matched through CPBR—with non-federal funding of more than $78 million, for a total of more than $147 million for research and technology transfer. Nearly 500 university research projects have been supported with these funds. CPBR's structure and background have provided the perfect framework for the partnership with DOE's Office of Energy Efficiency and Renewable Energy through grant GO-12026.

CPBR has provided some of the latest and most exciting projects—peer reviewed and destined for the market through the CPBR competition process—thereby assisting BETO in meeting its objectives. Our partnership has resulted in clean technologies that strengthen the U.S. economy and the lives of millions now and in future years. CPBR projects are selected through a highly competitive process that includes an industrial review for practical applications and peer review for scientific merit. The projects are matched 130 percent on average with non-federal matching, of which industry provides more than 50 percent in cash. This proves the economic value of CPBR research. With CPBR support, scientists have produced more than 2,360 publications in refereed journals and trained over 1,200 postdoctoral fellows



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

and graduate and undergraduate students. CPBR's commercialization results (active licenses per million dollars of federal funding) are 3,687 percent higher than what universities receive. Several companies have been started up based on IP resulting from CPBR-funded projects. The research, training, and commercialization from CPBR projects have created thousands of jobs. CPBR project results include developing plants with faster growth; plants with disease, insect, and herbicide resistance; plants as bio-factories; improved biomass production (biodegradable plastics, epoxy fatty acids, industrial enzymes, other bio-based products); improving biomass-to-energy conversion (bioethanol, biodiesel); and bio-remediation of hydrocarbons, as well as heavy-metal phytoremediation.

Overall Impressions

- A track record of success indicates that this project can be a valuable extension of the BETO-managed Technology Area.
- Appears to accelerate research and maximize DOE funding instead of adding overhead. Lack of continued funding will undoubtedly keep viable projects from being funded.
- Outcomes and impacts resulting from this funding are dynamic and encouraging for researchers over a broad spectrum of disciplines and affiliations. Few other projects have provided funding that resulted in commercial applications of this magnitude. Utilization of peer review has been critical to the success. Continued, long-range funding must be encouraged.
- Small, competitive grants program (practical and scientific merit) using BETO priorities with specific outreach to historically black colleges and universities.
- The Consortium for Plant Biotechnology Research has an energy and biomass component that matches university researchers with industry partners. Requests for proposals are limited to member universities, which have to recruit companies that contribute annual funds. There is a diversity of specific technical targets related to each project. The presenter was able provide details about only a few projects, which was quite disappointing given the size of funding over a nine-year period (plus the current ramp-down phase). While the program is reasonably successful in some respects, given the level of funding, its impact has been quite limited relative to other projects in the BETO portfolio. The program has a serious lack of transparency, with not even project titles or university recipients listed on the CPBR website. Industry involvement with project scoping and selection results in significant leveraging of industry dollars, as well as substantial output in terms of academic publications, IP patents, licenses, etc. Industry involvement and funding is a requirement, and in the plant biotechnology world, this quite naturally leads to success in various IP metrics. However, the statistics were compared with total university research portfolios, not plant biotechnology research, which has a much higher inherent patent, license, and commercialization rate. The inherently high IP and commercialization rate in plant biotechnology research is clearly enhanced by the industrial funding requirement. A comparison with the IP and the numbers of publications that result from government plant biotechnology funding would provide a better benchmark.
- The success of CPBR in generating successful proposals may have encouraged others to emulate its process while bypassing the consortium.

PI Response to Reviewer Comments

- CPBR and its 80 university and industry members appreciate the DOE funding CPBR has received. The funding has supported a total of 299 university research projects. With regard to transparency, the 330-page, publicly available CPBR publication, Funded Projects Report, describes all of the projects and their scientific, economic, and education results in transparent, non-confidential form, available to anyone upon request. Also, the 105-page, non-confidential Publications from CPBR Funded Research Report lists the 2,504 scientific publications from CPBR-funded research. This is way too much information to attempt to paste into the website without significant cost in both dollars and unwieldiness. The industrial involvement in CPBR does result in significant leveraging of industry dollars. In fact, of the 130.00 percent average non-federal matching CPBR obtains for its federal funds, 50.00 percent is in the form of cash matching from industry. With regard to other evidence of CPBR's significant impact, CPBR's average commercialization rate is 1670.00 percent higher than the average of university commercialization rates reported in the latest Association of University Technology Managers AUTM survey. Companies that have matched CPBR's federal funds report a minimum projected investment of $1,207,490,000 to commercialize the results of CPBR-funded research. So the federal funds will have supplied 5.00 percent and the companies at least 95.00 percent of the funds for the development of new technologies. The companies will have invested at least 2000.00 percent of the federal funds invested, in addition to the original matching the companies provided.

RENEWABLE ENHANCED FEEDSTOCKS FOR ADVANCED BIOFUELS AND BIOPRODUCTS (REFABB)- DEVELOPMENT PROGRAM

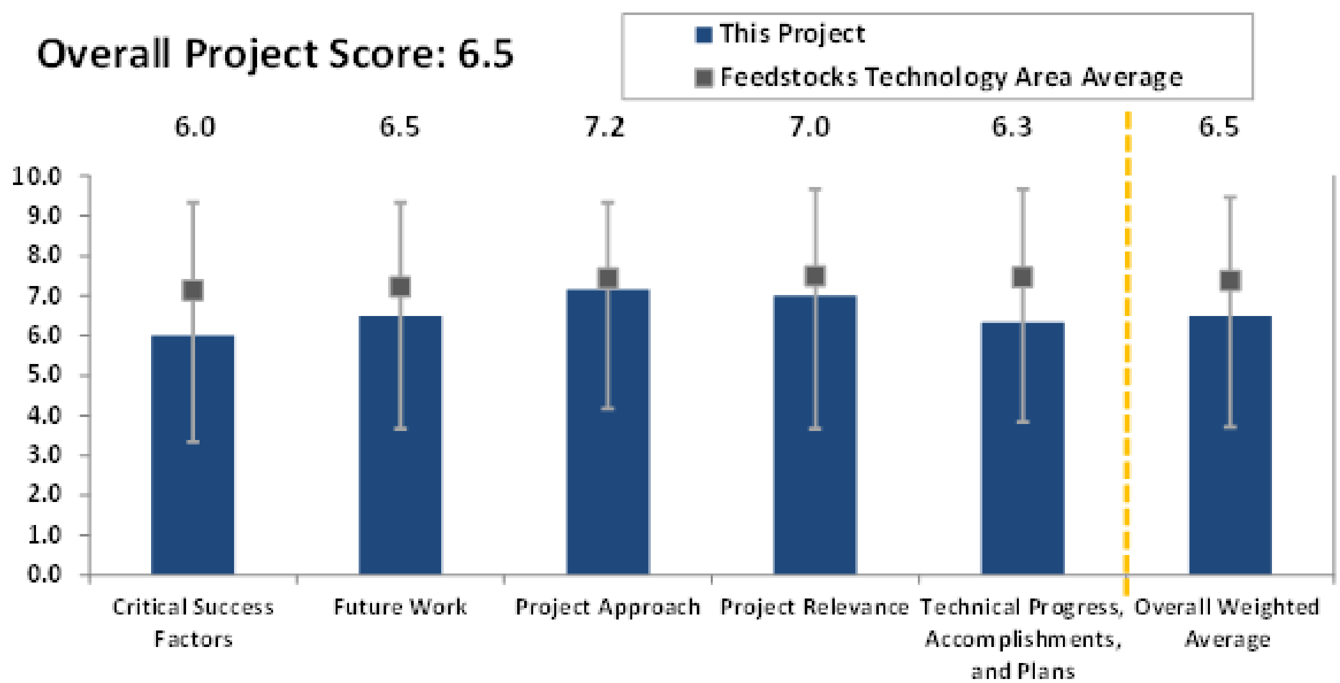
(WBS#: 1.2.3.1)

Recipient:	Metabolix
Presenter:	Oliver Peoples
Total DOE Funding:	$6,000,001
DOE Funding FY13:	$2,293,960
DOE Funding FY12:	$2,300,000
DOE Funding FY11:	$1,406,040
Project Dates:	2011-2014

Project Description

Photo Courtesy of Metabolix

The Renewable Enhanced Feedstocks for Advanced Biofuels and Bioproducts project is a development project that uses the tools of metabolic engineering to couple the advantages of dedicated bioenergy crops with the enhanced value and capital efficiency of torrefaction for the production of biofuel and biobased products. Metabolix multidisciplinary program combines the advanced genetic engineering of polyhydroxbutyrate (PHB) production in switchgrass with a proprietary thermal conversion process to produce a densified biomass and a platform chemical precursor crotonic acid. The densified biomass retains 80% of the energy and can be consolidated at world-scale biorefineries for biofuel production. Crotonic acid can be converted to a range of industrial chemicals including bio-butanol, bio-propylene, and bioacrylic acid, whose markets scale with the energy sector. Using proprietary genes, Metabolix has demonstrated increased carbon fixation in switchgrass that may result in higher PHB expression levels and higher fermentable sugar content. Metabolix has also achieved promising results in developing gene containment technology, which will



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

reduce cost and timelines for regulatory approval and large-scale production of engineered bioenergy crops. Metabolix—in cooperation with its partners—has demonstrated and will continue to develop and optimize the torrefaction process with the goal of achieving 90% recovery of PHB in biomass to crotonic acid. Metabolix has also demonstrated metathesis conversion of crotonic acid to acrylic acid, and hydrogenation conversion of crotonic acid to butanol. The company is currently in the process of demonstrating the conversion of crotonic acid to maleic anhydride. The Renewable Enhanced Feedstocks for Advanced Biofuels and Bioproducts technology provides an integrated economic and environmental value proposition for combined production of biobased commodity chemicals and biofuels not available with existing technologies.

Overall Impressions

- Continued work could be more focused with specific outcomes. More connections with respect to various aspects of the work would be beneficial.
- The fundamental approach of this project is viable, but they are still a distance away from achieving their goals for chemical production in the plants. While their process has promise, it is difficult to assess the probability of achieving the goals they say are needed to achieve financial viability. There is significant concern that independent demonstration of tasks in isolation will not be an adequate analysis of the envisioned system for energy and co-product production.
- This group is taking a supply chain approach to couple crop genetics and development, feedstock harvest and densification, and conversion to crotonic acid as a platform chemical for fuels (butanol) and chemicals. The goal is to modify four-carbon grasses to express high levels of PHB in the plant in ways that can be easily extracted. Setaria is the model grass species for this work, and they are scaling up in switchgrass. They then use torrefaction to process the biomass and recover crotonic acid, followed by catalysis to final products. The focus of this project is on high-value chemicals, specifically higher-value chemicals with fuels as a by-product. They have set a target of 10% of the biomass converted to high-value chemicals with 90% of the biomass for lower value fuels is quite logical, and mimics many successful refineries as well as food biorefineries. The team has characterized 16 accessions of Setaria viridis and developed two genome transformation methods. Overexpression of key genes involved in carbon flow has resulted in a 60% increase in biomass, four-fold increase in soluble sugars and starch, and two and a half times in the baseline of total chlorophyll and carotenoids. They are planning to now increase expression of the PHB gene in this system and observe its potential. They have also developed a gene containment system based on excision of transgenes in pollen. They are currently working to express the PHB operon in their platform vector for switchgrass plasmid transformation. PHB biomass levels should be in the range of 4 to 6% in switchgrass leaf biomass, although they are having trouble with scale-up at Kentucky Biomass. Initial conversion yield is approximately 56% in torrefaction trials, and they need 90% recovery for commercial viability. Lab tests indicate this may be possible, but challenging to achieve. Development of the conversion process to produce final products is well underway, with some products demonstrated in the lab. This team would like to achieve 10% PHB in switchgrass and 90% yield of crotonic acid from thermolysis. Economic modeling, including price targets of 60 cents per pound for PHB, indicates these targets will make the remainder of the biomass viable. Timelines for crop engineering remain challenging. Discussion about commercial opportunities is ongoing, but no specific commitments at present. They did not consider the transgenic nature of this project a barrier, but the assumption that public resistance to transgenes is rapidly diminishing seems highly optimistic. The researchers

are collaborating with Kentucky Bioprocessing and the USDA Eastern Regional Research Center, both of which are structured to do early stage and pilot demonstrations. The project needs more emphasis on understanding and overcoming the barriers to commercialization. Technical success in a transgenic energy crop does not equal commercial potential, and the approval process is both long and expensive. Both regulatory approvals and process development pathways toward commercialization seem possible, but there is no current commitment to make them happen. The team clearly needs a strategic partner with financing and market capacity for a three- to six-year commercialization trajectory. Such a partner should be firmly committed before additional funding is awarded. This is a high-risk, high-reward project. In a rapidly evolving industry with significant cost challenges, projects of this type should be a significant part of the BETO portfolio.

- This project creates the pleasant dilemma of choosing to manage for chemical production or for energy production. If the answer is to do both, Metabolix's method would make a valuable case study.
- Using gene insertion to increase a desired chemical component for release and conversion during torrefaction to support the feasible commercialization of torrefied biomass as a substitute for coal. Fairly high-risk, but seem to be making good progress.
- Very compelling project that could have great commercialization value if all of the tasks come together.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

DEMONSTRATION OF ON-FARM PRODUCTION OF A DEDICATED ENERGY CROP INCORPORATING MULTIPLE VARIETIES OF SWITCHGRASS SEED (SWITCHGRASS PRODUCTION)

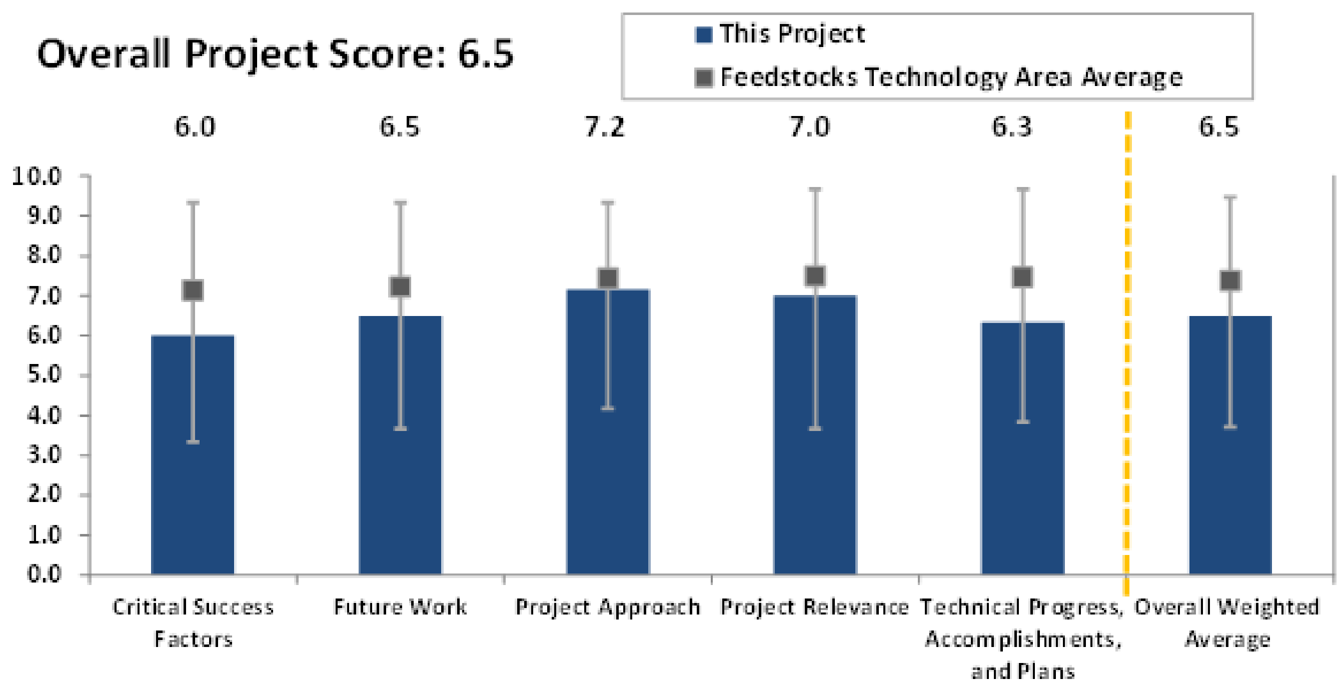
(WBS#: 1.3.1.5)

Recipient:	University of Tennessee
Presenter:	Samuel Jackson
Total DOE Funding:	$2,301,783
DOE Funding FY13:	$800,382
DOE Funding FY12:	$596,084
DOE Funding FY11:	$905,317
Project Dates:	2010-2013

Project Description

The development of improved varieties of dedicated energy crops is critical to ensuring the sustainability of bioenergy production. By improving yields and conversion performance of the plants, producers can reduce the land required to produce feedstocks. This project involves a 2,000-acre, demonstration-scale project to compare three varieties of switchgrass, one standard and two improved varieties, through various production factors including feedstock genetics, management practices, and harvesting equipment and timelines in Eastern Tennessee. The project utilized field demonstration plots that incorporate different varieties of switchgrass seed. The demonstration planting involves 1,000 acres of the current, unimproved Alamo switchgrass variety; 800 acres of the Ceres EG 1101 improved Alamo variety; and 200 acres of the Ceres EG 1102 improved Kanlow

Photo Courtesy of University of Tennessee



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

variety. The demonstration of improved feedstocks at a large scale allows for significant farmer education and outreach, expanding the knowledge base of potential biomass producers. Two large field workshops were held with a combined attendance of more than 1,500 individuals who learned about feedstock production and preprocessing. The project also advances the conversion industry by analyzing the chemical and structural characteristics of the switchgrass, evaluating the preprocessing of switchgrass, and evaluating the biochemical conversion of the switchgrass materials into liquid fuels. Significant compositional data has been collected. The data and information related to switchgrass composition changes over time and variability enables conversion industry partners to better optimize their technologies. Models developed through the collection of biomass samples on the study will allow for rapid throughput analysis of incoming feedstocks and a much broader understanding of feedstocks in real time.

Overall Impressions

- Broad-based workshops covered in-field operations, equipment, market development, and conversion were successful; being requested to run workshops again. Leveraging project information to address additional questions; providing data to the Biomass Library and Knowledge Discovery Framework.
- Excellent program with relevant species for energy crop. Initial structure including State of Tennessee, University of Tennessee, ORNL, Tennessee Valley Authority, DuPont, and numerous producers was critical. For commercial production, producers must be confident continued years of development will be imminent; otherwise, cultural practices, equipment, seed acquisition, pesticides, fertilizer usage, and off-farm storage may introduce bumps in the road. Inclusion of thousands of acres, in various soil types and terrains, continues to be a major need for continued development.
- Really nice project within its scope. Including sustainability is an important part of this. Important results will come from not just the technical outcomes, but farmer learnings.
- The primary value of this project has been to expand the quantity of switchgrass grown in Tennessee, thus enhancing the potential for a biorefinery at some point. The information gained regarding varieties and their composition could have been obtained with a more limited and lower-cost project.
- This project did a great job of bridging between two communities: potential producers and the supporting industry.
- This project involved field-scale development and demonstration of switchgrass in Tennessee. The project included extensive farmer education that laid a foundation for increased farmer interest and capacity. 2,000 acres of switchgrass established in 2010, including two new Ceres varieties and Alamo. Successful harvests were completed in 2010, 2011, and 2012. There were more than 1,400 attendees at two, two-day field demonstrations, with multiple technical tours, speakers, and equipment demonstrations. Biomass composition sampling and analysis was conducted over a five-acre grid, with 240 to 700 samples per year, including more detailed analysis on some farms. Sampling proceeded throughout the growing season with three to six growth stages analyzed for yield and composition. Extensive statistical analysis of composition indicated little significant difference between varieties for various components. A major finding was the higher level of extractives in year one at harvest, and a life-cycle analysis has been published for a pellet end use. There is intent to provide sample characteristic data to the INL Biomass Resource Library and other data to the ORNL Knowledge Discovery Framework, but this has not yet been done. Ceres and University of Tennessee have each developed near infrared

calibration for biomass characteristics, but these calibrations are proprietary and will only be available through a licensing arrangement. With public research dollars funding this project, valuable data and the associated characterization models should be available to the public. Future BETO contracts should be written in a way that guarantees data sharing and transparency. Long-term success for local farmers will be dependent on viable markets for the crop. There are about 5,100 acres of switchgrass planted, most of which is now coming out of contract, and there is a question about a commercial market. The project's initial commercial partners included DuPont, Genera (now TennEra), and Ceres. Ceres is still involved, and DuPont remains a partner that they hope will come back to site a cellulosic facility in Tennessee, but they are currently focused on corn stover in the Midwest. The interim markets are likely in combustion or forage.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

SOUTH DAKOTA STATE UNIVERSITY, SUN GRANT INITIATIVE, REGIONAL BIOMASS FEEDSTOCK DEVELOPMENT PARTNERSHIP

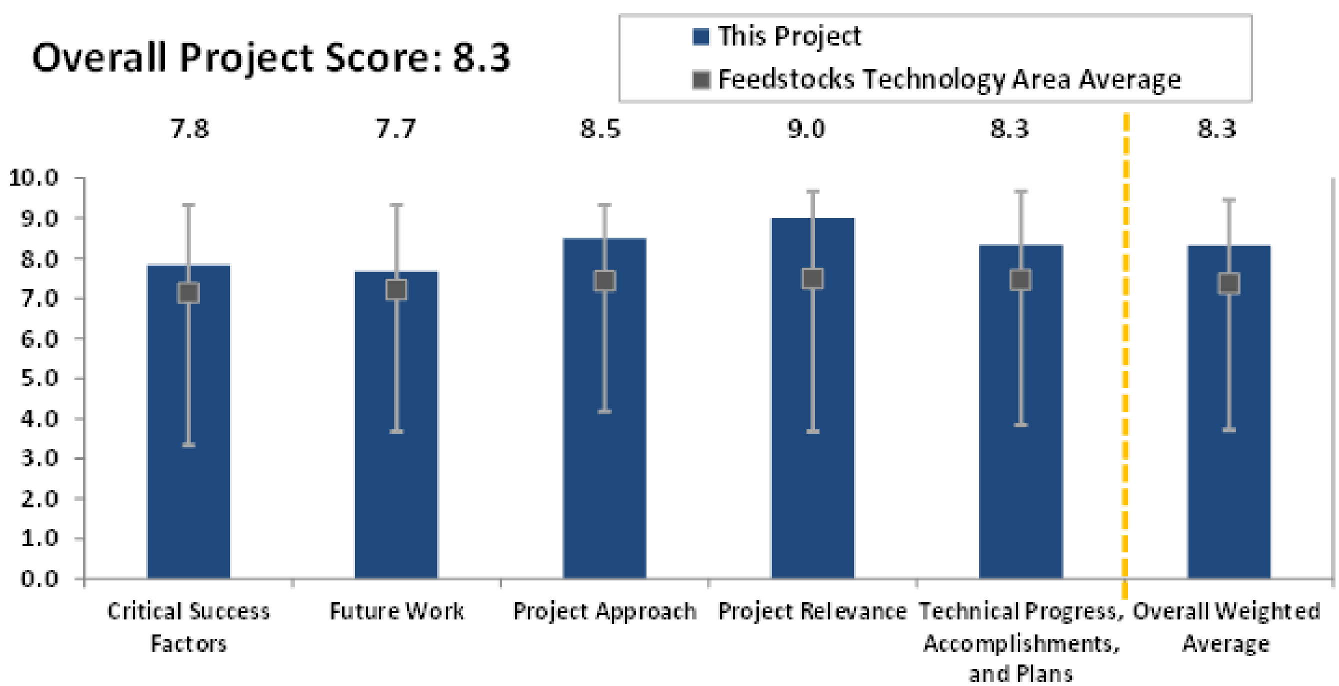
(WBS#: 7.6.2.6)

Recipient:	South Dakota State
Presenter:	Vance Owens
Total DOE Funding:	$10,492,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2008-2013

Project Description

Photo Courtesy of South Dakota State

The purpose of this project is to help develop more accurate feedstock cost supply information and improved communication with partners in the biomass feedstock supply chain. To accomplish this, replicated field trials were established across regions to determine the impact of residue removal on future grain yield, and to develop energy crops within geographical regions. Further, a regional assessment of feedstock resources is being completed to determine feedstock supply curves. Field trials of corn, switchgrass, *miscanthus*, sorghum, energy cane, Conservation Reserve Program land, poplar, and willow were initiated in 2008 primarily, with some sites coming online one or two years later and some sites being planted before 2008. Much of the data from these trials has been uploaded to the KDF and additional data will be uploaded in the future. Key tasks also included development of BioWeb and the Regional Feedstock Partnership website.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Significant accomplishments across a broad range of feedstocks, logistics, production, economics, and conversion options. Highly relevant to BETO priorities related to sustainable feedstock production and related properties; opportunities to leverage these funds/projects to extend and expand the work and the outcomes. Well-run regional program that is delivering useful results applicable across multiple regions.
- The number of projects supported with this funding are diverse and the knowledge gained adds to the overall bioenergy knowledge base.
- The PIs appear to have taken a well-disciplined approach to project selection and funding, with a large portfolio of successful outcomes.
- The Sun Grant Regional Biomass Feedstock Partnership is an umbrella program that entails a range of projects that included 75% of funds to competitive grants to land-grant universities and industrial partners. The competition was run nationwide, but with projects that targeted the north central region. More than two dozen projects were funded, with most of the funding distributed to feedstock development (56%), then logistics (26%), followed by economics and conversion technologies. Projects had 20% cost share. Major progress was made on novel feedstock mixtures and cropping strategies (including nurse crops, winter crops, and legumes); feedstock establishment (including switchgrass dormancy); intelligent bale staging (20% cost savings) and handling; wet storage, cubed bales, and other densification strategies; AFEX co-products to high-value cattle feedstocks; and biochar co-product impacts as a soil amendment. Human dimensions—including not just economics, but also farmer values and decisions—were included in some projects. The overall program developed a broad and comprehensive set of partnerships across the north central region, with several projects including industrial collaborators. The new cash matching requirement for commercialization projects provides a novel way to achieve broad industry impact. This is a great example of a competitive process that leveraged some of the best minds and institutions in the nation to create novel approaches to some major challenges to biomass feedstock development, logistics, and sustainability concerns.
- This program illustrates that successful project selection and management can occur under a range of funding scenarios and sponsoring agencies.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

GASIFICATION

TECHNOLOGY AREA

INTRODUCTION

The Gasification Technology Area was one of nine technology areas reviewed during the 2013 Bioenergy Technologies Office (BETO or the Office) Project Peer Review, which took place on May 20–21, 2013, at the Hilton Mark Center in Alexandria, Virginia. A total of 17 project presentations were reviewed by six experts from industry, academia, and other government agencies. The panel reviewed a portfolio of gasification (indirect liquefaction)-related projects worth approximately $70 million, the majority of which had closed out in previous years. One principal investigator (PI) for each project or project grouping was given 30–45 minutes to deliver a presentation and respond to questions from the review panel and the audience. Projects were evaluated and scored on project approach, technical progress, relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the project review, including full scoring information for each project, summary comments from each reviewer, and the PI's response to the summary comments, if provided. Overview information on the Gasification Technology Area, the Review Panel Summary Report, and the BETO Programmatic Response are also included in this section. The BETO-designated review leads for the Gasification Technology Area are Paul Grabowski and Prasad Gupte.

GASIFICATION TECHNOLOGY AREA

OVERVIEW

The Bioenergy Technologies Office's Gasification (indirect liquefaction) research and development (R&D) focuses on developing technologies that convert biomass to gaseous intermediates (e.g., synthesis gas or renewable methane), and then other oxygenated intermediates for the production of fuels, chemicals, and power. Synthesis gas (primarily hydrogen and carbon monoxide) can be generated via gasification of biomass, municipal solid waste (MSW), or other organic material. Renewable methane is generated by processes such as catalytic hydrothermal gasification or anaerobic digestion, and may also be obtained from landfill gas. Each of these gaseous intermediates may be further converted to fuels or chemicals via biological and/or catalytic processes.

GASIFICATION SUPPORT OF OFFICE STRATEGIC GOALS

The Gasification R&D strategic goal is to:

> *Develop commercially viable technologies for converting biomass feedstocks into energy-dense, fungible hydrocarbon liquids, such as renewable gasoline, jet and diesel fuels, bioproducts, chemical intermediates, and bioenergy.*

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

GASIFICATION SUPPORT OF OFFICE PERFORMANCE GOALS

The Gasification R&D overall performance goal is to reduce the estimated mature technology processing cost for converting cellulosic feedstocks to advanced biofuels. Specifically, by 2022, achieve the overall Office performance cost goal of $3 per gallon of gasoline equivalent (2011 dollars) via catalytic upgrading of biomass synthesis gas to gasoline-, jet-, and diesel-range hydrocarbons.

Milestones towards accomplishment of those performance goals include:

- By 2014, establish out-year cost goals and technical targets based on completed techno-economic analysis for at least one gaseous intermediate conversion to hydrocarbon fuels pathway.
- By 2022, validate integrated conversion process for woody biomass to renewable gasoline or diesel via conversion of gaseous intermediates at a scale sufficient enough for transfer to pilot-scale operation.

TECHNICAL AND MARKET CHALLENGES AND BARRIERS

BETO has identified the following technical challenges for achieving the goals of the Gasification Technology Area:

APPROACH FOR OVERCOMING CHALLENGES

BETO's approach to overcoming these challenges is to work closely with our partners to identify and develop solutions to the technical challenges of indirect liquefaction of biomass resources. One of the benefits of this approach is to develop liquid fuels and products that cannot be replaced by other renewable sources. BETO's efforts to overcome the challenges and barriers associated with the Gasification Technology Area are organized within five categories: analysis and sustainability, feedstock interface, conversion technologies, conversion enabling technologies, and integration and scale-up.

Research is performed by national laboratories, industry, non-profit organizations, and universities, as well the National Advanced Biofuels Consortium. BETO, via the national laboratories, has process demonstration units (PDU) that are utilized for R&D. Near-term R&D efforts focus on indirect liquefaction of woody biomass. Indirect liquefaction of agricultural residues, dry-sorted MSW, energy crops, and formulated-feedstocks will also be examined.

For more information on the Gasification Technology Area, please review BETO's Multi-Year Program Plan at bioenergy.energy.gov/pdfs/may_2013.pdf.

Technical Challenges
Feeding Dry Biomass
Feeding or Drying Wet Biomass
High-Temperature Gas Production from Biomass
Low-Temperature Production of Gaseous Intermediates
Gas cleanup and Conditioning
Validation of Syngas Quality
Gaseous Intermediates Process Integration
Liquid Intermediates Process Integration
Fuel Synthesis and Upgrading
Process Modeling and Optimization

REVIEW PANEL

The following external experts served as reviewers for the Gasification Technology Area during the 2013 Project Peer Review.

Gasification Reviewers	
Suresh Babu (Lead Reviewer)	Brookhaven National Laboratory
Foster Agblevor	Utah State University
Jack Lewnard	Gas Technology Institute
John Scahill	Thermal Biofuels Consultants, LLC, retired National Renewable Energy Laboratory and Golden Field Office
David Sudolsky	Anellotech, Inc.
Nathan Weiland	West Virginia University

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

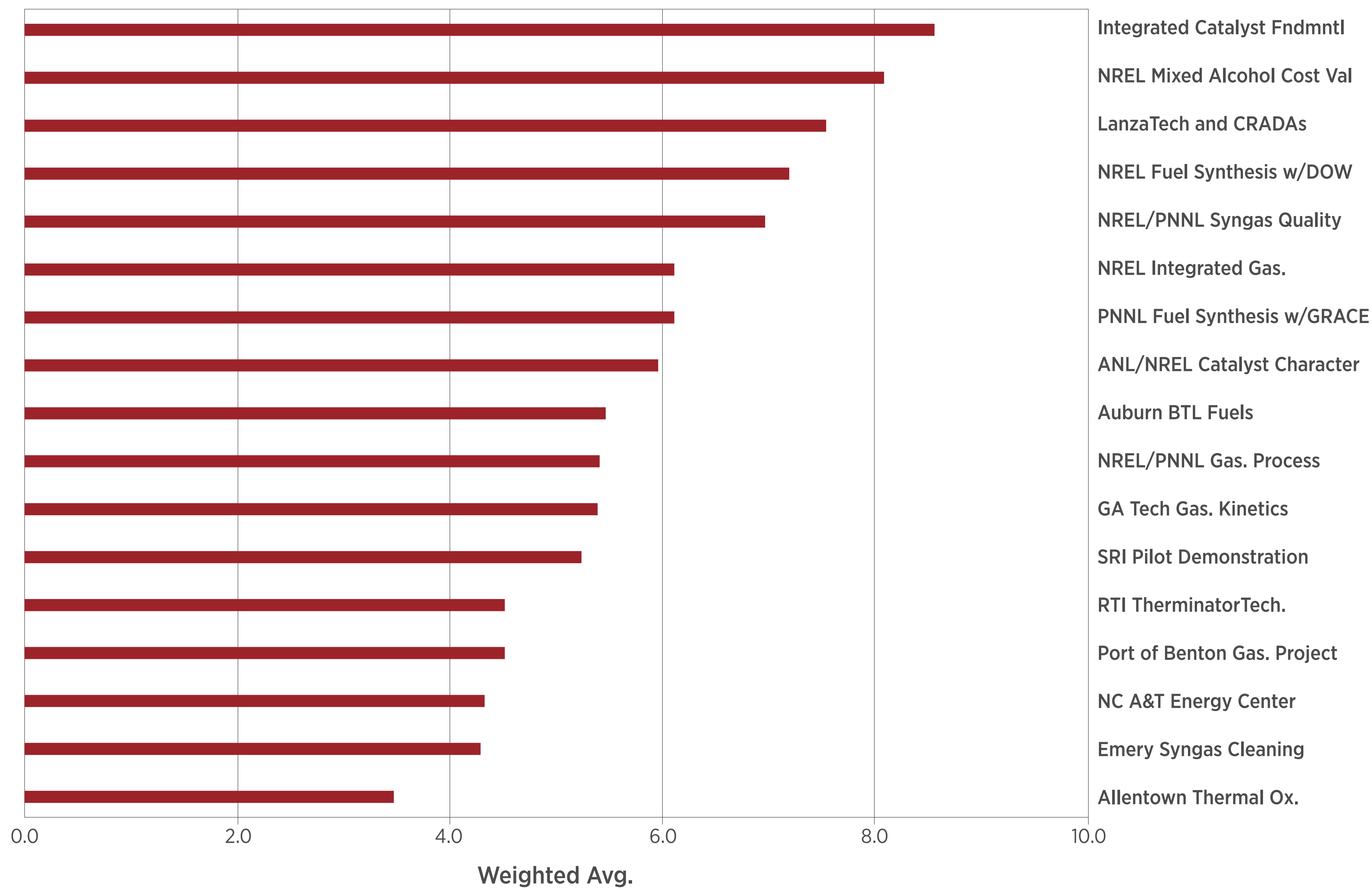
- **Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.
- **Project Scoring Information and Short Names Key**: The final score charts depict the overall weighted score for each project in each technology area. Short names for each project were developed for ease of use in the scoring charts, the table of contents, and other locations. Full project names, along with their designated short names and their work breakdown structure (WBS#), are provided in the Short Names Key.
- **Review Panel Summary Report**: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.
- **BETO Programmatic Response**: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.
- **Project Reports**:
  - **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space constraints allotted.
  - **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
  - **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and

the whiskers depict the range of scores for each category within each technology area.

- **Reviewer comments** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant by BETO's director were excluded from the final report.
- **PI Responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the

TECHNOLOGY AREA SCORE RESULTS



SHORT NAMES KEY

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
3.2.5.6; 3.2.5.8	Catalyst Fundamentals & Catalyst Fundamentals Integration	PNNL; NREL; Enerkem	Integrated Catalyst Fndmntl
3.6.1.1	Sygnas Mixed Alcohol Cost Validation	NREL	NREL Mixed Alcohol Cost Val.
3.3.1.6; 3.3.1.7; 3.3.1.8	A Hybrid Catalytic Route to Fuels from Biomass Syngas Including NREL and PNNL CRADAs	LanzaTech, Inc.; NREL; PNNL	LanzaTech and CRADAs
3.3.2.8	Fuel synthesis catalyst - Work with DOW Chemicals	NREL	NREL Fuel Synthesis w/ DOW
3.3.2.1; 3.3.2.2	Advanced Thermochemical Biofuels; Syngas Quality for Fuel Synthesis.	NREL; PNNL	NREL/PNNL Syngas Quality
3.2.5.7	Integrated Gasification and Fuel Synthesis	NREL	NREL Integrated Gas.
3.3.2.7	PNNL Fuel Synthesis Catalyst - CRADA with GRACE	PNNL	PNNL Fuel Synthesis w/ GRACE
3.2.5.17; 3.3.2.1	Catalyst Characterization	ANL; NREL	ANL/NREL Catalyst Character.
7.7.3.6	Auburn University, Biomass to Liquid Fuels and Electric Power Research	Auburn University	Auburn BTL Fuels
3.2.1.1; 3.2.1.3	Gasification Process Modeling and Optimization	NREL; PNNL	NREL/PNNL Gas. Process
3.2.1.5	Development of New Gasification Processes for Biomass Residues: Gasification Kinetics at Pressurized Conditions	Georgia Institute of Technology	GA Tech Gas. Kinetics
3.2.5.13	Pilot-Scale Demonstration of a Fully Integrated Commercial Processes for Converting Woody Biomass into Clean Biomass Diesel Fuel	Southern Research Institute	SRI Pilot Demonstration
3.2.5.12	Validation of the RTI Therminator Syngas Cleanup Technology in an Integrated Biomass Gasification/Fuel Synthesis Process	RTI International	RTI Therminator Tech.
7.4.3.13	Biomass Gasification Research and Development Project	Port of Benton	Port of Benton Gas. Project
7.3.2.6	Renewable Energy Center	North Carolina A&T State University	NC A&T Energy Center
3.2.5.9; 3.2.5.14	Novel Approach for Biomass Syngas Cleaning and Conditioning for Liquid Fuel Synthesis Applications & Associated CRADA with INL	Emery Energy; INL	Emery Syngas Cleaning
7.7.2.22	Near Zero Carbon Footprint Energy Creation through Thermal Oxidation (Hydrothermal Decomposition and Resource Recycling)	City of Allentown	Allentown Thermal Ox.

REVIEW PANEL SUMMARY REPORT

INTRODUCTION

A six-member team of gasification peers reviewed a total of 17 project presentations; these projects are referred to using their designated names in the Short Names Key. They consisted of eight presentations from national laboratories—six from the National Renewable Energy Laboratory (NREL), one from Pacific Northwest National Laboratory (PNNL), and one from Argonne National Laboratory (ANL); five from private research organizations—RTI, SRI International, Emery, Enerkem, and LanzaTech; one from a city municipality (Allentown, Pennsylvania); and four from universities—Georgia Institute of Technology, North Carolina Agricultural and Technical State University (NC A&T) and Tennessee State University, Washington State University (WSU), and Auburn University. Enerkem gave a joint presentation with NREL in the Integrated Catalyst Fundamentals project.

The 17 projects cover a range of subjects: one on fundamental studies (Georgia Institute of Technology); two on gas conditioning (RTI and NREL); nine on thermochemical catalytic conversion and fuel synthesis, which included two cooperative research and development agreements (CRADA)—NREL Fuel Synthesis with Dow and PNNL Fuel Synthesis with W.R. Grace; one on hydrothermal conversion (City of Allentown); two on hybrid thermochemical and biochemical conversion (LanzaTech and WSU); one on an advanced concept (Emery); and two on modeling studies (NREL). Of these, ten have been completed and seven are currently active projects.

From the collective review of project presentations and the ensuing discussion, primarily with the active participation of the panel of gasification peers, the following summary was prepared. The summary is subdivided into impacts (including high-impact projects, lessons learned, and innovations), recommendations for monitoring ongoing projects and future program review presentations, program and project gaps, synergies, and overarching recommendations.

IMPACTS

1 What are the key strengths and weaknesses of the projects in this technology area? Do any of the projects stand out on either end of the spectrum?

2 Is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry in this technology area? Is the government's focus appropriate in light of private-sector investments? Are there any projects that stand out as meeting (or not meeting) this criterion?

During the two years preceding the 2013 Project Peer Review, almost all of the Bioenergy Technologies Office gasification research projects were focused on completing the balance of scope of work for this period with few new initiatives. In spite of the limited activity, the review panel observed that significant progress has been reported by some projects to advance the state of the art of biomass gasification. They include the Integrated Catalyst Fundamentals project, with advances in hot-gas conditioning and synthesis-gas conversion to ethanol; NREL's Fuel Synthesis CRADA with Dow, with the development and evaluation of a molybdenum disulfide (MoS_2) alcohol synthesis catalyst; and NREL's Mixed Alcohol Cost Validation, a techno-economic analysis (TEA) and modeling project that provides useful research guidance to choose pathways leading to performance and economic targets.

HIGH-IMPACT PROJECTS

The four high-impact projects that were identified along with their proven and prospective contributions are:

- Integrated Catalyst Fundamentals is recognized for accomplishments in hot-gas cleanup, synthesis gas conditioning, and catalytic conversion to ethanol (EtOH); for licensing patented research to industry; and for the productive coordination with industry to advance the development of the Enerkem process.
- NREL Fuel Synthesis with Dow is recognized for deploying a technically successful development pathway, involving prompt exchange of information between lead researchers, and for taking into consideration the guidance provided by NREL's TEA.
- NREL Mixed Alcohol Cost Validation, now expanded to address the evolving sustainability criteria, is acknowledged for the guidance it continues to provide in potential pay-off research pathways through its TEA support, most noticeably for advanced gas cleaning, conditioning, and catalytic fuel synthesis projects.
- The Hybrid Catalytic Route to Fuels from Biomass Syngas pursued by LanzaTech through CRADAs is recognized for the prospects it offers to completely circumvent the challenges of raw gas cleanup, which could significantly reduce the cost of gasifier downstream processing.

LESSONS LEARNED

Most of the 17 projects were conducted by research partnerships involving one or more organizations. While partnerships are encouraged to bring together special capabilities and expertise to add value to research programs, most of the presenters did not highlight the benefits, if any, resulting from such cooperation. A majority of partnerships simply led to parallel efforts in performing organizations with very little interaction and redundant or unproductive work. Partnerships should be strategically aligned to bring unique capabilities to the parent project, enhancing the potential for success in addition to advancing technical innovation. Therefore, BETO should review proposed partnerships to ensure that they shall work jointly in delivering value to projects. Trivial and non-essential partnerships, particularly with national laboratories, should be discouraged.

The review panel believes that lack of success in the partnership in RTI's Therminator Technology could be attributed to the unanticipated circumstances that potentially led RTI to conduct the Therminator synthesis gas conditioning scale-up tests at the University of Utah. The indirectly heated gasifier at the University could not be operated at the desired temperature, thus depriving RTI the opportunity to test and evaluate the integrated operation of tar decomposition in conjunction with a biomass gasifier. The RTI and University of Utah partnership may have been formed out of necessity. The team was not able to effectively utilize the resources, probably because of poor communication on the required metrics for conducting scale-up experiments.

Another unsuccessful partnership was within the Emery Syngas Cleaning project, between the Emery Energy Company and Ceramatec. Its lack of success is attributed to improper planning between the principal researchers, namely Emery and Ceramatec, in the less than technically and economically successful effort to apply plasma reforming to treat raw product gases.

The partnership between NREL and PNNL in the NREL/PNNL Gasification Process could have achieved more with well-organized and coordinated interaction between principal researchers. Moving forward, BETO should review and redirect productive partnerships to avoid pursuing test campaigns that do not create meaningful data. BETO should consider putting into place stronger contract cancellation options, with more aggressive program management. This might prevent spending money after projects like RTI/Utah and Emery/Ceramatec, where project issues overwhelmed the technical teams and BETO may not have made adequate effort to conserve funding resources.

The scope of work presented by SRI Pilot Demonstration, PNNL Fuel Synthesis with W.R. Grace, and NC A&T Energy Center are rudimentary in nature and in general were repeating previous efforts with little or no prospect for innovative contributions. The review panel believes that investments in these projects could provide value if they could focus their efforts to develop operating gasifiers with reliable analytical instrumentation. Once tested and proven, these could be useful for academic research and student training. They could also be made available to the gasification community as a whole, as low-cost, early-stage exploratory research facilities for characterization and screening of biomass materials, and any innovative downstream gas conditioning and conversion concepts.

Allentown Thermal Oxidation is another effort that was reinventing proven concepts. The city of Allentown depends exclusively on a private contractor for project execution with no technical interaction. BETO should consider requiring the research performance organizations to have the necessary technical expertise within its own staff to ensure productive, subcontracted research and technology deployment (R&TD).

The review panel believes that, in general, the congressionally directed project (CDP) initiatives result in inefficient use of limited R&D resources, invariably pursue activities that are not supportive of the prevailing BETO mission, and tend to repeat past research. However, it should be pointed out that the CDP, Auburn BTL Fuels, could be considered as an exception if the beneficial claims—50% higher fuel yield, 30˚ Celsius (C) adiabatic temperature rise compared to 900˚C, and low methane (CH_4) production—attributed to supercritical Fischer-Tropsch synthesis (FTS)—operating at 70 bar and 240˚C—could be validated.

INNOVATION

3 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach these barriers? Do any projects stand out as meeting (or not meeting) this criterion? Can you recommend new ways to approach these barriers?

The projects with proven successful innovations supportive of BETO's mission include:

1. The team effort in Integrated Catalyst Fundamentals developed catalysts for hot-gas cleanup and synthesis gas conversion to EtOH. The practical usefulness of the catalysts and associated processes are demonstrated in the scale-up efforts in advancing commercialization of the Enerkem process. The patents resulting from innovations were licensed to industry, further enhancing the productivity of this team effort.
2. The rigorous full-development pathway followed in NREL Fuel Synthesis with Dow has characterized the MoS_2 catalysts for EtOH synthesis, thus identifying further improvements that are required in catalyst composition to improve product selectivity and yield, and in sulfur management.
3. NREL Mixed Alcohol Cost Validation continues to guide potential pay-off research pathways for several ongoing and evolving concepts for biomass gasification.
4. LanzaTech and CRADAs circumvent the challenges of conventional gas cleanup requirements intrinsic to thermochemical conversion. The biological conversion step can tolerate less-than-squeaky-clean synthesis gas for conversion to EtOH, thus offering an alternative path that could have a major impact if economic benefits are validated.

RECOMMENDATIONS FOR MONITORING ONGOING PROJECTS AND FUTURE PRESENTATIONS

The review team has the following recommendations for monitoring the progress of ongoing projects, in completing and closing projects, and for future project review presentations:

1. In pursuing hydrocarbons R&TD, BETO should negotiate with project teams on the appropriate technical milestones that could be related to TEA financial metrics—namely capital expenditure (CAPEX) and operational expenditure (OPEX)—as a consistent tracking tool for potentially diverse technical pathways, and to create a basis to compare across the portfolio.
2. BETO should proactively interact with the principal researchers during early stages of project execution to frame tasks for achieving the Office's mission. The proposed ten-year effort in ANL/NREL Catalyst Characterization requires selection of starting molecules by mutual consent to target prioritized conversion platforms.
3. As stated before, the review team observed the interesting chemistry involved in the supercritical FTS process presented in Auburn BTL Fuels. If successfully developed with industrial partnership, such a process could expedite advancement of FTS liquids technology with a small footprint and simple product separation methods that could significantly improve the economics of converting synthesis gas to hydrocarbon fuels and high-value intermediates.
4. It is interesting to note that the high-impact (and most innovative) projects generally involved TEA and/or industry participation. Perhaps one of these two items should become mandatory for projects going into later-stage development and/or when contract values hit certain thresholds.
5. SRI Pilot Demonstration and NC A&T Energy Center require careful monitoring to ensure project completion within budget and timeline for achieving tangible deliverables. As stated earlier, BETO should consider directing efforts to build and successfully operate pilot-scale gasifiers with state-of-the-art analytical capabilities; this will enable screening and characterizing dedicated and mixed biomass feedstocks or novel downstream unit processes. Such facilities will be useful for training students and also made available for gasification screening research by any interested party under certain working arrangements.
6. PNNL Fuel Synthesis with W.R. Grace has ambitious goals that may be hard to achieve with the present resources. The BETO project manager should devote time to closely review the project status and help close the current project with practically achievable deliverables.
7. All close-out projects should be required to document all equipment descriptions, analytical techniques and protocols, experimental procedures, and data obtained from both successful and less-than-successful experiments. The procedures for data evaluation should be included and all process performance data should be compared and contrasted with related publications from previous research efforts to highlight contributions advancing the state of the art.
8. Future project presentations should clearly illustrate data transparency supported by material and energy balances, and comparison and improvements over published literature.
9. Presentations involving industrial collaboration should include industry representatives, as was the case with the NREL and Enerkem project.
10. BETO should proactively encourage publishing innovations, including advanced analytical techniques, in leading peer-reviewed journals for information dissemination.

GAPS

4 Are there any other gaps in the portfolio for this technology area? Are there topics that are not being adequately addressed? Are there other areas that BETO should consider funding to meet overall programmatic goals

1. Research projects developing catalysts for converting synthesis gas to fuels or co-product chemicals should identify benchmarks for fuel or chemicals acceptability/qualification, starting very early in the project. The protocols, particularly for seeking fuel qualification, are expensive and time consuming; hence, staying engaged with the petroleum industry during technology development for promising processes would help retain focus on conversion pathways and expedite fuel acceptability. This effort should also be cognizant of potential future fuel chemistry and tied to advanced engine designs requiring more demanding specifications to achieve improved fuel efficiency.

2. The review team believes it is essential to have access to an integrated pilot-scale PDU that could evaluate improved unit operations and processes in advancing biomass gasification to desired products. NREL Integrated Gasification used the existing NREL PDU facilities, which are not designed for this purpose. The NREL PDU is drawn into this project, as well as others, because nothing else may have been available. BETO is currently funding too many redundant, small-scale systems, and underfunding development and operation of an integrated test facility. This strategy results in many starting points, but does not allow any technology to progress to the point where it is ready to move to commercialization. The Department of Energy (DOE) should explicitly rationalize its early-, mid-, and late-stage investment strategy.

3. While the review team believes it is desirable to build a 10+ tons-per-day facility, the high cost of building and maintaining such facilities with public funds presents a formidable challenge. Private organizations involved in scale-up of successful processes should be encouraged to develop and use such facilities not only for their own use, but also to make them available for others under certain working arrangements. While most of the R&TD needs in such facilities are applicable to advance high-throughput bubbling fluidized bed or circulating fluidized bed gasifiers, BETO should recognize that the existing updraft, downdraft, or cross-draft gasifiers would also be useful research platforms for developing combined heat and power projects.

4. The review team recommends that BETO should compile an inventory of operating or operable PDUs that have been built with DOE funds. Besides the NREL PDU, other pilot-scale units to PDUs are at SRI; the Energy and Environmental Research Center in Grand Forks, North Dakota; Rentech; ThermoChem Recovery International, located in Durham, North Carolina; GTI; and Emery. Additional options include the Range Fuels pilot facility in Colorado, a gasification facility in Toledo, Ohio, and any other gasification facilities that may have been built as part of the Integrated Biorefinery Technology Area. The information compiled with description, operating capabilities, and facilities owners and their contact details could be posted on the BETO website for reference and use by the gasification R&TD community.

5. The Celanese's TCX catalytic EtOH synthesis process is widely recognized for its commercial success. The performance results of this process should have been the benchmark to beat by other EtOH synthesis R&TD projects. While researchers sometimes reference their results against other researchers, it seems like there is a gap in benchmarking against real commercial projects.

6. Relying totally on researchers to craft cooperation could lead to unproductive work, such as the three-inch and four-inch diameter reactors employed in the catalytic gasification research conducted in NREL/PNNL Gasification Process and PNNL Fuel Synthesis with W.R. Grace. BETO should consider taking an active role in approving partnerships, especially in situations where partners drop out in the middle of a project. In this case, BETO—not the researchers—should have the lead responsibility for developing the new team. At present, prime contractors have too much leeway in changing team members once the project is in execution. It seems like the outcome in these cases is generally not good, so perhaps these kinds of changes should be a flag for BETO to step in.

SYNERGIES

5 What synergies exist between the projects within this technology area? Is there more that BETO could do to take advantage of these synergies and better enable projects to meet their objectives?

1. BETO should continue to promote productive cooperation between research organizations and industry for high return-on-investment investigations.
2. BETO should also promote smart partnerships with prospects for high-value deliverables, but should not be of redundant necessity to spend out-project funds or for publicity.
3. BETO needs to provide adequate resources for the project manager to search across the portfolio to explore potential synergies between ongoing projects. For example, promoting cooperation between GTI and Enerkem to investigate the production of char with preferable morphology and surface properties should be of process scale-up interest to Enerkem in improving the effectiveness of gas conditioning in the gasifier free-board.

RECOMMENDATIONS

6 Is BETO funding projects at the optimal stage of the technology pipeline? Is there more that BETO could do to orient technologies toward successful commercialization? Are there any projects that stand out as positive or negative examples of this orientation?

7 What are the top three most important recommendations that would strengthen the portfolio in the near to medium term?

The review team has several overarching project management recommendations that are classified and listed below:

A. Recommendations to advance the state of the art of biomass gasification
   1. The review team believes that the front-end feed preparation and handling unit operations should be well integrated with the gasification island to ensure successful overall facilities operations. Increased communication and collaboration between these technology areas is recommended to better optimize the techno-economics of the overall field-to-fuel process. Effective trade-offs between feedstock supply economics and gasifier operability (as determined by feedstock particle size, moisture content, bulk density, and other pre-processing parameters) could be guided by

TEA modeling to ensure reliable and cost-effective conversion of biomass to synthesis gas.

2. A crucial unit operation linking feed preparation to biomass gasifier is the biomass feed system. The importance of a reliable feed system was also recognized as a critical gap in the Integrated Biorefinery Technology Area review. Hence, it is essential to identify and, if necessary, develop reliable feed systems for all types of high-impact U.S. biomass, especially across pressure barriers.

3. Having completed extensive screening of catalysts for gas conditioning and conversion, there are opportunities to further reduce the cost of catalysts—particularly those effective across a range of preferred temperatures—by seeking recourse to advances in nano-structured catalysts (to minimize the use of noble or strategic metals) and reaction systems. Furthermore, future solicitations should seek proposals to develop low-cost, multi-metallic, and multifunctional catalysts for gas cleanup and conditioning in order to reduce downstream processing costs.

4. Successfully developed sorbents and catalysts should be evaluated in extended-duration, integrated scale-up tests to evaluate their longevity.

5. In pursuing hydrocarbons R&TD, BETO should negotiate with project teams on the appropriate technical milestones that could be related to TEA financial metrics—namely CAPEX and OPEX—as a consistent tracking tool for potentially diverse technical pathways, and a basis to compare across the portfolio.

6. Integration of process-derived carbon dioxide (CO_2) in thermochemical conversion should be addressed in future R&D plans that could contribute to reducing the water and carbon footprints of biomass conversion processes.

7. The review team feels strongly that the significant investments made to the Gasification Technology Area over the last twenty years, and findings resulting from these investments, should be captured in a comprehensive document and publicly disseminated. This is especially important as the Office direction may be moving away from gasification.

8. With access to significantly large shale-gas resources, the future strategy for biomass R&TD could possibly involve co-conversion with nonrenewable carbonaceous fuels. All co-conversion R&TD could benefit from cooperation with DOE's Office of Fossil Energy.

9. BETO should consider soliciting proposals to investigate direct and complete biological conversion of raw synthesis gas with minimal cleanup to hydrocarbons.

B. Recommendations for Project Management

1. Researchers should be required to comply with data transparency. All research and process performance results should be compared with state-of-the-art published results to clearly identify progress in science and engineering. This was missing with almost all projects that were presented to the review team. Furthermore, researchers should be required to document the entire research effort in a comprehensive final report. This should apply to both successful and less-than-successful efforts. BETO should proactively encourage publishing innovations, including advanced analytical techniques, in leading peer-reviewed journals for information dissemination.

