# DATA, MODELING, AND ANALYSIS PROGRAM

TECHNOLOGY AREA

# CONTENTS

# INTRODUCTION

The Data, Modeling, and Analysis (DMA) Technology Area is one of 12 technology areas that were reviewed during the 2021 Bioenergy Technologies Office (BETO) Project Peer Review, which took place virtually March 8–12, March 15–16, and March 22–26, 2021. A total of 23 presentations were reviewed in the DMA session by six external experts from academia, nonprofits, and other government agencies. For information about the structure, strategy, and implementation of the technology area and its relation to BETO's overall mission, please refer the corresponding Program and Technology Area Overview presentation slide decks, which can be accessed here: https://www.energy.gov/eere/bioenergy/2021-project-peer-review-data-modeling-and-analysis.

This review addressed a total U.S. Department of Energy (DOE) investment value of $32,205,000, which represents approximately 4.8% of the BETO portfolio reviewed during the 2021 Peer Review. During the Project Peer Review meeting, the presenter for each project was given 15 to 45 minutes to deliver a presentation and respond to questions from the Review Panel.

Projects were evaluated and scored for their project management, approach, impact, and progress and outcomes. This section of the report contains the Review Panel Summary Report, the Technology Area Programmatic Response, and the full results of the Project Review, including scoring information for each project, comments from each reviewer, and the response provided by the project team.

BETO designated Alicia Lindauer as the DMA Technology Area Review Lead, with contractor support from Camryn Sorg (Boston Government Services, LLC). In this capacity, Alicia Lindauer was responsible for all aspects of review planning and implementation.

# DATA, MODELING, AND ANALYSIS REVIEW PANEL

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# DATA, MODELING, AND ANALYSIS REVIEW PANEL SUMMARY REPORT

*Prepared by the Data, Modeling, and Analysis Review Panel*

## INTRODUCTION

The BETO DMA Technology Area offers a strategic and valuable portfolio to DOE, to the industries that comprise the bioeconomy, and to the broader national and global sustainability agenda. The Peer Review of this program took place during 4 days, March 9–12, 2021, with 24 principal investigators (PIs) presenting their research to a six-person Review Panel. This report synthesizes the panel's impressions of the program as a whole—especially its strategic management in pursuit of program goals—and offers targeted recommendations for future direction.

The 2021 Peer Review of the DMA Program (referred to here as the Analysis Program) presented an impressive portfolio that is a making critical contributions toward its stated goal to *"develop science-based strategies to understand and enhance the environmental, economic, and social benefits of advanced bioenergy and bioproducts relative to conventional energy systems."* Throughout the Peer Review process, PIs and program staff have demonstrated how this portfolio builds the knowledge base necessary to advance a sustainable bioeconomy, exhibiting a mix of projects ranging from broad bioeconomy models to more granular analytical and field-based projects focused on a specific technology or indicator.

The DMA Program portfolio continues to be very diverse and strong, and it ties in well to strategic BETO goals. Many of the projects are on the leading edge of work in the field, with some, such as the Biofuels Information Center and the Biofuels National Strategic Benefits Analysis, offering key resources for the U.S. bioeconomy as a whole; others, such as the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model, provide critical methodological rigor for policy application at local to global scales. The program is strategic in responding to changing priorities/needs in the bioeconomy, including an expanded focus on ecosystem services, marine and aviation fuels, carbon capture, and biomaterials, as evidenced by projects such as the Bioeconomy Scenario Analysis project and the study of Multi-Input, Multi-Output Biorefineries.

The Review Panel was very impressed with both the individual projects and with the program as a whole. We thank the PIs for their creative, rigorous, and innovative contributions to a sustainable bioeconomy. We also want to commend the program managers for their strategic and responsive approach to managing across the portfolio.

## STRATEGY

The Analysis Program portfolio displays a coherent and well-considered strategy that is doing tremendous work to advance the state of modeling, knowledge, and sustainability of the bioenergy industry. This strategy is structured around providing tools and analysis to support strategic investments in other BETO technology programs while also ensuring that existing and emerging bioeconomy pathways deliver on sustainability goals, particularly through the provision of ecosystem services.

The panel commends the Analysis Program for its clear, strategic focus on emerging technologies in the bioeconomy space. In particular, programmatic investments in pathways targeted at marine and aviation fuels, waste-to-energy (WTE) systems, woody residues from forest restoration, and nonfuel biomaterials indicated a sophisticated understanding of the shifting bioeconomy landscape. We note that this could be augmented with

additional focus on emerging WTE pathways, such as uses and markets for woody residues, as well as support for bioenergy with carbon capture and storage.

A number of the projects in the technology area include engagement with industry stakeholders involved in the bioeconomy. The Review Panel recommends further effort to engage with other types of stakeholders—particularly nongovernmental organizations (NGOs) and policymakers—and to do so in a more coherent fashion to elicit strategic input at the programmatic rather than the project level. One approach might be to support social science research using interview or survey methods to rigorously collect strategic insights into emerging challenges in the bioeconomy from a range of stakeholder groups. This could aid in answering questions related to barriers to the uptake of new technologies and ideas, whether among farmers, industry, or policymakers.

Program managers could also consider convening a stakeholder advisory panel to inform program and project strategy. This could aid not only in informing the program's work but also in elevating its visibility and impact. Many of the projects and tools in the program's portfolio have clear policy applications, and in some cases, they are being applied. But in others, there seems to be a gap between research and adoption. This is not an indictment of the PIs, their work, or the program managers because this is a very common challenge, but organized stakeholder engagement at the programmatic level could aid in bridging this gap. Projects such as the Biofuels National Strategic Benefits Analysis are very policy relevant, and it is important that the program's findings and tools make their way into the hands of, for example, analysts at the Congressional Research Service. Application in these contexts would not only make good use of good work but would also reinforce for decision makers the value of this portfolio.

Two facets of sustainability—environmental and economic—are very well represented in the program research portfolio; however, the Review Panel agreed that the program would benefit from a renewed focus on social sustainability, including equity and environmental justice. The Peer Review presentations suggest that the program is already taking some of these issues into consideration; the justice, equity, diversity, and inclusion (JEDI) tool is a good start to quantify the economic opportunities from bioenergy, and some projects have assessed the air pollution impacts of bioenergy or the health impacts of biomaterials. To better assess these impacts, it may be necessary to take a more intentional, centralized approach to map out and model the key socioeconomic, environmental, and health trade-offs of expanding the bioeconomy. Further, this approach could identify which groups would bear the burdens or benefit from the transition.

We do not suggest making this a general project criterion because this would divert funds from each team's core competencies while leading them to attempt analyses without the requisite coordination or expertise. Energy justice is a field unto itself, and BETO would do well to hire, fund, and elevate its experts rather than append an environmental justice lens to existing efforts. This is an area of growing attention in energy systems and in society writ large, and the Analysis Program is well positioned to foster thought leaders in addressing it for the bioeconomy. In addition, equity and energy justice should not be relegated only to research but woven into the fabric of the research teams themselves and the program as a whole. BETO and the Analysis Program should provide support and training to ensure that research teams employ inclusive practices in their collaborations and operations and that stakeholder engagement processes are engaging diverse participants.

## STRATEGY IMPLEMENTATION AND PROGRESS

The projects in the DMA Program are closely tied to and aligned with the program's strategic direction. The majority of the projects in the program are exceptionally well integrated and supportive of each other and of the program's overarching mission. Numerous projects have demonstrated that they have developed tools that

are in wide use by policymakers, industry, and academia. This suggests that the program area is on the leading edge of work in the field and is providing valuable tools for decision making.

One area in which the program seems to be focusing and making good progress is in coordination across its portfolio. The Sustainable Land Management Working Group seems to be an example of this, and it is an excellent initiative. It is clear that program management has worked to encourage sharing data sets, practices, and mutually reinforcing rather than duplicative efforts. Many of the studies in the portfolio depend on this coordination across research teams. Projects such as the National Strategic Benefits Analysis and others depend on many research teams feeding data into a single analysis. This leverages existing work and is a useful approach, but it should be carried out in a limited and organized fashion to avoid "engagement fatigue" across research teams.

One area in which coordination is particularly important, if also particularly difficult, is the integration of modeling efforts with one another and with field pursuits. Because the Analysis Program supports such a modeling-intensive portfolio, it is critical to ensure that where possible, the models are aligned with one another and are working from a consistent set of assumptions. Moreover, in some cases, it can be difficult to separate out the new analytical work from the use of existing models and resources. It would be helpful in the future to more clearly delineate the unique contents of a given project from the existing resources within the portfolio. Given the amount of model scope overlap, explicitly addressing this through deliberate model intercomparison and meta-analysis can turn a potential liability into a strength. We are encouraged by the strides made in cross-portfolio coordination since the last Peer Review, and we suggest that these efforts be further strengthened.

While working to harmonize across the different models in the portfolio, we also recommend that the Analysis Program continue to pursue strategic field studies to better parameterize its models. Models require empirical validation and parameterization, while field studies require models for generalization and scale-up. In this way, these types of research can be mutually supportive if structured intentionally to leverage one another. Designing these field studies offers another opportunity to encourage collaboration across modeling teams because research questions and study sites could be designed explicitly to address key uncertainties and sensitivities identified by the Analysis Program's model portfolio.

It was clear to the Review Panel that projects awarded via open funding opportunity announcements (FOAs) brought important perspectives, novel thinking, and innovative approaches to bear on BETO goals, and the panel encourages program staff to continue seeking to leverage the significant expertise outside of the national labs; however, outside projects did not appear to be as well integrated with other BETO efforts as those funded as part of the program's annual operating plan. It is also important that the competitively funded researchers be able to place their work in the context of the ongoing BETO portfolio to leverage and add value to existing work as well as ensure that the products of each project will contribute to ongoing efforts across the BETO portfolio.

The Analysis Program portfolio supports an impressive diversity of topics across the bioenergy sector, with projects that engage varied stakeholder groups, from farmers and landowners to industry. The funded projects indeed represent the leading edge of research in the field, and progress to advance the state of the art (SOA) through innovative research areas was evident even since the 2019 Peer Review. Overall, the Analysis Program is making good progress toward the goals stated in its Multi-Year Program Plan. In particular, the focus of several projects on quantifying ecosystem services provided by integrated biomass cropping systems has made significant progress toward the 2030 goal of "verify[ing] at least two biomass production systems at

field scale that provide ecosystem services which, when valorized, equate to at least a 10% reduction in biofuel MFSP [minimum fuel selling price]."

## RECOMMENDATIONS

The Review Panel has conferred and has arrived at the following key recommendations to further strengthen the Analysis Program's efforts in support of a sustainable bioeconomy.

### 1. Harmonize across models within the BETO portfolio.

Because the Analysis Program supports such a modeling-intensive portfolio, it is critical to ensure that where possible, the models are aligned with one another and are working from a consistent set of assumptions. Given the amount of model scope overlap, explicitly addressing this through deliberate model intercomparison and meta-analysis can turn a potential liability into a strength. We are encouraged by the strides made in cross-portfolio coordination since the last Peer Review and suggest that these efforts be further strengthened.

Model overlap is not necessarily a problem because it can lead to more rigorous characterization; however, the program should leverage its model portfolio by supporting meta-analysis efforts to generate harmonized findings and to quantify uncertainties. In cases where it is feasible, it would be beneficial for the modeling teams to develop a systematic approach to compare their results and assumptions. This would help to ensure narrative consistency of BETO's messaging as well as enhancing the rigor of its models.

### 2. Continue/expand field research to ground-truth models and analyses.

While working to harmonize across the different models in the portfolio, we also recommend that the Analysis Program continue to pursue strategic field studies to better parameterize its models. Some of the strongest work in the Analysis Program portfolio utilizes fieldwork to provide ground-truthing and empirical parameterization for models. On the other hand, field studies alone are of limited utility without models to enable generalization and scale of impact. In this way, these types of research can be mutually supportive if structured intentionally to leverage one another. Designing these field studies offers another opportunity to encourage collaboration across modeling teams because research questions and study sites could be designed explicitly to address key uncertainties and sensitivities identified by the Analysis Program's model portfolio. In this way, regular and coordinated ground-truthing could strengthen the program's model portfolio overall.

While we encourage further field study in support of the Analysis Program's model portfolio, we also recognize that BETO's scope to fund field studies is limited and variable, especially in light of potential for overlap with various research efforts supported by the U.S. Department of Agriculture (USDA). This could be an area for interagency coordination to ensure that research programs are mutually supportive in key priority areas, such as climate change, soil and water resource conservation, and ecosystem service provision.

### 3. Increase support for social science research, including a focus on equity and justice.

Many of the scientific studies in the Analysis Program portfolio have clear policy applications; however, there seems to be a recurring gap between research and adoption. More support for research employing social science methods (beyond economics) could be a useful supplement to increase the efficacy of the existing portfolio. This could aid in answering questions surrounding barriers to the uptake of new technologies and ideas, whether among farmers, industry, or policymakers. Moreover, this could be an area of comparative advantage and impact for the Analysis Program within the broadly technology-oriented BETO portfolio.

Moreover, as BETO moves to advance the bioeconomy, it is critical to ensure that emerging systems reduce rather than duplicate or exacerbate inequities present in the fossil fuel-driven economy. The Peer Review presentations suggest that the program is already taking some of these issues into consideration, but we

encourage program managers to support organized efforts on the equity and justice implications of emerging bioeconomy systems. These efforts should be carried out by one or more *dedicated project teams* rather than being added as an additional task to existing projects. We recommend the development of a social sustainability/equity "home" in the Analysis Program portfolio, with a team comprising true subject experts in energy and environmental justice, that could collaborate across the program to support research into equity, justice, and other aspects of social sustainability across the broader BETO portfolio. This effort should also include support for any necessary internal work to address equity and inclusion in BETO's operations, processes, and research teams.

# DATA, MODELING, AND ANALYSIS PROGRAMMATIC RESPONSE

## INTRODUCTION

The DMA program would like to thank the Review Panel for their time and effort during the review process and for their careful review of the portfolio. The team appreciates some of the smaller recommendations, such as engaging more with stakeholders to help facilitate the uptake of research findings and continuing to award projects outside of the national labs when possible. The recommendations from the Review Panel will be discussed and taken into consideration when working on future project selection and program design, as future appropriations allow.

### Recommendation 1: Harmonize across models within the BETO portfolio.

The DMA team appreciates this recommendation and agrees that ensuring models are working from a consistent set of assumptions to the extent possible is a potential strength of BETO's diverse modeling portfolio. The program also appreciates the recognition that there has been work done since the 2019 Peer Review to try to encourage more harmonization and to clarify the links between different models in the portfolio. It can be difficult to set aside time so that every modeling team can meet and agree on consistent assumptions when models are in different phases of development, but the team intends to keep working in this area.

The DMA team has previously held biannual summits with as many of the modelers as possible to address concerns like harmonizing assumptions. The most recent of these meetings took place shortly after the 2021 Peer Review and included additional discussion about how to harmonize assumptions in several key models as well as potentially come up with a set of standard conditions that modelers can reference for different scenario runs, similar to existing assumptions used by the International Panel on Climate Change and other international groups. Moving forward, the DMA team will work with relevant projects to increase communication between modeling teams and harmonize and coordinate where possible.

### Recommendation 2: Continue/expand field research to ground-truth models and analyses.

Field studies play an important role in better understanding the sustainability of biomass systems, and the DMA team agrees that they are an impactful use of government funding. The decarbonization of the agricultural sector is expected to be a research priority for BETO in coming years, which is an area that would be significantly enhanced by collecting data in the field. Because field studies last longer than a typical project funded by DMA, they require a larger budget and more planning to implement. These factors may make it difficult to commit to funding anything new in this area until out-year budgets are released, but the DMA team will make every attempt to collaborate with other entities and encourage field research where possible.

DMA's largest current investment in field studies are the three selections (totaling $9.2 million) made in July 2020 under the Biomass to Restore Natural Resources (BioRestore) topic area of BETO's Fiscal Year 2020 Multi-Topic solicitation. More information about each of the selected projects can be found here. These projects aim to enable the quantification and valuation of ecosystem services to support BETO's goal of $2.50/gallon gasoline equivalent (GGE), but because they were all still in the negotiation phase at the time of the review, they did not present to the Review Panel. These projects will be reviewed in 2023 and represent an important part of DMA's portfolio going forward.

### Recommendation 3: Increase support for social science research, including a focus on equity and justice.

BETO as a whole has committed to better integrate JEDI principles into the office's goals and practices, and the DMA team is also committed to focusing more attention in this area. In addition to this recommendation, the DMA team especially appreciates the Review Panel's thoughtful comments on this recommendation during the review itself. BETO and the DMA team recognize that these areas represent complex challenges and that they deserve a thoughtful response designed to result in impactful changes. In addition to the JEDI principles, the DMA team agrees that there is a role for incorporating social science principles into the portfolio, and they are open to adding more work in this area as allowed by the program budget.

Based on internal conversations as well as this recommendation from reviewers, the DMA team is running a topic in the annual national lab call for proposals for FY 2022 focused on generating a full picture of the impacts of JEDI principles on the bioenergy supply chain. Based on recommendations from the Review Panel, the intent of this 1-year project would be to better understand where BETO can focus efforts in these areas and create a coordinated response to areas of high need going forward. The DMA team agrees that a single team working on addressing these issues will be a more impactful than having projects attempt to integrate them individually. Similar to the panel's first recommendation, it will be critical for the DMA team and all of BETO to plan an active role in coordinating efforts in this area.

In addition to incorporating a consideration of JEDI into the research portfolio, BETO is also participating in a number of internal DOE efforts to better incorporate these principles in internal processes, such as proposal selection and reviewer and subject matter expert identification.

# GREET DEPLOYMENT AND BIOFUEL PATHWAY RESEARCH AND ANALYSIS

## Argonne National Laboratory

### PROJECT DESCRIPTION

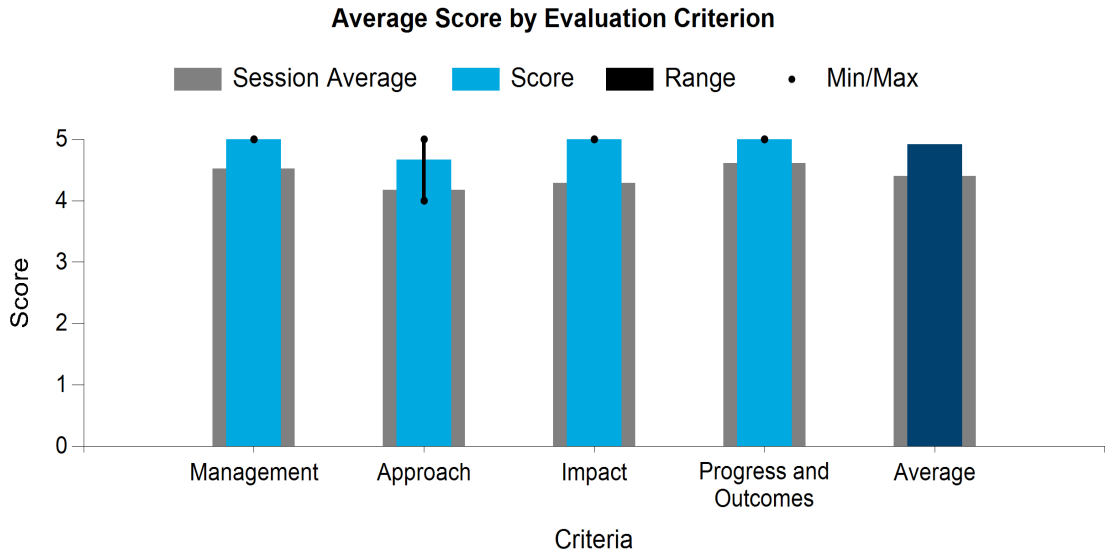
| | |
|---|---|
| WBS: | 4.1.1.10 |
| Presenter(s): | Michael Wang |
| Project Start Date: | 10/01/2020 |
| Planned Project End Date: | 09/30/2023 |
| Total DOE Funding: | $3,175,000 |

With BETO support, Argonne National Laboratory (ANL) continues to develop the GREET model to conduct life cycle assessments (LCAs) of biofuel/bioproduct pathways to holistically quantify the energy and environmental effects of production and the use of biofuels and bioproducts. GREET and its results have been used by BETO and other agencies/organizations to provide information about the energy and environmental implications of biofuel/bioproduct systems to help guide research and development (R&D) and policy decisions. Companies have also been using GREET and results for prioritizing R&D and bioenergy technology deployment. With this project, ANL has been developing the GREET model with consistency and transparency to provide BETO and the bioeconomy community with rigorous, reliable, and timely results in response to key questions regarding biofuel/bioproduct energy and environmental sustainability.

ANL's key accomplishments since March 2019 include:

1. Adding new biofuel and bioproduct pathways and updating baseline pathways; for example, including a few electro-fuel production pathways with carbon dioxide ($CO_2$) utilization, expanding aviation and marine modules in GREET, and continuing supply chain sustainability analysis.
2. Developing the International Civil Aviation Organization (ICAO)-GREET to estimate carbon intensities of sustainable aviation fuel production pathways for ICAO Carbon Offsetting and Reduction Scheme of International Aviation (CORSIA).
3. Addressing soil organic carbon changes from land management change (besides land use change) for biomass farming by expanding the Carbon Calculator for Land Use Change from Biofuels (CCLUB) module in GREET.
4. Conducting LCA of $CO_2$ utilization for electro-fuel production pathways so that low-carbon liquid fuels from waste $CO_2$ streams and renewable electricity can help deep decarbonization of transportation.

GREET has been an integral part of BETO analysis to address bioenergy sustainability with consistent, complete modeling of the bioenergy supply chain with close interactions with other national labs (including the National Renewable Energy Laboratory [NREL], Pacific Northwest National Laboratory [PNNL], and Idaho National Laboratory [INL]), agencies, and key stakeholders. ANL has published extensively to document data, methods, and results of GREET model development and applications. At present, there are more than 43,000 registered GREET users globally, with key users including governmental agencies, conventional and renewable energy companies, universities, and research institutions.



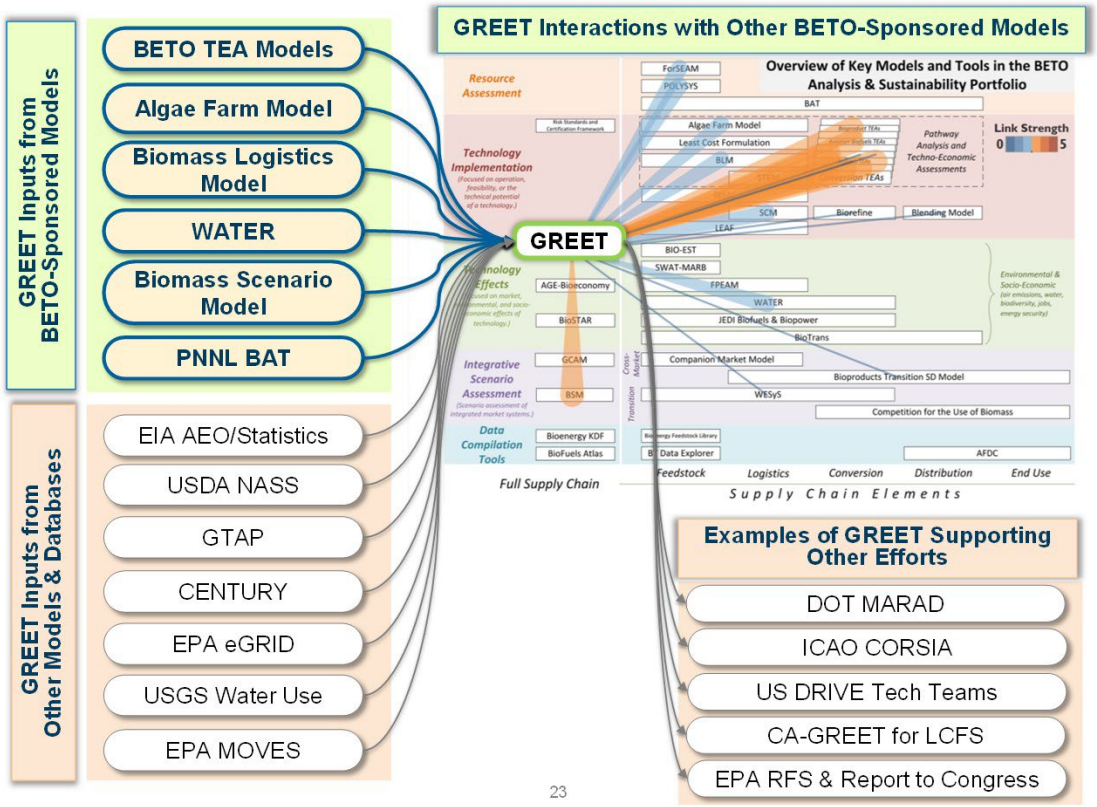




*Photo courtesy of ANL*

## COMMENTS

- GREET continues to be a flagship model for DOE BETO and, as such, is a critical resource for researchers, fuel producers, and regulatory bodies throughout the country and globally. The approach is clearly outlined both technically and in terms of where GREET sits in relation to other BETO models, external models, and external efforts. There has been clear and extensive progress in adding new pathways/technologies and updating data in GREET in the review period. The new work on temporal

carbon effects of woody biomass is an important layer of detail to take into account in greenhouse gas (GHG) LCA. The addition of "e-fuels" to GREET is an important expansion given the growing interest in fuels in this area. The inclusion of specific performance metrics on downloads, etc., were helpful for evaluating progress. Given the expanding complexity and size of GREET, it would be helpful to know if there has been any evaluation of whether it makes sense to transition GREET away from Excel to some other open-source platform or if Excel is still the best primary platform.

