ADVANCED DEVELOPMENT AND OPTIMIZATION: INTEGRATION AND SCALE-UP

TECHNOLOGY AREA

CONTENTS

INTRODUCTION

The Advanced Development and Optimization (ADO): Integration and Scale-Up Technology Area is one of 14 related technology areas that were reviewed during the 2019 Bioenergy Technologies Office (BETO) Project Peer Review, which took place on March 4–7, 2019, at the Hilton Denver City Center in Denver, Colorado. A total of 26 projects were reviewed in the ADO: Integration and Scale-Up session by six external experts.

This review addressed a total U.S. Department of Energy (DOE) investment value of approximately $322,323,910 (fiscal year [FY] 2016–FY 2019 obligations), which represents approximately 37.5% of the BETO portfolio reviewed during the 2019 Project Peer Review. During the Project Peer Review meeting, the principal investigator (PI) for each project was given 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 and accomplishments, relevance to BETO goals, and future plans. 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 ADO: Integration and Scale-Up Technology Area full scoring results and analysis, the Review Panel Summary Report, and the Technology Area Programmatic Response are also included in this section.

BETO designated Ms. Liz Moore as the ADO: Integration and Scale-Up Technology Area review lead, with contractor support from Mr. Remy Biron (Allegheny Science & Technology). In this capacity, Ms. Moore was responsible for all aspects of review planning and implementation. Mr. Joshua Messner also assisted with technical and logistic aspects of the review.

ADO: INTEGRATION AND SCALE-UP OVERVIEW

The ADO Technology Area conducts integrated systems research up to and including the engineering scale. ADO addresses components and systems scalability capable of handling industrially relevant and economically advantaged feedstocks to produce renewable fuels and bioproducts. Engineering-scale verification also provides biofuels and bio-oil intermediates for testing and certification to ensure that those products can seamlessly integrate with existing distribution infrastructure. It also enables petroleum refineries to evaluate the effect of coprocessing biobased intermediates and reduces technical uncertainties for how biobased intermediates can be integrated into existing operations.

The ADO: Integration and Scale-Up session reviewed projects that focused on first-of-a-kind or early investigations into integrated systems and use of industrially relevant materials. ADO recognizes the critical need to transition from a controlled bench environment to the variability likely to be encountered as technologies progress toward the commercial scale. At these scales, in addition to the process optimization and intensification that can occur, quantities of materials needed for product testing and acceptance can be produced.

ADO: INTEGRATION AND SCALE-UP REVIEW PANEL

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Daniel Lane	Saille Consulting, LLC
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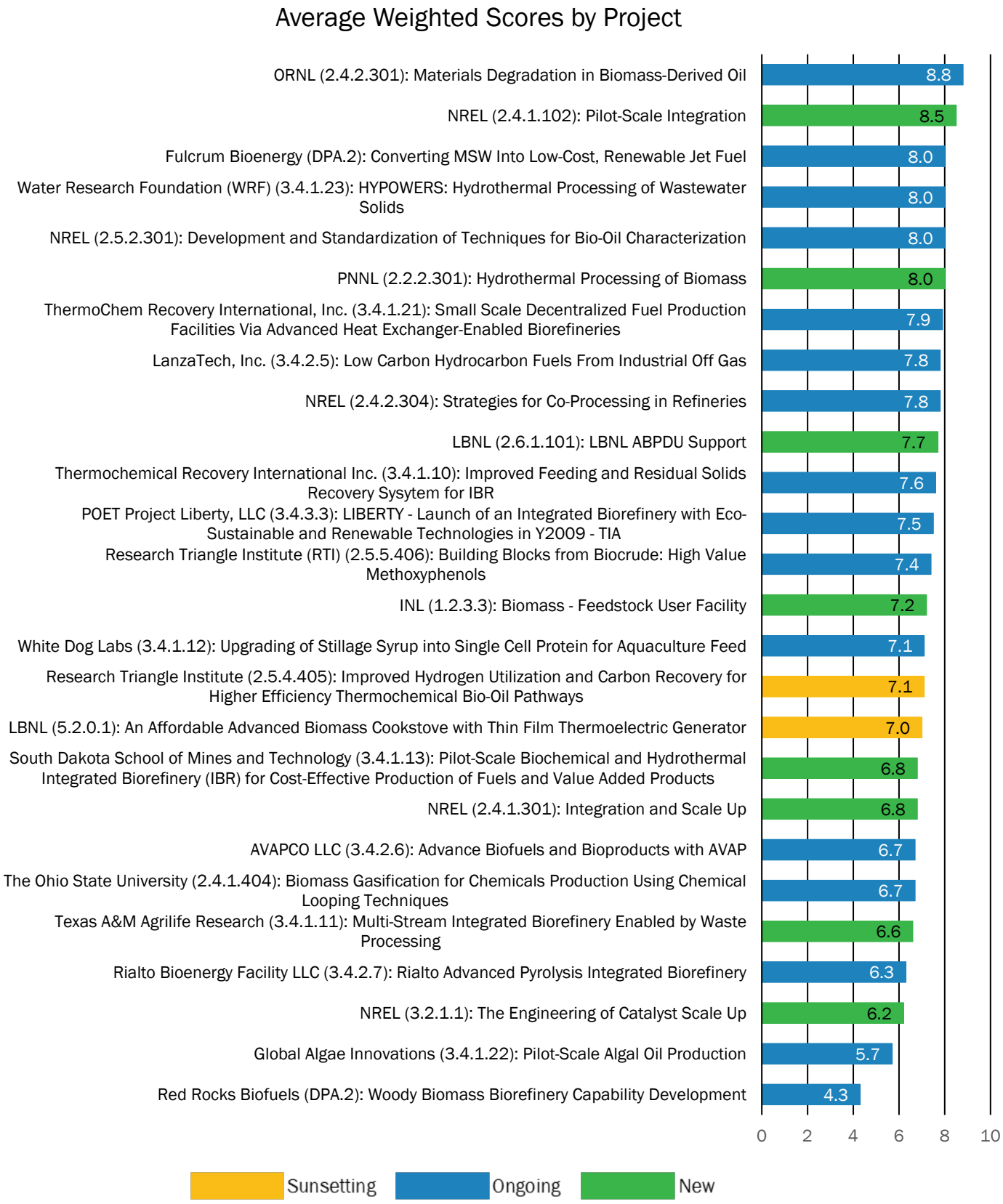
TECHNOLOGY AREA SCORE RESULTS



ADO: INTEGRATION AND SCALE-UP REVIEW PANEL SUMMARY REPORT

Prepared by the Advanced Development and Optimization: Integration and Scale-Up Review Panel

ADO (previously known as Demonstration and Market Transformation) at BETO serves as a critical interface between the BETO research-and-development (R&D) projects and the deployment of advanced bioenergy technologies for end use. This team has been organized to manage the translation of R&D into technology demonstration and integration through well-established processes for project definition and execution using competitive solicitations. ADO is currently managing a diverse set of projects in its portfolio of technology areas (biochemical, thermochemical, etc.), technology-readiness levels (TRLs) (4–8), and feedstocks used (wood, stover, waste). Key barriers to market adoption of the technologies remain, including unfavorable market drivers such as low prices of oil and natural gas and no price on carbon emissions, as well as technology challenges associated with long-term reliable and robust operations of pilot plants, feedstock logistics, costs and long-term supply contracts, conversion and separation costs, and, most importantly, financing of demonstration and first-of-a-kind commercial facilities.

On behalf of the review panel, we thank the ADO team for the invitation to review the projects. It was a great learning experience for the panel members. We sincerely hope that comments provided by the review panel members on the individual projects are helpful in shaping better outcomes for the projects in the future.

SCOPE

From the panel's review of 26 projects in the ADO: Integration and Scale-Up portfolio, it was clear that ADO is managing engineering-scale systems development to verify and validate technologies in relevant environments (with real feedstocks and under realistic operating conditions) using engineering prototypes developed from the knowledge gained in early TRL R&D projects. In addition, ADO is providing a critical link to other BETO platforms, such as the Agile BioFoundry, Co-Optimization of Fuels & Engines (Co-Optima), Feedstock-Conversion Interface Consortium (FCIC), Chemical Catalysis for Bioenergy Consortium (ChemCatBio), Bioprocessing Separations Consortium, and DISCOVR Algae Consortium. Application of learnings from these targeted consortia to technical development and verification is a critical function that ADO is undertaking to reduce the overall cost of conversion and technology risk for commercial deployment.

ADO is also overseeing the BETO user facilities and connecting them with users to advance the technologies funded by BETO from the laboratory/bench scale to the pilot scale. These facilities include the biochemical conversion facility at the National Renewable Energy Laboratory (NREL), feedstock user facility at Idaho National Laboratory (INL), bio-oil testing for corrosion facility at Oak Ridge National Laboratory, Advanced Biofuels and Bioproducts Process Development Unit (ABPDU) at Lawrence Berkeley National Laboratory (LBNL), thermochemical pilot plant at NREL, biomass cookstove facility at LBNL, and the hydrothermal liquefaction (HTL) facility at Pacific Northwest National Laboratory (PNNL). In addition, ADO is putting concerted efforts in developing methods and tools at the national laboratories (e.g., NREL) that can be leveraged by other BETO projects. These include analytical methods development for the characterization of bio-oils, process modeling tools, and techno-economic analysis (TEA) and life cycle assessment (LCA) methodologies. Enabling and cross-cutting technologies such as corrosion testing, analytical methods development, and feedstock handling are critical for the success of the entire portfolio. In sum, risk management associated with the development and deployment of new bioenergy technologies through technology verification and validation is ADO's primary role in BETO.

IMPACT

DOE investment through cost-shared projects to scale up the technologies from the bench to pilot and pilot to commercial demonstration is critical for future private investment in these technologies. The ADO team, through its structured project management practices, has generally done a very good job.

The POET (Liberty) project in the ADO portfolio is essentially in commercial operation, although some long-term operability issues are being addressed. Two other projects—Fulcrum BioEnergy (using waste gasification) and Red Rock Biofuels (RRB)—are at commercial demonstration scale, which are part of the Defense Procurement Act projects. These projects should be in operation by next year, if everything goes as planned. The success of these projects is critical to demonstrating the technology and to attracting commercial interest and investment capital for future deployment of the underlying technology.

Several other technology projects are at the pilot scale. This program review shows that these small pilot-scale projects are moving along well and form a good basis for taking them to commercial demonstration. These projects include chemical looping biomass gasification at Ohio State University, continued process and technology improvements at ThermoChem Recovery International, Inc. (TRI), treatment of biorefinery wastes at Texas A&M and South Dakota School of Mines and Technology, and the production of coproducts along with biofuels at Research Triangle Institute (RTI). Successful execution of these projects is critical to determining their merit for future investment to take them to the next scale.

The peer review noted that several projects awarded under the Project Development for Pilot- and Demonstration-Scale Manufacturing of Biofuels, Bioproducts, and Biopower (PD2B3) funding opportunity announcement (FOA) underwent a very structured stage-gate review. Based on the results, some projects were discontinued after Budget Period 1 and others moved forward to Budget Period 2. The currently ongoing projects in this category are making good progress to qualify for commercial demonstration. DOE funding was critical for them to undertake front-end engineering and design and permitting activities to attract project financing for commercial demonstration plants. Examples include LanzaTech, which is converting ethanol into jet fuel; biosludge conversion to fuels by the Water Research Foundation using PNNL's HTL technology; and AVAPCO, which is converting ethanol into nanocellulose and jet fuel. Commercial demonstration of some of these technologies will pave the way for their market acceptance and widespread deployment.

INNOVATION

With ADO's mission of technology verification and validation, major technology innovations through the projects are not expected. With ADO's emphasis on the use of real feedstocks under relevant conditions and promoting the use of national laboratory user facilities for pilot testing, however, the review panel noted several engineering innovations in various projects. For example, process intensification work done at TRI by integrating advanced heaters and novel particle-flow designs promise significant process improvement in future TRI biomass gasification projects. The production of coproducts along with biofuels is a desired pathway to enhance the attractiveness of bioenergy technologies. Several projects are pursuing new catalysis and process designs to meet this goal. Some modeling work done at NREL and other places is providing insights into solving operational problems and improving process designs.

PROJECT MANAGEMENT

The review panel made the following observations on ADO's project management practices:

- The use of an independent engineer for project validation is a very good practice that allows for checking the claims made by project performers through on-site visits and rigorous analysis. The timing of these validations could be improved to avoid excessive delays in the project schedule. Some delays were apparently caused by project performers not having a clear understanding of validation requirements. BETO should consider including information about the independent engineer validation process as an appendix in various FOAs.

- It was not clear how learnings from individual projects (both successes and failures) were shared with the wider community and other project performers. There are industry best-practice guidelines to share these findings.
- It was not clear how much support ADO/BETO provided to the project participants in technology transfer. Researchers are heavily focused on solving technical problems without much understanding of business aspects and industry relevance. Having a small technology-transfer team at BETO (similar to Advanced Research Projects Agency-Energy but focused and at a much smaller scale) would be helpful to guide the projects to generate industry interest.
- Value chain analysis in some of the projects was missing. For example, if ethanol is a feedstock to produce biojet, analysis of long-term cost and availability of ethanol should be an important part of the project. Also, the final product has certain specifications for selling, so the final process step must include a separation/purification box to obtain those specifications.
- For some projects, the development of coproducts appeared to greatly increase the complexity and potentially the capital cost. Although the cost per gallon of gasoline produced through these coproduct pathways was attractive, getting the investment capital to build the entire plant could be difficult because of high overall capital costs.
- For some projects, the price used by project presenters for gasoline or diesel as a selling price was not the commodity price that could be achieved by the seller on the market. The presenters did not always appear to know the difference between the "cost at the pump" and what they could sell the product for. ADO should provide some guidelines to the project to fix this anomaly.
- In general, transitioning from one budget period to the next took significantly longer than planned. If BETO has certain administrative processes for review and approval, these need to be included in the FOA for planning the budget periods.
- ADO/BETO should develop uniform guidelines for conducting TEA and LCA studies for all projects. For reference, the National Energy Technology Laboratory uses well-defined guidelines for TEAs in all their projects under the carbon dioxide (CO_2)-capture portfolio. Further, the assumptions and methodologies used for TEAs must be clearly defined and stress-tested (even if only shown to DOE), including coproduct valuation, market assessment, fully loaded costs, and use of tornado diagrams to prioritize future R&D work.
- Most projects provided a goal of meeting $3/gasoline gallon equivalent (GGE) as a target to meet the *Multi-Year Plan* (MYP) goals without providing enough specifics. For most projects, no real effort was made to quantify how much the project could contribute toward reducing costs. Further, this target was set a few years ago. With changes in market conditions, ADO/BETO should revisit this goal because making biofuels might not be the best market driver for using biomass.
- Some laboratory projects funded through annual operating plans (AOPs) need industry context. For example, process models must be validated with relevant experimental data. The catalyst scale-up project should include a commercial catalyst manufacturer to share industry practices. This work at the national laboratories will significantly benefit from strong industry partnerships from an early stage. Process modeling is not a substitute for industry input.

RECOMMENDATIONS

The Peer Review Panel makes the following three recommendations:

Recommendation 1: ADO/BETO should develop guidelines for uniformly conducting TEA studies for all projects using a systems approach. The assumptions and methodology used for these TEAs must be clearly

defined and stress-tested, including coproduct valuation and market assessment to constantly ask, “Does this technology make economic sense?” These TEAs should be used to prioritize future R&D work.

Recommendation 2: Project validations using independent engineers should be continued but with clearer directions provided to project performers.

Recommendation 3: Projects at the pilot scale must include a value chain analysis from raw material procurement to offtake agreements for the final product(s).

The overall assessment of the Peer Review Panel was that ADO is doing a good job of demonstrating and validating integrated biorefinery technologies by focusing on the evaluation of performance at the pilot, demonstration, and pioneer scale to reduce capital and operational expenses and validate product quality.

ADO: INTEGRATION AND SCALE-UP PROGRAMMATIC RESPONSE

INTRODUCTION/OVERVIEW

BETO thanks the Peer Review Panel for their time and active participation in the ADO: Integration and Scale-Up session, as well as the panelists and steering committee for providing their feedback during the Project Peer Review meeting in March 2019 and the Program Management Review meeting in July 2019. We appreciate the panel’s insightful and engaged review of the ADO: Integration and Scale-Up projects. The reviewers provided in-depth and constructive recommendations that can be used to inform the path forward for ADO: Integration and Scale-Up Technology Area in the coming years.

The 2019 Peer Review Panel commented that the ADO team, through its structured project management practices, has generally done a very good job. One instance specifically is that the projects awarded under the PD2B3 FOA underwent a very structured stage-gate review. BETO appreciates this feedback and continuously works to improve project and portfolio management to ensure that the proper controls are incorporated into the award documents and project management interactions. Conversely, the panel noted that it was not clear how much support ADO and BETO provided to the project participants in technology transfer, stating that researchers are heavily focused on solving technical problems without much understanding of business aspects and industry relevance. To clarify, ADO is emphasizing industry collaboration with national laboratory-operated process development units as well as other programs such as Energy I-Corps, which pairs teams of researchers with industry mentors where the researchers define technology value propositions, conduct customer discovery interviews, and develop viable market pathways for their technologies.

The panel also commented on innovation, stating that major technology innovations through the projects are not expected at higher TRLs, which is the general focus of the ADO Technology Area. But the panel does recognize the importance of the higher TRL work, especially work that emphasizes the use of real materials under relevant conditions. The panel also suggested that ongoing modeling work is providing insights into solving operational problems and improving process designs and that the production of coproducts will enhance the attractiveness of bioenergy technologies. ADO strives to strike a balance between innovation and technology readiness. Best practices from the BETO portfolio and elsewhere in industry support the use of industrially relevant conditions and materials, and ADO emphasizes this in its projects. Leveraging computational power by closely coupling with experimental efforts is becoming more widely used in the BETO and ADO portfolio.

The panel was asked to examine possible synergies between projects within ADO: Integration and Scale-Up Technology Area. The panel noted that enabling and crosscutting technologies such as corrosion testing,

analytical methods development, feedstock handling, and other technologies funded by ADO: Integration and Scale-Up have many synergies across ADO and are critical for the success of the entire portfolio. Additional synergies observed by the panel include ADO's efforts to manage the BETO process development units (PDUs) and encouraging teamwork to advance the technologies funded by BETO from the laboratory/bench scale to the pilot scale, which can be leveraged by other BETO projects. Last, the panel mentioned that risk management associated with the development and deployment of new bioenergy technologies through technology verification and validation is one of ADO's primary roles in BETO. DOE agrees, and ADO continues to emphasize total system development, including feedback to prior scale and upstream/downstream operations. For example, during FY 2019, ADO established the PDU working group with key personnel from each national laboratory PDU facility. The intent of this effort is to provide a forum for the various facilities to share best practices on technology, safety, project management, and other topics. In contrast, the panel found potential synergies in the TEAs and LCAs. Specifically, the panel suggested that ADO (and BETO as a whole) should develop uniform guidelines for conducting TEA and LCA studies for all projects. With that said, ADO projects all include a TEA element. ADO and BETO will continue to develop normalized TEA and LCA tools for industry use.

The panel was asked to discuss the focus of ADO: Integration and Scale-Up. The panel stated that some of the laboratory projects funded through the BETO AOPs need industry context. For example, process models must be validated with relevant experimental data, and the catalyst scale-up projects should include a commercial catalyst manufacturer to share industry practices. The panel noted that this type of work at national laboratories will significantly benefit from strong industry partnerships from an early stage and that process modeling is not a substitute for industry input. Additionally, the panel communicated that it was not clear how learnings from individual projects (both successes and failures) were shared with the wider community and other project performers. There are industry best-practice guidelines to share these findings. ADO agrees that industry involvement is critical for developing projects. Many AOP projects have industry advisory boards (IABs) or other industry involvement. BETO will encourage a higher degree of integration into project execution. ADO also notes that the dissemination of data is a core objective of publicly funded projects. ADO will continue to encourage collaboration and other forms of communication.

In addition to program-specific feedback, the Peer Review Panel provided project-specific feedback. The PIs and their project teams will work to incorporate this feedback as they continue with their projects.

As stated, the overall assessment of the Peer Review Panel was that ADO: Integration and Scale-Up is doing a good job of demonstrating and validating integrated biorefinery technologies by focusing on the evaluation of performance at the pilot, demonstration, and pioneer scale to reduce capital expenses and operational expenses and validate product quality. To conclude its review, the panel provided three overall recommendations for the ADO: Integration and Scale-Up Technology Area that, if implemented, would have the greatest impact on the portfolio and its ability to achieve its goals.

Recommendation 1: ADO/BETO should develop guidelines for a uniform basis for conducting TEA studies for all the projects using a Systems Approach.

ADO has consistently requested a TEA task in its projects; however, the feedback suggesting normalization for this process is fair. BETO has developed quick TEA methods to a certain extent, and ADO will collaborate with other BETO programs to determine how best to disseminate these tools and methodologies.

Recommendation 2: Project validations using independent engineers should be continued, but with clearer directions provided to project performers.

ADO and BETO have used many different forms of validation for different applications. This is a continuously evolving process seeking to ensure project readiness before proceeding. ADO has initiated discussions internally and with the independent engineer team to develop materials for applicants and recipients to better describe the expectations of these reviews.

Recommendation 3: Projects at the pilot scale must include a value chain analysis from raw material procurement to offtake agreements for the final product(s).

Although not all projects will address all elements in the value chain, ADO generally always requests target metric or key performance parameter information from projects at the time of application and during key project reviews. The sensitivity of these values might require additional review; ADO will reconsider how best to do this.

As mentioned in previous sections, BETO will consider the panel's recommendations and incorporate them, as appropriate, in program elements and future funding opportunities. The ADO team will also continue to coordinate with other areas of BETO to assess the potential for implementing some of the panel's recommendations for increased synergy among projects.

BETO, the ADO program manager, and the ADO technology managers thank the Peer Review Panel for their time and their engaged review of the BETO's ADO: Integration and Scale-Up Technology Area. The panel's comments were largely positive and provided the program with the type of actionable feedback that can help promote progress toward the development of commercially viable bioenergy technologies.

BIOMASS – FEEDSTOCK USER FACILITY

Idaho National Laboratory

PROJECT DESCRIPTION

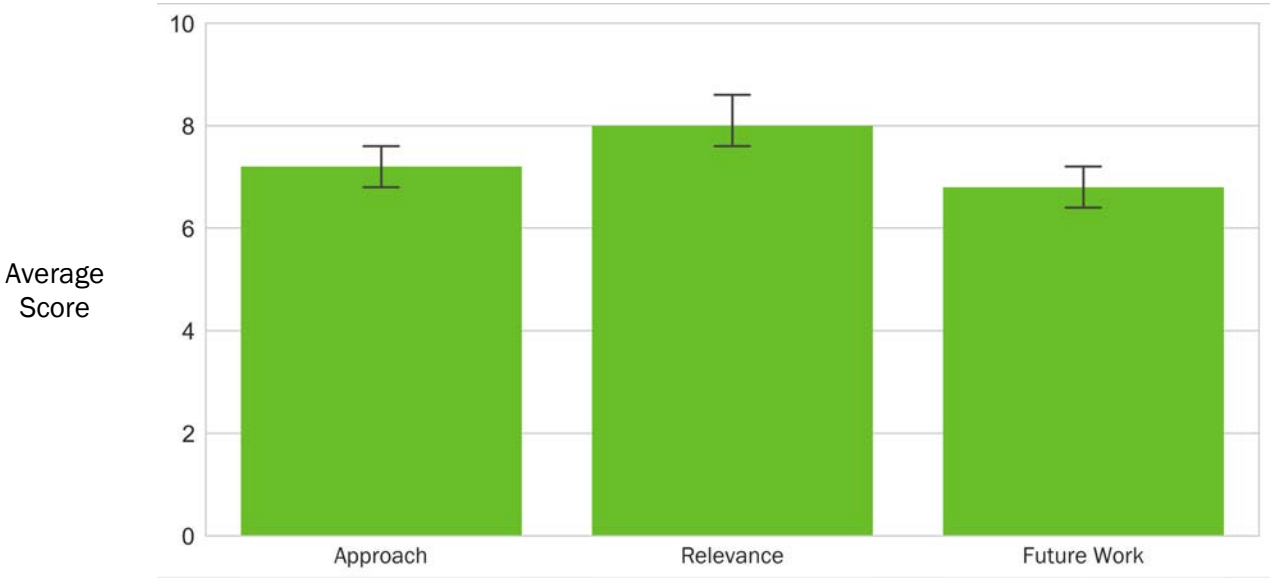
WBS:	1.2.3.3
CID:	NL0018159
Principal Investigator:	Mr. Neal Yancey
Period of Performance:	10/1/2015–9/30/2021
Total DOE Funding:	$5,900,000
DOE Funding FY16:	$1,700,000
DOE Funding FY17:	$1,700,000
DOE Funding FY18:	$2,000,000
DOE Funding FY19:	$500,000
Project Status:	New

BETO has recognized an INL core competency in scale-up and integration of biomass preprocessing technologies and process design. The foundation of this core competency is INL's biomass feedstock PDU, which is an integrated pilot-scale preprocessing system. This core competency is further supported by DOE's Office of Energy Efficiency and Renewable Energy (EERE) designation as a National User Facility in FY 2013. The Biomass Feedstock National User Facility (BFNUF) designation has expanded the use of the PDU in supporting collaborative projects with industry, universities, and other federal agencies. During the past six years, the PDU has been used extensively for preprocessing research, demonstration, and development; process development; toll processing (for feedstock supply) for both BETO- and industry-funded projects; third-party testing; and validation. The project is intended to transform the PDU to new and innovative uses in system-level research that enable and inform early-stage R&D in biomass preprocessing and handling.

This project has both technical and programmatic objectives. The primary technical objective is to eliminate the slugging caused by the Stage 1 grinder that is perpetuated through the preprocessing of baled biomass, resulting in inconsistent flow of biomass during the size-reduction process. This will be achieved by decoupling the first-stage grinding and bale deconstruction. The project will be replacing the high-speed, energy-intense bale grinder with a low-speed bale processor designed to use low speed and high torque to

Weighted Project Score: 7.2

Weighting for New Projects: Approach - 25%; Relevance - 25%; Future Work - 50%



I One standard deviation of reviewers' scores

convert baled biomass into a flowable loose feedstock. The system will be able to process both round and square bales.

A secondary technical objective of this project is to equip the PDU with visualization tools and real-time measurement capabilities that allow in-depth characterization of the interaction of material and machine. The use and benefit of these tools will be demonstrated with a specific study of the mechanics of deconstruction and conveyance of biomass materials. Process visualization and in-line sensor applications will inform early-stage R&D and define operational boundaries. The data generated will be collected and stored in a data collection system that is consistent with and accessible by other DOE laboratories.