2. DOE should consider requiring all funding opportunity announcement applicants to evaluate and document incremental benefits of proposed technology over the state of the art, in particular for out-of-the-box concepts. For example, in Em-

ery Syngas Cleaning, the cost of using an oxidant to raise the raw gas temperature to about 1100° C could have been substantiated by simple pro forma cost-benefit analysis that would form the basis of decisions to select a novel technology for gas cleaning, such as the plasma reformer.

3. Alternatively, where appropriate and during the proposal review and evaluation process, BETO could request principal investigators to provide cost-benefit analysis to justify initiating totally new research concepts.

4. As stated above under the lessons learned, the review panel recommends to the Office of Management and Budget and DOE to discourage CDP projects, which generally result in inefficient use of project resources, invariably pursue activities that are not supportive of the prevailing BETO mission, and tend to repeat past research.

5. Several contracts ran for more than five years, some more than seven. To prevent BETO from getting locked into projects that no longer have priority, stronger project management and contract cancellation terms might be useful.

6. Since BETO's primary mission is to support applied research, all project deliverables should include engineering design of the resulting conceptual process step or integrated processes.

7. DOE should provide adequate resources to enable BETO project managers to devote more oversight and engage more closely with projects in their portfolios to achieve related objectives, to guide researchers to review previous efforts documented in the Office of Scientific and Technical Information's archives, to evaluate the rationale and structure of partnerships, and to search for potential synergy across the portfolio to enhance the value of return on research investment.

8. The review team suggests holding Defense Advanced Research Projects Agency- or Advanced Research Projects Agency-Energy-type reviews more frequently than the current biennial events.

9. The review panel recommends continuing interaction of the NREL TEA team with industry, preferably with increased funding, to obtain accurate technical and economic data that constitute the basis for techno-economic, life-cycle, and structured-design analyses. This includes the most successful EtOH synthesis processes, though the Office emphasis has shifted to drop-in hydrocarbon fuels.

10. With across-the-board recognition of the usefulness of NREL's TEA capabilities, which are now being expanded to include structured-design criteria, BETO may want to organize an outreach introduction to the principles of TEA, life-cycle analysis, and structured-design analysis at an appropriate time and location, perhaps as an extension event at the Project Peer Review meeting.

11. As a reminder, upon distinguishing between energy conversion and environmental research projects, BETO should give higher priority to the former while the latter could be transferred to the Environmental Protection Agency (EPA).

12. For later-stage projects (e.g., technology readiness levels greater than five) BETO project managers and principal investigators should all be benchmarking against and guided by TEA. The market is indifferent to interesting technology; successful research projects are guided by economics, not curiosity or novelty.

BETO PROGRAMMATIC RESPONSE

IMPACTS

With respect to projects that underperformed, many of the observations made by the panel identified partnerships that did not produce the desired results. This is something that BETO is addressing through a focus on more active project (and grant) management, a focus supported by the Assistant Secretary for the Office of Energy Efficiency and Renewable Energy. As one example of this active management, BETO was able to terminate one of the project grants that failed to meet its technical criteria. By continuing to rigorously monitor projects, BETO will be able to make this type of assessment earlier. More effective, active project management will help to identify partnerships that are not taking advantage of the complementary skills that brought these organizations together in the first place. BETO will continue to ensure that project partners are working more cohesively and with greater synergy to meet the goals of the project.

INNOVATION

The panel made an observation that the highest-impact and most innovative projects tended to have strong techno-economic analyses and industrial participation. BETO has recognized this as well and is in the process of applying more rigorous and uniform TEA at both the project and portfolio level. The TEA can guide the research path earlier in the project's timeline toward more fruitful outcomes. Through a more uniform approach to TEA, with well-defined assumptions and methodologies, BETO will be able to better analyze and assess different technologies.

GAPS

The reviewers noted that projects should recognize, and have a path forward, for end-use fuel certification. BETO has been aware of this issue and is working to improve the ability of funded projects to address this market barrier. As one example, BETO initiated a funding opportunity in fiscal year 2012 to evaluate when and how intermediate biofuel products can integrate earlier in a process that leads to finished fuels. In addition, BETO is increasing its interaction with EPA, the American Society for Testing and Materials, the Federal Aviation Administration, and other entities at the end of the supply chain (such as engine manufacturers, automakers, and fuel laboratories). This increased interaction will help guide future research efforts to develop technology with a better sense of the end goal of selling advanced biofuels into the market.

The reviewers noted that partnerships could be improved. BETO agrees with this and, as noted previously, will work more proactively to facilitate partnerships between the federal government, industry, and universities that will bring together scientific and technical knowledge and facilities to achieve better outcomes.

Another area that the reviewers noted was access to the right facilities. Because of limited funding in the Gasification Technology Area, BETO has been requiring that PIs bring in operational gasifiers as part of any funding opportunity announcement proposal. Regarding the compilation of available PDU and pilot-scale units, BETO agrees that a simple and easily accessible database would be helpful. Through BETO-led efforts, there is already one available via the International Energy Agency Bioenergy Executive Committee. Additionally, BETO is developing a U.S-focused database on existing gasification facilities that will help facilitate more fruitful partnerships.

SYNERGIES

BETO concurs with the assessment of continuing to promote productive partnerships and manage projects more vigorously, as noted previously. As a recommendation, the review panel noted: "During the two years preceding the 2013 Project Peer Review, almost all of the Bioenergy Technologies Office gasification research projects were focused on completing the balance of scope of work for this period with few new initiatives. In spite of the limited activity, the review panel observed that significant progress has been reported by some projects to advance the state of the art of biomass gasification. They include the Integrated Catalyst Fundamentals project, with advances in hot-gas conditioning and synthesis-gas conversion to ethanol; NREL's Fuel Synthesis CRADA with Dow, with the development and evaluation of a molybdenum disulfide (MoS_2) alcohol synthesis catalyst; and NREL's Mixed Alcohol Cost Validation, a techno-economic analysis (TEA) and modeling project that provides useful research guidance to choose pathways leading to performance and economic targets."

BETO agrees that we should, and will, continue to seek to advance the state of the art in indirect liquefaction for the production of hydrocarbon liquids. This effort will include DOE lab-, university-, and industry-led projects that utilize TEAs and modeling to the best extent possible.

RECOMMENDATIONS

The biomass Gasification (and indirect liquefaction) Technology Area within BETO has gone through a number of changes over the years, reflecting the evolving capabilities of industry and market pulls. BETO is continuing to refine its strategic priorities within this Technology Area to maximize the output of our limited financial resources. Through requests for information, workshops, and continued discussions with stakeholders in this area, BETO will assess the path forward. The review panel provided ten excellent recommendations in the Recommendations for Monitoring Ongoing Projects and Future Presentations subsection, a top ten list for guiding BETO's future work.

CONTENTS

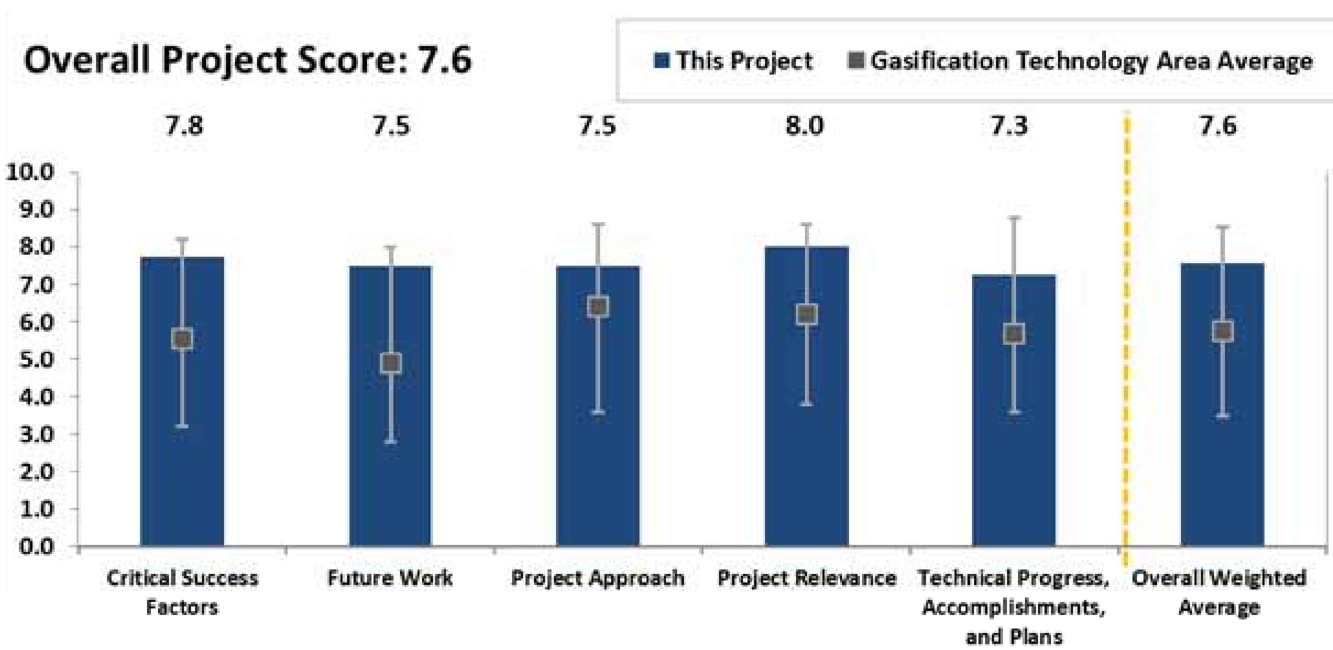
A HYBRID CATALYTIC ROUTE TO FUELS FROM BIOMASS SYNGAS INCLUDING NREL AND PNNL CRADAS

(WBS#: 3.3.1.6; 3.3.1.7; 3.3.1.8)

Recipient:	LanzaTech, Inc.; NREL; PNNL
Presenter:	Mike Shultz
Total DOE Funding:	$1,948,000
DOE Funding FY13:	$1,204,000
DOE Funding FY12:	$744,000
DOE Funding FY11:	--
Project Dates:	2012-2015

Project Description

LanzaTech is partnering with Imperium Renewables, PNNL, NREL, and the Boeing Company to develop a cost-effective hybrid conversion technology for catalytic upgrading of biomass-derived syngas to jet fuel that will meet the price, quality, and environmental requirements of the aviation industry. The specific objective of this project is to integrate all unit operations and optimize their interfaces to achieve the best overall system economics and drive down the price of biomass-derived jet fuel. The team is supported by Michigan Technological University for Life-Cycle Assessment, Orochem Technologies for separation of fermentation products, and the University of Delaware for catalyst fundamentals. The LanzaTech-led team is demonstrating an approach for converting syngas to hydrocarbon fuels that replaces the capital- and energy-intensive FTS process with a two-stage approach that exploits the natural advantages of biochemical and thermochemical processing. In the first step, syngas is converted to ethanol using a biochemical catalyst; in the second, a thermochemical catalyst is used to upgrade the ethanol to jet fuel. A fermentation co-product, 2,3-butanediol, is converted to the value-added chemical product butadiene, thus maximizing the use of biogenic carbon and improving the output and economics of the biorefinery. The result is an economical route to drop-in renewable aviation fuel that avoids the competition for food or water resources. The specific objectives of the project include the following: determine impacts of syngas contaminants on fermentation productivity and stability, with the goal of optimiz-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

ing syngas cleanup costs; optimize alcohol upgrading catalyst and process conditions through screening and mechanistic/kinetic studies coupled with computation ; determine impact of water and other impurities in the fermentation broth on catalyst stability and product yield, with the goal of optimizing alcohol recovery cost; validate process stability through extended operations and detailed catalyst characterization; design an integrated process that optimizes the performance of each step, as well as material and energy integration between steps, producing a globally optimized process design; and complete analysis of the biomass-to-jet process scheme, techno-economics, and life-cycle impacts. Currently, the dual 3–10 liter (L) fermentation system has been installed, as well as the 100-L fermentation system; the gasification–fermentation process has been integrated; stable operation on simulated syngas, stable biomass gasification operations, and integrated operations have been demonstrated; several potential syngas contaminants for toxicity to the fermentation microbe have been identified and tested; a path forward for stable integrated operations has been identified, an activated carbon to operate with on biomass syngas; the catalyst development is on schedule; and the baseline TEA and life-cycle analysis (LCA) work has been initiated. Equipment issues caused project delay—the team is awaiting restart of equipment. This work will lead to a hybrid biorefinery design that enables the production of jet and other hydrocarbon fuels from waste biomass in an environmentally sustainable, cost-effective manner; this facilitates energy independence and job creation through techno-economics and an integrated conversion process for woody biomass to hydrocarbon fuels (e.g., gasoline, jet, and diesel). Furthermore, the project's new hybrid catalytic route will reduce risk and enable the Technology Area to meet its 2022 R&D performance goals to make cellulosic biofuels cost competitive with petroleum-based fuels, achieving a modeled cost for mature technology of $3/gallon hydrocarbon fuel (2011 dollars). Challenges and critical success factors depend on whether the alcohols produced by LanzaTech are suitable for upgrading by PNNL, and whether the catalyst and process step will allow for cost-competitive jet fuel and butadiene. Equipment reliability has been a challenge encountered early within the initial stages of this project. Meanwhile, integration of process technologies and partner coordination will be a long-term project challenge. The techno-economics of the full supply chain will inform the progress toward further development work at scale.

Overall Impressions

- A complete program, including some fundamentals and one of the few to include fuel qualification as a specific task.
- Continue support of this work, including the catalytic work at PNNL, to develop the upgrading catalyst for ethanol to hydrocarbon. Investigate opportunities to leverage this work with funding support from the Department of Defense for military aviation fuels.
- The success of this hybrid thermochemical and biochemical process with the potential to reduce CAPEX and OPEX could be a major contributor to advance state-of-the-art biomass conversion to fuels and chemicals.
- This project incorporates a unique approach and features a large number of collaborators organized into well-planned tasks. Technical progress is sufficient for this stage in the project, but it needs to TEA earlier in the process. Forward-thinking aspects of the project include a targeted site for a demonstration plant and collaborators from the aviation industry for jet fuel product testing. As the syngas fermentation route to liquid fuels is relatively new, a detailed report to BETO is recommended to assist in evaluating the viability of this conversion pathway.
- This was an excellent project that was well executed.

PI Response to Reviewer Comments

- No official response provided at time of report publication

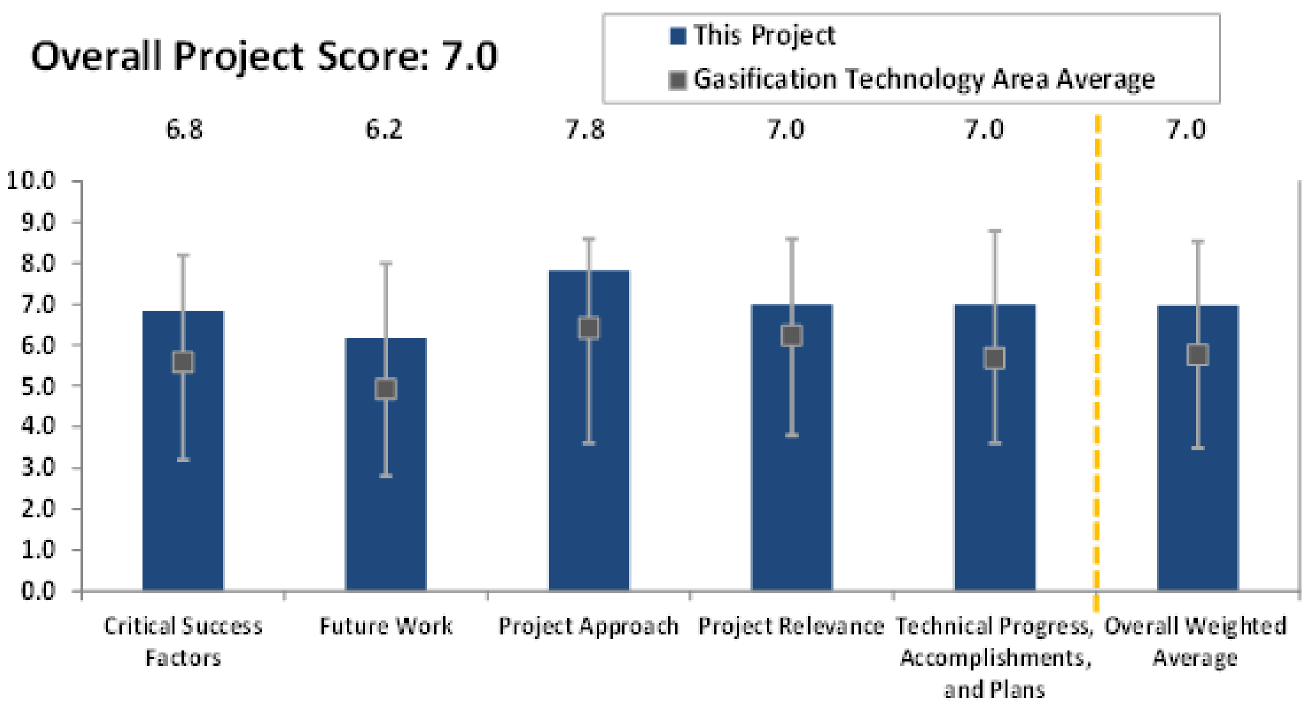
ADVANCED THERMOCHEMICAL BIOFUELS; SYNGAS QUALITY FOR FUEL SYNTHESIS

(WBS#: 3.3.2.1; 3.3.2.2)

Recipient:	NREL; PNNL
Presenter:	Jesse Hensley
Total DOE Funding:	$11,800,000
DOE Funding FY13:	--
DOE Funding FY12:	$2,400,000
DOE Funding FY11:	$2,300,000
Project Dates:	2005-2012

Project Description

The Advanced Thermochemical Biofuels tasks (formerly Syngas Quality for Fuel Synthesis) are a joint effort between NREL and PNNL to develop catalyst materials for the efficient conversion of biomass-derived syngas to ethanol. These tasks were developed to address two barriers to cost-effective ethanol production by thermochemical means— namely, the inherently low productivity and selectivity of known mixed-alcohol catalysts. Early in the project, technical targets were developed to quantify the improvements needed to achieve a minimum ethanol selling price (MESP) of $2.05/gallon by the year 2012, when combined with other advances in thermochemical biomass processing. These include incremental improvements to catalyst productivity and selectivity, as well as improvements in catalyst cost, lifetime, and balance-of-reactor operating costs. Research and development in fiscal years 2011 and 2012 featured improvements to two classes of mixed alcohol catalysts—rhodium manganese and metal sulfide materials—as well as pilot-scale demonstration of an integrated biomass-to-ethanol process. Through rational design, increases in ethanol yield and selectivity were demonstrated for both materials, and long catalyst lifetimes (greater than 3,300 hours) were demonstrated. As a result, the MESP target of $2.05 was met. Accomplishments above and beyond technical targets were also shown. For example, computational chemistry was used to understand the pathways to ethanol over rhodium catalysts and aided in the design of more selective mate-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

rials. Separately, detailed compositional and distillation analyses were performed on the crude alcohol products from sulfide catalysts, improving the understanding of separation requirements to obtain a finished ethanol product. This project is 100% complete and has met all of its technical targets. Knowledge gained in this project will be leveraged in future research that will focus on upgrading of syngas intermediates (such as mixed oxygenates) to drop-in hydrocarbon fuels like diesel and jet.

Overall Impressions

- A lot of good catalyst development work was achieved over the course of this long term project, and the totality of this work should be captured in a seminal report covering the entire scope of this project. The report should also include as much as possible of the Dow CRADA results considering intellectual property protection under a CRADA.
- Although it is a well-thought-out plan to develop EtOH synthesis catalysts, it does not appear that any effort was made to revisit procedures for catalyst synthesis to prevent the production of undesirable oxygenates such as esters and aldehydes. Attention was not paid to the fate of sulfur addition to the MoS_2 catalyst during EtOH synthesis. The unwanted oxygenates and the dimethyl sulfur contaminant in the raw product raises questions about its acceptance as transportation fuel. In pursuing catalyst development, the criteria for selection should be rigorously investigated and clearly defined in consultation with the DOE project monitor. Furthermore, catalyst development should address fuel acceptance specifications right from the beginning. Catalyst performance should be compared with those of related commercial catalysts. As a note, in fiscal years 2011 and 2012, more than half of the resources for this project were spent at PNNL pursuing the development of expensive rhodium catalyst. Investigation of expensive catalysts should be limited to catalysts with nano-layers of precious and/or strategic metals that could be economical for commercial production.
- Extensive programs, good progress
- There are many aspects of the fuel synthesis unit operation that affect the overall techno-economic feasibility of this platform: productivity, selectivity, operating pressure and temperature, degradation, and so on. The project performers seem to have a good handle on these tradeoffs and have addressed many of these technical challenges; however, industry has shown little interest in these catalysts to date. Part of the issue may be related to the synthesis focus on mixed alcohols rather than ethanol. If there is still room for improvement, some additional work on these catalysts may be warranted to push the remaining development into industry.
- This was a well-executed project, and such fruitful collaboration between national labs and private companies should be encouraged. This collaboration could serve as a model for other teams. Lessons learned from this team should be used to build other teams in future BETO projects.
- Well organized and well designed, and results communicated clearly. As this is not a focus for DOE any longer, up to industry to determine long-term value.

PI Response to Reviewer Comments

- We greatly appreciate the positive remarks, but feel that some of the negative remarks are unwarranted given the review we presented. As explained in the review, aldehydes and esters are necessary intermediates of the reaction sequence that forms higher alcohols, and revising a synthesis procedure will not remove them from a reaction pathway. Their concentration is low and initial discussions with our fuel validation colleagues suggest they may not pose a problem. Distillation experiments suggest these impurities will be removed and recycled to the reactor. Sulfur was tracked closely and we showed very clearly its forms in the product and its fate in distillation, backed with both experimental data and Aspen simulation. The presence of oxygenated by-products was addressed with respect to fuel use and was identified as a good area for future research. Performance was compared with industrial materials on many slides, and it is simply untrue that industry is not interested in these materials, given the active research on the materials in at least three multinational catalyst/chemical companies. The market for the catalysts is a different thing altogether, and any arguments on the market for these catalysts must be coupled with a consideration of the ethanol market. We agree that research should be guided by the market, but it must not be driven by the market. Thus, a product that may turn profits in tomorrow's fuel and chemical markets is worth evaluating today.

AUBURN UNIVERSITY, BIOMASS TO LIQUID FUELS AND ELECTRIC POWER RESEARCH

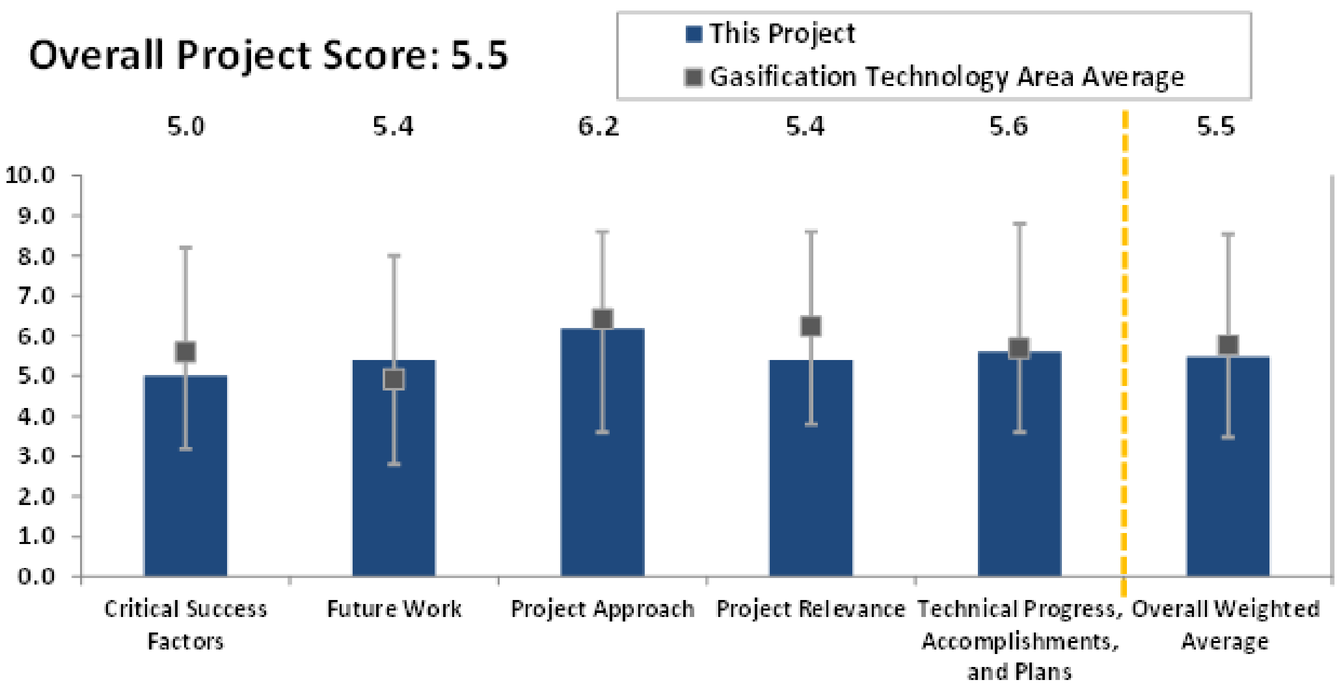
(WBS#: 7.7.3.6)

Recipient:	Auburn University
Presenter:	Steven Taylor
Total DOE Funding:	$1,500,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010-2013

Project Description

Photo Courtesy of Port of Auburn University

Auburn researchers are investigating systems that convert biomass into electrical power, liquid fuels, and other biobased products. Based on results from an earlier project, continuing efforts in this project focused on forest biomass. In this current research program, our specific objectives are: determine economic constraints associated with harvesting forest biomass from southern pine and hardwood plantations; refine techniques for biomass fractionation and conversion into forms suitable for trade in commodity markets; develop process simulation models representing biomass gasification and gas conditioning processes to allow rapid determination of operating parameters that result in highest quality syngas at lowest cost; and continue to develop and validate models of FTS using biomass-derived syngas. The presentation discusses research on gasification and FTS. Gasification campaigns are conducted to improve our understanding of the effect of biomass properties on syngas quality and contaminants (e.g. tar, hydrogen sulfide) and determine appropriate syngas conditioning and cleanup strategies for subsequent synthesis. Laboratory studies on supercritical phase FTS have shown that,



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

compared to gas-phase FTS, the supercritical process suppressed CH_4 and CO_2 formation, increased olefin selectivity at higher carbon numbers, improved activity maintenance, decreased adiabatic temperature rise, and enhanced diesel and wax selectivity. Process simulation studies have determined that operating the FTS reaction under supercritical conditions results in a significant increase in fuel production at the cost of only a modest increase in energy requirements. A novel supercritical adiabatic reactor design has been introduced that appears to have the potential to significantly reduce capital costs of liquid fuel production systems. Comparison of four different reactor systems (traditional Arge reactor, Arge reactor modified for supercritical phase FTS, single supercritical adiabatic reactor, and multiple supercritical adiabatic reactors) showed that supercritical adiabatic reactor configurations could be cost-competitive to both of the Arge reactor designs.

Overall Impressions

- Although this is a CDP project, it is very relevant to BETO's pursuit of hydrocarbon fuel processes. Work on supercritical FTS appears to be very promising from a techno-economic perspective; a more detailed TEA and collaboration with industrial partners will help move this technology to industry. Suggestions for additional work include validation of the process models and incorporation of syngas cleaning operations.
- Interesting chemistry with significant positive impact if supercritical FTS is proven successful and economical. The bench-scale gasifier illustrated in this presentation could be another early-stage screening and scouting experimental tool for the research community.
- Program may want to better define what is new/unique to distinguish from past and ongoing studies.
- The performers have demonstrated an innovative method of biosyngas processing that has the potential to advance the field of biomass gasification and product synthesis.

PI Response to Reviewer Comments

- No official response provided at time of report publication

BIOMASS GASIFICATION RESEARCH AND DEVELOPMENT PROJECT

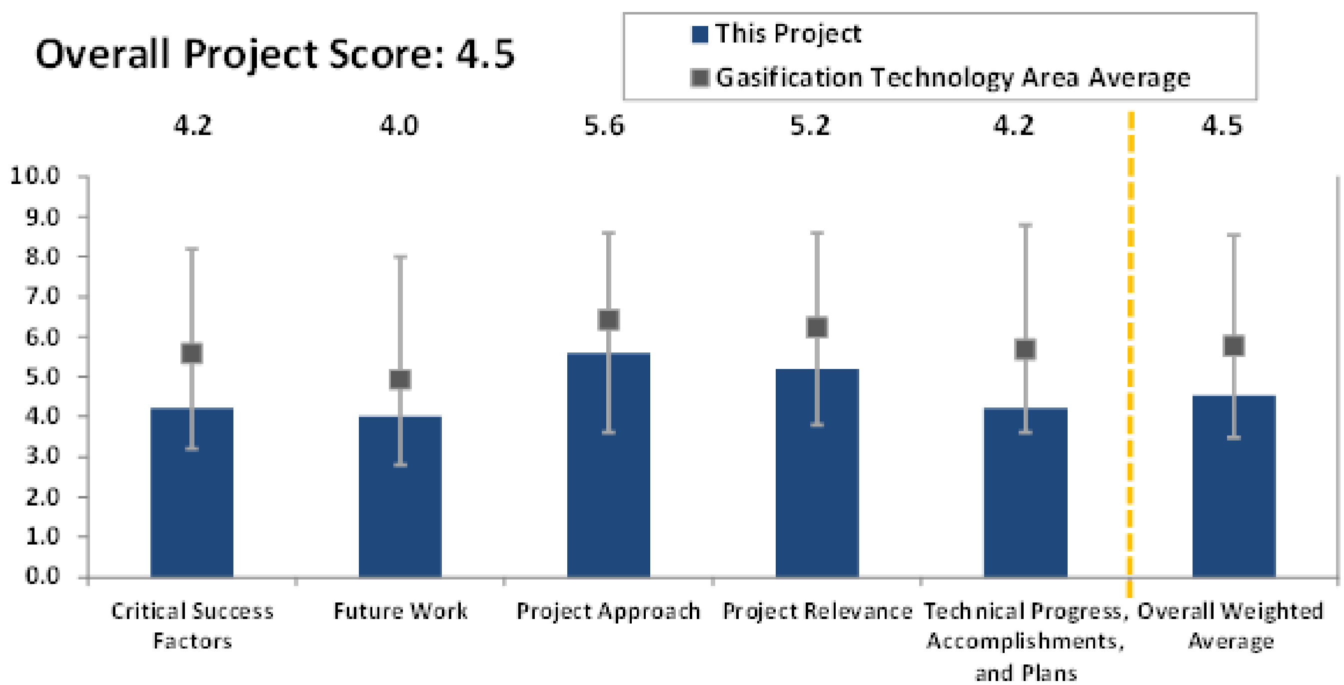
(WBS#: 7.4.3.13)

Recipient:	Port of Benton
Presenter:	Birgitte Ahring
Total DOE Funding:	$951,500
DOE Funding FY13:	$318,431
DOE Funding FY12:	$501,147
DOE Funding FY11:	--
Project Dates:	2010-2013

Project Description

Photo Courtesy of Port of Auburn University

The BioChemCat process employs a unique combination of process steps, which include: pretreatment technology (wet oxidation); fermentation using a mixed anaerobic consortium to produce platform molecules; separation of platform molecules; and catalysis reactions for upgrading the platform molecules into hydrocarbons. The key outcome of the project is the maturation of a promising concept for making hydrocarbons with an interesting commercial prospective. While key elements in the BioChemCat process such as pretreatment has been matured to a high degree, the project will mature other elements where further research and development is expected to mitigate risk during consequent up-scaling of the technology. Currently, the project team is demonstrating that a mixed consortia can successfully perform autohydrolysis producing its own cellulytic enzymes along with fermentation of pretreated materials into useable platform molecules; testing and evaluating different liquid/liquid and ion-exchange separation methods to recover platform molecules directly out of slip streams from the bioreactor during fermentation to decrease the cost of separation compared to more conventional processes (e.g., chemical precipitation, dis-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

tillation, or solvent recovery); and evaluating a two-step catalysis process with mixed alcohols as intermediates to produce a final diesel or jet fuel for an acceptable cost. Catalysis tests on model substrates to alcohols has been finished; the team has also finished initial testing before piloting in Washington State University's small pilot facility to confirm the assumptions made for the intermediate and target price of hydrocarbon biofuels. The pilot facility has now been completed and the overall BioChemCat process will be operated to produce and separate platform molecules from selected biomass materials during the next six months. Catalysis of these molecules into mixed alcohols for further upgrading will be done using the protocol produced during the first phase of the project. In the final part of the project, the project team will evaluate the techno-economic model using data from the pilot testing and will make an LCA analysis of the overall process.

Overall Impressions

- Early-stage research with ambitious goals that are difficult and challenging to accomplish with existing resources.
- The project has not advanced very much and very little technical data has been generated to enable product evaluation to be conducted. The performers should identify specific platform molecules to be targeted for the fermentation. Currently, as defined, there will not be much archived at the completion of this project, especially when 66.7% of the project has been completed.
- This is an interesting approach. Looks like progress has been made on digestion (with wild consortium versus xenic culture). Harder to judge progress on separation, reaction, and so on. Perhaps the scope is too big for the time budget. If so, may want to focus on critical path item.
- This project presents a novel pathway to liquid fuels from biomass, though the concept is not adequately validated with laboratory studies. Rather, the funding has been spent on a pilot-scale demonstration of the upfront portions of the process (feedstock processing and fermentation), while neglecting the equally important processes of parent molecule separation and upgrading to liquid fuels, as well as the integrated biogas production process. The commercial viability of this process will ultimately be determined from its cost competitiveness; thus, a detailed techno-economic analysis that is supported with process data will be needed and should be included in a final report to BETO.
- This project should be abandoned at the end of its period of performance.

PI Response to Reviewer Comments

- The project was wrongly placed in the Gasification Technology Area for review though the project doesn't involve gasification at all. The reviewers seems to have no understanding of the basic processes being utilized—such as the specialized pretreatment and the mixed culture fermentation—and did not understand that this was an up-scaling of a concept that has been tested in laboratory scale for years. The reviewers were told just after the review session what specific platform molecules we worked with, and further were told why we did not want to reveal this to the broad public due to pending patents; they still report that we have not identified what we work with. Overall, the techno-economic analysis that is being done in the coming final phase will show the viability of the new concept exactly as pointed out in the second-to-last comment. The final comment doesn't make sense at all: why should the project be abandoned if the concept is—at the preliminary level—economically sound as all our current data shows?

CATALYST CHARACTERIZATION

(WBS#: 3.2.5.17; 3.3.2.1)

Recipient:	ANL; NREL
Presenter:	Theodore Krause
Total DOE Funding:	$600,000
DOE Funding FY13:	$600,000
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2012-2022

Project Description

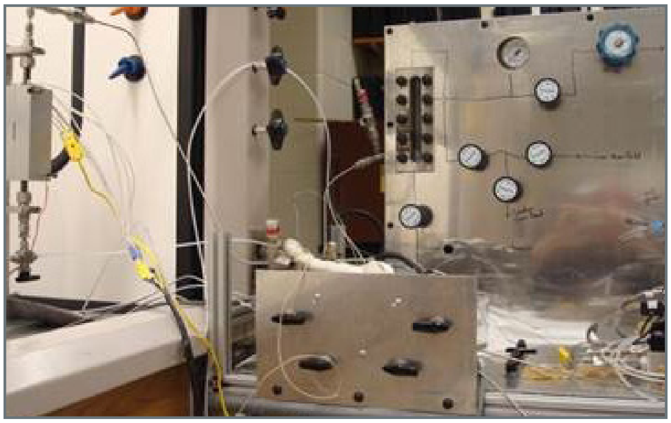
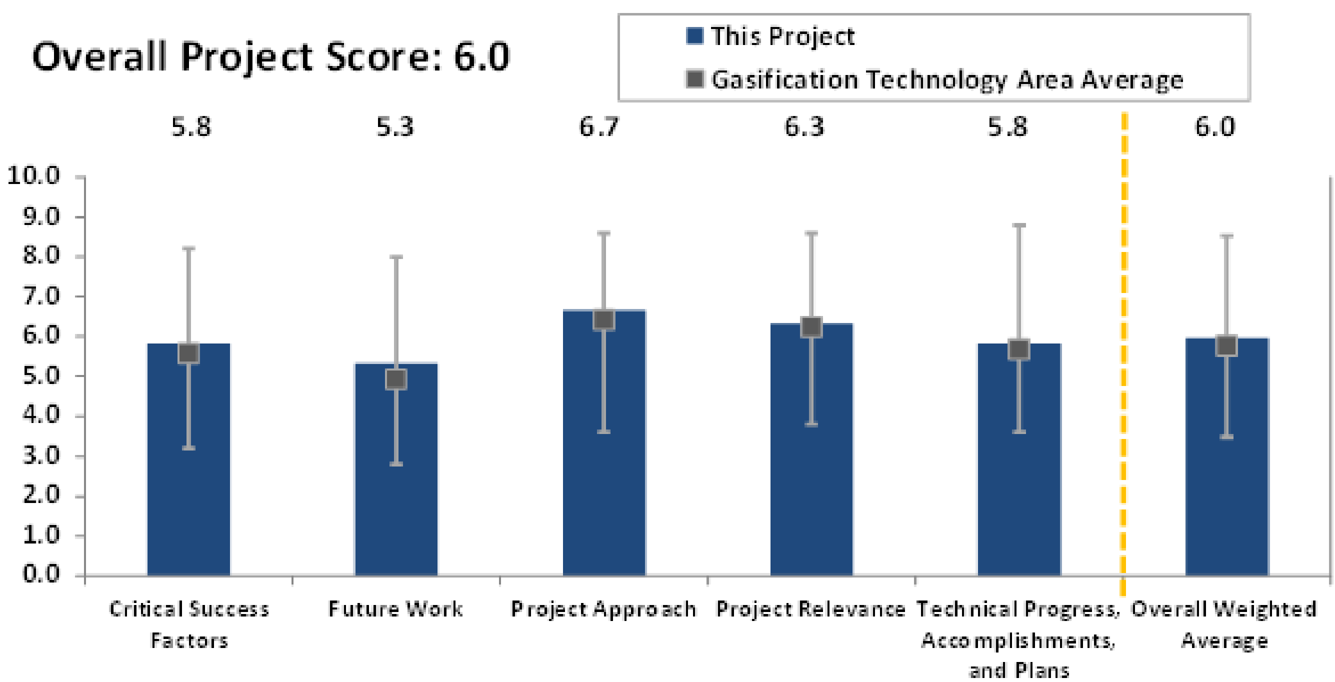


Photo Courtesy of ANL; NREL

NREL and ANL are collaborating in this newly funded project to develop cost-competitive technologies for the production of alkylates from biomass-derived, syngas-produced C1–C4 aliphatic oxygenates for use as a premium blendstock in petroleum refining. New catalyst and process technologies are being pursued that will allow the reaction to proceed at lower temperatures—200–240° C—and with fewer reaction steps compared to competing technologies, such as the ExxonMobil Methanol-to-Gasoline process for converting methanol to alkylates. The advantages of a low-temperature process are that lower reaction temperatures will not promote coke formation, unlike the higher-temperature ExxonMobil process that leads to catalyst deactivation; this will enable the use of boiling water-cooled reactors instead of adiabatic packed beds, as required for heat management in a methanol-to-gasoline process, thus allowing for higher per pass conversion and significantly reducing capital and operating costs. Our initial catalyst development is focused on metal-substituted zeolites, such as gallium-BEA, for



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

producing 2,2,3-trimethylbutane (triptane) from methanol. Triptane, with an octane rating of 112 compared to 92 for a typical ExxonMobil Methanol-to-Gasoline product, can be produced with high selectivity— nearly free of benzenes, toluenes, and xylenes—thus making it an excellent a premium blendstock. X-ray absorption spectroscopy studies of gallium-BEA, conducted at Argonne's Advanced Photon Source to understand catalyst structure-function relationships, shows that the gallium in gallium-BEA is tetrahedrally coordinated in the +3 oxidation state and stable towards reduction to metal or the formation of a bulk oxide in the presence of hydrogen and oxygen, respectively, up to 500°C. Preliminary reaction studies are underway at NREL. The project leverages the expertise and capabilities of NREL for developing biomass-derived syngas, mixed-alcohol synthesis technologies and ANL for applying novel catalyst characterization techniques to improve catalyst performance.

Overall Impressions

- Interesting approach. Good to see this type of fundamental work attracting funding.
- Smart people, broad goals. Too early in the project for me to make an opinion.
- The open-ended approach at the formative stage of this project may require DOE's proactive involvement in the selection of molecules to define a rational approach to explore their conversion to hydrocarbon fuels. Success in these efforts may lead to efficient and cost-effective alternatives to FTS.
- This project has potential in helping explain the performance of future catalysts to be developed for fuel synthesis.
- This project partnership is very well conceived and leverages significant NREL and ANL experience in catalyst development with ANL's excellence center in catalyst characterization. Overall, this project is in need of direction, beginning with a targeted conversion platform. Once chosen, this project will also benefit from early collaboration with industry.
- Too often, information gained from other DOE investments sits in the Office of Scientific and Technical Information's library without being proactively shared with other DOE researchers doing similar work. This project may be a good example of that lost opportunity.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

CATALYST FUNDAMENTALS & CATALYST FUNDAMENTALS INTEGRATION

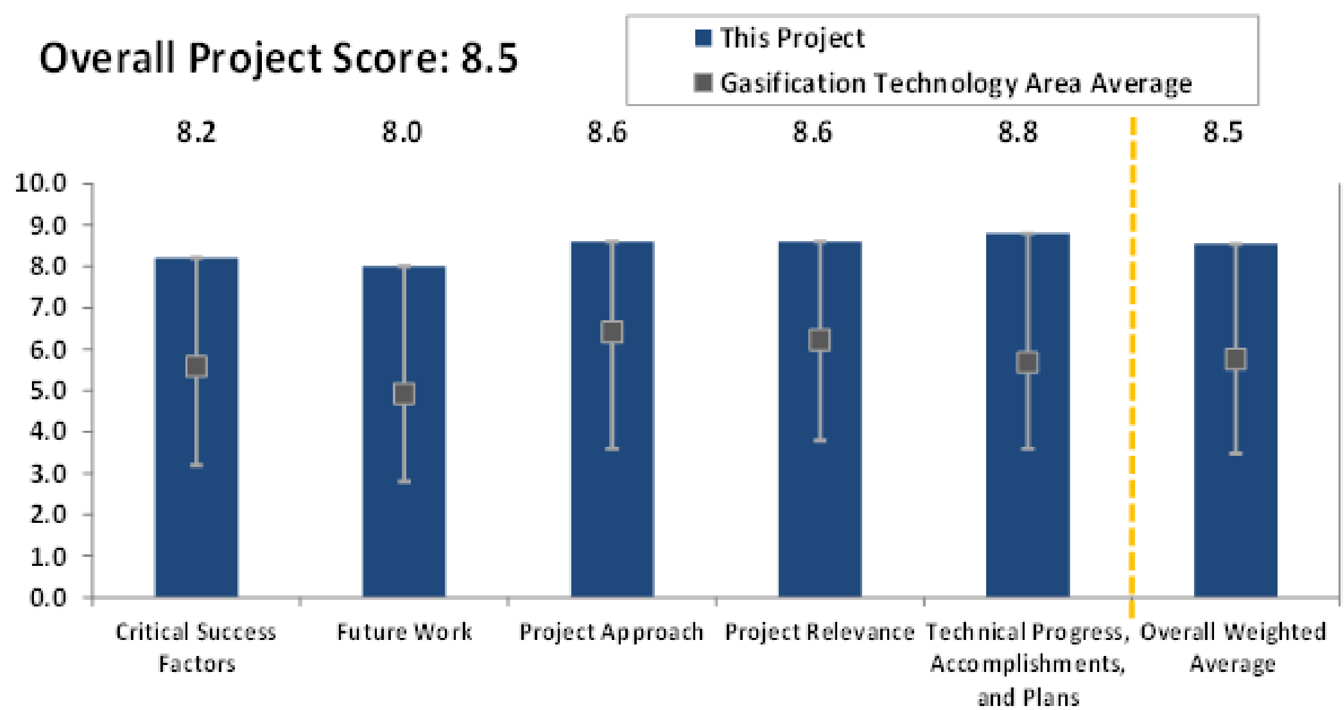
(WBS#: 3.2.5.6; 3.2.5.8)

Recipient:	PNNL; NREL; Enerkem
Presenter:	Kim Magrini
Total DOE Funding:	$4,600,000
DOE Funding FY13:	$2,000,000
DOE Funding FY12:	$2,6000,000
DOE Funding FY11:	--
Project Dates:	2006-2014

Project Description

Photo Courtesy of PNNL; NREL; Enerkem

The objective of the Integrated Catalyst Fundamentals task is to develop, evaluate, characterize, and understand the performance of catalyst and high-temperature, sorbent-based systems to achieve efficient biomass-derived syngas cleaning and conditioning through rational-materials design. These systems comprise novel tar reforming catalysts and high-temperature sulfur sorbents optimized first with model syngas to provide laboratory-scale performance data. The best materials are then used in pilot-scale operations with raw syngas for optimized biomass-derived syngas cleanup and conditioning for use in downstream fuel synthesis. Fiscal year 2011 work focused on evaluating four syngas cleaning process concepts using these materials for down-select for the fiscal year 2012 thermochemical biomass to ethanol demonstration. These concepts are: catalytic tar reforming; sequential sulfur removal and catalytic tar reforming; catalytic sulfur removal during



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

biomass gasification followed by tar reforming; and varying syngas composition to assess impact on reforming performance and regeneration via dry reforming and recycling downstream CO_2. Process results, while promising for all four unit operations, were most proven for standalone tar reforming and sequential sulfur sorption and tar reforming. These two processes were further developed in 2012 for down-select and scale-up for the pilot-scale demonstration. Preliminary catalytic gasification results showed significant tar reduction and enhanced carbon utilization in produced syngas, and 2012 work continued to refine this process by testing a suite of reforming catalysts in the NREL research gasifier. Reforming catalyst evaluation with oak syngas in 2011 work showed that two catalysts (NREL developed, Johnson Matthey) achieved or exceeded the 2011 goals for syngas cleaning, and comprehensive characterization was used to track activity changes and design efficient regeneration processes after extended use. These two reforming catalysts were tested to the limits of their performance for reforming lifetime and attrition resistance and were scaled up for the demonstration. The primary focus of 2012 task work was to down-select the best gas conditioning process for demonstration, produce 1000 kilogram (kg) batches of material, and provide comprehensive catalyst characterization and analytical support for the thermochemical ethanol demonstration. This work addressed and met the following thermochemical platform targets through 2012: improve tar-reforming catalyst performance for syngas cleaning requirements of greater than 80% methane conversion, greater than 99% benzene conversion, and greater than 99.9% total tar conversion with catalyst replacement decreasing to 0.1 weight percent per day. This project was completed with the successful demonstration of thermochemical biomass conversion to ethanol for 200 hours using NREL's pilot plant. Demonstration results will be published in a peer reviewed journal in fiscal year 2013.

Overall Impressions

- Joint CRADA with Enerkem is one of the major contributions of this project to advance the state of the art of biomass gasification.
- The NREL portion of this project is the best performing project in this conversion platform. It was well designed and executed, met its syngas cleanup goals in demonstration tests, and spawned several additional projects/collaborations in this topic area. The Enerkem CRADA is a valuable part of this project as well, and is poised to move new CO_2 utilization strategies straight to market.
- This was one of the best projects evaluated. It was clearly defined and showed excellent collaboration between NREL and Enerkem researchers. BETO should encourage such effective collaborative teams.
- Use this project as a benchmark model of how to leverage DOE knowledge and capability base with industry to rapidly advance practical technology development.
- Well-conceived, well-executed project.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

DEVELOPMENT OF NEW GASIFICATION PROCESSES FOR BIOMASS RESIDUES: GASIFICATION KINETICS AT PRESSURIZED CONDITIONS

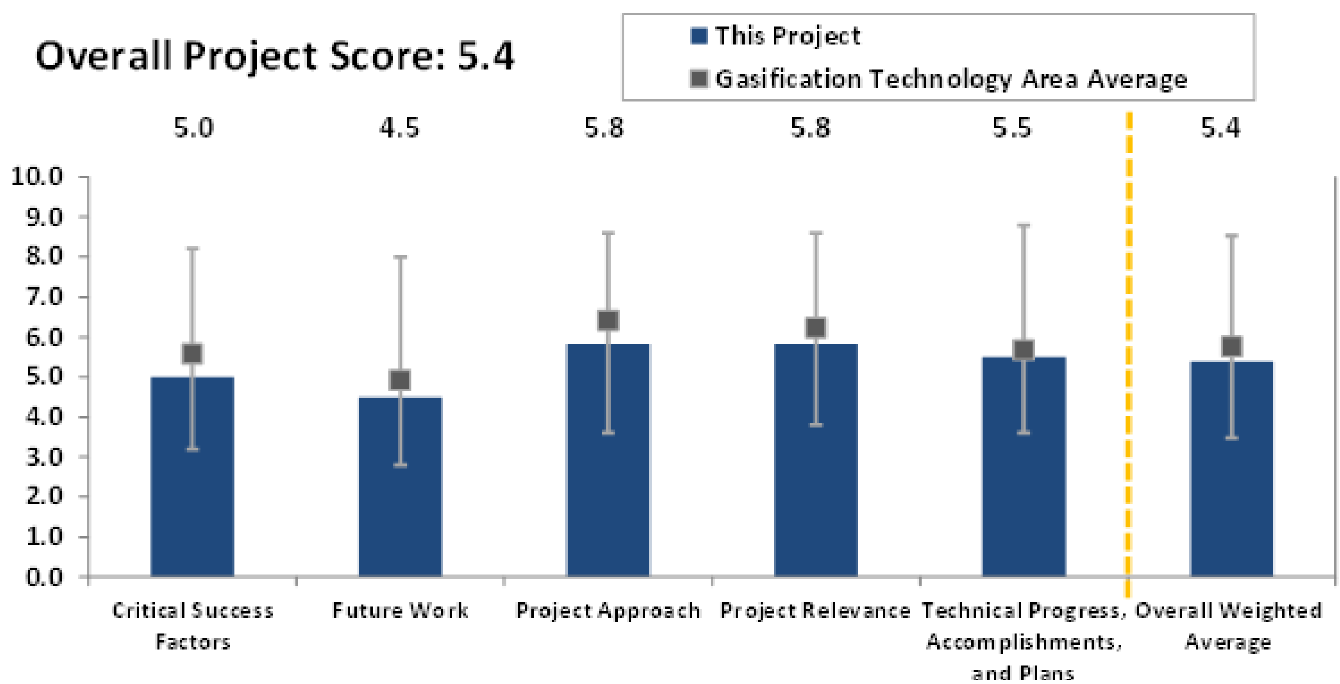
(WBS#: 3.2.1.5)

Recipient:	Georgia Tech Research Corporation
Presenter:	Pradeep Agrawal
Total DOE Funding:	$750,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2008-2013

Project Description

Photo Courtesy of Georgia Tech Research Corporation

The objectives of this research are to obtain experimental data on carbon gasification rate and the formation of hydrocarbon and tar contaminants during pressurized gasification of forest residues, and to develop mathematical models describing the experimental data. Two types of experimental reactors are utilized: a pressurized, entrained flow reactor and a pressurized thermogravimetric apparatus. Both are research reactors that are designed for obtaining kinetic data and not intended to simulate any specific type of gasifier. Through mathematical modeling, the rate data obtained in these reactors can be applied to a wide variety of gasifiers. The two reactors are complementary; the flow reactor provides high heating rates typical in an industrial gasifier, and the thermogravimetric apparatus allows for gasification rate measurements at longer residence times. The apparatus connected to a mass spectrometer and a Fourier-transform infrared analyzer also provides information on the evolution of gaseous species during pyrolysis. Three biomass species (southern pine, corn stover, and switchgrass) have been selected for this study. The results indicate a significant role of heating rate, pressure, and temperature on the



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

morphology of char formed. The char yield appeared to increase with an increase in pyrolysis pressure. The yields of the lighter gas components—carbon monoxide (CO), CO_2, hydrogen (H_2), CH_4, and water vapor—increased as the pressure was increased. The increase in the amount of char and lighter gases was accompanied by a decrease in the formation of tar species. This was supported by an observed decrease in furan and furfural, and higher hydrocarbon fragments with increasing pressure. The results suggest a complex role of pyrolysis conditions and biomass ash content on the char reactivity. Efforts are underway to develop a universal model for char gasification reactivity. currently estimated that the project will be completed by the September 2015 deadline.

Overall Impressions

- A reasonable approach, work still in progress.
- I think DOE should continue to fund this type of fundamental work. The results have implications for many thermal biomass conversion processes.
- The entire presentation addressed biomass behavior under pyrolysis conditions up to 1000°C. Lack of student help delayed extending investigations to gasification conditions. Pyrolysis behavior of biomass and the resulting char may even question whether addition of active bed materials serves any purpose. In gasification, the char properties and behavior are closely related to the extent of partial oxidation. Hence, the assumption that the results from char behavior in pyrolysis are independent of concurrently occurring gasification reactions may not be descriptive of biomass gasification as a whole. The application of the results to design and scale-up gasification is yet to be validated.
- The results of this work may have particular importance to an industrial partner (Enerkem) associated with another DOE-funded project. This is a good example of how DOE-funded projects could have synergistic benefits if the results of the projects were promptly exchanged between project PIs. If DOE project managers had the resources (and time) to engage PIs to facilitate the sharing of such project information, this would serve both the overall program and taxpayers.
- The stated goals of this project are to obtain experimental data on the rates of carbon gasification and hydrocarbons, and tar formation during pressurized gasification of biomass, and to develop kinetic models that describe the carbon gasification rates. In the absence of clearly defined deliverables and deadlines, this project has strayed from its stated goals with an extensive study of high-pressure biomass pyrolysis. While it is true that pyrolysis conditions can affect char gasification rates, this does not seem to have been studied in a consistent manner, and it is unlikely that this will be quantified for predictive modeling. This project needs to be refocused in the time remaining to provide data and predictive models that will be relevant to the pressurized biomass gasification industry in the future.
- There was very little effort in relating the research to real world problems. It appeared to be an academic study with very little practical application.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

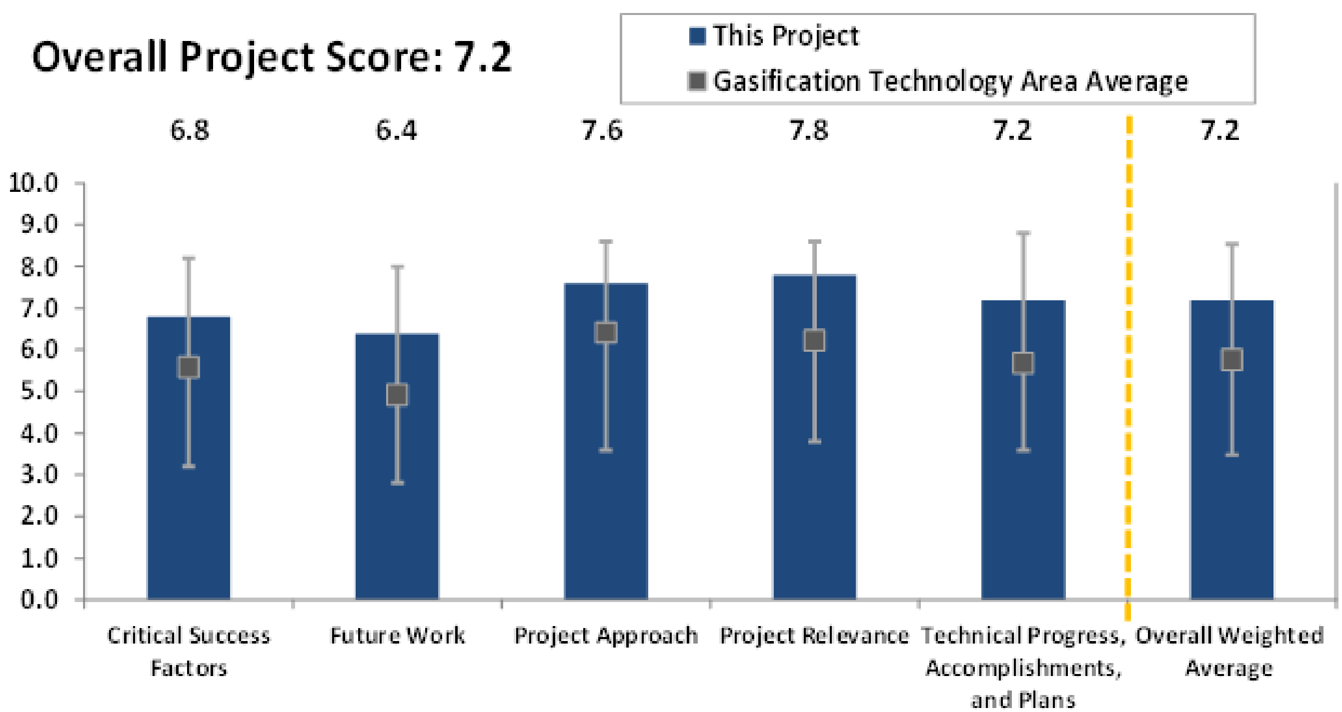
FUEL SYNTHESIS CATALYST - WORK WITH DOW CHEMICALS

(WBS#: 3.3.2.8)

Recipient:	NREL
Presenter:	Jesse Hensley
Total DOE Funding:	$1,500,000
DOE Funding FY13:	--
DOE Funding FY12:	$530,000
DOE Funding FY11:	$320,000
Project Dates:	2010-2012

Project Description

In fiscal years 2010–2012, NREL worked with the Dow Chemical Company to investigate mixed-alcohol synthesis from biomass syngas (a mixture of H_2, CO, and light gases) through a cooperative research and development agreement. Early in the project, NREL and Dow concluded that process design and validation were critical to achieving BETO's targeted MESP of $2.05 per gallon by 2012. Therefore, efforts were focused on validating the performance of a sulfided mixed-alcohol catalyst at various scales under various operating conditions, modeling catalyst performance, and producing well-integrated biomass to ethanol process designs. The results of these efforts were an industry-informed process design and significant contributions to the achieved MESP target in 2012. Research and development in 2011 and 2012 focused on studies of catalysts' response to major syngas contaminants—like methane and carbon dioxide—and incorporation of proprietary kinetic models into larger biomass-to-ethanol process designs. Catalyst performances were also compared when feeding bottled or biomass-derived syngas. Results showed that sulfide-type catalysts, such as those developed by Dow, are robust in most syngas environments and don't appear to be compromised by biomass syngas. Syngas composition was shown to be critical to performance, however, with high ratios of H_2:CO resulting in losses in ethanol selectivity, and high levels of inert gases (like CH_4, CO_2, and nitrogen) resulting in decreased catalyst productivity. This project is now 100% complete. Overall, the NREL/Dow collaboration was critical to achiev-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

ing MESP targets, due in large part to the use of Dow's proprietary kinetic models. Thus, this CRADA was both impactful and productive.