- GREET has become the industry standard LCA tool, and its targeted and specific scope is a strength as it facilitates impact. The PI is also a masterful communicator, clearly describing the approach and importance of their work. I appreciate their focus on pushing the tool's scope in the direction of emerging technologies, such as WTE, bioplastics, and $CO_2$ utilization. It was not immediately clear what scope this project is versus ongoing programmatic GREET support. If programmatic, that might be a good thing, allowing the GREET team to strategically broaden and deepen its tool rather than constantly responding to changing winds. As suggested in the last Peer Review, it would be worthwhile to support a concerted peer review effort to refine and test the GREET model's assumptions and inputs.

- GREET has contributed major benchmark support to a diverse array of collaborators. The number of developments (pathways and modules) in just the past 2 years is impressive, let alone prior to this funding cycle. The presentation clearly articulated all major aspects of this review, with emphasis on how the project addresses BETO key research areas and key topics—an impressive feat, given the complexity and number of collaborations. The user base analysis was helpful to understand the impact of the GREET tool across multiple axes, number of users, geographic locations, and stakeholder sector.

- It is good to see GREET supporting the office's work around aviation, marine, deep decarbonization, and plastics.

- The GREET team has done a phenomenal job developing a model that is as comprehensive as it is well regarded and widely used. This project delivers on its stated goal of quantifying the outcomes from different bioenergy and bioeconomy products while also doing an excellent job of making the modeling framework and results accessible to a wide audience, which is very clear from the list of partners and model download data shared by the presenters. The usage metrics provided in the presentation illustrate this project's growing success and influence within the community. Further, the ongoing work to update the model to match progress with its covered technologies and to expand its scope of coverage is critical to its continued relevance. A few notes of caution, however. It is critical that the modelers take the opportunity to validate the model assumptions and results against real-world data as part of a systematic approach. It may be necessary to regularly conduct sensitivity analyses and investigate how assumptions in GREET may be influencing the results or causing them to diverge from real-world findings (for example, for soil carbon changes in CCLUB). Further, the expansion to cover more nonfuel biomaterials is potentially risky, particularly in cases where the scope and assumptions for product use and lifetime differ from fuels because it may introduce additional complexity and layers to what is already a very complex model.

- The integration of the wide range of other BETO models and inputs is impressive. The impact of the project is clearly high—from extensive stakeholder engagement (43,000 users, wow!), to the expansion of the modeling capabilities, to the increasing growth in users. The approach related to the bioproducts portion of the work was not well described. It would be nice to see more on how the bioproducts pathways were developed. As you build out more bioproducts, be sure that you are collaborating with the USDA. Same for buildings: Work with NREL and Lawrence Berkeley National Laboratory (LBNL) and the U.S. Green Business Council. As you develop "extensive databases" (per your presentation), investigate ways to make those databases available in other LCA software environments or databases, like the Federal LCA Commons.

## PI RESPONSE TO REVIEWER COMMENTS

- We appreciate the reviewers' recognition of the contribution of ANL's LCA for the BETO program and the GREET model development and the advances made during the past 2 years. The ANL team is committed to continuing to provide timely and high-quality LCA results in support of BETO programs.

- In response to the reviewer's question regarding whether ANL has evaluated if it makes sense to transition GREET from Excel to another platform: Yes, we have given this considerable thought and took steps in this direction with the creation of GREET.net. Nonetheless, we anticipate maintaining GREET Excel based on user feedback. GREET has been expanded significantly since its first version in Excel in 1995. Although Excel is transparent in presenting data and results, calculation logic and configuration of simulation pathways/options in Excel are difficult to follow and execute. In the early 2000s, we began to make efforts to add extensive user interfaces inside GREET Excel to help users make simulation choices and follow through data, calculation logic, and results. In the mid-2000s, we further began to develop GREET in the .net programming platform. The .net platform for GREET is designed with dynamic picking and dropping functions that users can readily configure simulation options and get results; however, the extensive databases built in GREET are not as transparent in the .net platform as in the Excel platform. We initially envisioned that we would eventually stop the Excel platform for GREET to move it completely to the .net platform. But many GREET users (some of whom are intensive GREET users) continued to use the Excel platform and asked us to continue to maintain the Excel platform; thus, we have maintained the two modeling platforms for GREET for more than 15 years. Nonetheless, many new GREET users in fact use the .net platform. Although it is time consuming to maintain the two parallel GREET modeling platforms, we have found that the development and maintenance of the two platforms give us a unique opportunity to cross-check GREET expansion for quality assurance/control; thus, we will maintain both platforms for the foreseeable future. Both are open-source platforms where users can expand LCA simulation options and conduct LCA simulations, which are free of charge to download from the GREET website (https://greet.es.anl.gov/).

- Thank you for requesting additional information regarding this project versus programmatic support of GREET. This project is one of three core projects contributing to the further development of GREET; the others are through the Vehicle Technologies Office and the Hydrogen Fuel Cell Technologies Office. Other projects further contribute to the development of new pathways in GREET. The core GREET LCA efforts have two integral parts: LCA research efforts and GREET model development. LCA research efforts at ANL are essential to our services to DOE programs to provide holistic energy and environmental results of energy technologies, including biofuel technologies. The results of our LCA research for DOE (and other agencies) are rolled into the GREET model, with new fuel pathways, new data, revised modeling approaches, and programming enhancements, so that GREET users can benefit from our LCA research results with hands-on LCA simulations using the GREET model. Our GREET LCA project for BETO—as for other DOE programs, such as the Vehicle Technologies Office and the Hydrogen Fuel Cell Technologies Office—focuses mainly on LCA to characterize new technologies and to address emerging issues for aspects of their LCA modeling. Each summer, we incorporate new LCA research results from the fiscal year for a new GREET release in October. GREET model development and programming is usually a small portion of our LCA project efforts.

- GREET has been expanded significantly in the past 15 years, with new energy production pathways, vehicle technologies, and end-use sectors. We also continue to address emerging LCA issues so that GREET can generate comprehensive, reliable results. GREET pathways are reviewed every time when we complete LCA research of specific pathways through peer review of our publications documenting data, methodology, and results, and by cross-checking new programming features in GREET between the Excel and .net modeling platforms; however, we have not had a complete GREET model review since the mid-2000s, when a review was done externally. Review of the GREET model with such broad coverage of energy systems, vehicle technologies, and end-use sectors requires significant resource commitment by DOE, as well as reviewers with both broad LCA expertise and in-depth knowledge of

the technologies and end-use sectors. That said, a review of LCA modeling of specific, critical technologies in GREET, if not the entire GREET model, can be done with some limited resource commitment.

- The reviewer's point about validating GREET model assumptions and results against real-world data is one we take very seriously, which is the subject of constant discussion and updates within our group. There are key experts in our group responsible for each of the pathways in GREET, and we monitor the literature for new data to inform the pathways. These data are considered for updates to key parameters during each GREET release and are documented in GREET release memos. New pathways and significant changes to pathway models are published in peer-reviewed articles. Nonetheless, this is a struggle, in general, for the field of LCA. The nature of LCA that covers the entire supply chain of a fuel/product makes the validation of LCA results with measured data impractical because there are no reported/measured results for the entire supply chain of a fuel/product; however, data for key stages of a supply chain are indeed available, and we regularly use these to validate key input data in GREET. For example, for the corn ethanol supply chain, fertilizer use in corn farming and energy use in ethanol plants are two key input parameters and are reported in government statistics and in private benchmarking database. We validate key GREET input parameters with such data from agencies and industry sources. We use government statistics, such as U.S. Energy Information Administration's data on the energy use of various sectors and the Environmental Protection Agency's (EPA's) emissions data from its annual emissions inventory report in the annual release of the new GREET version. Further, we periodically validate specific fuel pathways with up-to-date input data. For example, we used the USDA farming data and an ethanol plant benchmarking database in 2020 to update corn farming inputs, corn yield, ethanol plant energy use, and ethanol product yield between 2005 and 2019 for corn ethanol pathway simulations. We documented the update in a forthcoming journal article, and the results will be incorporated into GREET 2021. At present, we are conducting a similar effort to update and validate biodiesel and renewable diesel pathways in GREET.

- The soil organic carbon changes calculated in CCLUB are based on simulation results with the Century model, which was originally developed at Colorado State University in the early 1990s. The model has been validated with measured soil organic carbon associated with different soil types, climate regions, and diverse farming practices. Further, in the past few years, we took extra steps to collaborate with several organizations specialized in soil sciences and agronomy (e.g., USDA Agricultural Research Service in Iowa and Minnesota, and South Dakota State University) and conducted meta-analyses of the literature and/or open-source database for soil organic carbon changes and $N_2O$ emissions in Midwest states. With the meta-analysis results, we validated soil organic carbon changes simulated with the Century model and adjusted soil $N_2O$ emissions in CCLUB and GREET.

- Expansion of GREET from fuels LCA to products LCA has been an effort for more than 5 years at ANL. This was driven by BETO's new R&D efforts in the chemicals and plastic area. LCAs of fuels are somewhat straightforward with their combustion to end their lives. Chemicals, especially plastics, may not be destroyed at the end of their use. The fate of these products is important in their LCA, especially when we examine life cycle GHG emissions. In these cases, we track down fates of products after their uses, such as their degradation and decomposing, so that environmental releases such as methane emissions are captured in product's LCA. For all the pathways implemented in the GREET model (biofuel or bioproducts), we have peer-reviewed documentation available on the GREET website (https://greet.es.anl.gov/publications). The intent with these documents is not only to have the pathway descriptions and explanation of the methodology and data source but also to present sensitivity analyses results, which help understand the variability in the results led by key parameters. The need for constant monitoring of LCA models requires the continued support of GREET, which plays a critical role in harmonizing and providing consistent and accurate data, allowing comparisons across the technologies in which DOE invests.

- We appreciate the reviewers' interest in our work on bioproducts, plastics, and chemicals. Our LCA of products, including chemicals and plastic, benefits from our ongoing collaboration with other national labs, including NREL, PNNL, and LBNL. We also collaborate with industry stakeholders, such as member companies of the American Chemistry Council, through projects. We have been engaged with USDA related to the analysis of biofuels and will continue to seek opportunities to deepen our collaboration related to bioproducts. Technology development efforts and data accumulated by the national labs and industry stakeholders have helped our LCA efforts tremendously. Within GREET, we have expanded our LCA to fossil-based and bio-based chemicals leveraging the new biorefinery models. In addition, we are currently developing an analysis framework for the circular economy of plastics. Several publications are available on our GREET website, which reflect the efforts in the LCA of chemicals and plastics. The results of our LCA have helped identify the key drivers that influence GHG emissions and other sustainability metrics and pursue opportunities to mitigate the adverse environmental impacts. For example, we have shown that sodium hydroxide, used during pretreatment of corn stover, is a major GHG driver in biochemical conversion technologies; therefore, collaborators at other national labs have been expanding their research to find less GHG-intensive chemical agents for the pretreatment of feedstock. We recently expanded GREET to the buildings sector. This expansion benefits from our LCA efforts for key materials such as steel, aluminum, and cement that we have built in GREET for vehicle cycle analyses. We have been interacting with other national labs, including Oak Ridge National Laboratory (ORNL), PNNL, and LBNL; as well as government agencies, such as the National Institute of Standards and Technology; industry, such as vacuum insulation panel manufacturers; architecture firms, such as Skidmore, Owings & Merrill; and trade associations, such as North American Insulation Manufacturers Association, to benefit our LCA efforts on building envelope and insulation materials, building construction, and building operations.

# MULTI-INPUT, MULTI-OUTPUT BIOREFINERIES TO REDUCE GREENHOUSE GAS AND AIR POLLUTANT EMISSIONS

## University of California, Berkeley

### PROJECT DESCRIPTION

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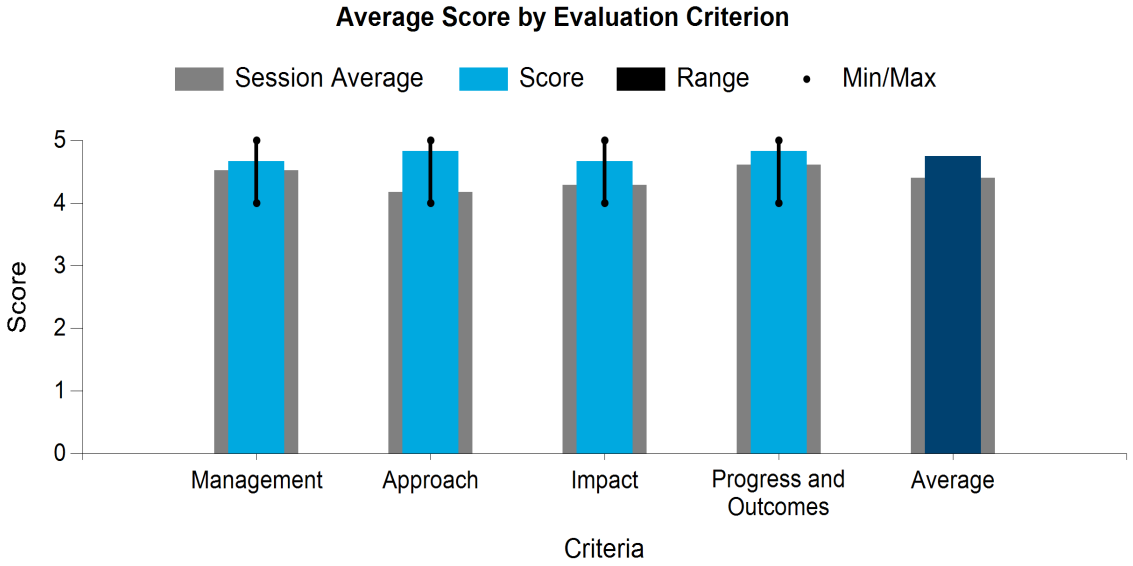
|---|---|
| WBS: | 4.1.1.100 |
| Presenter(s): | Corinne Scown |
| Project Start Date: | 10/01/2019 |
| Planned Project End Date: | 03/31/2023 |
| Total DOE Funding: | $1,000,000 |

Lignocellulosic biorefineries can produce renewable liquid fuels vital to the transportation sector, including replacements for gasoline, diesel, aviation fuel, and marine fuel; however, they also have an important potential role to play in manufacturing high-value bioproducts, creating jobs, supplying electricity, and treating waste in rural communities. The goal of this project is to conceptualize, design, and assess the economic and environmental performance of multi-input, multi-output biorefineries that can convert locally produced lignocellulosic biomass, manure, and other wet organic waste into liquid fuels, platform chemicals, and high-value products. By the end of the project, the resulting techno-economic analysis (TEA) and LCA models will be released as highly customizable, transparent, web-based tools for public use. The optimized biorefinery designs will produce a suite of fuels and products that will reduce GHG emissions by at least 70%, reduce fossil energy consumption by 50%, and reduce air pollutant emissions by at least 20%. Challenges include balancing the cost of biogas upgrading to products and increasing the capacity of the on-site anaerobic digester with the environmental benefits of organic waste treatment. To date, the project has produced preliminary results for multiple biorefinery scenarios and produced a machine learning model for predicting biogas yield and composition from different inputs to the digester section.



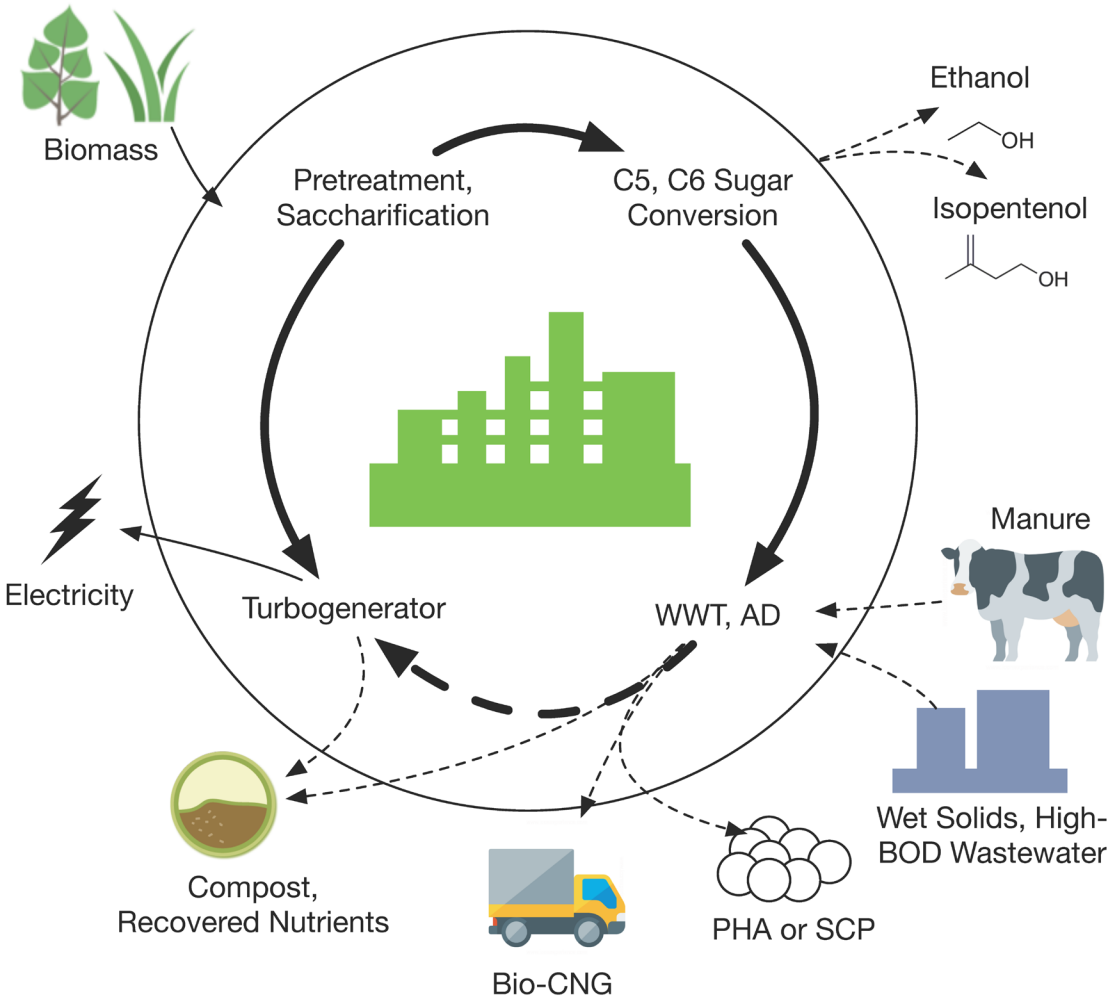



*Photo courtesy of University of California, Berkeley*

## COMMENTS

- The timeline was very helpful to see where the project stands and that it is on schedule. The progress and models appear to be solid. The results are compelling, though not surprising. Questions to consider: How can the tool help the system with the factors that seem to be the most important—the tipping fees and polyhydroxybutyrate price? Are there other stakeholders that could/should be engaged as you develop the tool, to ensure usability?

- Impressive effort for such a new project, and very clearly communicated. Though this work may overlap some of the efforts elsewhere in the BETO portfolio, the connection with the state utility creates synergies that may propel this effort further. The project is bounded by clear goalposts and includes a multiscalar lab-to-launch approach for thorough proof of concept. The PI clearly articulated the connection of the approach to potential impacts and multiple deliverables. The project appears on schedule despite the COVID-19 pandemic-related challenges, and it is moving toward project goals.

- The concept of this project to incorporate the feedstock flexibility of anaerobic digestion into biorefinery concepts is strong, and it is great that this project includes real-world collaboration with industry participants who are actually implementing elements of the multi-input/multi-output approach to biorefineries. Scale-up is a key challenge for any industrial process, and while I'm not sure anyone has solved how to overcome "the valley of death," getting input from industry advisers may not be sufficient

to address this risk. Progress appears appropriate for the stage of the project. One of the proposed revenue elements for the biorefineries is organic waste tipping fees. As mentioned in the presentation, a critical challenge for wastes is that when they become a commodity, they stop being a waste and start having a price associated with them (rather than being free or getting revenue for them); the example of manure in California was given. The project should consider the long-term revenue viability of and alternatives to waste tipping fees even where they are currently available. This project is likely to result in some real-world techno-economics and life cycle GHG numbers that would be very valuable for validating other models and estimates within the BETO portfolio, and an effort should be made to ensure that the data coming out of this project get to the appropriate teams across BETO.

- The project team has assembled a very comprehensive project plan with outcomes highly relevant to BETO, particularly on cost reductions and emissions reductions at biorefineries. Further, the project is working closely with industry and utilizing their feedback for building up a commercial-scale biorefinery model. The incorporation of biogas capture and upgrading into biorefinery design fits in well with the program's LCA and TEA resources and could provide outputs relevant to the goals of reducing costs and environmental impacts. An important consideration for the development of the TEA/LCA web tools will be how to balance their accessibility and applicability for potential stakeholders. Given the extensive amount of modeling necessary to evaluate the biorefinery scenarios as part of this project, there is a risk that (1) the web tool will require extensive data inputs on behalf of users, making it suitable only for experts, or (2) to make it broadly accessible for users, it will be too broad to be applicable to individual projects with their own site-specific cost concerns and operating parameters.

- This is an interesting technology development project in the DMA portfolio. It is focused on a promising future direction of development in the bioenergy space—that of agile WTE biorefineries co-digesting different waste streams. Its collaboration with the local utility offers a comparative advantage by facilitating access to otherwise proprietary data. It is not immediately evident how/whether the waste digester system is a critical or supportive part of the conventional biomass crop refinery system.

- This project seeks to take environmental problems and turn them into solutions, which is very exciting. It seems conducive to themes growing in popularity and importance, including the circular economy and reducing waste/pollution.

## PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their supportive and helpful comments. We agree that the strong industry partnerships in this project have helped us ground our assumptions and research plan in practical experiences. The reviewer comment about waste tipping fees as a viable long-term revenue stream is an excellent one. This is exactly why we run scenarios that assume waste comes at a positive, negative, and zero cost to understand the impact on overall facility economics. Some wastes—such as fats, oils, and greases—are likely to increase in value over time given their value in anaerobic digestion facilities and, now, for hydroprocesses esters and fatty acids production. Other mixed waste streams may continue to come at a negative cost (tipping fee) if there are few competing valorization routes. Manure in California is a special case because policy incentives are driving its value as a feedstock. These policy-driven dynamics can be highly regional and difficult to predict, but we plan to account for them through scenario and uncertainty analysis. Regarding the dissemination of results to other teams in the BETO portfolio, we have been in contact with the GREET team at ANL regarding the integration of our results into their tool, and we will continue to conduct outreach in addition to dissemination through peer-reviewed journal articles and online tools. In response to the comment about dissemination through the BioC2G web tool, the reviewer makes a very valid point. There is always a trade-off between usability and the degrees of freedom that an expert user might want, in addition to challenges in providing enough flexibility to be broadly useful. We will continue to gather feedback from industry partners to understand what startups and research teams looking to commercialize their technology would require of a web tool in order to effectively support their decision-making process.