The programmatic objective is to increase PDU use. PDU use during the last six years has ranged from 30%–40% (the ratio of the number of days the PDU was in use to the number of days the PDU was available for use). PDU use is a combination of internal use, support of national laboratory AOP projects, and external industry collaborations. The end-of-project goal for the programmatic objective is to increase user facility use from the current baseline of 30%–40% to 60%, with tactical upgrades and improvements along with demonstrated examples and successful use of the PDU and associated capabilities for system-level R&D.

Accomplishing the technical (segmented bale deconstruction) and programmatic (increase BFNUF use) objectives will involve an approach that combines (1) testing new bale deconstruction methods that use low-speed deliberate bale deconstruction methods specifically developed for square or round bales; (2) developing and implementing in-line sensors and visualization tools that will enable the study of basic material and airflow properties within equipment (grinders and mills, conveyors, and other processing equipment) that will lead to more even flow, reduce equipment wear, and enhance separation capabilities; (3) developing data management tools that will increase access of PDU data to FCIC, other labs, and industry; (4) continuing to adapt the PDU to include improvements identified through FCIC, INL, and industry research and interactions; and (5) applying the system-level research capabilities (developed in 1–4) to study the biomass deconstruction and conveyance process in the PDU.

Photo courtesy of Idaho National Laboratory

OVERALL IMPRESSIONS

- The BFNUF offers industry a huge advantage when it comes to the preparation of and dissemination of knowledge related to handling and preprocessing cellulosic feedstocks. This project very much needs to remember that dissemination of this knowledge—especially to equipment manufacturers—is going to have the greatest impact on industry.

- This project focuses on feedstocks that can be economically baled, which likely pertains to feedstocks sourced in the rural arena. The program seems to be focused on making incremental improvements to existing equipment, but ultimately it will result in increased capital expenditures (CapEx) and operating expenditures (OpEx) for feedstock processing. It is aspirational that something new and disruptive will result from this approach.

- There is clearly a need to marry the "smarts" of the national laboratories with the practical considerations of operating biomass preprocessing. Although biomass testing has been performed in the past, it seems we did not always know what we should be looking for. Making this new and improved capability open to industry testing, combined with the expertise of the laboratory personnel, could help industry take leaps forward.

- The facility is a great resource for generating valuable material handling data that are key to biorefinery scale-up. The technical work is well planned and executed, with a good upfront strategy. It is unclear how well integrated the testing is with bale manufactures and equipment vendors to produce a feedback loop.

- This project is aimed at decoupling bale deconstruction from grinding to develop sensing and visualization modeling capabilities with the goal of creating a uniform flow from heterogeneous nonuniform feedstocks. Further, INL wants to achieve greater than 60% use for this facility.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- This is a very good point. We will continue to share data and knowledge gained with industry and equipment manufacturers.
- We have shown that a large portion of the variability observed in grinding and milling can be controlled through proper equipment and controls. This will lead to great control over particle size and potentially other quality parameters.
- We agree.
- This is a good comment, and we will work at better engagement with industry and equipment manufacturers.
- Correct.

HYDROTHERMAL PROCESSING OF BIOMASS

Pacific Northwest National Laboratory

PROJECT DESCRIPTION

Scaling up conversion processes results in changes to proportions, such as surface area to volume or mass, and to flow regimes, and hence fluid mechanics and even reaction kinetics. Scale-up also affects the control of unit operation parameters, such as temperature and pressure, which can impact the management and efficiency of separations. Designing, building, operating, and maintaining PDUs is essential for de-risking the scale-up of conversion process technologies.

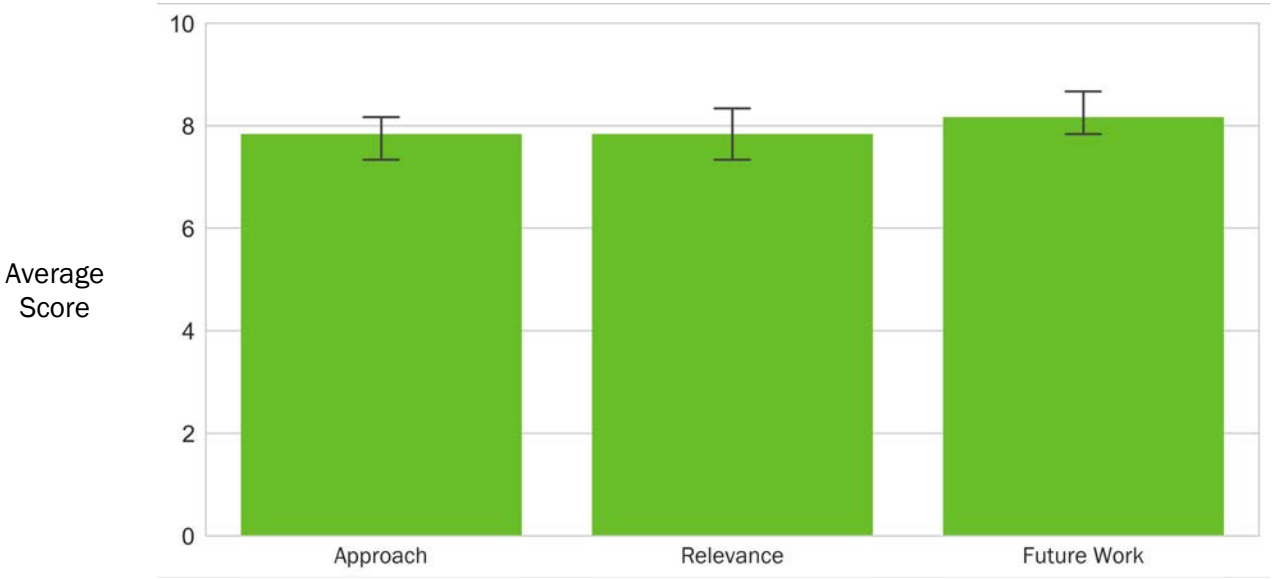
WBS:	2.2.2.301
CID:	NL0026720
Principal Investigator:	Mr. Dan Anderson
Period of Performance:	10/1/2015–9/30/2020
Total DOE Funding:	$7,285,613
DOE Funding FY16:	$2,200,000
DOE Funding FY17:	$2,050,000
DOE Funding FY18:	$1,866,105
DOE Funding FY19:	$1,169,508
Project Status:	New

The PNNL PDU program currently focuses on adapting and applying hydrothermal PDU capabilities to produce biofuels and coproducts from wet-waste feedstocks. The project has four major objectives: (1) conduct enabling R&D for hydrothermal processing, (2) performance testing and scale-up using wet-waste feedstocks, (3) support system modifications and capability management, and (4) support collaborative R&D projects.

The PNNL PDU program is addressing engineering scale-up challenges that must be resolved to move forward with later-stage integrated pilot and demonstration testing. Collaborative R&D projects hosted by the PNNL PDU program will produce the data and transfer of technology required for investment and commercialization.

Weighted Project Score: 8.0

Weighting for New Projects: Approach - 25%; Relevance - 25%; Future Work - 50%



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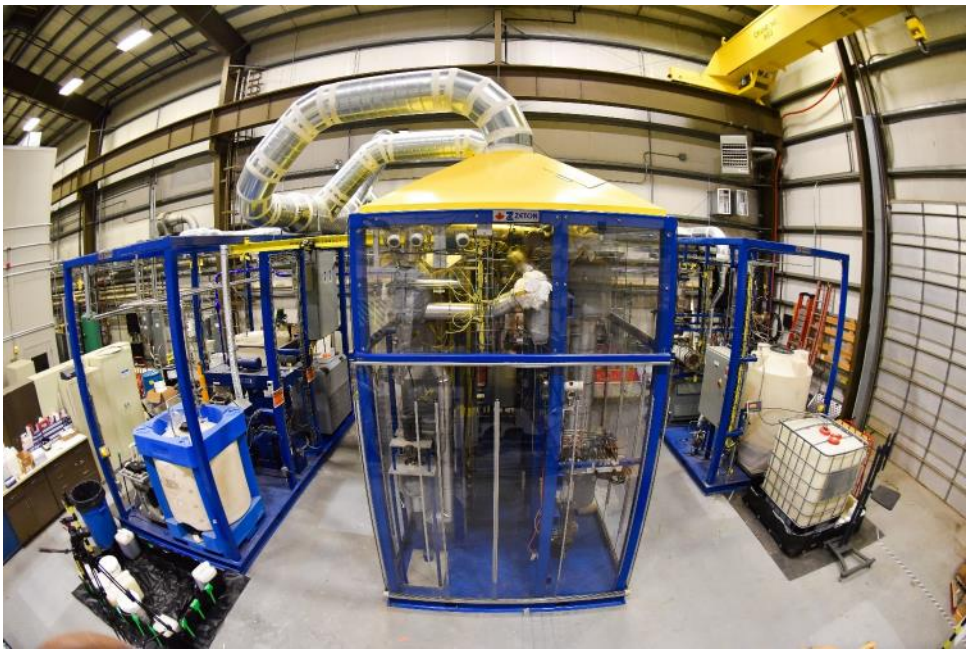


Photo courtesy of Pacific Northwest National Laboratory

OVERALL IMPRESSIONS

- This project is conducting process development research to evaluate the feedstock impact on HTL yields, valorization of waste streams, PDU operations, and scale-up challenges. In order to produce directly blendable diesels, hydrotreating is required due to the presence of heteroatoms (oxygen, nitrogen, and sulfur). Catalytic hydrothermal gasification has been applied to other streams, and this project is trying to apply it to HTL streams. The block flow diagram shows lots of issues to resolve.

- This project is aimed at the development and commercialization of PNNL's hydrothermal processing to convert wet feedstocks into transportation fuels. This PDU capability has been developed during the last 30 years, and its use is now extended to process wet solids.

- Overall, this project appears to be well thought through, targeting a less-developed process with the unique skills and equipment available or to be available to the national laboratories.

- The discussion of using a centrifuge to separate similar-density liquids did not make sense, and this equipment would not be used in industry for such a task. It seems there must be better equipment to address this separation, even going after the last bit.

- This is a clear and well-organized presentation. The team did a good job describing the technology and plans for continued hydrothermal processing technology development. The approach and planned work are well thought out and focused on value-added areas. The system design focuses on skidding, and the mobile units adds value and flexibility.

- This is a laudable anticipated and continuing use of existing facilities.

- The development of a pilot/demonstration facility for a technology with such potential impact is a critical activity and clearly an important mission for a national laboratory. The impact and support to the industry at large cannot be underestimated. Of relevance is the effort to make this facility flexible and capable to provide engineering data of immediate use for scale-up activities. The only area of concern is the reliance on catalytic technologies that might be of limited scalability and questionable economics. Nonetheless, this is a good platform for a variety of hydrothermal processing R&D activities.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- The greatly appreciates the input. Many of the comments affirm the value of the project to BETO and reinforce our R&D and project management approach. Two important areas included a number of comments that will be briefly discussed here: (1) our approach to industrial engagement and (2) what we are doing differently versus our focus in previous years.

- From the onset, this project has heavily relied on industry to provide candidate feedstocks, and generally, the feed suppliers have a vested interest in the application of HTL to their wet waste. Through our collaborative work with the Water Research Foundation, member municipalities (more than 15) are tracking the progress of our work at PNNL and the work on the Hydrothermal Processing of WastewatER Solids (HYPOWERS) HTL demonstration project (a FOA) in Contra Costa County, California. As a result, municipalities are reaching out to us along with about a half-dozen entities working with venture capitalists. Additionally, BETO has set aside funds and is working to put out a broad solicitation for industry engagement with the PDUs.

- With respect to the new focus, as we advance HTL and test at larger scales, the project has identified a number of techno-economic and engineering challenges and uncertainties from feedstock assessment and formatting to HTL scale-up (pumping, heat exchanger evaluation, continuous oil/water separation) through water treatment and upgrading (metal removal, catalyst life, and throughput). Although we have improved in many of these areas during the past five years, the TEA along with interactions with architecture, engineering, and construction professionals (AECs) are helping us establish priorities on the R&D for further improvements.

PILOT-SCALE INTEGRATION

National Renewable Energy Laboratory

PROJECT DESCRIPTION

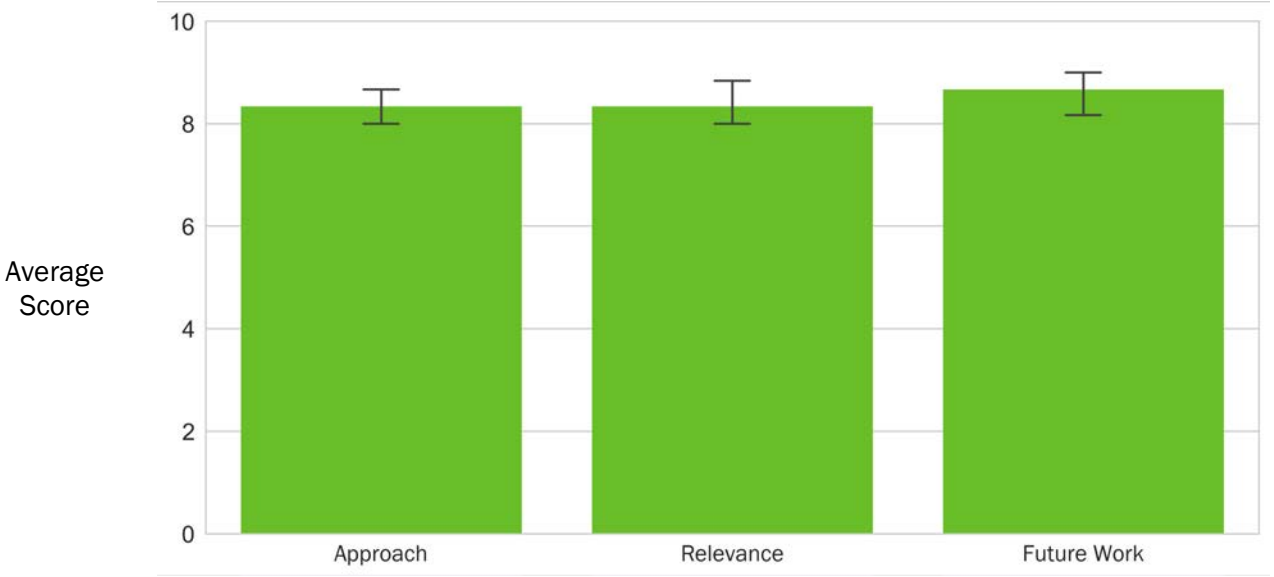
The goal of this project is to support BETO's and industry's mission to develop cost-effective biofuels and bioproducts by providing a well-maintained and process-relevant, engineering-scale pilot plant for process development and technology verification. BETO national laboratory projects and consortiums, as well as industry, use the pilot plant to test and develop new technologies supporting ADO's goals to reduce commercialization risk and solve scale-up problems. The plant also produces process-relevant materials for bench-scale research as well as byproducts for testing and market development.

WBS:	2.4.1.102
CID:	NL0010773
Principal Investigator:	Mr. Dan Schell
Period of Performance:	10/1/2015–9/30/2021
Total DOE Funding:	$5,604,000
DOE Funding FY16:	$2,000,000
DOE Funding FY17:	$2,000,000
DOE Funding FY18:	$1,604,000
DOE Funding FY19:	$0
Project Status:	New

The 27,000-ft^2 pilot plant has two high bays housing feed handling through bioconversion and downstream separation equipment with approximately 1,500 analog and digital signals for process monitoring and control using a sophisticated process control system. The project has two tasks: (1) pilot plant upkeep and process material production and (2) development of new capabilities. The former work (Task 1) is organized effort to maintain the pilot plant (equipment maintenance and repair), generate and update plant documentation (Process and Instrumentation Diagrams [P&IDs], operating and lockout procedures, etc.), upgrade and maintain instrument and control systems (calibration, software and hardware changes, etc.), adhere to safety programs (process hazard analysis, change management, permits, etc.), and produce materials (pretreated biomass, enzymatic hydrolysis-derived sugars, soluble and insoluble lignin) for bench-scale research efforts. The goal of the second task is to find new capabilities—in

Weighted Project Score: 8.5

Weighting for New Projects: Approach - 25%; Relevance - 25%; Future Work - 50%



I One standard deviation of reviewers' scores

collaboration with other BETO projects and industry partners—that enhance the pilot plant's ability to support future R&D work. At a minimum, yearly brainstorming sessions with BETO project leaders as well as our informal interactions with industry partners are used to identify needed equipment and capabilities. Then we define and implement milestone key decision points (go-no-go) to manage acquisition and installation activities using the available resources.

Future work in Task 1 includes ongoing efforts to maintain, repair, and upgrade existing equipment and instrument systems, update and maintain plant documents, and observe safety programs. Last year, we supplied seven BETO projects with research materials, and we expect to supply 18 projects with materials in FY 2019. We will also complete an update of the control system operator screens using a cheaper, versatile, modern, and more user-friendly software by the end of FY 2019, and we will complete the implementation of a new pilot-plant data-management system by mid-FY 2020. Future Task 2 work will continue efforts to find and acquire new capabilities. One current effort is to assess and modify the pilot plant's existing crossflow filter unit to perform ultrafiltration. Finally, we are beginning the procurement and installation of an advanced pretreatment process known as deacetylation and mechanical refining (DMR), two-stage refining of deacetylated biomass. We have purchased the first-stage 22-in. disk refiner (the delivery date is midsummer 2019), and we are beginning the design of a pilot-scale DMR system with installation targeted to occur in FY 2020 (we still need funds for additional equipment acquisition and installation). Prior to performing biochemical 2022 process verification in this facility, it will be necessary to begin planning in FY 2020 by defining the scope of the effort and needed capabilities to complete the work.

OVERALL IMPRESSIONS

- Pilot-scale operations are critical to any scale-up. Many startup companies cannot afford to move directly to the pilot scale without additional validation or demonstration at scale; this PDU offers that opportunity. Other startups might need to focus on realistic feedstocks to demonstrate the viability of their processes or technology, and again, this PDU offers that. Support of industry at this scale is critical, and this project continues to be highly valuable to the portfolio.

- This project supports a worthy and demonstrated pilot plant.

- Considerable thought and planning have gone into the development of this project, which were supported by this presentation.

- The presentation did not address whether the refiner had been modified for this specific work. Typical pulp and paper refiners are used at a much lower solids ratio than this application. Hopefully the equipment was tested in a manner prior to purchase to confirm that it did what was needed for this application.

- The facility provides key scale-up data for biochemical processes. The project is being refunded and appears to be meeting its stated goals. The asset has proven performance and is a critical resource for the scale-up of biotechnologies.

- This is a national resource for developing and improving biochemical conversion technologies to produce cellulosic fuels and other products. This facility has served well to help scale up technologies, produce relevant product samples, and reduce commercialization risks. This facility has been well maintained.

- A flexible and agile pilot infrastructure open to the industry can considerably speed up the delivery of new ideas to market. Nothing specifically objectionable has been presented. It would be desirable to have a bit more clarity on the mechanism for accessing the capabilities of the facility and on the rationale for specific decisions regarding new capabilities and/or upgrades. The lack of gas fermentation capabilities and the inability to handle hazmat materials might limit use in emerging areas. The decrease

of industrial usage is concerning, and it would be valuable to understand why and if it is a significant, sustained trend. Lastly, it would be good to know what the use statistics are, in particular average use time and average uptime, the latter being the time that the facility—or a specific section—is available for use regardless of whether it is being used or not.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We appreciate the reviewers' comments and their efforts reviewing this work. This project's primary goal is to maintain a safe and process-relevant pilot plant for BETO and industry research needs that produces quality data. We continue to assess new capabilities to enhance the plant's ability to support R&D, and then we will prioritize and acquire equipment considering safety, future BETO R&D directions, and potential needs of industrial clients. As technology development continues and other process options for pilot-scale verification are found, we will continue to increase our collaborations with other BETO projects in the biochemical conversion area. Although the building housing the pilot plant has some limitations for hazardous operations, there are many options for facility modifications and new equipment siting (indoors and outdoors) that would support the investigation and development of new technologies.

INTEGRATION AND SCALE-UP

National Renewable Energy Laboratory

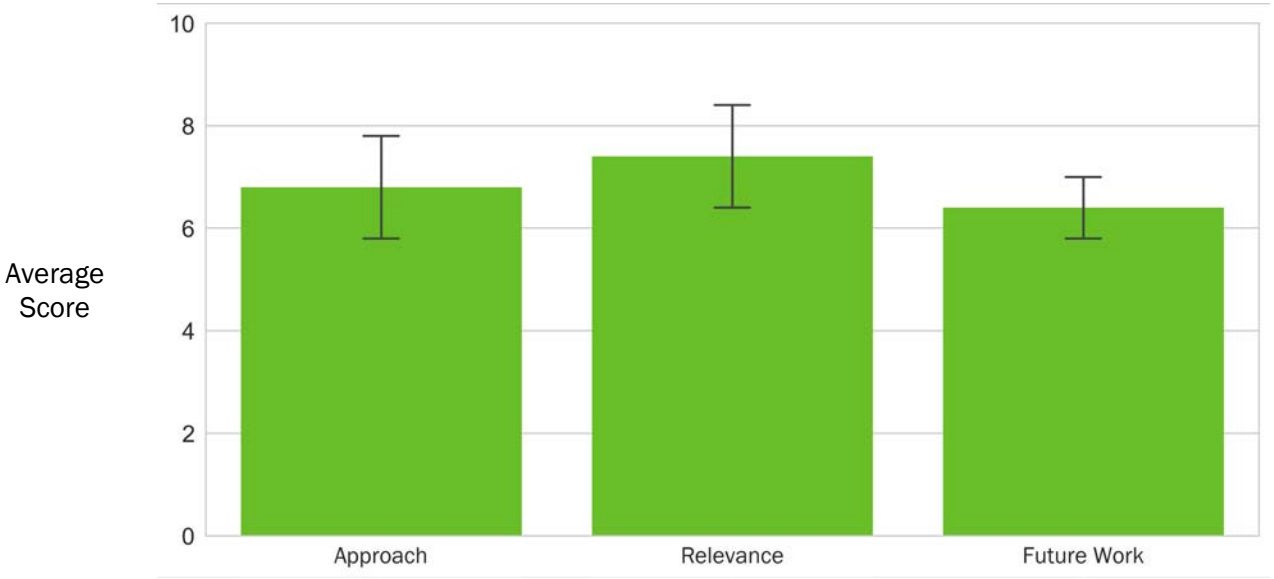
PROJECT DESCRIPTION

WBS:	2.4.1.301
CID:	NL0025580
Principal Investigator:	Dr. Kristin Smith
Period of Performance:	10/1/2015–9/30/2021
Total DOE Funding:	$7,725,000
DOE Funding FY16:	$2,500,000
DOE Funding FY17:	$2,500,000
DOE Funding FY18:	$2,275,000
DOE Funding FY19:	$450,000
Project Status:	New

The goal of this project is to verify thermal and catalytic conversion technologies at an industrially relevant pilot-scale facility to denote progress over the current state of technology (SOT) for biomass-derived pathways. To achieve this, the Integration and Scale-Up project operates NREL's largest thermochemical pilot facility: The Thermal and Catalytic Process Development Unit (TCPDU). The TCPDU is a highly instrumented, half-ton of biomass per day R&D facility designed to be functionally flexible to adapt to the needs of both BETO and industry partners. Starting a new three-year cycle, the TCPDU will be used to support the FY 2022 catalytic fast pyrolysis verification target by combining technologies developed in BETO's ChemCatBio, FCIC, and the Consortium for Computational Physics and Chemistry (CCPC). This presentation details our plans for the next three years to prepare for this technology verification, specifically in maintaining consistency with bench-scale SOT and minimizing losses from scaling. This will include installation and commissioning of new capabilities within the TCPDU to meet the catalyst and feedstock requirements set by the bench R&D efforts. To meet the catalyst performance targets, we will install a new packed-bed reactor setup as well as a hydrogen-feeding system. Further, we will work with the core R&D projects (i.e., ChemCatBio, FCIC, and CCPC) to develop scaling relations that link bench and pilot operations. These relations will move beyond traditional, empirically based relations by including a physics-

Weighted Project Score: 6.8

Weighting for New Projects: Approach - 25%; Relevance - 25%; Future Work - 50%



I One standard deviation of reviewers' scores

based foundation that will allow the relation to extend beyond the systems found at NREL. Finally, as the largest pilot facility dealing with thermal and catalytic technologies in the BETO portfolio, our dedicated team of operators is ideally placed to identify and develop engineering solutions that mitigate scaling losses from operational challenges that are apparent only when technologies are scaled and integrated. Together, this project reduces the risk to industry by bridging the technology "valley of death," thereby enabling the successful industry adoption of biomass technologies to support the continued growth of the U.S. bioeconomy and the jobs it supports.

Photo courtesy of National Renewable Energy Laboratory

OVERALL IMPRESSIONS

- As with other national laboratory PDUs, there is tremendous opportunity to have an impact on commercial applications, especially with the ability for industry to use the physical resources available within this project. Key to future performance is decoupling reactor-specific impacts from the kinetic model; the team should focus as many resources as they can on achieving that goal because it will tremendously simplify additional development.
- Continued funding of the PDU is supportive of long-term BETO goals for biofuels cost reduction.
- The project is well defined and clearly directed at supporting BETO's data needs to verify cost production goals. The project team understands the critical nature of the data need and has contingencies in place to mitigate potential issues.
- This project is aimed at developing experimental/modeling approaches to successfully scale up thermochemical biomass conversion technologies from the bench scale to the pilot scale, leading to successful industry adaptation of biomass conversion technologies. The key technology being investigated is biomass pyrolysis.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

The recipients choose not to respond to the reviewers' overall impressions of their project.