Overall Impressions

- BETO should continue to encourage industry-initiated CRADA projects and require industry to present (or jointly present) project results at Project Peer Review meetings.
- Good to see lab/industry collaboration. Interesting to see how collaboration suggested modification of process design. Ongoing challenges with getting pilot plant to operate close to design conditions, again suggesting that modeling team incorporate ranges in results to reflect level of uncertainty in data and/or model inputs.
- NREL and Dow Chemical have excellent synergy in collaborating and were effective in execution of the CRADA. This is a very good match.
- This CRADA was instrumental in helping to meet the Office's ethanol price target of $2.05/gge, and is a great example of leveraging strengths between industry and a national lab to achieve a common goal.
- Use this project as a successful model of how to rapidly advance technology development by collaboration with industry.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

GASIFICATION PROCESS MODELING AND OPTIMIZATION

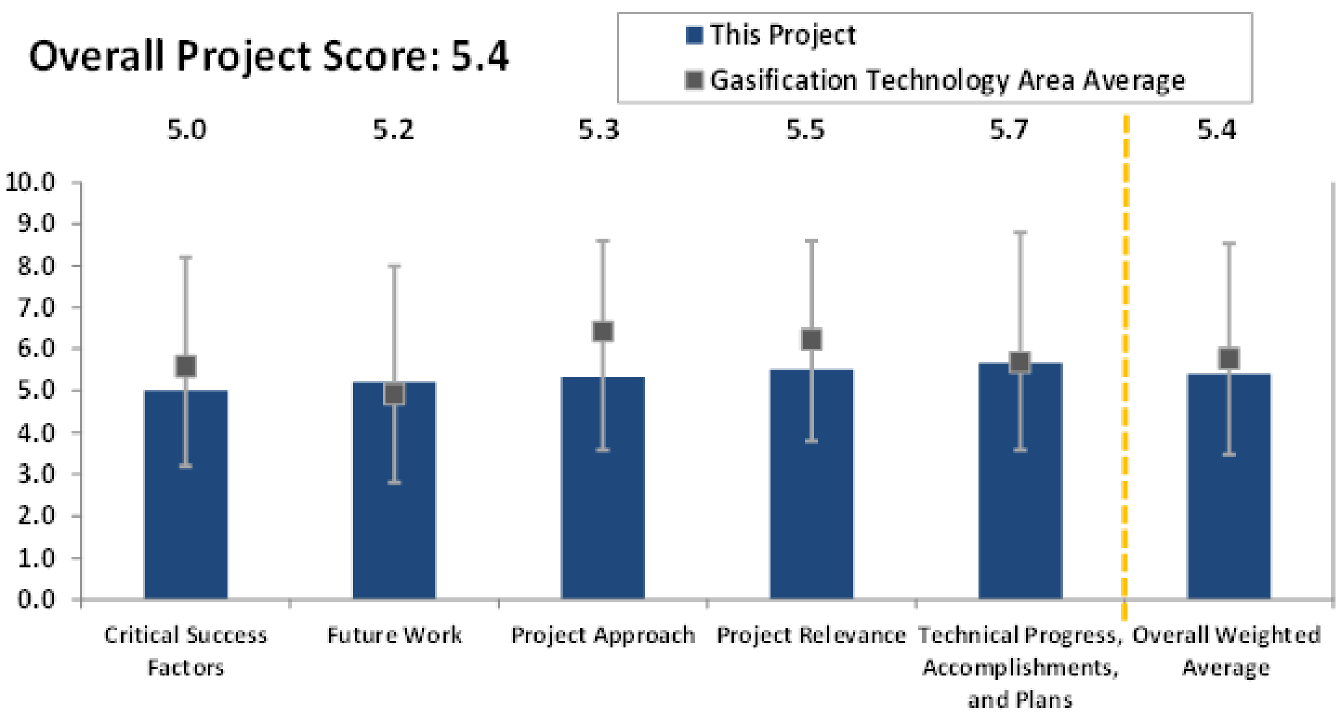
(WBS#: 3.2.1.1; 3.2.1.3)

Recipient:	NREL; PNNL
Presenter:	Mark Nimlos
Total DOE Funding:	$14,300,000
DOE Funding FY13:	--
DOE Funding FY12:	$2,500,000
DOE Funding FY11:	$2,600,000
Project Dates:	2006-2014

Project Description

Photo Courtesy of NREL; PNNL

The research in this project involved laboratory and modeling studies in support of BETO's fiscal year 2012 technical targets to achieve $2.05/gallon fuel by gasification and mixed alcohol synthesis. This gasification project finished at the end of fiscal year 2012. Experiments were conducted using realistic laboratory-scale fluidized bed reactors to show that there is little variation in the composition of the syngas from the gasification of different feedstocks. This suggests that this fuel production pathway can use a variety of biomass sources, reducing risks associated with biomass supply. Experiments were also conducted that showed that the tars and methane in the syngas can be reduced when catalysts are used in the gasification step. Further studies are needed to determine how this approach will allow the simplification or elimination of the syngas cleanup step and improvement of the system economics. Mechanistic and modeling studies were also conducted to understand the chemistry and mass transport in gasifiers so that their performance can be improved. The models developed in this task are being adopted by Theromochem Recovery International, Inc., to simulate their commercial-scale reactors. Finally, a laboratory-scale reactor was used to conduct integrated studies of gasification and alcohol synthesis and to help with pilot-scale demonstrations of



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

gasification/alcohol synthesis. The pilot studies achieved technical targets for conversion and helped validated the cost goal of $2.05/gallon.

Overall Impressions

- The coordination of efforts between the institutions executing this research did not appear to work well. The tests conducted at the two labs using the three-inch reactor and four-inch reactor did not seem to be well coordinated, and therefore relevance of the results was confusing. The project would have had a greater impact if it was focused on the ethanol catalyst as originally articulated; however, in the course of execution of the project, this was lost.
- DOE should require complete documentation of experimental details and results in a comprehensive final report that should help identify lessons learned. The method of operation and the difference in analytical techniques adopted with the three-inch- and four-inch-diameter gasifiers is a potential problem in relating the results obtained from these two experimental apparatus. The information gathered from the continuously fed, four-inch-diameter gasifier is of significance to this project. The qualitative claim of 70–79% tar reduction should have been supported by actual tar concentrations to help matching the raw gas with a compatible EtOH synthesis process. The claim of tar formation at the wall of the four-inch reactor should be reviewed to determine the influence of thermal effects, including the uniformity of externally heating the gasifier. Overall, the project has missed the opportunity to produce meaningful results that could be used for reactor scale-up. It is not obvious how and which of the results from the four-inch reactor tests would be useful to pursue the ThermoChem Recovery International process development effort.
- As a recommendation, this work should be well documented, in a single-source document to capture all of the good work that has been accomplished over the years. It should also be referenced to other work to reflect the similar findings found by other researchers in other organizations.
- From a project management perspective, it might be better to concentrate dollars and efforts into fewer, more discrete projects. This project had many partners, and diversity and depth from teaming is generally good. However, maybe there were too many parallel efforts, too much duplication—for example, to see how three-inch and four-inch projects were connected.
- Overall, this had the potential to be a strong project, with issues addressed experimentally in multiple barrier areas. Lack of a clear vision and cohesive experimental plan were a problem. More transfer of the lessons learned and technology to industry should be pursued. Also, the Technology Area as a whole would have benefitted from more collaboration with the Feedstocks Technology Area on the techno-economic effects of various processing methods (particle size, moisture, torrefaction, compression, etc.) on gasifier operability and products.
- Use of multiple test systems not optimal. Would have liked to have seen techno-economic analysis.

PI Response to Reviewer Comments

- We thank the reviewers for their comments, but want to clarify the following points in response. The goals of this project, which ranked high in earlier reviews, were to help understand the science of gasification and to help with the fiscal year 2012 demonstration. This project was not involved in ethanol synthesis, techno-economic analysis, or feedstock handling, which were covered by other projects, though the results from this project informed that work. This research was more fundamental and long term than other work in the BETO portfolio. When BETO changed their primary R&D focus away from gasification and towards pyrolysis in fiscal year 2012, many tasks could not be completed by the end of this reporting period, but the project lead to several important benefits: the fiscal year 2012 pilot-scale demonstration of integrated gasification/ethanol synthesis was reached and the four-inch gasifier—and the operation thereof—played a critical role in this achievement; project work was published in the open, peer-reviewed literature and presented at international conferences, including 12 publications and 14 presentations during this reporting period; and the technology that was developed in this project is being used to address important technical barriers in pyrolysis.

- Finally, the use of the three-inch and four-inch reactors should be addressed. These were developed at PNNL and NREL to address long-term research needs. At PNNL the three-inch reactor was built to conduct gasification and pyrolysis research and was used in this project to conduct important parametric studies of gasification. The four-inch reactor at NREL was constructed to serve as a bridge between laboratory experiments and pilot studies, and was used to explore approaches for tar reduction. Both of these tools are being used in ongoing research in pyrolysis and gasification for BETO.

INTEGRATED GASIFICATION AND FUEL SYNTHESIS

(WBS#: 3.2.5.7)

Project Description

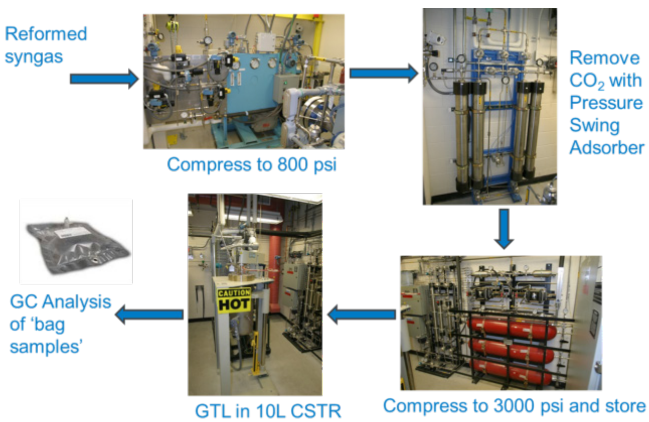
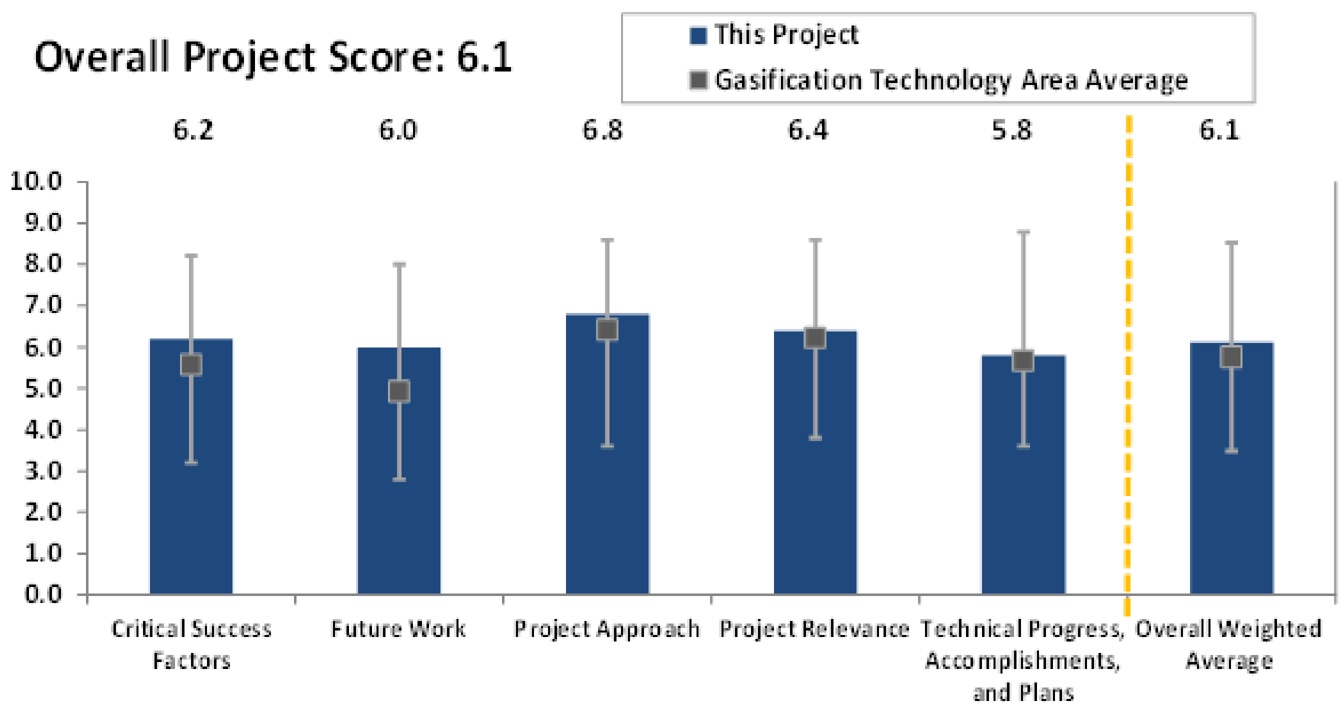


Photo Courtesy of NREL

Recipient:	NREL
Presenter:	Mark Davis
Total DOE Funding:	$10,906,813
DOE Funding FY13:	--
DOE Funding FY12:	$2,100,000
DOE Funding FY11:	--
Project Dates:	2002-2012

This project demonstrated the integrated production of cost-competitive ethanol from mixed alcohols produced from biomass-derived syngas at pilot scale. The objectives of the project were to integrate the unit operations; evaluate the performance of all unit operations using state-of-the-art analytical techniques; validate syngas quality, cleanup, and fuel synthesis processes; and provide performance input to TEA models. The project is directly relevant to BETO's mission of "developing technologies for converting feedstocks into cost-competitive commodity liquid fuels such as ethanol, renewable gasoline, jet fuel, and diesel." Core topic areas included gasification, syngas cleanup and conditioning, and fuels synthesis. This presentation will discuss the project accomplishments related to meeting the fiscal year 2012 strategic and performance goals, including installing plant equipment and demonstrating that the reforming and regeneration catalyst met the technical targets of 80% methane and 99% tar conversion. The main critical success factor was achieving steady-state operation in an integrated pilot plant that meets techni-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

cal targets at each unit operation. The largest challenge to achieving the project's goal was managing the timeline of equipment delivery, as well as ensuring that the equipment met the performance specifications from the external vendors. Integrated gasification, reforming, acid gas removal, and mixed alcohol synthesis were demonstrated at pilot scale for 330 hours using both industrial and in-house catalysts.

Overall Impressions

- Good to see emphasis on longer-term integrated operations. Although expensive, this type of testing is required to ensure commercial viability and attract investment for larger-scale demonstration units.
- Overall, this project was very important in meeting BETO's goal to demonstrate an integrated biomass gasification-to-mixed-alcohol synthesis process. With some additional advanced planning, however, the project could have avoided the mad dash to the finish line caused by inevitable equipment commissioning and integration issues. This would have fielded a more relevant pilot plant before the project's close. This aside, a short extension of the project to work out a few of the integration issues would have been a better use of the project's significant capital expenses, allowed a more thorough optimization of the plant performance, and permitted investigation of the effect of feedstock properties on operability of the plant for better integration with the Feedstock Technology Area's activities. Finally, additional relevance to the overall Gasification Technology Area's goals would have been achieved with the incorporation of alcohol separation processes and methanol recycle streams.
- The NREL thermochemical user facility is a valuable tool in the DOE capability portfolio, especially its ability to chemically analyze process-stream chemistry in real time. However, in this project, it may have taken on too much with the development efforts associated with integrating the recirculating/regeneration reactor into the existing process. Sometimes trying to be all things to all customers is counterproductive and that may be the case here.
- The existing research units are not appropriate for any attempt to demonstrate integrated operation.
- There was extreme redundancy that makes the process too complicated. It was not focused. Modeling could have been used to reduce the number of units operations and make the process more effective. TEA could have also been helpful to this project in the selection of the unit operations.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

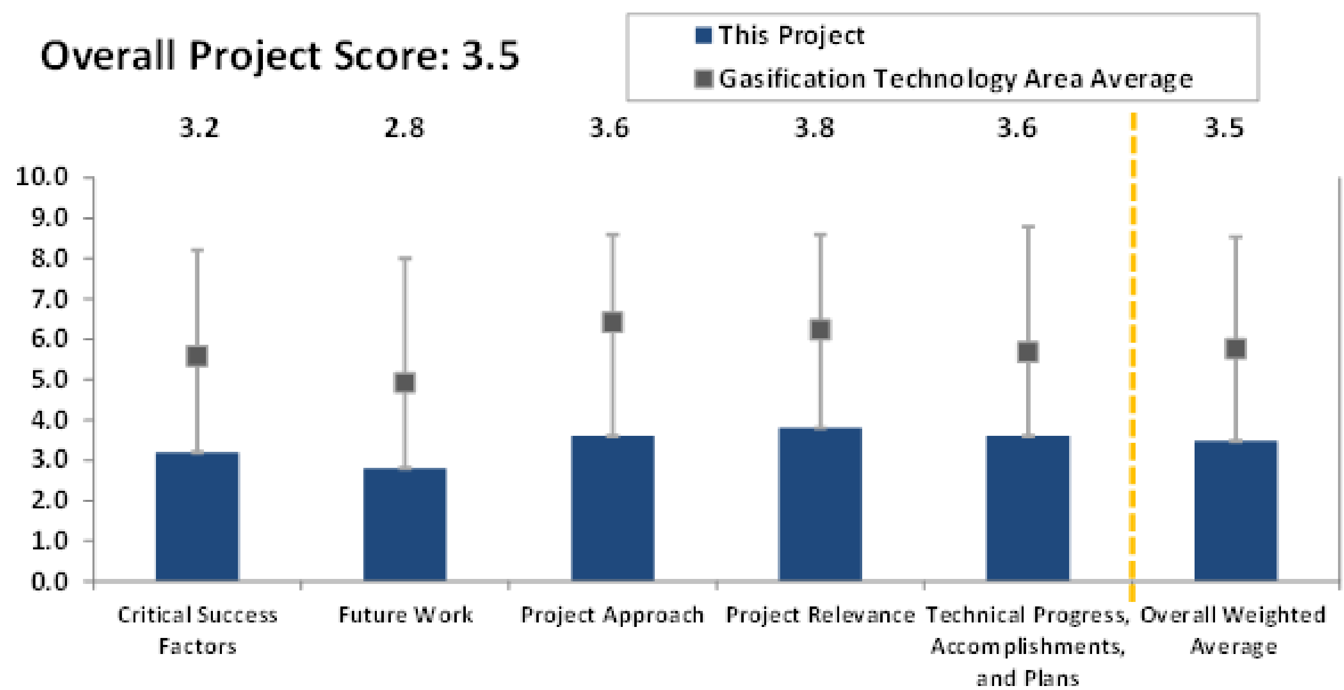
NEAR-ZERO CARBON FOOTPRINT ENERGY CREATION THROUGH THERMAL OXIDATION (HYDROTHERMAL DECOMPOSITION AND RESOURCE RECYCLING)

(WBS#: 7.7.2.22)

Recipient:	City of Allentown
Presenter:	Lauren Giguere
Total DOE Funding:	$1,000,000
DOE Funding FY13:	$315,000
DOE Funding FY12:	$685,000
DOE Funding FY11:	--
Project Dates:	2010-2013

Project Description

Hydrothermal Decomposition, as a means to produce clean energy, is operating in other countries; however, it must be proven in the U.S. This research was to select, test, and design an innovative solution for the transformation of municipal solid waste and sewage sludge into renewable energy. The work performed to date was twofold: first, designing and installing a test system; and second, designing a complete plant for transforming approximately 150 tons of MSW and sludge per day to generate 4 megawatts of electricity. The test system encompassed two technologies— the Resource Recycling System transforms, via hydrothermal decomposition, the feedstock into a pulverized material; and the Water Treatment System, which treats and cleans excess water from the hydrothermal decomposition process before it can be discharged to the sewage. The design of the complete process—from receiving feedstock in a tipping floor to the generation of clean energy—is also complete. A process patent was filled and is pending approval. This project's relevancy is highlighted by its capacity to create renewable energy without fossil fuels. It also offers a solution to the waste issues faced by our cities, especially those seeking an environmentally effective answer. Delta Thermo Energy's energy process will treat both MSW and sewage sludge combined. Additionally, it will help cities like Allentown to save millions in disposal costs and increase recycling levels. The pilot system was used to test Allentown's MSW and sludge. Test results were sent to Environmental Pro-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

tection Agency-certified labs in Pennsylvania and New Jersey. They were also used in the design of the overall process plant. They show a renewable fuel with high caloric content, and fewer pollutants than those present in the MSW and sludge before the hydrothermal decomposition process.

Overall Impressions

- If the project is successful, DOE should consider whether to explore transferring this environmental project to the Environmental Protection Agency.
- It is good to see that a municipality is interested in waste-to-energy processes, though this particular process may not be developed enough for their needs. The city of Allentown and its residents would be better served by using a more proven approach, rather than funding a company to develop its commercial operations. The techno-economics behind this system installation needs to be studied in greater detail by an independent entity prior to moving forward with a commercial installation. Allentown should also inquire about the technical and economic viability of waste-to-energy plants in other municipalities.
- The lack of concrete data on this project makes it difficult for one to assess it future prospects.
- This project appears to have significant technical and economic risk.

PI Response to Reviewer Comments

- The second reviewer comment is not applicable; please note the city of Allentown is not funding the project. All funding has come from private investors and other sources.
- The second reviewer comment is not applicable. The city has retained third-party independent consultants as reviewers and advisors for the duration of the project.
- The city of Allentown has indicated its willingness to share all pertinent test data of the project, as well as relevant independent studies.
- The city has no economic risk, since it is neither responsible for financing nor pays for its service until the plant is fully commissioned and operational.

NOVEL APPROACH FOR BIOMASS SYNGAS CLEANING AND CONDITIONING FOR LIQUID FUEL SYNTHESIS APPLICATIONS AND ASSOCIATED CRADA WITH INL

(WBS#: 3.2.5.9; 3.2.5.14)

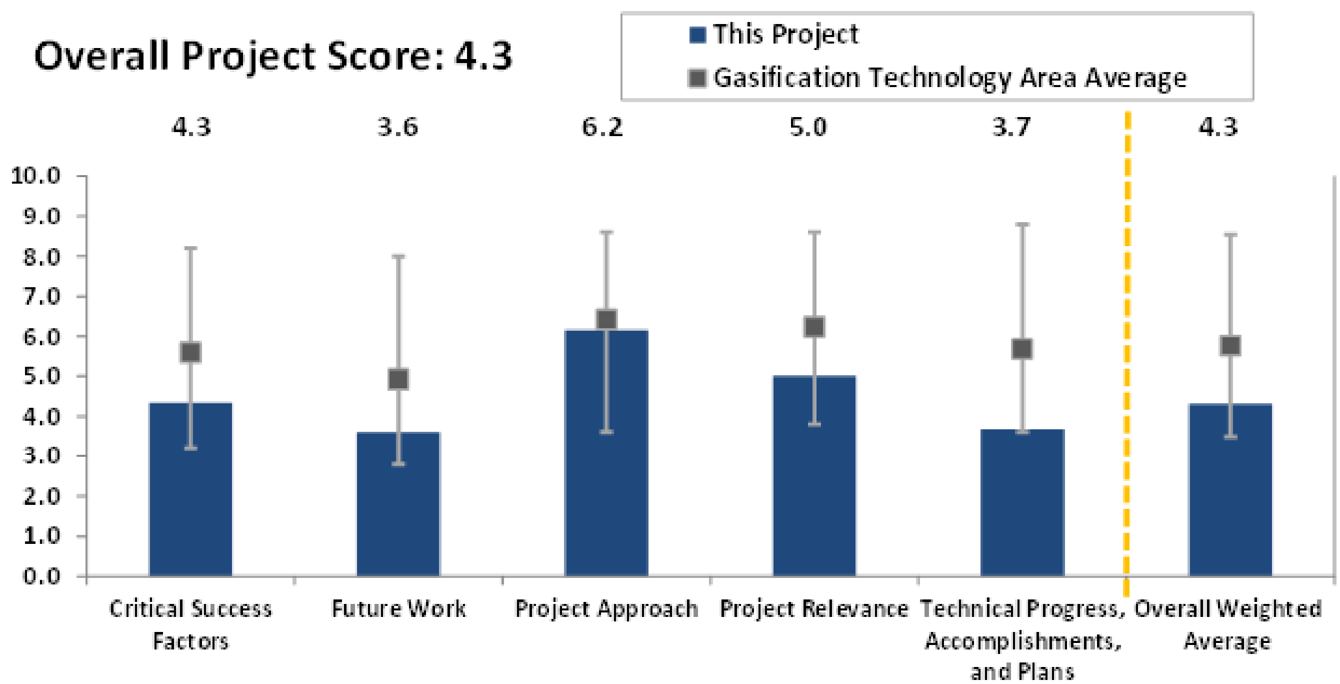
Recipient:	Emery Energy; INL
Presenter:	Ben Phillips
Total DOE Funding:	$1,734,459
DOE Funding FY13:	--
DOE Funding FY12:	$137,102.84
DOE Funding FY11:	$293,161
Project Dates:	2008-2012

Project Description

Photo Courtesy of Emery Energy; INL

The objective of this project is to demonstrate, at a pilot-plant scale, the ability of a novel low-temperature, oxygen-assisted plasma reformer to destroy tars and oils from a tar-laden stream of biomass-derived syngas. Technical and commercial success would eliminate the need for other forms of catalyst reforming and techniques involving tar removal by water quench.

Work to date has included completion of the first phase of the project, including running more than 300 hours of woody biomass in an oxygen-blown, fixed-bed updraft gasifier with the reformer operating immediately downstream. Idaho National Laboratory (INL) completed testing of the reformer efficacy and Western Research Institute took a slip stream of the gas for further gas sampling for impurities removal. The testing showed



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

that certain longer chain hydrocarbons were reduced, proving basic functionality of the technology, but that better syngas mixing with oxygen may be required for optimization of the technology.

Overall Impressions

- Require at least some level of preliminary economics in the funding opportunity announcement for projects to at least show the potential for improved CAPEX and OPEX compared to current best practice. This project also had relatively poor performance results and would have probably benefited from better project management oversight. Another reason for DOE to provide better resources (time) to their project management team, although it is recognized that American Recovery and Reinvestment Act-funding requirements had deleterious effects on DOE's project management resources.
- Results didn't show a benefit. Need process economics compared to simpler approaches.
- The plasma-reforming concept for syngas cleaning holds promise from a technical standpoint, though the pilot-scale demonstration showed that it is not ready for commercial implementation. Integration of the reformer into a working biomass-gasification-to-fuels platform remains a challenge, and TEA of this concept is needed.
- The project was poorly executed. The partners did not work well; not much data were collected to justify the funding. Perhaps this was a question of poor marriage of partners. The full potential of the cold plasma torch was never demonstrated, which is a sad commentary on this promising technology. Perhaps BETO should require a statement from the collaborators that they can work together or they have worked together in the past.
- The technical and cost-benefit analysis of plasma reforming over thermal oxidation (by introducing air or oxygen) to raise exit gas temperature to about 2100° Fahrenheit (F) compared to 1700–1800°F reformer operation (employing air or oxygen to raise raw gas temperature from 800°F) should have been investigated prior to proposal preparation and submission. The reported rate of raw gas contaminants in the plasma reformer is not consistent with 96–98% tar destruction claims. Project should present variation in post-reformed concentration profiles rather than one set of contaminant-reduction data for 300 hours of operation.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

PILOT-SCALE DEMONSTRATION OF A FULLY INTEGRATED COMMERCIAL PROCESSES FOR CONVERTING WOODY BIOMASS INTO CLEAN BIOMASS DIESEL FUEL

(WBS#: 3.2.5.13)

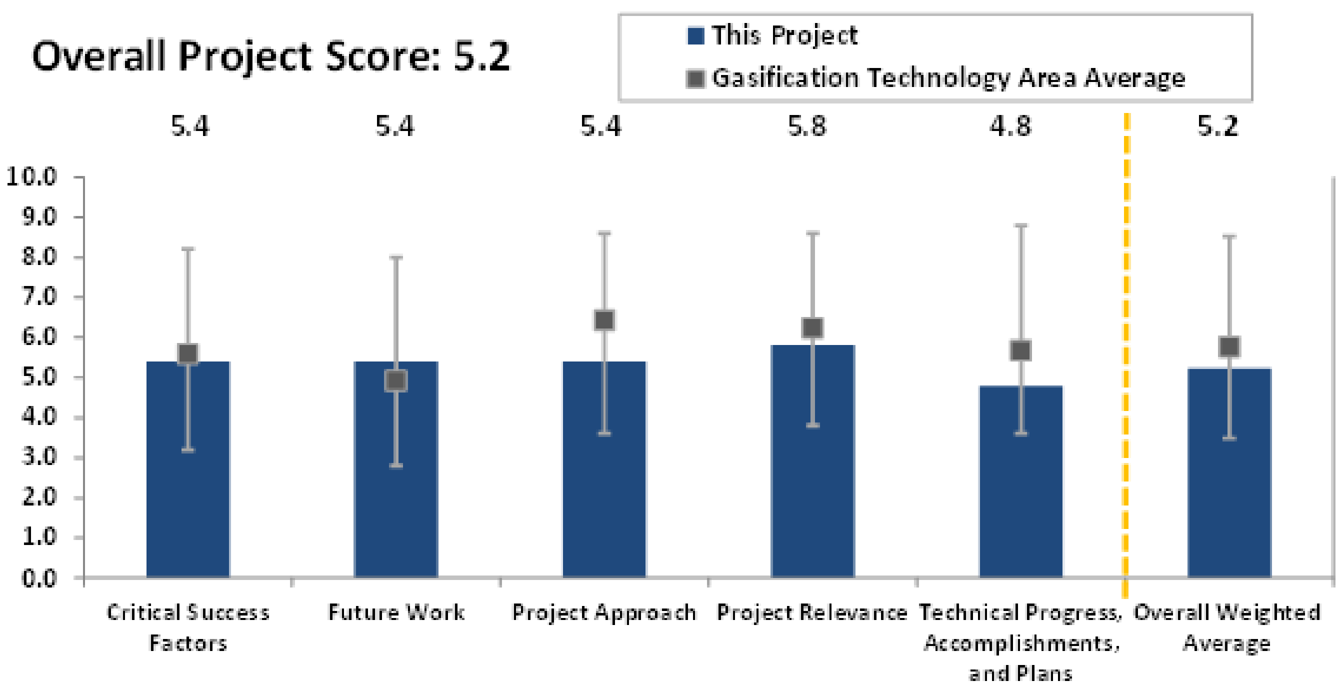
Recipient:	SRI
Presenter:	Andrew Campos
Total DOE Funding:	$1,997,793
DOE Funding FY13:	$682,424
DOE Funding FY12:	$488,847
DOE Funding FY11:	$49,010
Project Dates:	2008-2014

Project Description

The Southern Research team is developing a novel two-phase, pilot-demonstration program—in collaboration with Mott Corporation and with the support of DOE—to configure and demonstrate a hot gas cleanup system to prove its technical and economic viability at scale that reduces contaminants to levels below the acceptable poison tolerances for the FTS catalyst. The system will be based on a commercially tested, sintered-metal filter technology and proven gas-cleanup sorbents and catalysts. They will be combined and sequenced in an innovative and efficient way to maximize economic viability and facilitate early commercialization of the system.

Phase one of the project involves the integration of the sorbent and hot gas cleanup system components with Southern Research's biomass gasifier with a milestone of 300 hours of operation. Phase two of the project will

Photo Courtesy of SRI



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

involve the integration of the syngas cleanup system with a FTS liquid train process to validate the fully integrated system's performance with an operation milestone of 500 hours. Syngas measurements upstream of the liquids train (composition, particulate loading, etc.) will be collected to obtain information on the syngas cleanup system performance. Engineering work accomplished thus far includes thermal-pipe stress calculations, piping and instrumentation diagrams, a hazard and operability study, and specifying and ordering all of the appropriate equipment for the syngas cleanup portion of the project (phase one). Construction and controls of the system to the gasification PDU are imminent, which will be followed by system shakedown and commissioning. The project objectives are to validate the performance, efficacy, and cost-effectiveness the fully integrated unit; show that biomass-derived syngas contaminants can be reduced to levels that are tolerable to FTS catalysts; and validate the cost-effective conversion to on-specification, FTS-diesel fuel from biomass-derived syngas.

Overall Impressions

- An alternative approach. Not sure how it fits into overall BETO portfolio.
- DOE project managers should engage this project with tighter control, given the similarities with other poor-performing projects due to partner restructuring. In addition, the selection of sorbents should be narrowed down rather than expanded. It would also be a useful comparison to baseline sorbent performance against the commercial RTI sorbent that was vetted in a coal gasification plant.
- Overall, the economic feasibility of this project does not seem to have been carefully considered. Work is slowly progressing towards the demonstration of the hot syngas cleanup technology, but given the short timeline, it seems unlikely that this milestone will be met.
- Successful completion of projects with many challenging tasks could lead to many benefits, such as a robust demonstration and deployment gasifier that could be used for a variety of applications including combined heat and power. A properly shaken-down, successfully operated pilot plant will provide BETO another test bed for innovative R&TD.
- This project has not made much progress and unless there is rapid progress, the project results will become obsolete by the time it is completed.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

PNNL FUEL SYNTHESIS CATALYST - CRADA WITH W.R. GRACE

(WBS#: 3.2.5.13)

Recipient:	PNNL
Presenter:	Richard Hallen
Total DOE Funding:	$910,000
DOE Funding FY13:	$41,182
DOE Funding FY12:	$39,624
DOE Funding FY11:	--
Project Dates:	2008-2012

Project Description

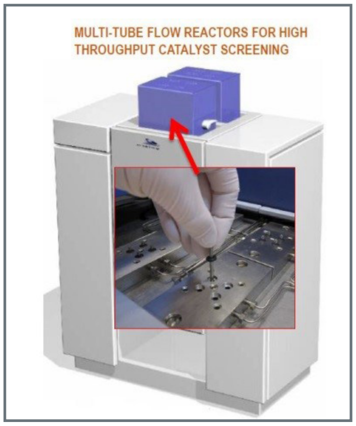
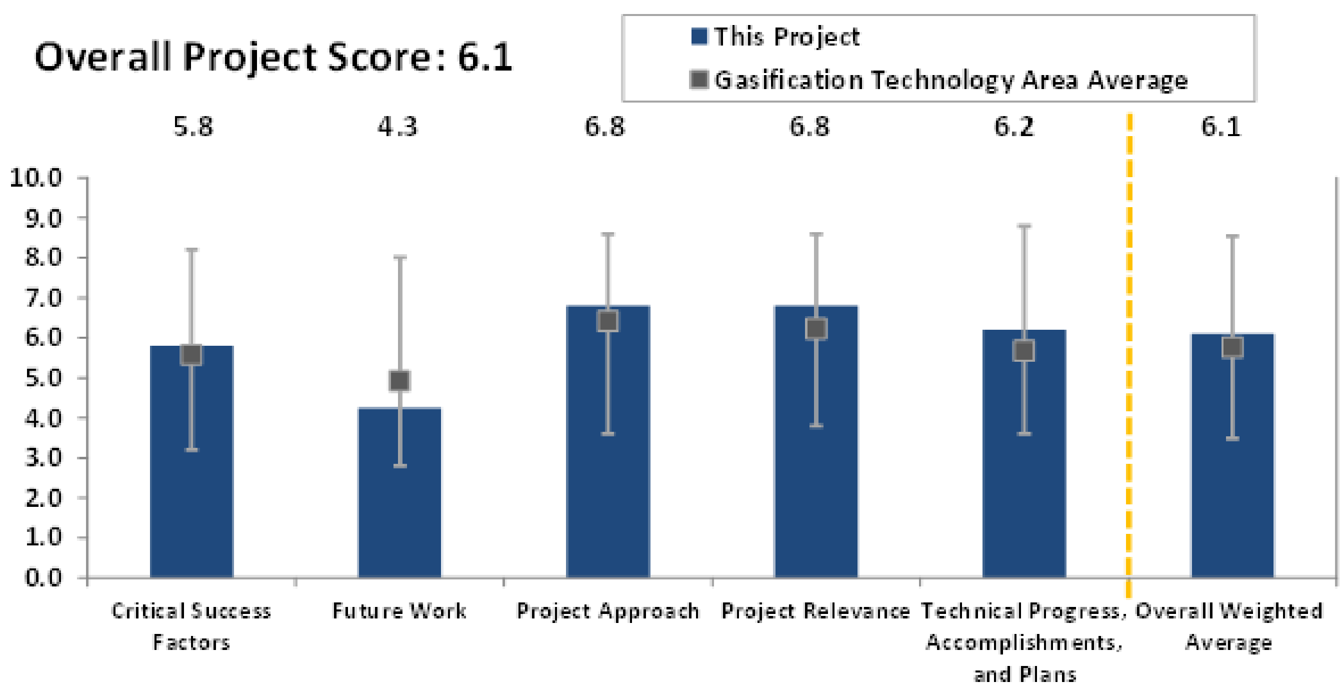


Photo Courtesy of PNNL

W. R. Grace entered into a CRADA with PNNL on October 19, 2010, to conduct a joint research and development project on catalysts for mixed-alcohol synthesis from biomass-derived syngas. The W. R. Grace Company was developing industrial-relevant catalysts for production of mixed alcohols from synthesis gas under internal R&D projects and partnered with PNNL to conduct further evaluation, both experimental and techno-economic analysis. PNNL conducted experimental evaluation and process-condition optimization studies utilizing the Grace-prepared catalysts. The combined experimental and TEA identified areas for catalyst improvement. The initial catalysts formulations were based upon molybdenum sulfide, and the preferred catalyst was used to produce a mixed-alcohol product stream for upgrading to hydrocarbon fuel. Later work examined non-sulfide catalyst compositions. PNNL utilized the Avantium Flowrence high-throughput, catalyst-screening system to screen catalyst formulations prepared by Grace. The top performing catalysts were further evaluated in single-tube reactor systems. The catalyst screening results were validated and catalyst performance over a range of process conditions was determined. The catalysts' composition showed high productivity and selectivity to C2+ oxygenates



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

compared to other catalyst formulations. However, the selectivity to methane was higher than desired for a commercial process. The CRADA was successfully completed on April 30, 2013.

Overall Impressions

- Despite good use of techno-economic modeling to inform catalyst decisions, this project was largely unsuccessful, due mostly to inaction by the industrial partner. Most of the catalyst screening had been performed in the first part of the CRADA, so it is uncertain why this CRADA was extended for one year.
- Good to see the labs and private industry collaborate.
- It would be most useful to document the results of this project with those of the Dow CRADA work in a single, comprehensive report. Recognizing there is sensitive intellectual property information that would need to be fenced off from such a report, the remaining results and operating conditions would hold significant value to future technology developers and also document the legacy of DOE investments in this field of syngas to mixed alcohols.
- There is a need to improve on the catalyst development to be effective and economical. Aldehydes appear to be more problematic for the process. The aldehydes destabilize the catalyst and catalyst produced too much methane.

PI Response to Reviewer Comments

- With the successful demonstration of thermochemical conversion of biomass via syngas to ethanol at NREL in 2012, research and development into catalysts for the conversion of biomass-derived syngas into ethanol was de-emphasized in 2013 by the Bioenergy Technologies Office. As such, this project is closing out in 2013 after making significant progress with both sulfided and non-sulfided fuel-synthesis catalysts to produce mixed oxygenates. After extensive high-throughput screening of catalysts and lifetime studies, this collaboration with W.R. Grace included development of industrial-relevant catalysts and demonstration of robust performance. The W.R. Grace catalyst/process was quite unique in the production of alcohols higher than ethanol with very little methanol. This work will be useful in the future as indirect liquefaction to gaseous intermediates and, subsequently, hydrocarbon fuels are developed, since it has been shown that conversion to hydrocarbons can be easier with alcohols of greater than C2 carbon chain length.

RENEWABLE ENERGY CENTER

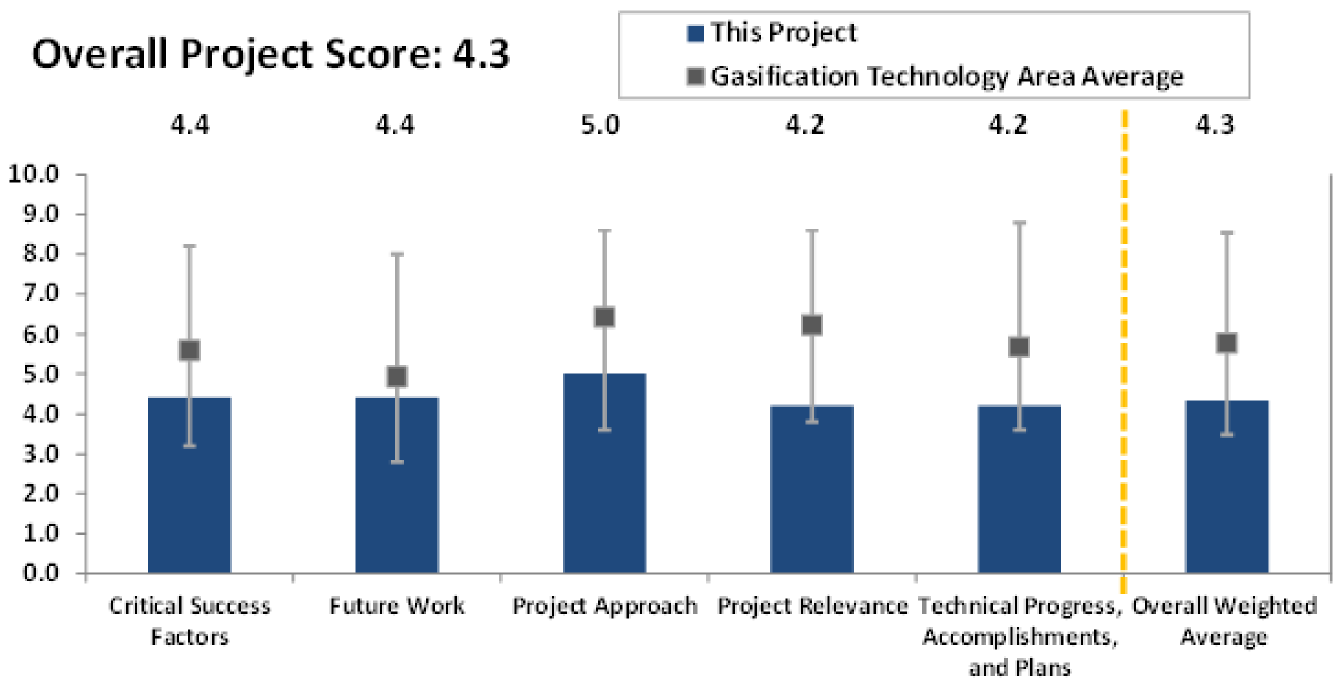
(WBS#: 7.3.2.6)

Project Description

Photo Courtesy of North Carolina A7T State University

The goal of this project is to develop an efficient gasification system to convert woody biomass and agricultural residues to syngas, a catalytic process to convert the syngas into liquid fuel, and a syngas-based heat and power system. Specific objectives include characterization and pretreatment of biomass as a feedstock of gasification; analysis of biomass gasification chemistry and kinetics; computer simulation of reactive particle flow in a fluidized bed gasifier to advance the gasifier's design and operation; investigation of hot-syngas cleaning technology; development of novel catalysts and reactor for Fisher-Tropsch synthesis; and investigation of a syngas-based combined heat and power system. Some accomplishments for the project include the measurement of physical and chemical properties of different biomass materials; use of a thermogravimetry/differential scanning calorimetry analyzer to analyze the thermal degradation kinetics of different biomass materials; development of a chemical equilibrium model to estimate the yield and composition of syngas during biomass gasification; and investigation of steam as a gasifying agent to increase the molecular ratio of H2 to carbon monoxide in syngas. The team has designed and built a laboratory screw-auger reactor to torrefy biomass and

Recipient:	North Carolina A&T State University
Presenter:	Abolghasem Shahbazi
Total DOE Funding:	$750,000
DOE Funding FY13:	$192,000
DOE Funding FY12:	$300,000
DOE Funding FY11:	--
Project Dates:	2012-2015



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

a steam biomass fluidized bed gasifier with 10 kg/hour loading capacity. A 10 kilowatt downdraft gasifier has been purchased from All Power Lab in Berkley, California, for comparison. A gas cleaning system consisting of a four-cubic feet canister filled with wood shavings, two one-liter impingers connected in series fashion, and a water blocking filter to remove the water and tar from the syngas at room temperature has also been fabricated. A tri-gas engine generator has been purchased and tested with simulated syngas. The operation of the generator with online experimental syngas will face difficulties due to presence of contaminants in the fuel, non-uniform gas composition, and low gas pressure. Four Ph.D. students have been recruited to work on the project toward their dissertations. Challenges include completing all aspects of the proposed project within three years, and cleaning and conditioning syngas to produce high-quality gas for Fisher-Tropsch reactions and heat and power generation.

Overall Impressions

- Good educational outreach; includes undergrads and graduate students.
- In case the 10 kilowatt downdraft gasifier was purchased with DOE funds, and if there are opportunities for distributed energy conversion or combined heat and power applications in the Southeast, NC A&T and BETO should decide on allocating resources to employ this equipment for the stated southeastern U.S. applications besides training students. With waste biomass, NC A&T may require compaction or pelletizing capabilities as a feed preparation requirement for the downdraft gasifier.
- The strength of this project is in its educational component, which will train future researchers in the biomass gasification field. The research component is mundane without much innovation.
- This is a congressionally designated project that leverages funding from two other sources. The scope of work is enormous, and contains far too much to be done effectively with the funding provided. The only novel portion of this project is cleaning syngas with torrefied, steam-activated biomass material. It is suggested that the project be refocused on this and other potentially novel aspects, such as the effects of biomass pretreatment conditions of its gasification and syngas cleaning requirements. Otherwise, the primary relevance of this project will be in training students for work in the biofuels industry.

PI Response to Reviewer Comments

- We agree with the reviewers that this project has a strong educational component. However, there are also strong and innovative research components, including studying the effect of biomass pre-treatment on the gasification, cleaning syngas using torrefied and steam-activated biomass, and development and testing of low-cost catalysts for synthesizing renewable fuels. We also recognize that the scope of work for the amount of funding we have is too much. Since the downdraft gasifier that was mentioned in the report was purchased from a non-DOE funding source, there is an opportunity to trim the electrical power generation component if the project manager and project engineer both approve the change.

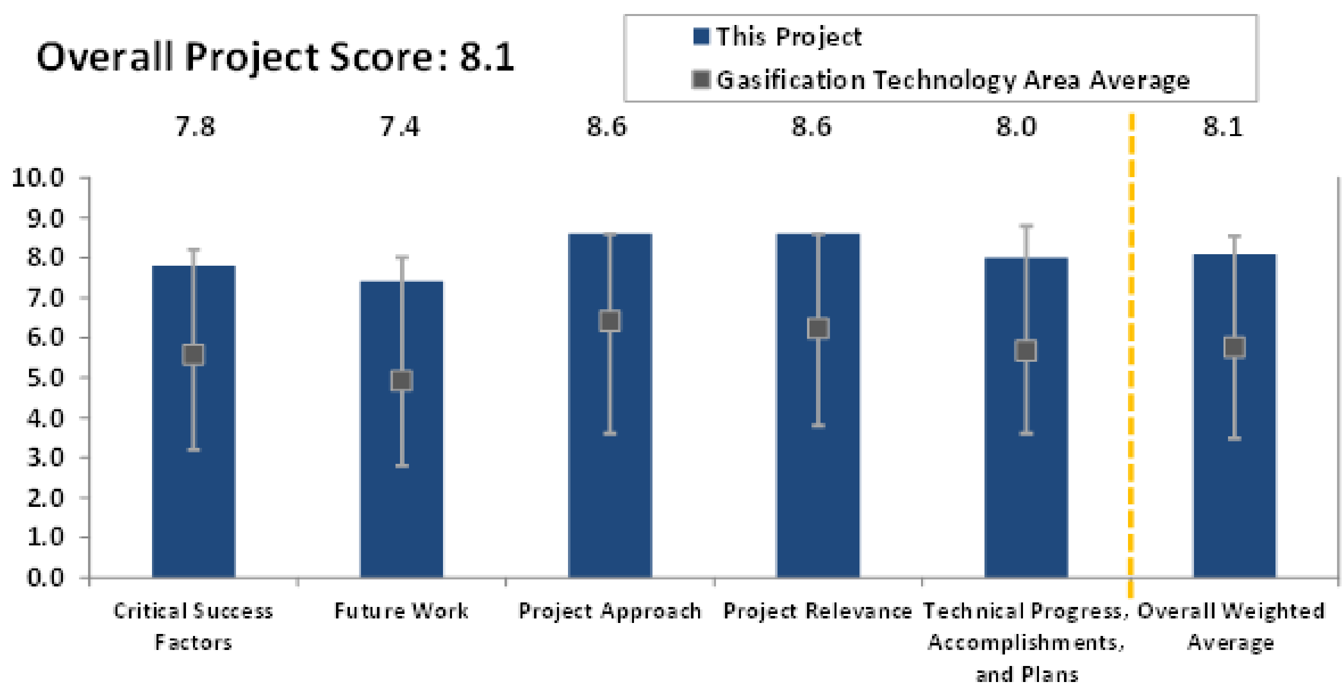
SYNGAS MIXED ALCOHOL COST VALIDATION

(WBS#: 3.6.1.1)

Recipient:	NREL
Presenter:	Abhijit Dutta
Total DOE Funding:	$4,900,000
DOE Funding FY13:	--
DOE Funding FY12:	$700,000
DOE Funding FY11:	$800,000
Project Dates:	2007-2012

Project Description

This task provides techno-economic analysis for biomass-to-liquid-fuels processes with the aim of helping the Technology Area develop cost-competitive conversion technologies via targeted research. Until fiscal year 2012, the primary objective of this task was to support the research and use experimental results to derive current costs based on the state of technology. This work was to help achieve BETO's goal to demonstrate integrated conversion technologies capable of producing cost-competitive ethanol from biomass by 2012. A modeled MESP target of $2.05/gallon by 2012 was established based on a set of assumptions in a detailed design report published in 2011. The primary research goals were the development and improvement of catalysts for reforming biomass-derived syngas and for alcohol synthesis. Demonstration experiments were conducted in 2012 and the results were used to show that the developed technologies can lead to the $2.05/gallon modeled MESP goal in a mature plant. The longer term goal of this task is to continue to work with the research on cost reduction of biomass-to-liquid hydrocarbon fuels processes. To this end, this task provided key input to the Analysis and Sustainability Technology Area--led effort to identify future research pathways. Key accomplishments since the last review include the publication of an updated design report for the production of mixed alcohols from biomass via indirect gasification and subsequent validation of the 2012 ethanol MESP goal of $2.05/gallon. The success of the task depends on providing objective analysis based on recent costs, constant



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

interaction with research to outline the most economical processes, and evaluation of ongoing and future research routes. Challenges include the availability of relevant data for new processes and current equipment capital costs, which need to be addressed via experiments and outreach to industry and vendors, as well as checks through peer reviews.

Overall Impressions

- Continue support of this function within BETO because of its critical need to inform decision makers regarding BETO's direction. Continue to encourage interaction with industry to obtain accurate and current technical and economic data that feed into these types of analysis.
- Running the process simulations and economic analysis in conjunction with the R&D testing is critical. DOE should continue to fund this type of work. See notes above about concerns for modeling hydrocarbon pathways.
- This project served as a focal point for all of the activities in the portfolio, identifying performance targets for technological improvements, and using the resulting experimental data to validate the model's cost predictions. Continuous interaction with researchers and industry was used to great effect to help meet the modeled cost target of $2.05/gallon of gasoline equivalent for this Technology Area, the capstone accomplishment for many years of development. The significant differences between the NREL pilot plant and the modeled benchmark plant are somewhat concerning, but can be clarified in a recommended revision to the updated design report. It is hoped that the models developed here for mixed-alcohol synthesis will continue to be supported by NREL as long as industry shows interest in them.
- This was a well-executed project with strong input from Dow. This is an excellent example of good collaboration between the private sector and a national laboratory.
- With the recognition of importance of addressing sustainability issues/criteria, it is essential to build upon the existing TEA database to evaluate long-term viability and environmental compliance of research innovations and pathways. DOE may find it beneficial to explore supporting the setup of a similar database for TEA, LCA, and sustainable development by at least one other organization that would be complementary to NREL's efforts. DOE should consider organizing an outreach introduction to the principles of TEA, LCA, and sustainable development to interested members of BETO's "extended family" at a convenient time and location.

PI Response to Reviewer Comments

- We will leverage current work and methodologies for the future hydrocarbon pathways analysis. Regarding your concern about the consistent handling of uncertainties among the various pathways, we will follow protocols established under BETO's Analysis and Sustainability Technology Area.
- We submitted a journal article for peer review on June 30, 2013, detailing the demonstration efforts. It includes significant information and direct comparison of experimental data with the 2011 design report, with explanations for variances. It gives a detailed cost breakdown for a lower pressure case with experimental basis, which also shows we met the cost target. A poster was displayed at TC Biomass 2013.
- We share the hope that the significant progress in mixed-alcohol synthesis from biomass-derived syngas will be leveraged by interested industrial partners; we will be willing and happy to help and participate in the further advancement of this technology.