# AGENT-BASED MODELING FOR THE MULTI-OBJECTIVE OPTIMIZATION OF ENERGY PRODUCTION PATHWAYS: INTEGRATED TECHNO-ECONOMICS AND LIFE CYCLE ASSESSMENT

## Colorado State University

### PROJECT DESCRIPTION

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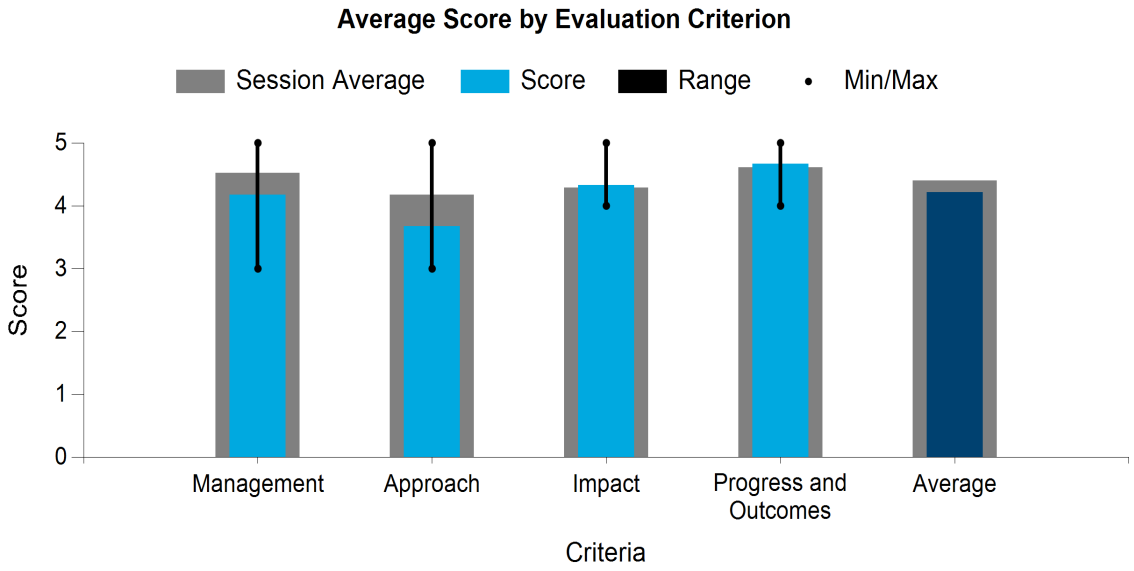
|---|---|
| WBS: | 4.1.1.101 |
| Presenter(s): | Jason Quinn |
| Project Start Date: | 10/01/2019 |
| Planned Project End Date: | 03/31/2023 |
| Total DOE Funding: | $1,000,000 |

The proposed work will develop a tool set that is capable of identifying promising combinations of production pathways and performance targets for bioenergy and coproduct systems. This is a new paradigm for bioenergy modeling. The work will leverage agent-based modeling for the optimization of biofuel production pathways with geo-spatial resolution and multiparameter optimization that includes cost, energy, water, and emissions criteria.

The initial efforts of the project focus on the development of foundational sustainability models. The work includes integrating existing subprocess models with the development of new subprocess models to accurately capture the performance of various demonstrated and innovative bioenergy production pathways. The engineering process models will be constructed in a modular fashion to support the agent-based and multi-objective optimization work in the second budget period. The developed modular engineering process models will serve as the foundation for sustainability assessment through techno-economics and life cycle modeling. We will identify the energy, mass, labor, and financial inputs required for each production pathway, such that synergies and optimizations can be formulated in the second budget period.

Later work will focus on integration and optimization techniques based on the foundational work developed in the first budget period. The various system configurations will be evaluated through agent-based modeling, multi-objective optimization, and carbon accounting through coupling economic and environmental assessment. In addition, resources are allocated to the development of additional subprocess unit operations to capture new and innovative technologies, such as favorable configurations of bioenergy with carbon capture and storage. The results from the project will be transformed into an open-source tool set that will support the evaluation of various combinations of technologies—such that a use can evaluate trade-offs of bioenergy production pathways.




## COMMENTS

- This project would greatly benefit from a pause to investigate how it can utilize various DOE models. It would not be a good use of resources to recreate existing process or LCA models. As the team further develops the agent-based model, they should think carefully about defining the rules for the various agents and ensure that the methods that are being used will ensure that those rules are realistic. For example, if you never speak to a farmer, you may not be properly defining the rules for their decisions. Consider utilizing the positions on the advisory board to increase the diversity of your team.

- It is good to see this project targeting office interests in heavy fuels and jet fuels. I find this analysis to be helpful in guiding trade-offs among economic, land use, and climate priorities.

- Linking TEA, agent-based modeling, and spatially discrete LCA is an estimable goal, though it is difficult to do all of these things rigorously, and it risks a superficial approach to each. How, for example, does this work weight and quantify the various decision factors influencing a farmer agent's crop choices? Such considerations presumably vary across demographic, geographic, and economic conditions, making rigorous treatment in such a large effort difficult. The team's aim at explicitly identifying the trade-offs that may emerge among cost, GHG emissions, land use, and other parameters is a useful lens. It is not clear, however, that this research is sufficiently well situated within ongoing literatures in each of the disciplines it touches. How does it build on, and where does it depart from, ongoing related work?

- The project has a mostly clear management plan, with an implementation plan that includes risks and mitigation strategies. The routes for communication and collaboration were clearly presented but lacked some detail. The approach has substantial merit to advance the SOA through innovation. There seems to be some overlap with other models in the BETO portfolio, such that the project may benefit from synergistic collaborations/communications with those researchers. These communications may clarify the intended impacts and project direction as well as potentially amplify the work of all parties. The project appears to be progressing on time toward addressing the project goals.

- This project has the potential to be very impactful by helping to identify optimal biofuel supply chain performance based on production potential, supply chain structure, and economic conditions. The ability to evaluate trade-offs among performance metrics will be very helpful. The complementary use of multi-objective modeling to identify pathway optimization and agent-based modeling to address farmer

adoption/biorefinery investment should provide useful insights. This project is just starting, so there are opportunities to leverage and link this project with ongoing work at BETO. NREL's "Strategic Support" project seems to address many of the same areas of interest (TEA, sustainable process design, refinery optimization), as do others. The researchers should become familiar with other existing models in the BETO portfolio and ensure that the work under this project leverages that information/those models as appropriate, or the researchers should clearly justify why existing BETO models or data are not suitable and what the advance or benefit is of the project's approach. For example, it appears the PIs intend to perform their own TEAs and LCAs for the pathways in question; BETO has extensive work in both of these areas, so there should be a good rationale for performing separate analyses like this, and if undertaken, they should be compared with DOE BETO TEA and LCA for further validation of both approaches. There can be value in doing fresh, separate analyses, but it should be done purposefully and should contribute to the refinement/validation of BETO models as well.

- This project incorporates sustainability, LCA, and techno-economics to optimize biofuel deployment across a selection of possible pathways. The optimization approach incorporates spatial analysis, which adds a unique element to similar models in the program. This type of larger system approach could be very useful for informing the program areas strategic goals. This project would benefit from providing additional clarity on which inputs into the analysis, particularly on TEA and LCA, are derived from DOE resources and which are developed in-house by the project team. For those resources developed in-house, the project team should justify those decisions and provide context.

## PI RESPONSE TO REVIEWER COMMENTS

- We have grouped the comments into themes. Comment: Utilize the various DOE models. Response: We agree and are using models when available. A challenge with the work we are doing is it fills a gap in the portfolio that is concurrent assessment and optimization. For example, ANL specializes in TEA and NREL in LCA. One issue with some of the models identified by the reviews is they are not publicly available. We are currently working with various national laboratory teams to support streamlining our modeling development and data integration work and note there are a variety of the tool sets identified that are open source. Additionally, we are evaluating feedstocks that have not been extensively evaluated by DOE national laboratories. Comment: Increase diversity. Response: We agree the diversity of the team needs to be improved. We have a female researcher joining the team this May and will work to recruit a more diverse advisory board. Comment: Validate agent-based model. Response: This represents a critical aspect of the work, and we plan to address as we ramp up this part of the modeling work. We will not be doing extensive surveys and plan to use literature to define agent behavior.

# STRATEGIC ANALYSIS SUPPORT

## National Renewable Energy Laboratory

### PROJECT DESCRIPTION

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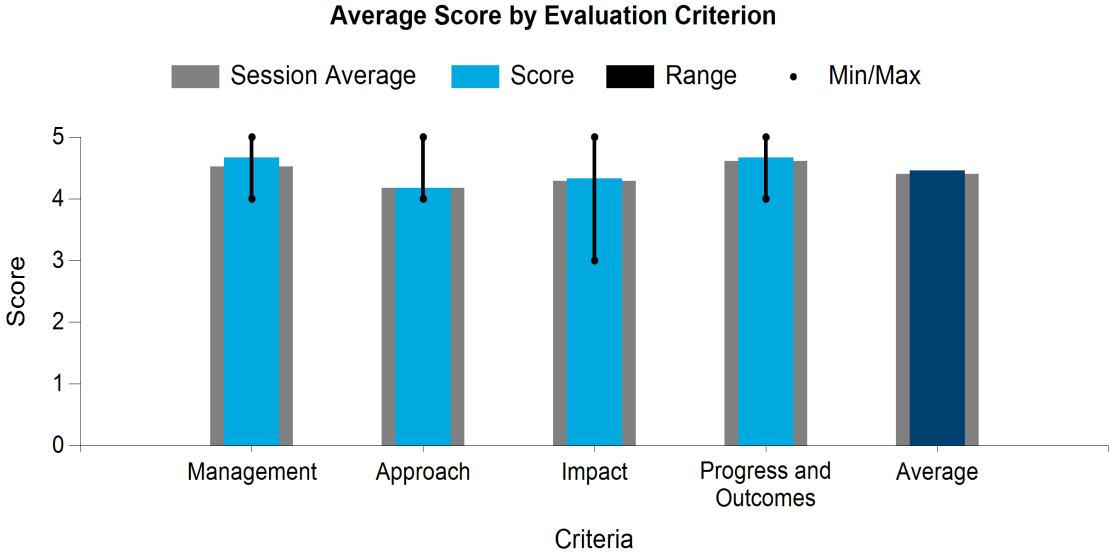
|---|---|
| WBS: | 4.1.1.30 |
| Presenter(s): | Ling Tao |
| Project Start Date: | 10/01/2018 |
| Planned Project End Date: | 09/30/2021 |
| Total DOE Funding: | $1,400,000 |

The objective of the NREL strategic support project is to provide sound, unbiased, and consistent analyses to inform the strategic direction of DOE BETO. This project addresses key technological questions, provides critical data needed to inform strategy, and highlights barriers, gaps, and data needs in support of DOE BETO's mission to improve the affordability of bio-based fuels and products. This task employs various quantitative (e.g., TEA) and qualitative (gap analysis) approaches to allow for direct comparisons of biomass conversion technologies across a wide slate of processing platforms, products, and impact categories. Further, this project develops and utilizes novel analyses beyond traditional biorefinery-focused TEA/LCAs to identify both technical (e.g., in sustainable design) and nontechnical (e.g., in value proposition) barriers, as well as to outline mitigation strategies and highlight R&D needs for emerging technologies. Additionally, the project is tasked with evaluating drivers that support the growing bioeconomy, which is achieved by the development and public release of tools to advance the understanding and facilitate comparisons of socioeconomic impacts along the supply chain. Critical to the success of this project is the development of defensible methodologies, analyses, and tools that are publicly available to support stakeholders and bioeconomy growth. To develop such high-quality analyses, the biggest challenge to this project, as with most analysis-focused projects, is the availability and reliability of the underlying data; therefore, the project team works extensively with key stakeholders (e.g., policymakers, bioenergy technology developers, and investors) in developing, validating, and reviewing the results of these analyses to overcome this challenge. Any remaining uncertainties associated with the analysis efforts are clearly defined and quantified.



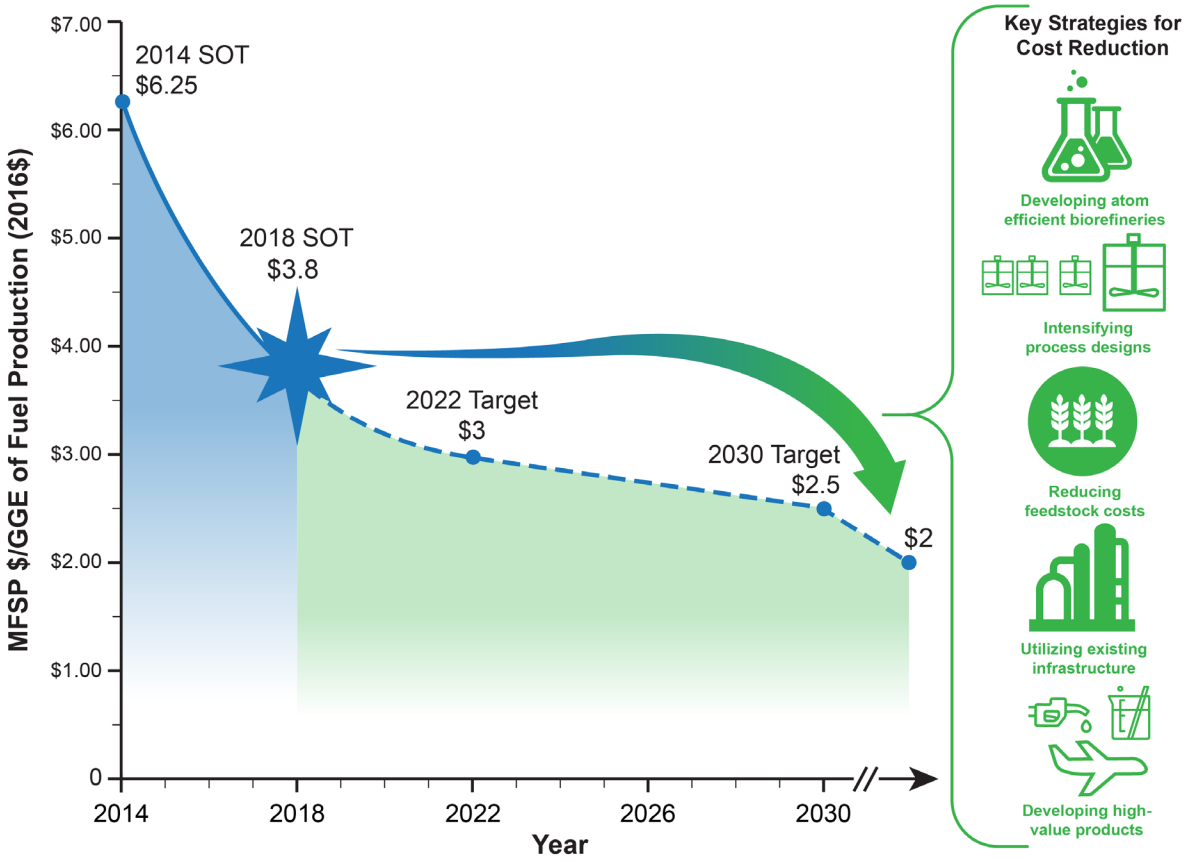



*Photo courtesy of NREL*

## COMMENTS

- Having consistent models and assumptions across a range of modeling projects and analyses is extremely important to provide comparability and consistency. This is a wide-ranging project encompassing a number of important overlapping areas of modeling and analysis needs. The project areas outlined are valuable additions to the public data; however, it is challenging to understand what this project is actually executing (i.e., building actual models) versus just coordinating among projects to ensure assumptions, etc., are all aligned among other projects in the portfolio. It is not clear how the TEA work going on in multiple groups (e.g., Analysis and Sustainability interface, this project, and others) are complementing or aligned with each other. It would be helpful for the overview presentation in the Peer Review to outline all the TEA work going on among the projects and how they complement/avoid duplication and which models they support. The integrated strategies to enable lower-cost biofuels effort that will identify opportunities to meet cost goals are very valuable across the sector for identifying areas in which effort should be made to reduce costs. The researchers indicated that they are working closely with the GREET team to consider how refinery optimization would change LCAs. This collaboration and the results should be addressed in future Peer Reviews. One challenge with things like the Biofuels TEA database is that incorporated into the modeling are assumptions about cost targets and drivers that have been set by BETO; however, it may not always be evident to the user that the cost information and/or technology is driven by those cost targets. Understanding how to reach those cost targets is very valuable, but it can potentially be misleading to new users who are not aware that the targets are driving assumptions in the TEA. It should be prominently indicated in the TEA repository that these are driven by the $2.50 GGE cost target. Baseline TEAs that do not incorporate those targets might be useful as well. Multivariate sensitivity analysis is a significant advance over single sensitivities and would help identify trade-offs and synergies among drivers. The synergy/trade-off analyses between the

GREENSCOPE process sustainability evaluation and cost drivers is very valuable. It would help to clarify if the JEDI modeling aspect of the project will be a repository of multiple bioenergy pathways/types of projects and if it is primarily intended as a tool for BETO users.

- I find this project to have some ambiguity about what it is and what it seeks to accomplish. Perhaps that is an asset, and it makes the work more nimble to respond to changing dynamics. If that's not the purpose, I would explore creating a clearer objective. The addition of the TEA database to the Knowledge Discovery Framework (KDF) is a great accomplishment to ensure this important research is publicly accessible and consolidated in a central location. The GREENSCOPE tool is valuable to the portfolio's work and should probably have linkages to other models in the Analysis work area that do not account for sustainability indicators. Because GREENSCOPE measures so many different indicators, it would be great to see it assist other projects that have a more limited take on environmental sustainability to help assess trade-offs.

- Most aspects of this project were clearly communicated, articulating the position of this project as a bridge and support for a diverse array of collaborative efforts. The multipronged approach applied to diverse projects, combined with the transparency of challenges and mitigation strategies suggests a high level of merit for supporting the goals of the project. Regular communication with collaborators and multiple deliverables suggests an active and on-time approach. This project looks to create both a secondary layer of review as well as an analytical tool kit for the projects it supports, both internally and externally. The number of stakeholders represented in various project segments is highly diverse. The presentation lacked some clarity about what the project creates and contributes to other collaborators versus what the project is leveraging from collaborators and other open-source models/data.

- Strategic support is crucial to synthesize the findings from disparate work streams within the portfolio and turn them into useful recommendations for BETO. This project had a clear map of the management plan, illustrating the how the overarching strategic support links together four different teams in order to develop harmonized analysis toward DOE's broader goals. This project establishes a clear management plan on what outputs are expected from each team they are working with and how they fit into the overall approach. The progress of this project already includes outputs relevant toward BETO's overall strategy on the economics and sustainability of emerging bioenergy pathways.

- The external and DOE internal partners engaged seem extensive and appropriate; however, it was unclear via the communication plan how much and in what capacity these stakeholders and partners are engaged. The impact is high, especially given the range of partners and applications. The project approach is quite extensive and has substantial merit to advance the SOA. A detailed timeline was not provided, so the progress related to expected deliverables and schedule was difficult to evaluate. Overall, the scope is large, and the project appears to have significant impact.

- This project has a strong focus on emerging areas of interest and importance to the overall BETO portfolio, including jet fuel, WTE, and biochemicals. It also seems well integrated with other analytical teams, though it was unclear at times what modeling and analysis is being done under this projects umbrella versus being leveraged from other teams in the BETO portfolio. The PI was able to identify and describe specific examples of applications of their tool kit. Insofar as BETO seeks to have this project serve as a nexus for applying the various tools in its portfolio for strategic insights in a harmonized and concerted fashion, it would be necessary for the performers to have sufficient visibility and authority within the BETO ecosystem to harmonize effectively.

## PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their helpful feedbacks and comments. Our goal for all of our analyses is to develop defensible studies and tools in support of the strategic direction of BETO. Going forward, we will work to adopt suggestions from the panel to integrate analysis aspects in this project by performing

assessments on cost, environmental, and socioeconomic metrics in a holistic approach. We will continue to publish TEA data via a KDF database so that valuable analysis research data are publicly accessible. Taking suggestions from the panel, we will add additional features/data to the TEA database: (1) add economic assumptions table, (2) make clarification on which TEA is for targets or for state of technology, and (3) add a summary table on key TEA metrics for more general audiences. Focusing on sustainable aviation fuel and marine fuels, the refinery models as an optimization tool with targeting on maximizing gross refinery margins will provide insights on opportunities and dynamics impacts when integrating bioenergy with refinery. We will continue to implement the GREENSCOPE sustainability framework to assess the impacts of BETO's core and novel conversion pathways, focusing on key metrics on environmental sustainability to help assess trade-offs. Additionally, we will integrate sustainability and economic analysis with a multi-objective decision analysis approach when comparing design options or pathway alternatives. Our job analysis on estimating local (e.g., county) green jobs will be coupled with demographic information/projections to understand how social and economic benefits may distribute among different population and communities. Finally, we appreciate the encouragement on advancing single sensitivity analysis to multivariate sensitivity analysis or stochastic analysis as a new tool to help identify trade-offs and synergies among drivers for BETO's strategic directions. Our team works diligently to be highly integrated within the DMA platform portfolio and the overall BETO portfolio.

# SUSTAINABLE BIOMASS THROUGH FOREST RESTORATION

## Pacific Northwest National Laboratory

### PROJECT DESCRIPTION

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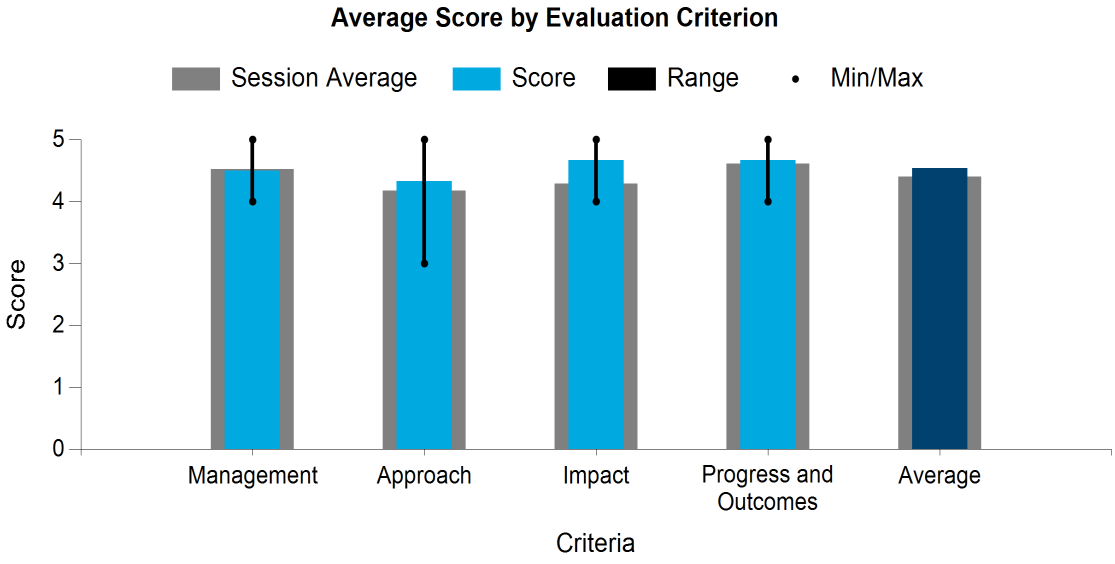
|---|---|
| WBS: | 4.1.1.52 |
| Presenter(s): | Mark Wigmosta |
| Project Start Date: | 10/01/2019 |
| Planned Project End Date: | 09/30/2022 |
| Total DOE Funding: | $400,000 |

In 2020, major wildfires in the western United States killed at least 37 people and caused more than $19.9 billion in damage and $3.4 billion in fire suppression costs. Sustainable biomass from forest restoration to reduce high fuel loads and fire risk is a potentially significant source of bioenergy with numerous potential environmental benefits; however, additional planning and decision support tools are needed to ensure economic and environmental sustainability. A multiagency collaboration between DOE and the U.S. Forest Service is using high-resolution spatial vegetation characteristics data to develop accurate estimates of sustainable forest biomass along with distributed hydrological and wildfire risk modeling in a multi-objective analysis framework. We are initially focused on high fire risk areas in the Pacific Northwest at the subbasin to regional scale using data, models, and analysis techniques that can be applied nationally. We have developed a decision support tool, and initial results demonstrate the potential of forest restoration to provide sustainable biomass for energy considering collection and transport costs, wildfire mitigation, smoke emissions, and improved snowpack and streamflow. This effort has resulted in two follow-on projects: one funded by the Upper Columbia Salmon Recovery Board/State of Washington to improve salmonid habitat, the other by the DOE Water Power Technologies Office to improve hydropower operations.