BIOMASS GASIFICATION FOR CHEMICALS PRODUCTION USING CHEMICAL LOOPING TECHNIQUES

The Ohio State University

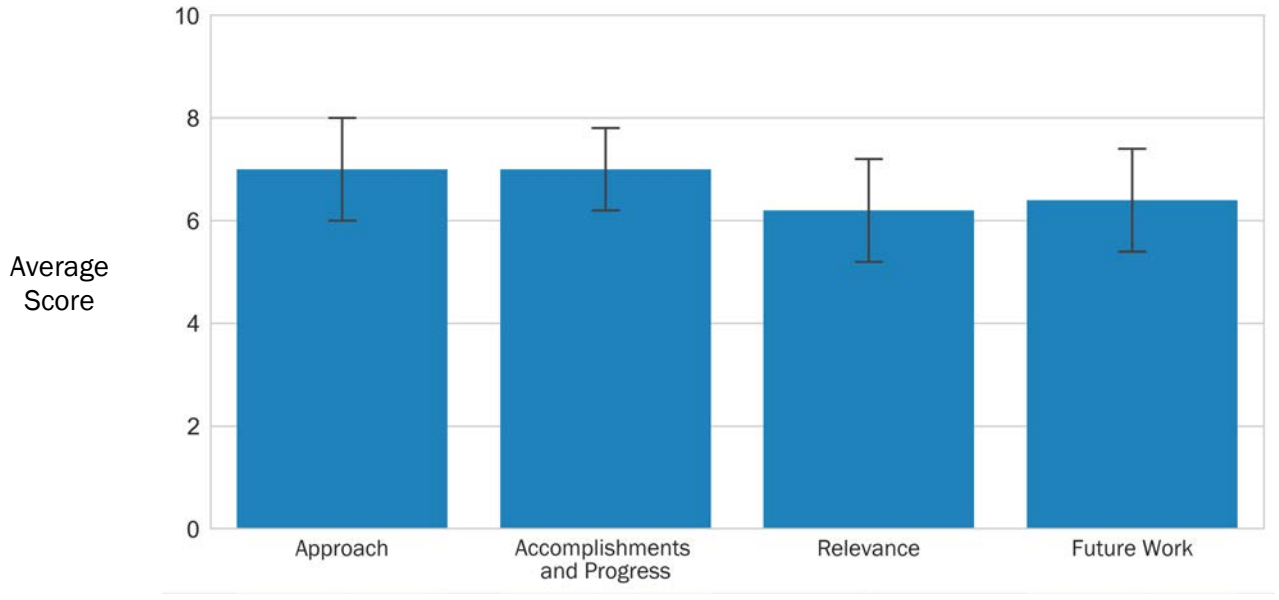
PROJECT DESCRIPTION

WBS:	2.4.1.404
CID:	EE0007530
Principal Investigator:	Mr. Andrew Tong
Period of Performance:	10/1/2016–9/30/2019
Total DOE Funding:	$1,500,000
Project Status:	Ongoing

The Ohio State University (OSU) is investigating the biomass-to-syngas (BTS) chemical looping technology to produce syngas for chemical production applications from biomass under DOE Award #DE-EE0007530. The BTS process aligns with the programmatic area of interest of "Conversion, via biological, thermal, catalytic, or chemical means, of acceptable feedstocks into advanced biofuels and/or biobased products including intermediate and end-use products." Compared to conventional biomass gasification processes, the BTS process eliminates the need for air separation units and tar reforming reactors, which leads to energy-efficiency improvement and capital-cost reduction. The overall objective is to ascertain the potential of biomass gasification based on the chemical looping technique through mitigation of the possible techno-economic challenges in the steps of scale-up for commercialization. The scope of work consists of (1) designing, constructing, and operating a 10-kWh commercially scalable sub-pilot BTS system; and (2) completing a comprehensive TEA of the BTS process using methanol production as an example.

Weighted Project Score: 6.7

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



I One standard deviation of reviewers' scores

OVERALL IMPRESSIONS

- This project has high potential for success, in no small part because of the approach of building and testing a transparent, cold system first to validate flow performance—an excellent approach.
- The use of chemical looping techniques represents a transformative, and perhaps disruptive, approach to the transformation techniques for biomass so far considered, promising increased conversion efficiency, reduced costs of production, and relative ease of integration into existing fossil-fuel production facilities.
- It will be a big step from the bench scale to the PDU scale for this process because of the difference in design and integration. I look forward to seeing how this process progresses and the results of the studies.
- This project was awarded under the Biomass Research and Development Board in 2016 to develop a chemical looping gasification process for biomass. OSU has been a pioneer in chemical looping reactions for several applications. Theoretically, this concept looks elegant because it can combine gasification, tar reforming, and oxygen separation all in one reactor. Significant operation challenges are associated with this type of system. This project has completed Budget Period 1 and moved on to Budget Period 2, in which a small pilot plant is being assembled for testing. TEA studies are being conducted by Nexant in parallel.
- Gasification of biomass is a key unit operation in converting biomass to fuels and chemicals; however, the presentation did not clearly identify what was new or novel to be demonstrated from this grant. Technical issues such as syngas contaminants and biomass feeds did not appear to be adequately addressed. The project scope should be more clearly defined as gasification alone, not resulting in a methanol product.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

The recipients choose not to respond to the reviewers' overall impressions of their project.

MATERIALS DEGRADATION IN BIOMASS-DERIVED OIL

Oak Ridge National Laboratory

PROJECT DESCRIPTION

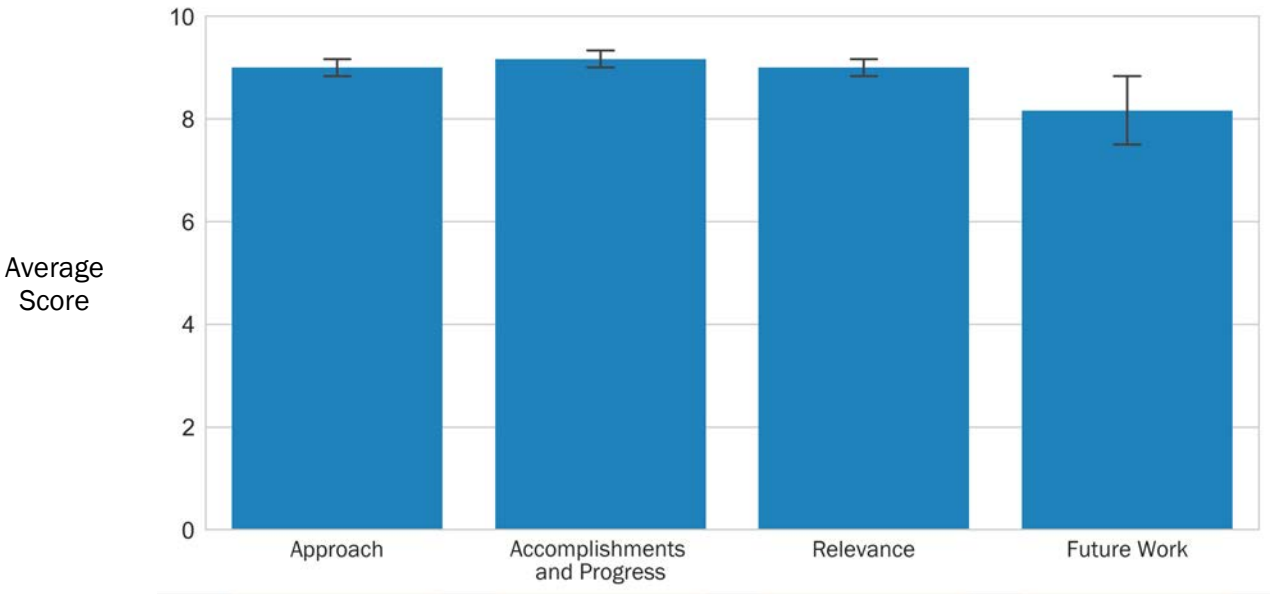
WBS:	2.4.2.301
CID:	NL0019454
Principal Investigator:	Dr. Jim Keiser
Period of Performance:	10/1/2015–9/30/2020
Total DOE Funding:	$4,940,000
DOE Funding FY16:	$1,600,000
DOE Funding FY17:	$1,600,000
DOE Funding FY18:	$1,180,000
DOE Funding FY19:	$560,000
Project Status:	Ongoing

Thermochemical processing of biomass provides a means to convert biomass resources—including trees, grasses, and agricultural waste—into fluids that can serve as liquid fuels or as feedstock for subsequent conversion into more refined liquid fuels or higher-value chemicals. As a result of the significant oxygen content of biomass, the products of biomass liquefaction contain a wide range of oxygen-containing compounds that are components of the biomass-derived oil. Organic (carboxylic) acids are one family of oxygen-containing products, and the presence of these products in bio-oil can make the oils highly acidic (pH often in the 2–3 range). In addition, the bio-oils often contain a significant amount of water as well as contaminants such as sulfur, chlorine, and nitrogen. Because of the acidic nature of these liquids as well as the presence of other potentially damaging organic compounds and certain contaminants, it has been shown that degradation of metallic containment materials and nonmetallic components is a serious concern and has been identified in industry as an issue.

There is not a good understanding of the role in the corrosion of various oxygen-containing organic compounds, nor is there an accepted test to measure the corrosivity of bio-oils. This project is intended to identify and increase our understanding of corrosive organic compounds in bio-oils as well as the degradation

Weighted Project Score: 8.8

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



I One standard deviation of reviewers' scores

mechanisms of metallic and nonmetallic structural materials. Our previously reported studies have demonstrated that in some cases a low-nickel, high-manganese stainless steel appears to perform better in some, but not all, of the processing environments, but considerably more work is needed to determine if this alloy offers a good alternative to 300-series stainless steels. Other studies have suggested that ketones and possibly aldehydes might be responsible for the degradation of some nonmetallic materials. Again, further studies are needed to confirm the causes of degradation and which alternate materials have enough corrosion resistance.

There is also a significant lack of fundamental knowledge regarding the interactions occurring on the surface of corroding materials, so we have added tasks to help us develop a more fundamental understanding. This could lead to the identification of degradation mechanisms occurring on both metallic and nonmetallic materials.

The overall objective of this project is to identify the components of bio-oils that cause degradation of metallic and nonmetallic materials, identify the degradation mechanisms, and then acquire enough information so that materials with acceptable corrosion resistance can be identified. By achieving these goals, materials issues should not prevent the successful commercialization of any biomass liquefaction technology.

OVERALL IMPRESSIONS

- This is an excellent project that clearly focuses on an industry-specific need. Dissemination of knowledge acquired during the project will be critical to the successful implementation of lessons learned.
- The project has largely met its objectives. The information produced is valuable for selecting materials of construction, both metallic and nonmetallic.
- The work overall is impressive. At first glance, I felt the scope was too broad, but the team was able to meet its objectives. I look forward to more work of this kind.
- The project supports wide commercial usage of biofuel/oils in existing fuel storage and delivery systems.
- This is a good example of core research to enable bioprocess commercialization. Materials of construction are a significant decision, and on new processes, necessary data often do not exist. This work is valuable to provide data necessary to mitigate project risk.
- During the pyrolysis process, a significant amount of oxygen in biomass manifests into bio-oils containing compounds extremely corrosive to many structural materials, both metallic and nonmetallic. This project is aimed at identifying suitable materials of construction for biomass conversion systems that handle bio-oils. Mechanistic studies are being conducted to understand corrosion mechanisms and eventually identify suitable materials that are corrosion resistant.
- This is an excellent project. An industry is built by creating standards and shared knowledge, which is essential to translating process ideas into operating plants. The selection of material is one area of shared knowledge that DOE can effectively foster. There is nothing to add or remove to the project as it stands today other than inviting its continuation and hope for more like this.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We appreciate the positive comments, and we will work to disseminate the information to a broader audience.

STRATEGIES FOR COPROCESSING IN REFINERIES

National Renewable Energy Laboratory

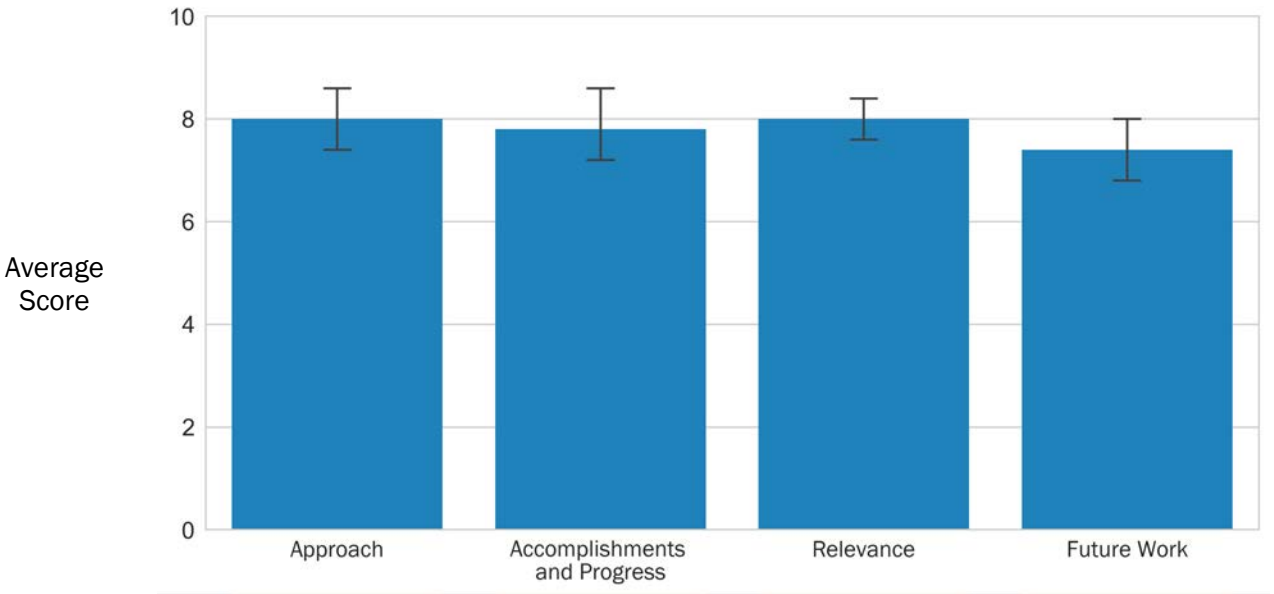
PROJECT DESCRIPTION

WBS:	2.4.2.304
CID:	NL0032422
Principal Investigator:	Dr. Robert Baldwin
Period of Performance:	8/1/2017–9/30/2020
Total DOE Funding:	$3,300,000
DOE Funding FY16:	$0
DOE Funding FY17:	$1,000,000
DOE Funding FY18:	$1,200,000
DOE Funding FY19:	$1,100,000
Project Status:	Ongoing

The objective of this project is to accelerate the adoption of coprocessing biomass-derived feedstocks with petroleum feedstocks in current refineries by (1) identifying blend levels for fast pyrolysis, catalytic fast pyrolysis (CFP), and HTL bio-oils and biocrudes that achieve ≥5 wt % biogenic carbon incorporation into coprocessed fuels via fluid catalytic cracking (FCC) and hydrotreating/hydrocracking; and (2) advancing catalysts used in existing FCC and hydrotreating refinery processes to increase biogenic carbon incorporation into finished fuels while maintaining catalyst lifetime to be consistent with current industrial operation. Coprocessed fuels will be comprehensively analyzed for hydrocarbon and oxygenate composition and biogenic carbon content. Additionally, tracking isotope-labeled biomass throughout coprocessing will provide detailed chemical information on conversion and upgrading that does not currently exist. FCC catalyst performance will be measured by producing hydrocarbon fuels of ≥ 5 wt % biogenic carbon incorporation, a factor of two improvement compared with the 2 wt % incorporation recently achieved with fast pyrolysis oil coprocessed at Petrobras. Hydrotreating catalyst performance will be measured by a 50% improvement of activity (heteroatom removal rate per catalyst volume) for coprocessing at least 10 wt % bio-oil biocrude blending in the feed compared to a commercial $NiMo/Al_2O_3$ baseline catalyst. Catalyst lifetime will be assessed by measuring and mitigating coprocessing coking rates and/or degradation rate. FCC and

Weighted Project Score: 7.8

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



I One standard deviation of reviewers' scores

hydrotreating/hydrocracking operations are the first industry coprocessing options to be developed as pilot-scale equipment, and industrial catalysts are available at both laboratories, with NREL focusing on FCC coprocessing and PNNL focusing on hydrotreating/hydrocracking coprocessing. Alkylation units are also an option if biogenic carbon can be directed to C2–C5 olefins.

Increasing biogenic carbon incorporation into conventional fuels is a critical step in biofuels development and adoption. Coprocessing petroleum feedstocks with biomass-derived feedstocks leverages the existing petroleum-refining infrastructure, which significantly reduces CapEx. The coprocessing opportunity is significant because 106 of 136 U.S. refineries have conversion capabilities using FCC and/or hydrotreating. Research to date has explored only FCC coprocessing of raw pyrolysis bio-oil with vacuum gas oil at low blend levels (less than 10 vol % with 2 wt % biogenic carbon incorporation) and hydrotreating coprocessing of vegetable and animal fat oils. Many data gaps still exist, and this ongoing project is establishing the baseline and filling in the data gaps across different oil types, blend levels, and coprocessing strategies. Additionally, the performance challenges associated with coprocessing requires catalyst development targeting bio-oil crude conversion. Catalyst improvement will focus on (1) catalyst modification (using industrially available catalysts) to improve biogenic carbon incorporation efficiency into fuels and (2) understanding the impact of coprocessing on catalyst lifetime and developing deactivation mitigation strategies.

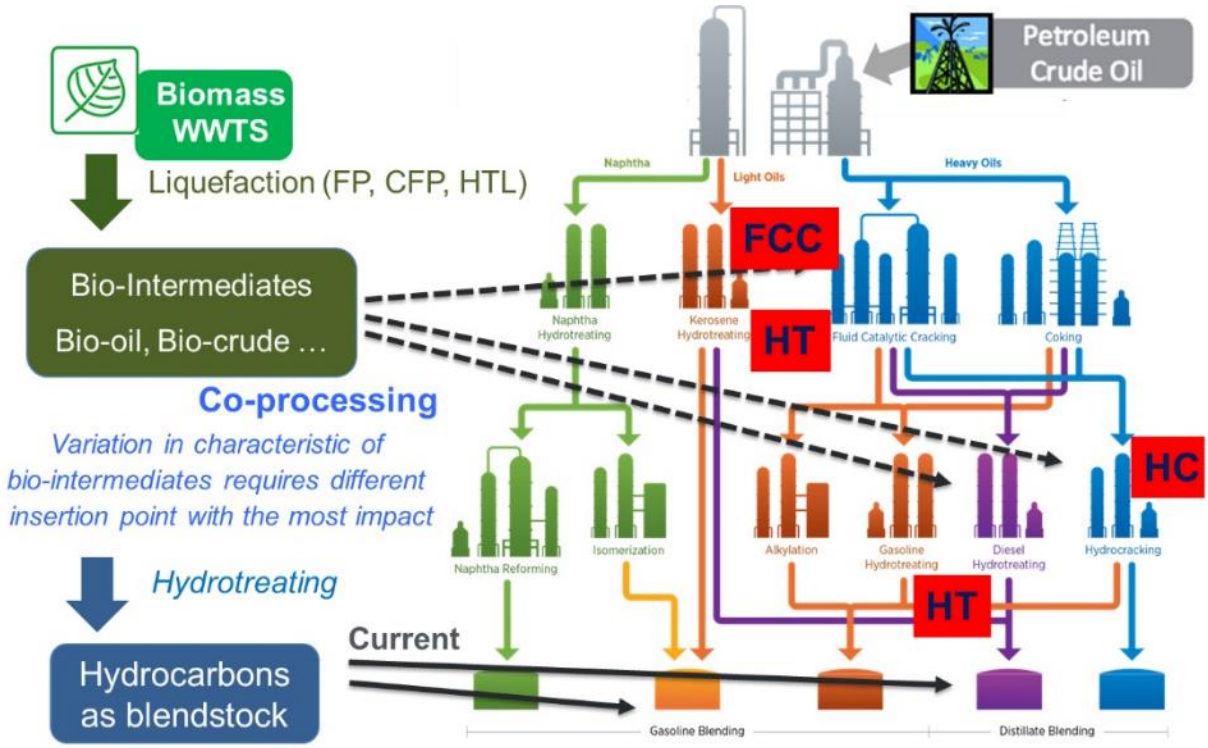


Photo courtesy of National Renewable Energy Laboratory

OVERALL IMPRESSIONS

- This project has tremendous potential to shortcut the financing and commercial-scale construction required for many biofuel projects. The key concern is whether there will be enough de-risking the use of biofeedstocks within petrochemical facilities to actually convince those facilities to essentially upset the balance they have developed throughout decades.

- This project is aimed at coprocessing biocrude (produced from biomass pyrolysis) into an existing refinery infrastructure by understanding fundamental chemistry and process-engineering issues. Two main insertion points in the refinery have been identified: FCC and hydrotreating/hydrocracking units.

- The petroleum industry needs to see biofuel production as part of their portfolio rather than a competitor for the biofuel industry to be a success, so finding a way to make the "marriage" work is important. This project could certainly help incorporate the synergies, but I do not see petroleum industry involvement in this project. The presenter did an excellent job of showing the complexity of what was being/will be accomplished.

- Coprocessing of bio-oils can provide a robust pathway to increasing biobased fuel production and distribution by using existing assets. The project has good representation of industry insight, but it had limited information on performance to date.

- This is a much-needed project whose success will significantly advance the displacement of fossil carbon with biogenic carbon.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- Reviewer comments focused on three primary areas: scalability, catalyst development, and refinery involvement. We are addressing scalability by developing FCC and hydrotreating/hydrocracking coprocessing at the laboratory, in small and large pilot scales with enough generated operating data provided to refiners to assess adoption potential. FCC catalyst development is being conducted with Johnson Matthey, a major industrial supplier of FCC catalysts. Refinery involvement is accomplished with biannual project review of progress with our industry steering committee, which provides guidance on the future direction of interest to the petroleum industry.

DEVELOPMENT AND STANDARDIZATION OF TECHNIQUES FOR BIO-OIL CHARACTERIZATION

National Renewable Energy Laboratory

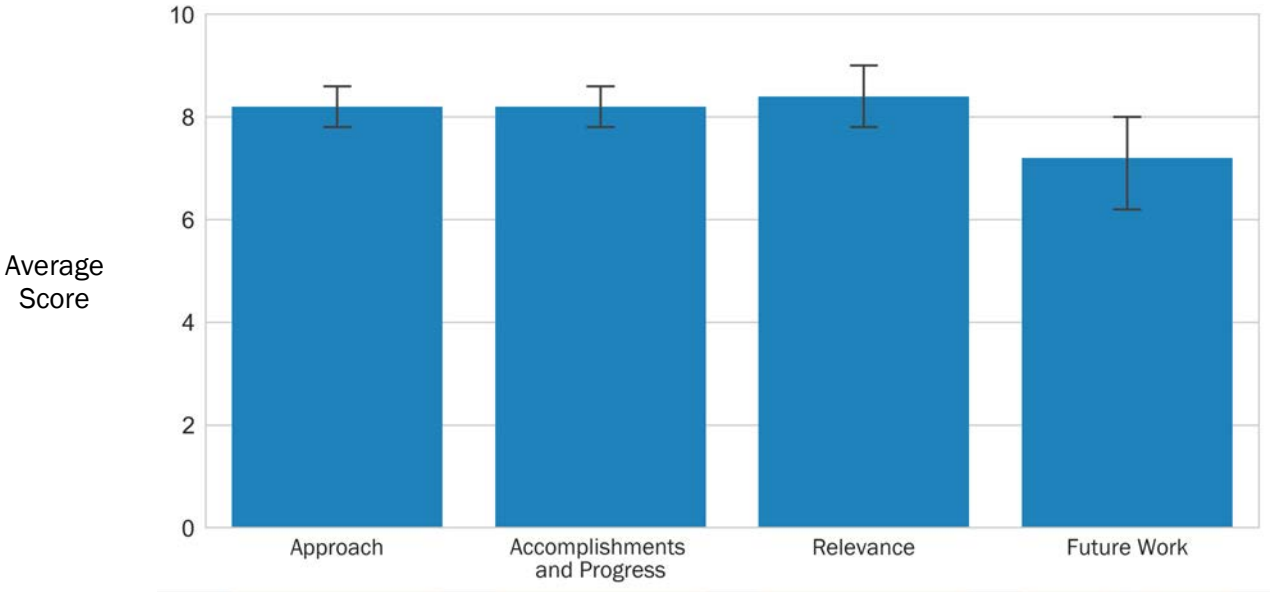
PROJECT DESCRIPTION

WBS:	2.5.2.301
CID:	NL0026690
Principal Investigator:	Dr. Jack Ferrell
Period of Performance:	10/1/2015–9/30/2021
Total DOE Funding:	$2,812,000
DOE Funding FY16:	$1,000,000
DOE Funding FY17:	$1,000,000
DOE Funding FY18:	$512,000
DOE Funding FY19:	$300,000
Project Status:	Ongoing

This project began in FY 2014 to address the lack of standard chemical characterization analytical methods for bio-oils. Bio-oils are very complex and present numerous analytical challenges, yet reliable chemical information (quantification of both individual compounds and chemical functional groups) is needed to inform upgrading research and refinery coprocessing. In this project, analysis needs are first determined from engaging the bioenergy community; we ask different entities about the biggest analytical challenges they face. Next, standard methods are developed to meet these needs, and then they are subsequently validated via interlaboratory studies with external partners. Methods that are successfully validated (greater than 10% variability) are then shared as laboratory analytical procedures (LAPs), which are free and publicly available. We have been tracking LAP use for several years and have seen sustained usage, as evidenced by an average of 500 page views and 100 downloads per quarter, demonstrating the value of these methods to the bioenergy community. LAP methods that are particularly useful and reliable will be chosen for the next level of standardization through ASTM. ASTM standardization is being pursued to facilitate worldwide adoption of methods standardized in this project. Additionally, standard methods from an agency

Weighted Project Score: 8.0

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



such as ASTM are required to enable commerce with bio-oils. During the past two years, we have engaged with ASTM and successfully achieved approval by ASTM for our carbonyl titration method. This method (ASTM E3146) is now available and is the first example of an ASTM standard solely focused on the chemical characterization of bio-oils. This method has a broad scope (applying to bio-oils with a carbonyl content between 0.5–8 mol/kg) and is intended to help reliably describe bio-oils as intermediates that will undergo further upgrading. Work in this project is meeting the analysis needs of the bioenergy community and will ultimately help enable the commoditization of bio-oils.

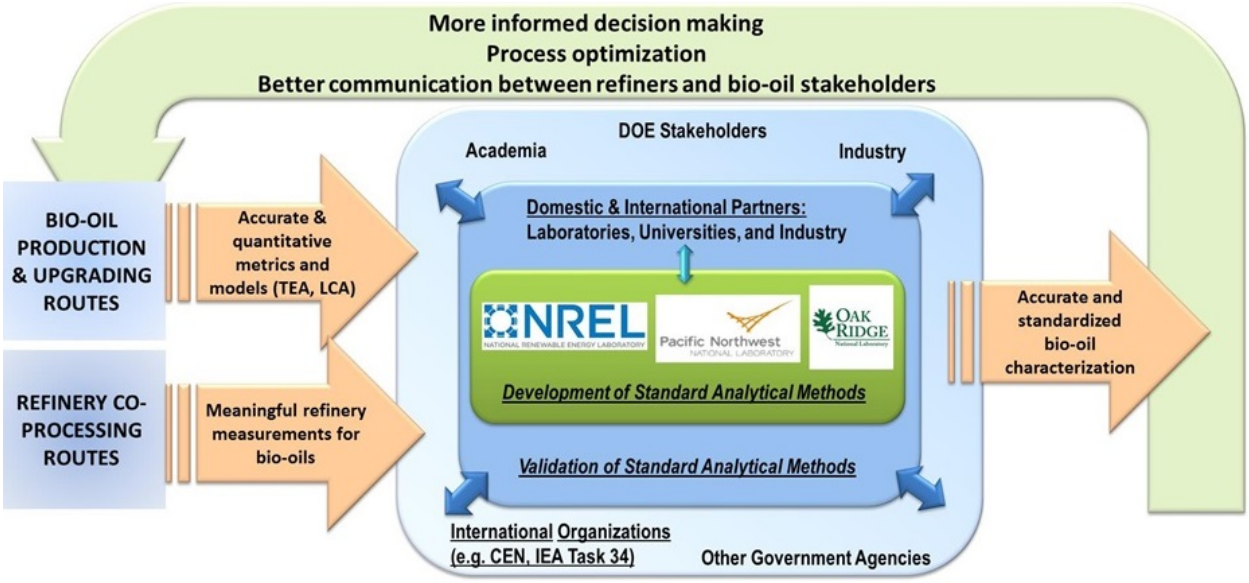


Photo courtesy of National Renewable Energy Laboratory

OVERALL IMPRESSIONS

- This project clearly meets an industry need, and the described approach offers a high likelihood of success. Dissemination of the knowledge should help drive acceptance and use of the standards and methodologies developed.
- This project is targeted toward the development of analytical methods to characterize the bio-oils produced in pyrolysis processes (fast pyrolysis [FP], CFP, HTL). Chemical compositions of these bio-oils vary widely, and there are no standard methods to measure the chemical composition. Several very useful analytical methods were developed and disseminated to various participants to validate them.
- This project is a perfect example of work that should be done by national laboratories to promote biofuel understanding and specifications.
- This is valuable R&D work supportive of industry needs. It is aspirational to think that national laboratories could be a repository of standards—the collaboration with ASTM is key to this work for global dissemination.
- Standardization of analytical procedures is a key and valuable goal. The project generated positive results, including publication of an ASTM procedure. More information on milestones and project management criteria would have been valuable.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We thank the reviewer for the comment, and we agree that engagement with ASTM is essential for global dissemination (and use) of our methods. In addition, we believe the publication of LAPs is very

useful for the research community, and it is also a good first step before approaching ASTM with a specific analytical method.