- TEA for future hydrocarbon pathways will be conducted jointly by NREL and PNNL, similar to your suggestion that “at least one other organization” be involved in the efforts. Various aspects of LCA are already being addressed by multiple national laboratories, including ANL, NREL, PNNL, INL, and others. While the 2011 design report Aspen Plus model was not made publicly available because of proprietary content from the Dow Chemical Company provided under a CRADA, previous versions of this and other TEA models are made publicly available by NREL online. The models and methods have been leveraged in the past by multiple entities including industry, national laboratories, and universities. Modeling information is shared with all interested parties, and reasonable efforts are made to reply to queries on a regular basis. In addition, a collaboration between NREL, Iowa State University, and ConocoPhillips resulted in joint model development and multiple publications using the TEA methodologies developed at NREL.

VALIDATION OF THE RTI THERMINATOR SYNGAS CLEANUP TECHNOLOGY IN AN INTEGRATED BIOMASS GASIFICATION/ FUEL SYNTHESIS PROCESS

(WBS#: 3.2.5.12)

Recipient:	RTI
Presenter:	David Dayton
Total DOE Funding:	$2,000,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2008 - 2013

Project Description

RTI International, in cooperation with North Carolina State University and the University of Utah, is addressing the Department of Energy's requirements for validating biomass gasification syngas cleanup and fuel synthesis technologies. The project is organized in two phases separated by a go/no-go decision. Phase one (gas cleanup) focused on demonstrating the integrated gasification/gas cleanup operation for 300 hours. Phase two (fuel synthesis) was focused on validating the clean syngas quality by operating the integrated gasification/gas cleanup/fuel synthesis process for 500 hours. In phase one, biomass-derived syngas was generated in the University of Utah's pilot-scale (50 pounds per hour) gasification system from woody biomass and a combination of wood and torrefied biomass generated at

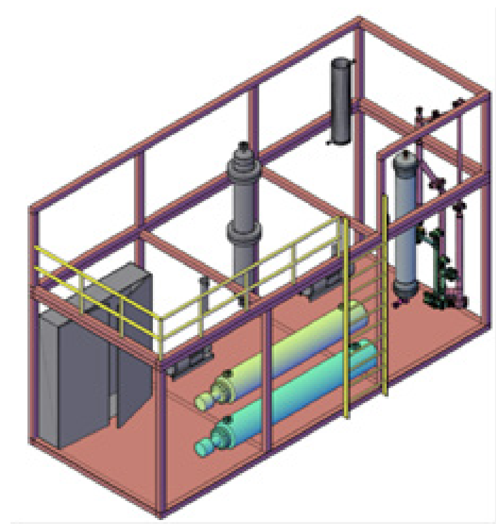
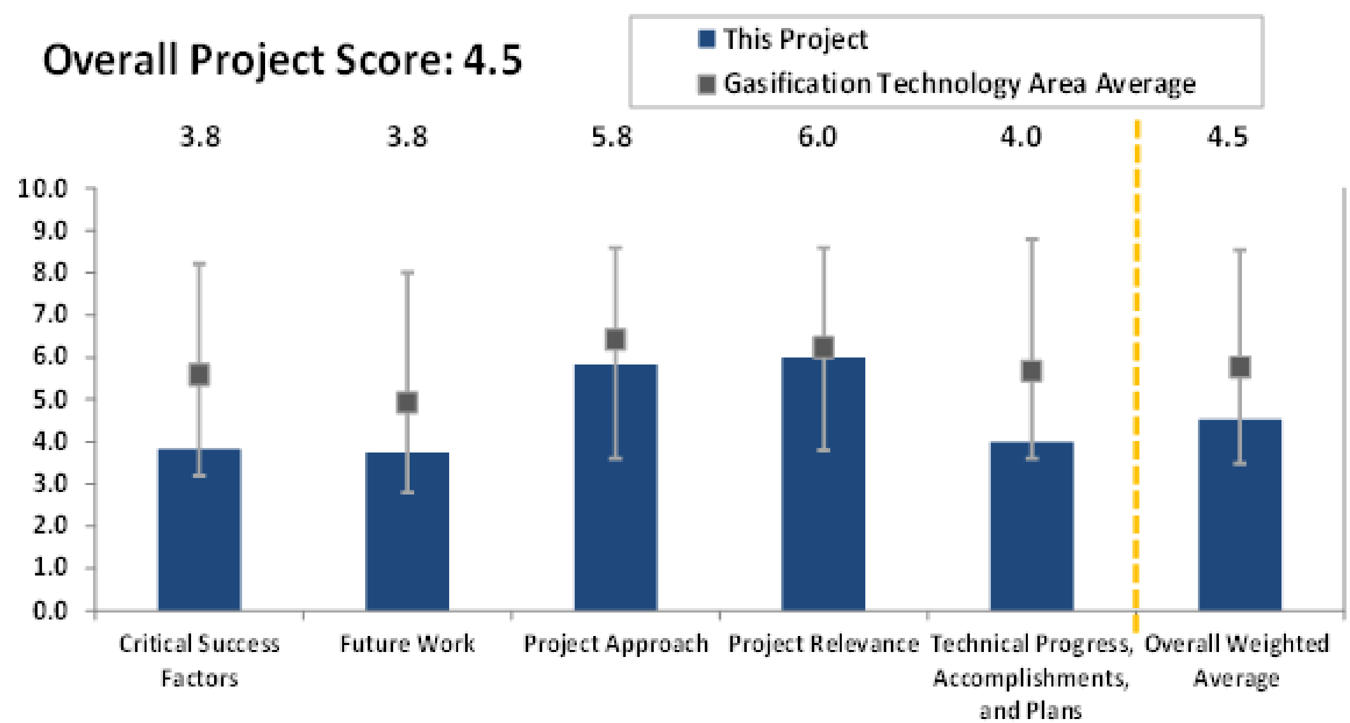


Photo Courtesy ofRTI



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

North Carolina State University. A circulating, fluidized-bed-reactor system was designed and fabricated by RTI and installed in the gasification facility. The syngas cleanup unit operates between 600–700ºC (1112–1292ºF) with an attrition-resistant, tar-cracking catalyst to remove biomass-derived tars. The catalyst circulates between the bubbling fluidized bed absorber to crack the tars and the riser regenerator to oxidize coke deposits on the catalyst to recover activity. Tar-cracking temperature was maintained at 620°C (1150°F) and the catalyst was circulated at a rate of 750 pounds per hour. Tar concentration in the raw syngas ranged from 40 to 6 grams per normal cubic meter. The integrated, indirect biomass gasification and gas cleanup system was operated for a total of 63 hours. The measured tar concentration in the cleaned, cooled syngas ranged from 0.4 to 1.3 grams per normal cubic meter with 90–97% tar conversion in the gas cleanup unit. The results from these tests were used as input for gasification process models to evaluate the techno-economic potential of an integrated biomass gasification, gas cleanup, and catalytic fuel synthesis process comparing the RTI gas cleanup technology with developing tar reforming technology.

Overall Impressions

- Good effort in the face of many obstacles. Good use of stage-gate process.
- It appears that non-technical issues in formulating and launching the project may have deprived proper coordination of efforts between RTI and the University of Utah. The indirectly heated, pulse-combustion gasifier could not operate at the desired temperature for the integrated operation of the Therminator for tar decomposition. Results do indicate fluid catalytic cracking does reduce tar in product gases and the project may have achieved the targeted operating hours if the gasifier could have been operated at the desired temperature. Moving forward, DOE is requested to review research partnerships to ensure the combined experimental capabilities will facilitate conducting planned parametric studies over a range of predetermined operating conditions.
- Project didn't achieve stage-gate goals and ended early.
- This project was fraught with starts and stops because of changes in original project partners. This had a number of negative consequences leading to failure to achieve project's original goals and objectives. Replacement of the original gasifier operator with the University of Utah resulted in a gasifier development effort that was outside of the scope of the original project. This experience shows the importance of proper project management, and possibly the need to cancel projects that stray too far from their original project partners. Often the original project team weighs heavily on why the project was selected in the first place. This, of course, requires adequate resources (including time) in the DOE project management staff. In the case of this project, the overburden of Recovery Act funding to additional projects played a major role in diverting DOE project management staff from proper oversight of this (and other) projects.
- This project was well conceived but did not succeed due to difficulties with the system integration process. There are technical merits to the Therminator syngas cleanup system that warrant continued development; though, additional development needs to be pursued on methane conversion to improve the techno-economic viability of this thermochemical conversion route.
- Too many problems in the execution of the project impeded progress. Equipment design and collaboration was not effective. Gas quality produced was below that desired. BETO should ensure that in the future, teams proposing any project should show some evidence that they have collaborated effectively in the past. This will ensure that the partners will

be able to deliver products, and that the equipment is compatible and can achieve the desired goals.

PI Response to Reviewer Comments

- This project was a challenge to manage and execute and we probably could have benefitted from closer interaction with our Project Officer to make more frequent revisions to scope and schedule. The technical targets were to complete 300 hours of integrated biomass gasification and gas cleanup at a minimum of 20 kg/hour feedrate in phase one followed by an additional 500 hours of integrated biomass gasification, gas cleanup and conditioning, and catalytic fuel synthesis in phase two after the go/no-go decision point. Total DOE project funding was $3 million with 30% cost share in phase one and 40% cost share in phase two. This proved to be a significant challenge for a not-for-profit organization and two university partners to complete the proposed bench-scale demonstration within budget. The project team was assembled with each organization responsible for part of the value chain—North Carolina State (feedstocks), University of Utah (biomass gasification), and RTI (gas cleanup and fuel synthesis). The gasification facility at the University of Utah had been successfully utilized for black liquor gasification and the modifications of adding a solids feeder for biomass seemed like a reasonable risk.
- The issues we encountered were not uncommon to similar projects where two unit operations are integrated and operated at the pilot scale. Fabrication and commissioning was a bit more challenging than originally expected and consumed a larger part of the budget than planned. Significant accomplishments were achieved, such as completing the fabrication of the tar-cracking unit that was a continuously regenerating circulating fluidized bed reactor; delivering and installing it in the Utah gasification facility; integrating two pilot-scale, fluidized-bed unit operations; and operating the integrated unit, albeit for less time than required by the original funding opportunity announcement.
- Gas cleanup and conditioning remains a technical challenge for cost-competitive biofuels production from integrated biomass gasification processes. This project advanced the state of technology by demonstrating significant tar cracking in biomass-derived syngas at the 20 kg/hour pilot scale with commercially available, fluid catalytic cracking-type catalyst that was continuously regenerated in a circulating, fluidized bed reactor system.

HEAT AND POWER

TECHNOLOGY AREA

INTRODUCTION

The Heat and Power Technology Area was one of nine key technology areas reviewed during the 2013 Bioenergy Technologies Office (BETO or the Office) Project Peer Review, which took place on May 23, 2013, at the Hilton Mark Center in Alexandria, Virginia. A total of 13 projects were reviewed by seven external experts from industry, academia, and other government agencies. This review represents a total U.S. Department of Energy (DOE) value of approximately $15 million, which is roughly 1% of the BETO portfolio reviewed during the 2013 Peer Review. The principal investigator (PI) for each project was given approximately 25 minutes to deliver a presentation and respond to questions from the review panel. Projects were evaluated and scored for their project approach, technical accomplishments, relevance to the field of bioenergy, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Project Peer Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI for the project. Overview information on the Heat and Power Technology Area and full scoring results and analysis are also included in this section. BETO designated Elliott Levine as the Heat and Power Technology Area review lead. In this capacity, Mr. Levine was responsible for all aspects of review planning and implementation.

HEAT AND POWER TECHNOLOGY AREA

OVERVIEW

Many of the Heat and Power projects reviewed at the 2013 Peer Review were funded as Congressionally-directed projects (CDP), meaning that Congress specifically directed allocation of funds for a particular project (e.g., earmarks). Projects funded in this manner avoid the merit-based or competitive allocation process established by BETO and DOE's Office of Energy Efficiency and Renewable Energy. This is often done without consideration of the Office's needs.

HEAT AND POWER SUPPORT OF OFFICE STRATEGIC GOALS

The Bioenergy Technologies Office places most of its resources into biofuels research, development, and demonstration (RD&D) and consequently has not placed a heavy focus on heat and power in its activities. BETO has not conducted competitive selections for heat and power projects for a variety of reasons, including:

1. Relative maturity of landfill gas and combined heat and power projects, and
2. Inability to leverage heat and power project results to augment mainstream biofuel projects

However, BETO is currently evaluating the merits of expanding its focus into waste-to-energy (WTE) activities. This review session favorably reviewed several novel waste-to-energy activities.

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

REVIEW PANEL

The following external experts served as reviewers for the Heat and Power Technology Area during the 2013 Project Peer Review.

Heat and Power Reviewers	
Ralph Anthenien	Army Research Office
Bill Crump	SAIC
James Doss	Professional Project Services, Inc.
Steve Moorman	Babcock & Wilcox Company
George Philippidis	University of South Florida
Dan Strope	Consultant, retired KiOR
John Wyatt	Carmagen Engineering, Inc.

FORMAT OF THE REPORT

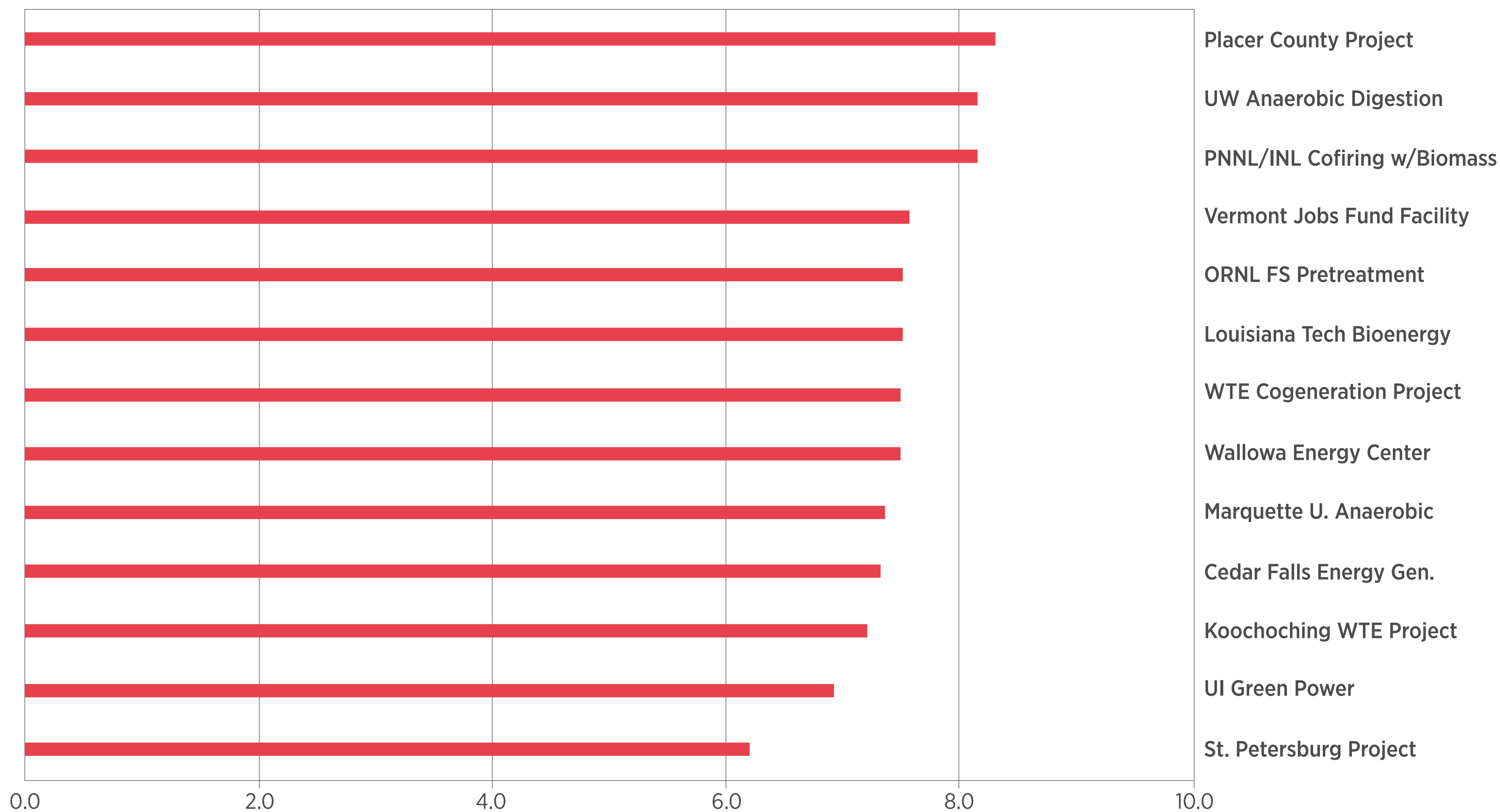
Information in this report has been compiled as follows:

- **Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.
- **Project Scoring Information and Short Names Key**: The final score charts depict the overall weighted score for each project in each technology area. Short names for each project were developed for ease of use in the scoring charts, the table of contents, and other locations. Full project names, along with their designated short names and their work breakdown structure (WBS#), are provided in the Short Names Key.
- **Review Panel Summary Report**: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.
- **BETO Programmatic Response**: The BETO Programmatic Response represents BETO's official response to the evaluation and recommendations provided in the Review Panel Summary Report.
- **Project Reports**:
    - **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space constraints allotted.
    - **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
    - **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and the whiskers depict the range of scores for each category within each technology area.

- **Reviewer comments** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant by BETO's director were excluded from the final report.
- **PI Responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the review panel. This unique formatting was maintained to uphold the integrity of the comments.

TECHNOLOGY AREA SCORE RESULTS



SHORT NAMES KEY

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
7.7.5.6	Placer County Cabin Creek Forest Biomass Project	Placer County Biomass Utilization Pilot Project (CA)	Placer County Project
7.2.2.4	University of Wisconsin Oshkosh's Anaerobic Dry Digestion Facility	University of Wisconsin Oshkosh	UW Anaerobic Digestion
10.1.1.1z; 10.1.1.2	Logistics, Costs and GHG of Co-firing with 20% Biomass	PNNL, INL	PNNL/INL Cofiring w/ Biomass
7.7.5.8	Vermont Sustainable Jobs Fund, Montpelier, Central Vermont Recovered Biomass Facility	Vermont Sustainable Jobs Fund, Montpelier	Vermont Jobs Fund Facility
3.1.2.5	Feedstock Pretreatment for Pyrolysis Upgrading	ORNL	ORNL FS Pretreatment
7.7.2.19	Bioenergy/Bionanotechnology Projects	Louisiana Tech University	Louisiana Tech Bioenergy
7.4.3.8	Waste-to-Energy Cogeneration Project	Waste-to-Energy Cogeneration Project (IN)	WTE Cogeneration Project
7.6.2.15	Wallowa County Integrated Biomass Energy Center	Wallowa Resources	Wallowa Energy Center
7.2.2.3	Municipal Anaerobic Co-Digestion for Renewable Energy	Marquette University	Marquette U. Anaerobic
7.4.3.14	Biomass Energy Generation Project	Cedar Falls Utilities	Cedar Falls Energy Gen.
7.3.2.5	Plasma Gasification Waste-to-Energy Project	Koochiching County, Renewable Energy Clean Air Project, Waste-to-Energy Project (MN)	Koochiching WTE Project
7.3.6.4	Green Power Initiative	University of Iowa	UI Green Power
7.7.4.12	St. Petersburg Sustainable Biosolids/Renewable Energy Plant	City of St. Petersburg, Florida	St. Petersburg Project

CONTENTS

BIOENERGY/BIONANOTECHNOLOGY PROJECTS

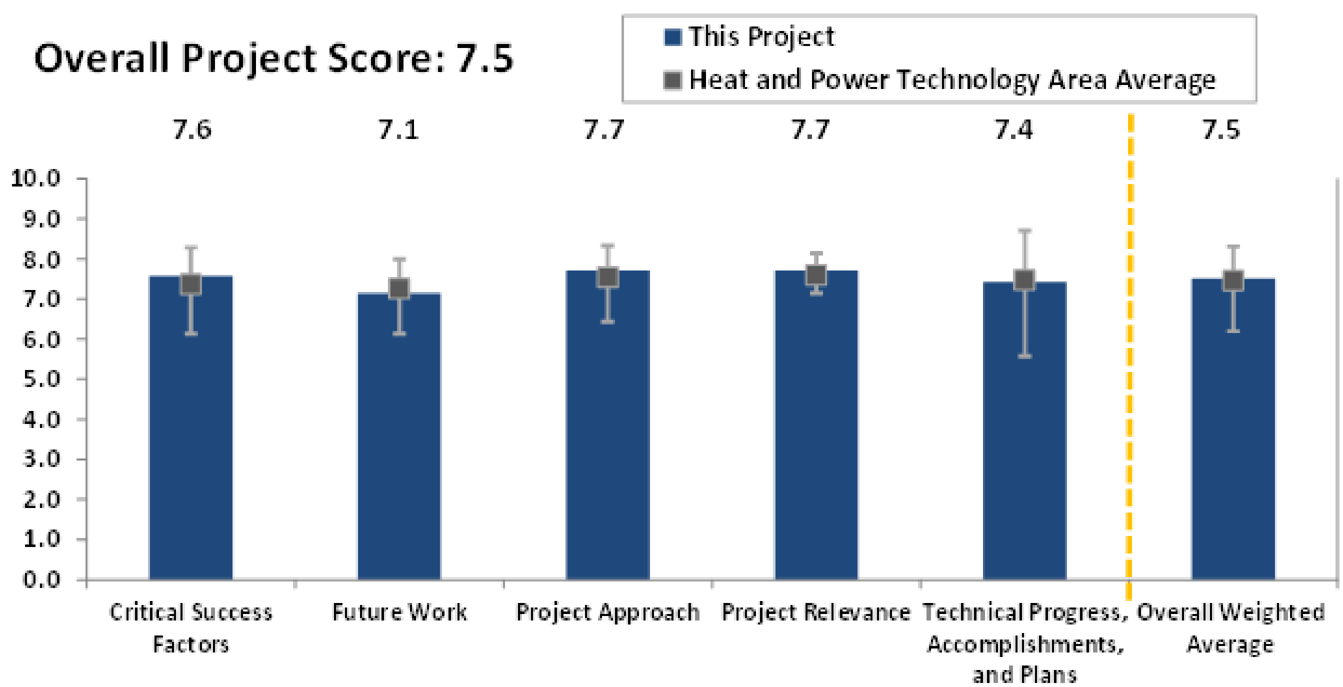
(WBS#: 7.7.2.19)

Recipient:	Louisiana Tech University
Presenter:	James Palmer
Total DOE Funding:	$264,194
DOE Funding FY13:	--
DOE Funding FY12:	$20,299
DOE Funding FY11:	$30,895
Project Dates:	2010–2012

Project Description

Photo Courtesy of Louisiana Tech University

The Wisconsin SEO's primary mission is to implement cost-effective, reliable, balanced, and environmentally friendly clean energy projects. To support this mission, the Wisconsin Biodiesel Blending Program was created to financially support the installation infrastructure necessary to directly sustain biodiesel blending and distribution at petroleum terminal facilities throughout Wisconsin. SEO (formerly the Wisconsin Office of Energy Independence) secured a federally directed award of $600,000 over 2.25 years. With these funds, SEO supported the construction of inline biodiesel blending facilities at two petroleum terminals in Milwaukee, Wisconsin. The Wisconsin SEO competitively solicited participation from companies at current terminals, such as those members of the Wisconsin Petroleum Marketers and Convenience Store Association and the Wisconsin Petroleum Council that showed interest in participating in the biodiesel distribution effort. The federal funding provided through the state provided a little less than half of the necessary investment to construct the terminals, with the balance put forth by the partners. Wisconsin is now home to two new biodiesel blending terminals. Fusion Renewables on Jones Island (in the City of Milwaukee) will offer a B100 blend to both bulk and retail customers. CITGO is currently providing a



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

B5 blend to all customers at its Granville, Wisconsin, terminal, which is north of the City of Milwaukee. The Milwaukee Terminal is CITGO's first fully operational biodiesel blending facility.

Overall Impressions

- Good fundamental study with the amount of funding provided. Much more work needed to make commercial.
- I do not feel I can fairly assess the value of this research.
- Interesting research. Not clear why this is in the Heat and Power Technology Area.
- Is there an appropriate larger scale, follow-on research project hidden inside of these results?
- The project appears to be very relevant for the development of biomass as an energy source. The project appears to have been executed satisfactorily, and the information has already been shared in the public domain.
- The work is very interesting and uses a novel approach to cellulase mounting and reuse. This could have significant positive impact on cellulose decomposition.
- This kind of project could be funded by an "incubation fund" that BETO could create in the future to have high potential impact, innovative ideas and technologies screened.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

BIOMASS ENERGY GENERATION PROJECT

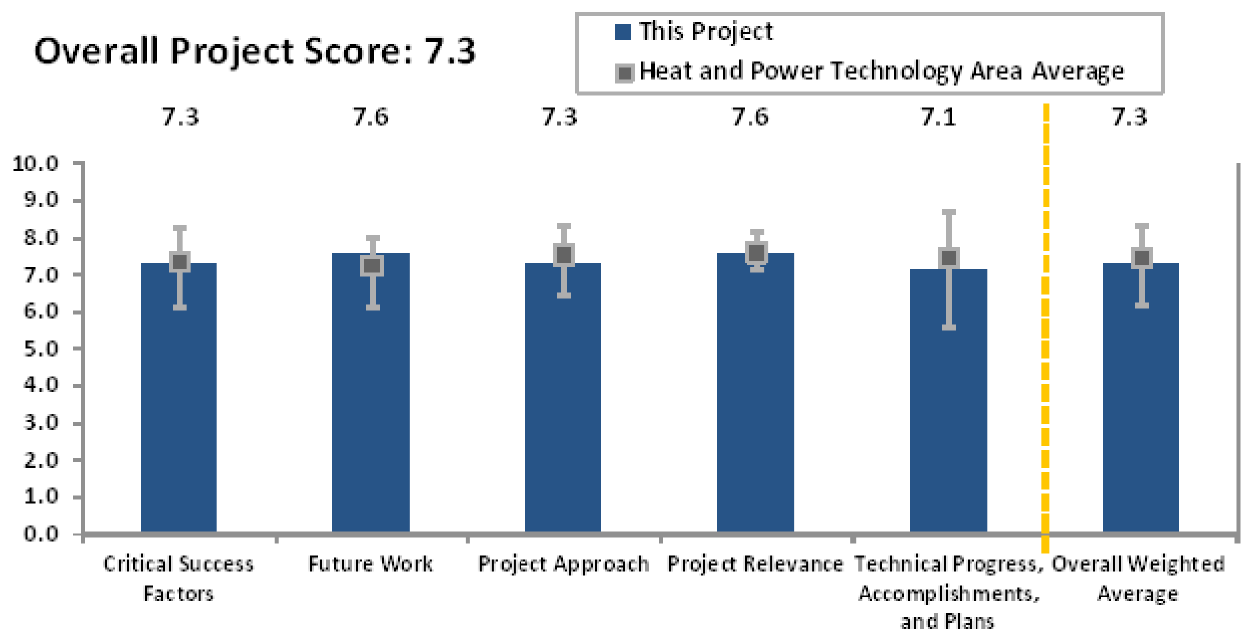
(WBS#: 7.4.3.14)

Recipient:	Cedar Falls Utilities
Presenter:	Edward Olthoff
Total DOE Funding:	$285,450
DOE Funding FY13:	$200,000
DOE Funding FY12:	$27,476
DOE Funding FY11:	$10,974
Project Dates:	2009–2013

Project Description

Photo Courtesy of Cedar Falls Utilities

Cedar Falls Utilities owns two electric generation units at Streeter Station in Cedar Falls, Iowa. Unit #6 is a steam electric generation unit with a stoker-fired boiler designed to burn bituminous Illinois stoker coal. If renewable fuel options can be compressed into a size and density that mimics stoker coal, Unit #6 can generate dispatchable renewable electricity when firing 100% of this solid renewable fuel. Solid fuels can be produced from renewable raw materials using several densification processes. Solid renewable fuel options have been purchased directly from suppliers; other fuel options have been custom manufactured from selected raw materials by contracted processors. Twenty-ton lots of solid renewable fuels have been and continue to be test burned to determine compatibility of the fuel with the subsystems of Unit #6: unloading and conveying, bunker storage, weighing and stoking, sustainable combustion, and full-capacity generation. These 20-ton burns furnish data for specifications for larger quantities of fuel. A 2,000-ton lot of the solid renewable fuel that complies with specifications will be contract manufactured for an extended test burn to determine the effects of a longer duration burn on the boiler. Boiler compatibility will be crucial to the possibility of longer duration burns and will precede commercialization of the project to continuous generation of renewable electricity. Additional factors considered



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

as critical to continuous generation are shelf-life and storage requirements of the fuel, shipping options, ash characteristics, and cost. Applications of the research relate directly to electric generation from renewable fuels and a broader application to the commercialization of harvesting, shipping, and densification of renewable raw materials as feedstocks for other renewable energy applications.

Overall Impressions

- The project appears to be very relevant for the development of a biomass feedstock for power generation. Very little detail on how the project was planned and executed was provided. The testing performed appeared to direct future testing and was relevant. The project may benefit from pellet densification work done in Europe.
- Good work internally and with use of vendors. Could do more looking outside for other lessons learned.
- High value potential to capture greenhouse gas (GHG) credits and provide energy security. Low heating value and emissions of biomass presents challenges.
- It might have been more efficient and cost effective to have all the densification work done at once, followed by evaluation of the properties of the pellets, and then proceed to burn tests with only those feedstocks that can be well densified.
- The boilers will unlikely be able to meet capacity on 100% biomass. I would suggest that you work with the stoker and/or boiler supplier. I believe you will find they have a lot of experience with the issues surrounding burning biomass on a stoker. They could also give you some ideas regarding the issues you will find after burning biomass for long periods.
- The performer's goal of 100% biomass may not be attainable due to a mismatch in feeder and fuel British thermal unit (Btu) availability, however if a suitable fuel is found, this may be useful for a blended biomass approach.
- This was definitely a "real world" project that was well executed. Nice job.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

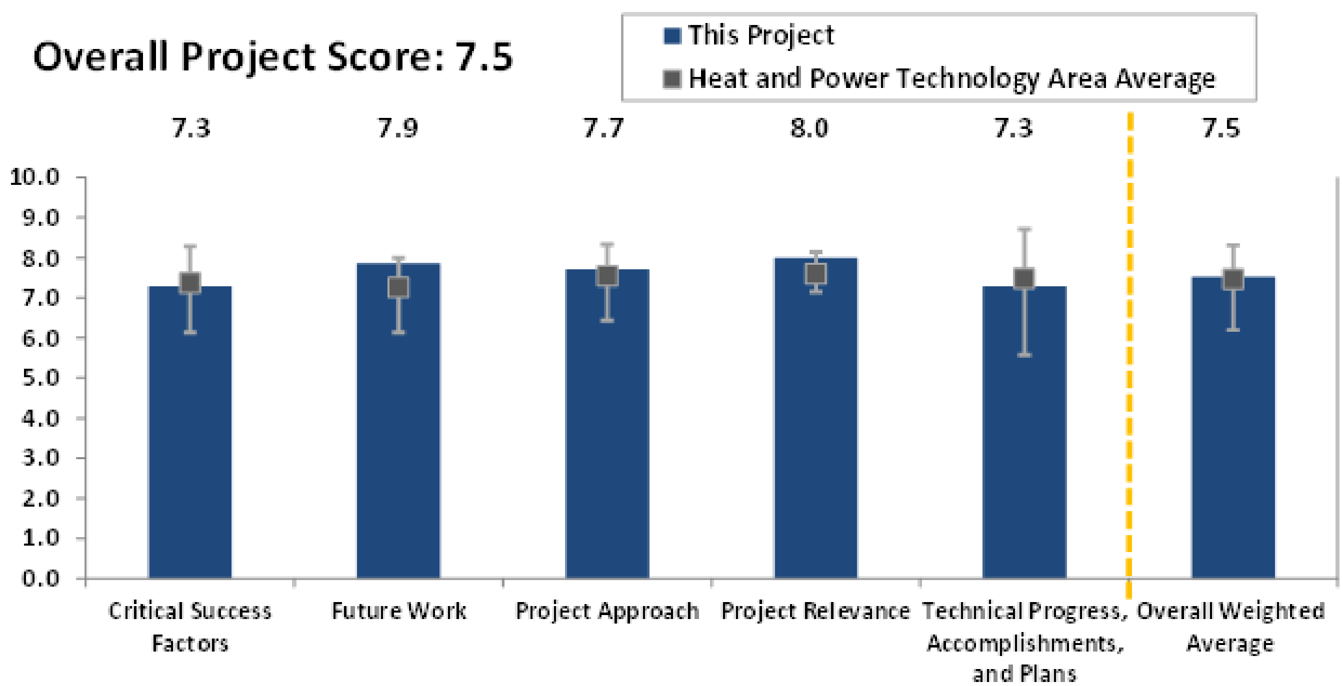
FEEDSTOCK PRETREATMENT FOR PYROLYSIS UPGRADING

(WBS#: 3.1.2.5)

Recipient:	Oak Ridge National Laboratory (ORNL)
Presenter:	Shahab Sokhansanj
Total DOE Funding:	$160,000
DOE Funding FY13:	$80,000
DOE Funding FY12:	$40,000
DOE Funding FY11:	$40,000
Project Dates:	2011–2017

Project Description

A dense, flowable feedstock with low moisture content outperforms untreated feedstock in gasifiers, combustion chambers, and bio-oil reactors. Partial or total carbonization (torrefaction) enhances energy density and hydrophobicity of biomass. Torrefied wood pellets and briquettes can be co-fired with coal in large proportions. Improving energy input to biomass size reduction and densification, as well as integrating these improvements with logistics models, are critical for minimizing the delivered cost of biomass. To this end, the objective of this research is to understand structural and compositional characteristics of cellulosic feedstock responsible for low-cost grinding, drying, densification, and storage. This deep understanding will lead to the development of equations and engineering data for design and analysis of least cost supply infrastructure. Our research to date shows that the traditional equations used for scaling up size reduction operations for non-fibrous solids are applicable to biomass fibers (von Rittinger equation). Dry torrefaction (250ºC –300ºC) enhances the energy density of biomass, but reduces the natural binding. Forming durable pellets becomes more difficult with the severity of torrefaction. Steam explosion or steam treatment—especially in the presence of a catalyst like SO_2—improves the binding characteristics of torrefied biomass. Wood pellets emit gases like CO, CO_2, CH_4,creating an oxygen-deficit environment in enclosed spaces. The storage structure must be designed with adequate ventilation to minimize self-heating and off-gassing. We are conducting research on converting regular pellets to torrefied pellets. The advantage of this technique is that no modification to pelletization is



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

needed. However, our initial tests show that the torrefied pellets produced through this process exhibit a lower density and durability. Finally, we are experimenting on leaching salts and chlorine from low-quality, low-value biomass. The research will continue at the Clean Energy Research Center at the University of British Columbia, where the PI (Sokhansanj) is an adjunct professor.

Overall Impressions:

- A reasonable project. It is unfortunate that a wider range of raw feedstocks were not studied.
- Focused on energetics of pellet prep. Hopefully will broaden focus to performance.
- Good work on fundamental understanding of key factors. Further testing of lignin synergies, and SO_2 catalysis would be useful.
- Project is anticipated to be complete in 2017, but some preliminary results suggest very good progress toward stated project goals.
- The project appears to be very relevant for the development of biomass as an energy source. Only very high-level project execution information was provided, making it unclear how well the project is being managed. No information on how these results would be made to industry was presented. However, I do note that their response to this issue in the 2011 review talked about publications and workshops where this information may be made available.
- This project adds to the body of knowledge regarding biofuels preparation and upgrading.
- Useful project with direct application to BETO's pyrolysis program. Conditioning of biomass to make it amenable to bioenergy applications is a crucial factor of success for the entire industry. It is suggested that the research looks into the use of low-quality lignin (generated in the biochemical process) as a torrefaction binder.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

GREEN POWER INITIATIVE

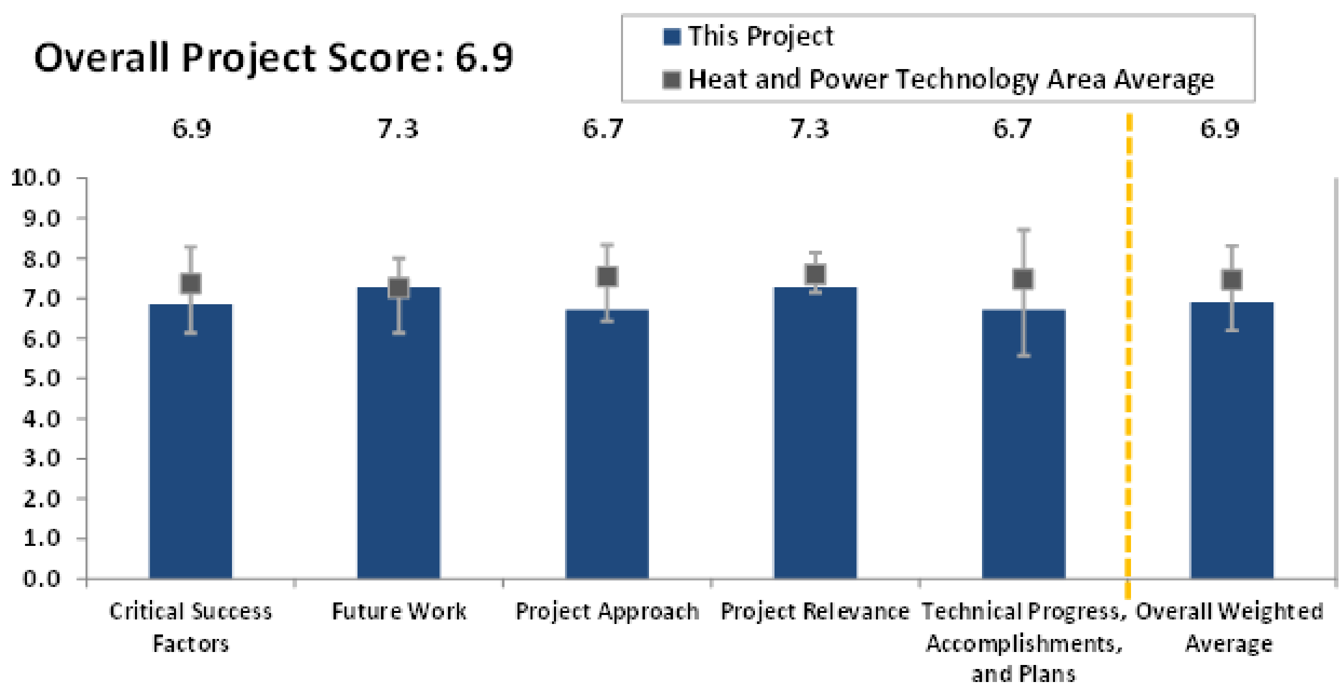
(WBS#: 7.3.6.4)

Recipient:	University of Iowa
Presenter:	Ferman Milster
Total DOE Funding:	$1,016,193
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	$1,016,193
Project Dates:	2010–2012

Project Description

The Green Power Initiative project is enabling expanded use of locally derived, solid biomass fuel sources for producing thermal energy in a district energy system. The project enabled replacement of a gas boiler that reached end of useful service life with a modern solid fuel biomass boiler (27.5 million British thermal units per hour or 8.05 MWt/hr heat input) and an attached atmospheric downdraft research gasifier. The gasifier is used in graduate and undergraduate research programs to study and characterize steady-state syngas production from the following currently permitted feedstocks: oat hulls, chipped poplar wood, untreated and unpainted wood chips, wood pellets, corn cobs, corn seed, soybean seeds, cardboard, corn stalks/stover, and recycled paper sludge. All of these feedstocks are locally available solid fuel sources. Additional biomass feedstocks and industrial organic by-products will be added as they are identified and sourced.

Thermochemical conversion of relatively low-value biomass to biopower via gasification offers advantages, especially when compared to direct combustion. While combustion is the most direct and relatively easy, production of syngas offers opportunities to produce low-Btu gaseous fuel for internal combustion engines, combustion turbines, and processing into transportation fuels. The availability of simple, affordable, and deployable gasification equipment is a barrier to expanding this biopower opportunity. In the Midwest, there is an



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

abundance of agricultural-related biomass feedstock, as well as numerous organic industrial by-products. This project uses a gasifier design developed by a local Iowa inventor (www.agbiopower.com/). The combination of material availability and relatively simple, proven gasifier design will create opportunities for additional uses of solid biomass for biopower generation.

Overall Impressions

- Given the interest in biofuels use for renewable power production, the project should offer a valuable contribution to learning at the university. Training for future designers and operators of biofuels systems should offer valuable experience that will be useful to students in getting jobs in the commercial biofuels industries.
- Good application-oriented project. Safety issues were realized and addressed. It could have benefited from a better analysis of key success factors. Such projects should be run by experienced engineers rather than by researchers. Useful experience. Deployable to many agricultural areas.
- Technology is at an early stage. Good educational opportunity for students.
- The key players were not all skilled with solid fuel boilers or with capital project procedures, or with restrictions imposed by university capital purchase systems. A quote from their slides: "In the future, would look to separate major capital project from research equipment installation."
- The performer has done a good job overcoming several challenges to installing and integrating the gasifier into the existing plant.
- The project appears to be very relevant for the development of biomass as an energy source. The project appears to have been executed adequately. They have several outlets considered for sharing of information.
- Useful project in learning real world issues of retrofitting for new technology and fuel. Lots of work opportunities for optimizing operations.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

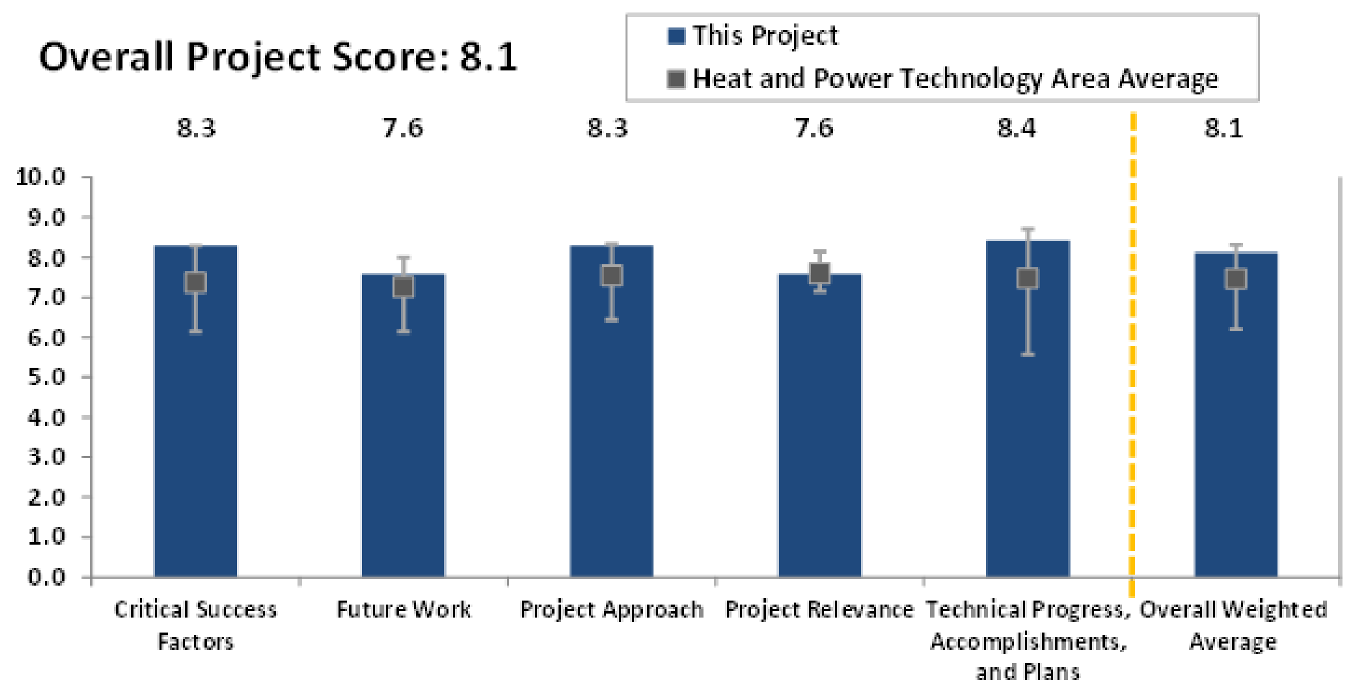
LOGISTICS, COSTS AND GHG OF CO-FIRING WITH 20% BIOMASS

(WBS#: 10.1.1.1; 10.1.1.2)

Recipient:	Pacific Northwest National Laboratory (PNNL); Idaho National Laboratory (INL)
Presenter:	Jonathan Male
Total DOE Funding:	$812,000
DOE Funding FY13:	--
DOE Funding FY12:	$462,000
DOE Funding FY11:	$350,000
Project Dates:	2011 - 2013

Project Description

To date, published analyses of biopower via co-firing with coal have been limited to 10% (LHV basis) biomass. This is related to practical constraints associated with utilizing biomass in a coal-based infrastructure. This study examines the costs, benefits, logistics, and sensitivities associated with co-firing specification-qualified biomass at rates of up to 20% in utility-scale coal-fired power plants representative of the current U.S. fleet. The dependence of levelized cost of electricity on feedstock costs, power plant feed system retrofit, and impact on boiler performance is evaluated. The overall life-cycle assessment of greenhouse gas emissions savings is also evaluated. Higher rates of co-firing require development of a biomass feedstock production and supply system tantamount to coal, including the ability to meet stringent specifications to ensure reliable conveyance to boiler burners, efficient combustion, and no adverse impact on heat transfer surfaces and flue gas cleanup operations. This study provides an initial assessment of the critical logistical challenges to increasing the use of biomass for power generation by evaluating the impact of torrefaction pretreatment and densification to pellets as a preprocessing technology combination. Some biomass materials, especially herbaceous materials, may also require leaching to reduce soluble alkaline salts that may foul boiler tubes in the furnace. Co-firing scenarios considered include large utility-scale power plants in central Alabama and the Ohio River Valley. These locations are representative of the concentrated coal-fired power generation regions—providing a



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

relevant analysis of potential early entry of biomass co-firing on a scale that can begin to impact total GHG emissions. When used in conjunction with a depot concept, pretreatment operations could enable biomass to be produced as a commodity that could serve as a near drop-in replacement for coal in many power plants.

Overall Impressions

- A fairly large and comprehensive collection of front-to-back requirements and project deliverables made for an impressive project. Project not only looked at viable percent of biomass for co-firing, but also at transportation and logistics issues.
- Side-by-side comparison of biomass versus existing fuels is very useful for policymakers and the commercial sector.
- Successful completion has provided useful logistic information to BETO for biomass natural gas co-firing.
- The model will aid the community in considering how/if to implement biomass co-feeds into power plants.
- The project appears to be very relevant for the development of biomass as an energy source. The project appears to have been executed adequately. They have several outlets considered for sharing of information.
- This is an interesting study and needs to be made available to the industry for their consumption.
- Very good and useful technical work. Best benefits will be introduction of data to broader power community, adjustments as needed to further data development and DOE approaches.

PI Response to Reviewer Comments

- We wish to thank the reviewers for their positive feedback confirming the importance of this collaboration to examine the logistics, cost- and greenhouse gases reduction-opportunity upon co-firing with 20% biomass, and its relevance to industry. We are ardently working with the Bioenergy Technologies Office to enable the broad dissemination of the final report.

MUNICIPAL ANAEROBIC CO-DIGESTION FOR RENEWABLE ENERGY

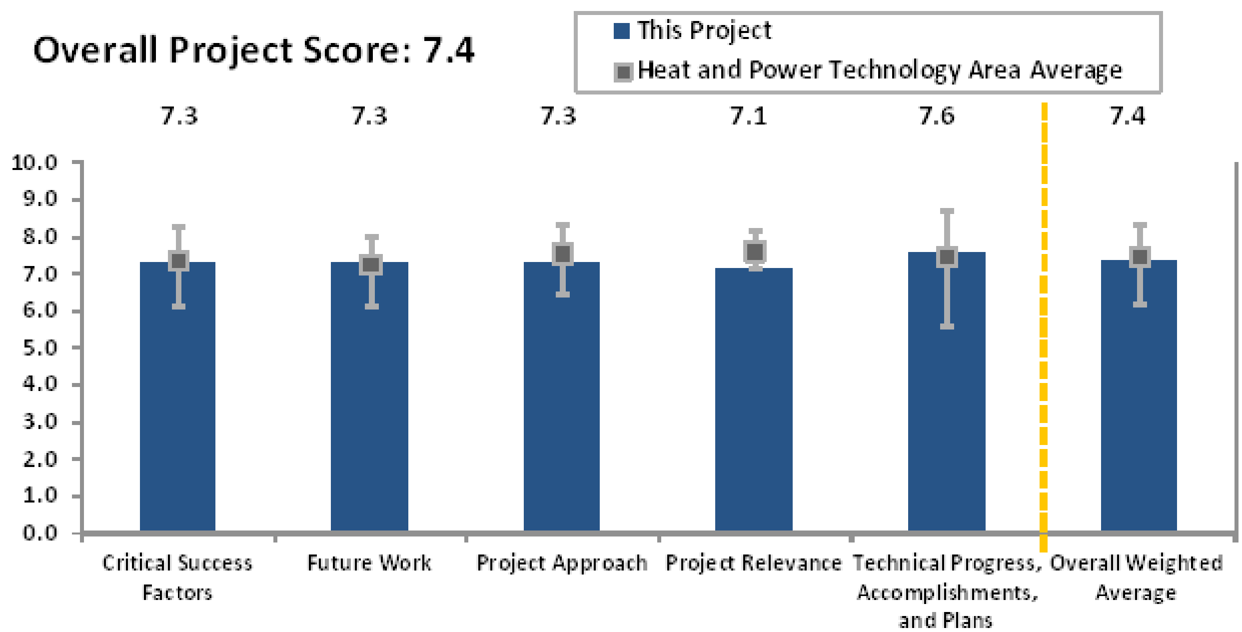
(WBS#: 7.2.2.3)

Recipient:	Marquette University
Presenter:	Daniel Zitomer
Total DOE Funding:	$475,750
DOE Funding FY13:	$53,000
DOE Funding FY12:	$10,000
DOE Funding FY11:	$177,000
Project Dates:	2009–2012

Project Description


Photo Courtesy of Marquette University

The purpose of this research was to increase renewable energy production via anaerobic co-digestion of municipal wastewater biosolids with various biomass residuals. In co-digestion, a mixture of organic residuals is contacted with select microbes in the absence of oxygen, yielding biogas that contains methane. The biogas can be used for combined heat and power. Completed tasks included the following: identified more than 65 organic industrial and agricultural residuals within 160-kilometer radius of existing digester; characterized more than 40 promising residuals for co-digestion; operated six anaerobic digesters and defined operations to maximize biomethane; and determined the influence of co-digestates on digester microbial community structure using molecular techniques. Residuals' co-digestion significantly increased biomethane production. Synergistic outcomes were observed in which some wastes produced more methane when digested together in comparison to the sum of the methane yielded when they were digested separately. Synergistic outcomes were correlated to a change in digester microbial community. Therefore, co-digestion caused a beneficial shift in digester microbial community, resulting in increased methane production. Success factors included close cooperation between the university researchers and the public utility (i.e.,



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

MMSD). Based on project results, MMSD constructed a $450,000, high-strength waste receiving facility at its existing digestion location. Additional biomethane will be used to fuel existing electric generators with heat recovery. This publicly owned facility is anticipated to accept more than 200,000 liters of organic residuals per day yielding at least 5,300 cubic meters per day (m^3/d) more biomethane resulting in an additional 185 thousand megajoules per day of heat and electricity (enough to deliver electricity to 600 homes). This project has served as a model for utilities in Green Bay, Wisconsin; Chicago, Illinois; and other locations. Future research should determine the residual constituents that result in the most beneficial shift in microbial communities for increased biomethane and energy production.

Overall Impressions

- Co-digestion makes good use of existing extra capacity at municipal anaerobic digesters, but applicability from a practical standpoint (logistics) remains problematic.
- Good technical study from lab to full scale of co-digestates. Would benefit from testing upsets and their impacts on populations and recovery.
- Interesting research, but not clear how it could be directly applied to BETO.
- It will be essential to locate the most significant opportunities for co-digestion across the entire U.S. as a “next-step” for a follow-up to this project.
- The project appears to be very relevant for the development of biomass as an energy source. The project appears to have been executed adequately. They have several outlets considered for sharing of information.
- The project is successful in characterizing co-digesters to improve performance of normal anaerobic digesters. An economic study should be conducted to determine if/how far the waste can be moved and still be economically viable.
- This is an interesting project. The results of this project need to be evaluated in concert with a biogas power project to determine how this process impacts the economics.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

PLACER COUNTY CABIN CREEK FOREST BIOMASS PROJECT

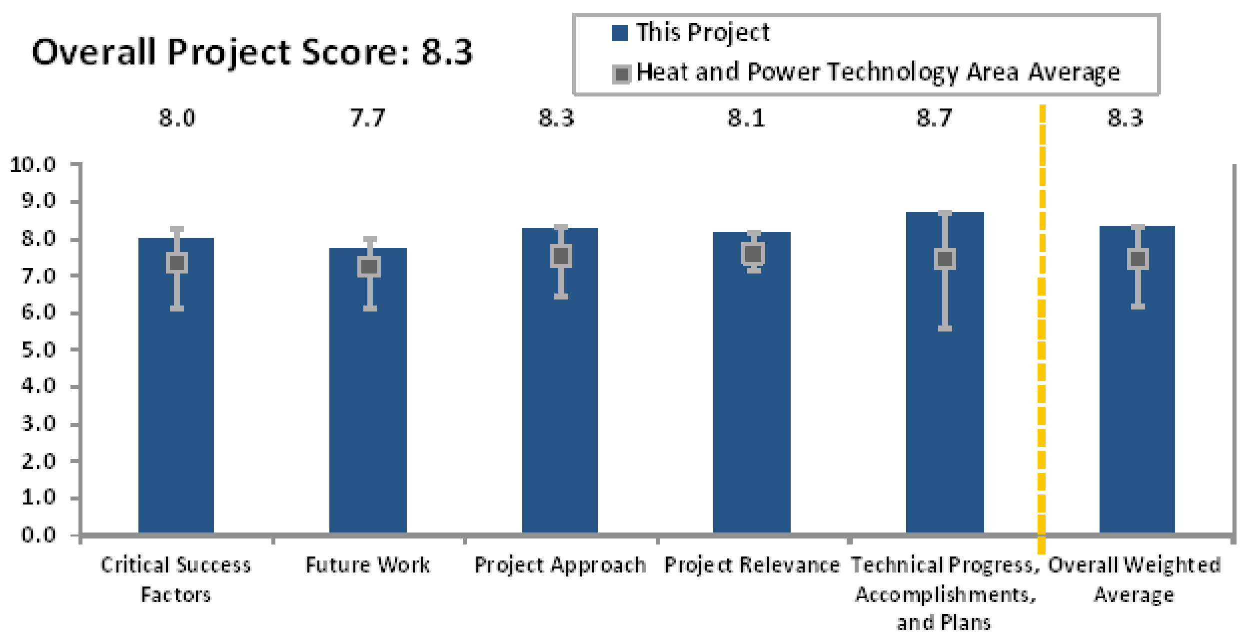
(WBS#: 7.7.5.6)

Recipient:	Placer County Biomass Utilization Pilot Project (CA)
Presenter:	Brett Storey
Total DOE Funding:	$2,999,000
DOE Funding FY13:	$1,000,000
DOE Funding FY12:	$500,000
DOE Funding FY11:	$500,000
Project Dates:	2008–2014

Project Description

Photo Courtesy of Placer County

Placer County has been developing the Cabin Creek Forest Biomass Utilization Project since 2008. The principal investigators have several years of experience in analyzing, developing, funding, building, and operating renewable energy projects. Using a three-phase approach, the county team has performed a number of detailed analyses that have placed it in a position to construct and operate a two-megawatt biomass gasification system that can produce heat, power, bio-char, and possibly carbon-related credits as marketable products. The direction from the Placer County Board of Supervisors was to seek a solution to a growing set of risks including wildfire, air and water pollution, greenhouse gases, public health, and jobs in the Lake Tahoe region. Our solution, to capture forested biomass historically burned in the open and turn into energy, has exceeded their expectations and may yet provide solutions to other areas with these same risks. Over the last five years, the project has conducted considerable technical investigation into small-scale electric generation systems that can utilize forest-sourced woody biomass waste. Both gasification (with internal combustion engine) and direct combustion (steam cycle) systems were examined with particular emphasis on meeting the stringent regional air quality standards. Detailed emissions profiling was



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

conducted for several technology systems. Ultimately, gasification was chosen as the preferred technology, as air pollutant and water emissions were lower. Financial analysis conducted found that small-scale gasification could be more economic over the life of the facility than direct combustion. Critical investment tax credits and cost sharing with local fuel supplier agencies tipped the scale to economic viability for this project. We have demonstrated that local communities can successfully work with a myriad of local, state, and federal agencies, and non-governmental organizations in the attempt to reduce catastrophic wildlife potential by the use of biomass waste to create renewable energy.