*Photos courtesy of PNNL*

## COMMENTS

- This project presents a timely and innovative response to increasing wildfires in the western United States as well as a growing interest in forestry biomass in the bioenergy sector. The approach is holistic, including ecosystem restoration, stream hydrology, and aquatic ecology. Communication and collaboration with other projects is clearly articulated and adds nuance (e.g., the inclusion of ecosystem service valuation based on nonmarket values) to the decision-making framework dynamics. Progress is appropriate at this stage in the project, despite reported setbacks due to COVID-19.

- There is a growing need for this work as wildfires pose greater threats to society and exacerbate climate change. A decision support tool is vital for weighing the trade-offs of biomass harvests for wildfire reduction. This project looks at wildfire severity, economic viability and usability of biomass, and hydrology. As far as GHG emissions go, the research should not assume that forest management will necessarily lead to GHG benefits. Existing literature has demonstrated that the benefits of wildfire treatment vary based on wildfire risk, and they are not always a benefit from a carbon pollution standpoint. This research could incorporate burn probability modeling and carbon stock assessments to evaluate both the severity and likelihood of fire in order to map out risk. This burn probability modeling could inform the carbon accounting variable in the decision support tool, measured in either (1) time frames of carbon payback or (2) priority interventions for carbon benefits. Similarly, down the line, the project may want to model economic/health impacts: How likely regions are to experience deadly or destructive wildfires, especially considering proximity to population centers, public health impacts of smoke, and economic impacts of commerce paused due to unhealthy air quality. This type of assessment would be especially important to policymakers. Another variable that would be valuable is biodiversity/wildlife impacts. How do the forest management treatments impact habitat when compared against the likelihood of wildfire? Resources to inform wildfire decision making are desperately needed, and they will become increasingly so as wildfires get larger, more severe, and deadlier. It's good to see that the U.S. Forest Service is a collaborator, as they are a key stakeholder. It may be of interest to the project to incorporate incentives for forest treatment other than biomass markets. The direction this tool is moving could have profound impacts on the conversation of where to target forest management treatments. The Pacific Northwest is a key research area, but this work is needed in many regions of the country.

- This is an extremely timely project that links BETO's goals of expanding the bioeconomy with reducing wildfires and forest restoration. This analysis produced several valuable insights, including forest biomass potential, recommendations on forest management practices, and impacts on streams. Further, the cost estimates for forest biomass recovery align well with BETO's focus on assessing the costs of biomaterials. Given the extent to which forest biomass flows are tracked and quantified in this project, it would be extremely helpful to present the GHG impacts of different management practices, perhaps as a component of the decision support tool. It would also be helpful to evaluate the economic impacts of wildfires (and associated benefits of avoiding them) to the extent possible given data limitations.

- This model and project are excellent; they have significant potential to positively impact reforestation after wildfires. Considerations of how the scope of this work could be expanded beyond the Tahoe Central Sierra Initiative. While the goal states that this project will evaluate GHG emissions, GHGs weren't actually covered anywhere. These are important data that should be aggregated and reported. Similarly, the methods used to evaluate ecosystem analysis and habitat suitability were not clearly described and linked. Many individual metrics were presented, but they were not presented in aggregate. Metrics like biodiversity, soil health, etc., could improve the work.

- This project provides important information on synergies among forest management, wildfire management, and energy production. The impact of contributions to agency analyses and decision making is well described. The evaluation of trade-offs among priorities is a key advance that this project offers, as too often evaluations focus on a single performance metric or aligned performance rather than

identifying difficult choices/prioritizations that need to be made. It is great to see that collaborations with other researchers (e.g., Jager et al.) are adding additional dimensions of analysis to these different management regimes. The description of the metrics for quantifying the trade-off analysis do not include any soil characteristics, nutrient leaching/release, or habitat evaluations, which would be affected by biomass removal. It would be useful to include these and other aspects of the ecology in the trade-off analysis, or potentially as part of collaborative projects like that done with Jager et al. Given the high variability of streamflow and its responsiveness to the forest management, soil nutrients are likely to be affected and should be part of the evaluation. Some discussion of scalability of these management approaches in the Pacific Northwest as well as whether there is applicability in other forest systems/regions would be beneficial to understand the full impact and potential of these management regimes.

- This project's focus on woody biomass and forest restoration is strategically aligned with an emerging trend in bioenergy and climate mitigation as well as the imperatives of forest management for wildfire risk and severity mitigation in the western United States. Its approach of modeling impacts from different management strategies in order to quantify the trade-offs between them is a useful framing. It is worth their increasing the detail of their quantification of climate impact and clarifying which of the many elements of this analysis are actually being carried out under the project versus leveraging work and expertise of collaborators.

## PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their valuable and encouraging input. The project team is encouraged by all the positive comments made by the panel. Forest restoration is being used to reduce wildfire risk and has been identified as a potentially significant source of bioenergy; however, additional planning and decision support tools are needed to access economic and environmental sustainability. As noted by the reviewers, there is a growing need for this work as wildfires pose greater threats to society and exacerbate climate change. A decision support tool is vital for weighing the trade-offs of biomass harvests for wildfire reduction. We acknowledge the broad scope of this project, given its size. Each task has a designated lead based on expertise. For the most part, we are utilizing existing models (the Distributed Hydrology Soil Vegetation Model; LANDIS-II for fire, carbon, and forest regrowth; U.S. Forest Service's Forest Vegetation Simulator for operational costs) and input data sets that have been exercised (independently) in the study domain. We chose to use an existing U.S. Forest Service decision support system tool (Ecosystem Management Decision Support, or EMDS) to speed technology transfer. This work builds off a previous PNNL-U.S. Forest Service collaboration (funded by the State of Washington) to develop a tool to estimate the impact of forest restoration on streamflow in the North Central Cascades. We extend this work significantly under this project with detailed consideration of wildfire, merchantable and nonmerchantable (residue for energy) biomass yield, economics, and decision support. Technology transfer has been achieved using these capabilities on follow-on projects. This research considers smoke emissions (i.e., total carbon release and $PM_{2.5}$ and $PM_{10}$) rather than the full suite of GHG emissions. The research will not assume that there are immediate benefits to smoke emissions. Smoke emissions will increase for a period of decades until the effects of 150 years of fire exclusion are minimized. We intend to use weather streams consistent with late 20th century (RCP4.5) and late 21st century predictions for the RCP8.5 GHG emissions scenario on the fully calibrated Distributed Hydrology Soil Vegetation Model and for 100-year LANDIS-II vegetation growth simulations. Our simulated fuel treatments will begin at year 1 and will continue until year 100. Wildfires that exceed a 97th percentile fire weather threshold will be allowed to burn each year. Until the sum of escaped wildfires plus forest and fuel treatments treat a large enough portion of the landscape, we expect emissions to steadily increase. This is a consequence of a fire deficit coupled with a fuel surplus. Until the fuel surplus is adequately depleted, emissions will remain high and then drop off to a metastable condition. Thereafter, we will show the benefits of wildfire smoke emissions reductions through forest thinning and prescribed burning and collecting biomass for energy use, and long-term

wood in service. Rather than using burn probability estimation in our risk assessment, we are modeling flame length probability and crown fire initiation and spread potential. Flashy grass and shrub fuels have the highest burn probability each year, and they release the least emissions; thus, probable burned area is not a useful measure of the effects of treatments on forest mortality or emissions. With high flame lengths, the likelihood of forest burning or reburning is highest, likewise for crown fire initiation and spread potential. Management treatments involving thinning and burning reduce fuel ladders and surface fuels, thereby reducing flame lengths and crown fire potential. These will be our metrics modeled over 100 years. We will be able to show land sector carbon stocks (and perhaps soil carbon) associated with each treatment year. Changes in streamflow volume and timing along with water temperature can be compared to regulatory requirements as an indicator of habitat suitability, or this information can be used in more detailed modeling such as that by Jager et al. The general hydrologic information could also be used to examine the impacts of streamflow variability on soil nutrients, or the impact of increased streamflow on riparian invasive plant species; however, these investigations are currently beyond our current scope of work.

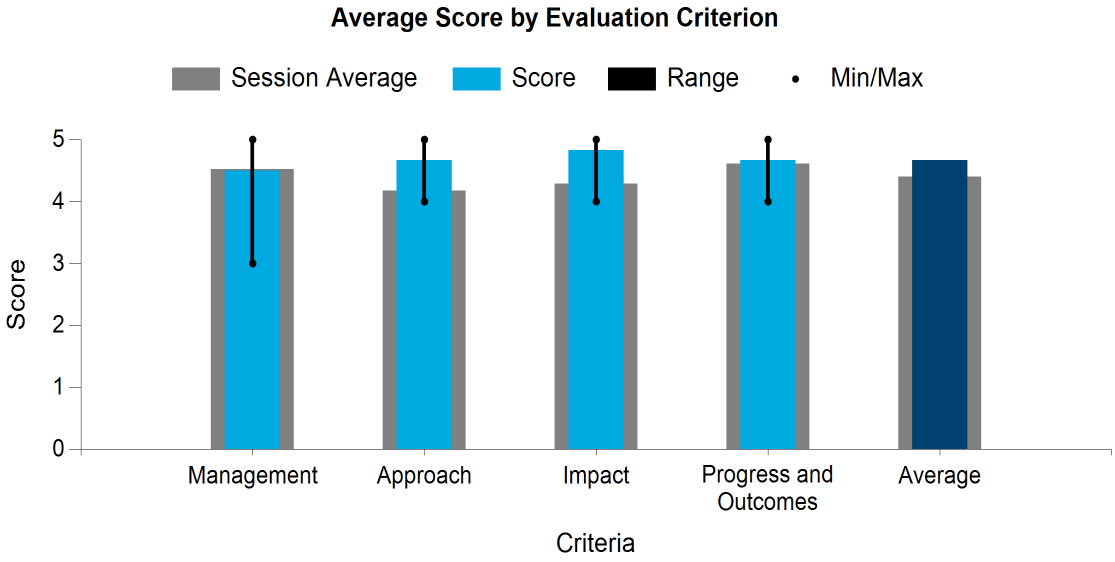
# ANALYSIS OF THE BIOECONOMY FOR CARBON DRAWDOWN

## Lawrence Livermore National Laboratory

### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 4.1.1.80 |
| Presenter(s): | AJ Simon |
| Project Start Date: | 09/30/2019 |
| Planned Project End Date: | 09/29/2022 |
| Total DOE Funding: | $600,000 |

The objective of this project is to identify the conditions under which bioeconomy pathways are fundamentally carbon-negative and value-positive. This project is an outgrowth of an FY 2019 analysis seed project that assessed the breadth of opportunity to remove carbon from the atmosphere with bioeconomy-based technologies. In FY 2020–2022, we will extend and refine these analyses to cover a larger section of the technological possibilities. Specifically, we will construct a library of detailed analyses of the major classes of bioeconomy technology pathways that could contribute to carbon drawdown, such as bioenergy carbon capture and storage, biofuels production with carbon capture and storage, synthesis of durable and nondurable bioproducts with and without carbon capture and storage, and bioenergy and bioproduct pathways with biochar and other immobilized carbon as a product or a byproduct. We will analyze variations on these pathways, including feedstock/agricultural practices that enhance carbon drawdown, conversion technology (combustion, gasification, pyrolysis, etc.), the fate(s) of products and byproducts (including long-lived wood products), and how their carbon drawdown potential varies with product lifetime.



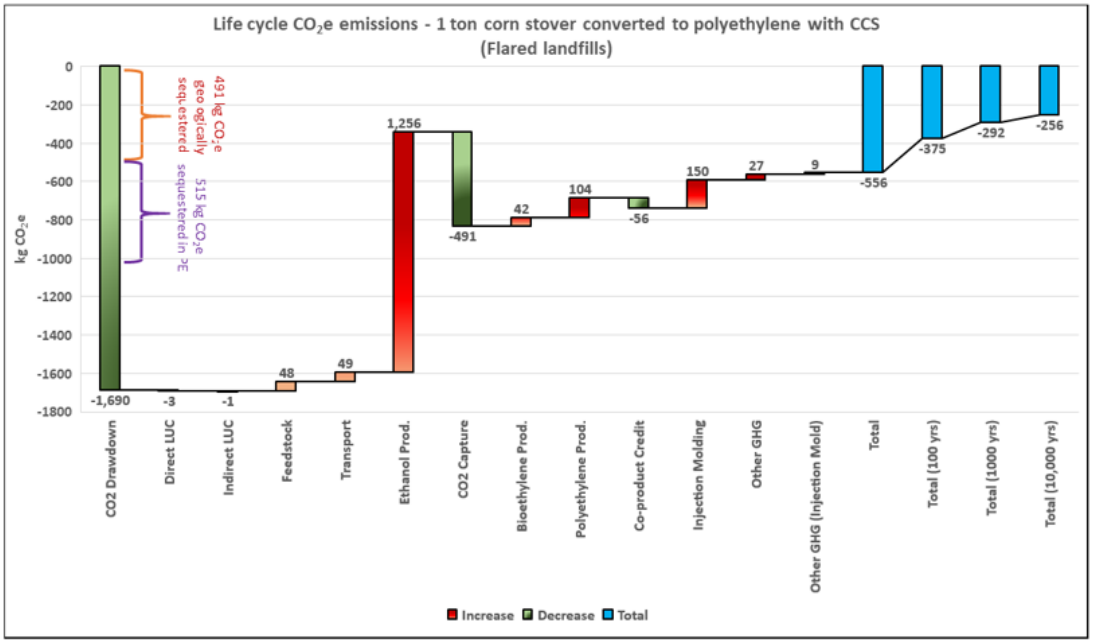



*Photo courtesy of LLNL*

## COMMENTS

- This is an exciting and much-needed project, given the goals of BETO and the current research portfolio. The management was sufficiently communicated. Sufficient progress was reported, and the team was responsive to suggestions incorporated from previous review. The project aligns with BETO goals and develops sectors thus far underdeveloped, given that current TEA and LCA do not account for atmospheric, biogenic, and sequestered carbon. Despite the nascent nature of this project, the development to date is impressive, and its importance for pushing the energy conversation in new directions was clearly communicated.

- Carbon drawdown is the next big frontier in decarbonization. This project is generating important information about the relative performance of carbon drawdown/sequestration approaches. The visual representation of the data in the Sankey and waterfall diagrams will be very valuable for helping stakeholders understand contributions of different elements of pathways to carbon flows. It is great to see that the data from these efforts will be posted on the KDF so that other researchers can use them. The incorporation of carbon management into GREET discussed during the presentation would be valuable outlet for this work. The GREENSCOPE approach at NREL seems to be a useful complementary analysis to ensure that pathway carbon drawdown is not leading to trade-offs with other sustainability performance metrics, and it could offer additional collaboration opportunities. The comparison of multiple diverse pathways on a feedstock unit basis is very helpful for considering how to best allocate resources to maximize drawdown. The consideration of other metrics for comparison would be helpful (e.g., the suggested approach of addressing metrics on a per unit of carbon basis).

- The area of negative emissions technologies for deep decarbonization is very important, and I applaud this team's (and BETO's) focus on it given the analytical challenges posed by biogenic carbon accounting. Some of the technologies under consideration (e.g., biomass cofiring) do not seem necessarily carbon negative, however, without fugitive methane avoidance or carbon capture and storage. One small note: Given Paul Hawken's very able communication around his project drawdown, there is public awareness around that term; however, that team's definition of the term is different

(focusing on net emissions reduction rather than necessarily negative emissions). This could pose a messaging challenge.

- This is a magnificent project, and I'm glad to see the office prioritizing this work. I don't see how this work is being used by BETO, and it might be good to identify a more robust outlet for how the Analysis team can use this work (we don't want it to just float into the ether). Any way this work can be used to inform BETO publications would be wise. One way the drawdown analysis can improve is by factoring in other environmental indicators. It already did a good job of factoring in economic trade-offs. But there can be enormous trade-offs with using biomass for carbon sequestration—even planting trees can have deleterious effects on biodiversity. This may be a good opportunity to partner with GREENSCOPE. On that note, this work could gain depth from soliciting input from the environmental nonprofit community. The distinction of focusing on carbon that will remain sequestered (rather than just utilized) is a strong characteristic and well worth adhering to.

- This is an important project because it draws from so many disparate work streams, harmonizes their findings, and presents critical findings relevant to BETO's goals, as well as to benefit outside researchers and policymakers. The project has a clear, defined approach for which bioeconomy pathways they seek to incorporate into their framework and what their research needs are to integrate TEAs and LCAs into that framework on a consistent basis. The outcomes from this project are insight-rich and would be highly relevant to policymakers and BETO's mission. The project performers met the project goal across several different measures, illustrating the economy-wide potential for carbon drawdown but also by presenting a per-technology comparison of carbon drawdown potential. The incorporation of techno-economics and life cycle results into the analysis here illustrate excellent use of the modeling resources within BETO by recontextualizing them into the carbon drawdown framework.

- This is important work to support carbon capture, utilization, and storage, as well as carbon drawdown. While a few partners were mentioned, the impact could be far greater with engagement of more stakeholders. I appreciate that the PI is thinking of making this work accessible in many ways, from publishing your own code on GitHub, to sharing with models that you work with, such as GREET. It would be helpful to clarify these impacts in a chart or a set of deliverables.

## PI RESPONSE TO REVIEWER COMMENTS

- The project team appreciates the recommendations of the reviewers to formalize our collaborations, and we will look into ways of doing so. We also appreciate that the reviewers identified complementary aspects of our work with project GREENSCOPE at NREL, and we will reach out to NREL staff to explore ways to enhance each other's work.

# BIOECONOMY SCENARIO ANALYSIS AND MODELING

## National Renewable Energy Laboratory

### PROJECT DESCRIPTION

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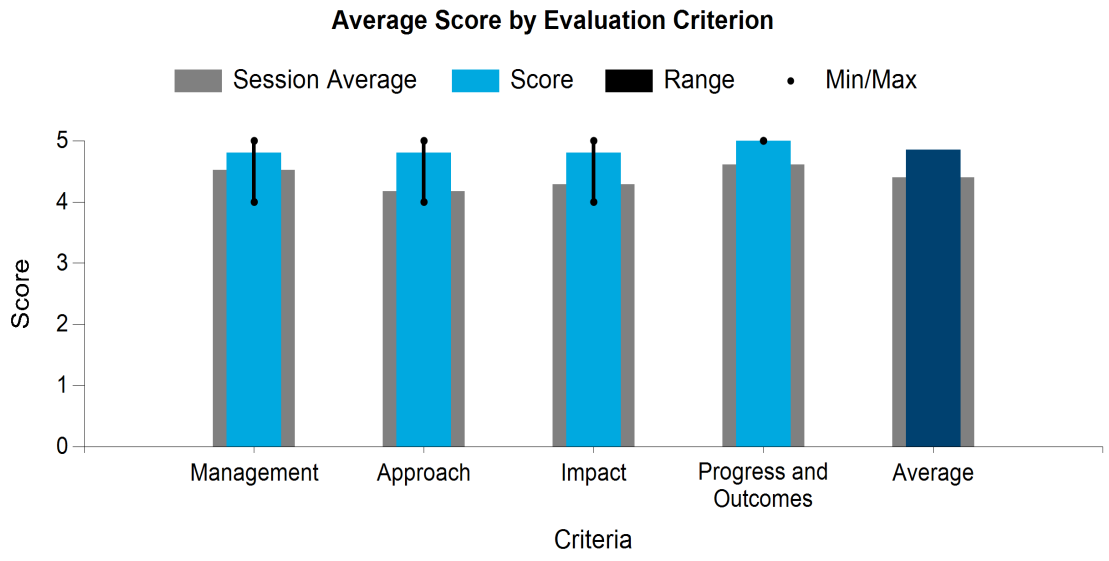
|---|---|
| WBS: | 4.1.2.32 |
| Presenter(s): | Emily Newes |
| Project Start Date: | 10/01/2020 |
| Planned Project End Date: | 09/30/2023 |
| Total DOE Funding: | $1,350,000 |

The Bioeconomy Scenario Analysis project uses systems thinking and analysis to assess current and/or prospective techno-economics, R&D, deployment strategies, policy, and market conditions and their impact on the potential development trajectories of the bioenergy industry over time. Results from this project include identification of opportunities and constraints to industrial development, quantification of multiple metrics (energy, economic, environmental) and informing researchers, decision makers, and industry of the steps needed for a sustainable, nationwide biofuels industry. Analyses from this project enable the creation of a bioenergy industry by (1) inciting policymakers to explore scenarios for nationwide biofuels production, identifying policy actions consistent with pathways for growth; (2) improving industry's understanding of industry growth potential under different technology and investment conditions, better targeting their development efforts; and (3) providing universities and other interested stakeholders with tools and analyses that can be adapted to meet research and teaching objectives, connecting students with careers that build the industry.

One of the many modeling tools used in this project, the Biomass Scenario Model (BSM) is a publicly available, unique, validated, SOA, award-winning, fourth-generation model of the domestic biofuels supply chain that explicitly focuses on how and under what conditions biofuel technologies might be deployed to contribute to the U.S. transportation energy sector. We use models like the BSM to examine the implications of policies and incentives as well as their potential side effects. The BSM uses a system-dynamics simulation to model dynamic interactions and transitions across the supply chain; it tracks the deployment of biofuels given industrial learning and the reaction of the investment community in the context of land availability, projected oil markets, consumer demand for biofuels, and government policies over time. Under expected market conditions, analyses using the BSM suggest that the biofuels industry may require significant external actions in the early years to thrive. Interventions that accelerate the industrial learning process (e.g., operation of precommercial and commercial facilities) have been identified as having strong influence in starting the growth of a commercial biofuel industry. Policies that are coordinated across the whole supply chain in BSM foster the growth of the biofuels industry, and the production of tens of billions of gallons of biofuels may occur under sufficiently favorable conditions.


Average Score by Evaluation Criterion
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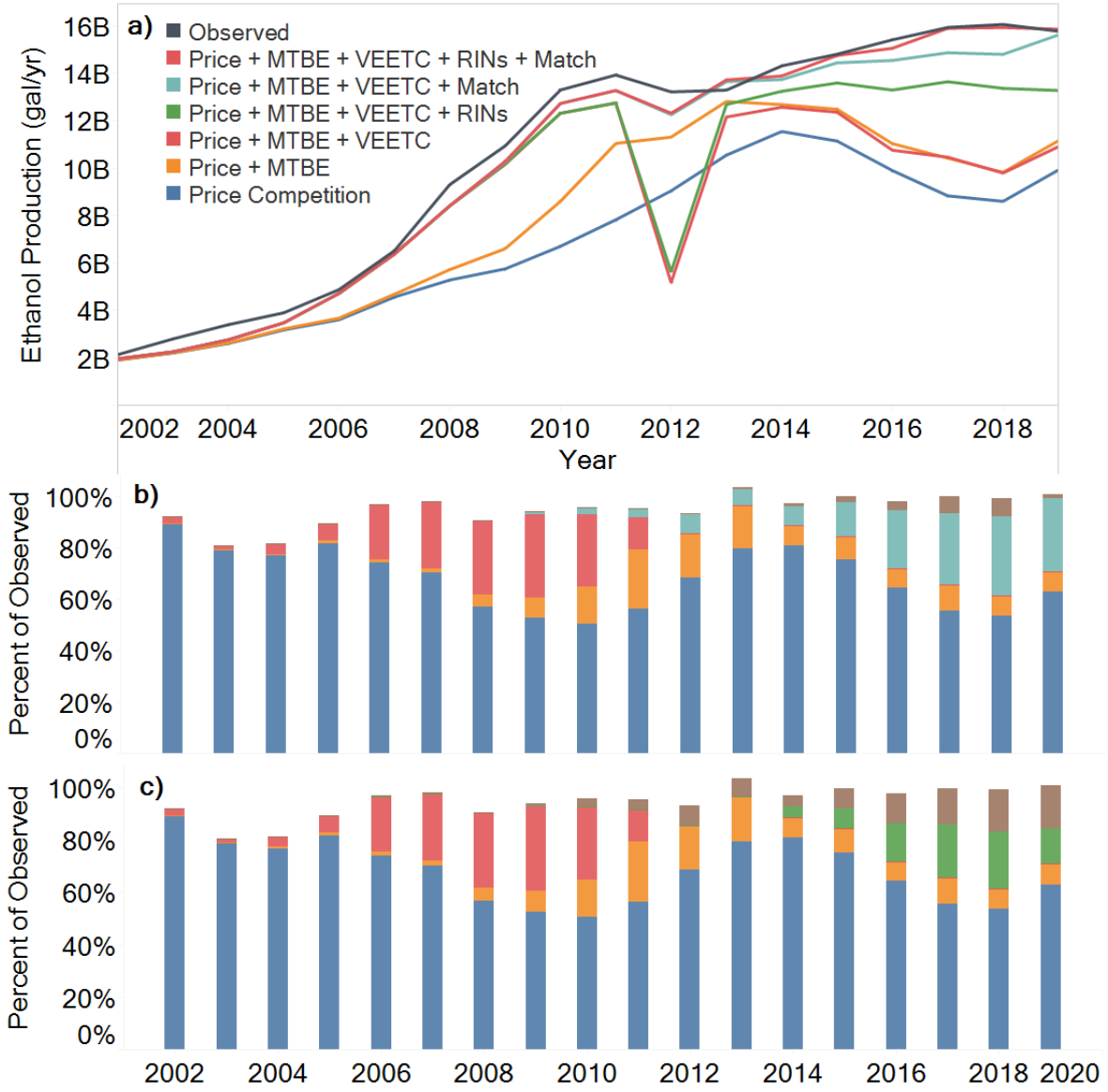


*Photo courtesy of NREL*

## COMMENTS

- The management, risk, mitigation strategies, and communication were all very well communicated here. I appreciated that this project emphasizes the importance of and engages with policy, using the BSM to gauge the impact of various policy scenarios. In this way, the BSM seems to offer innovation within the broader portfolio as well as potentially significant impacts for collaborators. The progress and outcomes comply with the project's stated goals and applications.