- We thank the reviewer for the comment. In the future, we will aim to clearly provide more information on milestones and specifics on project management.

IMPROVED HYDROGEN UTILIZATION AND CARBON RECOVERY FOR HIGHER-EFFICIENCY THERMOCHEMICAL BIO-OIL PATHWAYS

Research Triangle Institute

PROJECT DESCRIPTION

WBS:	2.5.4.405
CID:	EE0006636
Principal Investigator:	Dr. David Dayton
Period of Performance:	9/1/2014–8/31/2019
Total DOE Funding:	$3,140,526
Project Status:	Sunsetting

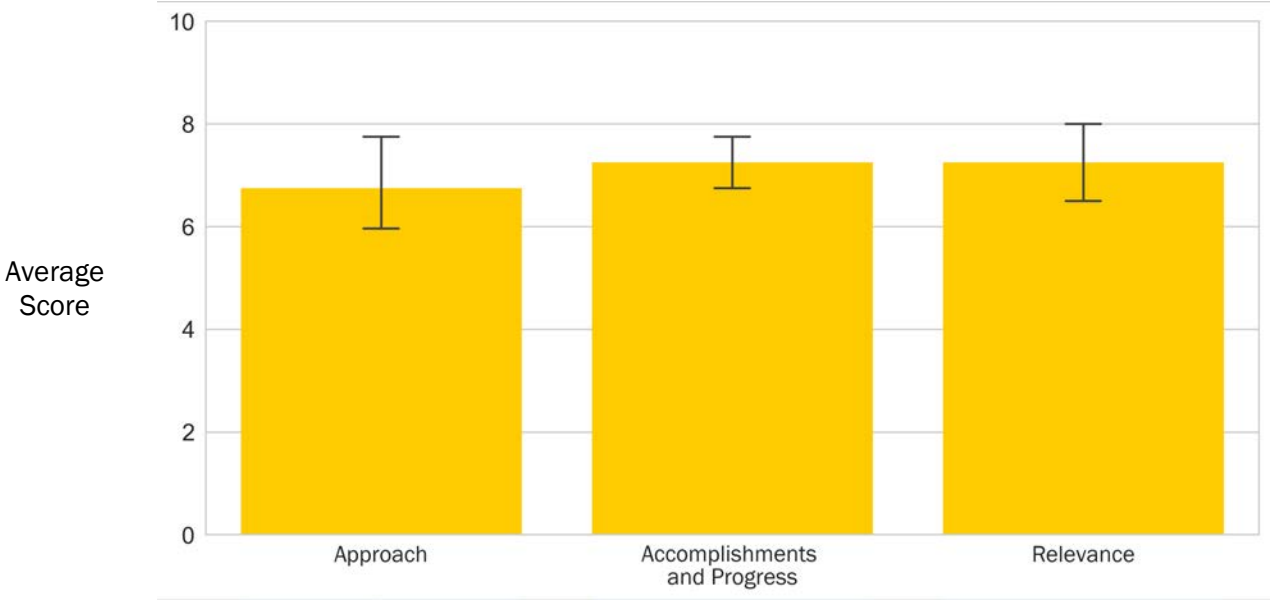
The objective of this project is to evaluate the potential for improved hydrogen use and carbon recovery in a novel, direct biomass liquefaction process. The primary aspect of this concept is to use hydrogen during *in situ* catalytic biomass pyrolysis to maximize the biomass carbon and energy recovery in a low-oxygen-content, thermally stable biocrude intermediate that can be efficiently upgraded into a finished biofuel. The secondary aspect of this concept is to improve the carbon efficiency of the integrated process by (1) converting the carbon in the various aqueous streams to methane for hydrogen production, (2) recovering oxygenated hydrocarbons for hydroprocessing, or (3) upgrading aqueous-phase carbon to value-added byproducts.

New and novel catalysts are being developed to improve hydrodeoxygenation during catalytic biomass pyrolysis to reduce biocrude oxygen content. Hydrogen in the pyrolysis reactor improves biocrude yield and quality while reducing char and coke formation.

Anaerobic digestion (AD) is being evaluated for aqueous-phase carbon conversion to methane that can be reformed for hydrogen production. Carbon recovery from the aqueous phase maximizes the renewable carbon efficiency, provides a renewable hydrogen source for the process, and improves water quality so freshwater consumption is reduced.

Weighted Project Score: 7.1

Weighting for Sunsetting Projects: Approach - 25%; Accomplishments and Progress - 50%; Relevance - 25%



Experimental results inform the TEA and LCA to determine the technical and economic feasibility and environmental sustainability of the integrated process. The overall hydrogen demand is comparable to other integrated thermochemical conversion processes, and the potential to reduce biofuels production cost with this novel, low-severity *in situ* CFP process to convert lignocellulosic biomass to hydrocarbon fuels has been validated. This proposed project supports the DOE BETO goal of producing hydrocarbon transportation at less than $3/GGE with greater than 50% greenhouse gas (GHG) emission reduction potential compared to fossil fuels.

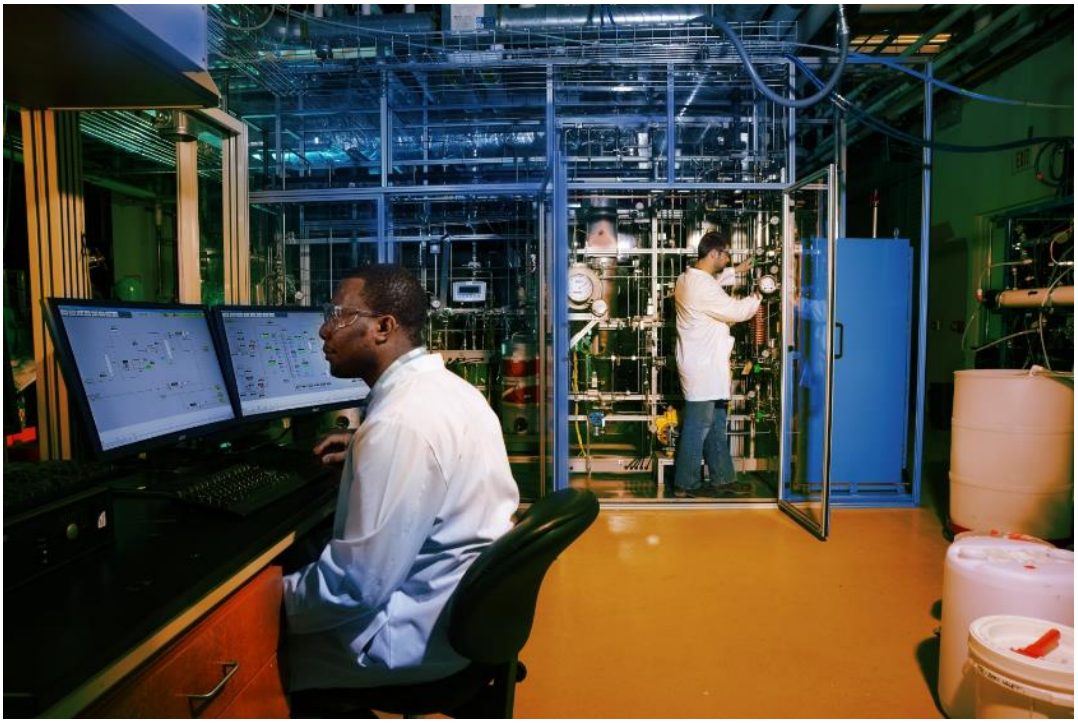


Photo courtesy of Research Triangle Institute

OVERALL IMPRESSIONS

- This is a worthy project with the long-term potential for success.
- The modifications to the scope required during the project could likely have been foreseen at the start.
- The team ran out of biocrude during the project because of significant losses. Given the length of the trial, it would seem prudent to have significant biocrude on hand.
- This is a well-organized presentation with strong project management. Representative materials were produced and sent to industry partners for conversion testing. Significant data were presented supporting the achievement of goals, which provides credibility to the project.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- This project was selected in FY 2014 in response to the FOA on "Carbon, Hydrogen, and Separation Efficiencies in Bio-Oil Conversion Pathways." At that time, our approach was to improve both carbon efficiency and hydrogen use by leveraging two complementary technologies in an integrated direct biomass liquefaction process called reactive catalytic fast pyrolysis (RCFP). Hydrogen is added during the *in situ* catalytic pyrolysis to improve yield and the quality of the biocrude intermediate and reduce

char and coke formation. Liquid products separate into an organic biocrude and an aqueous phase. Under optimized reaction conditions, the RCFP biocrude contains as low as 6 wt % oxygen, compared to 20–30 wt % for a conventional CFP process. The improved quality of the RCFP biocrude is expected to be more readily integrated with downstream hydroprocessing to produce drop-in blendstocks or finished biofuels for transportation. RCFP upgrading studies to be completed by the end of the project will verify process improvements. Recovering carbon from the aqueous phase with AD was a new concept at the time this project began. Clearly, AD as an alternative to wastewater treatment provides a solution for improving carbon efficiency in the integrated process by producing renewable methane that can be converted to hydrogen for RCFP. The efficiency of methane production has been improved 150-fold with microbial population adaption such that 70% of the aqueous phase carbon is converted into methane. TEAs and LCAs to be completed by the end of the project will demonstrate that carbon and energy recovery from the aqueous phase has the potential to reduce the hydrogen demand and overall GHG emission for the integrated direct biomass liquefaction process to meet the BETO goal of producing transportation fuels for $3/GGE with greater than 50% GHG emission reduction potential compared to fossil fuels.

BUILDING BLOCKS FROM BIOCRUDE: HIGH-VALUE METHOXYPHENOLS

Research Triangle Institute

PROJECT DESCRIPTION

Integrating biofuels production with bioproducts presents an opportunity to explore options for recovering high-value chemicals as additional revenue-generating products from biofuel conversion pathways. Also, the inherent functionalized nature of biomass offers a unique opportunity for producing oxygenated chemicals that are not easily synthesized from petroleum; however, efficient separation approaches are required to recover the oxygenated species as marketable value-added products.

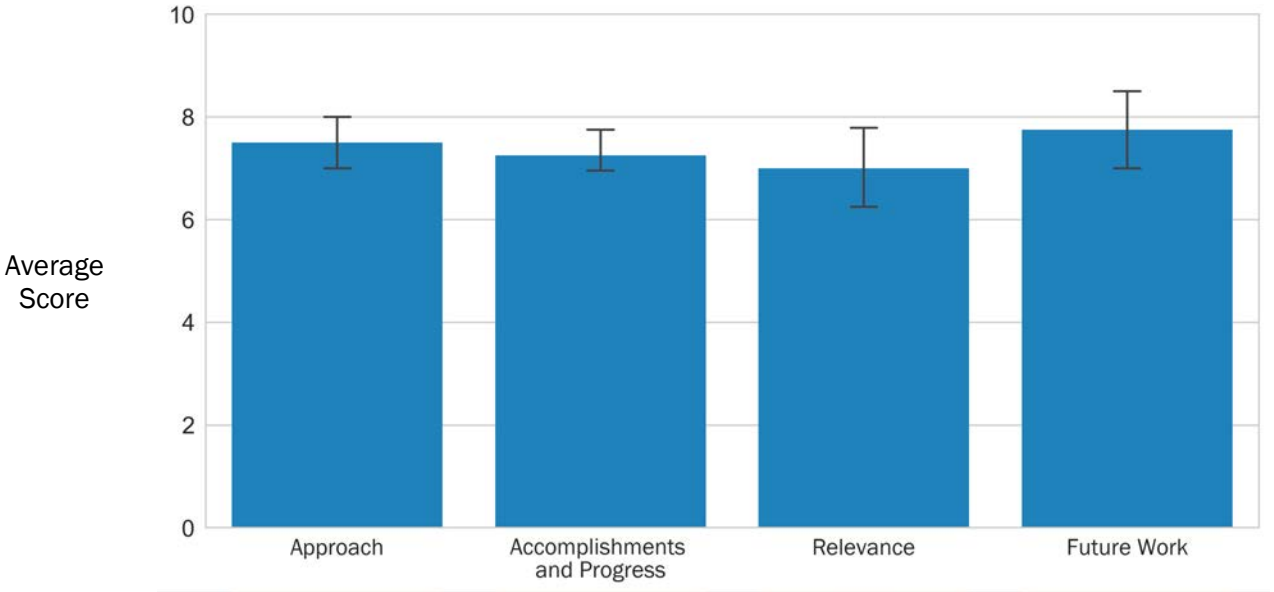
WBS:	2.5.5.406
CID:	EE0007730
Principal Investigator:	Dr. Ofei Mante
Period of Performance:	10/1/2016–9/30/2019
Total DOE Funding:	$1,987,148
Project Status:	Ongoing

RTI, Arkema, and AECOM are investigating the technical feasibility and economic potential as well as the environmental and sustainability benefit of recovering mixed methoxyphenols (eugenols and guaiacols) from biocrude as building-block chemicals alongside the production of biofuels. The optimization of a comprehensive separation strategy to recover the target methoxyphenols as a bioproduct is at the heart of this project.

Successful completion of this research will result in a process design, TEA, and LCA of an integrated biorefinery (IBR) for biofuel production and coproduct recovery. A product development assessment will also be conducted. Achieving technical success in recovering high-value methoxyphenols from biocrude prior to

Weighted Project Score: 7.4

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



upgrading to biofuels could provide a significant source of revenue to improve overall process economics and help meet the $3/GGE modeled production cost target for advanced biofuels technologies by 2022.

Photo courtesy of Research Triangle Institute

OVERALL IMPRESSIONS

- It is good to see projects focusing strongly on the generation of valuable coproducts to offset biofuels production costs and achieve market-reasonable sales prices. Much of the current research focuses strongly on the primary product or a specific production technology, whereas this project looks at developing a separations technology that has the potential to be applied more broadly.
- This is a potentially useful line of R&D that could result in the supply of valuable methoxyphenols to industry. This is a great presentation with good justification for the project going forward.
- Although there appears to be an improvement to the cost of fuel production by adding value-added coproducts, I wonder if a biorefinery could be financed with the added complexity of additional new technology risk.
- Fractionation of biocrude to high-value products has the potential to improve overall pathway performance. Compounds in bio-oil have high value if they can be economically isolated. The large number of unit operations outlined in the proposed process flow generates concerns of unacceptable recovery yield; however, initial results appear favorable.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- A hybrid separation strategy has been developed and optimized to recover high-value methoxyphenols from biocrude to improve the process economics and environmental impact of advanced biofuels production via catalytic pyrolysis integrated with hydroprocessing. Seventy-five percent efficiency can be achieved for recovering a bioproduct with more than 90 wt % purity and no residual losses. The integrated strategy consists of permutations of three techniques: distillation, extraction, and adsorption chromatography to achieve different bioproduct purity levels depending on the end-use application. A 7-gallon-per-day laboratory-scale separation unit has been designed, fabricated, and installed to demonstrate the scalability of the separation strategy. Market prices and market demand for recovered methoxyphenols has been evaluated to identify specific product-development pathways. Product-development activities include the identification and evaluation of chemical pathways for vanillin synthesis, flame-retardant additives, biocidal products, caprolactone synthesis, and bisguaiacol F production. The results demonstrate the use of the mixed-methoxyphenols bioproduct as a feedstock for other applications, showing the potential of matching the bioproduct volume with market demand. Preliminary TEA based on a 2,000-bone-dry-ton/day plant with a separation unit for bioproduct recovery suggests that the methoxyphenols could help reduce the cost of fuel production. Cost estimation was based on factoring/parametric estimation and vendor quotes. The analysis indicates that the minimum fuel selling price (MFSP) decreases by 20% if the methoxyphenol bioproduct sells for $2/kg and by 40% if the methoxyphenol bioproduct sells for $3/kg. Preliminary capital costs increase by 5% or less if a separation unit operation is added to the base biofuel process for methoxyphenol recovery. Preliminary sensitivity analysis shows that the initial mass concentration of the methoxyphenols in the biocrude and the market price of the recovered methoxyphenols bioproduct has the largest impact on the MFSP.

ADVANCED BIOFUELS AND BIOPRODUCTS PROCESS DEVELOPMENT UNIT (ABPDU) SUPPORT

Lawrence Berkeley National Laboratory

PROJECT DESCRIPTION

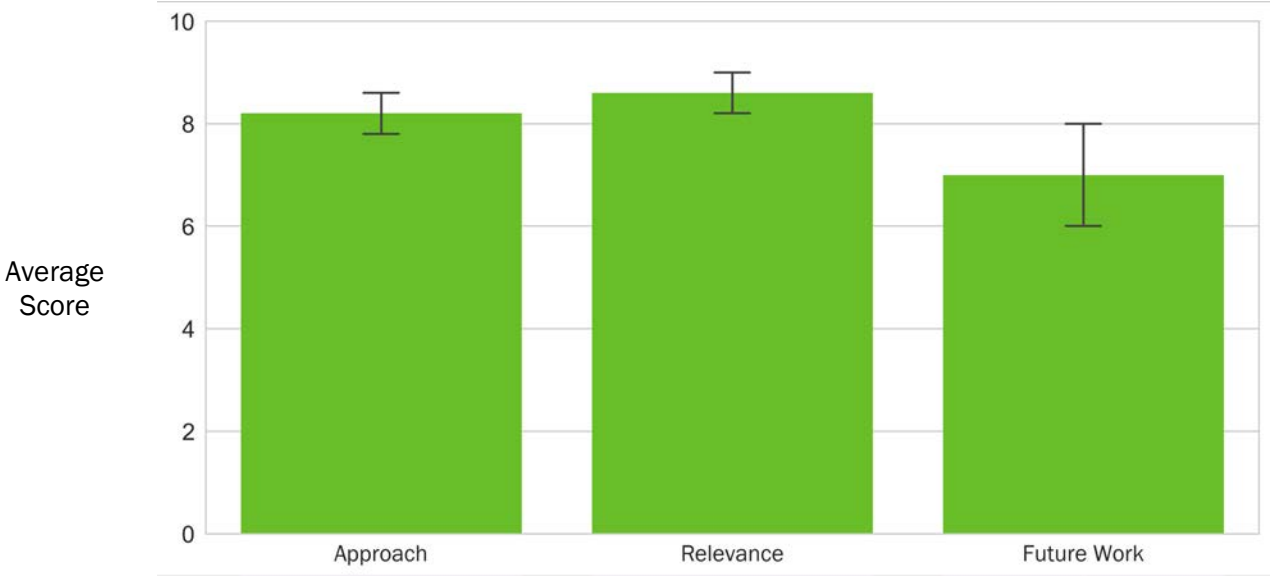
WBS:	2.6.1.101
CID:	NL0022407
Principal Investigator:	Dr. Todd Pray
Period of Performance:	10/1/2015–9/30/2021
Total DOE Funding:	$10,750,008
DOE Funding FY16:	$2,750,000
DOE Funding FY17:	$2,500,000
DOE Funding FY18:	$3,000,008
DOE Funding FY19:	$2,500,000
Project Status:	New

The ABPDU was established nearly 10 years ago to provide process optimization, scale-up, verification, and feasibility analysis services to the biofuels and bioproducts community, including industry, academia, and the national laboratories. This AOP project covers expenses related to facility readiness, process benchmarking, PDU teaming, and partnering and project development. The base operations budget is required to maintain the ABPDU in a not-for-profit collaboration facility model. In addition, the ABPDU's sponsors and collaborators fund full cost recovery for their specific statements of work and the team's actual expenses associated with the work at this facility. The partnerships enabled by this BETO-supported model allow for the advancement of key technologies from the early stages to deployment in industry, bringing value to the entire biofuels and bioproducts community and providing high-visibility examples relevant to the BETO mission.

To provide cutting-edge technical services and process development expertise, the ABPDU will repeatedly baseline its processes to ensure team training and robust performance across all unit operations, from deconstruction through fermentation, separations, chemical catalysis, purification, and analytics. The ABPDU

Weighted Project Score: 7.7

Weighting for New Projects: Approach - 25%; Relevance - 25%; Future Work - 50%



I One standard deviation of reviewers' scores

will also maintain and upgrade its equipment and physical plant to offer access to technologies, processes, and analytics in demand by its clients, whether using small-scale process optimization capabilities or scaling up to the 300-L fermentation suite and biomass deconstruction and chemical catalysis capacity.

To date, the ABPDU team has worked with more than 40 industry partners in either company-sponsored or federally funded, competitively awarded projects. Industry projects at the ABPDU have spanned several sectors and product types: biomass and waste-stream use; biofuels production; biobased chemicals and biomaterials production and characterization; more sustainable food and protein production process development; and microbiome production and characterization for the waste remediation, agriculture, and health care industries. To date, three ABPDU partners have launched products that are commercially based, at least in part, on processes developed in working with the ABPDU team.

The ABPDU group and facility participate very broadly across several DOE project areas, also in a full-cost recovery model where these projects fund incremental work. BETO consortium projects that the ABPDU plays key roles in include the Agile BioFoundry, the Bioprocessing Separations Consortium, Co-Optima, and the FCIC. The ABPDU team also recently was asked to join the Fuel Cell Technologies Office (FCTO) BioH2 Consortium. The ABPDU capability is also leveraged by Office of Science programs such as the Bioenergy Research Centers, and the ABPDU group is also actively involved in BETO new consortium development and in a recently formed PDU working group. The goals of this working group are to share best practices in industry engagement, team training, and process safety, development, and scaling.

Another key activity supported by the ABPDU is workforce development and education. The team usually has at least one, and very often several, interns each academic semester. These students can get hands-on experience in all the unit operations at the facility and emerge as well-qualified candidates for industry employment or to pursue higher degrees at top academic institutions.

This combined set of activities, prioritized in close consultation with BETO management as well as LBNL stakeholders, continue to maintain the ABPDU as a critical resource and key shared capability to enable the bioeconomy's growth into more products, processes, and sustainable feedstocks.

Photo courtesy of Lawrence Berkeley National Laboratory

OVERALL IMPRESSIONS

- This is a tremendous resource to industry, and the model that has been used for the past several years (industry collaboration via essentially "rental" of resources and expertise) is clearly successful. Future work should focus on expanding this role and working to identify areas in which industry is lacking in both expertise *and* equipment for testing of novel technologies, such as gas fermentation with flammable

gases. The application of federal funds to support this type of work will have a significant impact on startup and small companies working to commercialize expensive but potentially lucrative biotechnologies.

- This is a good programmatic approach to operation and maintenance of a critical resource that supports BETO goals.
- This project has a strong and clear mission with good performance and a history of success. The facility is impressive, with significant equipment and qualified staff.
- This project is aimed at enabling biofuels and bioproduct commercialization, verification, and scaling in a DOE-funded facility that acts as an incubator/accelerator for bioprocess research. This has attracted industry and startups in multiple sectors: biofuels, materials/chemicals, food, health, environment, and agriculture.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their time and thoroughness of their reviews. We look forward to implementing their constructive feedback. A reviewer identified a focus area with which we are in complete agreement: gas fermentation. We made a strategic hire three years ago who was awarded internal LBNL laboratory-directed R&D funds to ensure that gas fermentation capabilities are established at the ABPDU. We are pursuing other funding sources for the purchase of pressurizable bench-scale bioreactors. Also, as a part of the Bioprocessing Separations Consortium, we are developing technologies to continuously recover high-vapor-pressure molecules from the gas phase of bioreactors. Not having to perturb the liquid phase in fermentation and thereby prolonging biocatalysis can provide economic incentives. Further, we collaborate with NREL on a biological production of hydrogen project funded by the FCTO. The ABPDU will continue to prioritize this area of using gaseous feedstocks and generating and recovering gaseous products. A reviewer opined that ABPDU is a critical resource supporting BETO goals. The ABPDU and LBNL management work closely with BETO's technology managers to ensure that the ABPDU continues to add value to the BETO portfolio. This aspect is given very high emphasis at the ABPDU by its core team members. Our equipment and staff were referred to as "impressive." We are rigorous in our approach of maintaining state-of-the-art scale-up equipment and expertise. ABPDU researchers routinely participate in I-Corps programs to identify industry-wide issues and develop technologies and services that will be widely adopted. We will continue to be an empathetic listener to industry needs. One key aspect to the ABPDU's culture is maintaining an agile environment and adapting to our collaborators' needs. For example, our engineering and facilities teams customize equipment as desired by our collaborators. This approach opens us to multiple sectors, as identified by the reviewer.