Overall Impressions

- Applies existing technology to improve air quality and offset costs by producing energy.
- Good project with a lot of work done. The use of biomass for power generation via gasification (and other) technologies is an attractive way of producing bioenergy.
- Their cost-share strategy is very good by allowing kilowatt-hours at near market rates. This is an excellent, well-managed program. Transportation in the rugged area of the location is the only issue I can see.
- This appears to be a long-horizon project. They are in the beginnings of this project. It appears that there are financing hurdles.
- This project would be a good example for other similar projects looking to better manage forest wood waste. We have seen other projects this week that could benefit from a successful completion of this project.
- This reviewer is encouraged to see the involvement of municipalities and municipal officials as an integral component in solving our environmental problems across the country. Keep up the great work.
- Well-orchestrated project so far in terms of pulling together public entities. Next step will be actually implementing technical aspects of project.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

PLASMA GASIFICATION WASTE-TO-ENERGY PROJECT

(WBS#: 7.3.2.5)

Recipient:	Koochiching County, Renewable Energy Clean Air Project, Waste-to-Energy Project (MN)
Presenter:	John Howard
Total DOE Funding:	$2,345,100
DOE Funding FY13:	$690,000
DOE Funding FY12:	$368,000
DOE Funding FY11:	$368,000
Project Dates:	2008–2014

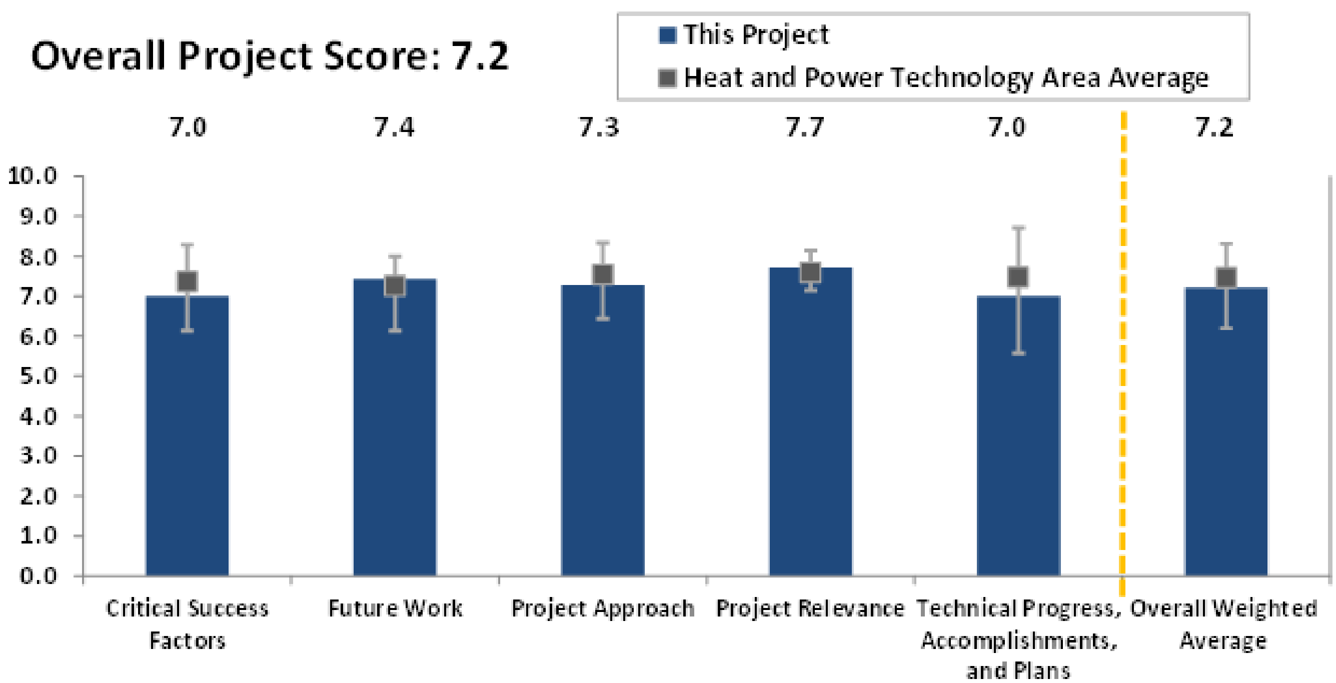
Project Description

Photo Courtesy of Koochiching County

Proposed Plasma Gasification Waste-to-Energy Demonstration-Scale project. 180–200 tons/day of biomass waste resources (municipal solid waste). This project will output clean, renewable energy in the form of synthetic gas, steam, biofuel or electricity, and vitrified non-leaching solid by-products. The project is located near an energy host in International Falls, Koochiching County, Minnesota. This project reduces the need for landfilling and decreases the release of methane; high temperatures provide efficient, environmentally friendly process. process.

Overall Impressions

- A sound approach for waste to energy. It appears the project is beginning to fall behind schedule.
- Feasibility studies, like this one, for new or commercially, not well established (this project is capturing the syngas and will convert to products; it's



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

not simple destruction of the waste) bioenergy technologies is an area that needs attention and financial support by DOE. It is an essential prerequisite to wider deployment of bioenergy systems.

- It will be interesting to see if a plasma gasification technology can be successfully transitioned to a municipal solid waste project.
- Not clear if other options are being considered. Technology is purported to handle multiple waste streams robustly. Could be a promising alternative biomass gasification technology.
- The project appears to be very relevant for the development of biomass as an energy source. Good project execution information was provided, and the team appears to be addressing proper criteria for the advancement of this project. No information on how this information would be made available to industry was presented.
- Use of public advisory group is useful. Lessons learned from Japanese company, good vendor for waste to energy. Tough project to sell in light of number of waste-to-energy facilities shut down.
- Very novel technology for the United States. It will be most interesting to see how the economics of the process prove out relative to competing technologies in this space.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

ST. PETERSBURG SUSTAINABLE BIOSOLIDS/ RENEWABLE ENERGY PLANT

(WBS#: 7.7.4.12)

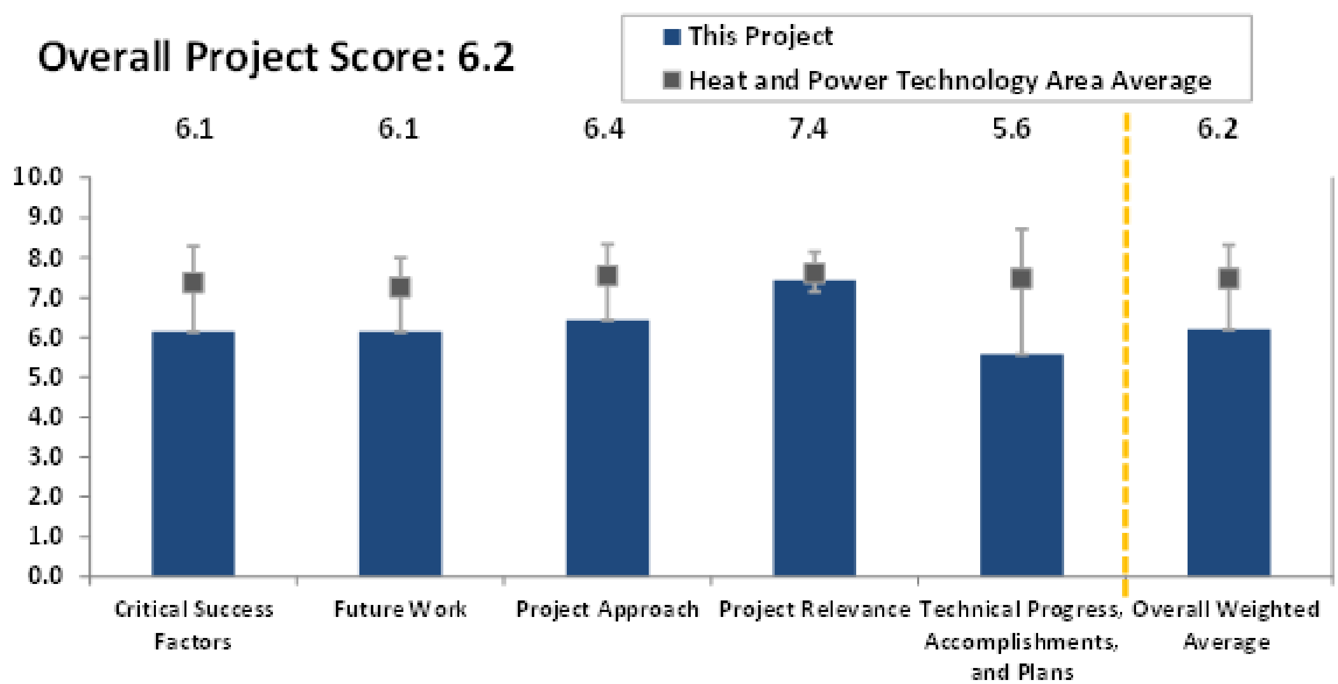
Recipient:	City of St. Petersburg, Florida
Presenter:	Steve Marshall
Total DOE Funding:	$2,500,000
DOE Funding FY13:	$909,595
DOE Funding FY12:	$163,844
DOE Funding FY11:	$163,844
Project Dates:	2011–2015

Project Description

In keeping with its designation as being Florida's first "Green City," the city of St. Petersburg's primary purpose in this project is to process and dispose of biosolids in a manner that produces thermal energy, electrical energy, gas, or some other form of energy. This project will be accomplished in three phases. Phase one of the project was to conduct a feasibility evaluation to determine potentially applicable technologies. Phase two will be to complete the design and permitting of the selected technologies. Phase three will be to construct and operate the plant.

Overall Impressions

- Feasibility study reviewed multiple options for processing the municipal waste water. Applies conventional technology and provides cost benefits for St. Petersburg.
- Gasification of yard waste and biosolids in municipalities is an opportunity for significant, local, small-scale power generation and for reducing landfill waste. The feasibility study is essential before a decision is made.
- Overall, the program appears a bit to be a solid waste plant rebuild with a waste-to-energy aspect thrown on it. It is unfortunate that the presenter mismanaged his time and was unable to fully give his presentation.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

- Project defined appropriate with current stage of development. Looks like further technology definition is advisable.
- The construction and operation of this project appears to be several years into the future.
- This appears to be a long-horizon project. They are in the beginnings of this project. This project will face challenges with the state of gasification technology and gas cleanup technology and acquiring sufficient funding.
- This looks to be a good environmental/bioenergy project. Successful completion of this project looks to be valuable to the city of St. Petersburg and will provide valuable information and insights for other cities that might be considering similar projects.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

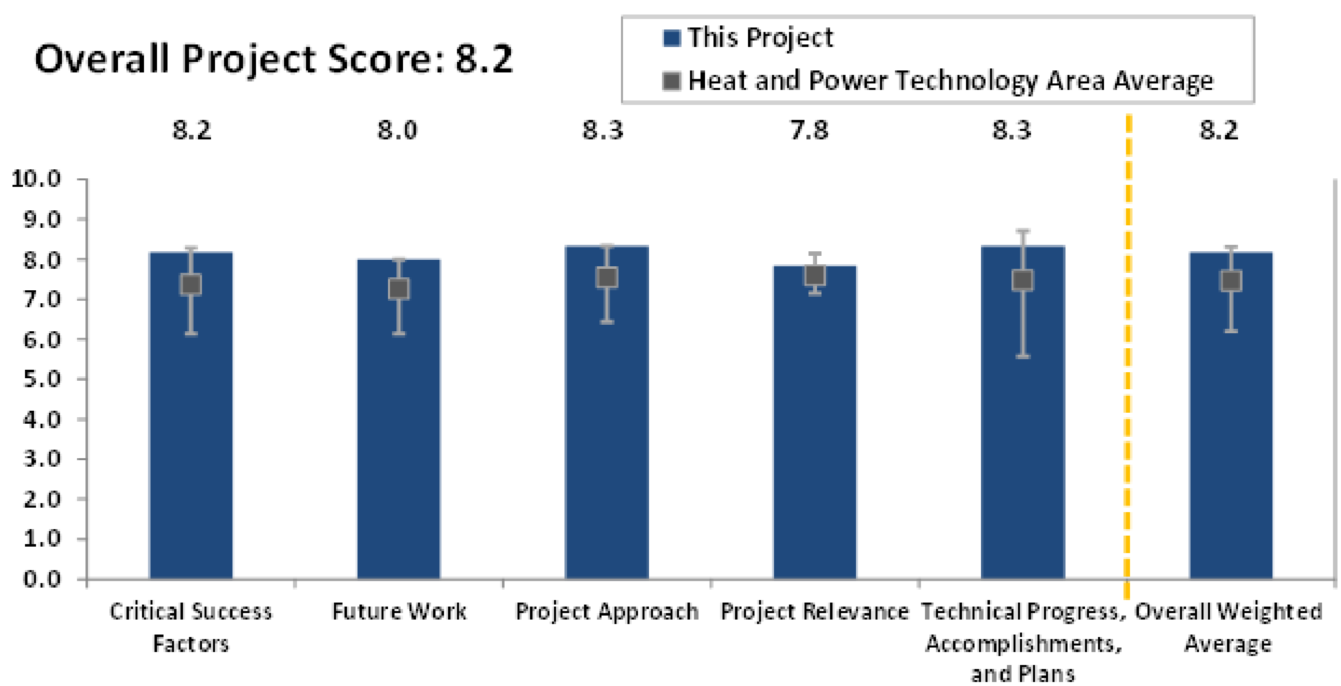
UNIVERSITY OF WISCONSIN OSHKOSH'S ANAEROBIC DRY DIGESTION FACILITY

(WBS#: 7.2.2.4)

Recipient:	University of Wisconsin Oshkosh
Presenter:	Gregory Kleinheinz
Total DOE Funding:	$500,000
DOE Funding FY13:	--
DOE Funding FY12:	$500,000
DOE Funding FY11:	--
Project Dates:	2011–2012

Project Description

The overall objective of this project was to evaluate the feasibility of operating a dry anaerobic digester in Oshkosh, Wisconsin. The specific tasks included evaluating design and equipment options, identifying feedstock that may be suitable for this application, testing the feedstock for biogas potential, conducting the bidding and procurement of an operational system, and operating and managing the full-scale dry anaerobic digester. The facility was successfully constructed and has been operating for more than a year. A variety of feedstocks were identified and tested for biogas generation potential. The best were selected for incorporation into the system. A collaborative management approach between the University of Wisconsin Oshkosh, the University of Wisconsin Oshkosh Foundation, and local partners has allowed for the effective operation and management of the facility. Moving forward, challenges are numerous as this facility deals with feedstock changes throughout a seasonal environment and optimization challenges. This is the first of three anaerobic digestion installations owned by the University of Wisconsin Oshkosh. Together, with the first small-farm containerized anaerobic digester and traditional anaerobic digestion system, we offer a suite of unmatched research and training capabilities.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Good niche application of existing technology. Good to see it immigrate to the United States. Hope the University will train students using this facility.
- Good practical project. First deployment of dry anaerobic digestion according to the presenter.
- Multiple project-related hurdles were overcome, and a first-of-a-kind facility is now functional. Nice work.
- Presenter did not show.
- The project appears to be very relevant for the development of biomass as an energy source. The project appears to have been executed satisfactorily, and the information has already been shared in the public domain.
- The project is congratulated for their work. This is a success story for BETO.
- Well-run project that could be beneficial for DOE to spread as one part of lessons learned in addition to benefits University of Wisconsin will receive.

PI Response to Reviewer Comments

- As pointed out by the reviewers, this project was a first-of-a-kind facility and provided numerous lessons for technology transfer. These lessons are being brought to our partners to assist in more efficient technology transfers in the future. The project has been a success and continues to employ students that train and optimize operations at the facility. While this facility is the first version in the U.S., we hope to help the next generations optimize operations for additional installations. Taken together with our traditional wet digester, small farm digester, and state-of-the-art biogas testing laboratory (Environmental Research and Innovation Center), the university offers an unprecedented array of anaerobic digestion technologies. These are not only fully functioning industrial-scale facilities, but also training and demonstration sites available to our partners. The university hopes the use of this facility for training and education can be expanded through future partnerships. Thus, the benefits of our experience in this biodigester, and all our installations, can be leveraged as living, learning laboratories of renewable energy infrastructure to enhance the future spread of diverse anaerobic digestion technologies.

VERMONT SUSTAINABLE JOBS FUND, MONTPELIER, CENTRAL VERMONT RECOVERED BIOMASS FACILITY

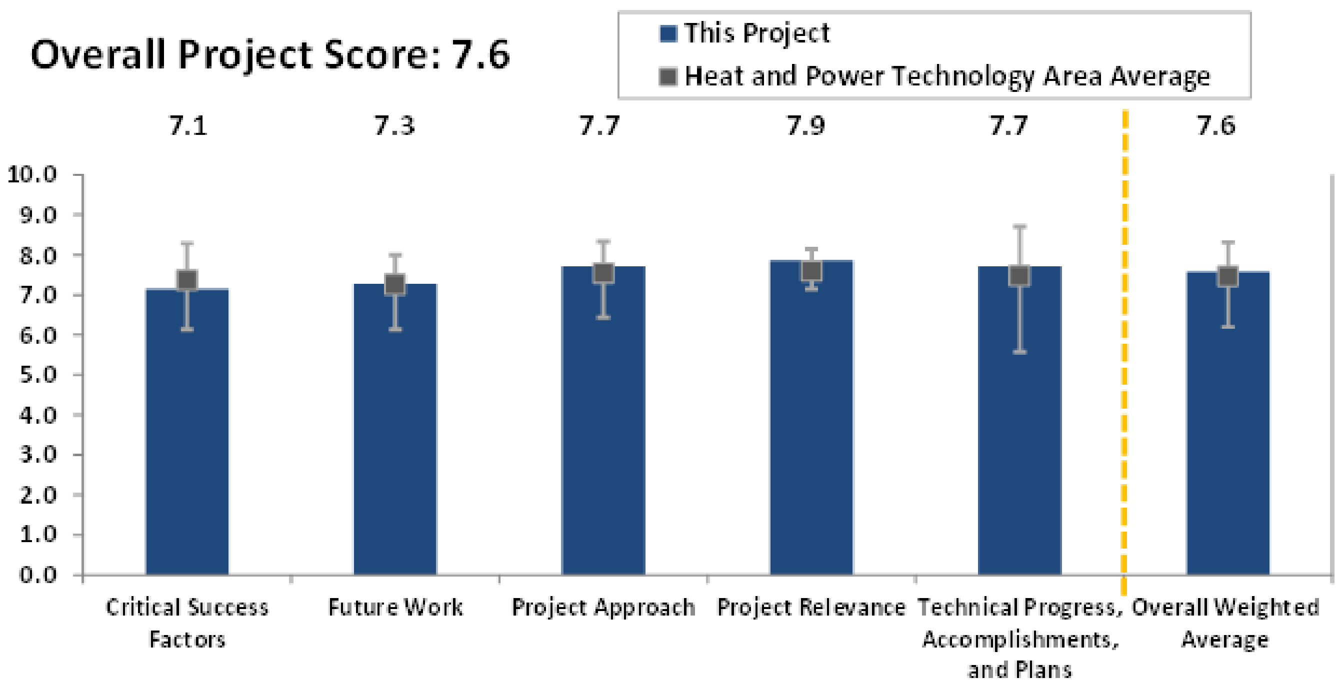
(WBS#: 7.7.5.8)

Recipient:	Vermont Sustainable Jobs Fund, Montpelier
Presenter:	Donna Barlow Casey
Total DOE Funding:	$1,992,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2008–2013

Project Description

Photo Courtesy of CVRBF

The purpose of the biodigester project is to determine the scientific, technical, social, and economic feasibility of building a community-scale food waste processing/bio-digester facility. The facility will generate electricity and heat from biomass feedstock composed of cow manure and food scraps. The Central Vermont Recovered Biomass Facility (CVRBF) is designed to be a 375-kilowatt facility. A minimum of 51% of its feedstock will be derived from agricultural producers, including Vermont Technical College's farm. This will primarily be manure, but waste crops and silage may also be in the mix. As a farm methane project, the CVRBF received a preferential rate for the electricity it will produce under the State of Vermont Standard Offer Program SPEED



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

contract. The remaining 49% of the feedstock "recipe" will be food scraps that would otherwise go to waste. Because more feedstock will be brought in from producers other than Vermont Tech and its dairy farm, the project falls into the category of a community-scale biodigester and is the first in Vermont.

Overall Impressions

- A good approach for using low-quality, small-scale biomass. An economic viability study should be conducted, however.
- Educational component of this project a strong positive. Good fit in a college environment. Project had broader impact by influence of local and state regulations. Project needs to focus on excellent operational performance to increase acceptance of this approach at other institutions.
- Good project in terms of community involvement and addressing many of the non-technical issues. Real tests now will be consistent operation to meet targets and keep community involvement.
- Interesting because it looks at a biodigestor that serves a whole community for better economies of scale, and its success (as well as the success of other bioenergy projects around the country) depends heavily on buy-in from the local community.
- Interesting project for small power generation. Were the air and solid waste emission requirements from both the digester and the diesel/electric generator difficult to meet?
- The PIs have done an excellent job of including a wide variety of participants into this project.
- The project appears to be very relevant for the development of biomass as an energy source. The project appears to be executed in a thoughtful manner and has an excellent outlet for the information generated. Good work has begun on the feedstock supply chain. They are relying heavily upon technology provider claims and are not doing testing on their own. Additional challenges may be the suitability of the remaining solids for land application and the development of the power island.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

WALLOWA COUNTY INTEGRATED BIOMASS ENERGY CENTER

(WBS#: 7.6.2.15)

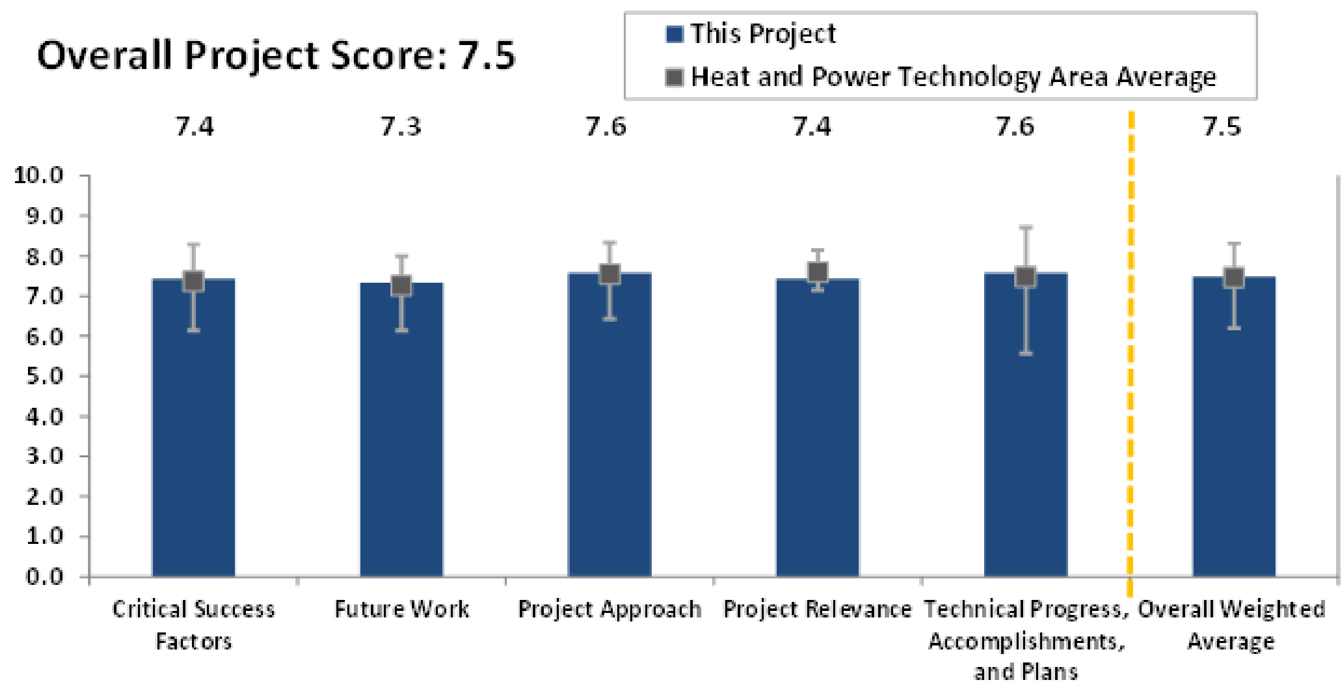
Recipient:	Wallowa Resources
Presenter:	Matt King
Total DOE Funding:	$747,000
DOE Funding FY13:	--
DOE Funding FY12:	$467,000
DOE Funding FY11:	$280,000
Project Dates:	2010–2013

Project Description

The Integrated Biomass Energy Center (IBEC) is the realization of a vision to integrate business, environment, and economic benefits in rural areas. IBEC is a small-scale, combined heat and power plant that utilizes waste streams from small businesses co-located at a wood products campus. The result is a mutually beneficial relationship which captures renewable energy, while achieving nearly 100% feedstock stream utilization. With funding from federal, state, local, and private sources, WR Community Solutions, Inc., has provided a suite of project management services, including financial sourcing, technology identification and sourcing, and economic modeling.

Overall Impressions

- Good approach to multiple public benefits from "waste" to energy processes. Key factors will be continued economic viability of overall approach.
- Good integration of bioenergy in local businesses, making them more self-sufficient with regards to electricity and heat and creating jobs. Financial data would be useful.
- Improved forest health. Some GHG emissions credits



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

- Not really a biomass project, more of a mill project that happened to use biomass. Nevertheless, it does aid in furthering the goals of BETO.
- Project recognized the wood waste associated with current harvest techniques. Nice effort.
- The project appears to be very relevant for the development of biomass as an energy source. Only very high-level project execution information was provided; however, they are almost done with the project, implying adequate project management. No information on how this information would be made to industry was presented.
- The project needs to provide a clear description of the economics surrounding the project in their final report.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

WASTE-TO-ENERGY COGENERATION PROJECT

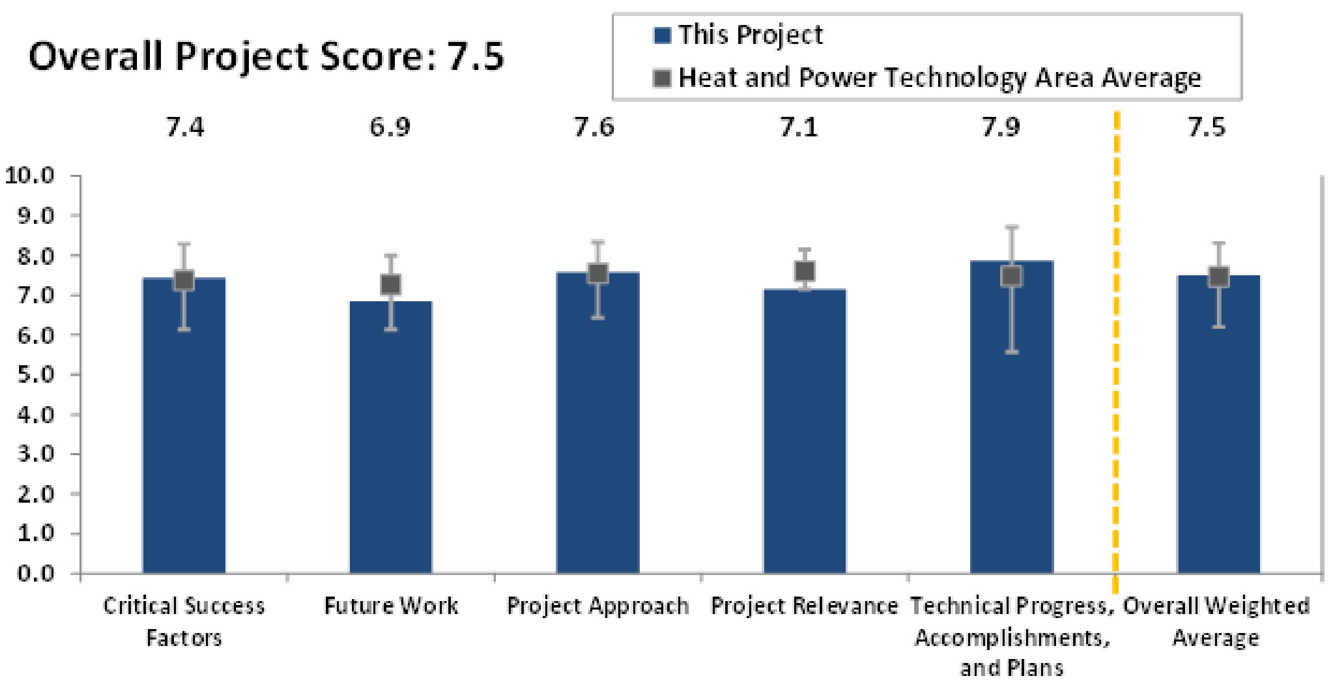
(WBS#: 7.4.3.8)

Recipient:	Waste-to-Energy Cogeneration Project (IN)
Presenter:	Clay Johnson
Total DOE Funding:	$1,385,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2008–2012

Project Description

Photo Courtesy of Waste-to-Energy Cogeneration Project

The Waste-to-Energy Cogeneration Project at Centennial Park has allowed methane from the closed Centennial landfill to completely power the recreational facility and export excess power into the grid for resale. This project is part of a greater brownfield reclamation project to the benefit of the residents of Munster and the general public. Installed gas-to-electric generators take methane by-product and convert it into electricity at the rate of about 103,500 megawatt-hours/year for resale to the local utility. The benefits of such a project are not simply financial. Munster's Waste-to-Energy Cogeneration Project at Centennial Park will reduce the community's carbon footprint in an amount equivalent to removing 1,100 cars from our roads, conserving enough electricity to power 720 homes, planting 1,200 acres of trees, or recycling 2,000 tons of waste instead of sending it to a landfill. Project Goal: Take the 500–800 standard cubic



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

feet per minute of gas and divert to the south side of the landfill. At this point, the gas will be flared or burned as fuel through a combustion-engine generator. The produced electricity will then be exported to the grid as part of the local utility's feed-in tariff.

Overall Impressions

- A successful effort; however, I have to question the wisdom of pushing for the increased rate tariff by a factor of five. This cost will obviously be passed onto the community. As pointed out earlier, the attitude and will of the electorate is critical. Upsetting the community/electorate with a significant electric rate increase will not endear them to future green projects.
- Good application of existing technology. Hopefully this will be an example that other municipalities can follow.
- Good project in terms of integration of multiple stakeholders. Could be considered a pilot (due to scale) for other landfills.
- Simple project—commercial technology used. Such systems already installed at many municipal landfills. A bit hard to understand why DOE funds should be used in such a project. It could have been launched based on its own merit by the municipality, as done at other places, perhaps with support from other programs of the federal and state governments.
- The project appears to be very relevant for the development of biomass as an energy source. Good high-level project execution information was provided and the project was successfully completed. No insight on how this information would be made to industry was presented.
- This was a difficult project that the city should be commended for in bringing to a successful completion. There is a lot of good experience that the city should share with other municipalities to help make these projects successful.
- Very nice work. This reviewer applauds the willingness to take on political risk, the foresight, and the diligence that went into this successful project.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

INTEGRATED BIOREFINERIES

TECHNOLOGY AREA

INTRODUCTION

The Integrated Biorefineries (IBR) Technology Area was one of nine key technology areas reviewed during the 2013 Bioenergy Technologies Office (BETO or the Office) Project Peer Review, which took place May 20–22, 2013, at the Hilton Mark Center in Alexandria, Virginia. A total of 21 projects were reviewed by a minimum of six external experts from industry, academia, and other government agencies. This review represents a total of approximately $890 million in U.S. Department of Energy (DOE) awards, which is approximately 55% of the total BETO portfolio award amount reviewed during the 2013 Peer Review. The principal investigator (PI) for each project was given 45 minutes to deliver a presentation and respond to questions from the review panel. Projects were evaluated and scored for their project management, technical progress over two years, relevance to BETO goals, identification of critical success factors, and future plans.[1]

This section of the report contains the results of the Project Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI for the project. Overview information on the IBR Technology Area, full scoring results and analysis, the Review Panel Summary Report, and the BETO Programmatic Response are also included in this section. BETO designated Travis Tempel as the IBR Technology Area review lead. In this capacity, Mr. Tempel was responsible for all aspects of review planning and implementation.

INTEGRATED BIOREFINERIES TECHNOLOGY AREA

OVERVIEW

The role of the Integrated Biorefineries Technology Area is to demonstrate and validate cost and performance data for various biofuel conversion pathways through building and operation of pilot-, demonstration-, and pioneer-scale IBR facilities via public-private partnerships. The IBR Technology Area is focused on resolving key issues involved in the scale-up of IBR systems. These projects will help overcome barriers and promote commercial acceptance, ultimately reducing risk for private sector financing of follow-on plants.

The activities of this Technology Area contribute to all of BETO's conversion pathways. BETO is committed to completing the construction and operation of pilot-, demonstration-, and first-of-a- kind, commercial-scale projects that convert biomass into advanced biofuels. The cost-shared partnerships are essential to bridging the "valley of death" between research and development (R&D) and commercial deployment of renewable biofuels technologies.

BETO's R&D is focused on developing the scientific and engineering underpinnings of a bioenergy industry by understanding technical barriers and providing process and engineering solutions. The IBR public-private partnerships offer a unique opportunity to validate technologies at scale and leverage additional assets to resolve underlying technical problems.

The product of these partnerships is primarily operational data that BETO will use to validate the cost and performance of the respective technology. The partnerships must report on technical progress, including process flow diagrams, mass and energy balances, and process performance parameters by unit operation. The partnerships also provide financial data, including pro

[1] More information about the review criteria and weighting information is available in the Peer Review Process section of the final report.

forma and actual capital and operating costs. Sustainability metrics associated with the facility or system will also be collected. The data from the IBR partnerships are evaluated and used as input to BETO portfolios and strategic planning.

INTEGRATED BIOREFINERIES SUPPORT OF OFFICE STRATEGIC GOALS

IBR projects are the mechanism used by BETO to validate its technology goal: to develop and deploy sustainable, commercially viable biomass conversion technologies that produce biofuels. This supports meeting the Energy Independence and Security Act Renewable Fuel Standard (RFS) targets. This goal is best accomplished through public-private partnerships.

The IBR Technology Area's strategic goal is to:

Demonstrate and validate integrated technologies to achieve commercially acceptable performance and pro forma cost targets.

INTEGRATED BIOREFINERIES SUPPORT OF OFFICE PERFORMANCE GOALS

The 2014 performance goal of the IBR Technology Area is to validate a total annual production capacity of 40 million gallons of advanced biofuels. The final intent is for the six commercial-scale facilities to be viable, ongoing production facilities that contribute to meeting the RFS targets. The pilot- and demonstration-scale projects may not be economically viable for ongoing biofuel production at their respective scales. Rather, at the pilot and demonstration scales, these IBR projects will generate at least 1,000 hours of continuous operational data that support the design of a techno-economically viable commercial-scale facility. Pilot- and demonstration-scale facilities can also help identify additional barriers that need to be addressed through further R&D to enable a viable, commercial production stage.

TECHNICAL AND MARKET CHALLENGES AND BARRIERS

BETO has identified the following key challenges for achieving the goals of the Integrated Biorefineries Technology Area:

Market Challenges	Technical Challenges
Inadequate Supply Chain Infrastructure	End-to-End Process Integration
Agricultural Sector-Wide Paradigm Shift	Demonstration-Scale Facilities
Lack of Understanding of Environmental/ Energy Trade-Offs	Risk of First-of-a-Kind Technology
High Risk of Large Capital Investments	Engineering Modeling Tools
Lack of Industry Standards and Regulations	End-to-End Process Integration
Cost of Production	
Off-Take Agreements	

APPROACH FOR OVERCOMING CHALLENGES

BETO's efforts to overcome the challenges and barriers associated with successful commercialization of IBRs are organized around five pathways: agricultural residue processing pathway, energy crops processing pathway, forest resources pathway, waste processing pathway, and algal processing pathway. Each pathway includes the following activities:

- **Deployment**: includes all of the major IBR projects
- **Technical Assistance**: covers smaller R&D projects that are identified by the IBR team, industry partners, and stakeholders as critical to improving existing biorefinery operations

- **Technical Analysis**: includes a broad range of technical, economic, and environmental topics and is used to assess the individual progress of the IBR projects, as well as the collective status and progress of the bioindustry.

For more information on the Integrated Biorefineries Technology Area, please review BETO's Multi-Year Program Plan (MYPP) at bioenergy.energy.gov/pdfs/mypp_may_2013.pdf.

REVIEW PANEL

The following external experts served as reviewers for the Integrated Biorefineries Technology Area during the 2013 Project Peer Review.

Integrated Biorefineries Reviewers	
Bill Crump (Lead Reviewer)	SAIC
Ralph Anthenien	Army Research Office
James Doss	Professional Project Services, Inc.
Steve Moorman	Babcock & Wilcox Company
George Philippidis	University of South Florida
Dan Strope	Consultant, retired KIOR
John Wyatt	Carmagen Engineering, Inc.

FORMAT OF THE REPORT

Information in this report has been compiled as follows:

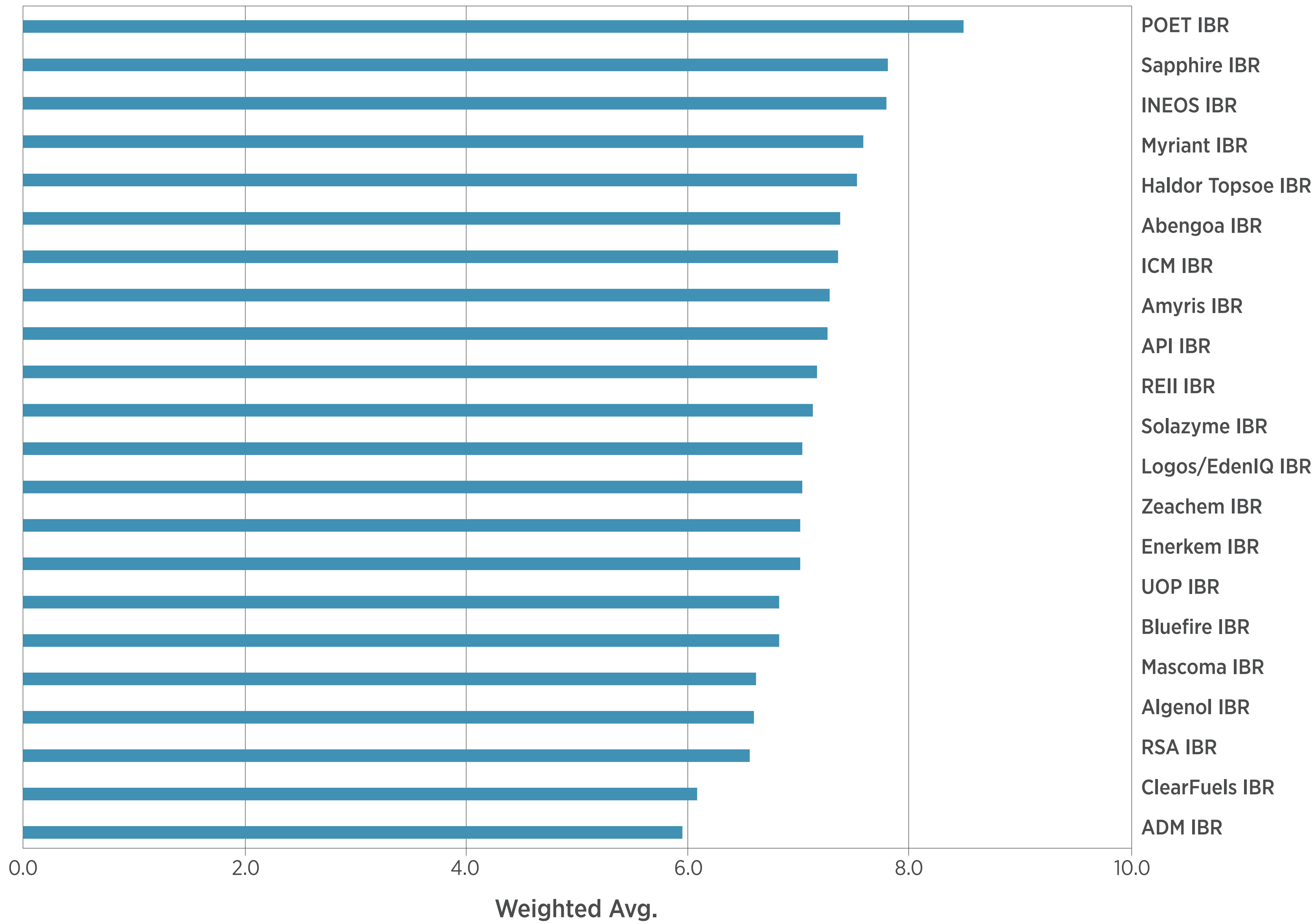
- **Introductory Information**: Overview information for each technology area was drafted by BETO review leads to provide background information and context for the projects reviewed within each technology area. Total budget information is based on self-reported data as provided by the PIs for each project.
- **Project Scoring Information and Short Names Key**: The final score charts depict the overall weighted score for each project in each technology area. Short names for each project were developed for ease of use in the scoring charts, the table of contents, and other locations. Full project names, along with their designated short names and their work breakdown structure (WBS#), are provided in the Short Names Key.
- **Review Panel Summary Report**: The Review Panel Summary Report was drafted by the lead reviewer for each technology area, in consultation with the other reviewers. It is based on the results of a closed-door, facilitated discussion following the conclusion of the technology area review. Consensus among the reviewers was not required, and reviewers were asked to include differences of opinion and dissenting views within the report. All reviewers were asked to concur with the final draft for inclusion in this report.
- **BETO Programmatic Response**: The BETO Programmatic Response represents BETO's official

response to the evaluation and recommendations provided in the Review Panel Summary Report.

- Project Reports:
  - **Project descriptions** of all reviewed projects were compiled from the abstracts submitted by the PIs for each project. In some cases, abstracts were edited to fit within the space constraints allotted.
  - **Project budget and timeline information** is based on self-reported data as provided by the PI for each project.
  - **Scoring charts** depict the average reviewer scores for each criterion and for the overall weighted project score. Average overall scores for each technology area are represented, and the whiskers depict the range of scores for each category within each technology area.
  - **Reviewer comments** represent the reviewer comments as provided in the overall impressions criteria response. Each bulleted response represents the opinion of one reviewer. Reviewers were not asked to develop consensus remarks, and in most cases did not discuss their overall comments on each project with one another. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant by BETO's director were excluded from the final report.
  - **PI Responses** represent the response provided by the PI to the reviewer comments as included in the final report. In some cases, PIs chose to respond bullet by bullet to each of the comments made by the reviewers, and in other cases provided only a summary response.

Each chapter of the report follows this basic format; however, some variations in formatting exist from chapter to chapter based on the preferences of the PIs and the

TECHNOLOGY AREA SCORE RESULTS



SHORT NAMES KEY

WBS #	PROJECT NAME	ORGANIZATION	UNIQUE PROJECT NAME
5.4.3.3	LIBERTY - Launch of an Integrated Bio-refinery with Eco-sustainable and Renewable Technologies in Y2009	POET	POET IBR
5.11.1.1	Sapphire Integrated Algal Biofinery	Sapphire Energy Inc.	Sapphire IBR
5.2.4.1	INP BioEnergy Indian River County Facility	INEOS New Planet Bioenergy LLC	INEOS IBR
5.2.3.1	BEI - Myriant Succinic Acid Biorefinery (MySAB)	Myriant (Myriant Lake Providence Inc.)	Myriant IBR
5.7.4.1	Green Gasoline from Wood Using Carbona Gasification and Topsoe TIGAS Processes	Haldor Topsoe Inc.	Haldor Topsoe IBR
5.4.4.1	Integrated Biorefinery for Conversion of Biomass to Ethanol, Synthesis Gas, and Heat	Abengoa	Abengoa IBR
5.5.12.1	Pilot Integrated Cellulosic Biorefinery Operations to Fuel Ethanol	ICM Inc.	ICM IBR
5.1.4.1	Scale-Up and Mobilization of Renewable Diesel and Chemical Production from Common Intermediate Using U.S.-based Fermentable Sugar Feedstocks	Amyris Biotechnologies Inc.	Amyris IBR
5.7.1.1	Alpena Prototype Biorefinery	American Process Inc.	API IBR
5.7.3.1	Demonstration of a Pilot Integrated Biorefinery for the Economical Conversion of Biomass to Diesel Fuel	Renewable Energy Institute International REII	REII IBR
5.11.3.1	Solazyme Integrated Biorefinery : Diesel Fuels from Heterotrophic Algae	Solazyme Inc.	Solazyme IBR
5.7.5.1	Modification of Corn Starch Ethanol Refinery to Efficiently Accept Various High-Impact Cellulosic Feedstocks.	Logos/EdenIQ Technologies	Logos/EdenIQ IBR
5.5.11.1	High-Yield Hybrid Cellulosic Ethanol Process Using High-Impact Feedstock for Commercialization by 2013	ZeaChem Inc.	ZeaChem IBR
5.5.10.1	Heterogeneous Biorefinery Project	Enerkem Corporation	Enerkem IBR
5.4.10.1	Pilot Scale Biorefinery: Sustainable Transport Fuels from Biomass and Algal Residue via Integrated Pyrolysis and Catalytic Hydroconversion	UOP LLC	UOP IBR
5.5.3.2	Fulton Ethanol Facility: A Landfill Waste Feedstock to Cellulosic Ethanol Facility - Award 2 - ARRA	Bluefire (BlueFire Ethanol) LLC	Bluefire IBR
5.5.7.1	MAS10BIO5	Mascoma	Mascoma IBR
5.11.1.2	Integrated Pilot-Scale Biorefinery for Producing Ethanol from Hybrid Algae	Algenol Biofuels Inc.	Algenol IBR
5.6.2.1	Demonstration of an Integrated Biorefinery	RSA	RSA IBR
5.5.9.1	Integrated Biorefinery Pilot Project for Diesel and Jet Fuel Production by Thermochemical Conversion of Woodwaste	ClearFuels / Rentech Technology	ClearFuels IBR
5.4.9.1	Conversion of Lignocellulosic Biomass to Ethanol and Ethyl Acrylate	Archer Daniels Midland	ADM IBR

REVIEW PANEL SUMMARY REPORT

INTRODUCTION

On May 20–22, 2013, BETO held its biennial Project Peer Review of the Integrated Biorefinery Technology Area. The Peer Review featured introductory presentations by BETO staff to provide information on the Technology Area, as well as presentations by the principal investigators of the federally funded projects that comprise the IBR portfolio.

The goals of the independent review panel were to provide an objective and unbiased review of the individual projects, and a review of the overall structure and direction of the IBR Technology Area.

At the review, project PIs presented their project budgets, goals, accomplishments, challenges, and relevance to the IBR Technology Area. They also answered questions from the review panel and general audience. Projects were evaluated by the review panel solely based on the information presented by the PIs. The information presented was limited to discussions about project management practices, progress achieved, relevance of project to BETO's goals, barriers overcome, and future work to be accomplished. Detailed information regarding the technology processing conditions or certain metrics of technology performance was not provided if the PI felt that this information was confidential to the company. However, the panel understood that the company's confidential information was provided to BETO and DOE's independent engineer for review throughout the term of the project. Reviewers used a software tool to facilitate both scoring and constructive comments on a range of evaluation criteria.

Overall, the panel thought BETO was doing an excellent job of supporting a variety of projects with different technology readiness levels (TRL) representing an appropriate mix of technologies. This is not to imply that the panel believed all of the projects in the portfolio would ultimately succeed in meeting their originally proposed goals—in fact, based upon the panel's considerable experience in evaluating the performance of new technology projects, the panel expects that the portfolio will achieve varying levels of success. The panel also recognized that many of the projects being reviewed either are in a successful stage of construction or in start-up/commissioning and, as a result, would tend to have more positive messages attached with the individual review. The panel understood that perception of success can easily be influenced by a project's stage of development during the time of review and that projects that are currently in a successful stage of construction or are in start-up/commissioning would provide more positive information. However, if many of the projects are struggling through technology issues or having long construction delays, the perception of BETO's successful implementation could be negative when, in fact, BETO's execution had not changed. The panel expects that successful execution of the BETO portfolio includes projects that are experiencing difficulty in acquiring funding, technology issues, construction delays, and extended time delays in start-up and commissioning, as well as many projects that are not able to reach nameplate capacities or expected conversions. The fact that these challenges exist are not a reflection on BETO's quality of execution; rather, the panel applauded BETO's patience and thoughtful assistance in helping the projects work through challenges.

IMPACTS

1 What are the key strengths and weaknesses of the projects in this technology area? Do any of the projects stand out on either end of the spectrum?

2 Is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry in this technology area? Is the government's focus appropriate in light of private-sector investments? Are there any projects that stand out as meeting (or not meeting) this criterion?

The panel noted that the actual construction of facilities was the biggest strength of the portfolio; these facilities were preparing to produce significant quantities of advanced biofuels. In addition, the variety of technologies funded meets the goals of BETO's MYPP. The project scales funded had a good balance of many small-scale projects, fewer mid-scale projects, and even fewer commercial-scale projects. The panel believed the approach of funding many small pilot projects led to a few commercial-scale projects, and is important to advancing the industry. The panel noted that the projects poised to have the biggest impacts—due to their strong potential to put significant quantities of advanced biofuels into the market in the near future—are the commercial projects by POET and Abengoa, and the commercial-demonstration project by INEOS. The panel noted that commercial-sized facilities were uniquely positioned to attract private investment and leverage the federal investment in these projects. The grants to the commercial-sized facilities were equivalent to a "carrot" for attracting investment. The commercial projects had additional piloting that had to be finished prior to scaling up. The "carrot" of the grant helped attract funds to complete the pilot work because investors knew that the commercial-sized facility had already obtained substantial investment. In addition, the panel felt that BETO's use of stage gates and its willingness to take risks on a large number of projects—allowing them to either succeed or fail—was critical to the success of the commercial projects. BETO provided appropriate financial resources for the commercial projects to advance; however, the office was not willing to let the projects advance into construction until the appropriate amount of pilot testing was complete. The panel felt it was critically important that BETO did not cut funding when progress was not being made according to the original intended schedules. Rather, BETO was willing to allow the PIs time to work through rough spots. The panel felt the Technology Area portfolio was executed in a diligent manner that gave the projects enough time to advance, while also protecting federal investment in the projects by requiring successful completion of stage gates prior to receiving funds. BETO's focus has been important for attracting private investment. In particular, the use of grants is necessary for reducing project capital investment; providing project credibility, which served as an attractant for private investment; and providing a path for demonstrating technology proof of concept and market viability, which is necessary for private industry to invest in future projects.

As mentioned previously, the projects in the IBR Technology Area were not reviewed based on their viability or likelihood to achieve commercial success; the information required for this type of review was not available in this venue. Rather, the projects were reviewed based on their ability to execute plans and progress made. On this basis, it was clear to the panel that the majority of projects reviewed had passed a considerable number of stage gates, and most scored fairly well. Generally—with some exceptions—some common themes emerged among the higher-scoring projects. These themes include having previous experience in the execution of projects; having a well-experienced engineering, procurement, and construction contractor; and having well-developed feedstock supplies. Also of note, the highly rated, larger projects had all received loan guarantees to assist with project development (although the POET project later declined its loan guarantee).

In general, all of the projects were perceived as having strong potential; however, when projects rated lower, it was typically because they were not able to obtain the funding necessary to proceed. Other areas the panel saw as challenges for the portfolio include the inability to share critical information between similar projects due to intellectual property concerns; the large number of remaining projects that were focused on producing ethanol; and the lack of projects focused on producing drop-in fuels.

Two major market events have significant potential to impact BETO's program goals. The first market event is reaching the United States' ethanol blend wall. Without a mandate to increase the required blending of ethanol, the panel felt that increased ethanol production would have to either be exported, or would potentially displace starch ethanol already on the market, thereby undercutting BETO's overall goals.. A significant increase in the ethanol market would improve project financing opportunities. The second major market event is the availability of increased amounts of natural gas at lower prices. The panel noted that companies once solely involved in the conversion of biomass to synthesis gas (for eventual conversion to biofuels) are now exploring opportunities to reform natural gas into synthesis gas. This trend has the potential to draw private investment away from biofuels into the natural gas-to-fuels market. However, the current abundant natural gas supply also has the ability to reduce the technical risk for this portion of the conversion technology; to help develop this fuels market; and to advance the methods for fuels qualifications. The panel felt that BETO should continue its efforts in developing biomass-to-synthesis gas conversion technologies; this will de-risk the conversion processes and enable commercial implementation.

INNOVATION

3 Are the projects in this technology area addressing the broad problems and barriers BETO is trying to solve? Do these projects represent novel and/or innovative ways to approach these barriers? Do any projects stand out as meeting (or not meeting) this criterion? Can you recommend new ways to approach these barriers?

The panel evaluated the projects to determine if certain identified market and technical barriers were addressed. Market challenges included successfully obtaining investment for project development; developing feedstock supply chains and the potential to develop the feedstock supply for commercial-sized applications; developing product standards, acceptance tests, and off-take agreements; and needing to reduce capital and operating costs through innovation and value engineering. A key technical challenge was the projects' inability to demonstrate proof of concept in an integrated facility. The larger commercial-sized facilities needed to include the development and proof of concept of feedstock activities in sufficient quantities—and with sufficient sustainability considerations—to support the facilities over an extended period of time. Smaller projects, such as pilot and demonstration facilities, needed to develop sufficient information to evaluate the value of pursuing the technology application to the next TRL. Required proof-of-concept information included capital and operating costs, utility and chemical consumptions, and equipment design criteria information.

The panel found that the suite of projects reviewed was generally making excellent progress in addressing the market and technical challenges, as stated in the 2013 MYPP. Two of the commercial facilities and one of the larger commercial-demonstration facilities made great progress in securing their feedstocks. The commercial-demonstration project (INEOS) is in start-up, and the two commercial projects (Abengoa and POET) are scheduled to finish construction in 2013 and 2014, respectively. All three of these projects invested considerable time and effort in identifying sustainable, high-quality feedstock supplies; working with suppliers in the feedstock chain to develop the suppliers' abilities to consistently provide the feedstock; identifying the range of feedstock characteristics the plants may receive; and progressing their respective feedstock industries in order to operate at the size needed for commercial-scale supply systems. Several of the projects have been working with oil upgraders and laboratories to understand the necessary qualifications for their oil products. One of the projects participated in multi-year testing with the U.S. Navy in its marine fuel testing and certification program. While all of the projects have innovative technologies, one project of special interest was Solazyme. The panel recognized that the industry is faced with certain challenges around the use of ethanol and noted that Solazyme is advancing a technology that explores a pathway for converting lignocellulosic sugars and sugars from starch; these products can be converted directly to oil and upgraded to a drop-in fuel.