- The project approach has substantial merit to advance the SOA and is relevant to the BETO Program and Technology Area goals. The system dynamics modeling was clearly described, including the calibration and validation. The project approach has significant potential for innovation in its application. The project has a clear management plan and a successful implementation strategy. The risk identification and mitigation strategies were well identified and seem to have been managed. The project provides routes for communication and collaboration with relevant stakeholders. The collaborations and

connections with other national lab models are excellent and comprehensive. Stakeholder engagement of others in academia and industry could improve the impact and reach of the project.

- This is an important project, and it seems as though a vital metric of success is whether the information gets into the hands of policymakers. It's good to see robust stakeholder outreach. This is a project where the focus on environmental equity will be a particularly valuable metric.

- This project is well positioned to provide strategic insights to key stakeholders, such as policy audiences. Its backcasting to project the impact of the renewable fuel standard for the report to Congress is a great example of this impact. I further appreciate its strategic approach to key pinch points (e.g., infrastructure for sustainable aviation fuel for an airports consortium). It would be good to see more clarity around who target policy audiences are and strategy around how to reach them and influence their decisions. Further, in such a complex model, how is the team quantifying, addressing, and communicating uncertainty?

- This project occupies an important niche within the program areas portfolio while also drawing on valuable resources and models elsewhere within BETO to reduce redundancy. The insight provided by the BSM on the deployment of new pathways in the bioeconomy is novel and can help guide strategic decision making. The project team was very clear on the risks inherent to this modeling approach and developed an impressive risk mitigation approach based on frequent stakeholder feedback and model calibration. Their efforts to ensure that the results of the modeling are transparent, reproducible, and consistent with historical data should be commended. The use of BSM by industry stakeholders as well as policymakers points to both the importance of this work as well as its analytical rigor.

## PI RESPONSE TO REVIEWER COMMENTS

- We appreciate the numerous positive comments that the reviewers offered and are grateful to the reviewers for their time, consideration, and support. We are glad that the reviewers found useful the overview of project approach, management, and risk mitigation. We are always cognizant of making model results comparable, transparent, and reproducible, and we are pleased that our attention to collaboration, outreach, adaptability, and defensibility of inputs is apparent. We too feel that our collaboration with bioenergy stakeholders has been impactful in helping them think through different investment and policy decisions. We will continue to network with academia and industry to build more relationships and increase the impact and reach of our work. Historically, our target policy audience was the U.S. federal government agencies and journal readers; however, that has been shifting recently to include industry. We are working now on a strategy to broaden our dissemination of analysis results. While not a primary focus of this project, we will be looking into ways of incorporating environmental justice into our model outputs. This is especially true as we develop the Regional Bioenergy and Economy Model (RBEM). In addition to RBEM, team members are involved to varying degrees in projects that address environmental justice. We anticipate that knowledge gained in these areas will help to inform our efforts in this project. We have completed extensive sensitivity analyses of the BSM, upon which uncertainty analyses may be performed. Pervasive uncertainties regarding many aspects of the biomass-to-bioenergy supply chain persist. The strategies around the calibration and validation of our models described in the project approach build confidence in but cannot dispel these uncertainties. We are limited by data availability because we are looking into the future for processes that don't fully exist today. To address this challenge, studies with the BSM routinely test hundreds to thousands of unique conditions, based on combinations or statistical samples of inputs, and we develop and improve the computational infrastructure to perform and track large numbers of simulations. We incorporate the ranges of results that are included in some of the model inputs, such as techno-economic factors and feedstock production levels for many of our model runs. Instead of making predictions, we strive to report results that are robust to those uncertainties. Reporting may highlight a small number of simulations to illustrate system behaviors, while large numbers of simulations in the background provide data on the prevalence of those behaviors. We continue to look for more effective ways of quantifying, addressing, and communicating uncertainty in our models.

# BIOFUELS NATIONAL STRATEGIC BENEFITS ANALYSIS

## Oak Ridge National Laboratory

### PROJECT DESCRIPTION

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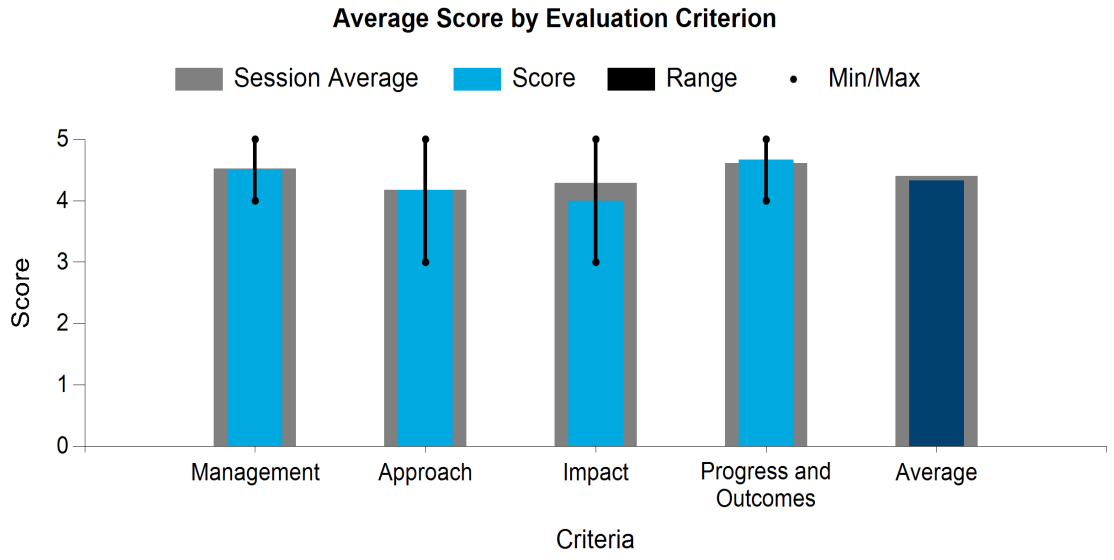
|---|---|
| WBS: | 4.1.2.41 |
| Presenter(s): | Paul Leiby; Rocio Uria Martinez |
| Project Start Date: | 10/01/2018 |
| Planned Project End Date: | 09/30/2021 |
| Total DOE Funding: | $650,000 |

This project helps DOE assess, quantify, and explain the economic and energy security/resilience benefits of biofuels and bioproducts. It identifies opportunities and contributions of bioenergy and bioproducts to advance economic welfare and improve resilience in the context of changing market conditions and incentives. To meet its objectives, the project approach is twofold. First, BioTrans—a mathematical programming model that optimizes long-run investment and operation decisions along the U.S. biofuel/bioproduct supply chain—is used to simulate scenarios of interest regarding market conditions, policy changes, and supply chain configurations. Second, empirical analysis of historical data is conducted to analyze the dynamics of the price relationship between biofuels/bioproducts and the corresponding petroleum-based incumbents. During the current merit review cycle (FY 2019–2021), this project focused on the economic analysis of various opportunities for bioeconomy growth: first, the potential value of biofuel to improve light-duty vehicle fuel economy through an octane performance standard; second, the role of bioproducts to support growth and improve resilience of the U.S. advanced biofuel industry; and third, opportunities and challenges for biofuels in the marine shipping sector. Additionally, the project team tested the potential benefits from high-performance computing implementations of the BioTrans model to enable richer scenario sets and increased model granularity.




### COMMENTS

- A key strength of this study is not only its insight but also the multiple levels of applicability, whether to inform individual producers of product slate shifts, and also to inform broader, national-level policy considerations on the bioeconomy; however, there appears to be too much focus on ethanol in lieu of more relevant long-term analyses. the focus on octane standard seems a bit outdated compared to this model's potential to evaluate sustainable aviation fuels and bio-based materials.

- Although this is good research, I struggle to see how this work is made useful. The PI mentioned presenting results at industry conferences, which is good. Finding ways to move the analysis from the theoretical to the applied is key for this project's success.

- The project analyses are impressive and offer depth on the topics they explore, complementing other efforts in the BETO portfolio that remain largely high level. What was less clear was the target audience for these analyses, and any stakeholder involvement in defining what information would be most useful. Making this connection seems critical for the communication of this important research, especially as the project moves to incorporate another sector (marine) going forward.

- This project brings a strong expertise in fuel markets to the BETO portfolio. The expertise of this PI is seemingly unique within the BETO portfolio. Research questions such as those being asked under this project (e.g., what would be the expected impact on fuel markets from a proposed octane performance standard) are very policy relevant. Enough so that I encourage BETO and this project's PI to work on outreach to relevant policy audiences to ensure that this tool is applied where it can be effective. It is easy to imagine entities such as the Congressional Research Service using this tool or contracting with the project team on one-off analyses in support of ongoing legislative deliberations. This would require that the work be structured to be nimble and able to answer new questions quickly rather than built from scratch for each new analysis. Presumably there are models like this one already being used in the private sector because there's significant money to be made from projecting future fuel price. What distinguishes this work from other tools that are available?

- This project is very important for providing the economic and security justification of the bioeconomy, which brings more stakeholders to the table and provides long-term justification for investment in the bioeconomy. The approach is laid out clearly with a helpful comparison of the options for addressing different components and how the current project is addressing them. The analysis of the value of bioproducts for biorefineries is an important contribution because it shows that if a biorefinery has product slate flexibility, then the fluctuations in petroleum prices are not as problematic for the continued production of bio-based fuels and other materials. One of the challenges for the reviewers was in understanding how this model differs from other economy-wide models in and outside the BETO portfolio (e.g., Global Change Analysis Model [GCAM], Global Trade Analysis Project [GTAP])—it would be helpful for future presentations to clarify the distinctions in more detail. The analysis on an octane performance standard was very interesting hypothetically, but based on the presentation, it appears that its utility was superseded by events because the octane performance standard stopped being pursued between the time the analysis plan was developed and the completion of the work. It would be helpful as the model matures for the analysis responsiveness to be faster/more nimble so that the modeling team can respond to policy questions more rapidly. Given the potential interest in these analyses from policymakers and nonresearchers, the team should consider how to provide this information to different audiences rather than focus primarily on peer-reviewed journal articles.

- This tool to evaluate the fuel market impacts of biofuel is well developed in its approach. The results certainly will be useful to the biofuels community. The PI should clarify how this model is different from and/or contributes to or collaborates with other computable general equilibrium models that are available. It seems that only ORNL and BETO marine fuels teams were engaged in the collaboration. The addition of other relevant stakeholders would benefit the development and impact of the model. Stakeholder engagement can improve the model development and user experience and increase potential that the model is used by stakeholders.

## PI RESPONSE TO REVIEWER COMMENTS

- The team thanks the Review Panel for their positive comments regarding project content and relevance and their thoughtful suggestions on how to maximize project impact. A first set of comments pointed to the need for a clearer explanation of differences between our market equilibrium model (BioTrans) and

other models using the same general approach. A potentially useful way to compare these models is in terms of scope and level of detail. Rather than covering all sectors of the economy as other models (e.g., GCAM, GTAP) do, BioTrans focuses on the markets along the bioeconomy supply chain and their substitution and complementarity relationships with petroleum products. The representation of foresight in the model is another example of a modeling trade-off between detail and computation cost. Economy-wide market equilibrium models are typically treated as dynamic recursive models that solve for one period at a time and do not account for intertemporal linkages. BioTrans assumes imperfect foresight as a default, and it is capable of a range of foresight between myopia (static/recursive) and full foresight. The 30-year model is solved in 6-year windows where the solution window is rolled 1 year forward each time (i.e., market participants see 6 years out and update their expectations every year). This treatment of foresight allows modeling market responses to shocks in a more nuanced way than a no-foresight or a perfect foresight model would. Our attention to volatility, shocks, and the flexibility/resilience of bioenergy and fuel systems are unique focus areas facilitated by our approach. Moreover, we believe a strength of our project is the combination of market equilibrium modeling with empirical analysis of historical market data to inform our model input parameter choices. We will develop some material (slides or a short write-up) highlighting differences between our modeling tools and other bioenergy models to include in future presentations.

- Reviewers suggested the need to engage more stakeholders, broaden the target audience of the project, and "move the analysis from the theoretical to the applied." The comments of the reviewers in this regard are very well-taken and very much in line with our goals at this point. Our initial target audiences have been BETO and other researchers in energy economics/bioenergy, and our deliverables (peer-reviewed articles, technical reports/slide decks to BETO) have reflected that view; however, we strive to consider stakeholder views collected as part of larger BETO projects, regulatory proceedings, and conferences/webinars. As our model matures, our focus moves from the more technical aspects of model development to making the model results more widely known and actionable. We will actively consider how to better reach audiences of bioeconomy participants (farmers, marine shippers, policymakers, investors) as we plan our future deliverables and dissemination strategy. Apart from expanded direct conversations with stakeholders, writing articles for trade magazines and participating in industry-led events are two ways we plan to reach those audiences.

- The reviewers also called for the project to become more nimble in terms of the topics it considers and raise the concern of excessive focus on ethanol. We agree with the importance/value of being nimble, in keeping with changing technological options and evolving programmatic priorities. The content of the model and questions of analysis have evolved over time to stay in synch with the priorities in the BETO Multi-Year Program Plan. Aviation and marine fuels are gaining increasing relevance for BETO, and we are in the process of redirecting our analysis toward them, in connection with the larger DOE Office of Energy Efficiency and Renewable Energy (EERE) research community and the U.S. Department of Transportation/U.S. Maritime Administration. We do believe it is important to continue including light-duty vehicle ethanol/biofuel use in the model because it remains a large biomass use over the intermediate term (transitional period) and may influence biomass volume availability and cost for other sectors. Our goal is for the project to offer tools to assess bioenergy market outcomes in a variety of scenarios, including alternative policy incentives/policy designs, and to have a framework that is sufficiently flexible to be able to look at many potential policies without requiring extensive modifications of model structure. We note that, operationally, we promote the flexibility of our tools and approaches through the modular separation of data (domain of application) versus analysis (the reusable model structure and estimation routines) and through a well-documented/replicable code and workflow.

- The BioTrans model is version-controlled in GitLab and can be shared with interested stakeholders should they request it, but it is not publicly available yet. All associated R-based empirical analyses are similarly documented and replicable. At this point, the full version of the model is written in commercial software (General Algebraic Modeling Language, or GAMS) and uses commercial solvers, so only users that have a license to that software could run it; however, one of the goals and benefits of our current process of transition to high-performance computing is that the high-performance computing version uses open-source software and solvers, making it more widely accessible.

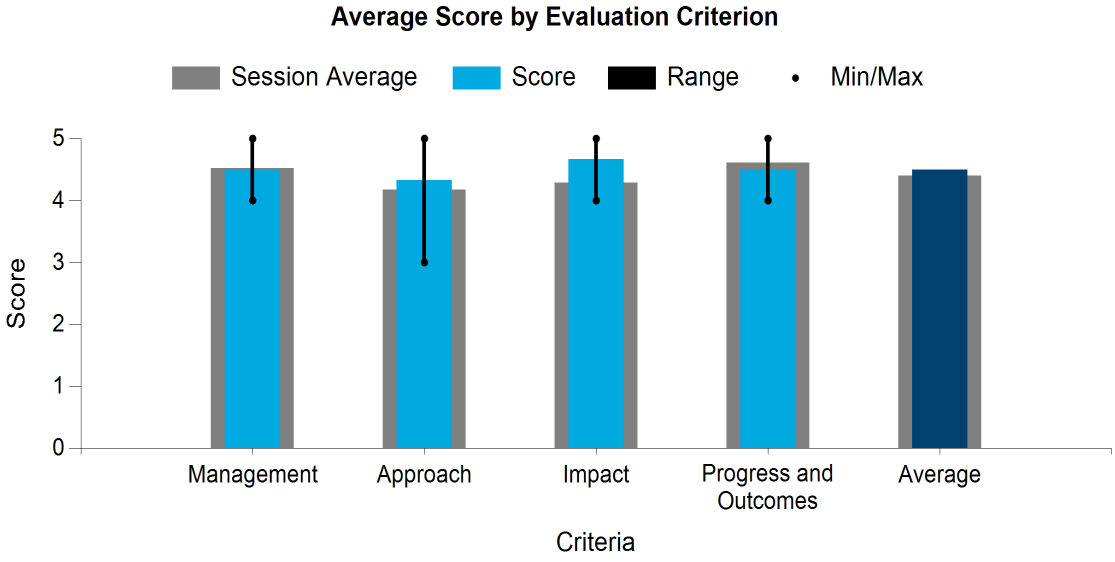
# GCAM BIOENERGY AND LAND USE MODELING AND DIRECTED R&D

## Pacific Northwest National Laboratory

### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 4.1.2.50 |
| Presenter(s): | Marshall Wise |
| Project Start Date: | 10/01/2018 |
| Planned Project End Date: | 09/30/2021 |
| Total DOE Funding: | $475,000 |

This project provides a quantitative analysis of bioenergy in a long-term, multisector context. The PNNL GCAM is a community model of global energy and land use. GCAM has an international user base, and it has been widely used for DOE, EPA, and private industry. GCAM provides complementary insights into TEAs and LCAs in that it gives a long-term, multisectoral economic context for the scale, role, and impact of bioenergy. The project's main challenge is to manage the complexity of modeling detailed bioenergy systems and data within the larger GCAM structure. The focus of this FY 2019–2021 project is to analyze bioenergy in the integrated context of energy, land use, and carbon management. In studying the economics of a system that credits carbon captured for carbon capture, utilization, and storage rather than carbon abated, we found that the carbon capture, utilization, and storage credit system did not favor biopower over fossil power. We are also performing a joint modeling exercise with GCAM and the NREL BSM team in which we share concepts and data while running parallel scenarios of bioenergy and carbon management. The goal is to explore insights gained from using these two models of complementary scope and detail. Finally, in conjunction with a multi-lab BETO team, we are developing modeling methods to explore bioenergy and soil carbon as part of an effort to consider the value of ecosystem services in an integrated analysis of the trade-offs between land and energy.



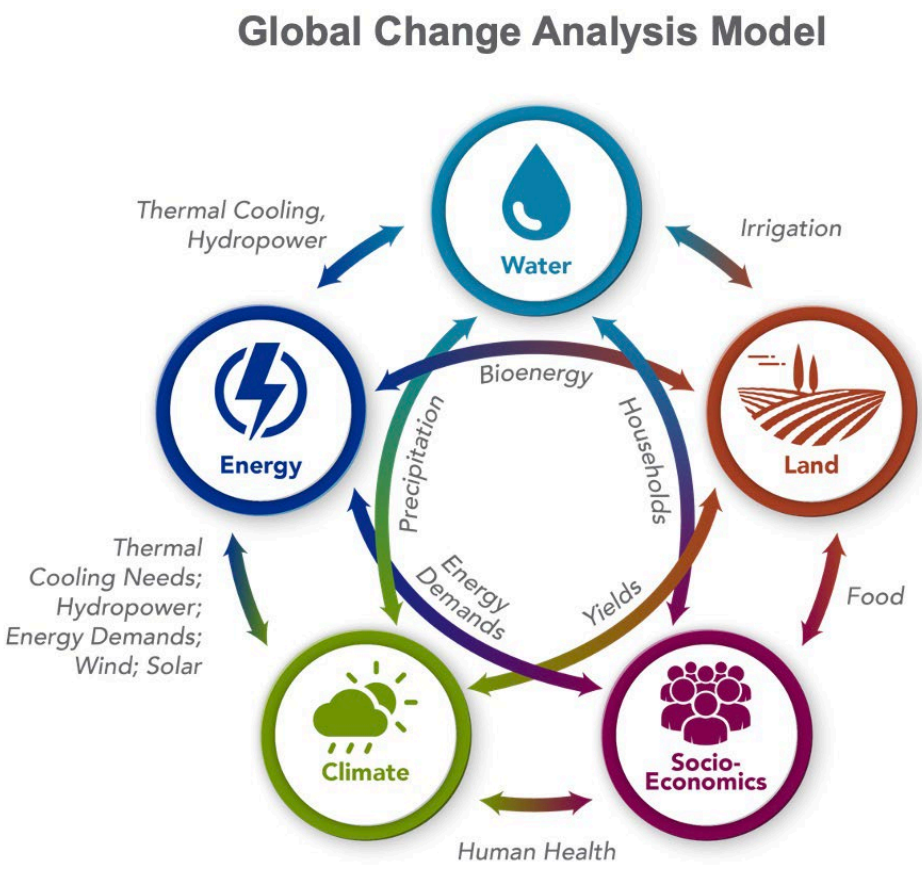



*Photo courtesy of PNNL*

## COMMENTS

- This is another impressive multipronged project within the portfolio. The management plan was successfully articulated, with clear communication pathways and schedules. The project seems to allow for multiple avenues of communication both within the project and with BETO, collaborators, and the open-source user community and an impressive level of transparency and access in addition to the responsibilities of developing and maintaining the GCAM model itself. I appreciated the note that one of the major challenges was defining an appropriate complementary scope and level of detail to provide insights while avoiding unhelpful complexity, which I imagine is a major challenge for all projects playing a similar support/tool-building role. I was encouraged by the inclusion of ecosystem services in the model, though I was left wondering at what scale this aspect would be applied. It seems the inclusion of ecosystem services would offer helpful insight at higher resolutions in the U.S. context. If ecosystem services will be incorporated into GCAM-USA, I would encourage the project performers to consider communicating with other projects in the portfolio that are more focused on biodiversity as an ecosystem service. Although this variable may be beyond the scope of GCAM per se, the inclusion of biodiversity ecosystem services in GCAM may drive important feedback loops that influence variables more squarely within the scope, especially at greater spatial resolution.

- Big applause for getting the word out to industry (presenting at the airport consortium). This work relates to the decarbonization project, and it should also consider adding the ecosystem/biodiversity impacts to assessing the water and soil trade-offs of land use change.

- GCAM is an important model that supports bioenergy and the BETO goals. The stakeholder engagement in the project is excellent; hosting an annual meeting specifically for this model is an excellent idea, and it should be adopted by other major national lab models!

- The GCAM project is a particularly valuable component of BETO because it represents the bioeconomy's impacts in a wider, global integrated assessment framework. This allows BETO to assess the role of its portfolio in a broader context, thereby fulfilling an important role. The modeling framework is versatile and can be used to assess important topics such as the 45Q tax credit or the value of ecosystem services. The model's importance is underscored by its usage outside of DOE and its wide user base. In particular, the recent efforts to coordinate modeling runs with the BSM model speak positively of the project team's effort to review their assumptions about biofuel pathway techno-economics and improve their model. It would be helpful to see a similar effort to compare the model assumptions on measurable assumptions such as soil carbon fluxes and feedstock yields.