THE ENGINEERING OF CATALYST SCALE-UP

National Renewable Energy Laboratory

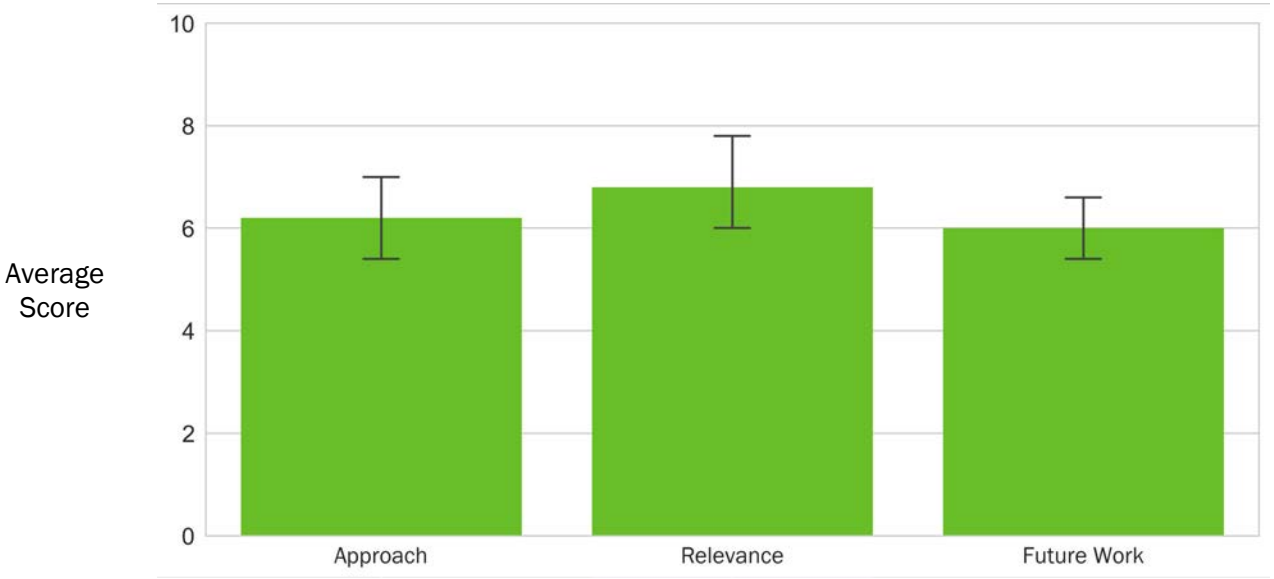
PROJECT DESCRIPTION

WBS:	3.2.1.1
CID:	NL0034842
Principal Investigator:	Dr. Fred Baddour
Period of Performance:	10/1/2018–9/30/2021
Total DOE Funding:	$400,000
DOE Funding FY16:	$0
DOE Funding FY17:	$0
DOE Funding FY18:	$0
DOE Funding FY19:	$400,000
Project Status:	New

The goal of the Engineering of Catalyst Scale-Up (EOS) project is to create a flexible, engineering-scale catalyst synthesis capability within BETO to develop the critical scientific basis of catalyst scale-up required to translate emerging biomass conversion materials from the laboratory to commercial relevance by supporting engineering-scale performance evaluation of novel catalytic materials. The use and performance verification of next-generation catalyst materials at the engineering scale requires the development of strategies for preparing complex technical bodies (i.e., active phase, support, binder, modifiers, filler, porogen) suitable for operation in pilot reactors. Moreover, the impact of translating the syntheses of these catalysts from the laboratory scale to the engineering scale on the key catalyst physical properties (e.g., ionic speciation, colocation of active sites, active site ratios, particle size) is nontrivial and remains largely unexplored for research catalysts being developed in BETO's conversion portfolio. This development of methodologies to prepare engineering-scale quantities of technical catalysts based on the products of the robust catalyst development cycle that operate at the core of the ChemCatBio is critical to enabling the evaluation of advanced catalytic materials within DOE's pilot plant PDU and reducing the risk associated with the commercial adoption of these technologies. Further, the five-year biomass conversion pathway verification cycle employed by BETO has demonstrated that the consistent year-over-year

Weighted Project Score: 6.2

Weighting for New Projects: Approach - 25%; Relevance - 25%; Future Work - 50%



I One standard deviation of reviewers' scores

performance improvements yielded by fundamental catalyst design and synthesis at the laboratory scale does not trivially translate to larger scales, largely limiting the types of catalysts that can be tested in BETO's PDUs to commercial materials. Previous biomass conversion pathway verification efforts of internally developed catalysts have encountered significant scale-up challenges that have impacted catalytic performance.

The EOS project will address the needs of the catalyst development projects within BETO by decoupling fundamental (TRL 1–3) catalyst research from the scale-up of promising catalyst materials (TRL 4–6). The project's initial focus is on scaling up the catalyst candidates selected for the FY 2022 CFP verification while concurrently developing a capability that is broadly applicable to the catalysts developed across BETO's portfolio. These goals will be achieved through a multistep collaborative approach between NREL and Argonne National Laboratory (ANL) and will leverage existing scale-up technologies within ANL's Materials Engineering Research Facility, which include the Applied Materials Process R&D and Scale-Up and Advanced Materials Synthesis programs. This presentation highlights the unique set of capabilities and scale-up methodologies being developed by this partnership that are specifically tailored to the demands of preparing engineering-scale quantities of catalysts for bioenergy.

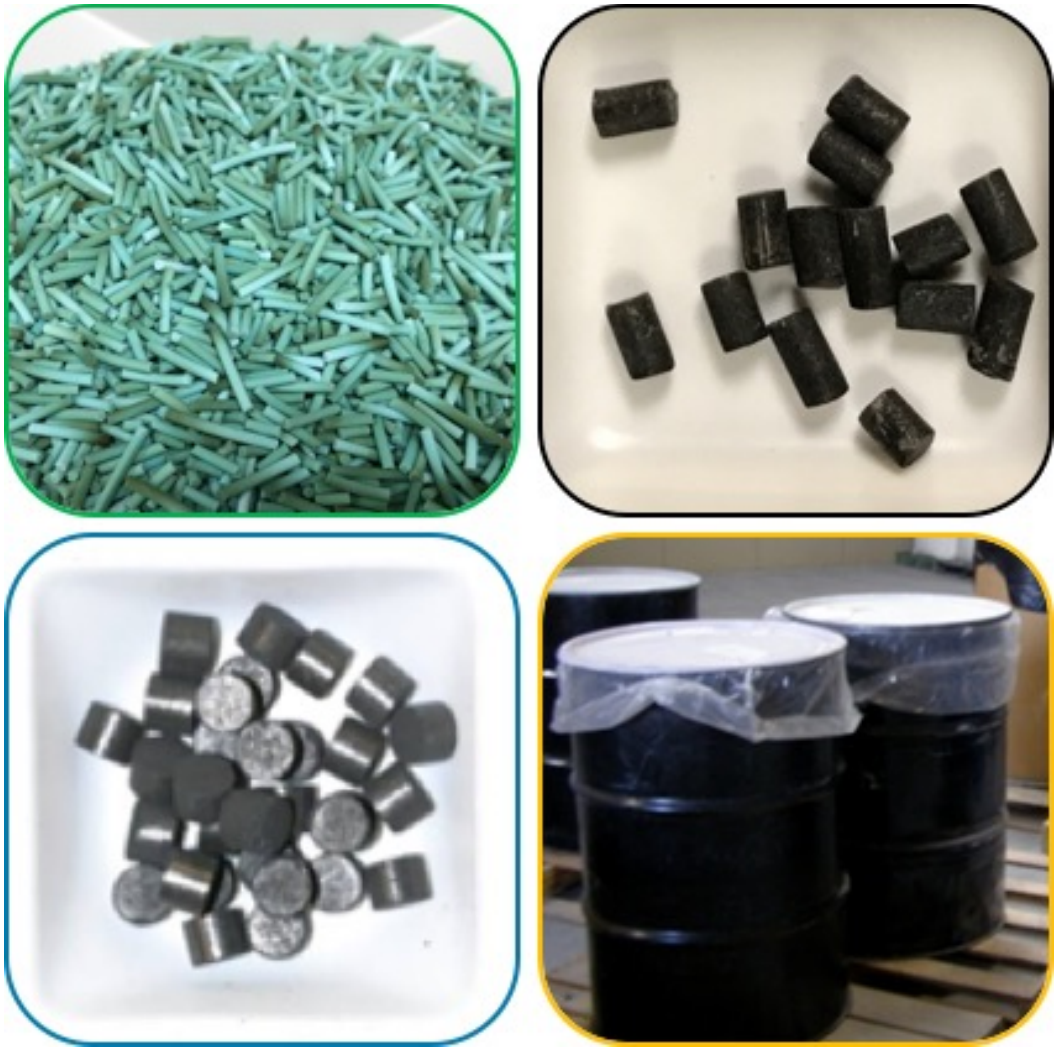


Photo courtesy of National Renewable Energy Laboratory

OVERALL IMPRESSIONS

- This project appears to have significant value to the industry inasmuch as commercial-scale production of novel catalysts is a clear bottleneck to rapid technology transfer to scale. Continued focus on adaptation/use of existing commercial production technologies will provide the fastest path to scale-up of novel catalyst production.
- NREL and ANL are developing a flexible, engineering-scale catalyst test facility to scale up catalysts used in biomass conversion. This is a very ambitious project because most of the catalyst scale-up knowhow is essentially a "black art."
- This project has newly started.
- The goals and objectives appear to be clearly defined.
- The go-no-go is outlined as part of future work. An IAB has been established.
- The project clearly meets DOE catalyst and technical needs for advancing the bio-industry through its PDU work.
- The project reduces risks for smaller/new businesses by providing testing at the pilot scale for catalyst-specific needs.
- The project clearly identifies current obstacles that need to be overcome to more efficiently scale up solid catalysts, but the presentation discussed the work at a high level with generic terms and did not provide adequate detail to evaluate the value. Future work should include a better definition of how the end work product will be used to advance BETO goals.
- This project nominally supports BETO goals and objectives by providing a de-risking step in catalyst manufacturing that should translate well to traditional manufacturers.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We appreciate the reviewer's feedback and agree that focusing efforts on reducing the bottleneck of commercial-scale production of novel catalysts is of potential value to the industry.
- We thank the reviewer for their comments and through this effort hope to address some components of the "black art" nature of catalyst scale-up.
- We appreciate the comments of the reviewer and will strive to achieve the outlined goals and enable engineering-scale evaluation of novel materials.
- We appreciate the insight of the reviewer and apologize if the presentation did not sufficiently highlight the value of the planned work. We see the value of this project being threefold:
    1. To prepare quantities suitable for operation in DOE PDUs that enable the evaluation of promising catalysts developed within the DOE national laboratory complex and directly support BETO technology verification efforts
    2. To reduce risks for smaller/new businesses by assisting with scale-up efforts, thus enabling pilot-scale evaluation
    3. To evaluate nontraditional manufacturing techniques for the preparation of catalytic materials.
- We agree with the reviewer that the EOS project provides an important de-risking step in catalyst manufacturing that should translate well to traditional manufacturers and that this effort supports the BETO MYP goals.

IMPROVED FEEDING AND RESIDUAL SOLIDS RECOVERY SYSTEM FOR IBR

ThermoChem Recovery International, Inc.

PROJECT DESCRIPTION

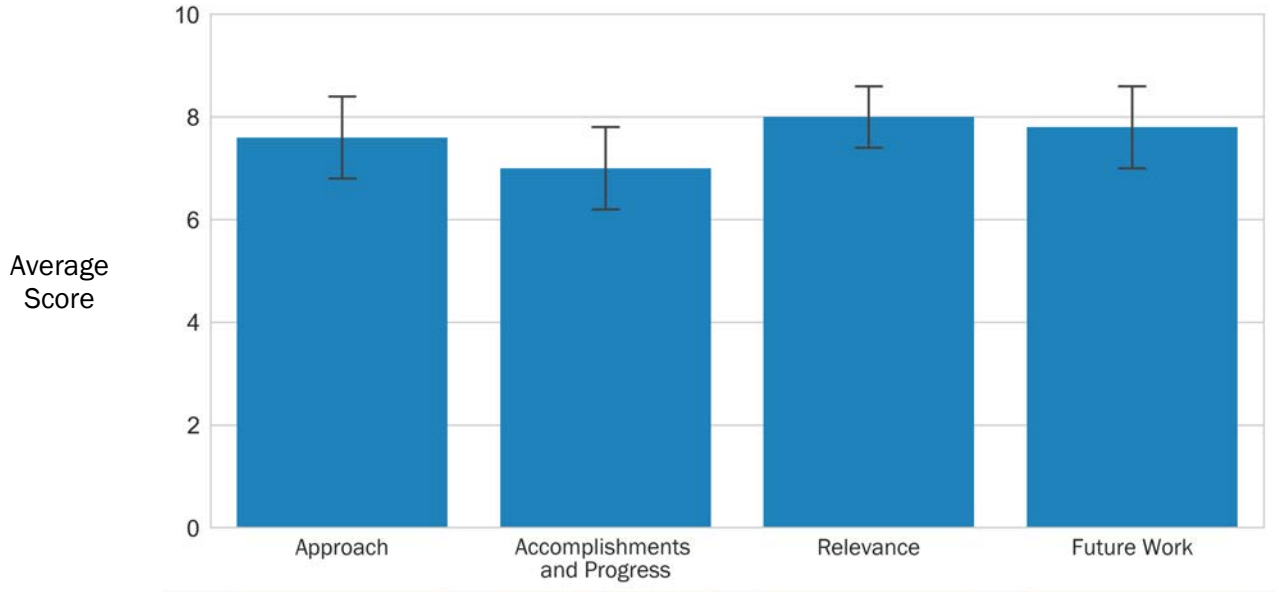
WBS:	3.4.1.10
CID:	EE0008249
Principal Investigator:	Dr. Ravi Chandran
Period of Performance:	10/1/2017–11/30/2021
Total DOE Funding:	$1,578,776
Project Status:	Ongoing

This project aims to enhance the versatility and economic viability of IBR technologies. Specifically, this project will enable IBRs to employ a greater variety of non-pristine feedstocks that differ in geographic source, age, composition, size, energy content, and moisture content. It also incorporates improved solids-handling systems to selectively remove inert solids and discharge residual fine solids (ash) from the reactor more reliably, efficiently, and safely. These will increase annual feedstock throughput, decrease energy costs, decrease GHG emissions, and accelerate IBR deployment. These improvements could be offered together or individually and will catapult the state-of-the art technology available to all IBRs. These will also help meet BETO objectives to dramatically reduce dependence on imported oil and spur the development of the domestic bio-industry.

This project will leverage the existing commercial, technical, and operational capabilities of TRI to reliably introduce a variety of feedstocks into a reactor and remove process residuals safely and economically. Aligned to accommodate the FOA's intent, the present project will use TRI's existing four-ton-per-day PDU at the TRI Advanced Development Center (ADC) in Durham, North Carolina, with modifications to its first-generation feed system and residual fine solids discharge system and the addition of a classifier system for selective removal of inert solids and agglomerates from the reactor. The project will be validated by performing a continuous, long-duration trial with forest residuals, agricultural waste, and sorted municipal solid waste

Weighted Project Score: 7.6

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



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(MSW) feedstock in the four-ton-per-day PDU and evaluating the benefits for a reference 500-ton-per-day biomass-to-diesel commercial plant. The anticipated benefits at this scale are:

- Thirty percent increase in feedstock annual throughput per feeder
- Energy savings of 3,500 MWh per year
- Reduction in GHG emissions of 2.5 CO_2 equivalent g/MJ diesel (i.e., 3,000 tons CO_2 equivalent per year).

TRI has completed successful experimental validation of all three unit operations in Budget Period 1A. Budget Period 1B is in progress with mechanical design of the three systems ongoing. Feedstock selection and design of experiments for the PDU trial as well as National Environmental Policy Act (NEPA) documentation have been completed.

Photo courtesy of Thermochemical Recovery International, Inc.

OVERALL IMPRESSIONS

- TRI is addressing solids-handling issues in their biomass gasification system by improving biomass feeding to the gasifier, enabling more efficient removal of ash particles and the bed material from the gasifier to improve process stability and reduce CapEx and OpEx as well as improve efficiency. Handling of solids is one major issue in any gasification system, and the work done in this project provides a new approach to improve the reliability of the overall system.
- This project is designed to upgrade the feedstock and ash-handling capability of the PDU—goals that are supportive of integrated and long-term operations of the PDU.
- The work done by TRI is exemplary and appears to have addressed a significant gulf in the biomass industry for feeding a pressurized gasifier system. The approach and philosophy to develop scientific methods gives confidence to the work they do.
- The goal of the project is necessary for the success of larger-scale gasification. The use of multiple feedstocks under the testing program is valuable. The project needs a better definition on scope, and how it is integrated with other TRI projects was not clearly defined.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their thoughtful comments and insights. We agree. We do employ sound scientific- and engineering-based approaches to accomplish the project goals.
- The overall scope is to design, fabricate, test, and validate improvements to feed and solids removal systems to optimize IBR. Although this project is focused on solids feeding and handling, the other project has a different target directed toward the process intensification of biomass conversion and syngas cleanup to decrease the IBR CapEx and OpEx.

MULTI-STREAM INTEGRATED BIOREFINERY ENABLED BY WASTE PROCESSING

Texas A&M AgriLife Research

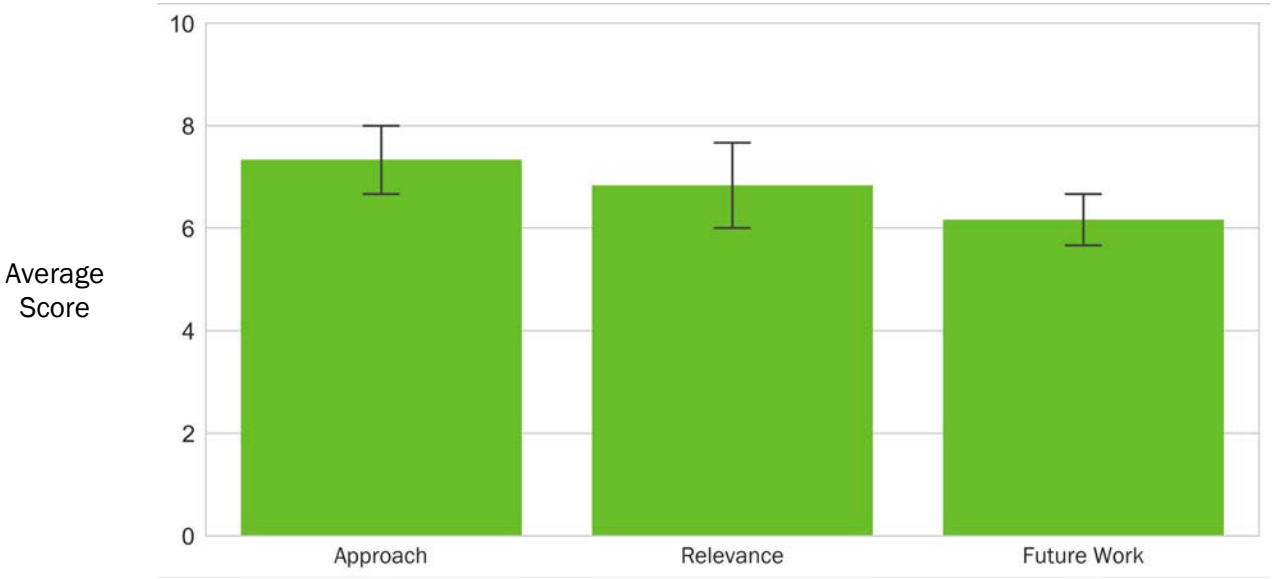
PROJECT DESCRIPTION

WBS:	3.4.1.11
CID:	EE0008250
Principal Investigator:	Dr. Joshua Yuan
Period of Performance:	5/1/2018–4/30/2021
Total DOE Funding:	$2,236,211
Project Status:	New

This project will integrate recent advances developed by a multidisciplinary academic-industrial coalition to address one of the most challenging issues in lignocellulosic biofuel: the use of biorefinery waste in producing valuable products. The success of a modern biorefinery heavily depends on the creation of diverse and valuable product streams using all fractions of input material. Essentially, all current lignocellulosic bioconversion platforms lead to a lignin-containing waste stream that needs further processing into valuable products. Although a certain amount of lignin (approximately 30%–40%) is needed for the thermal requirements of biofuel production, a modern cellulosic processing plant will have approximately 60% excess lignin that is mainly burned. Use of lignin-containing biorefinery streams as feedstock for renewable products offers a significant opportunity to improve operational efficiency, reduce costs, reduce carbon emissions, and enhance sustainability of lignocellulosic biofuels. We will uniquely address these challenges by developing technologies for a multi-stream integrated biorefinery (MIBR), where the lignin-containing biorefinery waste will be used for producing high-value products.

Weighted Project Score: 6.6

Weighting for New Projects: Approach - 25%; Relevance - 25%; Future Work - 50%



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This research will pursue three objectives:

1. MIBR development by advancing fractionation, conversion, and processing technologies to enable valuable bioproduct streams. Innovative chemical and biological fractionation technologies will be developed and enhanced to generate lignin fractions amenable to different applications in bioconversion, asphalt binder modifiers, and carbon fiber. The processing technologies will be advanced to enable the complementary use of lignin fractions based on their different structural characteristics.

2. MIBR optimization through process design, TEA, and LCA. Process design will be used to maximize MIBR profitability and enhance sustainability via the integration of fractionation, conversion, and processing technologies. TEA will be carried out to evaluate profitability, and LCA will be used to evaluate sustainability, with both guiding profitable and sustainable enhancements using process optimization.

3. MIBR scale-up to one dry-ton-per-day capacity. This will be done at an ICM, Inc. biorefinery site. Thus far, the project has successfully passed the initial verification and developed integrated processes for lignin-based carbon fiber, asphalt binder modifier, and lipid conversion.

The proposed research will leapfrog current technologies to address one of the most eminent issues in biorefineries and an under-researched topic of scientific and commercial importance. The research uniquely addresses all four priority areas in the FOA and represents a highly innovative solution for biorefinery configuration. The innovative effort has significant scientific merit, and the successful development of an MIBR represents a transformative solution for lignocellulosic fuel production. An MIBR will reduce fuel production cost by creating the means to produce high-value bioproducts, including asphalt binder modifiers and quality carbon fiber, and by mobilizing a valuable way of using all carbon in the feedstock. MIBR development will also promote rural economic development, build energy independence, and enhance U.S. agricultural incomes.

OVERALL IMPRESSIONS

- This three-year project to develop an MIBR is scientifically sound and well planned. It is highly relevant to the BETO MYP goals. A good team is in place for the project's execution. Successful completion of this effort is likely to lead to serious commercial interest in scaling up and deploying this technology.

- The processing of wastes to generate valuable coproducts is likely the only near-term path to the commercial application of cellulosic biofuels, and projects such as this greatly support the industry moving to this model. Focus on applications using real-world waste streams to achieve the fastest success, and do not spend time working to modify upstream processes to produce "improved" (waste) feedstocks, because the impact on the primary model will likely overwhelm any potential for positive impact.

- Valorization of waste streams is critically important to BETO's goals. This program is supportive in unique ways.

- This project has a specific target of reducing the cost of ethanol (by $0.50/GGE). Having a target instead of a general objective is more likely to get the team to achieve the target.

- This project has a strong industry partner in ICM. Hopefully the project will use ICM to keep the focus on pragmatic results.

- This project has a reasonable goal of turning waste biomass into asphalt filler that provides enhanced properties. The team is well qualified and organized, although it is very early in the project. The process is complicated, and it was difficult to understand from the presentation.

- This project appears to be a solution in search of a problem. This is a very complex process with too many different pathways. Any of these pathways could require more than 100% of the project resources for a complete investigation. It appears that the team might need to modify the front end, which is existing, thereby greatly increasing the cost of this integration. Overall, the project points to a lot of very interesting opportunities, but it appears to be more of a conceptual study than a real developmental one. There is no shortage of the former, and I think the latter should be preferred. A stronger focus on the fractionation and much less, if any, on the next phase of product development from specific lignin fraction would give this project more practical value and meaningful goals. The TEA is aspirational at best.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We appreciate the comment and acknowledgement of the potential impact of the project.
- We appreciate the comment and acknowledgment on the interest from industry. We agree with the reviewer that we should focus on real-time cases. The fractionation/pretreatment development focuses on tailoring existing pretreatment conditions without significant changes to biorefinery configurations. We will focus on scenarios close to current biorefinery configurations yet yielding lignin with better processability characteristics.
- We appreciate the comment and acknowledgement of uniqueness.
- We appreciate the comment and the acknowledgement of strong industry relevance and partnership.
- We appreciate the comment and acknowledgement of a strong team. We agree with the reviewer that an MIBR with different products is rather complicated. In fact, some current wet-milling corn ethanol refineries are also rather complicated in terms of different product streams.
- We appreciate the acknowledgement of interesting solutions and we agree that the project has three different product paths, which makes this project more complicated than a traditional project. In fact, some of the most profitable corn ethanol wet-milling biorefineries also produce multiple products, such as starch, corn oil, and syrup. The multiple-product approach is critical to avoiding market saturation and maximizing the economic return. The project actually focuses more on developing each product processing, instead of the fractionation. The pretreatment and fractionation technologies will be based on a modification of current pretreatment without change in infrastructure, which will allow us to quickly scale up the project within three years. We very much agree with the limited budget and resources available to the project; however, as discussed in the question-and-answer session, the project is based on an extensive preliminary study, a previous DOE project (DE-EE0006112), and internal support. The project is at the beginning stage, and the TEA has just begun.

UPGRADING OF STILLAGE SYRUP INTO SINGLE-CELL PROTEIN FOR AQUACULTURE FEED

White Dog Labs

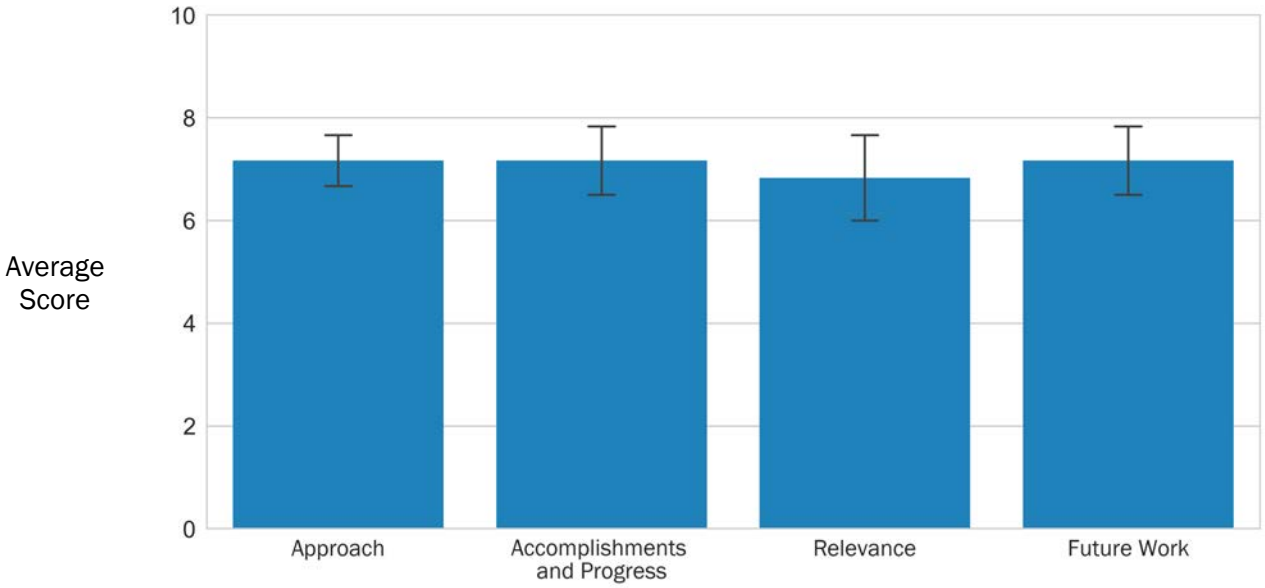
PROJECT DESCRIPTION

WBS:	3.4.1.12
CID:	EE0008251
Principal Investigator:	Dr. Shawn Jones
Period of Performance:	1/1/2018–10/1/2020
Total DOE Funding:	$2,233,290
Project Status:	Ongoing

In this project, the undervalued stillage filtrate from a cellulosic ethanol plant will be upgraded into a single-cell protein (SCP) product for aquaculture feed applications. Currently, the stillage stream is sent to an anaerobic digester for conversion into biogas; however, residual cellulosic carbon is still within this stream and can be converted into a higher-value product. White Dog Labs (WDL) proposes using this stillage stream to generate an SCP as a higher-value product than biogas. The generated SCP is a good alternative to fish meal in aquaculture applications because of its comparable protein content (greater than 60%) and amino acid profile (particularly in lysine, threonine, and methionine). For SCP generation, WDL will use its proprietary fermentation technology, called MixoFerm, which enables significantly higher cell yields than conventional fermentation. In the proposed project, led by WDL Vice President of Microbiology Shawn Jones, we will produce SCP from cellulosic stillage and undertake a salmon-feeding study to validate the nutritional value of the SCP. Inclusion of the proposed SCP process in an IBR will provide another high-value coproduct and help improve plant economics.