However, as expected, the projects' actual performance in addressing identified market and technical barriers was varied and included projects that have been performing significantly below original expectations. The main market challenge continued to be attracting sufficient capital for some of the projects to progress. In particular, Blue Fire, Mascoma, Red Shield Acquisition, and Enerkem continued to face the hurdle of obtaining the necessary investment to proceed into construction. In addition, the panel expected that the projects' technical accomplishments will vary. For example, the Rentech project presented final results from its performance testing that revealed it had performed at a level considerably under its goal. The panel did not believe that projects having difficulty in obtaining necessary investments, or some projects inevitably having technical performances under their stated goals, indicated a shortfall in the approach used by BETO. Rather, given the panel's extensive experience in new technology projects, the panel believed the suite of projects reviewed during this period is achieving results in line with expectations, and that the approach used by BETO is thoughtful.

The panel concluded that the IBR projects are addressing the broad problems and barriers that BETO is attempting to solve. The projects are developing actual capital costs; establishing feedstock growing, harvesting, logistics, and processing procedures and practices; determining the actual operating costs and technical performances for their respective technologies; and developing product off-take requirements. While all of the projects include novel elements that contribute to their ability to address barriers, the panel believed that the barriers are being overcome mainly through hard work and persistence.

GAPS

4 Are there any other gaps in the portfolio for this technology area? Are there topics that are not being adequately addressed? Are there other areas that BETO should consider funding to meet overall programmatic goals?

There was an even representation of thermochemical, biochemical, and photosynthetic conversion technologies. However, the panel noted the loss of several thermochemical projects from the portfolio. The panel did not believe the loss of projects pursuing the syngas conversion to biofuel route is necessarily due to problems inherent with the gas conversion technology, but rather, due to problems with financing and/or with successfully feeding and thermally converting biomass to clean synthesis gas. Therefore, the panel felt BETO would benefit the industry if they sponsored specific work on developing a reliable system for feeding and converting biomass to synthesis gas. Other areas the panel felt would merit from additional focus were:

- Finding a value-added purpose for utilizing the separated lignin for certain technology pathways (rather than just burning it as a fuel)
- Encouraging the development of high-value co-products in addition to biofuels, which helps with financial viability and diversification
- Helping to develop the rules for fuel qualifications, rather than having each company work through the hurdles
- Placing additional focus on producing drop-in fuels, as opposed to creating a feedstock for a refinery. While the market is immature and small, refiners are not necessarily motivated to receive small batches of additional feedstock.

SYNERGIES

5 What synergies exist between the projects within this technology area? Is there more that BETO could do to take advantage of these synergies and better enable projects to meet their objectives?

The panel established that—given the similarities among the groups of projects—considerable synergies could be found. For example, multiple projects are developing processes that use enzymes and yeasts; experiencing lignin fouling; trying to determine how the characteristics of biomass changes with increased storage time; aiming to learn how to operate efficient anaerobic digestion systems; and developing gasifier technologies that also need reliable biomass feed and gas cleaning systems. However, the sharing of this type of information is not possible due to the considerable effort and expense expended by companies, resulting in corporate intellectual property ownership. To share synergies between future projects, the panel recommended that BETO put certain stipulations into the grant awards regarding information sharing. However, it is not clear if this type of sharing during project development would always be beneficial, as it could hinder individual innovation for overcoming barriers.

RECOMMENDATIONS

6 Is BETO funding projects at the optimal stage of the technology pipeline? Is there more that BETO could do to orient technologies toward successful commercialization? Are there any projects that stand out as positive or negative examples of this orientation?

7 What are the top three most important recommendations that would strengthen the portfolio in the near to medium term?

The panel arrived at the following recommendations:

- BETO should continue funding IBR projects in the pilot, demonstration, and commercial stages—with a larger number of pilot-scale projects, fewer demonstration plants, and even fewer commercial plants. All of these are important.
- BETO should continue funding a variety of projects with different TRLs. Smaller projects that successfully pass through a stage-gate process should be given the “carrot” of additional, more significant

funds to build the next, bigger-scale facility. We believe this approach is necessary for reducing the investment risk (by buying down the investment with grant money), but it also leverages the grant money by attracting more private investment.

- Future funding efforts should not dictate the required capacity of the plant to be built, regardless of the technology being proposed. When deciding the required capacity of the plant, BETO should consider: what are the key technical parameters that dictate equipment scale-up to the next size, and what size should the plant be to demonstrate these parameters; and what is the minimum capacity of the facility to allow for "customer fitness for use" sampling and acceptance testing.
- BETO should consider requiring future pilot plants to be co-located with existing facilities where synergies exist.
- BETO could provide new biofuel producers with detailed assistance for getting their biofuel qualified.
- BETO should provide a common techno-economic model for projects to use when communicating and adjusting the economics.
- In addition to the grant program, projects need a financial assistance program that is willing to accept the risk associated with these projects.
- Sharing of information between common projects is complicated by corporate intellectual property ownership. In future grants, BETO should consider requiring projects to share certain information with other awardees. The panel recognizes that this recommendation may be very difficult to implement.
- Companies that were once solely involved in the conversion of biomass to synthesis gas to make biofuels are now exploring opportunities to reform natural gas into synthesis gas. This trend has the ability to help advance the synthesis gas conversion to fuels market; reduce the technical risk for syngas conversion technology; and aid in developing the fuels market. The panel feels that BETO should continue developing biomass-to-synthesis gas conversion technologies, which leads to de-risking technologies for eventual implementation.
- Companies involved in biofuel production are often faced with hurdles created by misinformed, partially informed, or biased opinions from the public, special interest groups, and media. BETO could help alleviate some of these barriers by clearly and frequently repeating the BETO message of needing to reduce dependence on foreign oil; develop domestic and sustainable feedstocks; establish a domestic industry to improve the economy and provide jobs; and reduce carbon emissions.

BETO PROGRAMMATIC RESPONSE

IMPACTS

We appreciate the participation of the review panel and the input we received from both the panelists and the Steering Committee during this Peer Review. The reviewers provided validation of the work being done in the Integrated Biorefineries Technology Area (also known as the Demonstration and Deployment Program) and additional comments on concrete actions that we could take for improvement. The Office's response to the Peer Review Panel Summary is below.

The panel recommended a distribution of project funding to a greater number of pilots, a smaller number of demonstration-scale plants and finally the smallest number of pioneer facilities. This consensus helps to confirm the Demonstration and Deployment Program's plan to validate technology pathways and that this is the most effective way to bridge the "valley of death." The panel supports DOE funding in multiple conversion pathways and our execution and project management, specifically our stage gate requirements.

The panel also highlighted the need to work with other agencies and with the financial community. Through our Analysis and Sustainability Technology Area and other recent initiatives, BETO has actively engaged with the Department of Defense, the Department of Agriculture, and the Environmental Protection Agency. This interagency work and outreach to the financial community is essential to helping these projects obtain financing and overcome the barriers to scale-up.

DOE agrees that one of the greatest challenges outside of obtaining private funding to proceed with project development is the management of intellectual property and proprietary information that is developed or discovered along the way. In the future, DOE is considering including intellectual property agreements in its contracts in order to counteract this negative effect.

As the panel noted, it is important to reinforce our testing and certification efforts to ensure that markets can accept all advanced biofuels and bioproducts, including ethanol. In addition, BETO has shifted focus to drop-in hydrocarbon fuels and has not awarded any cellulosic ethanol awards since the American Recovery and Reinvestment Act (ARRA) projects in 2010. This year, four innovative pilot projects were selected for funding, all of which will produce an end product that is a drop-in substitute for petroleum. Out of our 25 active projects, 12 are focused on drop-in hydrocarbon fuels. BETO will also explore natural gas synergies in this year's natural gas workshop.

INNOVATION

The reviewers highlighted the main challenges faced by these projects: financing, feedstock supply chains, product qualification testing, off-take agreements, and reduction of capital and operating costs. The report also noted that BETO's Demonstration and Deployment Program is taking steps to address all of these challenges.

GAPS

As mentioned previously, BETO has switched its focus to drop-in renewable hydrocarbon fuels and hopes to address the gap identified by the panel. This includes work in our conversion technology areas that incorporates refinery operators to determine viable insertion points and distribution methods for hydrocarbon biofuel. One of our most recent awardees will be using a Fischer Tropsch-to-hydrocarbon technology, ensuring that this conversion pathway remains in the overall biorefinery portfolio.

BETO is also interested in finding a higher value purpose for lignin residue other than burning it for fuel. We hope to accomplish this through our R&D work in this area. We also believe that high-value co-products will be essential to the profitability of an integrated biorefinery and that it is advantageous to include this in our future funding opportunities and MYPPs. For the present time, we are conducting a bioproducts life-cycle analysis study to determine the healthiest pathway towards substantial greenhouse gas reduction via bioproducts. In order to address specifications on fuel qualifications, BETO is working closely with the Environmental Protection Agency's Office of Transportation and Air Quality on general RFS pathway determinations

SYNERGIES

BETO has compiled lessons learned from previous IBRs' experience and has shared these both with the panel and with the IBRs themselves. We are glad the panel recognized the difficulty of protecting proprietary information, but note we are committed to working with our legal department on technology sharing stipulations that could be placed into any future awards.

RECOMMENDATIONS

The Demonstration and Deployment Program is pursuing a strategy that will fund additional pilot-, demonstration-, and pioneer-scale facilities. These public-private partnerships are necessary to attract the required amounts of private investment to make an impact on the domestic fuel market. By proving the performance of various technologies at progressive scales, banks and other traditional financial institutions will have greater confidence and interest in investing, ultimately providing lower capital financing to these types of projects.

In future funding opportunities, BETO plans to broaden the capacity requirements for plants that would qualify as demonstration or pioneer scale. BETO is also working to incorporate intellectual property sharing agreements where applicable and acceptable.

All funding opportunities are competitive and open to all performers. The Demonstration and Deployment team also makes every effort to fund technology at the appropriate scale based on the technology readiness level, and they coordinate with the research and development areas to assess each conversion pathway's readiness.

BETO believes that exploring the synergies between natural gas technologies and biomass conversion and utilization could be very valuable to commercialization of thermochemical pathways to biofuel. With the increase in natural gas production and processing, there may be greater advancements in technologies, equipment, and processes that could assist in proliferation of bioenergy as well. BETO recently held a Natural Gas-Biomass to Liquids Workshop in Chicago, Illinois, to better understand these opportunities and a potential role for the Office.

BETO continues to work with its communications team to promote biomass as a near-term, sustainable source for products, power, and fuel otherwise derived from petroleum. Efforts are made to reduce misinformation to consumers, as well as to clarify the Office's mission to create jobs, reduce the negative impact of greenhouse gas emissions from fossil fuels, and reduce our dependence on foreign oil sources.

ADDITIONAL COMMENTS

The panel's expertise in managing projects at various scales and technology readiness levels allowed for a very thorough, realistic, and helpful review of BETO's IBR portfolio. While identifying areas for improvement, the overall positive comments and project scoring showed that the IBR portfolio is well structured and well managed.

CONTENTS

SCALE-UP AND MOBILIZATION OF RENEWABLE DIESEL AND CHEMICAL PRODUCTION FROM COMMON INTERMEDIATE USING U.S.-BASED FERMENTABLE SUGAR FEEDSTOCKS

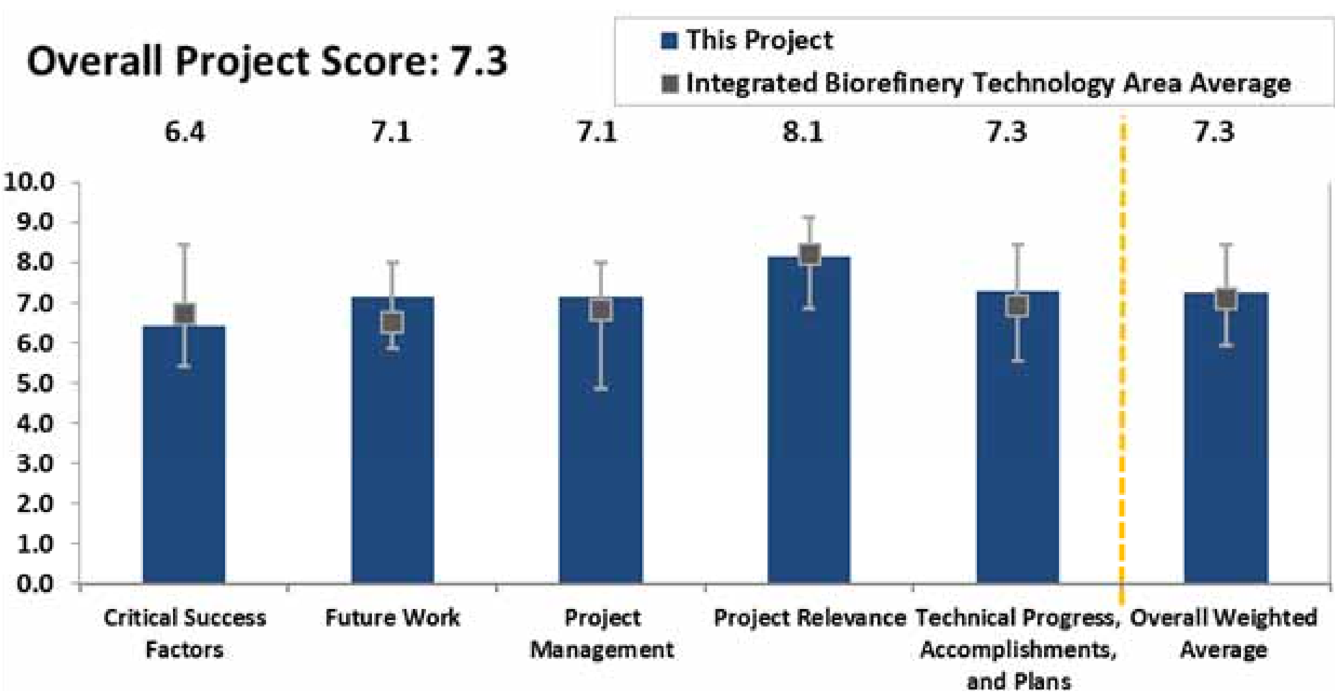
(WBS#: 5.1.4.1)

Recipient:	Amyris Biotechnologies, Inc.
Presenter:	Joel Cherry
Total DOE Funding:	$24,341,409
DOE Funding FY13:	$23,438,366
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2009-2012

Project Description

Photo Courtesy of Amyris

The Amyris pilot-scale integrated biorefinery project focused on operations and upgrades at Amyris' pre-existing Emeryville, California, pilot plant and support labs to develop U.S.-based production capabilities for No Compromise® renewable diesel fuel and key chemical derivatives, such as plasticizers. These Amyris products are derived semi-synthetically from high-impact biomass feedstocks via microbial fermentation of the hydrocarbon intermediate, farnesene, and subsequent chemical finishing. In particular, Amyris strains are feedstock tolerant and can utilize a range of defined, syrup-type and lignocellulosic-based sugars as a carbon source. We adapted existing technology to utilize sweet sorghum juice—instead of sugarcane juice—and have evaluated lignocellulosic sugars as a domestic feedstock alternative. To this end, Amyris has evaluated and adapted processes for diesel, aviation jet fuel, and chemical manufacturing from sweet sorghum and other high-impact feedstocks at pilot scale. This work has enabled robust techno-economic analysis,



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

industry standards development, regulatory approvals, and an understanding of key performance parameters and operational approaches needed for a commercial design. Amyris' integrated production process uses industry-proven, yeast-based fermentation of traditional or lignocellulosic-derived sugar feedstocks. Amyris' project partner, Ceres, Inc., provided sweet sorghum syrup to Amyris and bagasse to the National Renewable Energy Laboratory (NREL). NREL evaluated pretreatment and saccharification processes to optimize sugar yields from the biomass and provide feedstreams to Amyris. Additional lignocellulosic feedstocks based on wheat straw (M&G Chemtex) and wood chip (Old Town Fuel and Fiber) were also evaluated in the Amyris pilot plant. Farnesene is readily recovered as water-immiscible oil and is cost effectively purified prior to finishing. Fermentation waste has been successfully treated by anaerobic digestion—in collaboration with ICM, Inc.—to utilize residual sugars for biogas production. In coordination with Praxair, Inc., Amyris developed model biogas cleanup and steam-methane reformation processes for conversion to hydrogen for use in finishing reactions.

Overall Impressions

- Interesting technology. Versatility of the molecule application can be a plus to navigate business cycles for a biofuels plant. However, it is at too early a stage to be funded by the IBR Technology Area in my opinion.
- Productive use of DOE funds to test feed sources and make enough material for regulatory and customer testing.
- The company has developed a promising pathway converting sugars (including cellulosic) to diesel. Pilot tests so far look good, as do tests with the final product.
- The process seems to offer some flexibility going to farnesene. The process seems to be limited in scale-up.
- The throughput of the "pilot" plant is really lab scale. Additional funding at true pilot scale would need to be conducted before demonstration or commercial scale. The performer also needs a partner to provide sugars. The project really belongs in the biological conversion portfolio, not the IBR portfolio.
- This is a very different sort of project. Interesting!
- This project appears to have been fairly well executed and is a good pilot plant to demonstrate the conversion of sugar to farnesene.

PI Response to Reviewer Comments

- No official response provided at time of report publication

SAPPHIRE INTEGRATED ALGAL BIOREFINERY

(WBS#: 5.4.10.1)

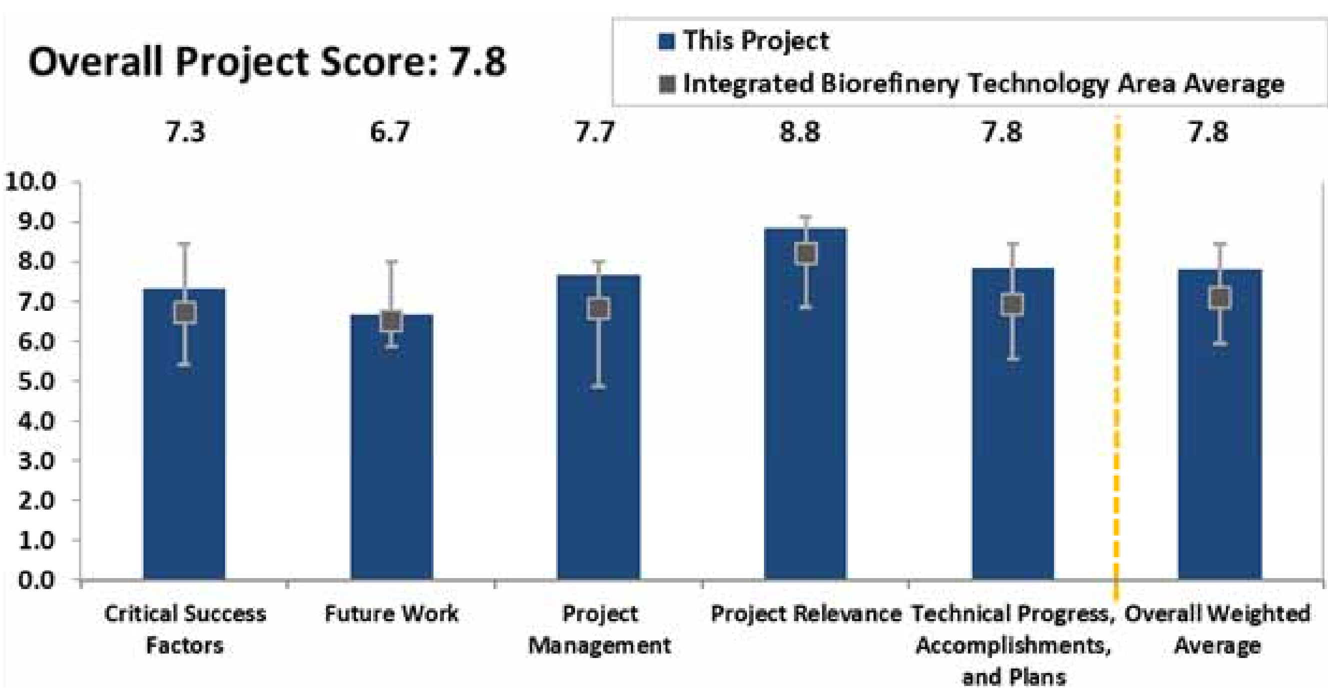
Recipient:	Sapphire Energy Inc.
Presenter:	Jaime Moreno
Total DOE Funding:	$49,725,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2009-2014

Project Description

The overall objective of the Integrated Algal Biorefinery (IABR) Project is to demonstrate the technical and economic feasibility of the algae to drop-in green crude process that will form the basis for the deployment of a series of commercial-scale biorefineries. The aims of the IABR are to: deploy the algae-to-green crude process at pre-commercial scale; integrate the key processes for the entire production chain from feedstock to transportation of final product; and continue to reduce capital and operational costs through an ongoing R&D effort. The IABR's relevance remains completely aligned with these original project goals from early 2009. It continues to be the key step in the development of commercial-scale drop-in crude from algae, sunlight, and carbon dioxide (CO_2). Technically, the IABR has focused purposeful and targeted technological development to deliver a large scale, outdoor production facility that produces crude oil suitable for refining and market use. To advance success, the project will be further expanded in capacity, will deploy next generation of technologies, and will continue to provide tangible proofs necessary to support continued policy and investment advancements.

Overall Impressions

- A well-managed project that has achieved several major technical successes and is very well positioned to commercialize the process.
- Good execution and progress; a lot of innovation and intellectual property. The company is producing oil that customers are willing to buy. Unfortunately, very limited technical and economic information



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

provided to judge the claims. BETO should scrutinize the technical claims, including those on water recycling/treatment.

- Project development looks advanced compared to others in the public domain. Not sure of overall technical/economic viability. Utility in refinery not technically surprising; need to address regulatory issues in the case of jet fuel.
- The phase one design is not what they intend for a commercial facility. According to the presenter, they intend to change the pond design and improve upon the extraction design for their next phase, and changes to the harvest system would only occur if they find a more optimal design. This project claims to be on scope, schedule, and budget, which would indicate good project execution. However, the project appears to be attempting to engineer a better design for the next phase.
- The project is providing significant knowledge of the outdoor algae process.
- This appears to be a nicely executed project by an enthusiastic project team.

PI Response to Reviewer Comments

- No official response provided at time of report publication

INTEGRATED PILOT-SCALE BIOREFINERY FOR PRODUCING ETHANOL FROM HYBRID ALGAE

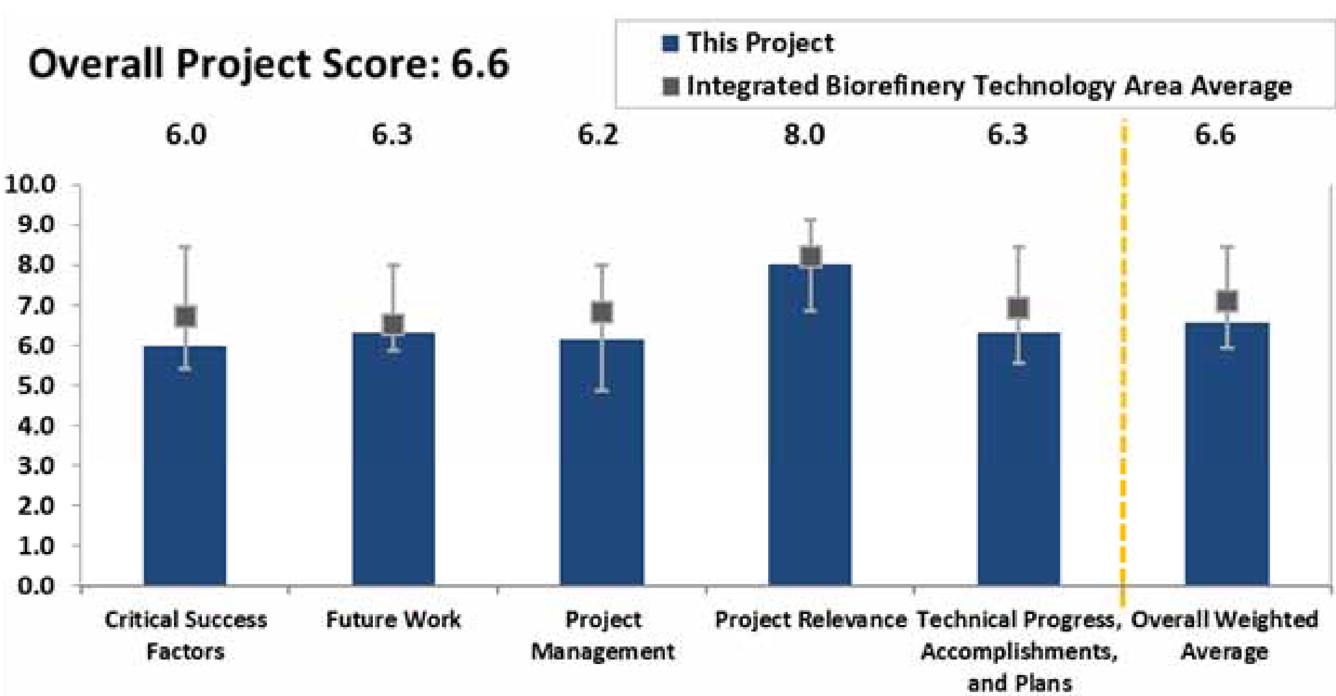
(WBS#: 5.11.1.2)

Recipient:	Algenol Biofuels Inc.
Presenter:	Ed Legere
Total DOE Funding:	$24,331,431
DOE Funding FY13:	--
DOE Funding FY12:	$8,500,000
DOE Funding FY11:	$9,200,000
Project Dates:	2010-2015

Project Description

Algenol's Direct to Ethanol® technology is based on overexpressing the genes for fermentation pathway enzymes—found widely in nature—in blue-green algae. The resulting metabolically enhanced, hybrid algae actively carry out photosynthesis and utilize carbon dioxide to make ethanol inside each algal cell. The ethanol diffuses through the cell wall into the culture medium within the photobioreactor. The ethanol is then distilled from the culture medium. The ethanol-water supernatant is collected and distilled into fuel-grade ethanol. The productivity of these algae is currently being optimized in several ongoing experiments at various scales, including fully operational and integrated commercial-scale photobioreactors operating at the integrated biorefinery in blocks of up to 4,000 reactors.

The proposed pilot-scale biorefinery will consist of up to two acres of fully enclosed, plastic, commercial-scale photobioreactors and supporting areas for testing, operations, distillation, and storage. The project has been divided into three budget periods. In budget period one, Algenol optimized strains of hybrid algae and photobioreactors, generated near final blueprints and construction plans, and identified all necessary regulatory approvals and permitting for construction and operation. In budget period two, Algenol will construct the biorefinery, establish minimum performance characteristics, and test second-generation ethanol/water separation equipment. In budget period three, Algenol will demonstrate commercially viable operations, optimize operating conditions, improve efficiency, and reduce costs.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Algenol and its collaborators have collectively established and advanced a project that is responsive to the selection criteria and the goals of the Office of Energy Efficiency and Renewable Energy. As the project transitions into budget period two, significant advancements have been made by the project teams executing the project with respect to molecular biology, engineering, pilot plant design and construction planning, and regulatory compliance. These advancements have continued to establish the commercial viability of the technology and, at a minimum, have met the budget period one gate criteria.

Overall Impressions

- After a rough start advancing their technology, the team and project appear to be demonstrating adequate project execution ability and success in meeting high biofuel production with algae.
- An interesting project; they have made significant progress over the recent two-year timeframe.
- Engineering and business are outrunning technology. Need to continue to focus on technology and understanding of how to better test/model scale-up issues.
- Interesting technology with significant risk involved in strain performance, downstream processing.
- Use of photobioreactors for algae is a very capital-expenditure- (CAPEX) intensive path. This is evidenced in this project. Unfortunately, the company has been grappling with contamination. Ironically, this is supposed to be the advantage of photobioreactors. Project funds are just being burned at this time. Only seeing 0.5% concentration. Distilling will be a significant hurdle to overcome.

PI Response to Reviewer Comments

- Given the public nature of this review, Algenol chose to limit the requested detail of this presentation to information that it deemed would not compromise its competitive and intellectual property positions. Reviewer concerns about various aspects of the project have, in fact, been addressed in significant detail during the execution of the project. Although detailed data was not presented in this particular forum to this review panel, it has been provided to the DOE project administrators and independent engineer during weekly teleconferences, annual project reviews, on-site visits, and other periodic reports. We apologize to the reviewers for failing to be completely responsive to their detailed information request.

SOLAZYME INTEGRATED BIOREFINERY: DIESEL FUELS FROM HETEROTROPHIC ALGAE

(WBS#: 5.11.3.1)

Recipient:	Solazyme, Inc.
Presenter:	Mark Warner
Total DOE Funding:	$21,765,738
DOE Funding FY13:	$1,800,000
DOE Funding FY12:	$10,600,000
DOE Funding FY11:	$5,900,000
Project Dates:	2010-2014

Project Description

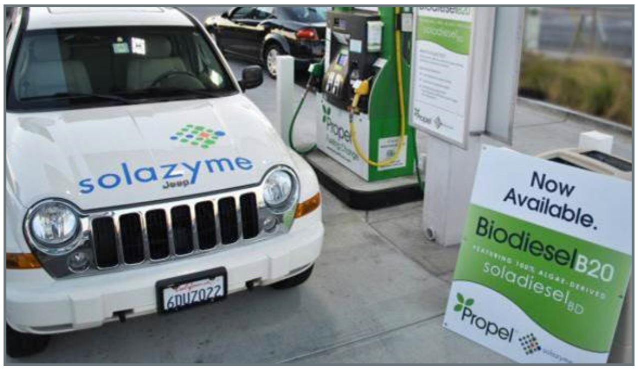
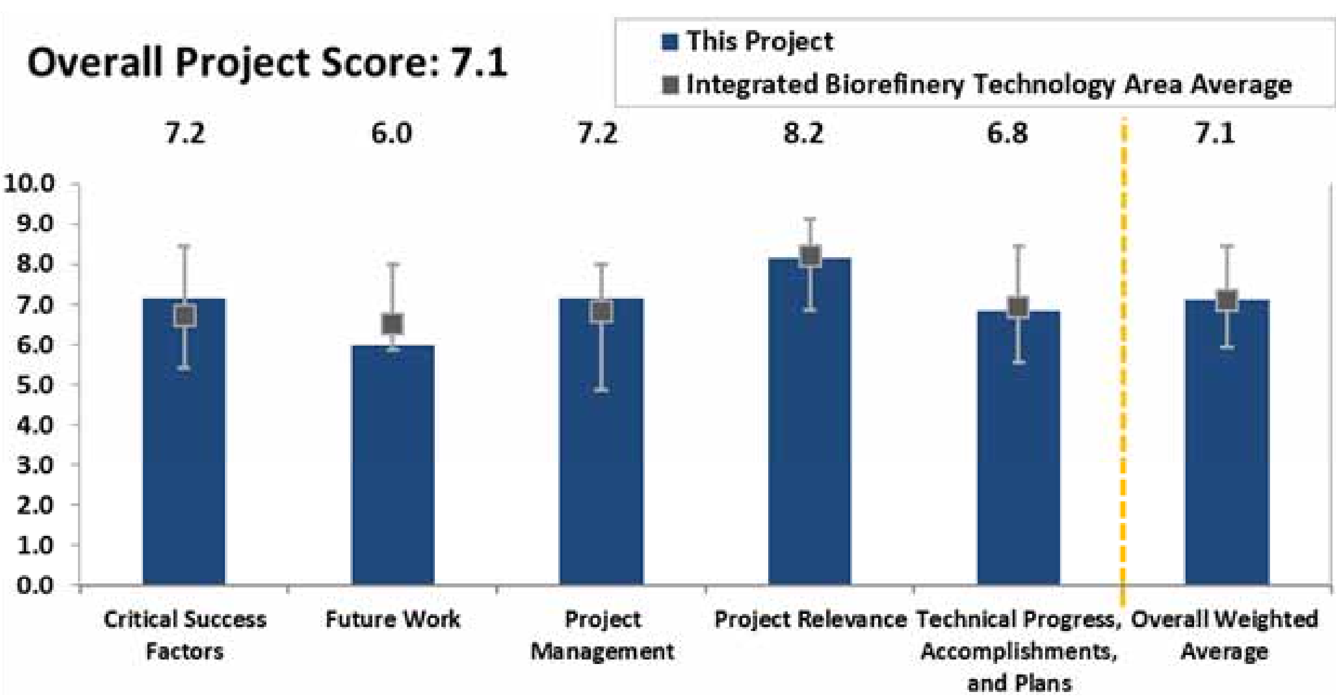


Photo Courtesy of Solayme, Inc.

Solazyme, Inc., has built a demonstration-scale Solazyme Integrated Biorefinery (SzIBR). The SzIBR provides integrated scale-up of Solazyme's novel heterotrophic algal oil biomanufacturing process, validates the projected commercial-scale economics of producing renewable oils for multiple applications—including production of advanced biofuels—and allows Solazyme to collect the data necessary to complete the design of its first commercial-scale facility. The project is on schedule and on budget. Solazyme's technology enables it to convert a range of low-cost, plant-based sugars into high-value oils. Solazyme's renewable products replace or enhance oils derived from the world's three existing sources—petroleum, plants, and animal fats. Solazyme tailors the composition of its oils to address specific customer requirements, offering superior performance characteristics and value. In support of U.S. Navy contracts, Solazyme manufactured an end product by contracting with refiners to produce fuels of targeted specifications. Fuels derived from Solazyme's oil are compatible with existing refining and distribution infrastructure, meet industry specifications, and are used with unmodified



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

factory-standard engines. Solazyme's approach to advanced biofuel production can enhance national energy security and help the United States reach the goals of the Renewable Fuel Standard, not only by displacing petroleum imports, but also by maintaining full compatibility with today's existing infrastructure. Solazyme's platform exploits the prolific oil production capabilities of microalgae as a biocatalyst while leveraging standard fermentation processes and existing industrial equipment to transform renewable biomass, such as plant-based sugars, into tailored oils. Solazyme has also pioneered methods to inexpensively recover algal oil with high yields. Solazyme has already produced hundreds of thousands of gallons of algal oil that it has refined into F-76 and other fuels, meeting applicable American Society for Testing and Materials standards without blending with other fuels/fuel feedstocks. SzIBR is Solazyme's first fully integrated refinery; today, Solazyme is successfully converting carbohydrate feedstocks into tailored oils at one location.

Overall Impressions

- After a very rough start—including a site change and difficulty in initiating their construction revamp at the new site—the project showed that the company was eventually able to get people who had the ability to execute the project and operate the facility. This is a good plant for the demonstration of this technology.
- Good overall performance despite setbacks. Thorough pilot testing to vet out each unit operation before scaling up. Successfully producing oil, although no performance or economic data were presented.
- Good project; well-executed at this stage of development; creative evaluations of multiple uses, including high-end products to give leeway on feedstock price swings.
- Solazyme has developed a small-scale, versatile, specialty oil manufacturing facility that should be useful in the future for more oil developmental work at larger scale.
- The presenter gave more of a sales pitch rather than a project overview. The presentation template was not rigorously followed, and requested information was not provided. This reviewer found himself confused (even after re-reviewing the presentation) as to what the project will produce, and from what feedstocks, or what the process is.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

BEI - MYRIANT SUCCINIC ACID BIOREFINERY (MYSAB)

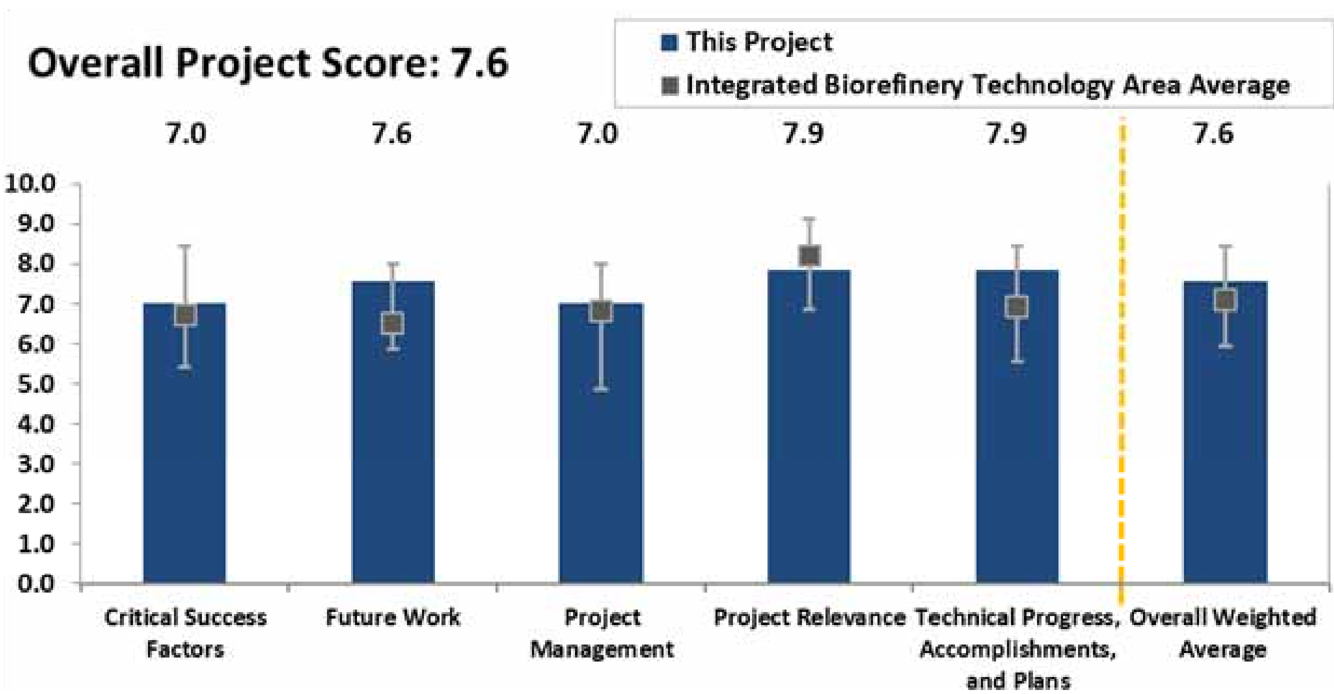
(WBS#: 5.2.3.1)

Recipient:	Myriant (Myriant Lake Providence, Inc.)
Presenter:	John Ellersick
Total DOE Funding:	$50,000,000
DOE Funding FY13:	$5,400,000
DOE Funding FY12:	$24,800,000
DOE Funding FY11:	$10,900,000
Project Dates:	2007-2013

Project Description

Photo Courtesy of Myriant

Myriant Succinic Acid Biorefinery (MySAB), located in Lake Providence, Louisiana, is a bio-succinic acid production facility with a name plate capacity of 30 million pounds per year. MySAB is a multi-feedstock facility built to process a variety of renewable feedstocks, including sugars derived from grain sorghum and other commercially available sugars. Myriant displaces petroleum-derived chemicals by making the equivalent replacement chemicals from renewable feedstocks with no green premium, and with reduced environmental impact. Recent project accomplishments include beginning commissioning in the first quarter of 2013, achieving facility mechanical completion in April 2013, and conducting first process operations. Major technical accomplishments since our last peer review include entering budget period two, site mobilization, project construction, third-party contracts negotiation and execution, and management of vendors through equipment receipt, construction completion, commissioning, and start-up of all unit operations. Equipment handover was phased with the commissioning of utilities and early process units in parallel with final unit completion, with the ultimate goal of minimizing start-up time and maximizing presence of mechanical contractors to address any early commissioning and start-up issues. The first fermentations at the plant occurred in late April. Challenges included dealing with site soil conditions that were less than optimal; a



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

mix of state and federal funds, which required Myriant to self-execute many of the contracts; and a longer-than-planned construction schedule. Many of the third-party contracts were integral to the project execution and required careful integration with our engineering, procurement, and construction contractor. The phased handover strategy was critical to our quick and effective start up; however, it presented a challenge for organizing and executing the mechanical completion handover packages. During the two-year construction phase of the project, Myriant employed between 250 and 450 people. The MySAB facility currently employs 53 direct personnel for operating the plant. The American Chemistry Council estimates that for every direct chemical industry job, approximately six to seven indirect jobs are created; therefore, Myriant's plant is supporting approximately 350 indirect jobs in the region. At this time, Myriant is continuing the start-up of the MySAB facility and is planning to be in full operation by the end of the second quarter of 2013.

Overall Impressions

- A very good project based on what limited information the representatives of the company shared with us. At face value, it appears to be generating a good return on investment for the U.S. taxpayer.
- Although difficult to assess from the lack of content in the presentation, it appears that the program will be successful in transitioning the developed technology for manufacturing succinic acid from cellulosic feedstocks.
- Based on this, it looks like some DOE research funding should go toward developing additional oxygen containing/fermentation-based chemicals to take advantage of low natural gas and sugar prices.
- Myriant looks to have been successful in designing, manufacturing, and installing its process. Long-term operation will now determine the commercial success of the project. They look to understand the market for their product and hopefully will be successful in proving their process.
- Not a perfect fit to BETO goals, but the project is an essential component of a forward-looking biomass energy strategy.
- Pending a successful start-up, this project appears to be a very promising lead-in to other commercial bio-chemicals facilities.
- The project is in commissioning and was apparently adequately executed. The lack of integrated piloting creates an unknown on what final product quality they can achieve.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

INP BIOENERGY INDIAN RIVER COUNTY FACILITY

(WBS#: 5.2.4.1)

Project Description

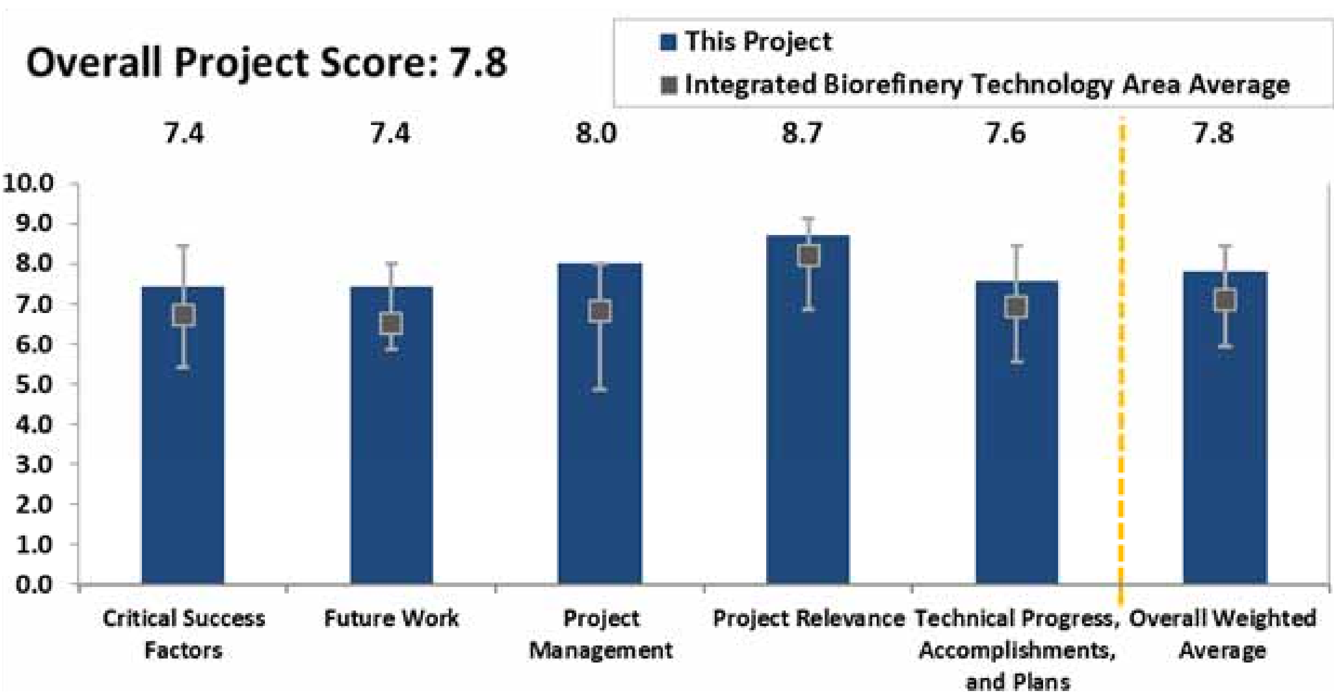
Photo Courtesy of INEOS, LLC

Recipient:	INEOS New Planet Bioenergy, LLC
Presenter:	Dan Cummings
Total DOE Funding:	$50,000,000
DOE Funding FY13:	$3,500,000
DOE Funding FY12:	$25,200,000
DOE Funding FY11:	$15,400,000
Project Dates:	2009-2014

INP BioEnergy has completed construction and commissioning and is now starting operations of the first commercial-scale facility employing the INEOS Bio bioenergy process technology on a site in Indian River County Florida (known as the Indian River BioEnergy Center). The facility will produce eight million gallons per year (mgpy) of cellulosic ethanol and 6 megawatts (gross) of electricity at full rates. The project is demonstrating key equipment at full commercial scale using vegetative, yard, and wood wastes as initial feedstocks and post-recycled municipal solid waste (MSW) as a feedstock (planned in late 2013). Lessons learned from the demonstration scale will be incorporated into the design, construction, operation, and rapid deployment of future projects by INEOS Bio and its licensees. INP BioEnergy has constructed the facility on a 70-acre site located one mile from I-95, adjacent to the Indian River County, Florida, solid waste landfill.

Overall Impressions

- This project appears to be well-supported with extensive pilot experience and data. The project



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

team has executed construction within cost and near schedule. Based on answers given by the presenter, there does not seem to be much feedstock logistics risk. This is an excellent project as a demonstration of this technology's conversion.

- A low-risk approach to a hybrid power/fuel generation plant. It is unclear how the company would move this beyond plant one, however.
- Due to the use of a downstream anaerobic fermenter, this is a first-of-a-kind facility.
- Good overall project. Not sure if it will be as simple and problem-limited as portrayed. Well-designed plant site reflecting experience of the company and vendors. The key now is identifying issues and mitigation as a function of feedstocks, especially MSW.
- Good project development and execution. Brought to conclusion successfully. Advantage of this technology is its hybrid nature (syngas-fermentation) with gasification, allowing the company to utilize a wide variety of feedstocks with negative cost (improving economics).
- The developers have done a good job of bringing this project to completion. Assuming the project proves successful, this will be a big success for BETO.
- World-class project performance. Good fit for MSW utilization at the local level. Apparently a smooth scale-up, design, construction, and start-up.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

PILOT-SCALE BIOREFINERY: SUSTAINABLE TRANSPORT FUELS FROM BIOMASS AND ALGAL RESIDUE VIA INTEGRATED PYROLYSIS AND CATALYTIC HYDROCONVERSION

(WBS#: 5.4.10.1)

Recipient:	UOP, LLC
Presenter:	Stephen Lupton
Total DOE Funding:	$25,000,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2009-2015

Project Description

UOP, LLC, a Honeywell Company, partnered with Ensyn Corporation to build and operate a pilot-scale integrated biorefinery located at the Tesoro Refinery in Kapolei, Hawaii. The biorefinery integrates Ensyn's rapid thermal processing (RTP) pyrolysis technology with UOP upgrading technology to demonstrate a feedstock-flexible process that will produce fungible transport fuels from lignocellulosic biomass. Feedstock producers sourced biomass samples and technical information used for assessing the detailed life-cycle impacts. Michigan Technological University and UOP conducted a life-cycle assessment that showed that drop-in biofuels derived from most of the feedstocks being evaluated under this project will meet the greenhouse gas (GHG) reduction threshold of cellulosic biofuels. Refiners and engine manufacturers

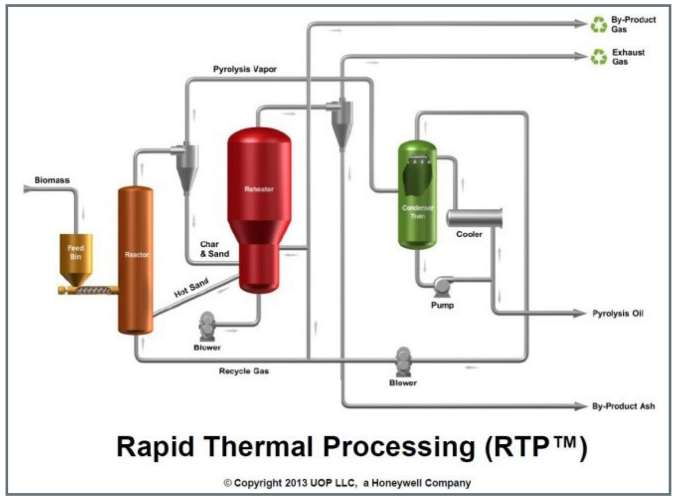
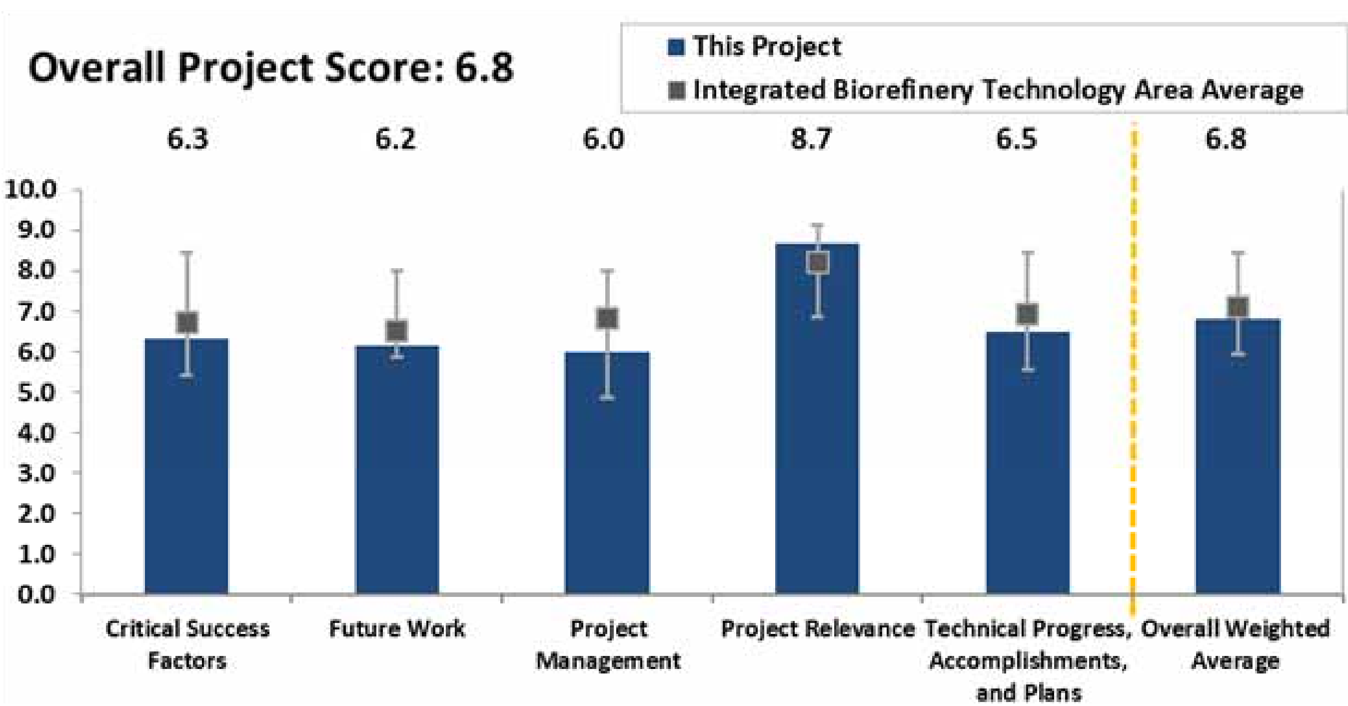


Photo Courtesy of UOP, LLC



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

are also team members and will demonstrate refinery compatibility and fuel properties, which accelerates qualification and acceptance. The RTP™ unit was fabricated and then installed at the Kapolei site in 2011. The project focus in 2012 was to shakedown the RTP™ unit, which converts solid biomass into a liquid pyrolysis oil product. During this shakedown, a number of minor equipment issues were identified and corrected. The pyrolysis oil produced from wood biomass was analyzed and found to have acceptable properties for upgrading to hydrocarbon fuels. The first-stage upgrading of the pyrolysis oil will be tested in June 2013. This first stage of upgrading will remove metallic contaminants from the pyrolysis oil produced. Detailed process and instrumentation diagrams for the second-stage upgrading unit to convert the de-metalized pyrolysis oil to hydrocarbon fuels were prepared and reviewed. However, a number of scale-up issues were identified during the piloting studies being conducted at UOP's R&D center in Illinois. As a result, the release of the second-stage upgrader for fabrication has been delayed. Also, the shutdown of Tesoro refining operations at the Kapolei site will necessitate looking at alternative options of hydrogen supply for the upgrader to convert pyrolysis oil to hydrocarbon fuels. Despite this delay, it is currently estimated that the project will be completed by the September 2015 deadline.

Overall Impressions

- UOP was in the process of debugging Upgrader 2 when it began construction of the facility. They have not yet debugged Upgrader 2, and construction of RTP and Upgrader 1 are complete. According to the presenter, progressing with construction of the first upgrader was done earlier than UOP would have typically done. The loss of the hydrogen supply appears to be a very big issue.
- Having the unfortunate circumstance to have lost both its host and hydrogen supplier, UOP has some significant hurdles to overcome in order to meet its project goals.
- This is a well-managed pyrolysis oil approach to achieving DOE's IBR goals.
- This project, although very interesting and relevant, has been plagued by technical and managerial issues. It is encouraging that the company recognizes the need to address those issues promptly and to shoulder the resulting financial responsibility for making the project successful. Producing such fuels from renewable biomass is very important.
- Unfortunately, with the shutdown of the Tesoro refinery, this project appears to be a stranded asset at the current time. This reviewer suggests a strategic decision-making session among all stakeholders to decide the future course of this project.
- UOP is investing its own cash, indicating continued interest in this technology. Hurdles to achieve critical success factors are significant. Surprising miss on scale-up of Upgrader 2 given UOP's reputation in industry.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

LIBERTY - LAUNCH OF AN INTEGRATED BIOREFINERY WITH ECO-SUSTAINABLE AND RENEWABLE TECHNOLOGIES IN Y2009

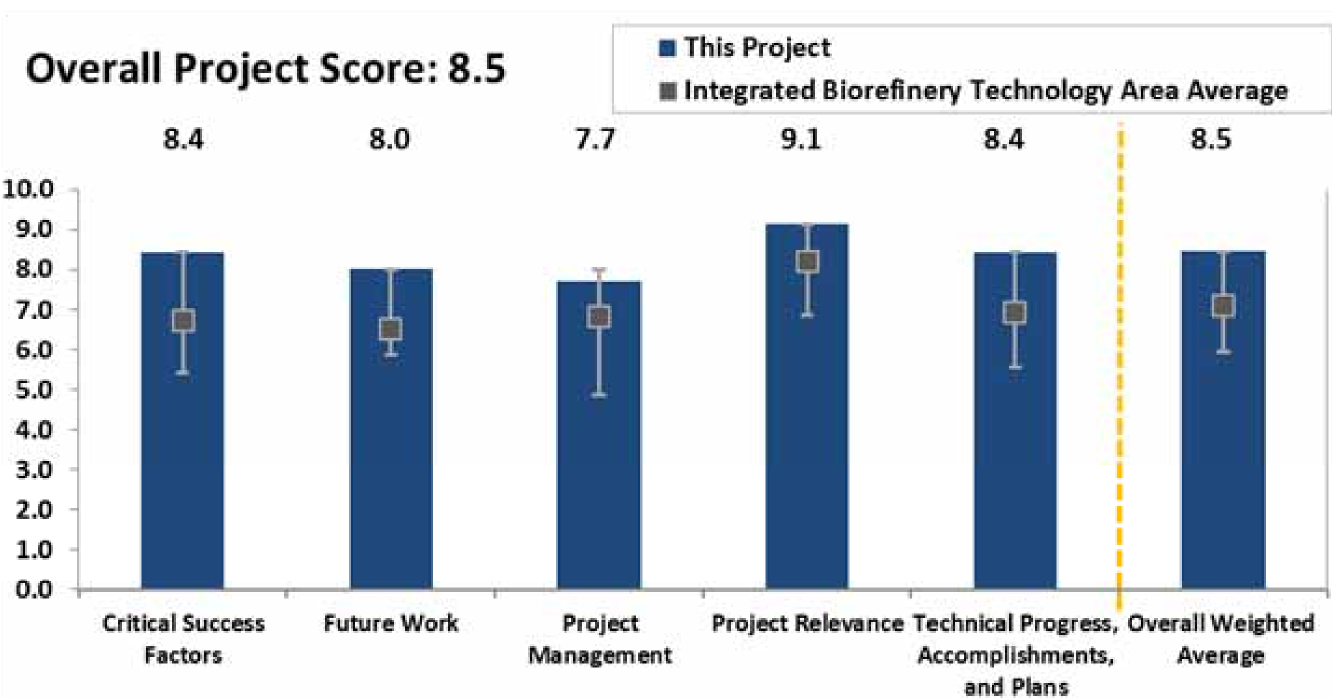
(WBS#: 5.4.3.3)

Recipient:	POET
Presenter:	Larry Ward
Total DOE Funding:	$100,000,000
DOE Funding FY13:	$10,200,000
DOE Funding FY12:	$4,600,000
DOE Funding FY11:	$3,200,000
Project Dates:	2007-2014

Project Description

Photo Courtesy of POET

Project LIBERTY is dedicated to the development and operation of a commercial-scale cellulosic ethanol biorefinery. Project LIBERTY will be co-located with POET Biorefining-Emmetsburg, an existing corn-based ethanol biorefinery in Emmetsburg, Iowa. The corn-based biorefinery currently has a name-plate capacity of 50 mgpy and is one of 27 POET biorefineries. Project LIBERTY will produce an additional 20 mgpy, increasing to 25 mgpy of ethanol from lignocellulosic material, namely corn cobs and high-cut material from the corn plant. Corn farmers from the surrounding area will supply the feedstock to the biorefinery. POET will convert lignin, the primary waste product from the cellulosic and corn-based biorefineries. The Project LIBERTY business model will enable rapid deployment of the cellulosic ethanol process across an expansive corn ethanol industry. Rolling out LIBERTY technologies to 180 biorefineries in the United States' "corn belt" would



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

represent 4.5 billion gallons of ethanol annually, more than 7,000 biorefinery jobs, and new revenue for more than 70,000 farmers harvesting biomass. The rollout of LIBERTY technologies will help the nation rapidly advance toward its biofuels mandates, as well as reduce its dependence on foreign oil.