- The global coverage and user base of this tool make it invaluable, and it is showing its impact through publications and policy application. The strong GCAM/BSM interaction leverages each tool's/team's capabilities and could reduce risk of duplicative effort. This is worth further promoting and clarifying relative roles. It is not clear whether the goal of this project is to maintain and build GCAM or to extend its capability and applications? Further, in such an extremely uncertain type of analysis, it would be good to see more recognition of uncertainty and clarity around how it is managed and communicated. Finally, I would have liked to see the PI clarify pathways for impact.

- Two key advances in the review period include alignment with the BSM and enabling use of GCAM-USA in BETO analyses. These efforts enhance the utility of the tool and provide more consistency among BETO analyses. The BSM/GCAM alignment leverages complementarities and reduces the risk of duplicative efforts. Adding economic value of ecosystem services would be excellent. The flexibility the PI described with regard to being able to use existing governmental or market carbon prices or to set targets and identify carbon prices to meet that will be very useful. Regarding the analysis of ecosystem services, it is important to clarify the distinctions of this modeling efforts relative to other similar models, such as GTAP-Bio, and the rationale for developing BETO's own tool. Further explanation of how this model differs from or contributes to others within the BETO portfolio (e.g., Integrated Life Cycle Sustainability Analysis tool, BioVest modeling collaboration, BioTrans) would be helpful. Concrete metrics such as the number of users, downloads, papers, etc., provide useful insight into the adoption of this tool. No explanation is provided of the peer review process for the model itself; this would be helpful to understand how thoroughly this model is vetted.

## PI RESPONSE TO REVIEWER COMMENTS

- Thank you to all the reviewers for your helpful comments and insightful questions. We too are very optimistic that the pieces have come together for us to be able to analyze bioenergy in the context of ecosystems services—in addition to its potential for carbon management in the energy system. In addition to Marshall Wise, the PI, much credit for the progress during the last 2 years on this project goes to Candelaria Bergero at PNNL, who will be lead and coauthor on forthcoming papers from this work. There are too many members to mention from the PNNL GCAM team who have built this capability over the years. For their specific efforts on modeling land use and agriculture, we acknowledge Kate Calvin, Page Kyle, Abigail Snyder, and Stephanie Waldhoff of PNNL. And for their foundational and continued efforts in developing the GCAM model as a whole, we acknowledge Jae Edmonds, Sonny Kim, and Pralit Patel. Within the scope of GCAM itself, we are best equipped to model the ecosystem services that have outcomes that can be clearly physically measured in a way that can affect the economic decision making. Ecosystem impacts that affect crop yields have a direct physical and economic impact on land use and agricultural decisions. Ecosystem impacts that affect water retention also affect yield as well as the demand for irrigation water, which can also be directly considered in GCAM. In addition, impacts on soil carbon can be valued directly as part of an incentive to

increase carbon stored. Biodiversity may be something that is beyond the scope and resolution of GCAM or GCAM-USA. But as part of discussions of the BETO Sustainable Land Management group, we are in regular discussion with staff using models like Oak Ridge's BioVest analysis that consider more factors at greater resolution. We do not have complete historical statistics on the total number of GCAM model downloads. By looking at traffic on the GitHub site for GCAM, we estimate the total number to be in the thousands. We have collaborated with users in dozens of countries during the last decade. In terms of model review, the initial peer review process is internal to PNNL. The BETO PI is on the GCAM core model review leadership team. All data, methodologies, and impacts on model results must be reviewed and approved before incorporation into the GCAM official model. All inputs must also be documented. The appropriateness of the level of detail for inclusion into GCAM must be defended, which is judged by the impact on the analysis as well as implementation feasibility and tractability. Impacts on model solution and size are always important.

In terms of outside validation, the journal peer review process for our published analysis is a key indicator of the quality of modeling. Recently, we have been publishing model description papers in journals devoted to model review such as *Geoscientific Model Development*. We also participate in most of the Stanford Energy Modeling Forum studies that involve multisectoral energy models. Our team has much experience with and respect for modeling efforts such as GTAP-Bio as well as Integrated Assessment Models that explore biofuels, land use, and the economy. We differ from computable general equilibrium models such as GTAP in that all of our modeling of technologies and processes is done in physical units rather than more abstractly with economic production functions that operate in monetary units. GTAP and other economic models are better equipped than GCAM to consider broader impacts of changes on near-term international trade as well as on the overall economy. As to the family of integrated assessment models, there is a heterogeneity of approaches that itself lends to complementary insights. GCAM's solution approach is nonlinear market equilibrium, which gives different insights than models that are based on linear optimization. GCAM also differs from some in the approach of modeling the potential for economic expansion into natural lands for bioenergy as a scenario assumption rather than assuming it is not allowed. In terms of the coordination with the BSM, we are learning from the complementary perspectives about scale and rates of expansion. That may lead to more precision in specifying technology parameters in GCAM that reflect shorter-term considerations that are not always captured well in GCAM.

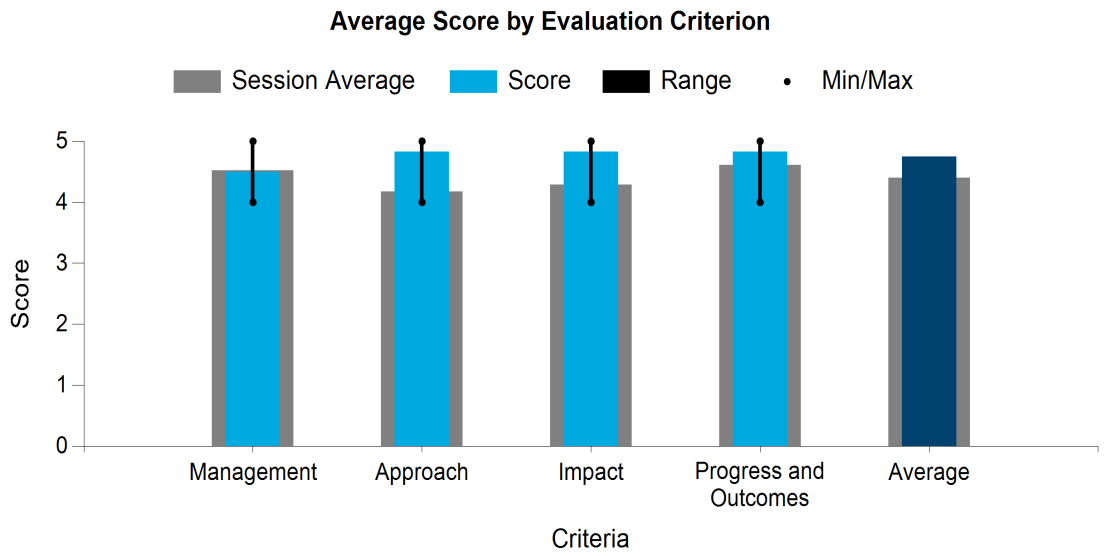
# WATER RESOURCE MANAGEMENT FOR BIOENERGY AND BIOPRODUCTS

## Argonne National Laboratory

### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 4.2.1.10 |
| Presenter(s): | May Wu |
| Project Start Date: | 10/01/2020 |
| Planned Project End Date: | 09/30/2023 |
| Total DOE Funding: | $1,500,000 |

This project aims to develop science-based tools and metrics for an improved understanding of the relationships between biofuel production and water intensity, regional freshwater availability, water quality, implication of alternative water use, and trade-offs. The objectives are achieved by three tasks: (1) develop models and analysis to estimate the water footprint of cellulosic and algae biofuel pathways and water availability at the regional, state, and county level; (2) develop watershed models to simulate landscape design with conservation practices using biomass and estimate cost benefits to water quality at the watershed scale; and (3) analyze biorefinery water management and explore reclaimed water use for bioenergy. The project delivers a set of analyses and data inventory to illustrate the impacts of water use and availability in future cellulosic and algae scenarios, available in the spatially explicit WATER model. The watershed modeling work provides economic and environmental cost-benefit analyses. These results feed to BETO's R&D activities to support informed decision making by stakeholders in collaboration with GREENSCOPE (NREL), Supply Chain Sustainability Assessment, and GREET.



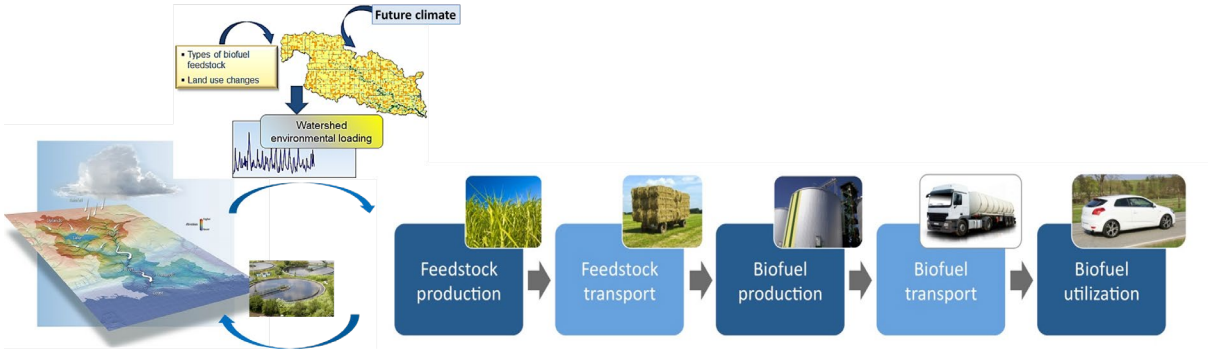



*Photo courtesy of ANL*

## COMMENTS

- The project contributes a solid effort on water expertise, and its contribution to the overall BETO portfolio was clearly communicated through this presentation. There are certainly benefits to the clear delineations created through resource expertise in research groups, and the presentation helpfully identified the diverse avenues for collaboration that bolster projects across BETO and beyond. The baseline analysis for the algae pond/reclaimed water aspect of the project seems a particularly important effort, and it is well executed. The trade-offs and efficiencies inherent in using reclaimed water were clearly communicated, and later more thoroughly elaborated in the Q&A, indicating an innovative, though realistic (and therefore more useful) vision of implementation. The list of deliverables since the 2019 Peer Review was impressive. This is certainly a crucial and cross-cutting component of the BETO portfolio.

- This is a great project. Of the stakeholders consulted, it would be good to see environmental NGOs added to the list to facilitate public acceptance of bioenergy.

- This project fills an important gap in many DOE BETO projects: water quality and water footprinting tools that are clearly defined (i.e., what is included in the water footprint) will help many tools improve their sustainability assessment. The types of collaborators seem quite extensive. The USDA Agricultural Research Service folks have many different water models (often for irrigation); have you connected with them? For the algae project, are you collaborating with the big hubs (e.g., Arizona State University)?

- This project provides a very comprehensive assessment of the water use impacts of biomass production. The project not only provides a geospatial assessment of water resources but also can provide more targeted assessments of water availability and resource use for specific bioenergy pathways, linking effectively with other projects. The work appears to be well coordinated with some parts of the portfolio, particularly the ANTARES integrated land management effort and GREET. This effort has been utilized to inform policymaking (renewable fuel standard evaluation) and by industry to assess its own performance.

- This project team has developed deep expertise in the water/bioenergy nexus. They appear to be a node for water impacts in the portfolio, and they should be leveraged to support other efforts that seek to address watershed-scale quality and quantity impacts in a harmonized fashion. This would leverage existing capacities as well as better parameterizing water modeling with ground-truthed data sets. They already appear well integrated—collaborating, for example, with the PNNL team, extending the site section and optimization conducted by the other team, and bringing in the watershed modeling element. An apparent new focus on reclaimed water is strategic and useful.

- Understanding the water impacts of bioenergy production is critical for the environmental evaluation of different pathways and supply chains. The outline of connections to other models is helpful, and this group can provide key support for a range of other projects regarding water availability and quality. The

reclaimed water analysis for algae production provides a useful perspective on how an algae production system could be sufficiently fed with water; it would be helpful to understand what current uses of reclaimed water are and whether the additional algae production would lead to competition for reclaimed water, or if there are barriers to using the reclaimed water. The finding that water intensity has decreased by 54% in 19 years is remarkable and a testament to the emphasis DOE and others have put on the water-energy nexus to raise awareness of water intensity as a concern. The WATER model appears to use soybean as the only representation of oilseed production, which may not be a good proxy for all oilseeds.

## PI RESPONSE TO REVIEWER COMMENTS

- The project team would like to express our appreciation for the reviewers' effort and input. Your compliments to the achievements, suggestions on potential water resource issues, gaps to be addressed in tools/models, and increased interactions with NGOs and additional projects in BETO's portfolio are extremely valuable to guide the project moving forward. We will take the advice in our work planning to continue addressing the impacts of bioenergy production technologies on water quality and quantity, contributing to BETO's mission of building an economically viable and environmentally sustainable bioeconomy.

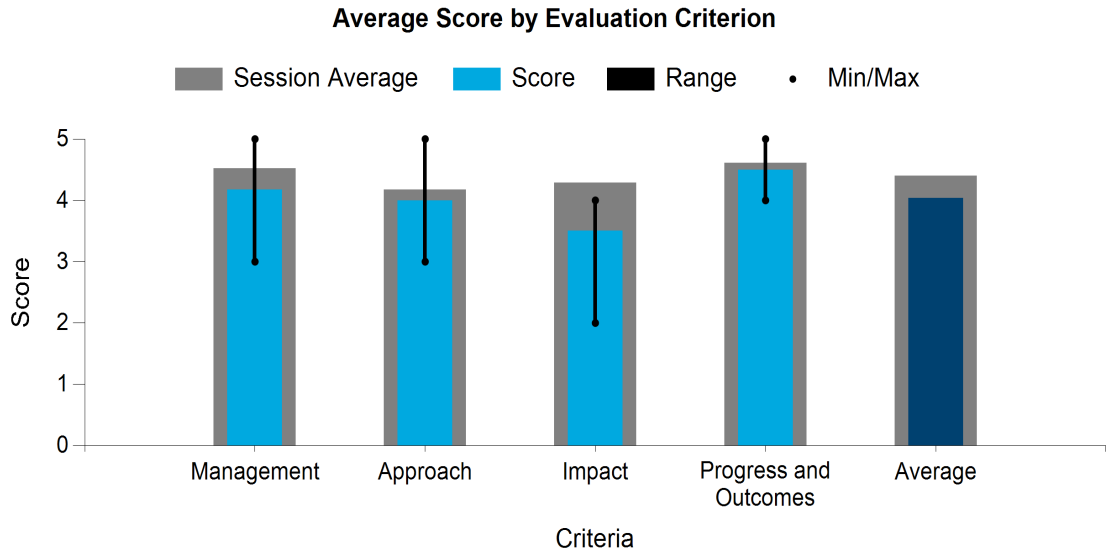
# INTEGRATED LANDSCAPE MANAGEMENT

## Idaho National Laboratory

### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 4.2.1.20 |
| Presenter(s): | Mike Griffel |
| Project Start Date: | 10/01/2020 |
| Planned Project End Date: | 09/30/2023 |
| Total DOE Funding: | $900,000 |

The primary focus of the Integrated Landscape Management project is to develop modeled pathways to augment bioenergy feedstock supply practices with established supply chains, such as traditional agricultural production systems. It is intended that potential pathways yield economic and environmental improvements while supporting an emerging bioeconomy. During the past 2 years, a land parcel scoring and design framework, known as the bioenergy Landscape Environmental Assessment and Design System (bioLEADS), was developed and used to show through modeling that it is possible to reduce herbaceous biomass feedstock access costs, improve revenue, and shift intensive agricultural row crop production away from subfield areas susceptible to erosion and low in soil organic carbon. The purpose of bioLEADS is to automate agricultural field selection and subfield allocation for perennial energy crop production and/or crop residue harvest and collection while incorporating reduced biomass feedstock access costs to support attaining DOE BETO cost targets. To support the development of bioLEADS, advanced geospatial, machine learning, and optimization techniques were utilized to improve industrial relevance and maintain parity with the digital agriculture state of technology. This resulted in the ability to leverage bioLEADS to reduce biomass feedstock access costs by 30% from baseline assumptions outlined in the Herbaceous Feedstock 2017 State of Technology Report while improving aggregate economic revenue at a field level and environmental outcomes. Additionally, the project's modeling capabilities have become a critical component of the larger BETO feedstock analysis modeling ecosystem spanning multiple national laboratories and the Feedstock Technologies and Data Modeling and Analysis platforms. The project has generated or contributed to multiple peer-reviewed publications, generated a patent application, and garnered an R&D 100 award. Starting in FY 2021, modeling efforts have shifted toward expanding Integrated Landscape Management analysis capabilities to woody feedstock supply systems.



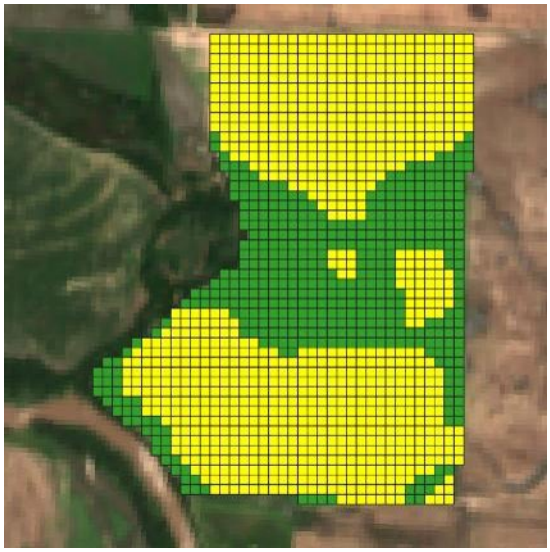


*Photo courtesy of INL*

## COMMENTS

- The goal of reducing the cost and soil impact of biomass cultivation is important, and the award this project has received is evidence of the novelty and potential of the tools it has developed. It is not readily clear, however, what pathways are available for its application. Do we anticipate that farmers would be willing to plant odd-shaped areas to biomass based on modeled optimization or that counties could allocate biomass cropping to privately held farms that have been found most suitable? A strategic approach to further model development and application would be welcome. It is not immediately clear what is occurring under the umbrella of this project versus leveraging other work from within the BETO portfolio. This would be useful to better understand how this project is unique within the BETO program rather than duplicative of other efforts.

- The management was clearly communicated, but it lacked a statement about risks and mitigation strategies, which seems crucial for a project proposing an integrated landscape production scheme. For example, what is the team's evaluation of the extent to which these technologies and tools will be adopted by the intended audience? While the field and subfield-scale analyses seem highly relevant and impressive, without mention of producer or landowner interest, it's unclear the extent to which the technologies will be a welcome tool.

- The objectives of the project are clearly stated and extremely important for the viability and performance of feedstock production. The diagram of how this project connects with other projects and labs is very helpful. The subfield crop allocation work is innovative and important, and it has implications for any agricultural producer, not just for bioenergy crop producers. A significant gap and future opportunity would be to verify the modeling in the field for both the equipment efficiency and crop allocation modeling. Another gap/future opportunity would be a pilot study to demonstrate farmer adoption of these modeling tools to make decisions about their land. The summary suggests the team is well-positioned to work in additional domains, such as municipal solid waste, but this idea is not fleshed out, and it is not evident how the team would address municipal solid waste with the tools developed for agricultural crop work.

- The project's findings answer the research questions well. The switchgrass results are very compelling, and it's good to know that there is potential for other crops to be subbed in, should there be no market for switchgrass. I don't feel that the environmental data are diverse enough to support fruitful decision making. In that regard, the Cristina Negri project 4.2.2.12 complements this work well, this one being

the economic justification and the other being the environmental. It would probably be more efficient to combine both tasks into one project.

- This project provides a very intriguing opportunity to optimize existing agricultural land through the use of modeling. The project team has shown significant progress by finalizing their crop yield prediction tool, which generates results very close to real-world data collected by satellite. Although this approach yields clear recommendations for optimal subfield crop allocation, this project may necessitate additional work to distill those recommendations into actions for stakeholders. Further, it may require an additional risk assessment strategy on implementation barriers for mixed crop allocation.

- This reviewer is not familiar with POLYSYS, and the presentation and model development were difficult to follow. Although the approach is relevant to this BETO program, it was difficult to tell if the project has significant potential for innovation in its application. More information on how the model was developed, its capabilities, and who uses it would be very helpful to complete a thorough review. The management plan and implementation strategy could have been laid out more clearly: who is doing what, what are the mitigation strategies and associated risks, who are the stakeholders and/or users. Industry engagement will be critical to enhancing impact. In particular, collaboration with USDA and USDA Conservation Action Plan projects could be advantageous. For the most part, it seems that the project has made appropriate progress toward addressing the project goals. A timeline or Gantt chart was not presented to adequately evaluate progress. Only one bullet really identified a project schedule action, which was very broad.

## PI RESPONSE TO REVIEWER COMMENTS

- This project has provided the foundational work on field/subfield-level concepts of biomass production as a way to improve on-farm profits and reduce environmental impacts of agriculture. This work has spawned the interest in quantifying the ecosystem services and potential impacts of supply at finer resolutions than the county level. We have served as a collaborator in these projects to maintain the tie between the larger Integrated Landscape Management concept and these additional analyses, so typically the work of this project is being leveraged in the other projects. We recognize that the approach that we present tends to go against convention; but if we are to rely on conventional practices, there has been little evidence that it will lead to the attainment of desired goals. Unless something drastically changes, bioenergy crops being produced at competitive prices with traditional cereal grains or soybeans will result in a feedstock that is too costly for fuel production. Using site suitability as a tool to assist in the tactical planning of potential firms that are interested in contracting for biomass feedstocks means they will be able to identify and prioritize locations to target for the establishment and production of bioenergy feedstocks. Although all the highest suitability areas will likely not choose to participate in the development of the supply chain, the approach of targeting the most suitable areas first will likely compress the amount of time needed to establish sufficient supply and reduce the overall cost of the material compared to a more random approach. Then through field optimization, a farmer can increase their per-acre revenue through the inclusion of bioenergy production. Although we are aware of the potential resistance to ununiform fields, we have addressed this through maintaining the operational requirements of production agriculture as a constraint on the field design. Additionally, with the adoption of Global Positioning System navigation and auto-steer, the barrier to innovative field design is reduced. Also, this approach is not that different from approaches used for precision agriculture, which is being embraced by producers. The observation of the close relationship between this project and 4.2.2.12 is not by coincidence, and we have collaborated very closely with Cristina and her project to provide benefits based on the expertise of the two teams. We are also working to improve the incorporation of the results of 4.2.2.12 into the economic framework; however, we feel that combining the two projects would potentially dilute the overall scope of work. Ultimately, the real value of this project will come with engagement with industry. We have been in discussions with two agricultural companies to potentially license the site suitability and crop yield models. We feel that these discussions are indicative of the potential impact that this project can have on the industry. Also, we are continually trying to engage

more stakeholders, and that is a key facet of our engagement with the USDA/DOE Interagency Working Group and our participation in the USDA Conservation Action Plan project. Currently, we have team members who are or have been directly involved with two of the USDA Conservation Action Plan projects.

# BIOFUELS AIR EMISSIONS ANALYSIS

## National Renewable Energy Laboratory

### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 4.2.1.30 |
| Presenter(s): | Danny Inman |
| Project Start Date: | 10/01/2018 |
| Planned Project End Date: | 09/30/2021 |
| Total DOE Funding: | $950,000 |

This project is focused on providing much-needed data and analyses that address biorefinery air permitting. This project develops models and quantitative analyses and measures progress toward meeting air quality regulatory requirements. It is important to emphasize that air emissions from biofuels depend in large part on how biomass is produced and converted to biofuels. An accurate air quality impact assessment requires understanding not only the type and magnitude of air pollutant emissions but also where and when pollutants are released to the environment, aligning with the latest understanding of how biomass will be produced, collected, and then converted to fuels. Since the initiation of this project, we have been building BETO's capability to meet stakeholders' stated needs to accurately assess potential air quality impacts by addressing a number of research gaps, including (1) a scarcity of spatially, temporally, and chemically resolved air pollutant emissions inventories for the biofuel supply chain(s); (2) a lack of understanding about the types and quantities of air pollutants emitted from advanced biofuel conversion process designs and whether these advanced design cases can meet federal air regulations; and (3) a dearth of quantitative emissions estimates on criteria air pollutant emissions from different advanced biomass logistics systems envisioned for biomass feedstocks to supply a large-scale bioenergy industry. In addition to filling research gaps, this project aims to disseminate and communicate our results to the relevant stakeholders at BETO, the national labs, and regulatory agencies.