Weighted Project Score: 7.1

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



OVERALL IMPRESSIONS

- SCP has been a coproduct goal for many years, and it is laudable when the concept is applied to coproducts for improved financial viability of larger projects; however, all these projects—including this one—need a more detailed assessment of the existing market and what the competition will be for commercial acceptance of the final product. Realistically, there is no path to $2/kg SCP from cellulosic feedstocks, so production costs *must* be kept to a minimum while maximizing proximate analysis/SCP value.

- This project is very supportive of overall BETO goals.

- This project is well focused at converting a low-value waste stream from cellulosic ethanol facilities and upgrading it to a protein product. The target of protein makes sense, and the basic technical plan is sound. The team is using real-world material from a commercial cellulosic facility. The team would benefit from integrating a better understanding of the target market into directing development efforts.

- The production of SCP from a biorefinery waste stream is highly relevant to the BETO MYP goals. The proposed technology appears to be scientifically sound. There were challenges with the filtrate materials received from POET. Identifying a suitable waste stream should be a project priority.

- The production of SCP is in theory scalable—as long as the market develops as promised—and the technology could have application in the conventional corn ethanol industry. It does not appear that the complexity of purifying the product has been considered—currently, there is very limited commercial SCP production using clean dextrose as a feedstock—nor the regulatory complexity. Last, the project overestimated the value of their SCP product using fish meal as a proxy. The lack of omega-3 fatty acid is likely to make soy meal a much more likely and less valuable proxy.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

The recipients choose not to respond to the reviewers' overall impressions of their project.

PILOT-SCALE BIOCHEMICAL AND HYDROTHERMAL INTEGRATED BIOREFINERY FOR COST-EFFECTIVE PRODUCTION OF FUELS AND VALUE-ADDED PRODUCTS

South Dakota School of Mines and Technology

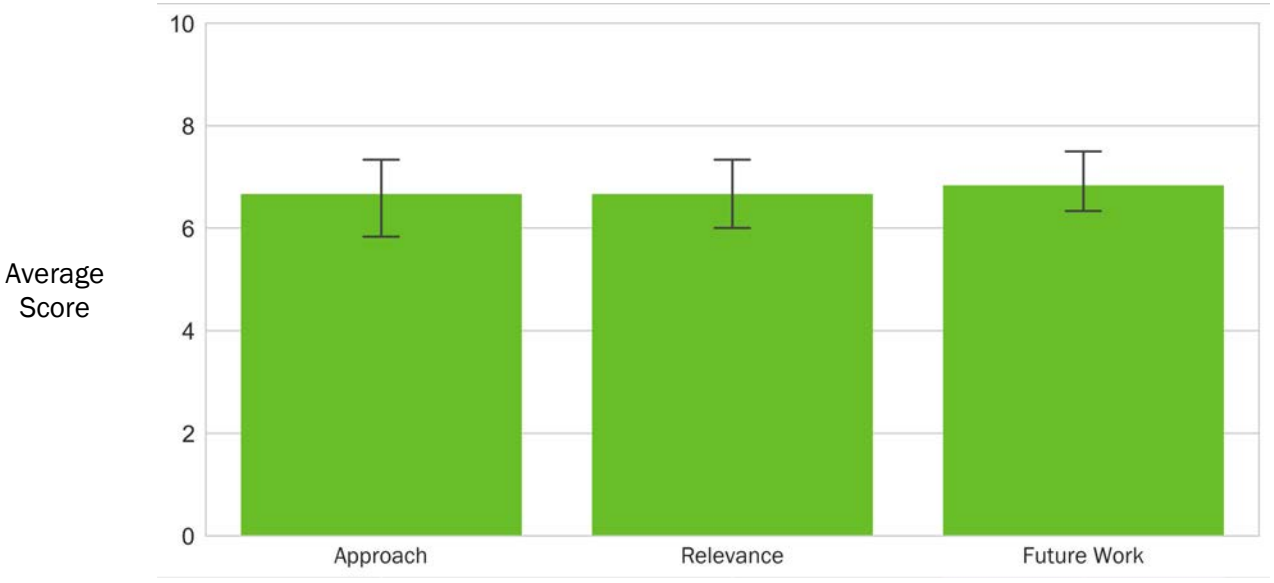
PROJECT DESCRIPTION

WBS:	3.4.1.13
CID:	EE0008252
Principal Investigator:	Dr. Rajesh Shende
Period of Performance:	2/15/2018–2/14/2021
Total DOE Funding:	$1,926,160
Project Status:	New

The major goal of this project is to demonstrate the production of value-added products from the waste streams generated during conventional biochemical processing of lignocellulosic biomass. These waste streams include unhydrolyzed solids (solid waste-I) and aqueous waste streams (I). Unhydrolyzed solids will be processed via catalytic hydrothermal treatment, which will produce biochar (solid waste-II) and aqueous waste streams (II). Typically, the proposed technology platform produces two aqueous waste streams and two solid waste residues, which will be converted into high-value products (lactic acid, phenols, biocarbon, and nanofibers). The solid waste lignin residue derived from corn stover will be treated hydrothermally to produce biochar, which will be converted into graphitic battery-grade biocarbon (product-1) and carbon nanofibers (product-2) as final products. Because biochar is commercially available, the production of marketable high-value carbon materials (biocarbon and carbon nanofibers) from biochar will have tremendous economic impact on reducing the fuel cost. Additionally, from the aqueous waste stream, coproduct lactic acid/polylactide (product-3) will be enriched. During hydrothermal processing of solid waste lignin residue, phenol (product-4) will be selectively produced and recovered as a coproduct. While generating these products, bio-oil is also generated, which can be upgraded to fuel quality. In our preliminary TEA/LCA, the products/coproducts derived from the

Weighted Project Score: 6.8

Weighting for New Projects: Approach - 25%; Relevance - 25%; Future Work – 5 0%



I One standard deviation of reviewers' scores

waste streams have been shown to reduce the fuel cost and reduce GHGs. The three major objectives to advance the technology include (1) demonstrate bioproducts from waste streams at the pilot scale with a minimum of one ton per day via integrated biochemical and hydrothermal pathways to validate the cost-effective production of the fuel, (2) document the final product yields and estimate the revenues that can be generated based on current market price and provide profit summary, and (3) perform detailed TEA and LCA using standard tools to understand the economic and environmental impacts of the proposed activities.

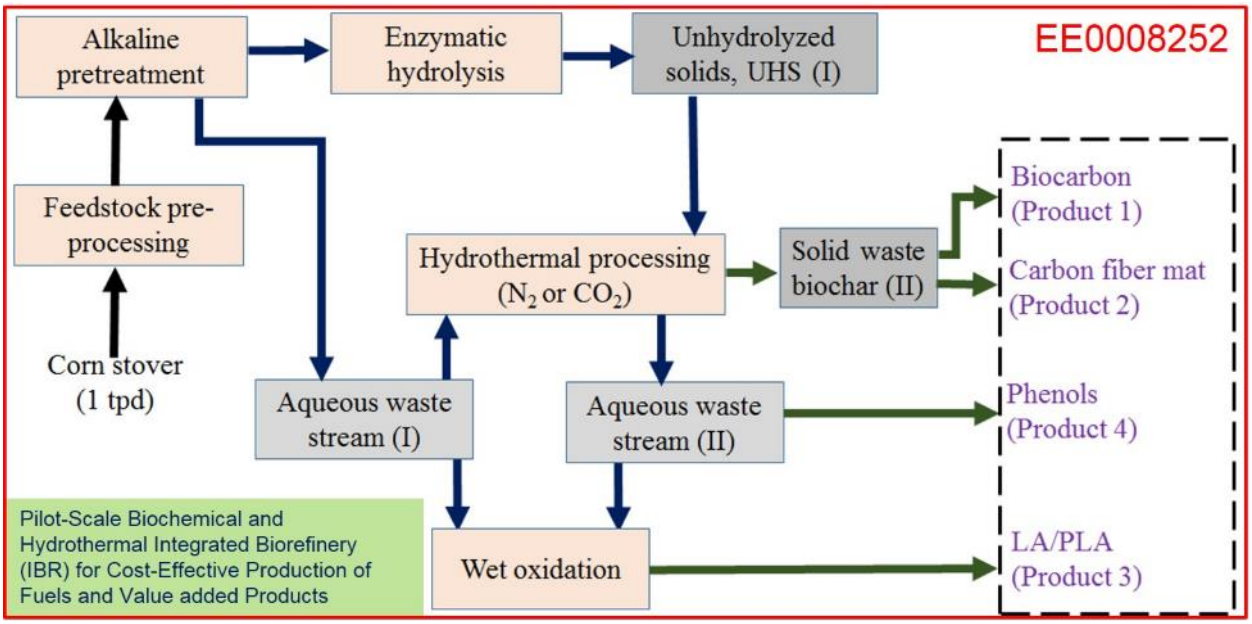


Photo courtesy of South Dakota School of Mines and Technology

OVERALL IMPRESSIONS

- Although it is always interesting to hear about methods of making a "silk purse out of sow's ear," the use of waste biogenic carbon streams to produce carbon fiber and powder to support new industry is intriguing.
- The project brings forward an interesting approach and range of products, with most of the work still pending. If proven successful, it has the potential to add great value; however, the large number of unit operations and wide range of products bring concern about reaching economic viability for the process.
- This is an important project to advance the BETO MYP goals to use waste streams to produce valuable coproducts. This project provides a holistic approach to use both solids and aqueous wastes to produce industrially relevant products.
- In process schemes designed to be attached on the back end of existing processes to improve the value of current low-value or waste streams, is not uncommon to see the process becoming more complex and expansive than the original process it integrates. It behooves the developer to prove that this is justified economically and that the process is indeed scalable. I look at this with some skepticism because (1) it appears to be tailored around the alkaline pretreatment of biomass, which is not a widely accepted process technology; and (2) it proposes a complex slate of coproducts whose economics and further processing complexity are only marginally investigated. This project would benefit from a stronger focus.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We truly value this viewpoint because both carbon fibers and biocarbon generated from waste carbon will support new industries.
- We understand the concern raised by the reviewer about the economic viability of the process. A specific task on TEA has been included in our proposed work.
- We appreciate the reviewers' comments.
- We believe that alkaline pretreatment-derived unhydrolyzed solids will be more suitable for the generation of coproducts with superior characteristics. Higher liquefaction or bio-oil yields were realized with the HTL of the solids derived from the alkaline pretreatment than with the dilute acid pretreatment. For the former, the char was found to have a higher specific surface area than the latter. Prior to the pilot-scale trials, we plan to optimize the alkaline treatment with the characteristics of the derived coproducts. We agree with the reviewer that the economics of the coproducts have not yet been fully investigated. Note that the processing complexity and economics of the coproducts will be fully investigated under specific tasks. The TEA will lead us to a stronger focus on certain project aspects. If the pretreatment method is only hydrothermal, the pH of the aqueous phase can drop to less than 3. The low pH (<3) of the medium causes the precipitation of solubilized lignin and catalyzes the degradation of hemicelluloses. To avoid the formation of inhibitors, the pH should be controlled between 4 and 7 during the pretreatment. This pH range minimizes the formation of monosaccharides and therefore the formation of degradation products that can further catalyze the hydrolysis of the cellulosic material during pretreatment. Maintaining the pH near neutral helps avoid the formation of fermentation inhibitors during the pretreatment. Therefore, we proposed the alkali-assisted pretreatment method, where potassium carbonate (K_2CO_3) is added in a small fraction to maintain the aqueous-phase pH near neutral. The approach is clearly different from the conventional alkaline, where pH is 8 or more by the addition of alkali.

SMALL-SCALE DECENTRALIZED FUEL PRODUCTION FACILITIES VIA ADVANCED HEAT EXCHANGER-ENABLED BIOREFINERIES

ThermoChem Recovery International, Inc.

PROJECT DESCRIPTION

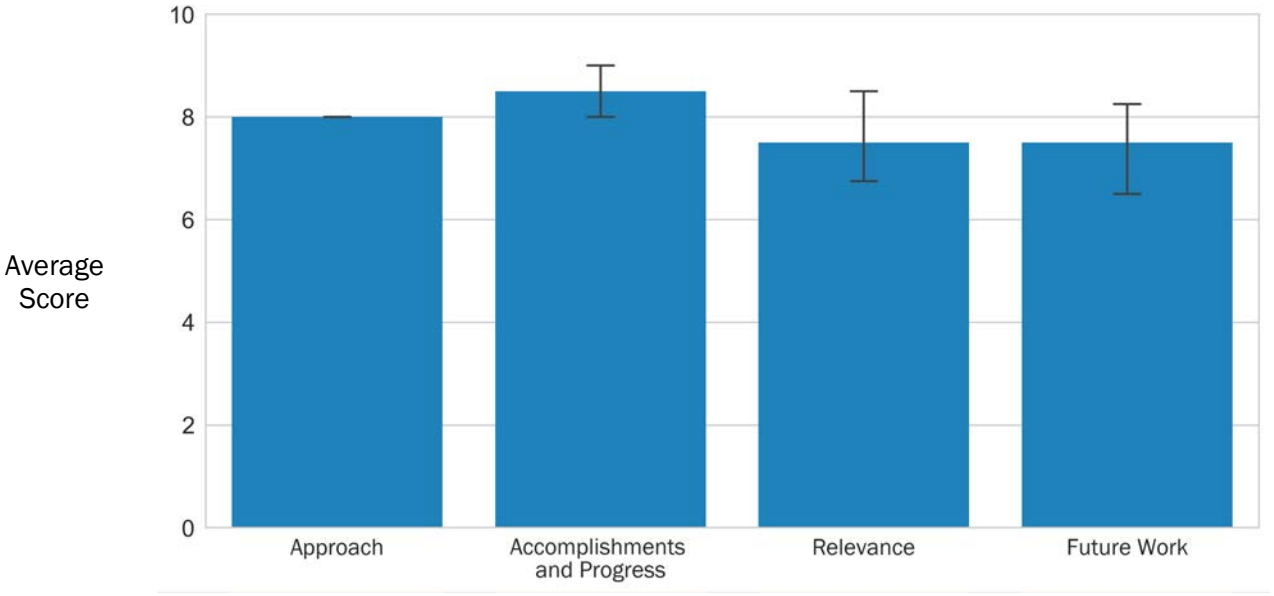
WBS:	3.4.1.21
CID:	EE0007964
Principal Investigator:	Dr. Ravi Chandran
Period of Performance:	1/15/2017–3/31/2019
Total DOE Funding:	$807,984
Project Status:	Ongoing

The steep CapEx and OpEx levels required by the first-generation IBR technologies have forced project developers to focus on very large-scale projects and negatively priced (i.e., MSW, hazardous waste) feedstocks, driving market pull forces away from the ample feedstocks that comprise the industry-defining DOE's *Billion-Ton Study* (2005), the 2011 follow-up report, and the expanded 2016 report. The resultant mass migration of project interest away from smaller-scale wood and agricultural waste projects represents an overreaction to existing market forces. Project developers' and owners' answers should not be to abandon otherwise solid projects because feedstock collection and transportation logistics unavoidably increase average delivered costs as catchment area radii increase, but rather to meet the market where it is (i.e., at significantly smaller scales than what has been pursued to date). This is where technologists such as Velocys, RTI International, and TRI, by openly working together, can help move the fulcrum just enough to usher in countless smaller biomass projects, thereby breaking the megaproject mindset.

Considering this decade-plus underperforming context, we believe that we need to go small to go big. It is a market-validated fact that the current thermochemical-to-fuels process configurations will simply not scale down to the circa 150-dry-ton-per-day size, a feedstock-supply size that is widely understood to be one that

Weighted Project Score: 7.9

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



could be met in countless locales, with multiple feedstock sources. Although these current "first-generation" configurations benefit from years of development and some demonstration, the team of TRI, Velocys, and RTI International have configured an advanced biorefinery to go small based on a key technical breakthrough, coupled with best-in-class gas cleanup, Fischer-Tropsch synthesis (via a modular, microchannel unit), and system-wide process intensification.

This project will leverage the existing commercial, technical, and operational capabilities of both TRI and Velocys to demonstrate this in a four-ton-per-day IBR PDU at the TRI ADC in Durham, North Carolina, which includes both TRI and Velocys systems. The modifications will include the addition of an advanced heater and changes to the gas cleanup system. The project will be validated by performing a continuous, long-duration integrated trial to produce diesel and naphtha and estimating the benefits for a reference 150-dry-ton-per-day biomass-to-diesel commercial plant. The anticipated benefits at this scale are:

- A 25% increase in usable syngas (hydrogen + carbon monoxide [H_2+CO]) per unit mass of dry feedstock
- A 35% decrease in overall CapEx of the IBR
- A decrease in IBR OpEx so as not to exceed $2/GGE.

The team has completed successful experimental validation of all the relevant unit operations in Budget Period 1. This included a 31% increase in syngas (H_2+CO) per unit of biomass, which surpassed the 25% target. Budget Period 2 is in process with the mechanical design of the advanced heater, CO_2 capture unit design, computational fluid dynamics and computational particle fluid dynamics modeling, and simulations and validation of data from Budget Period 1. The simulations indicate a 28% improvement in syngas (H_2+CO) yield per unit mass of biomass over that for the first-generation gasification system; this, again, surpasses the 25% target. NEPA documentation and permitting are nearing completion.

Photo courtesy of ThermoChem Recovery International, Inc.

OVERALL IMPRESSIONS

- This project continues to advance the promise of microchannel reactor development, which promises costs reductions in CapEx and OpEx when compared to traditional technology deployment for Fischer-Tropsch liquids products.

- This is a well-managed project focused on targeted improvements in gasification to address obstacles identified in first-generation technologies. Initial results showed strong validation of modeling with pilot operations.

- This project is trying to leverage process intensification to increase syngas yields per unit of biomass feed by the integration of an advanced heater, novel processes for the removal of CO_2 and syngas contaminants, and a novel microchannel Fischer-Tropsch reactor from Velocys. Budget Period 1 validation has been successfully completed, and now all the process components are being demonstrated to complete the remainder of the project.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their thoughtful comments and insights. We agree.

PILOT-SCALE ALGAL OIL PRODUCTION

Global Algae Innovations

PROJECT DESCRIPTION

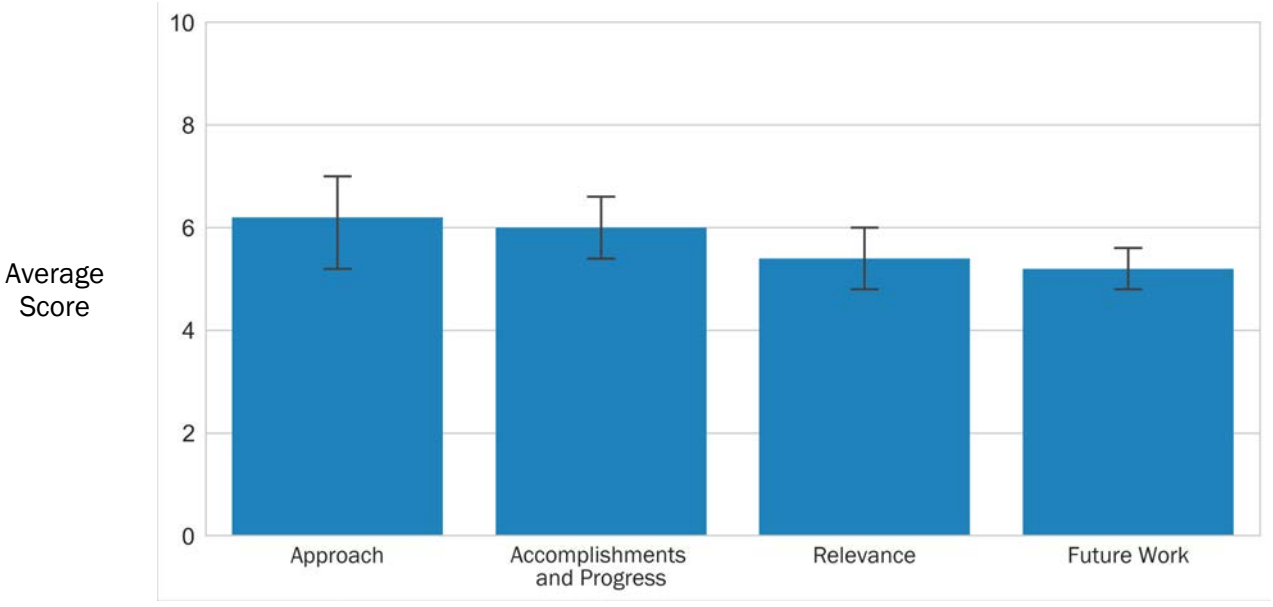
This project will scale up the advanced open raceway algae cultivation and processing technology developed by Global Algae Innovations (GAI) to design a pilot-scale algal biofuel facility for construction in the Imperial Valley of California. The project team includes the California Center for Algal Biotechnology at the University of California, San Diego and TSD Management Associates.

WBS:	3.4.1.22
CID:	EE0007965
Principal Investigator:	Dr. David Hazlebeck
Period of Performance:	1/15/2017–6/30/2019
Total DOE Funding:	$1,235,790
Project Status:	Ongoing

GAI has developed and demonstrated novel technologies to improve every process step in the algae production process. The technology includes massively scalable open raceways with cultivation innovations that attain triple the productivity of conventional raceways; the Zobi harvest system that achieves 100% harvest efficiency with 1/100th the energy use of centrifuges; a suite of contamination control innovations that enable stable, large-scale open raceway cultivation; and a CO_2 supply system using power-plant flue gas. All these technologies have been validated at the acre scale, and this project will provide the opportunity to validate them at the pilot scale for algal biofuel production.

Weighted Project Score: 5.7

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



OVERALL IMPRESSIONS

- It is not clear that this project advances the state of the art.
- This project needs a backup financing plan.
- This project is in the early stage and appears to be based on historic technologies that did not prove to be economically viable. It was unclear from the presentation and questioning of the presenter what will be different about this process. The goal of being profitable is overly aggressive and unlikely to be achieved.
- Although this project shows potential, the focus on building and operating a self-sustaining ("profitable") pilot plant has tremendous potential to distract from completing the necessary work. Pilot plants by their nature are too small to yield commercially viable cost of goods sold (COGS). Even if the goal is to charge research or access fees to achieve the self-sustaining pilot goal, it appears that the focus will be more on how to engineer and construct something ancillary to the R&D goals here rather than be supportive of them.
- This project is aimed at planning and designing an open raceway algae production facility to produce about 10 tons per day of algae, which could be commercially viable. Good effort has been made to identify the right technologies and equipment to reduce the technology risks. It appears that without significant government investment (>50%), it is unlikely that this technology will become commercially viable.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- The technology suite being scaled includes dozens of radical advances resulting in at least an order-of-magnitude cost reduction every process step. This project is the first scale-up effort for such an innovative process that is projected to be economically viable for algal-based commodities; thus, developing a pilot-scale design for these innovative technologies will greatly advance the state of the art for algal biofuel production.
- Financing is very important; thus, a business assessment and preparation of a business plan are a significant part of the project, and the design basis includes versatility in the selection of products to provide greater flexibility in options for backup financing plans.
- This project includes multiple advances that lead to order-of-magnitude cost reductions in each area of algae production. A few examples include (1) a 99% reduction in the inoculum size through open raceway contamination control; (2) a 90% cost reduction and 14-fold increase in flue gas carbon capture and use; (3) a raceway design that increases productivity threefold, reduces energy use by 90%, and enables a 100-fold larger raceway area; (4) harvesting technology that reduces the energy use by 98% and cost by 93% while attaining 100% capture efficiency and returning crystal-clear recycled media; and (5) an extraction system that reduces the cost by 91% and the energy use by 78%.
- The design objective is a self-sustaining pilot-scale facility to generate the long-term, large-scale data needed to drive investment in a commercial algal biofuel industry. The algal oil produced by the pilot-scale facility will be sold to cover the operating costs. The pilot-scale facility for biofuels will be larger than any of the current high-value algal farms and have much better technology, so the production of moderate-value algal oil products to cover the operating cost is reasonable.
- Full-scale algae production facilities are projected to be commercially viable without government investment. A pilot-scale facility is not economically viable for commodity production, so government investment is needed at this scale. This project includes the preparation of a TEA based on the pilot facility design that demonstrates that full-scale production facilities will be commercially viable.