Overall Impressions

- A good amount of front-end work; a number of thoughtful design reworks, and "what if" studies have resulted in a final feedstock management system and a cellulosic ethanol conversion process that ought to work very well. The Scotland, South Dakota, pilot plant has apparently proven to be invaluable during its five years of operation—it pays to pilot. It is obvious to this reviewer that they have done their homework.
- Excellent synergies with an existing corn ethanol plant, including relationships with local farmers, ethanol storage, and operations support. This project had a delayed start to complete piloting trials. The piloting work appeared to be extensive. After the piloting trials were complete, POET appears to be adequately executing the project. The project has performed extensive trials for the harvesting and handling of feedstocks. This project should be an excellent demonstration of this technology on a commercial size—from the harvesting efforts through the production of ethanol—and should be a starting point for future locations at POET's other existing plants.
- Overall, a well-managed project with good technical successes. The performer should put more focus on commercial and transition partnering and planning, especially with the saturation of the ethanol market. The fallback position in case of drought, etc., is in fact rather weak. The performer did not give a substantive answer to how they would deal with a shortfall of supply from the immediate region supplying the plant.
- Vast experience in ethanol operations. Good business model of integrating cellulosic technology at own facilities.
- Well-executed project. Attention to feedstock collection and preparation a significant plus. Realistic in their expectations for commissioning and start-up.
- A well-thought-out project reflecting the benefits of leveraging DOE money with a pragmatic operating company. Also impressed with their much greater focus on feedstock compared to other projects.
- With the project managed and operated by an experienced major ethanol producer, this looks like a very good project for BETO.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

INTEGRATED BIOREFINERY FOR CONVERSION OF BIOMASS TO ETHANOL, SYNTHESIS GAS, AND HEAT

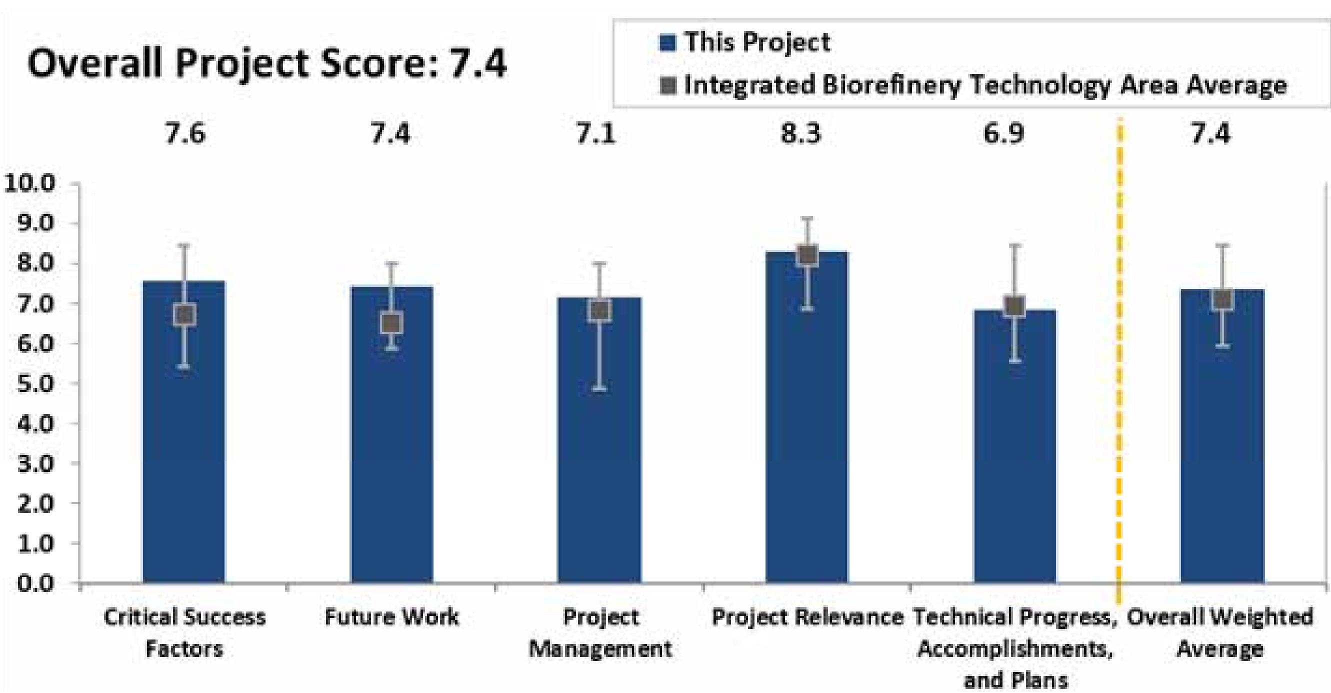
(WBS#: 5.4.4.1)

Recipient:	Abengoa
Presenter:	Joe Bradford
Total DOE Funding:	$97,452,893
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2007-2014

Project Description

Photo Courtesy of Abengoa

Abengoa Bioenergy Biomass of Kansas, LLC, is in the process of designing and constructing a biorefinery facility to produce cellulosic ethanol in Hugoton, Kansas. The process utilizes an enzymatic hydrolysis process to produce ethanol, process steam, and all electrical power required to operate the facility via an integrated biorefinery and cogeneration system. Initial feedstocks that will be used are corn stover and wheat straw, with other feedstocks planned for the future—including milo (sorghum) stubble, switchgrass, warm season grasses, and other opportunity feedstocks that are locally available. Use of multiple feedstocks will contribute to operational flexibility and will make the plant easily replicable in different geographical areas. The total biomass input for the facility will be 1,100 dry tons per day, resulting in 25 mgpy of ethanol production, sufficient process heat for the biorefinery operations, and 21 megawatts of renewable electricity—part of which is available for sale to the electrical grid. The cogeneration system will use the ethanol process by-products, including stillage, cake/syrup, biogas, and sludge, resulting in no planned landfill. When desirable, additional feedstock can be supplied to the boiler for increased electrical supply to the grid. With the facility producing all of the



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

biomass-generated site power, in addition to supplying remaining amounts to the grid, a high level of GHG reduction is achieved. Economic benefits include more than 300 (on average) construction jobs, 68 permanent jobs ($5 million annual payroll), and approximately $17 million in feedstock payments to local farmers. The project also includes the development of all biomass procurement processes and contracts, including the purchase of lands, easements, and utility supplies required to achieve an Abengoa-owned and operated facility. Cogeneration start-up is expected in late 2013, with the ethanol facility following in the first quarter 2014.

Overall Impressions

- This project appears to be heading toward the successful implementation of a commercial project. Despite a rough start, the project appears to have been adequately managed and supported with adequate piloting. However, the internal piloting of the Abengoa demonstration system was not the same as the project intends to use, and they appear to have relied more on vendor trials and guarantees. I expect them to have start-up/initial operations lessons learned with the AD system. After addressing initial operations issues, I believe this project will be an excellent demonstration of this technology on a commercial size. They have done extended feedstock testing and logistics.
- Given the project has progressed to completion of construction and is nearing start up, the project looks to be a success for BETO. Plant operations and testing will determine the ultimate success of the project to meet product cost goals.
- This looks like a well-thought-out and well-run project with significant support from current company personnel; not an isolated project.
- Solid project executed by an experienced company. Significant previous experience at pilot and demonstration scales serves well in the design and improvement of this commercial facility.
- Some concern that “surprises” in start-up and operation could arise because the project was not piloted on an integrated, demonstration scale.
- The presentation was exceptionally lacking in information. There was no information given even as to the type of process or its implementation.
- This appears to be a pretty good plant design; let’s see it run. Since Abengoa was one of the very early entrants into the cellulosic ethanol field at this scale, this plant design was “frozen” some time ago. There has been much progress in this area in the last few years, and there are probably several improvements that Abengoa now wishes it had incorporated into its original design. What are those potential improvements? Can they be retrofitted into the Abengoa plant?

PI Response to Reviewer Comments

- No official response provided at time of report publication.

CONVERSION OF LIGNOCELLULOSIC BIOMASS TO ETHANOL AND ETHYL ACRYLATE

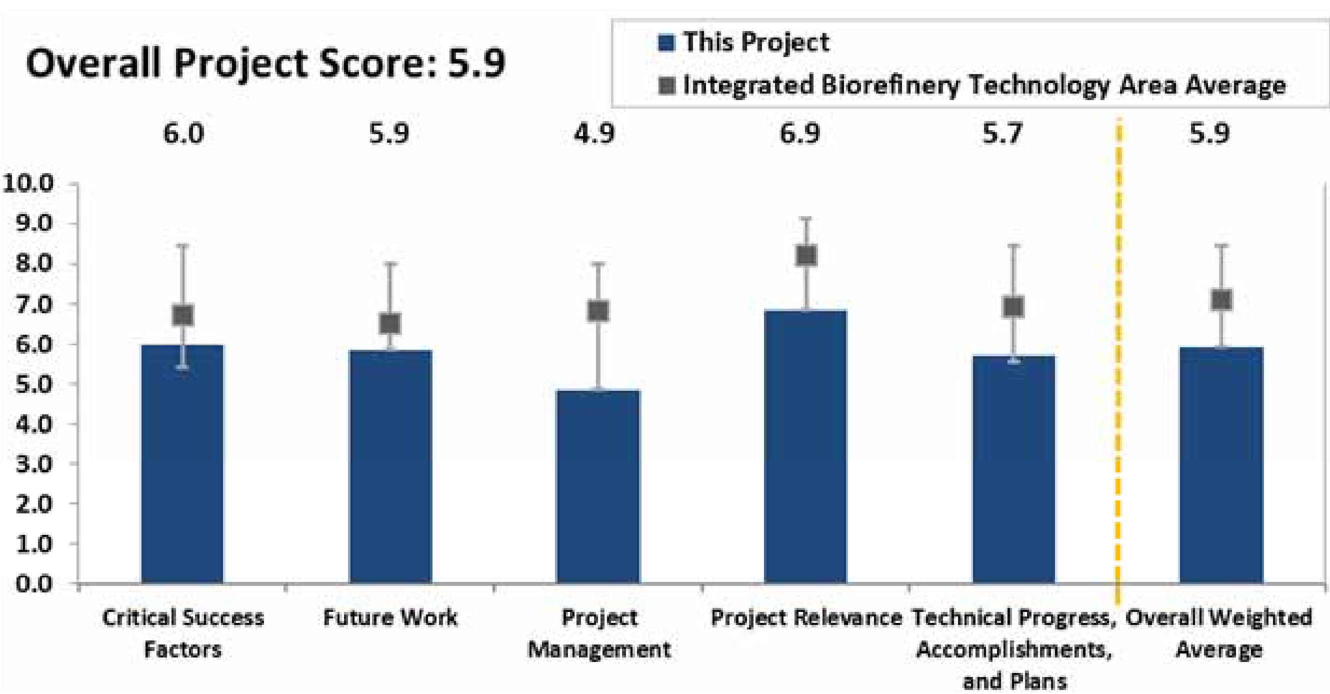
(WBS#: 5.4.9.1)

Recipient:	Archer Daniels Midland
Presenter:	Thomas Binder
Total DOE Funding:	$24,834,592
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010-2014

Project Description

Photo Courtesy of Archer Daniels Midland

The primary goal of this project is to demonstrate a process and technology to produce ethanol and chemicals from corn stover at a pilot-scale facility. The pilot plant construction phase is nearing completion, and the biomass fractionation and fermentation sections are currently being operated (with the longest run time to date being 12 hours). The cellulose stream has been successfully enzymatically hydrolyzed and fermented to ethanol. A slip stream of glucose from this process has been purified and converted to acrylic acid at the bench scale. For the next several months, the front end of the process will be optimized, and data concerning the fractionation process will be collected. Following the front-end optimization, the fermentation of the cellulose stream and then the hemicellulose stream will be conducted. Larger-scale purification of the dextrose for conversion to acrylic acid will begin once this optimization is completed. This project will be viewed as a success when the optimization of the process leads to a valid economic model that will determine scale-up potential for all products from the biomass fractionation.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- The Archer Daniels Midland project team appears to be ambivalent on this approach. A stronger ethanol market outlook could help to increase their interest.
- The project team recognizes the changing landscape in the ethanol business and is looking to develop other, more potentially valuable products from cellulose. Given the recent developments in shale gas production and horizontal drilling and fracking for previously poor-producing oil fields, the demand for increased ethanol production is questionable. Looking for more valuable products from the process is a must.
- Good overall impression. A company like Archer Daniels Midland has the ability to do a lot better, but the project does not seem to be a high priority for them.
- If possible, they should do more lab work on alternatives and slow down the current project, or look for other uses for the plant. This project reinforces the need for DOE to focus attention on feedstock preparation and separations versus conversion.
- Management seemed disengaged, and the performer/presenter seemed disenchanted with the project. There was some interesting technology presented, but without stronger management, it seems it will languish.
- Considering the overall perspective charts at the end of the talk, if we are at or near the overall U.S.-wide demand for ethanol based on RFS, then why are we working so diligently on cellulosic ethanol plants? Are these projects even necessary?
- This project appears to have faced more issues than expected due to insufficient upfront testing. However, they appear to have addressed many of the issues. Their longest continuous run was only 12 hours. I believe a truer test of their design and technology would be a significantly longer test run.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

HETEROGENEOUS BIOREFINERY PROJECT

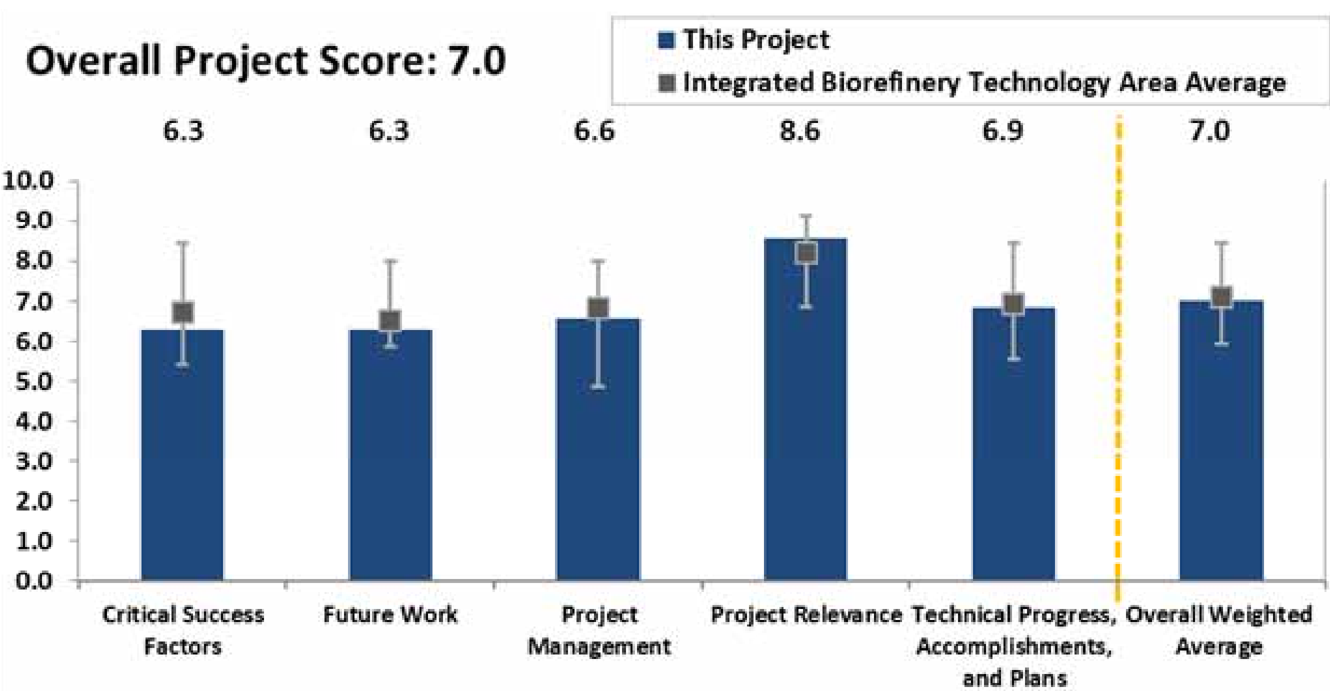
(WBS#: 5.5.10.1)

Recipient:	Enerkem Corporation
Presenter:	Tim Cesaek
Total DOE Funding:	$50,000,000
DOE Funding FY13:	$1,200,000
DOE Funding FY12:	$1,500,000
DOE Funding FY11:	$2,200,000
Project Dates:	2009-2015

Project Description

Photo Courtesy of Enerkem

Enerkem will build and operate an MSW-to-biofuels plant in Pontotoc, Mississippi, that will convert 100,000 dry tons of sorted MSW and other locally sourced residual woody biomass into 10 million gallons of RFS2-compliant cellulosic ethanol annually. The project will produce a renewable fuel from a non-food, sustainable source (MSW) that will reduce dependence on foreign oil, increase the life of existing landfills, and lower requirements for new ones. The process employed is environmentally friendly, energy efficient (low severity), and has air emissions well below established environmental limits. Enerkem has carried out the development of its technology from pilot plant to commercial-scale facility through carefully staged steps over more than 10 years. Scale-up has been rigorously tested at each stage. From the pilot to the beta plant, design capacity was scaled up by a factor of 10 and demonstrated through continuous operation since 2009. The proposed Pontotoc facility is scaled up in capacity by a factor of seven over the beta plant and is a carbon copy of Enerkem's first commercial facility in Edmonton, currently moving towards mechanical completion. To date, several technical/engineering challenges, including the production of chemically clean syngas produced from MSW,



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

as well as the conversion of syngas to alcohols using a thermo-catalytic process, have been overcome. Integration of the feedstock feeding system to the gasifier has been successfully completed. To date, methanol and ethanol synthesis of syngas has been successfully completed at the beta facility, and fuel-grade ethanol has been produced. Ten-million-gallon-capacity modules will be fabricated offsite and assembled in the field. This reduces construction complexity, risks, and costs. It also makes for a standard design that can be replicated easily and facilitates growth because several modules can be assembled in an array to increase plant capacity.

Overall Impressions

- A well-managed project that achieved the goals of the IBR Technology Area. Since this is plant number two, DOE should philosophically ask what it is trying to achieve. If they are trying to achieve risk reduction, there is little point in this plant. If they are trying to achieve market penetration and familiarization with the technology within the United States, then this project looks very good.
- Given the other projects in the pipeline for Enerkem, and assuming those projects can be operated successfully, the timing of this project should benefit from that experience. This project should have a good opportunity for success.
- Good opportunity for application in Mississippi. They have demonstrated technology at close to commercial scale.
- Good progress in running unit operations and completing construction. The parallel development of the Edmonton facility seems to contribute to the delay of the Mississippi facility, but at the same time, the latter benefits from lessons learned at the former. With regard to the presentation, the frequent reference to the Edmonton facility created a lot of confusion.
- Project appears to be reasonably well thought out and finally underway, pending financial closing, final engineering, construction, commissioning, and start-up. There is still a lot of work left to do.
- Reasonable to use phased approach, pilot and demonstration testing, and Edmonton learnings. Have a number of items to handle yet, with financing and contract issues as most limiting.
- The ethanol conversion portion is not ready and is pending additional work. The project is trying to go ahead with construction without having figured out the ethanol conversion step. This is not a good idea. In addition, this facility is in need of funds and, if true, could be in trouble.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

HIGH-YIELD HYBRID CELLULOSIC ETHANOL PROCESS USING HIGH-IMPACT FEEDSTOCK FOR COMMERCIALIZATION BY 2013

(WBS#: 5.5.11.1)

Recipient:	ZeaChem, Inc.
Presenter:	Tim Eggeman
Total DOE Funding:	$25,000,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010-2013

Project Description

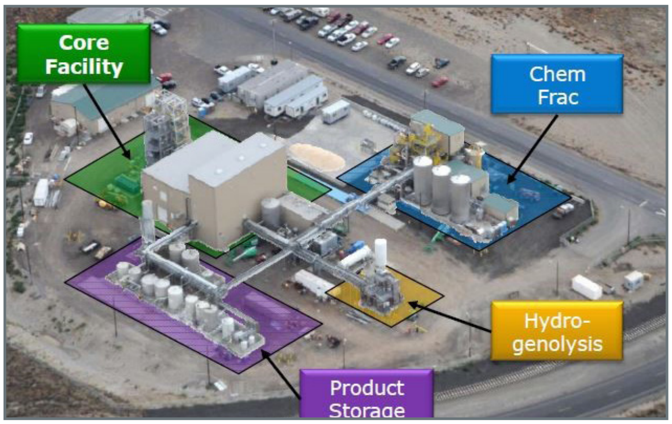
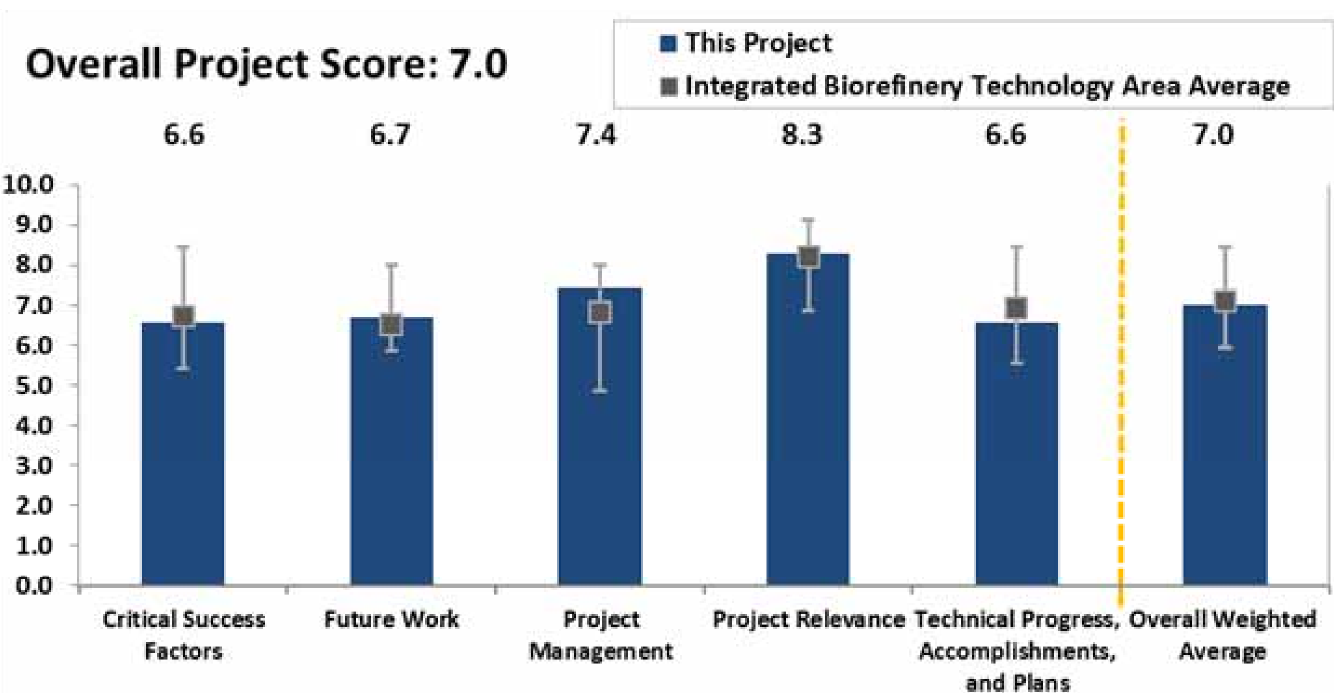


Photo Courtesy of Zeachem, Inc.

ZeaChem, Inc., has successfully constructed and operated a 10 ton/day integrated biorefinery in Boardman, Oregon, with assistance from a $31.25 million cooperative agreement with DOE. Cellulosic ethanol was first produced from the facility in February 2013 using hybrid poplar as the feedstock. This project is part of BETO's Integrated Biorefineries Technology Area and is well-aligned with the mission and goals of the MYPP. It's uses end-to-end process integration, in that it demonstrates and validates total process integration—from feedstock production to end product distribution. The IBR project has met expectations with respect to scope, is on schedule, and is on budget. The next major milestone is completion of the independent engineer's performance test, which marks the end of budget period two. The next go/no-go decision is Critical Decision 4 for entry into budget period three. Performance test runs of extended integration operations of the system will be conducted during budget period three. The test run



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

data is being collected in support of ZeaChem's ongoing project development efforts to finance, construct, and operate a follow-on first Commercial Plant. This follow-on first Commercial Plant is planned to be located adjacent to the existing IBR facility, will use the same feedstocks as tested in the IBR facility, and is planned to produce 25–50 million gallons/year of cellulosic ethanol as its primary product.

Overall Impressions

- Good synergy with existing site. Project is getting ready for IE performance test. A supply system is in place for feedstock (both poplar and wheat straw). Construction is being completed near schedule and cost (without use of their contingency). Excellent project as a demonstration of this technology's conversion.
- It appears that there is an interesting innovation in the zero-CO_2 fermenter, but so little (really none) information was given regarding this technology that it is difficult to assess its potential impact on the community. It does, however, show higher yields.
- A relatively new company (founded 2002). Funded by several tranches of venture capital money. Venture capital funding is leveraged with DOE money.
- The technology appears to be sufficiently flexible to manufacture fuel and petrochemicals.
- The project developers have done a good job of managing all aspects of this project—from feedstock, to design and construction, and now to start up. Operation of the plant should provide valuable insights for the commercial design.
- The project was well-run and so far has stayed on time and on budget converting woody biomass to ethanol. Unfortunately, no process or economic data were provided to judge the prospects for commercial development. The remaining performance runs will be critical in determining the ability to run the integrated process routinely.
- A well-run project on time and on budget. The main issues are feedstock related, and continued, integrated fermentation to acids and ability to swing between two-carbon and three-carbon products.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

PILOT INTEGRATED CELLULOSIC BIOREFINERY OPERATIONS TO FUEL ETHANOL

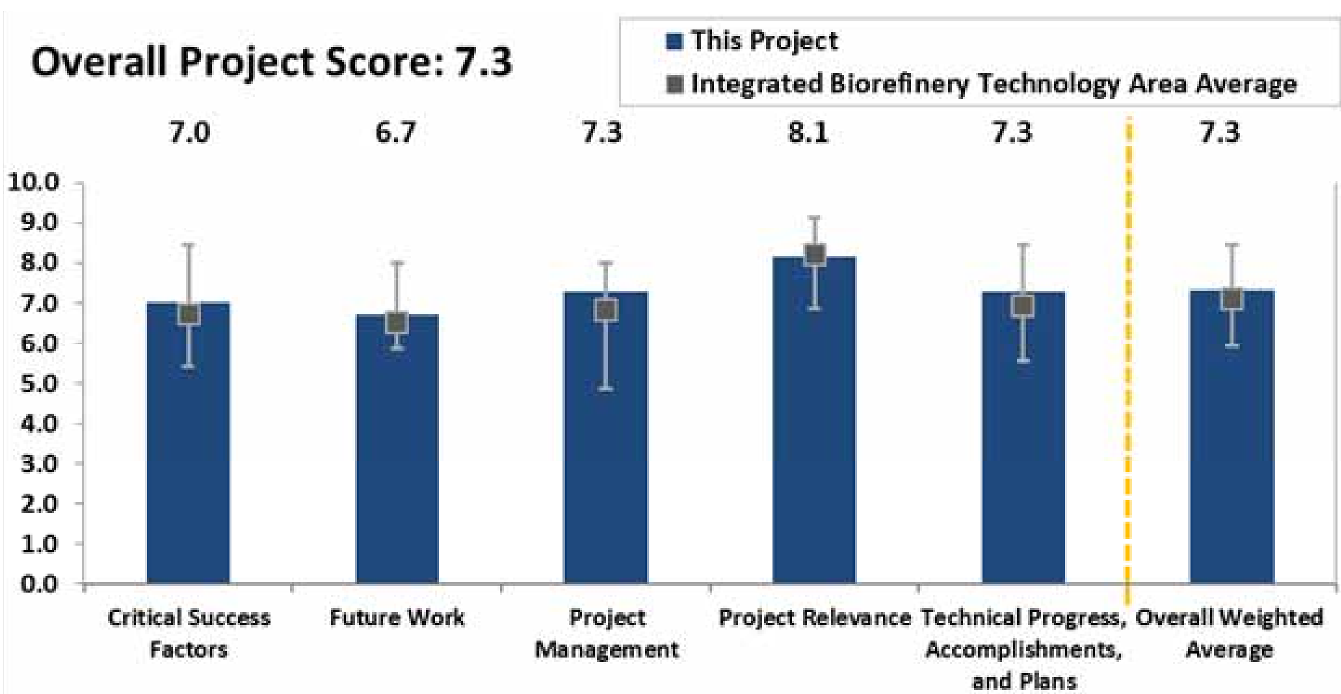
(WBS#: 5.5.12.1)

Recipient:	ICM, Inc.
Presenter:	Douglas Rivers
Total DOE Funding:	$25,000,000
DOE Funding FY13:	$2,429,304
DOE Funding FY12:	$4,223,739
DOE Funding FY11:	$10,362,734
Project Dates:	2010-2014

Project Description

Photo Courtesy of ICM, Inc.

ICM has modified its pre-existing grain pilot plant located in St. Joseph, Missouri, into a fully integrated cellulosic biorefinery capable of processing captive corn fiber, switchgrass, and energy sorghum. ICM uses an integrated biochemical platform that combines pretreatment and enzymatic hydrolysis technology, coupled with a robust five-carbon/six-carbon co-fermentation that produces fuel ethanol and co-products. Construction was completed on schedule in September 2011, and commissioning of the integrated pilot biorefinery began at that point. Following process water testing, the next six months of operations focused primarily on the pretreatment unit operation using captive cellulosic corn fiber as the feedstock. Pretreatment steps were modified to reduce fouling, facilitate proper level controls, pH control, temperature control, and to adapt the clean-in-place cleaning regimen to maintain proper operational conditions. Once pretreatment operations were opti-



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

mized, ICM prepared to conduct a process qualification campaign in March–April 2012. This campaign used corn fiber as the feedstock and followed the ICM co-located process design over a seven-week period. All operations functioned, but a number of opportunities for initial improvement became apparent. Following adjustments to the process, ICM conducted an initial 1,000+ hour campaign in October–November 2012 using its proprietary integrated fiber approach designed to capture the cellulose present in corn. Fermentations were completed at both 15,000-gallon and 585,000-gallon capacities, and proved an average increase in ethanol yield of about 10% per bushel. This confirmed the potential production of 1.3–1.4 billion gallons of cellulosic ethanol in the existing U.S. ethanol industry. The required bolt-on CAPEX is estimated at $2–$3/installed gallon of added production capacity. ICM will conduct additional optimization studies and campaigns using energy sorghum and switchgrass as the feedstocks.

Overall Impressions

- I appreciate candor on learnings in safety and fouling. Important for broad applicability.
- As a company successfully commercializing first-generation ethanol projects, ICM should understand the success criteria for second-generation cellulosic bioenergy systems. In the end, the final product cost and government policies surrounding the use of ethanol as a transportation fuel will determine the success of these ethanol-based projects.
- Interesting technology. Management of the program is unconventional, perhaps a bit lax. Implementation of conventional management tools may aid them in finding ways to further trim operational costs and control further schedule slips.
- Nicely done, very good project. Good project execution. Keep up the progress!
- Overall good impressions about progress and ability to overcome issues.
- This project appears to have been executed well. However, they said they have not dried their 120-proof ethanol to fuel grade and checked for American Society for Testing and Materials compliance. They indicated they would perform this quality task.
- Useful work for seeing if we can leverage existing mills and the issues around personnel, as well as technology. Actually had data, which is more than some other projects showed.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

FULTON ETHANOL FACILITY: A LANDFILL WASTE FEED-STOCK TO CELLULOSIC ETHANOL FACILITY - AWARD 2 - ARRA

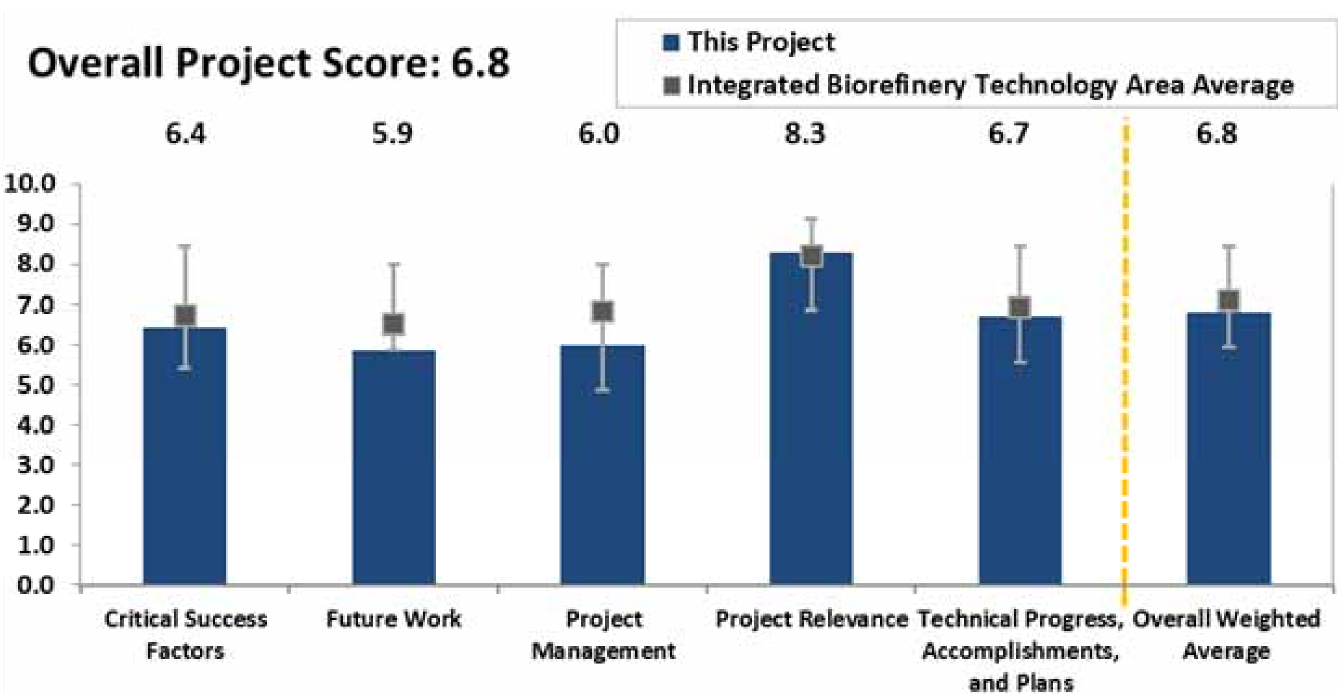
(WBS#: 5.5.3.2)

Recipient:	BlueFire (BlueFire Ethanol), LLC
Presenter:	Necy Sumait
Total DOE Funding:	$87,560,250
DOE Funding FY13:	$348,704
DOE Funding FY12:	$1,134,900
DOE Funding FY11:	$724,961
Project Dates:	2009-2014

Project Description

Photo Courtesy of Bluefire

BlueFire proposes to install integrated facilities, including a cellulosic ethanol plant and a solid fuel boiler. The plant is configured to be standalone, relying on process by-product lignin to produce its thermal and electrical requirements—this will achieve a very low carbon footprint through full utilization of the energy stored in biomass. Through the Arkenol-concentrated acid hydrolysis process, the facility will use forest and municipal cellulosic residues to produce ethanol, lignin, electricity, steam, gypsum, and animal feed. The Fulton project is situated on approximately 38 acres of land in the City of Fulton, within the Port Itawamba Industrial Park in Itawamba County, Mississippi, which is approximately 19 miles east of Tupelo, Mississippi. The site is within half a mile of I-22, with access to both commercial rail lines and the Tennessee-Tombigbee Waterway. The site is zoned commercial/ industrial. All site work, including clearing, grubbing, grading, and rough drainage, has been completed.



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Even with three site changes, this project has made reasonably good progress. It's now time to execute the plan. Financing of this first-of-a-kind plant has led to schedule setbacks; this project is not unique in that area. Financing of full-scale biofuel plants seems to be an ongoing issue that is restraining the introduction of cellulosic ethanol into the U.S. fuel supply.
- Lots of design studies, but minimal progress on implementation. The demonstration plant is critical to progressing the technology.
- Overall, good technical progress has been made. Securing financing continues to be a significant roadblock. Information provided by the performer did not instill confidence that this will be achieved by this fall as planned.
- Satisfactory technical progress. Ability to raise funds will determine whether this technology (in the works for more than 15 years) makes it.
- The project is delayed due to lack of funding. While design work and construction is delayed due to the lack of funding, they appear to have done considerable front-end engineering work.
- This project has been delayed for so long, and financing still looks to be in the distance. Does this project still offer benefits to BETO?
- A well-thought-out project that has benefitted from financing delays, allowing more time for optimization. The key question is value in a blend-wall world.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

MAS10BIO5 - COMMERCIAL SCALE PROJECTS: DEMONSTRATION OF INTEGRATED BIOREFINERY, PROJECT GO18103

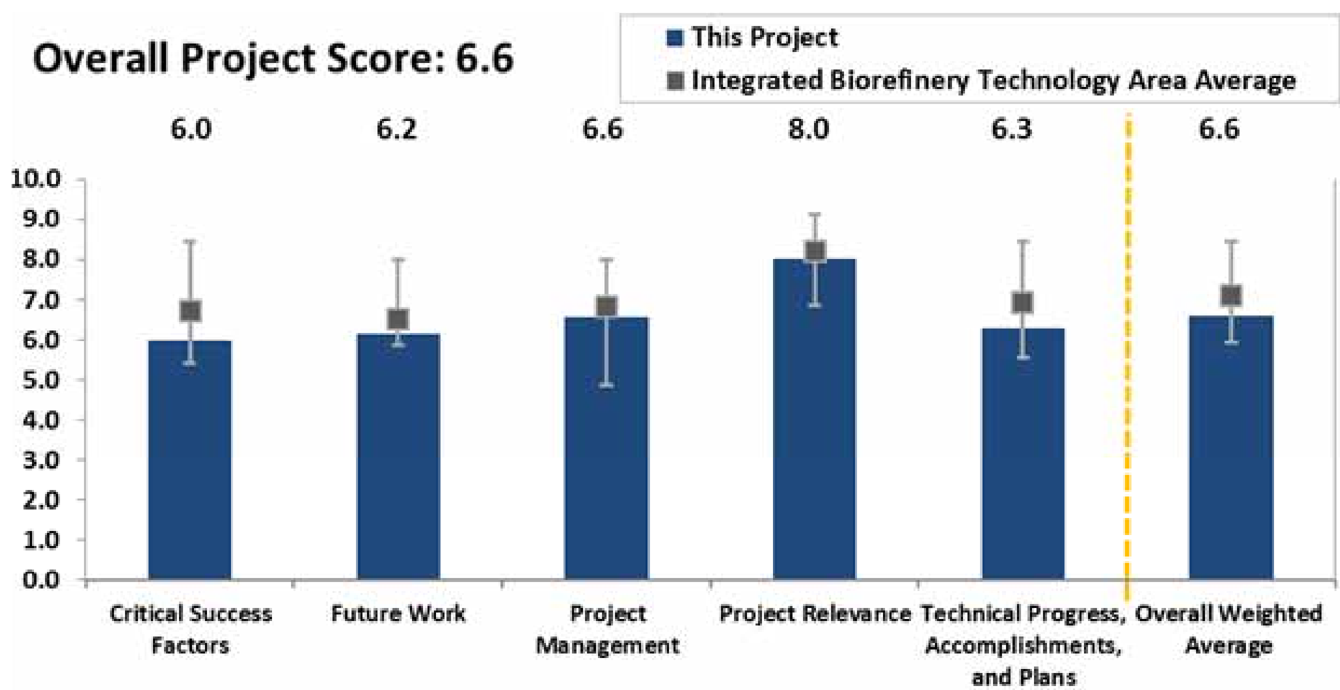
(WBS#: 5.5.7.1)

Recipient:	Mascoma
Presenter:	Michael Ladisch
Total DOE Funding:	$25,200,000
DOE Funding FY13:	--
DOE Funding FY12:	$5,300,000
DOE Funding FY11:	$7,400,000
Project Dates:	2008-2016

Project Description

Photo Courtesy of Mascoma

Mascoma's consolidated bioprocessing (CBP) technology is based on simple pretreatment of wood chips, followed by fermentation of the pretreated material using a genetically modified, proprietary yeast platform that converts five-carbon sugars—as well as cellulose-derived, six-carbon sugars—to ethanol. Economic advantages of the process relative to other cellulose conversion approaches include reduced capital cost and significant reduction in the cost of enzymes. Key accomplishments of this project since January 2011, when the last Peer Review was held, are the completion of piloting, fermentation scale-up, Front-End Loading 3 engineering design, pro forma analysis, and definition of a shovel-ready project. Pilot-plant validation of the CBP yeast fermentation with pretreated hardwood slurries combined with extensive operational experience in Mascoma's Rome, New York, pilot facility have demonstrated attainment of yields, use of recycled water, and operability of the CBP process. These data together with test data from vendor equipment—obtained as part of the DOE cooperative agreement—have informed the design of the commercial demonstration plant and a Front-End Loading 3 estimate of capital costs. The results have been integrated into financial analysis for a 20 mgpy-cellulose-to-ethanol biorefinery that utilizes 700



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

metric tons (dry basis) of wood chips/day, and meets the GHG reduction definition for cellulosic ethanol at a scale that enables profitable operation in Kinross, Michigan. The objective of this plant is to achieve commercial demonstration and to obtain information useful to our DOE partners, as well as the industry, for a first-of-a-kind energy project based on Mascoma's CBP technology. This project is shovel-ready. Construction will be initiated once financing is closed.

Overall Impressions

- The project appears to be adequately vetted; however, the project is on hold until financing is obtained. Presenter believes obtaining financing will be very difficult, if not impossible, in 2013. The technology appears novel with the potential for a significant operating cost reduction.
- Financial close is the primary work to be completed at this point. Reduction in the pretreatment times for the feedstock would seem to be one of the key technology improvements to be addressed.
- Innovative approach. Appears technically sound.
- The project appears to aim at demonstrating CBP technology and issues are the same for scale-up of any wood-to-ethanol facility. Mascoma should consider integration with a successful NREL project for ethanol for greater synergy before advancing further; this would allow Mascoma to get better data for DOE at larger scales. Work is careful and the science seems to be well understood at this stage.
- The project was planned at a sufficiently large scale, so as to provide actual operating credibility, as well as more favorable economics. The project has been slow to come out of the ground due to financing.
- Satisfactory execution and management at the pilot scale. However, the critical step of commercial development still remains to be realized. The company has had difficulties raising funds, and although economic conditions are changing, the high CAPEX ($250 million) may be a major hindrance.
- The presentation was very open in disclosure (this was much appreciated). This is an interesting piece of technology. Financing is a significant risk to the overall program, as it is essentially on hold to begin construction until received.

PI Response to Reviewer Comments

- To date, technical accomplishments include completion of the Front End Loading 2 and 3 engineering (cost) packages based on data from vendors and from Mascoma's Rome, New York, pilot plant facility, as well as the identification of an engineering, procurement and construction partner for the Kinross project. The next step for commercial development requires completion of project financing. Synergies between this project and other ethanol production projects are being developed as suggested in one of the reviewer comments. Mascoma is currently focused on securing the remaining financing for the Kinross, Michigan, facility, while at the same time continuing to develop and demonstrate CBP yeasts over a wide range of biomass types under industrial bioprocessing conditions.

INTEGRATED BIOREFINERY PILOT PROJECT FOR DIESEL AND JET FUEL PRODUCTION BY THERMOCHEMICAL CONVERSION OF WOODWASTE

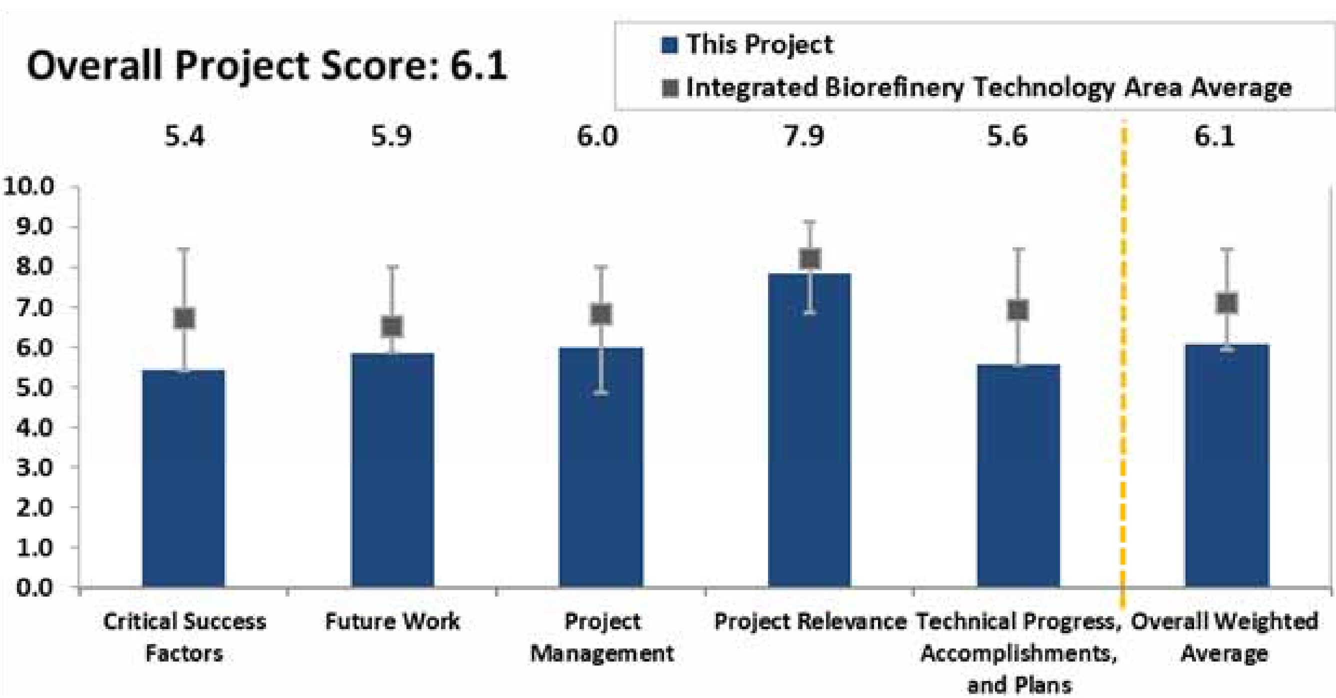
(WBS#: 5.5.9.1)

Recipient:	ClearFuels/Rentech Technology
Presenter:	Harold Wright
Total DOE Funding:	$22,632,939
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2009-2013

Project Description

This presentation outlines the work done by Rentech and its partners in the pilot-scale demonstration of an integrated biorefinery. The purpose of the project was to scale up a biomass steam reformer for the generation of synthesis gas from wood and bagasse materials. The project added biomass handling and biomass gasification to Rentech's gas-to-liquids demonstration facility. The project demonstrated integrated operation for more than 1,300 hours and produced on-specification diesel fuel from wood and wood-bagasse mixtures. The biomass steam reformer produced low-tar syngas, but only at substantially lower-than-design feed rates.

Photo Courtesy of ClearFuels/Rentech



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Overall Impressions

- Good synergy with existing site. Project has ended. The project unintentionally demonstrated some of the shortfalls with this technology.
- Good concept. Would have benefited from more effective engineering in scaling up from lab to demonstration scale.
- Overall, good execution and satisfactory data, but commercial development seems bleak as the company does not seem willing to undertake such efforts.
- Several hiccups along the way, but the PI was able to recover from most of them. Rentech has closed the demo facility as of February 28, 2013, so further progress will be nonexistent in the absence of additional monies. (Stranded DOE capital?)
- The project results did not look to meet the goals that the developer had set for themselves, and recognizing the potential difficulties that the ethanol market may face in the near term, decided to discontinue further R&D spending at this time.
- This was a low-risk approach that still did not do well. Issues that could have been predicted, as they have plagued this industry (tarring and feeding), still surprised the performer and had a significant, negative impact on performance.
- Useful project as far as demonstrating real-world issues around biomass feed preparation, gasification, heat integration, etc.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

DEMONSTRATION OF AN INTEGRATED BIOREFINERY

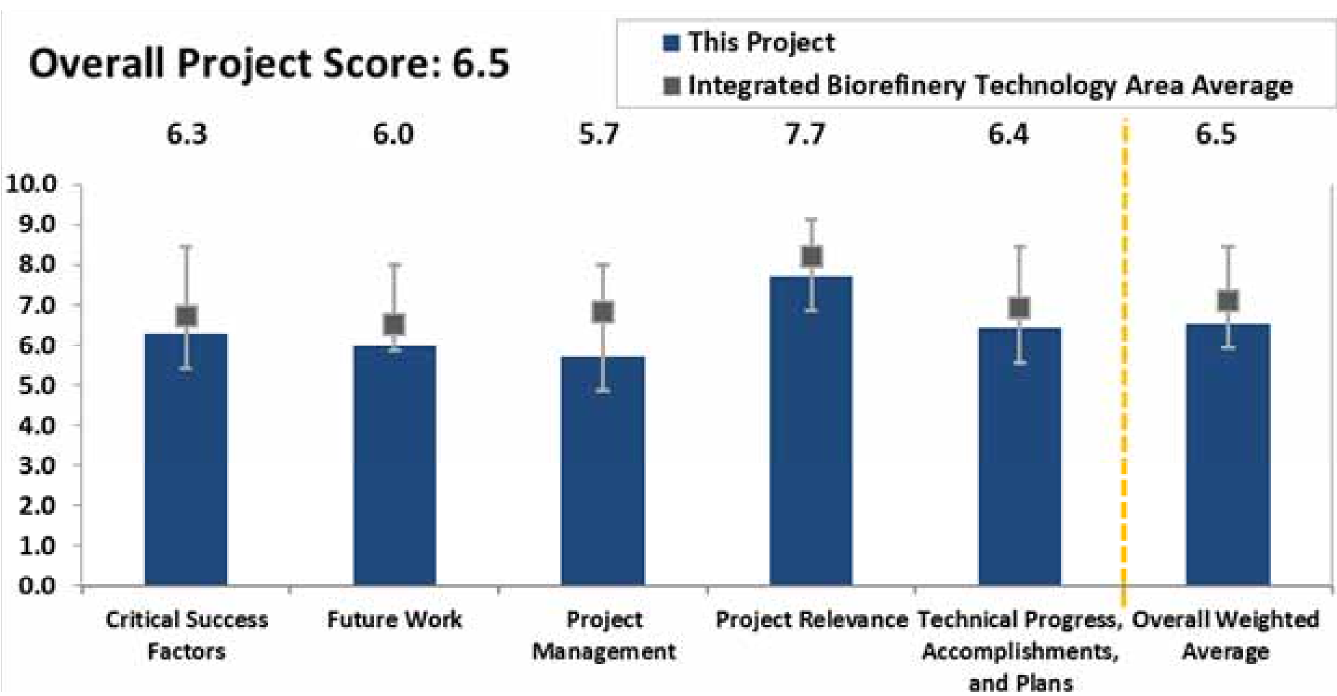
(WBS#: 5.6.2.1)

Recipient:	RSA
Presenter:	Jim St.Pierre
Total DOE Funding:	$34,500,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2009-2015

Project Description

Photo Courtesy of RSA

This project is to develop, design, construct, and operate a demonstration-scale facility—integrated within an operating pulp manufacturing mill—to convert woody biomass into cellulosic sugars, and then ferment those sugars to cellulosic ethanol for use in transportation fuels. Production of cellulosic ethanol from wood harvested in Maine's forests supports BETO's objectives to create clean, affordable biofuels that are domestically produced, advance economic development, and improve independent energy security. The cellulosic ethanol production at 13 mgpy contributes to the RFS target of 16 billion gallons by 2022. RSA has completed the initial hydrolysis step at commercial production rates in more than 10 actual campaigns, making approximately 10 tons of sugars each time. More than 20 tons of these sugars have then been clarified and distributed to customers for use in their development work. In all cases, the RSA-supplied sugars have performed comparably to the sugars normally used by customers. Challenges to this project are primarily economics driven. Pilot work has been using higher-quality (higher-cost) feedstock, whereas the project direction requires lower-cost feedstock and its greater variability. This variability will



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

likely require some adaptation after commissioning and start up. The hydrolysis conversion efficiency has exceeded 90% in pilot work, and continuous operation at demonstration scale is expected to improve this. Success factors are demonstrated use of 100% lower-cost woody biomass and continuous production of clarified sugars. The ethanol process is established technology, and operating performance is well understood.

Overall Impressions

- Good synergy with existing site. The site has a current operating pulp mill presently using some of the technology they plan to use for the IBR. The project was not settled on their primary technology at the beginning. Project execution up to this point has suffered from changes in project scope definition. .However, the technology, and its synergy with existing pulp mills, is promising (if it actually works). The independent engineer performance test is an excellent hurdle required by DOE.
- Good concept. Fits well with existing plant operation. RSA technical organization has experience in the critical steps of the process.
- Good example of the measured, pragmatic and open-minded approach used by smaller companies. Good example of issues around conversion of existing pulp mills. Identification of markets for sugars produced is key.
- Good overall performance. The company has done an in-depth analysis of market demand and processes, and has concluded that cellulosic biomass is the way to go. Still, the company plans to investigate the production of bio-based products for possible future operations.
- Most work remains in the future (2015). Hard to determine much more at this stage of the project.
- The program appears incorrectly focused on providing “on-demand sugars” to other performers rather than focusing on demonstrating biofuel at scale to support IBR goals. The effort is somewhat mismanaged in its general retreat away from risk, rather than getting over technical challenges. Economic risk aversion—a retreat to ethanol only—brings them to a market that is already saturated, and their chasing EPA RINs brings technical risk (unidentified by the presenter) in its switch of feedstocks from what has been proven to date. The actual process that they are using was utterly undisclosed, so assessing the development and scale-up of their technology is impossible.
- There seems to be a lack of commitment to a direction for this project. The pulp mill offers synergies that could be an advantage for the bioenergy facility, but it also seems to be a distraction.