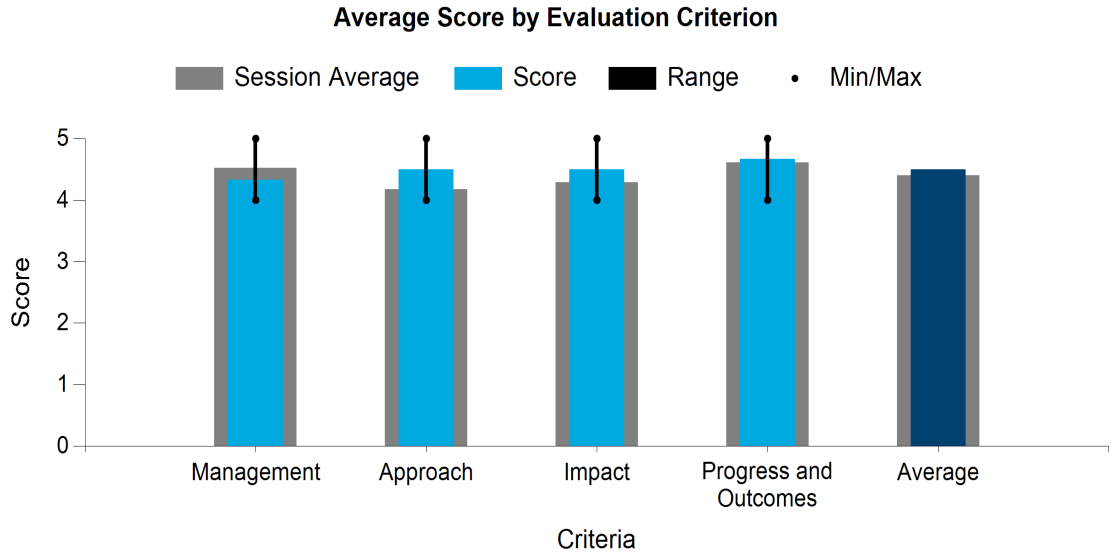



*Photo courtesy of NREL*

## COMMENTS

- The Feedstock Production Emissions to Air Model (FPEAM) is an important model quantifying air emissions for biorefineries. It's excellent to see that the model includes a smidge of environmental justice with respect to particulate matter (PM) 2.5 by demographics (step 6) and health impacts (step 4 in InMAP)—this should be expanded to enable analysis by demographic and socioeconomics; however, PM is only one important air emission that impacts health; more should be included. On slide 17, you include $O_3$; it's not at all clear how you estimate health or any impacts with this data. Although this is a good start, there is much more to be done to address environmental equity and access to clean air and water, per your market trends slide; one metric is not enough. Please be careful making equity and justice claims without much rigor. Slide 6 states that stakeholders are engaged, but it was originally not clear who, how, and to what end/outcome. Per the presentation, stakeholders engaged include the EPA's Motor Vehicle Emission Simulator (MOVES), Exxon, and a few air quality agencies, in addition to possibly some groups in a workshop. There are so many other companies and industries that should be engaged with respect to biorefinery air emissions. A more robust approach to stakeholder engagement, and connections across other DOE modeling efforts, should be made.

- It's great to see this project evaluates air quality emissions from not only a regulatory compliance vantage point but also a public health and environmental justice angle. This work is critical to understanding how to prevent bioenergy operations from affecting peoples' lives who live in close proximity.

- The project performers have outlined and implemented a well-defined and highly relevant project, given its target in the process design phase, that offers useful information to BETO partners and other stakeholders. The project appears to be on time with deliverables. The inclusion of an environmental justice component to this project is good to see and encouraged in future work. This and other projects in the portfolio might consider collaborating with researchers whose expertise centers on environmental justice to fine-tune the analysis and further elucidate patterns of injustice and inequity associated with air pollution exposure.

- The project team has deep background and expertise on air quality impacts of bioenergy production and processing. Their ability to inform policy by predicting emissions performance is useful, and efforts should be made to test its utility through strategic outreach to policy stakeholders. Their apparent focus on environmental justice as well as attention to the challenges posed by emerging pathways such as WTE systems in urban areas is strategic.

- This very innovative project provides pathway/process designers with a method to test emissions performance during design. The approach is clearly defined and leverages existing and previously developed models that are publicly available (e.g., MOVES, FPEAM, InMAP). The project provides process design feedback in a geospatially explicit way and prevents a major cost/pitfall of design implementation (exceedance of air quality requirements). The example results for hydrothermal liquefaction demonstrate the utility of this approach to identifying the implications of current process design as well as considerations for improving processes and/or siting facilities for hydrothermal liquefaction. It would be interesting to explore the option of having this model used by the EPA as a screening-level tool for permitting facilities. It was great to see the equity acknowledgement. Given the frequent confluence of air quality issues and environmental justice communities, an equity-focused team within the BETO portfolio could potentially complement this with additional analyses or tools.

- This work provides a targeted assessment of the air quality impacts of biomass production across the supply chain. The feedstock production emissions to air model appears to be well-integrated with POLYSIS and the EPA's widely used MOVES model. The preliminary outputs look very promising and offer an insightful look at the full supply chain air quality impacts of the hydrothermal liquefaction process. This project has a very clear goal and an effective management plan to get there; however, the risk assessment appears limited to budget uncertainty and uncertain requirements. This does not fully cover the full set of risks for this approach. An important consideration for continued work is the discrepancy between modeled and real-world emissions at biorefineries, at least for those bioenergy pathways that are already in operation. Additional work may be necessary to validate and ground-truth these estimates.

## PI RESPONSE TO REVIEWER COMMENTS

- Thanks for your comments. As for $PM_{2.5}$, InMAP is designed to take only $PM_{2.5}$ as input because the developers felt it to be the most impactful air pollutant. InMAP was developed and is maintained by Washington State University, and we use it in its "stock" form to link to our other models, such as FPEAM. We recognize that this is one limitation to using InMAP; however, it has not been within our scope of work to expand its capabilities. That said, in future years, we can work with the team at Washington State University on potentially expanding the inputs to InMAP.

  Our stakeholders have provided feedback on our modeling approach and have acted as collaborators over the years. The workshop that was mentioned was to solicit feedback on the usability of and to beta test FPEAM. This group consisted primarily of university and national laboratory researchers. That said, your point is well taken, and we will work to broaden our outreach efforts to involve additional stakeholders in our future work.

  Our work in environmental justice is in its nascent phase, and we are working to expand it and will be collaborating with other national laboratory partners in the future.

  We have been working to collect data on real-world emissions from biorefineries. We have assembled a database of existing biorefinery air permits. This can be found on the KDF here: https://bioenergykdf.net/content/database-biorefinery-air-pollutant-emission-permits. GREET is an LCA tool that performs high-level analyses. The GREET team uses process-level data from published design reports and other publicly available sources. We use Aspen and ChemCAD to examine process designs that are in development, and using those tools, we make process modifications to the design case(s). We maintain an active relationship with the developers of GREET for data exchange and sharing of results.

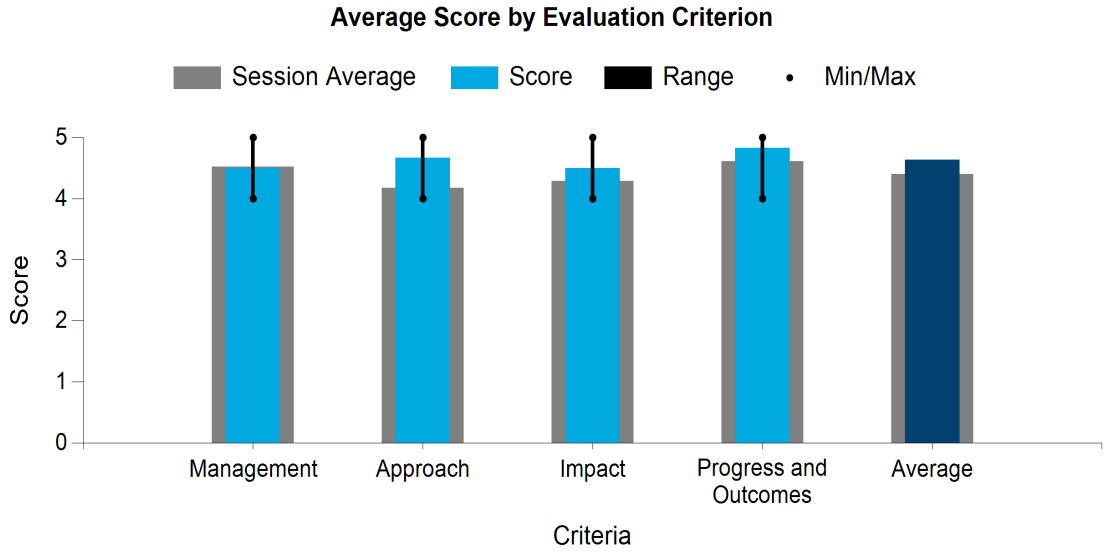
# INTEGRATED LIFE CYCLE SUSTAINABILITY ANALYSIS

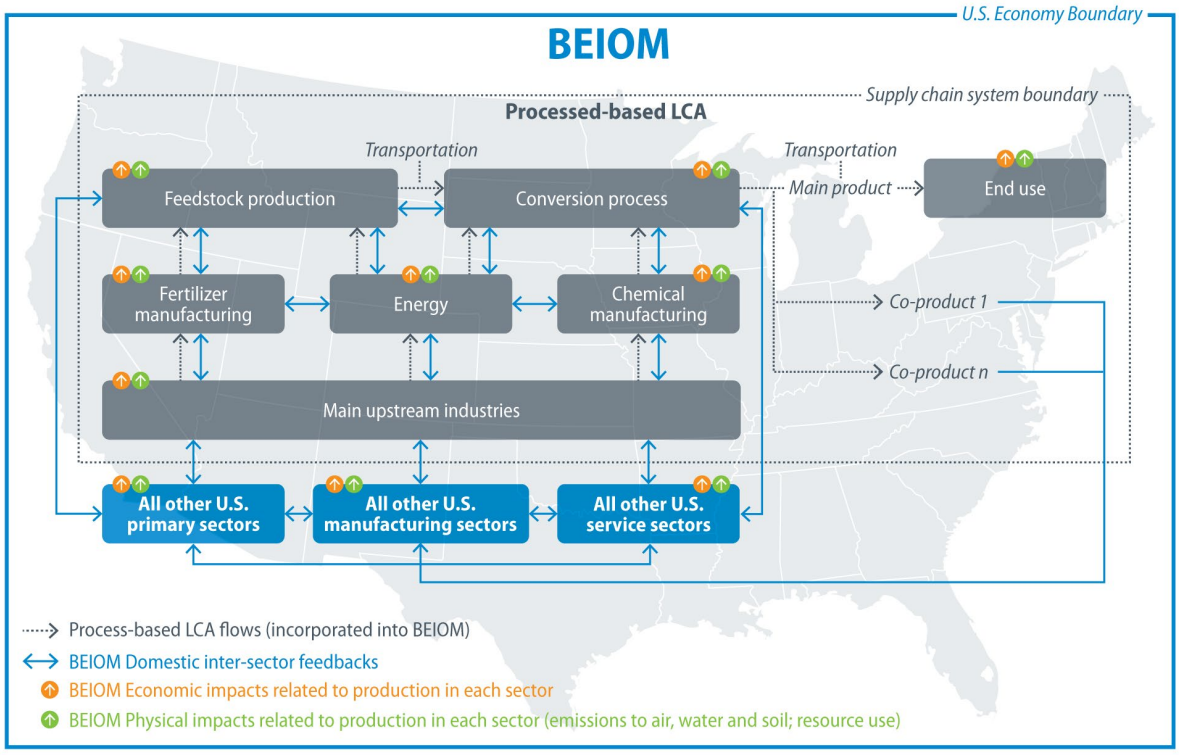
## National Renewable Energy Laboratory

### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 4.2.1.31 |
| Presenter(s): | Patrick Lamers |
| Project Start Date: | 10/01/2019 |
| Planned Project End Date: | 09/30/2022 |
| Total DOE Funding: | $1,200,000 |

This project provides BETO with strategic decision support for the evaluation of its R&D portfolio by developing, validating, and applying a coherent methodology and consistent model framework to quantify the net effects of an expanding U.S. bioeconomy. The framework fills an analysis gap previously identified by the Peer Review and supports a related milestone in BETO's Multi-Year Program Plan. The framework was scoped with inputs from practitioners in academia, national laboratories, and federal agencies. The model is a top-down, economy-wide framework using a coherent methodology to compute environmental and socioeconomic metrics. It is purposefully complementary to existing bottom-up, process-based TEA and LCA BETO tools and uses their data as inputs. Presently, the model covers several commercial and near-commercial biofuel routes and an emerging pathway for plastics upcycling. It covers temporal detail across four time steps and is currently being expanded with a prospective modeling capability. The model has provided analyses for the third Triennial Report to Congress on the environmental effects of the Renewable Fuel Standard, among others. As part of this project, NREL also provides scientific support to BETO in the International Energy Agency's Technology Collaboration Program on Bioenergy (IEA Bioenergy) Task 45 on Sustainability. Here, NREL evaluates and synthesizes activities that develop, compare, or apply metrics, methods, and tools to quantify sustainability effects of bioeconomy products. NREL also coordinates related national lab involvement and a BETO Working Group on Sustainable Land Management.






**BEIOM:** Bio-based circular carbon economy Environmentally-extended Input-Output Model

*Photo courtesy of NREL*

## COMMENTS

- Complexity is a risk factor. Because this model is a bit of a black box (or needs a more in-depth conversation than the Peer Review), expert vetting will best assist this model's outcomes. Another mitigation strategy is sensitivity analyses, which is particularly important when dealing with the different time frames of carbon accounting that require direction policymakers (for instance, see the EPA's Science Advisory Board—Biogenic Carbon Panel, which decided to provide the performance of woody biomass over all timescales in order to give policymakers the option to choose the time frame they feel is best). It's good to see this modeling build out areas of social and environmental equity. And the outcomes, feeding into executive and legislative reports and analyses, are quite good.

- The project's management, communication, and risks were clearly presented here. The project clearly complements the other bottom-up efforts in the portfolio by offering a top-down, high-level, decision-making tool. Progress appears on target. The PI clearly communicated that the model is limited by the input models it aggregates. The challenge of creating a generalized model for the whole of the U.S. economy while maintaining a useful level of resolution is no small feat, certainly. Still, it seems this project would benefit from the inclusion of more and diverse economic indicators to create a more nuanced understanding of the expanding bioeconomy's economic impacts.

- The time series of harmonized economic and environmental data sets are exceptionally novel and have potential to understanding resource intensity over the evolution of biofuels. Similarly, the ability to estimate impacts of emerging technologies, such as plastics upcycling, has potential to provide valuable information to growing industries and technologies. The ability to look into commodity sectors and their contributions to products and technologies will help drive the sustainable development of products and technologies. In terms of stakeholder engagement, the team seems to have collaborated with DOE labs and others (e.g., EPA, USDA), but the details and depth of these collaborations were not clear. The team

utilizes a working group to inform their progress, but, again, details and scope were lacking. The team would do well to engage a variety of stakeholders in their work, outside of federal agencies and labs. The team should reach out to university-led LCA-input/output models and collaborate where relevant. On the socioeconomic estimations, it was not clear how value added was calculated.

- This project addresses an important need for understanding the net overall effects of the bioeconomy. The presentation outlines significant progress in the review period on analyzing multiple commodities (ethanol, plastics). The team presents a useful effect contributions visualization method. Given the desire for a prospective model that can look forward to hypothetical scenarios, it is good to hear that the team intends to leverage the BSM and other BETO information to apply learning and economies of scale, TEA and LCA, etc. It is important to avoid duplication of effort with other projects in the expansion of this model. This modeling approach seems to be a good complement to other activities going on within the portfolio in that it is more of a high-level, national-scale assessment of the effects of production, compared to the more detailed case study analyses. The time-series analyses to assess change in overall resource intensity and environmental impacts over time is very interesting, but, as noted in the discussion of the "evolution of the U.S. bioeconomy," total effects may still be increasing, so these outputs should be presented together to ensure that identified increases in efficiency does not lead to complacency about the overall impacts of a given process/technology. It is great to see equity considerations acknowledged.

- This project complements the many bottom-up impact assessment and optimization tools in the BETO portfolio with a top-down, economy-wide analysis that is well positioned to aid in strategic decision making. It is encouraging to see the project team extend coverage to plastics upcycling and other emerging areas of interest. It would be encouraging to see more explicit collaboration between this team and other deeper but less broad models in the BETO portfolio to ground-truth broad impact assumptions.

- This project provides value to the program area through its use of the environmentally extended input-output framework, which provides a level of analysis missing from other process-level analyses of bioeconomy pathways. The results of this modeling can provide important projections of the aggregate impact of expanding the bioeconomy. This could provide a valuable way to inform higher-level decision making on how large policy decisions affect complex supply chains. This project is a good candidate to expand BETO's understanding of the social and economic impacts of the bioeconomy, particularly with a view toward equity impacts. It would be helpful in the future to have more explicit evaluations (i.e., for communities or regions, rather than economic sectors) of the equity impacts for different products or pathways to illustrate the models' contributions to decision making.

## PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their inputs and constructive suggestions. The model's macro-level structure and its large, national-level data sets often create communication challenges, especially with respect to the model's perceived uncertainty due to its structural complexity. We would like to stress that the national-level data sets are official U.S. federal government agency data and have, just as the process-level TEA and LCA data inputs, undergone external validation and review processes by the time they are used in our model. Further, we perform sensitivity analyses for any data inputs with variability and base these ranges on published literature (e.g., potential land use change related to energy crop expansion). Results are also always compared to process-level LCA, and given the differences in system boundaries, our total (direct and indirect) effects tend to be higher. This is largely due to the accounting of economy-wide, indirect effects (beyond the system boundary of process-based LCA). The range of these indirect effects depends on underlying economic structures and potential cross-sectoral shifts. Ongoing model developments focus on establishing a scenario analysis capability to quantify related uncertainty. Planned model expansions also include regional specificity within the United States, accounting for U.S. imports and exports, and the addition of more nuanced metrics to measure socioeconomic impacts. We want to highlight that this project has several explicit collaborations within and outside DOE. Apart from existing exchanges with process-level LCA and TEA teams at ANL, NREL, and PNNL, new

collaborations with the BSM, the Material Flows through Industry, and GREENSCOPE teams will support future efforts. External engagements go beyond regular updates of the EPA's U.S. Environmentally Extended Input-Output model development team (on code improvement, sectoral disaggregation, bilateral peer-review of results/reports, etc.) and biweekly check-ins with the EPA's Office of Research and Development and include regular exchanges with environmentally extended input-output modeling teams at Georgia Tech University (on regionalization) and Florida State University (with which an intern exchange has been established). The working group is a separate effort facilitating the incorporation of bioenergy co-benefits (via ecosystem services) in GCAM. It is linked to ongoing multilateral efforts for BETO under the IEA Bioenergy Task 45.

# ECOSYSTEM SERVICE PORTFOLIOS OF AGRICULTURAL AND FORESTRY BIOMASS PRODUCTION

## Oak Ridge National Laboratory

### PROJECT DESCRIPTION

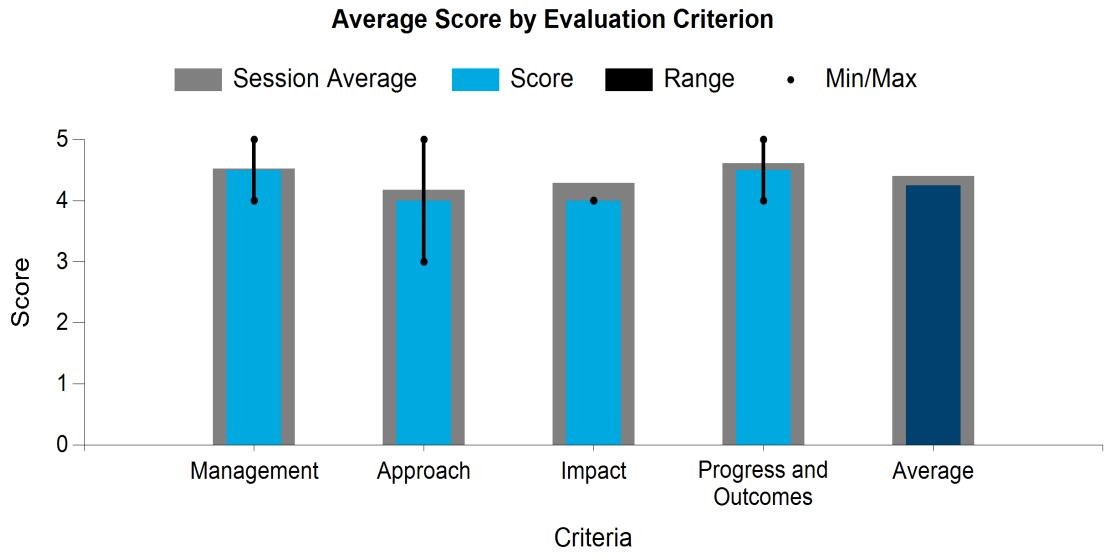
| | |
|---|---|
| WBS: | 4.2.1.40 |
| Presenter(s): | Yetta Jager |
| Project Start Date: | 10/01/2020 |
| Planned Project End Date: | 09/30/2023 |
| Total DOE Funding: | $1,200,000 |

Environmental credits are increasingly important sources of income to promote renewable integration. The goal of this project is to discover where environmental credits can push feedstocks in a watershed over a threshold for profitability. In the previous project cycle, we, with another ORNL project (Langholtz), developed the concepts of environmental supply curves and stacked value-supply curves. We implemented a software tool and used it to show that excess nutrient loadings could be avoided by excluding a small fraction of supply. The tool demonstrated that the value of water purification from planting perennial feedstocks, combined with a $60/dt farm gate price, would offset production costs for more than half of the projected 2040 dedicated feedstock production. In this cycle, our valuation tool is now being extended to include carbon and will be made available to stakeholders through the Bioenergy Sustainability Tradeoffs Assessment Resource (BioSTAR). A new initiative is to develop a Geospatial Roadmap in a region where environmental credits (e.g., low-carbon fuel standard [LCFS], RINx, nutrient markets) are strong. The roadmap will emphasize demand-side geospatial data to identify watersheds where water quality is threatened, where available credits co-occur with potential for supply, and where markets provide demand for biomass production. A full LCA using GREET will include pathways, such as renewable natural gas, that can help promote integration of variable renewables. The goal of the 3-year project is to demonstrate where 10% of full life cycle production cost can be offset by environmental credits.

Our project also has a strong track record for developing modeling tools to assess biodiversity responses. In the west, we collaborated with PNNL and the U.S. Forest Service to predict where selective forest treatments (burning, thinning) can increase early survival of listed Chinook salmon. The PNNL-led project demonstrated that selective treatments also reduced fire risk, produced more biomass, and more water in summer—a triple win.

In Iowa, we developed multispecies models and collaborated with ORNL colleagues and the ANTARES team to show how replacing unprofitable lands with switchgrass can increase species richness. Additional research to guide harvesting practices at the field scale to maximize biomass production and value derived from pheasant hunting is in progress.

During the previous cycle, we produced 12–15 peer-reviewed publications (several in high-impact journals) and two chapters in the EPA report to Congress. We also organized a Special Issue in Biological Conservation titled “Renewable Energy and Biological Conservation in a Changing World,” which has had four papers on biofuels submitted.