HYDROTHERMAL PROCESSING OF WASTEWATER SOLIDS (HYPOWERS)

Water Research Foundation

PROJECT DESCRIPTION

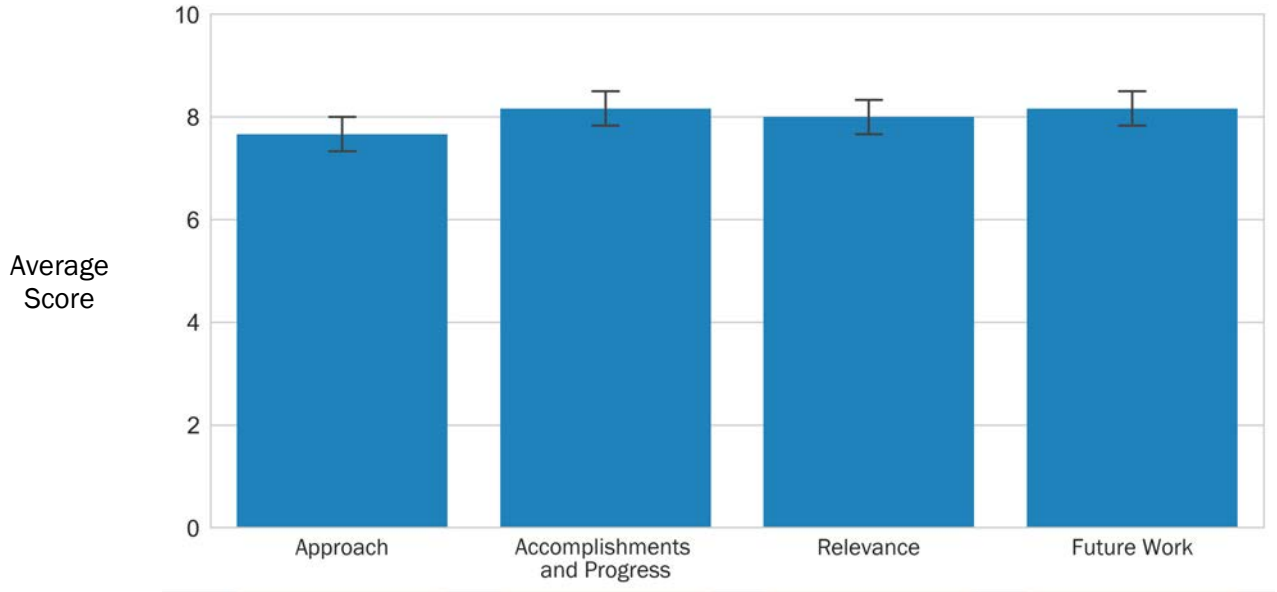
WBS:	3.4.1.23
CID:	EE0007969
Principal Investigator:	Mr. Jeff Moeller
Period of Performance:	1/15/2017–3/31/2019
Total DOE Funding:	$803,632
Project Status:	Ongoing

The purpose of the HYPOWERS project is to design, build, and operate a hydrothermal processing system to convert wastewater solids into renewable oil and natural gas at an operating wastewater treatment plant. The process has already been demonstrated at smaller scales, but a larger system running continuously in an industrial environment is needed to support full commercialization. The project has attracted intense interest from the wastewater industry because the technology addresses critical problems with specific advantages not provided by other processes. The HYPOWERS project will be located at the Central Contra Costa Sanitary District near San Francisco and will serve a portion of the district's wastewater flow equivalent to a population of approximately 45,000 people. The project is a critical step in the BETO goal to spur creation of a domestic industry for advanced and cellulosic biofuels.

Hydrothermal Processing (HTP) uses temperature (350°C), pressure (200 bar), and water in a continuous process that converts organic material into biocrude oil and natural gas. Typically, between 40%–50% of the dry equivalent mass of feedstock is converted to oil, with another 20%–30% converted to methane. HYPOWERS will produce both oil and gas, with oil output of approximately seven barrels of biocrude oil per day. The biocrude oil can be converted to finished fuels by a conventional upgrading step followed by

Weighted Project Score: 8.0

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



coprocessing with petroleum in an existing refinery. The methane gas can be inserted into a natural gas pipeline after a proven commercial process to remove a small amount of CO_2 from the methane. The overall TRL of HTP is 6, with a goal of achieving 7–8.

The project is structured in two phases. The goal of Phase 1 (the current phase) is to develop a project and business plan with enough confidence and detail to support immediate contracting for construction and operation of the system in Phase 2. Phase 1 will conclude on March 31, 2019. DOE will then evaluate the plan, and if approved, DOE will award funds for Phase 2, concluding in September 2023. The budget for Phase 1 is $2.4 million, and for Phase 2 it is $22 million, with the DOE expenditure limited to half of these figures. Phase 1 has 10 team members, and Phase 2 will have the same team members plus two new additions.

HYPOWERS is targeted for wastewater treatment plants (WWTPs), with more than 16,000 WWTPs in the United States alone. The potential world market for HTP systems is approximately $350 billion. Other organic feedstocks have also been tested and represent large additional potential, including wood, algae, agricultural waste, animal waste, food processing waste, chemical waste, and others. If fully exploited, HTP could produce renewable fuels to replace significantly more than 5% of total U.S. use of petroleum and natural gas for transportation, with corresponding reductions in GHG emissions. The nearest competitor to HTP is anaerobic digestion (AD), but compared to AD, the life-cycle cost of HTP is approximately 50% less while eliminating feedstock solids, which AD cannot do. Government incentives further improve the economics of HTP.

OVERALL IMPRESSIONS

- Processing biosolids from a WWTP using HTL to produce diesel and methane is being demonstrated in this project at a WWTP. Most process steps have been demonstrated at smaller scale at PNNL and other places. A key technology risk is process integration to obtain cost-effective production of diesel and methane.

- This is an excellent project with considerable opportunity for application and outstanding public (utility) partnership for knowledge and technology transfer.

- This is a valuable project with potential for commercial success and economic viability in regions where suitability incentives exist for favorable economics.

- This project has been well executed both technically and from a project management standpoint. The demonstration-scale unit will still have issues to work out, as noted in the presentation, which is often the case. Financing for the next phase is the main question left. Overall, this is well done.

- This is a well-defined and organized project, following industry best practices for design and scale-up. The size of the team and number of members is a concern, but they appear to be making it work and achieving positive results.

- Although this is still a pilot effort, bringing hydrothermal process technology to a real industrial setting is of extremely high value, and this is a very important project. Actual and forecast economics are not clear from this presentation. Also, some process technology solutions—such as catalytic hydrothermal gasification—might not be amenable to distributed deployment at a relatively small scale. The key question to address is whether the economics of bio-oils—and the potential supply—are such to make the delivery to refiners for centralized processing. This is currently largely unresolved.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

The recipients choose not to respond to the reviewers' overall impressions of their project.

LOW-CARBON HYDROCARBON FUELS FROM INDUSTRIAL OFF-GAS

LanzaTech, Inc.

PROJECT DESCRIPTION

WBS:	3.4.2.5
CID:	EE0007966
Principal Investigator:	Dr. Laurel Harmon
Period of Performance:	1/15/2017–3/31/2019
Total DOE Funding:	$3,644,107
Project Status:	Ongoing

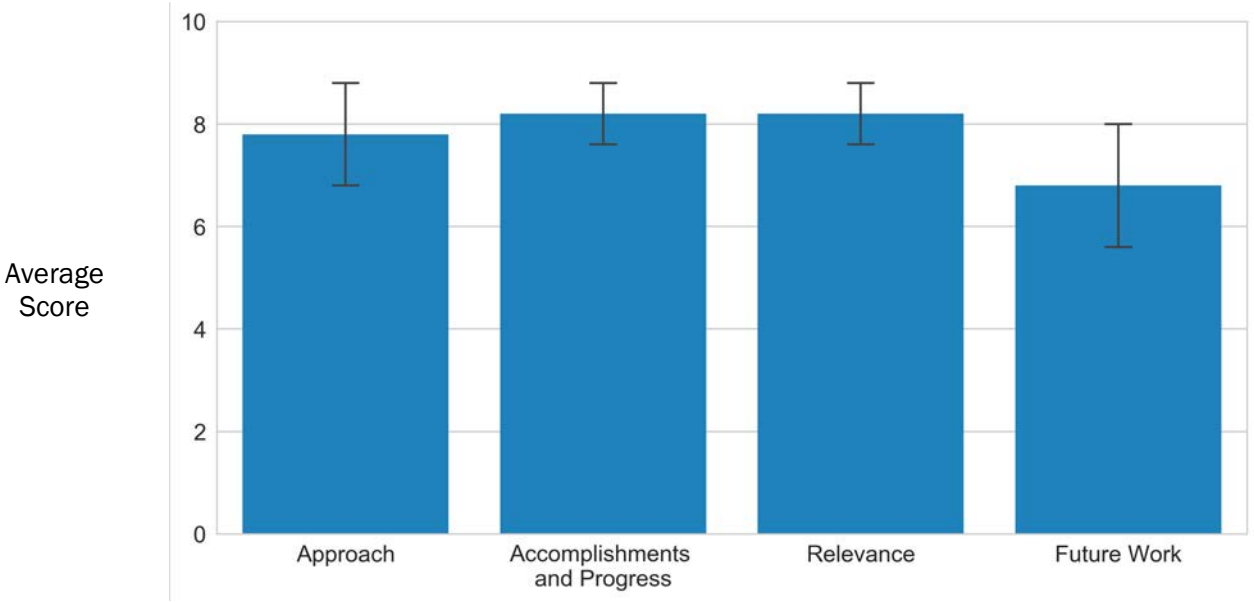
This Phase 1 project encompasses design and engineering required to achieve a -5/–+15 cost estimate and the necessary approvals for the construction of a demonstration facility to produce sustainable aviation fuel (SAF) from ethanol. The aviation industry is seeking economic and technically viable approaches to providing sustainable alternatives to petroleum-based jet fuel that reduce the carbon footprint of air travel, in part driven by the International Civil Aviation Organization's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which will require significant volumes of SAF to meet international commitments. Because jet fuel has accounted for as much as 40% of an airline's operating costs in 2013, and 20% today, reducing price fluctuations associated with petroleum is another significant driver.

This will be the first demonstration-scale project on the production of low-carbon jet and diesel fuels from ethanol. The project will demonstrate an entirely new pathway to low-carbon fuels from industrial waste and biomass, with the potential to create significant jobs and revenues in both agriculture and manufacturing.

Since the proposal, LanzaTech has commercialized its gas fermentation technology to produce an ethanol intermediate ("Lanzanol") from industrial off-gas. Therefore, the project is now focused on demonstrating the alcohol-to-jet (ATJ) process developed by LanzaTech and PNNL to convert ethanol to jet and diesel. The synthetic paraffinic kerosene from this pathway is now qualified for use in commercial aviation at blends of up

Weighted Project Score: 7.8

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



to 50% with conventional jet fuel. The facility will be located at LanzaTech's Freedom Pines Biorefinery in Soperton, Georgia. The demonstration will model commercial ATJ production, in which ethanol from multiple sources is processed in a larger, centralized ATJ unit.

An engineering-procurement-construction company is providing the design and engineering services, and other partners are providing catalyst and technology services. Michigan Technological University will conduct LCA of the integrated process. Engine manufacturers will support the project by evaluating fuel properties and advising on fuel registration and logistics requirements. To demonstrate process versatility, Aemetis, Inc. will supply cellulosic ethanol from a unit under development to produce ethanol via fermentation of biomass syngas, and qualifying ethanol feedstocks will be sourced from other suppliers. The primary fuel product will be sustainable aviation fuel, with some diesel production. Preliminary LCA shows more than 60% reduction in GHG emissions from this new fuel compared to fossil jet fuel with competitive costs of production.

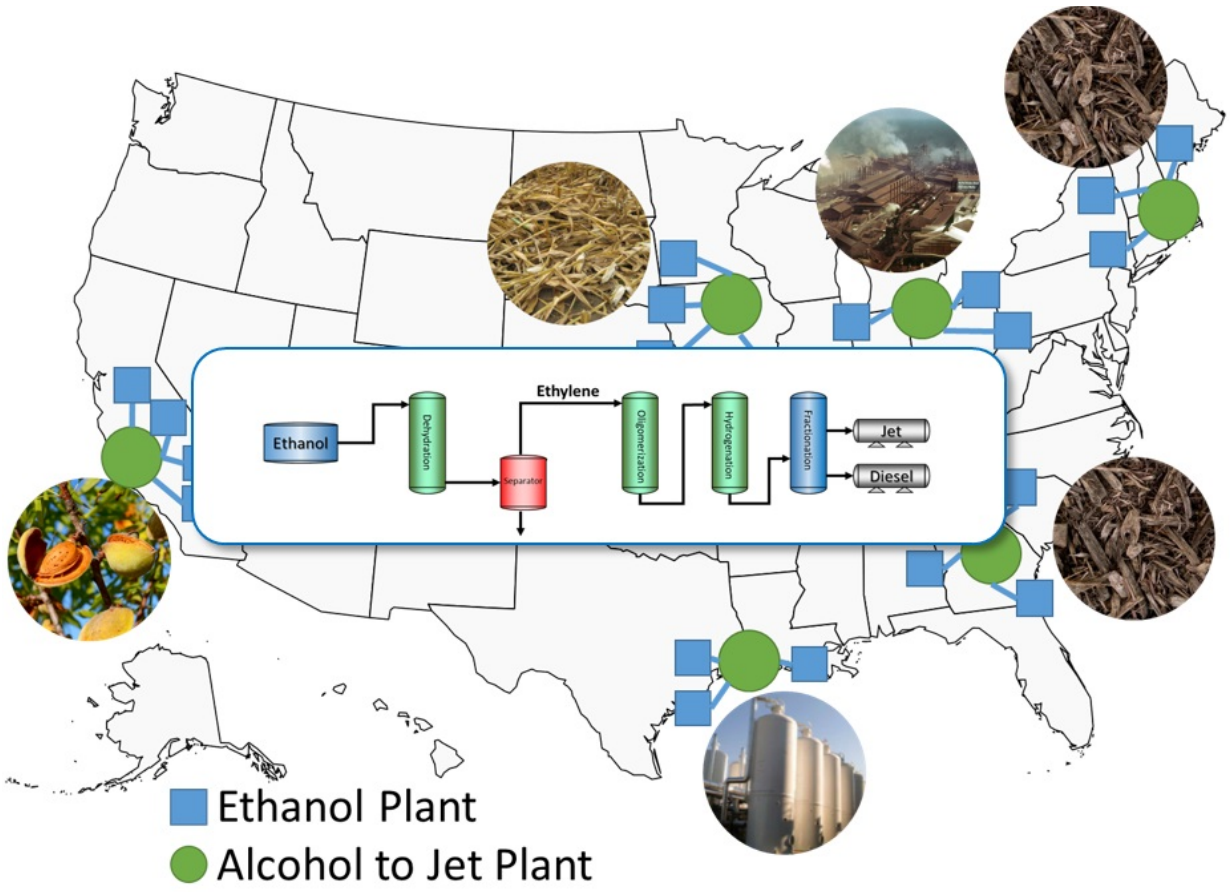


Photo courtesy of LanzaTech, Inc.

OVERALL IMPRESSIONS

- This is a worthwhile project with a high likelihood of success that will result in the further penetration of biofuels into the transportation sector.
- Many steps toward commercialization have been or are being approached as part of this project. One key element, besides financing, will be securing the appropriate ethanol feedstock to feed the plant, and it was not clear this is near or "on its way."

- This is a well-managed and technically sound project that has used industry best practices for the front-end loading to develop a project that can be financed from a technical perspective. The feedstock is based on the limited resource of cellulosic ethanol, which generates concern about the economic viability of the project.

- Most unit operations (ethanol to ethylene, fractionation, gas fermentation, etc.) for this process are already commercially proven, so a focus on the core oligomerization process is key here. Identifying a green source of hydrogen is going to be critical for any commercial scale.

- LanzaTech is developing a production facility to produce 10 million gallons per year of jet and diesel fuel. This project is aimed at planning and designing this facility. Significant progress was made in selecting a production site, obtaining environmental permits, and negotiating ethanol supply and product offtake agreements. Most technology risk was mitigated by having an operating plant in China, which started in May 2018.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We appreciate the positive feedback.

- LanzaTech is interacting with its own network of contacts with suppliers as well as with producers that are developing projects to produce qualifying ethanol.

- We appreciate the evaluation, and we certainly recognize that existing supplies of ethanol produced via enzymatic hydrolysis are limited. In 2018, 8.16 million gallons of cellulosic ethanol were available in the United States, 1.62 million of which were imported. That said, there are multiple indications that supplies of cellulosic ethanol are increasing: (1) multiple companies are commercializing corn kernel fiber ethanol technology, which can be integrated with existing corn ethanol facilities to produce cellulosic ethanol with a total U.S. potential of 450 million gallons; (2) Aemetis is building a commercial-scale gas fermentation facility to produce 12 million gallons of cellulosic ethanol per year from the gasification of residual biomass; (3) LanzaTech is working with other customers to develop additional cellulosic ethanol projects based on gasification and fermentation; and, finally, (4) LanzaTech is working with industry partners to develop regional supply chains of advanced (i.e., nonfood) ethanol from novel resources. The combination of these existing and potential sources will be enough to supply this project.

- The hydrogen requirements for ATJ pathways are significantly less than the requirement for other sustainable aviation fuel pathways. Although “green” hydrogen would further reduce the life-cycle GHG emissions of the final jet and diesel products, favorable emissions reductions have been calculated using merchant hydrogen or dedicated hydrogen production via steam methane reforming or electrolysis.

ADVANCED BIOFUELS AND BIOPRODUCTS WITH AMERICAN VALUE-ADDED PULPING

AVAPCO, LLC

PROJECT DESCRIPTION

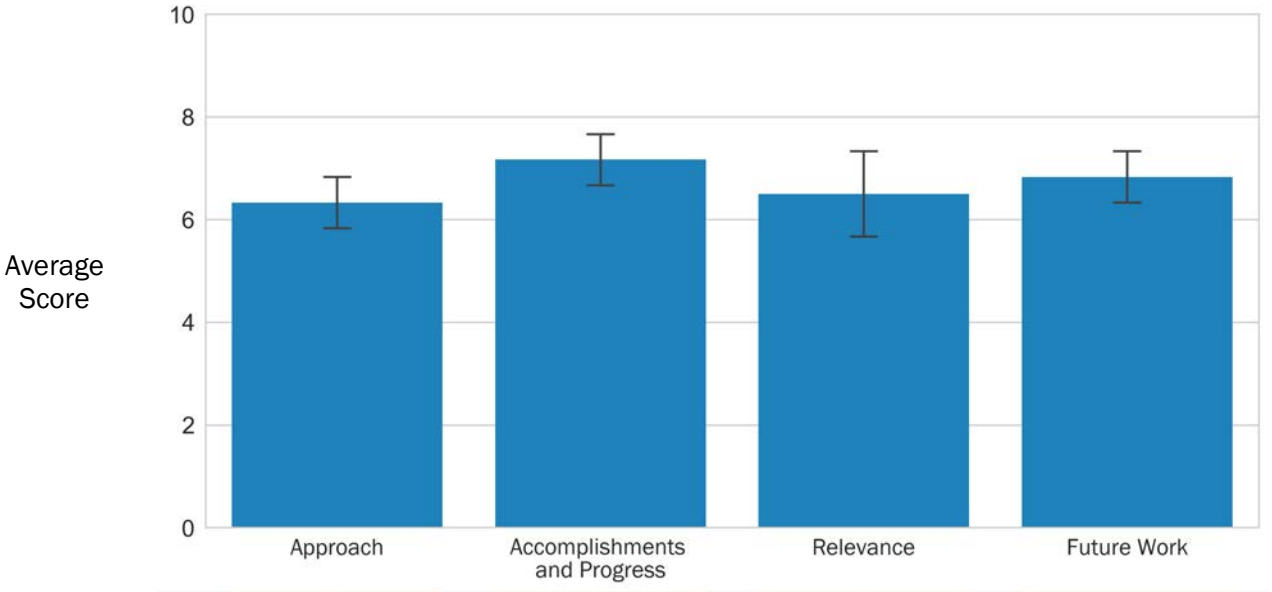
WBS:	3.4.2.6
CID:	EE0007967
Principal Investigator:	Dr. Theodora Retsina
Period of Performance:	1/15/2017–12/31/2019
Total DOE Funding:	$3,670,329
Project Status:	Ongoing

The project Advanced Biofuels and Bioproducts with American Value-Added Pulping (ABBA) involves upscaling the patented American Value-Added Pulping (AVAP) pretreatment technology from AVAPCO, coupled with innovative sugar fermentation to mixed alcohols, which are then converted to full replacement liquid hydrocarbon biofuels at the existing biorefinery site in Thomaston, Georgia. The targeted scale is 50 dry tons per day of woody biomass from neighboring sawmill residues and harvesting operations. The coproducts include revolutionary API BioPlus nanocellulose and biobased 1,4-butanediol (Bio-BDO) with project partner Genomatica. Both the nanocellulose and Bio-BDO production will use much of the existing pilot plant.

In the AVAP fractionation, the process starts with wood chips fed into a continuous digester. The chips are impregnated with sulfur dioxide-ethanol-water liquor and cooked for one hour at 150ºC. These conditions dissolve nearly all lignin and hemicellulose without creating unwanted side products. The chemicals are recovered via washing and stripping and recycled to the digester, resulting in a hemicellulose sugar stream and a high-purity cellulose stream. Part of the clean cellulose is directed to produce one ton per day of dried nanocellulose material. The rest of the cellulose is enzymatically saccharified at a low-enzyme dose to achieve 90% hydrolysis to C6 sugars. One ton per day of C6 sugars are directed to Bio-BDO fermentation and a

Weighted Project Score: 6.7

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



I One standard deviation of reviewers' scores

purification skid provided by Genomatica. Genomatica's direct fermentation to Bio-BDO is cost-advantaged to the petrochemical route.

The remaining 18 tons per day of cellulosic sugars and 10 tons of hemicellulosic sugars are fermented to produce a mixture of alcohols—namely, ethanol, propanol, and butanol. Remaining lignin and fermentation residuals are burned for process energy. In the hydrocarbon plant, these alcohols are converted to full-replacement liquid hydrocarbons using a catalytic synthesis process that produces petroleum distillate equivalents with overall LCA reduction of more than 60%. Alcohols are dehydrated over catalyst to produce alkenes using the technology from project partner Petron Scientech Inc. Using the technology from project partner Byogy, the resulting alkenes are then oligomerized to mixed olefins, which are then further molecularly adjusted to a variety of distilled biofuels, such as jet fuel, diesel, and gasoline. Jet fuel from the pilot plant has undergone advanced U.S. Air Force testing for JP-5 and JP-8 grades with the unique ability to vary aromatic content. Byogy was a finalist as one of four companies out of 90 under the Federal Aviation Administration's Continuous Lower Energy, Emissions, and Noise Program, in which rigorous engine testing was performed by Rolls Royce that demonstrated Byogy's fuel characteristics showing a premium full-replacement renewable aviation fuel. Byogy's technology is a direct, chemically and thermally efficient route to convert ethanol to jet fuel.

The ABBA process producing cellulosic liquid transportation biofuels with value-added products such as Bio-BDO and nanocellulose is expected to reach the goal of $3/GGE in commercial applications. The demonstration plant proposed herein is an essential step toward reaching this goal.

The ABBA process is innovative because of the unique integration of the process steps. The AVAP biorefinery can use any feedstock, especially abundant U.S. softwood. Because these sugars have high purity, conversion to ethanol, butanol, and propanol is done fast with high yields. The hydrocarbon plan is unique starting from alcohols.

Photo courtesy of AVAPCO, LLC

OVERALL IMPRESSIONS

- This project reflects the development of the biorefinery concept using high-value coproducts to reduce the overall cost of the production of a target biofuel.
- Overall, this project looks promising, and the coproduct clearly looks like a potential means to support the BETO $3/GGE MFSP. The reasoning for producing a biojet intermediate instead of sticking with cellulosic ethanol is not clear though, and the financial viability of the process is uncertain.
- Time needed for ASTM certification should not be underestimated and needs to be completed on the actual product that is produced in an integrated manner. A "raw jet equivalent" is not proof of a drop-in fuel until it meets certification.
- A sensitivity analysis should be done for the nanocellulose and other coproduct pricing because increased production could reduce the price.
- The project needs verification that the AVAPCO ethanol produced does not have bad actors that affect all the downstream processing.
- Loosening the ethylene production specification seems like it would be best considered when there is a plant that works, rather than beforehand.
- I am unsure how much of the facility is covered under the Front-End Loading Phase 3. Does this include feedstock processing and handling? Feedstock is changing form hardwood to softwood, but no information was given about why the change was made or the expected results with this process.
- This project is well organized and managed with clear goals. The inclusion of key process data performance against key performance indicators was very valuable and showed great progress. Multiple technology vendors combined with multiple changes in project management increases risk, but to date the project appears well managed.
- This is an IBR project to convert cellulosic biomass into ethanol through biochemical conversion and the conversion of ethanol into jet fuel via dehydration and oligomerization and nanocellulose as an additional product. The technical approach is sound and well established. The goal is to do project planning and engineering design of a biorefinery plant processing approximately 50 tons per day of biomass. The project has made good progress and has passed the DOE validation. It is now moving into Budget Period 2.
- The project is built on an excellent technology foundation but is also marred by being shoehorned inside the BETO requirements and the investigators' poor understanding of catalytic upgrading of ethanol and fuel fraction. The authors are misleading by mentioning the drop-in fuels or using terms such as "raw jet" that have no meaning in industry. In reality, they are producing a bioderived aliphatic middle-distillate stream that needs to be upgraded via hydrogenation to fuel specifications. That upgrade—which is technically very doable but economically burdensome—is ignored in all considerations. The conversion of ethanol to jet fuel is a particularly troublesome idea to begin with because one needs to lose considerable mass. In general, producing a highly reduced molecule from an oxygenated compound is likely to be economically unattractive. Further, losses in the oligomerization and the need to have highly refined ethanol make this even less attractive. The economics of this process are driven by nanocellulose, and under these conditions, ethanol is a coproduct that could be sold in the regular ethanol market. This process could bring to the market enough nanocellulose at a price that finally drives the adoption, and in that it is meritorious, but this is outside the scope of BETO.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- Producing fuel-grade cellulosic ethanol rather than U.S. pharmacopeia-grade ethanol for biojet fuel is a scenario that can be evaluated in the Budget Period 2 economic analysis.
- The certification of the biojet fuel is a Budget Period 2 activity as noted in the presentation. The production of the raw jet was a Budget Period 1 activity (Milestone 1.5) and should not be confused with the certification of the drop-in biojet fuel final product (Milestone 10.2).
- The AVAPCO ethanol produced from hardwood sources has not contained bad actors that could not be removed in the ethanol purification process. In Budget Period 2, AVAPCO ethanol will be produced from softwood to determine if there are any difficult-to-separate bad actors associated with that feedstock. The need for ethanol purification prior to dehydration was identified at the outset of the project, and it has been incorporated into the process. The purification operation was executed in the validation work of Budget Period 1, and it will be part of the final design.
- The feedstock for the project will be selected based on an economic analysis of the cost of both producing and purifying the ethanol from these two feedstocks.
- The Front-End Loading Phase 3 will cover the entire facility, including feedstock handling.
- The certification of the biojet fuel is a Budget Period 2 activity as noted in the presentation. The production of the raw jet was a Budget Period 1 activity (Milestone 1.5) and should not be confused with the certification of the drop-in biojet fuel final product (Milestone 10.2).
- Hydrogenation is part of the outlined process. It will be demonstrated in Budget Period 2 during the biojet fuel final product production and included in the economic analysis.
- Nanocellulose is indeed a very good coproduct, and it is a major driver in the overall process economics. A scenario of selling ethanol in the fuel ethanol market can be included in the economic analysis of Budget Period 2.