PI Response to Reviewer Comments:

- No official response provided at time of report publication.

ALPENA PROTOTYPE BIOREFINERY

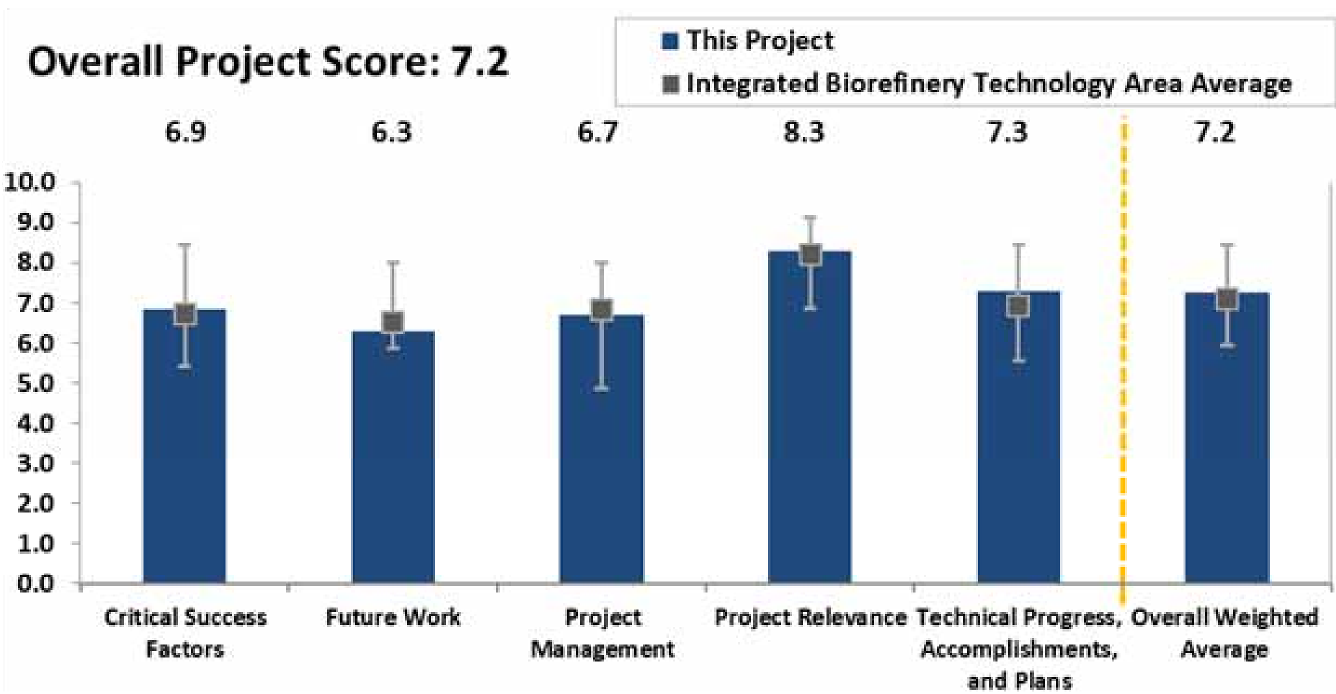
(WBS#: 5.7.1.1)

Project Description

Photo Courtesy of American Process, Inc.

Recipient:	American Process, Inc.
Presenter:	Kim Nelson
Total DOE Funding:	$17,944,902
DOE Funding FY13:	$200,000
DOE Funding FY12:	$7,400,000
DOE Funding FY11:	$8,500,000
Project Dates:	2009-2014

The goal of the Alpena Biorefinery is to demonstrate a modular, technically successful, and financially viable process of making cellulosic ethanol from woody biomass extract at wood-processing facilities. The biorefinery will produce approximately 800,000 gallons/year of cellulosic ethanol and approximately 800,000 gallons/year aqueous potassium acetate deicer. The biorefinery's feedstock is wood hydrolyzate produced by co-located Decorative Panels International in the course of board manufacturing. During plant commissioning from May to November 2012, there were significant challenges with the handling and removal of the condensed lignin formed during acid hydrolysis. A unique solution to this challenge was invented, engineered, and installed. Commissioning of the lignin separation equipment is scheduled for May 2013, with full plant start-up scheduled for July 2013. The project objectives and value proposition of the biorefinery promote the national goals of energy independence, greenhouse gas reduction, and green job creation and retention. Objectives include the demonstration of simultaneous fermentation of five-carbon and



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

six-carbon sugars, gathering metrics for the construction of commercial plants, and demonstration of the business model of adding cellulosic ethanol production to wood processing facilities, such as biopower plants, pellet mills, and pulp mills. Expected outcomes of the project include a commercial installation by 2016, with competitive, low-cost cellulosic ethanol production and a replication potential within the United States of approximately 2.1 billion gallons/year of cellulosic ethanol by 2022. The top challenges the project faces include effective handling of condensed lignin, and consistency of government regulations and support for cellulosic ethanol.

Overall Impressions

- Brute-force acid hydrolysis of woody feedstocks will work and should not have significant sensitivity to feedstock compositional changes. Relatively low CAPEX needs for this project are a result of integration into an existing facility.
- Good niche application; solves a waste disposal problem and creates additional product.
- Relatively low-cost project for demonstrating issues of small-scale bolt-on units. Useful lessons learned on impacts of non-technical issues. There are challenges ahead for start-up and continuous operation and handling of lignin.
- Satisfactory overall, but there are uncertainties about profitability given that the cost of raw material will be higher at other mills and potassium acetate does not contribute to the profit margin of the process.
- This is a well-managed program with a good technological solution and business model for a niche part of the overall biomass market.
- This project appears to be in a good position to operate successfully. However, it is not clear if the co-located plant synergies they are taking advantage of at this facility would have much opportunity for duplication for future plants.
- This project looks to have the potential to add value to existing plants as a bolt-on technology for ethanol production that could provide value where a waste stream once existed. Government policies surrounding the requirement for ethanol use could derail the value proposition.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

DEMONSTRATION OF A PILOT INTEGRATED BIOREFINERY FOR THE ECONOMICAL CONVERSION OF BIOMASS TO DIESEL FUEL

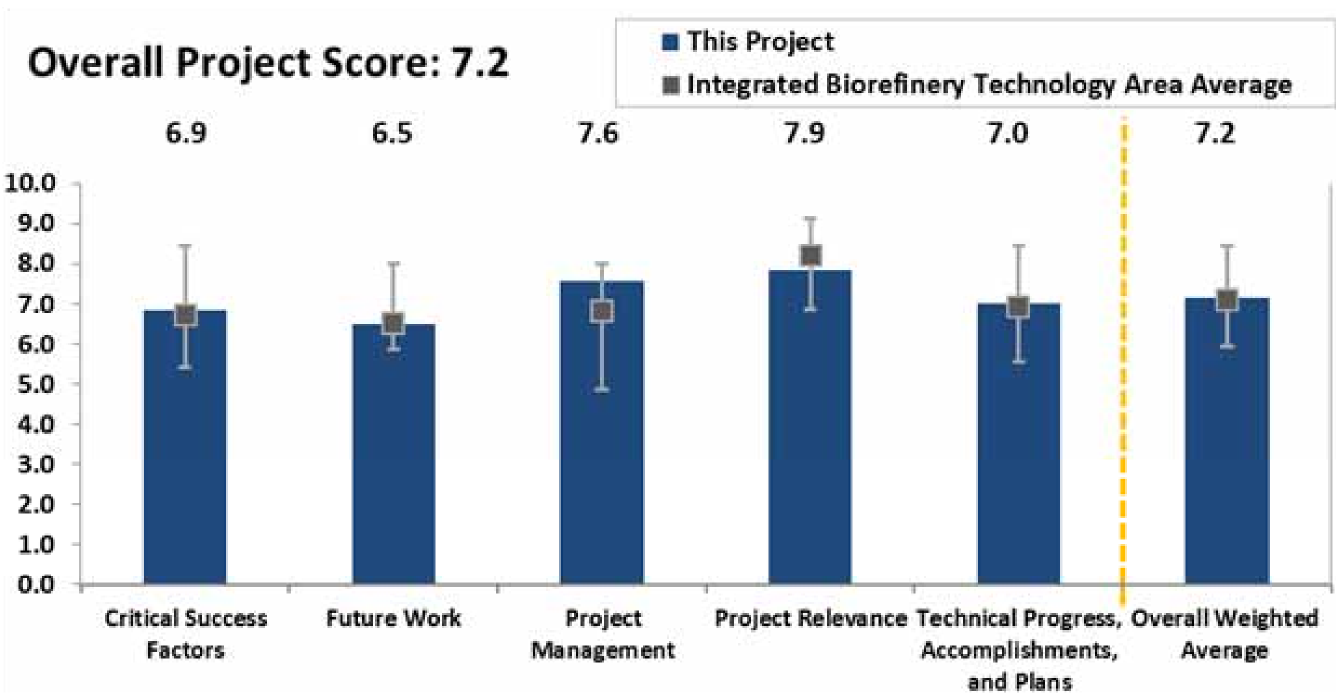
(WBS#: 5.7.3.1)

Recipient:	Renewable Energy Institute International (REII)
Presenter:	Gregory Tamblyn
Total DOE Funding:	$19,607,660
DOE Funding FY13:	$3,720,000
DOE Funding FY12:	$8,210,000
DOE Funding FY11:	$6,610,000
Project Dates:	2010-2013

Project Description


Photo Courtesy of REII

The objective of this DOE integrated biorefinery project has been to build, test, optimize, and validate a 25 dry-ash-free, ton (daft)-per-day plant for the conversion of biomass feedstocks to drop-in synthetic diesel fuel. This IBR plant embodies an integration of a two-step thermochemical conversion process developed by Red Lion Bio-Energy, and a direct diesel fuel production process developed by Pacific Renewable Fuels. Other major contributing organizations include Desert Research Institute, NREL, and Worley Parsons. The construction of the IBR plant was completed during April 2012 (on time and under budget). The Red Lion Bio-Energy thermochemical conversion process was demonstrated and efficiently converts biomass to syngas with 100–1,000 times less tar than is typically produced from other thermochemical approaches, which significantly reduces the cost of syngas purification. High-purity syngas is produced directly at the optimum H2 to CO



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

ratio of approximately two to one. Although wood and rice hulls have been used as the primary feedstocks, this technology is capable of converting a variety of biomass feedstock to synthetic diesel fuel as shown in demonstrations. The patented "designer" catalyst and catalytic reactor directly produces synthetic diesel fuel from the purified syngas without a need for further refining processes (e.g., hydroprocessing) at an average production yield of 54 gallons/daft of biomass. The large body of data generated from multiple test campaigns has been used to establish optimum plant operating conditions. The drop-in, synthetic diesel fuel has proven to be a premium product that can directly utilize the existing diesel fuel infrastructure for use in light-duty and heavy-duty diesel vehicles, off-road diesels (e.g., locomotives, construction equipment, and farm machinery), and diesel generators. This premium diesel fuel reduces emissions and improves engine performance for in-use and current diesel engines, and is forecasted to be the ideal fuel for the next generation of diesel engines. These premium properties are due to the fuel's high cetane content, good lubricity, reduced density, excellent storage stability, and low levels of aromatics and olefins compared to traditional petroleum-derived diesel. Life-cycle assessment modeling (through Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model) establishes that greenhouse gas emissions from the production and use of this synthetic diesel fuel are reduced by 89% compared to current petroleum diesel fuel. Red Lion Bio-Energy and Pacific Renewable Fuels have formed a joint venture (Synterra Energy) for commercialization of this technology. The comprehensive information generated from this project has been used by Synterra to design 240-daft, distributed-scale plants for commercial deployment.

Overall Impressions

- An excellent project from end to end. Good management. Good identification of critical issues in developing and running a pilot plant. The fuels have been tested and are pipeline compatible. A direct-to-diesel path producing fuel at 75 cetane with high lubricity was discussed. Excellent understanding of commercialization issues.
- Good project execution; engineering seems to be solid; issues are being addressed; and diesel has been produced at competitive cost according to the company. Remains to be seen whether equity financing will be successful to allow commercialization of the technology.
- Good technical research work appropriate to the current pilot scale. Translation to larger unit needs and expansion of appropriate data need to be done. Environmental Protection Agency and other regulatory approvals are needed.
- Not enough technical information and operational data presented to make sense to this reviewer.
- Technical analysis appears sound. No show stoppers identified. Appears to have successfully addressed critical success factors.
- The developer has done a good job of bringing this project to conclusion. The technology looks very promising. It is felt that the process looks too good to be true. Further, longer-term testing must be completed in order to fully prove the process.
- This project appears to have been fairly well executed and has a unique process to make diesel from biomass. However, the conversion with a single catalyst to only drop-in diesel (low wax, low oxygen) should be validated by an independent engineer. Pilot runs have been minimal, with the longest run being approximately 150 hours. Typical problems with the hopper/ram feeder slide-gate seals have been encountered. The project hopes to alleviate the feeder problem with a seal material change (I believe, even with this change, they will continue to experience common fouling issues in the slide gate). The project is in need of additional funding for future work.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

GREEN GASOLINE FROM WOOD USING CARBONA GASIFICATION AND TOPSOE TIGAS PROCESSES

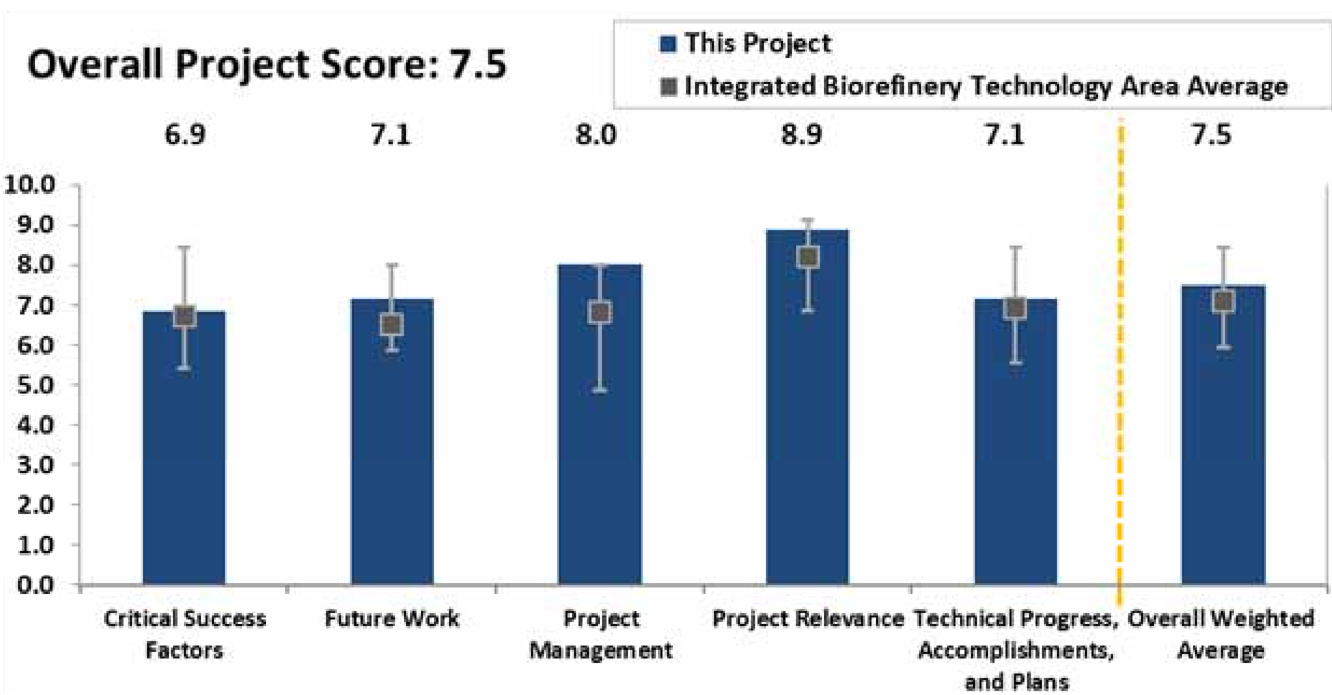
(WBS#: 5.7.4.1)

Recipient:	Haldor Topsoe, Inc.
Presenter:	Niels Udengaard
Total DOE Funding:	$25,000,000
DOE Funding FY13:	--
DOE Funding FY12:	--
DOE Funding FY11:	--
Project Dates:	2010-2014

Project Description


Photo Courtesy of Haldor Topsoe, Inc.

The goal of the project is to demonstrate a new, economical technology for the thermochemical conversion of woody biomass into gasoline. This approach uses Andritz/Carbona's fluidized-bed steam-oxygen gasification and catalytic tar-reforming systems to produce a clean syngas from wood, integrate conventional gas cleanup steps, and finally utilize the Haldor Topsoe innovative Integrated Gasoline Synthesis process. Testing is at the Gas Technology Institute in Des Plaines, Illinois; UPM-Kymmene, in Minnesota, supplies and prepares the feedstock; Phillips 66 labs, in Oklahoma, will analyze the gasoline product; and single-engine emission tests will be performed by the Southwest Research Institute in San Antonio, Texas. This will be followed by fleet testing. The project benefits from the use of the existing pilot-plant equipment at the Gas Technology Institute, including gasifier, hot gas filter, tar reformer, Morphysorb acid gas removal, associated syngas cleanup, and gasifier feeding and oxygen systems. The project is performed in two budget periods. During budget period one, detailed design and cost estimate (±10%) was made, as well as completed National Environmental Policy Act documentation and updated Risk Management Plan. Budget period two includes the modifications of the existing Flex-Fuel



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

Testing Facility, construction and installation of the integrated gasoline synthesis unit, addition of liquid product handling facilities, and the demonstration tests, analytical requirements, and liquid product sample collection for offsite testing. Budget period two also includes the single-engine emission test and the moderate fleet test, as well as the detailed technical analysis and process evaluation, including updating the business and commercialization plan based on the testing results. The technology will then be ready for a 4,000 tonnes/day commercial facility, offered through Andritz/Carbona and Haldor Topsoe.

Overall Impressions

- A generally well-managed and innovative project. Unfortunately, the presenter did not manage his time well and could not complete his presentation. Some focus on feed to get away from pellets to remove the cost of pelletizing should be explored.
- A good integration of technologies from various companies for conversion of wood to gasoline via gasification. Good management and progress; on time and on budget. Close attention to the upcoming critical tests is needed by DOE.
- Overall a solid project; well-planned and executed to date.
- The developers look to have made good use of the existing facilities at the Gas Technology Institute. Longer-term testing is necessary to better determine the potential for success of the technology. The developers have assembled an impressive project team.
- This appears to be a well-run project with excellent leverage of existing equipment and infrastructure using the Gas Technology Institute's site. The first test run stopping at 96 hours is a concern. Additional issues won't be discovered until the unit runs for an extended time.
- Use of an oxygen-fed gasifier in this application avoids tars. Elimination of water gas shift reactor (to increase H_2:CO ratios) saves on flowsheet costs. Does this route always work in the face of inevitable feedstock compositional changes?
- Well-managed project with capable partners. Progressing as expected for a demonstration facility. Executive committee demonstrates cooperation among partners. Initial technical results are encouraging. Competitiveness with conventional hydrocarbon economics remains to be seen.

PI Response to Reviewer Comments

- No official response provided at time of report publication.

MODIFICATION OF CORN STARCH ETHANOL REFINERY TO EFFICIENTLY ACCEPT VARIOUS HIGH-IMPACT CELLULOSIC FEEDSTOCKS

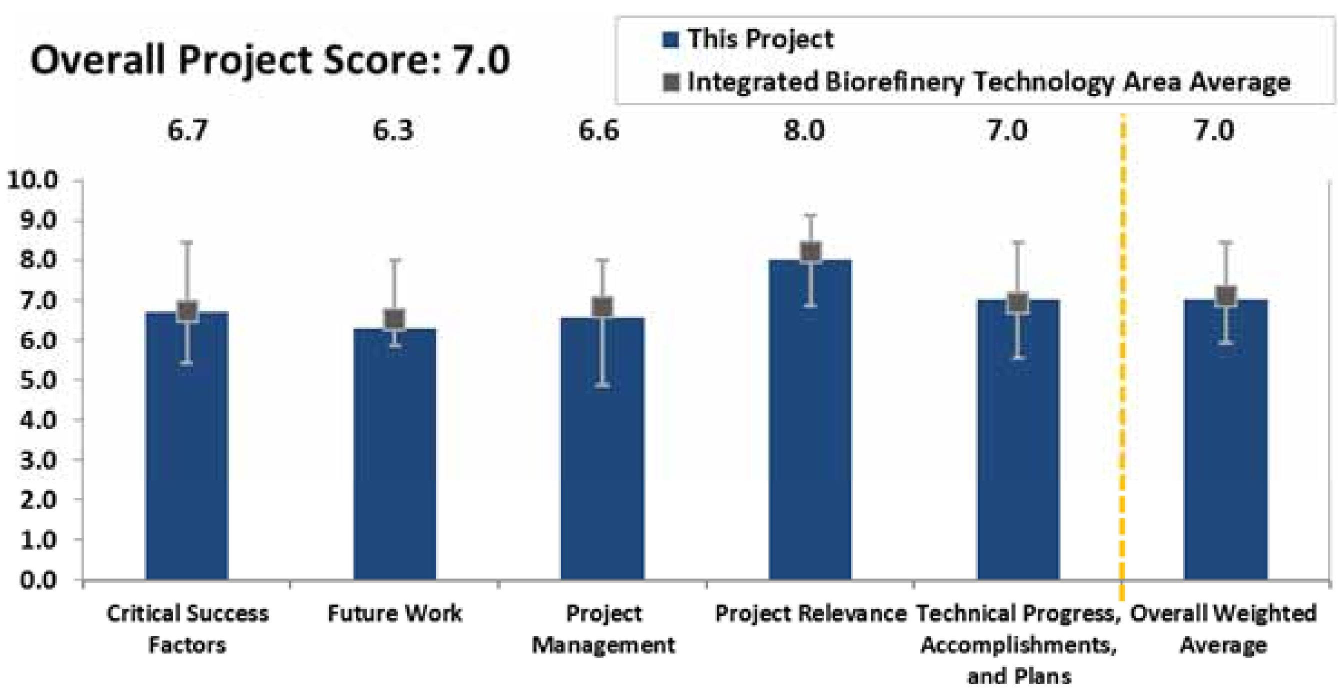
(WBS#: 5.7.5.1)

Recipient:	Logos/EdenIQ Technologies
Presenter:	Dan Derr
Total DOE Funding:	$20,455,849
DOE Funding FY13:	$2,300,000
DOE Funding FY12:	$8,200,000
DOE Funding FY11:	$8,100,000
Project Dates:	2010-2013

Project Description

Photo Courtesy of Logos/EdenIQ Technologies

The goal of the Corn-to-Cellulosic Migration pilot facility is to demonstrate the implementation of advanced technologies and methods to convert non-food, cellulosic feedstocks into ethanol; assess the economics of the facility; and evaluate potential environmental benefits for biomass-to-fuels conversion. The project was comprised of design, build, and operate phases, as well as a research and development component. Logos Technologies and Edeniq partnered to complete the project, and during the past year, completed construction, commissioning, and start up. Per the project plan, two 1,000+ hour continuous runs were also completed—one of which was part of the commissioning process. These continuous operations required overcoming several challenges described in the presentation and represent a major success in demonstrating the potential of this technology to be scaled to a commercial-sized



Whiskers represent the range of scores for each category across all projects reviewed in this technology area.

operation. The pilot plant will continue to operate and evaluate the use of additional feedstock sources unique to California. The pilot plant provided sufficient parametric information so that designs for commercial-sized operations will be undertaken.

Overall Impressions

- After an apparently rough start, this project appears to have been executed fairly well.
- I didn't get a strong feeling that this project has a large commercial potential.
- Disappointed with the company's decision to share mainly photos at the expense of data on process performance and economics.
- Good looking plant; interesting use of mechanical versus chemical or heat energy. Appeared to be able to successfully complete the project at this level.
- Relatively clean project. Rhetorical question: What would the PI have done differently if he had an opportunity to start all over? What are the "do-betters" and other lessons learned?
- The developers were successful in completing the project on schedule and on budget, and performing a 1,400 hour test run. Quite an accomplishment for a first-of-a-kind project. Further operation and testing should provide the information and data necessary to determine the potential for success at a larger scale.

PI Response to Reviewer Comments:

In general, the team would like to acknowledge the reviewers' contributions to the project. The feedback received through the Peer Review process is valuable, and appreciated. Thanks for highlighting some positives, and two concerns are addressed below:

- Commercialization potential was only discussed verbally to the chart titled "Meeting Bioenergy Technology Office goals." To recap those comments, it has been announced publically that commercial tests of the Cellunator with cellulosic feedstock will occur.[2] This is consistent with Edeniq's commercialization strategy as outlined on their website.[3] The approach outlined in these two references allows bridging of the second valley of death, as described in Brian Duff's presentation at the Peer Review meeting. The technology piloted in this plant can be bolted onto existing, commercially operating ethanol plants at the demonstration scale with a revenue increase. This allows incremental deployment with a large commercial potential.
- "Data on process performance and economics" could not be shared due to the public setting. All team members on our project take their responsibility seriously to protect confidential and proprietary information of any one team member. Providing more information would only be possible in a non-public setting. For example, at the confidential Comprehensive Peer Review that the team participated in back in March, the requested details were discussed in depth.

[2] Herndon, A. "Flint Hills Using Edeniq Gear to Boost Ethanol Yields." *Bloomberg*. June 4, 2012. www.bloomberg.com/news/2012-06-04/koch-s-flint-hills-installs-edeniq-gear-to-boost-ethanol-yields.html.

[3] "Edeniq Solutions Overview." Edeniq. Accessed June 19, 2013: www.edeniq.com/page/overview.

INTRODUCTION

The Bioenergy Technologies Office (BETO or the Office) technology managers are to be commended for the excellent job they have been doing to incorporate new projects and pathways into the programmatic purview, while advancing their technology portfolios and interfacing with other U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE) offices under the Sustainable Transportation umbrella. BETO's grouping into this new EERE re-alignment is very new at present, and the Steering Committee is interested in how this will eventually play out for biopower, bioheat and cooking, bio-derived home heating oils, and bioproducts—all of which are legacy activities in the BETO Office.

The review process for 2013 was vastly improved, and the addition of facilitated sessions at the end of the Project Peer Review provided the lead reviewers and Steering Committee members with an opportunity to share information and insights directly with the BETO management team, thus enabling a more refined understanding of the issues and a faster programmatic response.

Throughout the review process, the Steering Committee focused on a series of questions to frame its considerations, as well as the feedback it would communicate to BETO staff on the individual projects, technology areas, and overall program management of BETO since the 2011 Peer Review. These questions were grouped into the following areas: Strengths and Weaknesses; Impact; Innovation; Synergies; Areas of Concern—Gaps; New Research Areas; Strategic Planning; Innovation; and Recommendations.

STEERING COMMITTEE RESPONSE TO QUESTIONS

STENGTHS AND WEAKNESSES

1 What are the overall strengths and weaknesses of BETO's project portfolio? What areas are performing well? Where are improvements needed?

STRENGTHS

Diversity

By focusing on multiple feedstocks, conversion technologies, and products, the Office demonstrates awareness of regional and feedstock differences, as well as the range of potentially commercial-scale conversion technologies, which increases its probability of identifying and fostering the successful commercial deployment of these technologies. The portfolio includes projects that range in size from laboratory scale to commercial plants, and that address fundamental scientific issues as well as the very pragmatic challenges associated with large-scale production. The Steering Committee views the new emphasis on drop-in hydrocarbon fuels as an important area for the Office. Fungible drop-in hydrocarbon fuels eliminate blend wall issues and take advantage of existing infrastructure, both for production and for transport/distribution.

Continued Progress within the Office

The Office has made significant progress since the 2011 Peer Review, most notably by (1) getting the integrated biorefinery (IBR) projects underway and continuing to support industry partners willing to take on the challenge of large-scale biomass conversion, (2) funding high-tonnage feedstock demonstration projects that will help de-risk biomass use and move the industry forward, and (3) refocusing to include a variety of bioderived hydrocarbon-rich intermediates that can circumvent the ethanol 'blend wall' and expand the options for commercial deployment. The effort to create an effective, reliable feedstock supply system remains a critical challenge for all biofuels production routes.

Additionally, good progress has been made in defining and framing sustainability analysis and moving beyond life-cycle assessment (LCA)/carbon issues to a larger viewpoint that includes other important aspects of the sustainability discussion, such as water and soil quality, rural development, and food and energy security. Much of this work could influence policy decisions and help to improve analysis across the broad scientific community through the development of standard methods and data sets. Projects connecting techno-economic and sustainability analysis are more prevalent for a range of biofuel production alternatives, and an increased effort to conduct proactive (as opposed to reactive) studies—aimed at addressing questions important to the Office—was recognized and appreciated by the Steering Committee.

Many of the BETO technology areas make good use of techno-economic analysis (TEA) to guide research, development, demonstration, and deployment efforts. The Steering Committee felt that the use of TEA should be further expanded into areas where it is not being fully used, and that standard methods for these analysis should be applied. The Steering Committee also noted the use of TEA in other EERE offices where all project performers submit information into a standardized TEA program to show how their research compares with other projects in the portfolio and enable economically viable scenarios for meeting programmatic goals.

WEAKNESSES

Advancement in drop-in fuels will also require attention to a set of issues that have some similarities to ethanol, but also others that are specific to hydrocarbon-like fuels. Compatibility and blending issues and a shrinking blend space make blending complex, and refining/hydrocarbon expertise is needed in the Office to ensure that there is clear definition of target streams for the possible intermediates and fuels from the different technology pathways. Project-by-project insights in navigating the Environmental Protection Agency (EPA) fuel registration process are also needed, as any non-conventional fuel must meet strenuous fuel certification requirements. The source of the biomass will impact both the quality of the intermediate and the LCA footprint, and these issues were not consistently addressed. Working with agencies that have their own fuel certification programs, including EPA or the Department of Defense (DOD), might be useful. The process is expensive, requires thousands of gallons, and is required for all producers. DOE should look at the ways to process fuel as it goes into a refinery; understand how the process works; and educate stakeholders about the costs, timeline, and process.

The Office should continue to emphasize and facilitate sharing and use of data among projects. Data sharing will show areas where overlap and/or duplication of effort may exist and provide a means of validating results across similar projects. Intellectual property (IP) issues will make this challenging, and IP issues will need to be addressed if sharing of data is to be useful. An incentive for sharing data may be needed, especially in cases where overlapping work is being performed (projects or work could be halted).

Progress invariably leads to the discovery of new issues and areas requiring attention and resources. As the Office grows into new and more challenging areas, such as drop-in fuels, there is an increased need for standardized methods and assumptions in TEA and sustainability analysis to help researchers understand how their work will impact the cost and sustainability of the fuels. This is a challenging problem due to the various levels of research and development (R&D) in the Office, and one that will require a tool kit of methods to be successful. Other EERE offices (e.g., Hydrogen) have successfully developed common analysis systems (B2A), and BETO is encouraged to develop such a tool.

Despite the adjustments and improvements made in the overall process, the review of the IBR projects continued to be difficult due to the nature of the projects and IP concerns. One change made included the addition of one reviewer to serve as an independent engineer on IBR projects. While the addition of this review was valuable, some Steering Committee members felt that it also represented a perceived conflict of interest. It is recommended that the IBR team find a way to improve its Peer Review process through the use of a single non-disclosure agreement (NDA) with reviewers to insure against disclosure concerns. Additionally, the Committee recommends that future reviews include some amount of reviewer training; using the Golden Field Office's merit review training was suggested as one possibility. Furthermore, several IBR projects are having difficulty securing the appropriate capital financing needed to complete the projects—this appears to indicate that significant financial risks exist, and perhaps federal policy or the efforts to buy-down technical risks have not met the appropriate thresholds needed in today's biofuel marketplace.

Regarding the project portfolio, BETO appears to use a different contractual strategy than other EERE offices because not all BETO project performers are contractually required to attend the Peer Review. This ultimately results in some projects trying to opt out of the review process. In the future, BETO should amend its current contracts, or—at minimum—ensure that all future contracts require the projects to attend and present at the Peer Review as requisite for continued funding. The effort to actively manage projects is considered extremely important for BETO. The Office should continue to conduct regular project reviews and, as needed, stop work that does not support DOE's goals and/or is not making sufficient progress. The Committee saw several projects that probably should not have been funded, or should have been concluded early.

Additionally, many—but not all—of the Congressionally directed projects are weak, do not track DOE goals, or are not responsive to guidance from DOE program managers or the biannual Peer Review. In some cases, DOE should consider spending more time with the project sponsor at the start of a project to attempt to mold the scope of work into a more worthwhile project.

IMPACT

2 Overall, is BETO funding high-impact projects that have the potential to significantly advance the state of technology for the industry?

The large IBR projects have the potential to demonstrate real-world feasibility of cellulosic biofuel production at commercial scale. High-tonnage feedstock demonstration projects have significantly decreased risks and uncertainties associated with feedstock collection and handling.

Biochemical conversion is an important route for producing drop-in hydrocarbons. Projects focused on lowering the cost of biomass sugars (pretreatment and enzymatic hydrolysis) have the potential to significantly advance the state of technology in this area. Improving biocatalysts for the production of drop-in fuels and high-value co-products is also important to the success of deploying drop-in hydrocarbons via biochemical conversion.

The High-Tonnage Feedstock projects demonstrated the utility of existing and newly developed biomass harvest, collection, transport, and storage technologies at a large enough scale to develop economic and operational data and discover issues needing research, such as high moisture and ash variability, storage stability, and the need to further increase densification targets.

The Office should continue its commitment to defining sustainability and expanding analysis of the factors that affect environmental impact. This is an important, high-impact area, and BETO is well positioned to take a lead role in these efforts.

The production of hydrocarbon intermediates using novel pyrolysis routes shows technical promise. There are a number of high-quality projects within the national laboratory system, and with private or university partners.

3 Are BETO budget priorities adequately aligned to overcome key barriers and meet the goals and objectives of the Office? In which technology areas should BETO put more or less focus on for future budget planning?

Several big projects commenced and progressed (POET, Abengoa) with American Recovery and Reinvestment Act of 2009 funding; projects that created lasting impacts. The Office needs to determine how to help these big projects continue to move forward without another big influx of funding.

Short rotation woody and perennial biomass crops work has achieved significant new knowledge, but ongoing support is needed due to the long generation life of woody and perennial crop research.

Integration analysis is a key component of drop-in fuels research. Refinery integration could potentially reduce capital outlay and maximize the use of existing expertise, and the Office should make it a priority to develop this expertise within the program through collaborations with the refining industry.

Commercial technology aligned with the Bio-Oil Technology Area approach is coming online, and there is a need to understand and accelerate this technology and expand the options. There is also a need for more systemic analysis of the economic and LCA impacts of integrating bio-oil with specific refining processes.

BETO should consider expanding the use of TEA within the program. Some projects do an excellent job in utilizing this important analysis tool, while others need improvement.

Many projects that are entering the demonstration stage are planning to utilize high-fructose corn syrup as the feedstock for biofuels and biochemical production. BETO should explore opportunities to implement biomass sugar production technologies in collaboration with these companies.

INNOVATION

4 What feedback can you provide on BETO's focus on the new technology pathways, as described in the Wednesday morning (5/22) plenary session? Can you provide feedback on the pathways themselves, and the selection process?

The Office is at a crucial juncture, moving away from cellulosic ethanol to drop-in fuels. While there is great urgency in initiating robust R&D around hydrocarbon-like blendstocks, emphasis in developing TEAs around possible pathways prior to starting projects will help the Office articulate and quantify its plans and goals. At the same time, attention to emerging cellulosic ethanol industry stakeholders should still continue for the short term. In particular, collecting and disseminating all Office knowledge to the industry should be a priority before the knowledge becomes lost or dated.

The Office needs to undertake a systematic evaluation of the impacts of low-cost natural gas. The high oxygen content of biomass and the need to convert carbon will produce a consistent need for hydrogen. Low-cost natural gas will also be an attractive alternative fuel or source of process heat and power, for some applications.

Following the example of the current oil refinery and chemicals industry, there is great potential for the Office to support the development of co-products that enhance the commercial potential of biofuels technologies. Given the wide array of potential co-products, it will be critical for the Office to focus on co-products that match specific biofuels pathways. Co-products should be included in the TEA scenarios, including co-product value and market size.

5 Does BETO's portfolio include novel and innovative projects that represent the newest industry thinking? Is the focus of BETO support appropriate in light of private-sector investments in these technologies?

The Office's support of IBR projects, several of which are coming on stream with commercial operations of different technologies—e.g., the biochemical conversion of biomass to ethanol being deployed by Poet and Abengoa, and the gasification followed by syngas fermentation commercialized by INEOS shows the valuable connection between the Office and industrial innovation.

In addition, the Office is supporting fundamental technology development efforts that could support the commercialization efforts of companies that are developing technologies that do not rely on BETO funding—e.g., the bio-oil process being commercialized by KiOR, or the novel pretreatment approaches being practiced by Chemtex.

The Office is also supporting work to ensure the year-round supply of high-quality, cost-competitive biomass feedstocks that will be useful to all commercial development projects.

There are trends in the industry to decouple pretreatment from conversion by production of hydrolysate, sugars, and other liquid intermediates closer to biomass sources. The Office is encouraged to include de-integration of biorefinery units and depots in future TEA and related research.

SYNERGIES

6 Is there adequate coordination between the different technology areas? Are there synergies or lessons learned that BETO should be better taking advantage of?

In general, there are good connections between the feedstocks, conversion, and analysis teams within national lab projects. This needs to become more pervasive in the programs—to include non-national lab participants.

There are continuing challenges to balance the need to protect IP and competitive know-how for many of the projects, and the desire to share information and eliminate duplication. Managing this balance falls on the DOE program managers, and there is no single solution for this challenge. The program managers understand this tension and are generally successful in managing balance. However, IP protection should not be at the expense of the program's technical review. NDAs and closed-door sessions provide an opportunity for the technical reviewers to "see behind the curtain" to make sure there is something there.

There is an opportunity for DOE to conduct/publish a 'lessons learned' or post mortem for projects that are being closed. This could include both the technology challenges and the business challenges for the projects.

AREAS OF CONCERN—GAPS

7 Are there any gaps in the funding portfolio? Are there areas along the bioenergy supply chain where BETO should place more or less focus?

In terms of the overall options for the conversion of biomass into biofuels, the Office has a good balance of projects evaluating the alternative biochemical and thermochemical technologies, at both the bench scale and pilot/demonstration plant scale.

However, there are two areas where DOE can continue to improve the value of its projects. The real cost, quality, and reliability of biomass feedstocks remains a challenge, particularly as multiple plants come on stream. And these cost, quality, and reliability challenges will be regionally and even site-specific. For example, development of agronomic and pond management processes to increase algae/oil productivity is currently under-emphasized.

The projected capital expenditures (CAPEX) and operational expenditures (OPEX) for commercial-scale plants remains a challenge. DOE estimates are consistently lower than industrial experience. This challenge provides an outstanding opportunity for some benching and lessons learned as the IBR plants come on stream.

Better estimates for the biomass cost and sustainable supply, as well as the CAPEX and OPEX, would lower the risk for lenders and investors.

Low-cost natural gas can both help and hinder the commercial deployment of biofuels technology, and these benefits and risks need to be explicitly identified.

NEW RESEARCH AREAS

8 Are BETO's new areas of focus (incubator program, waste-to-energy, carbon fiber, and natural gas) valuable areas of strategic focus for the Office? Are there other areas that the Office should consider exploring?

The Committee provided initial feedback on the new areas of focus, including incubator program, waste-to-energy, carbon fiber, and natural gas.

The potential impacts of carbon fiber were questioned by the group, given the significant investments from other DOE offices, the need for extensive upgrading of any biomass stream, and the cost goals that must be met.

With the increased supplies of natural gas, the Steering Committee feels that the costs, benefits, and impacts for low-cost natural gas should be systematically evaluated; this should include the implications on both CAPEX and OPEX. Specific examples include co-conversion of natural gas and biomass for production of fuels, or the potential for reducing CAPEX by replacing a biomass boiler with a natural gas boiler.

There was a general agreement that the Office already has productive 'waste-to-energy' projects within its IBR and pilot-scale project portfolio. Both INEOS and Enerkem were cited as projects that use wastes from other processes.

An incubator program may help the Office explore new areas without significant time and resource outlay, and high-level analysis (i.e., product/feed economics, pareto-based capital cost analysis) should be an integral part of any incubator program. Competitive solicitations would be the most effective way to identify technologies, and these projects could either be conducted by consortiums or in some type of public-private partnership agreement to ensure that downstream commercialization can be expeditiously achieved. Additionally, preliminary economic and LCA analysis should all be conducted by a single DOE group, perhaps using the assets and capabilities of one of the national laboratories.

9 Are there other technology areas that you would recommend BETO start to invest in more significantly?

The Steering Committee was satisfied with the work done to establish the new hydrocarbon-replacement pathways. The Committee looks forward to the progress that will be made in that area between now and the next Peer Review when it can accurately assess other technology areas for investment.

STRATEGIC PLANNING

10 Are BETO's strategic planning efforts effectively structured to meet the overall objectives of the EERE Sustainable Transportation Sector?

The Committee was interested to note the new EERE research, development, and demonstration focus fields, specifically BETO's alignment in the Sustainable Transportation field with the Vehicle Technologies and Fuel Cell Technologies Offices. The Committee thought there were many synergies that could be realized by working more closely with these offices to improve vehicle platforms. The change will increase the need for BETO to be well-advised and knowledgeable about refining, and suggests industry experts from the American Petroleum Institute or other industry organizations become involved in BETO strategic planning, through both informal and formal mechanisms.

11 Are BETO processes—such as the Multi-Year Program Plan (MYPP), Resource-Loaded Planning, Annual Operating Plans, Project Management Plans, and roadmapping activities—sufficiently transparent and accessible to the wider stakeholder community? Do they adequately integrate stakeholder input, and are they developed in an appropriate time frame?

The Steering Committee discussions focused primarily on the MYPP, which is felt to be a highly valuable document due to its clarity and transparency. Suggestions to improve its value include making it more publicized, improving by-section accessibility to different audiences, enabling selective viewing from a set of Web pages, and making the version changes more obvious.

The Steering Committee applauds BETO's use of requests for information and workshops to understand, frame, and explore emerging needs and interests, leading to their inclusion in the MYPP and other plans.

COLLABORATION

12 Is BETO effectively coordinating with relevant partners in government and the broader stakeholder community? Is there more that BETO could do to expand collaborations with other partners?

BETO is to be commended on its open door policy that provides stakeholders and potential partners with an opportunity to meet face to face with staff to discuss ideas and issues.

The Steering Committee suggests an examination of the current collaborations to determine which are providing beneficial information on technology and economics, and also ensure that the information is being effectively used. The Office is encouraged to gather information about commercial costs and reliability from pertinent sectors—e.g., agriculture, forest products, chemicals, and petroleum.

The Committee recommends that project managers continue efforts to adopt an active role in guiding and steering technologies to facilitate introduction into the commercial sector. This will require continual management of their portfolios to de-risk technologies. This is particularly relevant with regard to national laboratory efforts.

International engagement efforts in analysis and sustainability are essential to create a "seat at the table" for the Office as international standards are created. Increased focus on the definition of what constitutes sustainability will vastly improve BETO analysis projects, as well as the entire sustainability landscape. Without strong government engagement, these international standards could become a barrier to trade or commercialization.

RECOMMENDATIONS

13 What are the most important, specific, actionable recommendations that BETO could adopt in the next year that would have the most significant positive impact on the bioenergy sector?

It is recommended that BETO implement the following suggestions:

a. Require some TEA and LCA for all projects, and integrated TEA/LCA when appropriate. Analysis should be performed on a consistent basis with BETO-approved guidelines and tools. Researchers should be required to connect their plans and targets to the high-cost/high-risk areas of a process and demonstrate that each project will really have an impact.

b. Address regional impacts of feedstock quality and connect those impacts to specific biofuels conversion processes. There is an opportunity for DOE partners to identify regionally or locally specific options that would allow for more rapid deployment. For example, many sources of biomass with higher mineral or ash are less problematic with biochemical processes, but very problematic for thermochemical processes. Lowering the delivered moisture content of the biomass has a significant process advantage for thermochemical processes, but a relatively small impact for biochemical processes.

c. Enhance the hydrocarbon fuels strategy to include more robust fuels testing and increased interaction with the refining industry. All hydrocarbon fuels projects need to have an explicit consideration of where the fuel will be integrated into a refinery, and should retain technical experts that can work with the individual project teams to help them identify these opportunities and challenges.

d. Encourage an increase in data sharing across the portfolio. This can be as simple as hosting webinars where all DOE-funded projects are expected to contribute, and hosting a website where the presentations are posted and archived. IP considerations are always present, but should not be used as an excuse for not working to improve technical communications.

e. Act to amend its current contracts, or—at minimum—ensure that all future contracts require the projects to attend and present at the Peer Review as requisite for continued funding.

f. Require that IBR performers disclose performance and economic progress in a closed-door session with the review panel.

g. Engage with the American Society for Testing and Materials and DOD to ensure certification of biofuel products.

h. Develop messaging for both the general public and Congress to clearly communicate the biofuels/bioenergy message to the public (reduce dependence on foreign oil; use of domestic and sustainable feedstocks; establishment of a domestic industry; reduce carbon emissions).

i. Include some amount of reviewer training prior to the Peer Review via webinar to ensure that reviewers are better prepared for reviewing the projects using a similar approach and standards. It was suggested that training similar to that used by the Golden Field Office merit review training would be a good starting point; with appropriate adjustments for the needs of this Peer Review process.

BIOENERGY TECHNOLOGIES OFFICE – OVERALL PROGRAMMATIC RESPONSE

INTRODUCTION

The Office of Energy Efficiency and Renewable Energy (EERE's) Bioenergy Technologies Office (BETO or the Office) would like to thank the Steering Committee for the hard work, technical support, and critical insights it provided throughout the design, development, and implementation of the 2013 Project Peer Review and Program Management Review. Office leadership has reviewed the Steering Committee Final Report and plans to work with BETO program managers and technology managers in the coming year to implement a number of the recommendations and address many of the concerns identified by the committee. The Office appreciates all of the committee's feedback and is encouraged by the committee's support for many of the current research activities undertaken by the Office. This section represents BETO's official response to the Steering Committee Final Report and is meant to summarize the key action items and next steps on the path forward.

STRENGTHS

The Office appreciates the Steering Committee's recognition that one of BETO's key strengths is its inclusion of a diverse mix of feedstocks, conversion pathways, logistics systems, and technology scales. The Office concurs that this diversity will be central to the success of a broad, geographically diverse, biobased national industry. The Office is encouraged by the committee's support of the significant progress that has been made in the deployment of integrated biorefineries, the demonstration of high-tonnage feedstock projects, and the Office's focus on new conversion pathways for hydrocarbon fuels. Since the last review, the Office has devoted significant effort toward improving sustainability analysis and integrating this analysis throughout its portfolio, and the Office is pleased that the results of these efforts are being recognized. BETO believes that each of these areas will be critical to the ultimate success of the bioenergy industry and appreciates the Steering Committee's support in these endeavors.

WEAKNESSES

The Office plans to move forward with many of the recommendations offered by the Steering Committee. In recognizing the need for greater interactions with the petroleum and refining industry, BETO is planning to establish a petroleum industry and refining infrastructure coordination group to help facilitate improved alignment and coordination with, and understanding of, the petroleum industry and other relevant stakeholders. The Office recognizes the challenges associated with the Environmental Protection Agency's fuel registration requirements and plans to consider ways to address these issues in concert with the U.S. Department of Energy's (DOE's) Vehicle Technologies Office (VTO) and other relevant stakeholders.

Regarding concerns about a lack of information sharing and technical overlap between the projects, a revised Annual Operating Plan (AOP) template is now being used to improve information sharing and overall coordination within the Office. BETO also plans to refine its use of techno-economic analysis (TEA) and life-cycle assessment, as well as the standardization of common assumptions and metrics through the technology pathways assessment and the algae harmonized modeling activities.

The Office appreciates the need for additional reviewer training, for full project participation, and for the concerns regarding the structure of the integrated biorefinery review session. BETO will aim to provide more extensive reviewer training and make other improvements during the next Office peer review cycle. Recommendations concerning the focus of future Congressionally directed projects are worth considering, and BETO will plan to explore how these recommendations can be addressed in concert with DOE's Office of Congressional Affairs.

IMPACT

The Office appreciates the committee's view on the important potential impact of many of BETO's current efforts. BETO recognizes the need for continued cost-share support of capital-intensive demonstration at increasing scale projects. The Office will continue to support the integrated biorefinery projects, many of which were funded under the American Recovery and Reinvestment of Act of 2009. In April 2013, the Office announced four awards for pilot-scale projects under BETO's Innovative Pilot Funding Opportunity Announcement (FOA) to produce jet and diesel fuel for military specifications. The Office also plans to continue working with the U.S. Department of the Navy and the U.S. Department of Agriculture under the terms of its memorandum of understanding to support the construction of additional advanced biorefineries within the budgetary limits defined by Congress. The Office is planning to move forward with other demonstration funding opportunities in future years.

BETO concurs with the committee's assessment of the significance of the high-tonnage feedstock logistics projects, the ongoing commitment to sustainability, and the analysis of the myriad factors that affect the environmental impact of biofuels. One of the Office's priority pathways, biological conversion of sugars to hydrocarbons, is focusing on the importance of catalytic routes to lower the costs of bio-intermediates and products.

INNOVATION

The Office has already completed technical memos for seven of its new priority pathways for hydrocarbon fuels and plans to publish new design case reports for all eight pathways through 2014 and 2015. BETO agrees that there are potential synergies between natural gas and biomass, and the Office is evaluating their potential for producing liquid fuels.

In September 2013, BETO held a Natural Gas-Biomass to Liquids (GBTL) Workshop in Chicago, Illinois, to collect stakeholder input. The Office plans to publish a white paper in 2014 on BETO's potential role in this area. Additionally, the Office plans to continue working with DOE's Office of Fossil Energy to further evaluate research needs and examine how these needs are best addressed within DOE's overall portfolio. BETO also contracted for an external feasibility study of TEA potential and life-cycle impacts of GBTL technologies and plans to complete a report by September 2014 on implications and future work. The Office also will consider issuing a GBTL FOA in 2015, as well as increasing its demonstration efforts with other new competitive opportunities in this area, pending funding availability.

BETO has long recognized the potential for co-products as a means to improve industry economics and enable the production of liquid fuels. BETO is moving forward with a new focus on renewable carbon fiber as a way to create new, high-value materials from sugars, lignin, and other biorefinery co-products. In June 2013, BETO held a workshop in Detroit, Michigan, to collect stakeholder input on BETO's role in this area. The results of this workshop, and the preceding Request for Information, were published in a summary report in October 2013. BETO plans to move forward with a possible FOA in fiscal year 2014, pending available funding.

SYNERGIES

The Office appreciates the Steering Committee's understanding of the challenges involved in balancing the need to protect intellectual property with the goals for technology transfer and accelerated industry development. BETO's new AOP process will help avoid duplication and overlap, as well as enhance overall coordination within the Office and among the various national laboratories. Moving forward, BETO will also look to broaden opportunities for coordination with industrial partners and other non-national laboratory participants through stakeholder workshops and other outreach mechanisms and industry collaborations.

Although the Office's biennial peer reviews are open to the public, and therefore have not generally included opportunities for closed-door external assessment of proprietary information, BETO also conducts annual comprehensive project reviews with each of its integrated biorefinery partners that do include the disclosure and review of non-public information. However, as mentioned, the Office will assess the need for alternate review structures, particularly in the Integrated Biorefinery Technology Area, in future peer review cycles.

BETO has actively considered the need for post-mortem reviews of terminated projects and will continue to evaluate this need, implementing these reviews as the Office deems appropriate. BETO is also currently engaged in an effort to compile non-proprietary "lessons learned" from the biorefinery project performers and make this information available to future project partners.

AREAS OF CONCERN

BETO recognizes that the cost, quality, and reliability of biomass feedstocks continue to be a significant concern for the industry. Although the Office recognizes that feedstock characteristics may vary by region, given BETO's role as a component of a national government agency, the Office must focus on an appropriately broad portfolio of feedstocks.

Higher-than-estimated capital and operating expenses for commercial facilities are also recognized as a legitimate concern. As mentioned previously, BETO will plan to incorporate lessons learned from the execution of its existing integrated biorefinery projects into the planning and implementation of future demonstration and deployment funding opportunities.

NEW RESEARCH AREAS

In collaboration with VTO, the Office plans to move forward with considering new funding opportunities for carbon fiber and the optimal usage of natural gas in the transportation sector. One example could be GBTL, but it will have to be assessed against all other routes to facilitate a focused pathway forward. As per the committee's recommendation, the most significant new area of near-term research will focus on the Office's planned Incubator Program. This program will solicit proposals for innovative, next-generation technologies not currently included within BETO's existing research portfolio. The Incubator Program also has strong support from EERE's Assistant Secretary and is seen as an invaluable means for DOE to support potentially disruptive or accelerator technologies not commonly recognized to be on the horizon. BETO plans to issue a FOA in 2014, pending available funding from Congress.

STRATEGIC PLANNING

BETO already collaborates with other offices in EERE's Office of Sustainable Transportation, as well as with other offices across DOE, and looks forward to future opportunities for expanded intra-agency collaboration. For example, BETO currently partners with VTO and DOE's Advanced Manufacturing Office in its research on renewable, low-cost carbon fiber, and with VTO and DOE's Office of Fossil Energy in its work on natural gas. BETO has plans to establish a petroleum industry and refining infrastructure coordination group that will help facilitate increased coordination with the industry.

The Office is encouraged by the committee's view on the utility and relevance of BETO's Multi-Year Program Plan (MYPP). The MYPP is already available on the Office's website, and updates are routinely mentioned in BETO's monthly electronic newsletter, which is distributed to approximately 12,000 stakeholders. However, BETO will look for additional ways to publicize the MYPP and the Office's other strategic planning documents and will also take the other recommendations for improvement to the document under advisement.

At the direction of DOE's new "One EERE" initiative, BETO has also participated in an extensive new effort to train staff on active project management and to streamline and improve the consistency of AOP and FOA development across all of EERE. The Office is also participating in a major effort to overhaul and modernize EERE's Internet technology software to integrate diverse EERE process operations into a single system.

COLLABORATION

The Office appreciates the commendation of BETO's open door policy in regard to meetings with stakeholders and potential partners. The Office considers the open solicitation of stakeholder inputs to be essential to understanding the needs of the industry, non-governmental organizations, universities, and the broader bioenergy community. An essential part of the agency's functional role is to understand these needs and work with partners to proactively facilitate their redress. This work is critical to achieving BETO's overarching goals of accelerating the commercialization of advanced bioenergy technologies.

BETO appreciates the Steering Committee singling out the importance of international engagements in the bioenergy sector, particularly in the development of international codes and standards. BETO will continue its support of these international efforts within existing multilateral organizations, as well as through a number of bilateral research collaborations, and balance this support against the need to be synergistic with the existing domestic efforts of research, development, and demonstration.

RECOMMENDATIONS

The Office sincerely appreciates all of the Steering Committee's work. The straight-forward layout of specific, actionable recommendations is extremely helpful. In this overall programmatic response, BETO has addressed nearly all of the specific recommendations. BETO has resolved to take concrete action on many of these recommendations and will continue to incorporate others into the Office's overall thinking for continuous improvement of its approach and research strategy.

Regarding BETO's communications strategy, the Office fully acknowledges the need to effectively convey its message to the public and to Congress. BETO invests significant resources in its messaging and outreach efforts by communicating success stories, participating in and hosting industry conferences, posting regular blog and social media updates, and actively maintaining its website and other communications materials. Recently, BETO initiated a new communications research and messaging strategy project and plans to share its results with other stakeholders in the bioenergy community.

The Office looks forward to continuing to leverage the active participation of all its stakeholders as it seeks to persuade the American people and their representatives in Congress of the significant achievements of, and enormous potential for, an advanced bioenergy industry.

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