RIALTO ADVANCED PYROLYSIS INTEGRATED BIOREFINERY

Rialto Bioenergy Facility, LLC

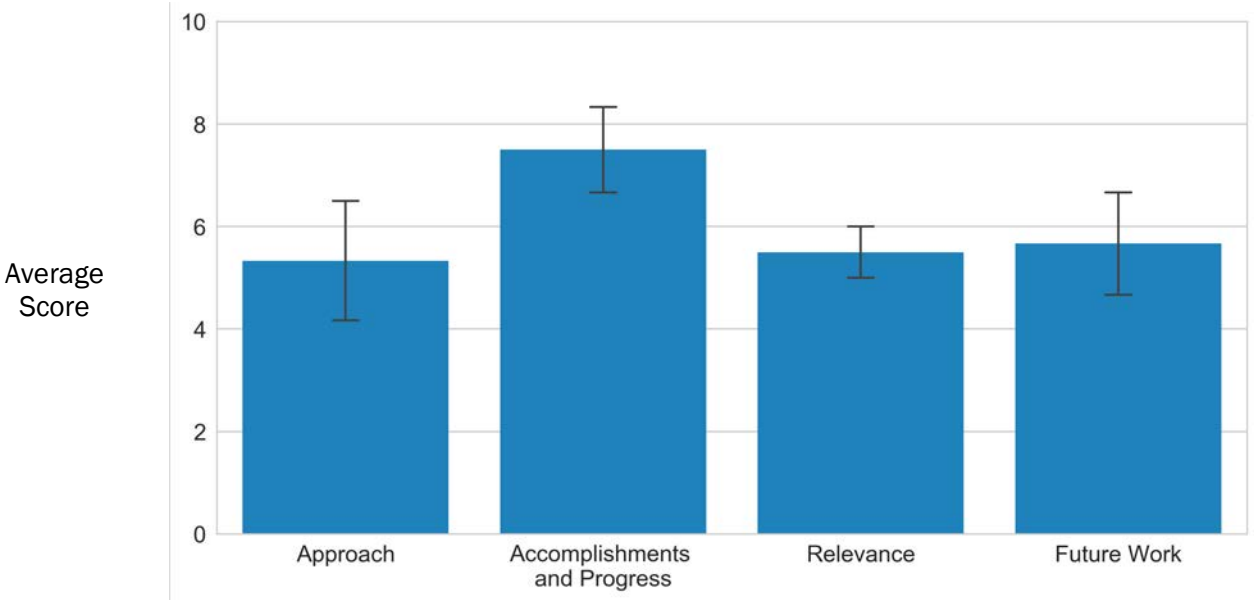
PROJECT DESCRIPTION

WBS:	3.4.2.7
CID:	EE0007968
Principal Investigator:	Dr. Yaniv Scherson
Period of Performance:	1/15/2017–3/31/2019
Total DOE Funding:	$1,999,096
Project Status:	Ongoing

Rialto Bioenergy Facility, LLC, a wholly owned subsidiary of Anaergia, proposes leveraging more than $150 million in prior investments at its project site to design, build, and operate an advanced, precommercial IBR system that will cost-effectively convert post-AD biosolids from regional wastewater treatment facilities and post-AD food waste residuals provided by Anaheim Energy, LLC into 6.4 MW of low-carbon, renewable biopower. The project will rely on self-generated waste heat to drive an advanced, low-temperature thermal conditioning process that will convert post-AD biosolids and food waste into a digestible substrate for enhanced biogas production. Subsequent AD will produce biogas for combined heat and biopower production. When fully operational, the proposed facility will consume 140 tons per day of post-AD food waste, which is currently landfilled, and 160 tons per day of post-AD municipal wastewater biosolids, which is currently land applied or landfilled. The project will use Anaergia's precommercial advanced thermal conditioning processes while demonstrating a novel option for the management of biosolids and residual digester solids. Thus, the project will address a critical need for biosolid mass reduction and ultimate reuse through the production of quality soil amendments (Class A biosolids or better) while producing renewable bioenergy. Through offsetting fossil-based power generation, the project will strongly reduce reliance on fossil fuels while reducing GHG emissions.

Weighted Project Score: 6.3

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



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OVERALL IMPRESSIONS

- This is a phoenix rising from the ashes of the EnerTech SlurryCarb project. This is an interesting combination of biogas production and pyrolysis for biochar production. The inclusion of the pyrolyzer is a significant advancement in the development of an integrated approach to biosolids processing as represented in this process flow diagram. It feels like there should be an available funding mechanism at the federal level for the integration of TRL 9 unit operations for the sake of demonstrating an optimized system (technologically and/or economically).

- This project is essentially a fully functional AD plant with a pyrolysis back end; given that the entire front end of the plant is a mature, well-proven technology, if financial viability is not proven to be achievable without government assistance then the project has a very slim chance of *ever* achieving commercial success. An evaluation of the issues and dissemination of lessons learned would go a long way toward helping similar future projects.

- The novel nature of the technology was not clear. The removal of pyrolysis from the project leaves a facility that uses proven technologies.

- This project was aimed at designing a facility to process food and other wastes and included a pyrolysis system for biosolids. Basic engineering design was completed, and various permits were obtained. BETO decided not to fund the pyrolysis, so the project went ahead with getting commercial financing without the pyrolyzer. The project is almost complete.

- From a commercial prospective, this is an interesting project, but when limited to the AD component, it is one that can be carried out without DOE support because it is a completely traditional mixed-waste AD project. DOE supports the demonstration and implementation of the pyrolysis of the digestate and subsequent use of the bio-oils inside the digester as an additional carbon source. The authors have demonstrated that bio-oils can be used in digesters—despite their intrinsic toxicity—without ill effect. Although interesting, this is not a completely surprising result because dilution always has a mitigating effect on toxicity. The relevant but unproven statement is about the increase in biogas production and the increase in the value of the residual biochar compared to the original digestate. The authors do not provide any indication to support this fact and whether those benefits are enough to pay the addition of the pyrolytic step. The information is also scant on the proposed implementation of this step.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

The recipients choose not to respond to the reviewers' overall impressions of their project.

LAUNCH OF AN INTEGRATED BIOREFINERY WITH ECO-SUSTAINABLE AND RENEWABLE TECHNOLOGIES IN Y2009 (LIBERTY)

POET Project LIBERTY, LLC

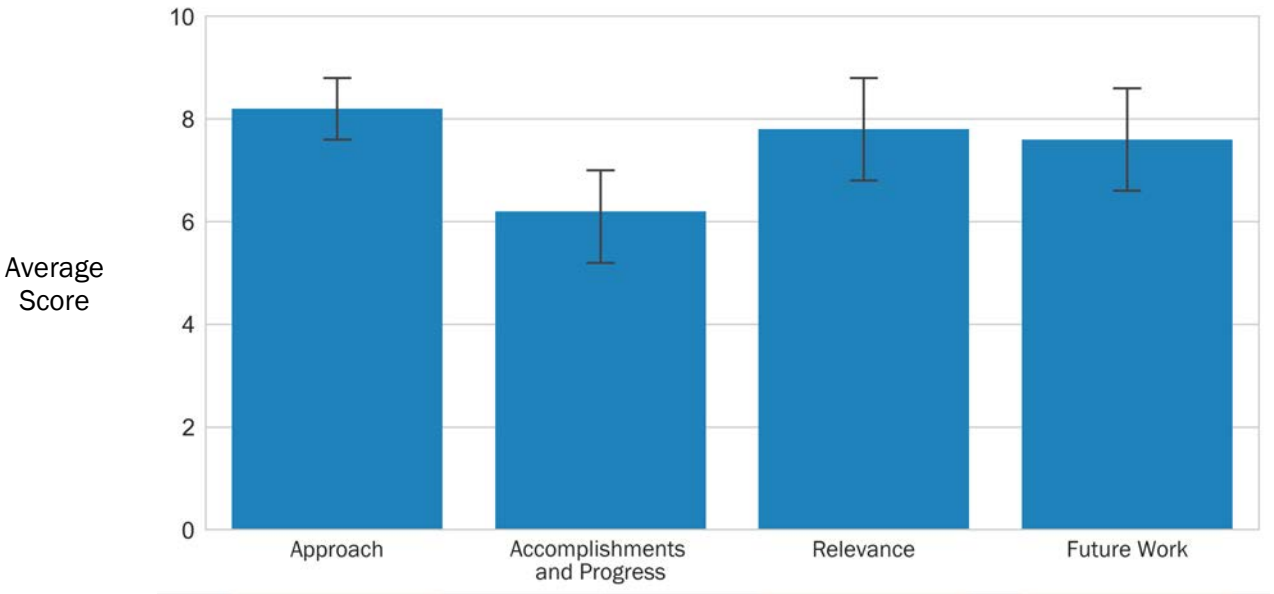
PROJECT DESCRIPTION

WBS:	3.4.3.3
CID:	GO18121
Principal Investigator:	Mr. Mike Dishman
Period of Performance:	10/1/2008–12/31/2019
Total DOE Funding:	$87,844,240
Project Status:	Ongoing

Project LIBERTY is dedicated to the development and operation of a commercial-scale cellulosic ethanol biorefinery. The plant is co-located with POET Biorefining-Emmetsburg, an existing corn-based ethanol biorefinery in Emmetsburg, Iowa. The corn-based biorefinery currently has a nameplate capacity of 50 million gallons per year and is one of 27 POET biorefineries. At full capacity, Project LIBERTY will produce an additional 25 million gallons per year of ethanol from a feedstock of lignocellulosic material (i.e., corncobs and high-cut material from the corn plant). Corn farmers from the surrounding area supply the feedstock to the biorefinery. The Project LIBERTY business model will enable the rapid deployment of the cellulosic ethanol process across an expansive corn ethanol industry. The rollout of LIBERTY technologies will help the nation rapidly advance toward its biofuels mandates as well as reduce its dependence on foreign oil.

Weighted Project Score: 7.5

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



I One standard deviation of reviewers' scores

Photo courtesy of POET Project LIBERTY, LLC

OVERALL IMPRESSIONS

- This project has accomplished a lot in the 11 years it has been underway and deserves significant praise for its achievements since startup. The lack of transparency and clear performance metrics limit the evaluation of success and commercial viability of the technology.
- Project LIBERTY is a showpiece of what DOE/BETO can do with industry participation.
- POET has made significant strides since the last BETO review in terms of uptime and production. Although this meets the BETO requirements from the year granted, it is still disappointing that the knowledge gained might only help POET with the advancement of cellulosic ethanol. POET has done the hard work and likely spent countless extra dollars on this project than was originally planned. What is most impressive is their commitment to this process/project. It is that kind of commitment that brings the technology forward.
- This is an impressive project that is well aligned with BETO program goals. POET-DSM has shown commitment to work through obstacles that have been identified. The project execution appears well organized and managed. Limited technical information was provided supporting reaching the technical goals, and this would have been valuable.
- POET Project LIBERTY is a flagship project to build a plant producing 20 million gallons per year of cellulosic ethanol using 700 metric tons per day of corn stover via a biochemical conversion route. This project started in 2007 and has resumed commercial operation—albeit it still does not meet the availability (uptime) and product yield targets. Continuous improvements are being made to reach the design targets.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

The recipients choose not to respond to the reviewers' overall impressions of their project.

AN AFFORDABLE ADVANCED BIOMASS COOKSTOVE WITH THIN-FILM THERMOELECTRIC GENERATOR

Lawrence Berkeley National Laboratory

PROJECT DESCRIPTION

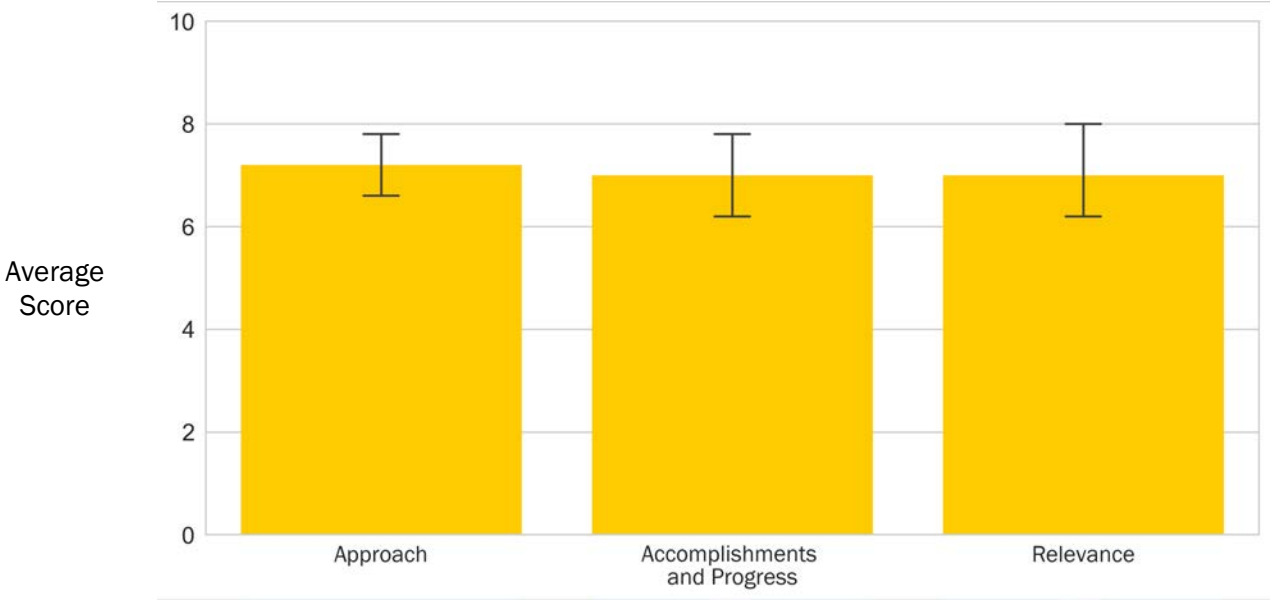
This project aimed at and achieved a technological breakthrough in major emission reductions and performance improvements in natural-draft air-assisted biomass cookstoves. These breakthroughs aligned with DOE goals of helping to reduce emissions from biomass cooking by 90% and fuel usage by 50%. Additionally, knowledge gained during the design, development, and testing was transferred to the cookstove community, by means of conferences and training, to spur innovation, a key component of BETO's mandate. Additional effort was invested to support the standardization of laboratory testing protocols via participation in the International Organization for Standardization and in creating a library of free web-based video tutorials.

WBS:	5.2.0.1
CID:	NL0026667
Principal Investigator:	Dr. Vi Rapp
Period of Performance:	10/1/2015–9/30/2019
Total DOE Funding:	$3,000,000
DOE Funding FY16:	$0
DOE Funding FY17:	$0
DOE Funding FY18:	$0
DOE Funding FY19:	$0
Project Status:	Sunsetting

Our technical approach for developing the Berkeley Advanced Stove was driven by (1) a design that is economically and aesthetically attractive, safe, and culturally appropriate; (2) an assessment of the current status of advanced technology for thermoelectric generators (TEGs) to produce electrical power with waste heat from the cookstove to drive a fan; and (3) innovative application of advanced combustion concepts of

Weighted Project Score: 7.0

Weighting for Sunsetting Projects: Approach - 25%; Accomplishments and Progress - 50%; Relevance - 25%



I One standard deviation of reviewers' scores

turbulent and swirl diffusion flames to reduce emissions—all while meeting the constraints of user-centered design within the limits of economically feasible electrical power for the fan (less than 10 W).

We aimed to apply our improvements to the Berkeley-Darfur Stove; which is already a success story of DOE's Technology Commercialization Fund applied to LBNL research. The Berkley-Darfur Stove offers an ideal scaffold for applying these breakthrough technologies because every aspect of its current design is fully understood, and its performance has been thoroughly characterized; therefore, breakthrough technologies or design changes are easily identified. This project has paved the way for novel designs, as well as subsequent manufacture and large-scale sales, of ultraclean self-powered biomass stoves by addressing the key cost and user-acceptance challenges faced by current unsuccessful fan stoves.

Photo courtesy of Lawrence Berkeley National Laboratory

OVERALL IMPRESSIONS

- This project has shown significant progress and offers value not only to the three billion people who could use the cookstove but also to other organizations doing similar work. The laboratory and test standards developed should be shared to further the overall SOT.

- This project appears to have been executed in a manner that reflects scientific and technical best practices and is well run from a project management perspective. Although the project is clearly a need, it will only reduce emissions and improve health to the level adopted.

- This is a project of questionable value to BETO, given indications that the produced intellectual property is worse in performance than the identified technology baseline, the three-stone fire (TSF), but certainly other funding programs should be interested.

- This is an interesting technology, and the loss of the TEG vendor limited its impact. The team appeared to do their best to meet the intent of the initial goals. End results were unclear and would have benefitted from the team focusing more on process technology and how to overcome them.

- This LBNL project started in 2013 and went through several scope changes. It is essentially finished and now wrapping up later in 2019. The goal was to design an improved cookstove that had 90% reduction in particulate matter. Several designs were evaluated, and significant reduction in the particulate matter emissions was achieved. The knowledge gained was widely disseminated. A state-of-the-art test facility was built at LBNL to test cookstoves.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

- Thank you for the feedback, and we agree that the laboratory and test standards developed should be shared. We have initiated this process through peer-reviewed journal publications, reports, and training videos, all of which are available on the website https://cookstoves.lbl.gov/.

- We agree with the reviewer that improvements in health will be realized only if the stove is adopted.

- We respectfully disagree with the reviewer's comment. This project added great value to BETO by identifying scientific underpinnings to reduce harmful emissions from biomass cookstoves and could inform design improvements to wood-heating stoves used in the United States. Additionally, the reviewer is factually incorrect because the produced final product presented demonstrated a 90% *reduction* in particle emissions and nearly *double* the efficiency (approximately 40% thermal efficiency) compared to the baseline TSF, as noted by a comment from another reviewer.

- We agree that the loss of the TEG vendor forced us to pivot from our original plans. The pivot, undertaken in consultation with a DOE funding manager, was successful. We respectfully disagree that "end results were unclear." In fact, the end results have led to major breakthroughs and insights in biomass combustion and ways to reduce emissions from such combustion, which were published in peer-reviewed top journals in the field.

- Thank you. We agree with this accurate and concise summary.

CONVERTING MSW INTO LOW-COST, RENEWABLE JET FUEL

Fulcrum BioEnergy

PROJECT DESCRIPTION

The project is currently constructing the Sierra Biorefinery, where a prepared municipal solid waste (MSW) feedstock produced at the adjacent Sierra Feedstock Processing Facility (FPF) will be converted into a low-carbon syncrude. The syncrude product will then be transported to a Marathon Petroleum refinery to be further processed into transportation fuel. The biorefinery, currently under construction, is expected to begin operation in 2020.

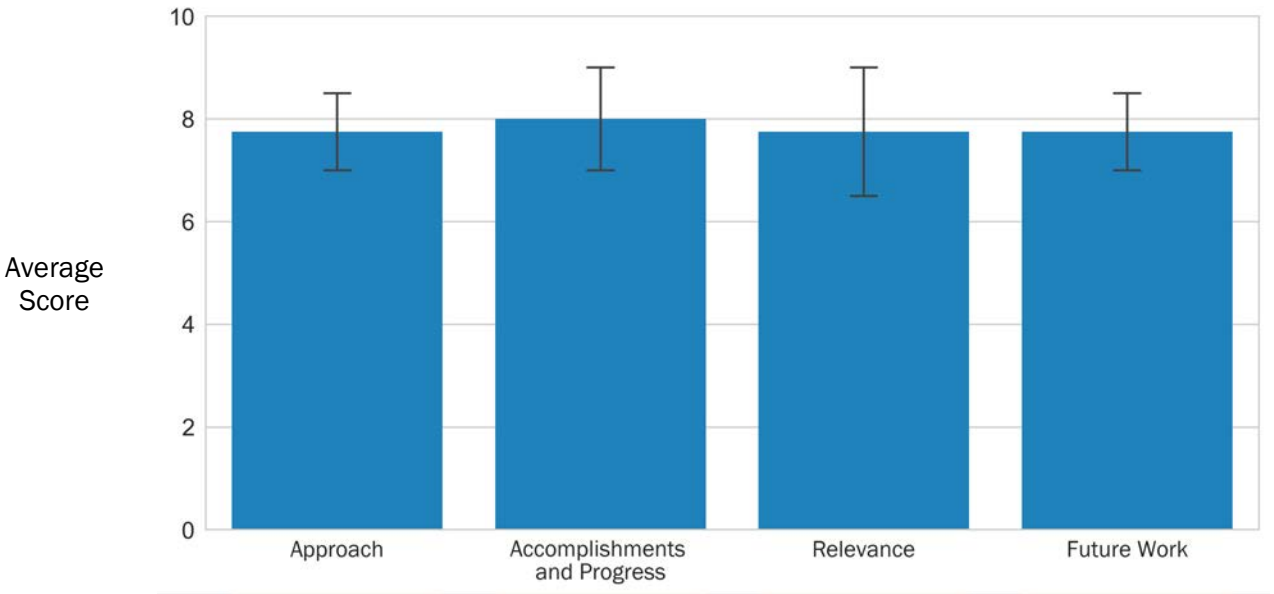
WBS:	DPA.1
CID:	EE000DPA1
Principal Investigator:	Mr. Pete Tiverios
Period of Performance:	5/1/2013–6/30/2021
Total DOE Funding:	$76,600,000
Project Status:	Ongoing

OVERALL IMPRESSIONS

- It is nice to see commercial-scale projects coming out of the extensive portfolio that BETO has been working on for many years. This project has a lot of potential, but it also made clear that there are issues to be resolved without discussing the plan or path to resolve these issues. The focus going forward should be a clear risk assessment and path to commercial success that is realistic and forward looking.
- This project, long overdue, makes use of a neglected feedstock and is worthy of BETO support.
- This is a well-managed and executed project with key approaches to mitigate risk. The design, based on 120 performance tests combined with bringing the MSW facility online in advance, improves likelihood of the project's success.

Weighted Project Score: 8.0

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



- This project is a demonstration project to convert 500 tons per day of MSW into Fischer-Tropsch products using a TRI gasifier and a commercial Fischer-Tropsch synthesis technology. This project was started in 2013 and is expected to produce Fischer-Tropsch fuels in 2020. This involves a major scale-up of the TRI gasifier, from the pilot scale to a commercial scale, along with all associated feed systems and downstream ash and syngas handling equipment. Successful demonstration of this project will pave the way for processing MSW into renewable transportation fuels.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

The recipients choose not to respond to the reviewers' overall impressions of their project.

WOODY BIOMASS BIOREFINERY CAPABILITY DEVELOPMENT

Red Rock Biofuels

PROJECT DESCRIPTION

WBS:	DPA.2
CID:	EE000DPA2
Principal Investigator:	Mr. Terry Kulesa
Period of Performance:	5/1/2013–6/30/2021
Total DOE Funding:	$76,600,000
Project Status:	Ongoing

RRB was founded in 2011 and is positioned to be the leading producer of drop-in, renewable, low-carbon jet and diesel fuels. With broad international agreement in the aviation industry for carbon-free growth beyond 2020 under CORSIA, airlines are actively seeking low-carbon jet fuel to reduce their GHG emissions. The civil aviation industry alone will require approximately 1.5 billion gallons per year of new renewable jet fuel production capacity to meet this commitment. The U.S. military has also emerged as a major driver in the renewable jet and diesel fuel markets. To meet these high demands for low-carbon renewable fuels, RRB will build a global portfolio of biorefineries to convert waste woody biomass into renewable jet and diesel fuels.

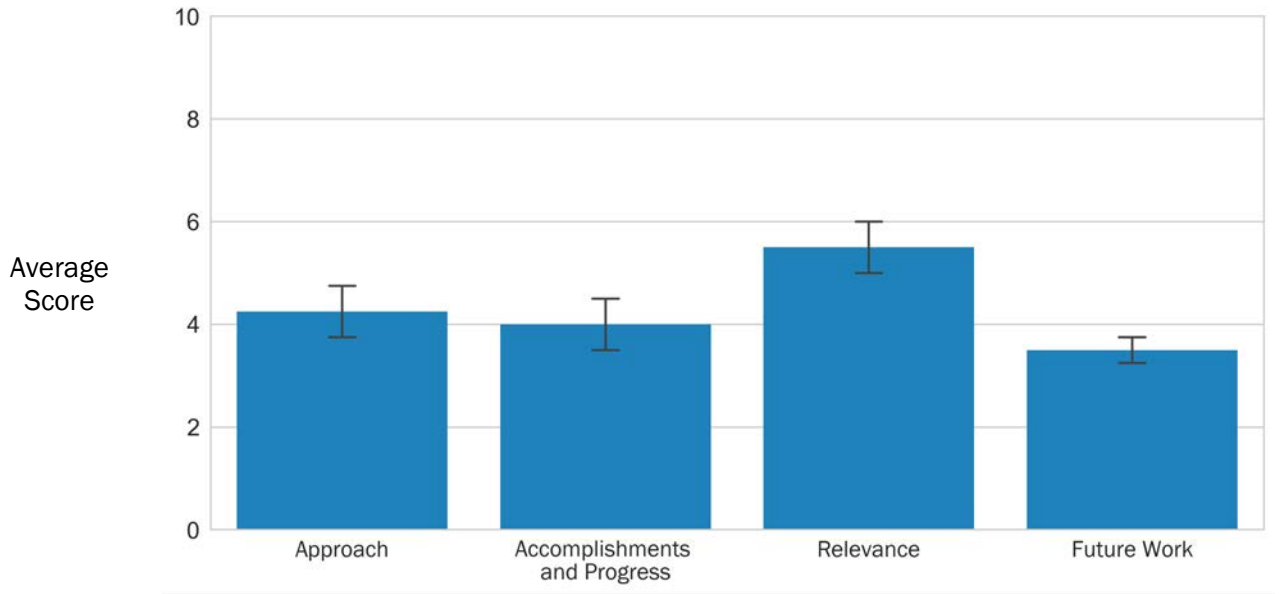
OVERALL IMPRESSIONS

- This project has great potential, but the presentation gave much less information than expected for a project of this size. Commercial application of these technologies clearly requires the input of government funding, but discussion of the challenges and risks that have prevented industry application and self-financing were neither mentioned nor discussed. Success with this technology is not guaranteed, and the funding recipient needs to focus future efforts on risk assessment and a risk management plan.

- This is probably a project worthy of BETO support, but it is not apparent from the supplied presentation, which was more suitable for marketing and fundraising.

Weighted Project Score: 4.3

Weighting for Ongoing Projects: Approach - 25%; Accomplishments and Progress - 25%; Relevance - 25%; Future Work - 25%



- There is no real way to judge on the necessary BETO criteria.
- The project did not follow the required template and provided little technical information to be able to evaluate it. The majority of the presentation was on unrelated wildfire topics. The funding of the project would indicate that major risk items and economics are covered, but without any information provided, it is not possible for a reviewer to provide an informed opinion with any credibility. Verbal discussions indicated that demonstration testing did not meet industry best practices.
- RRB is demonstrating the scale-up of a thermochemical conversion technology to produce 15 million gallons per year of Fischer-Tropsch products in Lakeview, Oregon, using forest residue. The plant construction started in July 2018 and is expected to be completed by the end of 2019. This project will demonstrate the first-time scale-up of TCG's biomass gasifier technology.

RECIPIENT RESPONSE TO REVIEWER COMMENTS

The recipients choose not to respond to the reviewers' overall impressions of their project.