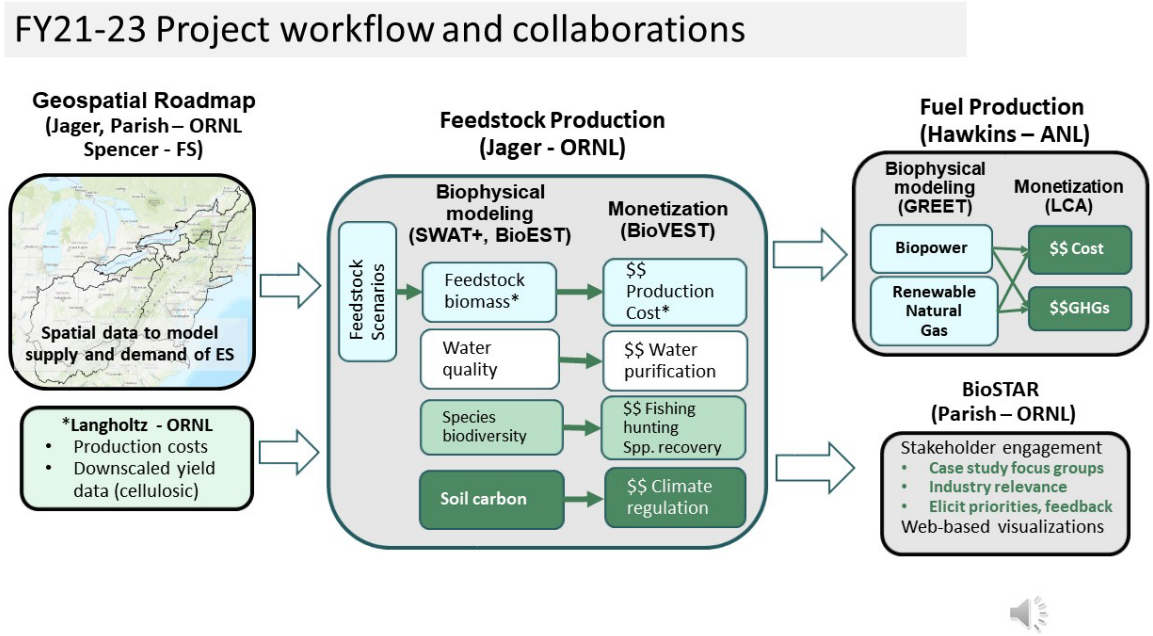




*Photo courtesy of ORNL*

## COMMENTS

- Ecosystem services could potentially be a key part of the value proposition of any agricultural production, but particularly of bioenergy/biofuels. This project contributes to the understanding of the potential for providing ecosystem services under different systems and conditions. The ANTARES collaboration to identify potential for increasing species richness and the separate collaboration to look at salmon habitat in response to forest management are excellent examples of cross-project collaboration and leveraging of field data within BETO. The authors identified a potential biodiversity benefit of perennial grass planting for bioenergy production. Biodiversity is not measured solely in number of species but also often considers other aspects, such as species evenness. The potential to inadvertently favor invasive species is also a risk. A potential future effort could investigate the potential increase in

native species richness versus invasive/non-native species. Management strategies, harvest timing, and other factors also affect how useful grass plantings are for species maintenance and could be investigated further. Although the project models "willingness to pay" to identify the value of ecosystem services, it is not clear to what extent current policies and regulations actually provide for the ecosystem services payments that would be needed for these to be leveraged to persuade producers to shift to bioenergy production and improve revenue for farmers. A future effort could include a collation and/or evaluation of existing incentive programs and compare those to the willingness-to-pay modeling as a method of "ground-truthing." A number of different projects within the DMA portfolio are incorporating aspects of ecosystem services valuation/payments (e.g., the "Scaling up of Ecosystem Services" project, among others). It would be helpful to clarify if these projects are using the same assumptions on willingness to pay versus real-world existing payment programs. The team noted that they achieved a 10 author/multiagency agreement on proposed forest treatments to reduce the risk of large, high-severity fires—this effort toward consensus building will be important for the future adoption of these forest treatments and potentially has impact on policies at multiple agencies.

- The biodiversity component of this project complements other efforts in the BETO portfolio well. More depth in the measures of biodiversity (evenness, native/non-native) would likely provide even greater clarity for ecosystem services valuation as well as understanding environmental synergies and trade-offs associated with land management scenarios. Given that advancing the SOA relies on payments for ecosystem services that are not ubiquitous, the move to the Mid-Atlantic region will presumably offer real-world scenarios that make ecosystem services valuation a viable consideration for farmers and other land managers. Continued integration with other projects in the portfolio is encouraged.

- The tasks for the project were clearly described, and, as such, it is clear that the project is on schedule. Consider starting LCA early in the project, rather than saving it for the end of the project. LCA can provide valuable information at the start of projects with respect to ways to minimize and mitigate environmental impacts. Overall, there was a lot going on in this project; some of the projects or case studies (e.g., fires, salmon) didn't seem well related and integrated into the overarching project goals presented in the beginning. The collaborations across national labs are impressive and appropriate; however, it appears as though industry and others were minimally, if at all, engaged. The beginning of the presentation outlined stakeholder engagement, which is very exciting, but it seems to have been omitted from the project. BioSTAR and the stakeholder engagement was missing from the task list, yet it was mentioned in the project description; the project should be clear on the scope and whether stakeholder engagement is included. This work would have greater impact and reach by engaging a larger range of stakeholders.

- This is extremely valuable work to understand the impact of biomass harvest systems on surrounding ecosystems. This project chose two species to study, one for each ecosystem type. It would be ideal to have more robust measures of biodiversity impacts. At the very least, it seems that species should be selected for consistent reasons, whether to measure biodiversity or to protect a culturally relevant species. For the woody biomass treatment, all forest stands should not be treated equally. Wildfire risk should be used as a variable in assessing the need for forest harvests. Wildfire risk and severity also stand to guide where the greatest gains in carbon storage can be made.

- This project is being conducted by a strong team with relevant experience, and the goal of identifying watersheds in which payments for ecosystems services could offset >25% of the cost of biomass cultivation is an interesting and strategic one. I also find it promising that they are considering a shift from quantifying ecosystems services value to quantifying willingness to pay, because that is what is ultimately needed. The project is strongly leveraging work from elsewhere in the BETO program, such as their evaluation of the salmonid impacts of the forest management treatments being modeled at PNNL. That said, it was, at times, difficult to ascertain a clear through line between their collection of case studies.

- This project provides valuable insight for the development of cellulosic biomass supply chains, their geospatial distribution, and associated ecosystem services. The approach for quantifying biomass supply and water quality improvement appears thorough; in contrast, it is less clear how the system for assessing biodiversity impacts can be expanded beyond bird coverage and to what extent birds are a proxy for overall biodiversity. A key question to explore is to what extent can the biodiversity assessment here be consistently applied alongside the other metrics? The efforts to expand the analysis to forest management illustrate the potential for future linkages between forest biomass recovery and habitat restoration for a single species.

## PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for recognizing the value of our efforts to work collaboratively in quantifying the ecosystem services and biodiversity enhancements associated with perennial grass feedstock production. We have done this both within agricultural systems and forested systems. We appreciate that the reviewers see the impact that our work can potentially make on forest management policy at multiple agencies from multiauthor publications and the impact that we are making through involvement with the EPA's Triennial Report and contributions to the U.S. Energy Information Administration's Task Force 45. As we wrap up case studies from the previous 3-year cycle, we hope to develop a cohesive research theme in the Mid-Atlantic centered on evaluating existing incentive programs. We recently submitted a Geospatial Roadmap plan with information about incentives for each state in the Mid-Atlantic, which addresses the recommendations of several reviewers. We are focusing on real-world scenarios with actual payment for ecosystem services, as suggested by reviewer 5, but we also agree with reviewer 3 that willingness to pay is important to quantify, which we will do using BioVEST. The idea of comparing payments for ecosystems services with willingness to pay is an interesting one that we will consider. Coordination among projects and stakeholder engagement were raised as both a strength of the project and a potential concern. We plan to continue integration with other projects, including the LCA collaboration with ANL. We will provide ANL specific information on carbon sequestration and carbon price, which we hope to complete in early FY 2022. The BioSTAR stakeholder engagement is currently funded as a separate project, and we meet monthly to ensure coordination, including plans for involving industry stakeholders. In addition, we are considering a collaboration with Sandia to strengthen our ecological economics team even more. In response to comments about biodiversity modeling, reviewers emphasized species evenness as a measure, possibly due to a concern about invasive species (i.e., large outbreaks or dominance by one invader may not be desirable); however, we did not include non-native species (the species were identified as important by the State of Iowa), and the ability to model evenness depends on having abundance data across the entire state of Iowa. Abundance data does not exist for all 20+ native wildlife species that we modeled. The challenge with quantifying effects on biodiversity is that one does not find the same species in different ecosystems. People value some species more highly than others, and for different reasons. This heterogeneity is inherent and requires a context-dependent approach. In the past cycle, we have developed tools to assess the effects on aquatic and terrestrial species, the latter at two scales that can now be used for appropriate case studies involving biofuels. In the future, the project's emphasis on biodiversity will be lower and will focus on general approaches in the context of climate change mitigation.

# ATTRIBUTION ANALYSES AND INTERAGENCY COLLABORATION

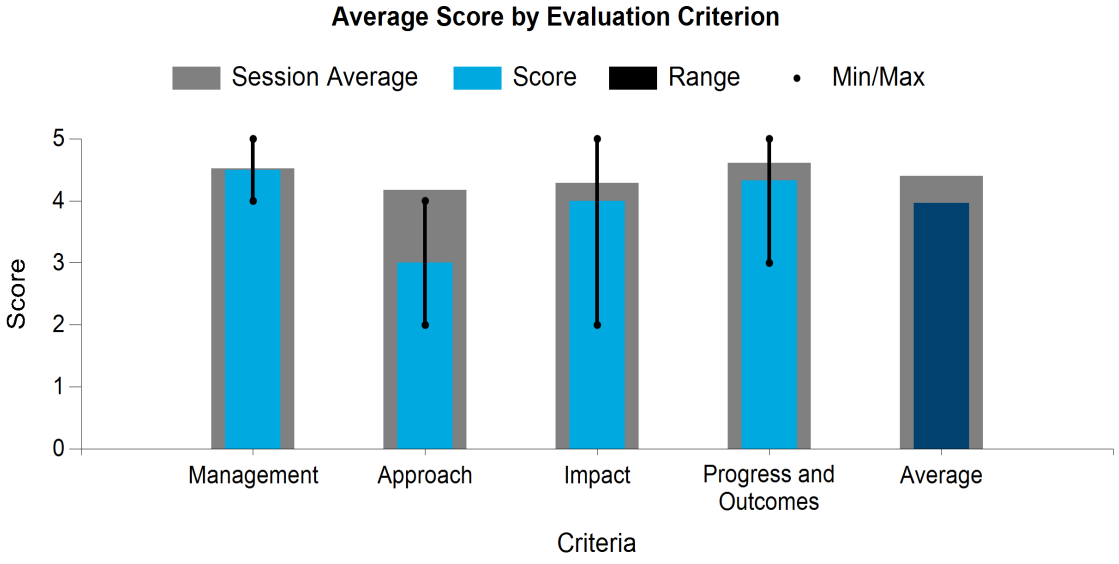
## Oak Ridge National Laboratory

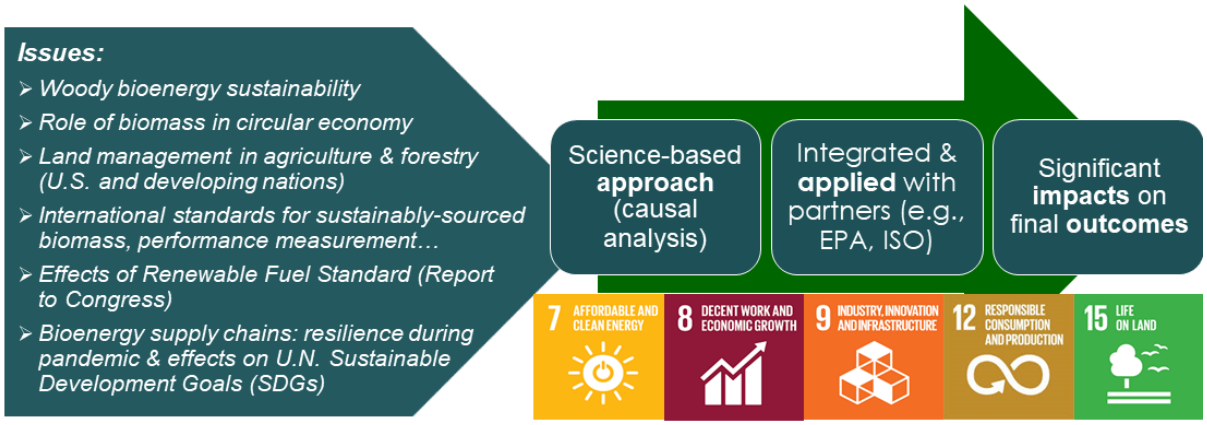
### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 4.2.1.42 |
| Presenter(s): | Keith Kline |
| Project Start Date: | 10/01/2019 |
| Planned Project End Date: | 09/30/2021 |
| Total DOE Funding: | $475,000 |

Quantification of bioenergy costs and benefits is hampered due to complex questions of attribution associated with resource management in bio-based production systems. Resolving attribution questions will enable agencies and private partners to verify the value proposition and to make comparisons among energy alternatives. This 2-year project addresses the need for consistent quantification of net effects attributable to bio-based fuel production chains as required to support BETO goals to enhance economic and environmental sustainability of an expanding U.S. bioeconomy. The project supports rigorous, interagency analyses to better quantify net effects based on scientific attribution methods. Project deliverables improve the ability of U.S. bioproducts to overcome barriers that otherwise could restrict market access due to inappropriate assumptions about attributed effects.

The project has two tasks: (1) enhance the scientific basis underpinning for the EPA-led Triennial Report to Congress on the effects of biofuels; and (2) strengthen coordination with stakeholders and IEA Bioenergy to address attribution issues, bioeconomy linkages to a more sustainable circular economy, and expand beneficial effects of BETO Analysis and Sustainability research. The project responds directly to recommendations of the 2019 Peer Review of the DMA platform to strengthen interagency coordination and increase research on attribution issues of biofuels, including the induced effects of an expanding U.S. bioeconomy.






**Over two years, the project contributed to 18 journal papers, 15 other reports and presentations, three international standards, and 8 draft chapters of the EPA-led Triennial Report to Congress.**

*Photo courtesy of ORNL*

## COMMENTS

- Management was clearly stated. The project seems to have contributed substantial outcomes, including contributions to nine sections of the Triennial Report to Congress. It's difficult to evaluate the project impacts overall given some lack of clarity on the causal analysis framework. I was interested in the international research component of this project and would have liked to have heard more about this aspect to understand how it fits with the rest of the work. The progress appears on target, given the two stated tasks.

- The causal analysis for attribution was not clear. It would be helpful for the PI to clarify what they mean by attribution; is this similar to allocation in LCA? The innovative nature of this approach was not clear. Alternative approaches should be described and analyzed. It was not clear that the project demonstrated a clear connection of project approach to the potential for significant impact and outcomes. The contributions to and collaboration with the EPA's annual report are certainly important; however, some of the successes highlighted were seemingly superficial, such as "clarified terminology." The engagement of private sector and other stakeholders is impressive, from the International Standards Organization to the *Biofuels, Bioproducts and Biorefining* journal.

- The team members have made contributions to the Triennial Report to Congress and performed U.S. case studies with IEA Bioenergy. It is valuable to have a project that enables contributions like these in national and global settings to ensure that DOE's technical information and understanding of the bioeconomy sector are represented. The case studies with the IEA Bioenergy slide indicate that the case studies from around the globe used comparable templates. More information on what these templates are/what they included would be useful. The project leverages a previously developed causal analysis framework—published by ORNL—and suggests that the model can be used to determine the level of causation of different policies on bioenergy outcomes. The actual data that are used to evaluate the causation were not clear from the presentation and should be better explained. There are extensive computable general equilibrium models and other models that are used to tease apart impacts of policies and other factors. Additional information from the PIs shared with the reviewers separately suggests that the causal analysis is combining high-level qualitative data (number of publications, perhaps technology readiness level?) and existing modeling to estimate different drivers of impacts of policies and/or bioenergy deployment, raising questions of whether the causal analysis framework is comparing apples to oranges; it would be helpful to provide a high-level view of this to better evaluate the contribution to policy/standards. An explanation/rationale for the use of this model instead of some of the existing sector- and economy-wide modeling approaches already within BETO and elsewhere would be helpful.

- This project addresses a topic of critical importance for the policy community, namely, the attribution of historical effects to biofuels policies. This project has a track record of substantial engagement with policymakers at high levels, high levels of collaboration with stakeholders, and, notably, played a crucial role in assessing the renewable fuel standard; however, the approach of this project is difficult to assess due to a lack of transparency on the causal analysis framework. To ensure that the causal analysis is robust, transparent, and reproducible, it would be helpful to have more information on data inputs and methodology. Further, methodological issues with the causal analysis framework could be incorporated into the risk identification and mitigation strategy.

- This project has important implications for national and international bioenergy policy, and it rightly recognizes the need for public acceptance in the fruition of the bioenergy industry. Being a champion for the environmental and economic sustainability of biomass will aid in this project's success.

- This project has yielded a great deal of international collaboration and interaction, which creates value for BETO. If BETO seeks to feed into global efforts such as IEA Bioenergy, this project is a useful forum, and the PI is well networked. The project PI is well positioned for roles such as the one he seems to have played in the report to Congress—that of organizer and convener. In these roles, his strong global network is an asset. Moreover, there are several sophisticated analytical tools in the BETO portfolio and elsewhere that seek to rigorously evaluate causality as described by the PI. They can and should be leveraged to evaluate the impact of a bioenergy system—not to promote it, to prove an *a priori* assumption that it is beneficial, or to cast doubt on rigorous analysis, which seems to be an unstated goal of this PI's assessment of causality.

## PI RESPONSE TO REVIEWER COMMENTS

- Thank you for recognizing the "critical importance" of the project achievements to BETO, the international bioeconomy community, and other decision makers. With support from BETO, external reviewers, and stakeholders, we agree that collaborations under the project have yielded high returns with demonstrable utility and impact. We therefore plan to continue building on these constructive and collaborative research networks as work proceeds. We also appreciate the reviewers' recognition of the important role of public opinion and acceptance of sustainable biomass production to enable the U.S. bioeconomy to fulfill its potential. In this regard, clarification of terminology is an issue that has proven to be essential, whether discussing "waste," baselines versus reference scenarios, forest residues and "whole trees," or land "uses" and "changes" versus consistent land cover classification. To ensure transparent, replicable analyses, we promote the use of clearly defined terms that can be linked with verifiable, publicly available data, such as that on production volumes, prices, imports, exports, land management, and land cover. These data are improving in terms of quality, quantity, and timeliness. Use of improved and expanded data sets permits more detailed analyses with statistical tools that complement the causal analysis method, such as Granger Causality.

- In response to review questions about the IEA Bioenergy reports and templates, we are pleased to announce that publications related to the case studies can now be accessed at IEABioenergy.com (see publications for Task 43 and Task 45).

- Other comments from reviewers relate to the omission of a detailed description of the causal analysis framework in our presentation, and most of the remainder of this response addresses those comments. The guidance and structure of the presentation template limited our 2021 presentation to project accomplishments in the preceding 2 years. Details regarding prior work including the genesis, development, and testing of the causal analysis approach for attribution were documented in prior Peer Reviews. In response to reviewer questions, complementary information on this approach and its application in 2019–2021 follows.

- The causal analysis approach is a well-established analytical tool, widely applied and tested in multiple disciplines. The approach involves a systematic process to examine the weight of evidence supporting specific hypotheses, assumptions, and linkages in a specified causal chain, thereby avoiding common issues in other approaches that may attempt to "compare apples to oranges." Causal analysis supports BETO and other researcher working in this sector by providing insight into the utility of some of the input values and assumptions supporting the many economy-wide modeling approaches employed within BETO and elsewhere.

- The reviewers specifically asked for information on data inputs and methodology used by the project. The causal analysis framework was initially developed as a broad, epidemiological, strength-of-evidence approach. It employs empirical data as well as results from best available modeling where direct empirical data are lacking. Because the EPA Triennial Report to Congress is classified as a high-impact, scientific assessment, the draft Triennial Report to Congress must proceed through multiple formal review steps before it can be released. Input to the Triennial Report to Congress was the focus for our work, and milestones linked to causal analysis during the 2-year review period presented. Thus, because the data used and results of the report are not yet public, we were not permitted to share the analyses or details for how evidence was collected and weighted for that task; however, the EPA has since allowed us to share the following information on the lines of evidence used for the draft report. Examples of the lines of evidence analyzed for attributing observed levels of ethanol production to the renewable fuel standard include: (1) observational data comparing renewable fuel standard mandates to actual consumption levels; (2) renewable identification number prices observed in the markets for conventional ethanol as well as advanced biofuels; (3) peer-reviewed literature relevant to the assessment goals; (4) results from NREL's and EPA's BSM; (5) the EPA's Office of Transportation and Air Quality's analysis of blending; and (6) a preliminary examination of the plausible causal chains linking observed biofuel consumption to the renewable fuel standard and to other potential drivers (e.g., replacement of methyl tert-butyl ether [MTBE], price of oil [fossil-based blendstock], octane enhancement). Project contributions associated with causal analysis are directly related to the attributional analysis of observed biofuel production to the renewable fuel standard. The project made other substantive contributions to other chapters of the draft Triennial Report to Congress. And most other chapters will now consider the effects of the renewable fuel standard as framed by the results of the attributional analyses when drawing conclusions about environmental effects (e.g., to soils, air, water) attributable to the renewable fuel standard. Please also see documentation for 2017 and 2019 BETO Peer Reviews and the literature cited in the current 2021 Review presentation for more information. Anyone encountering difficulty in accessing these materials is invited to contact the PI, who will happily facilitate access to the reports and papers.

- Finally, the established goals for this project are: (1) demonstrate approaches that improve quantification and documentation of net effects attributable to bio-based fuels, products, and an expanding U.S. bioeconomy; and (2) build productive research relationships among the EPA, USDA, DOE, IEA Bioenergy, and other stakeholders. The project supports research and analyses that improve the reliability of future estimates of the effects of specified bioenergy systems using the best available data. We appreciate the reviewers' comments and hope to employ the thoughtful suggestions in future work on risk-based assessment and mitigation strategies.

# BIOBASED AND BIOBENIGN, AN ENVIRONMENTAL REFERENCE FRAMEWORK FOR PRODUCT DESIGN: RIPE

## Argonne National Laboratory

### PROJECT DESCRIPTION

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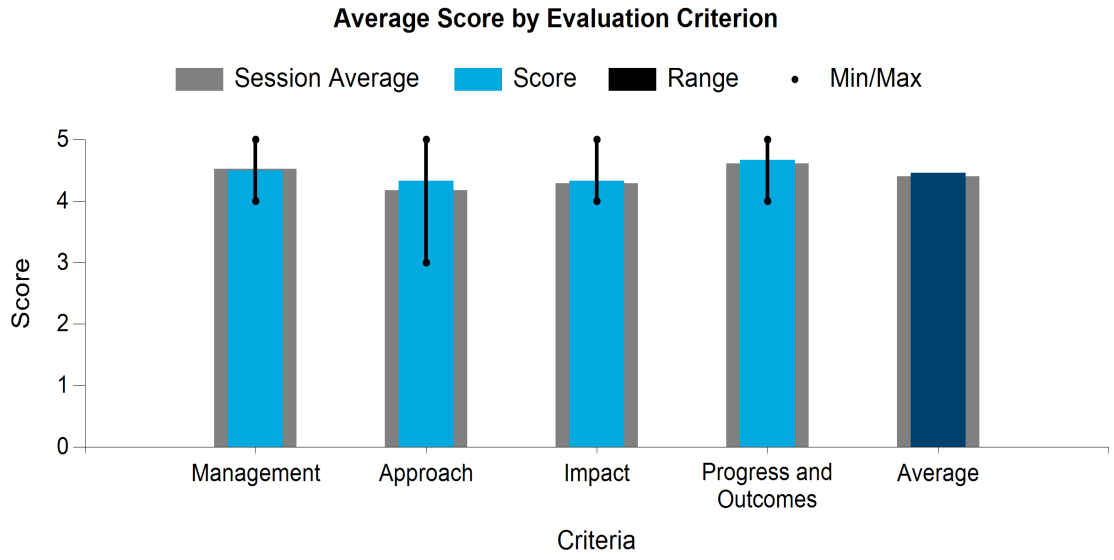
|---|---|
| WBS: | 4.2.2.11 |
| Presenter(s): | Cristina Negri; Margaret MacDonell |
| Project Start Date: | 10/01/2019 |
| Planned Project End Date: | 09/30/2022 |
| Total DOE Funding: | $800,000 |

The time is ripe for bringing responsible innovation to bioplastics by informing product design with the end in mind. Globally, the United States generates the most plastic waste and ranks third in coastal litter, while plastics production continues to grow. Combined with resource linearity, concerns center around environmental persistence and associated ecological and health risks. A systematic approach to account for such afterlife risks has been lacking, and the Responsible Innovation for bioPlastics in the Environment (RIPE) project addresses this need with a predictive modeling framework. The anticipated impact is that polymer developers will be able to consider the post-use fate of candidate products at the outset, thus enabling the design of more environmentally benign bioplastics. Key challenges are data limitations and stakeholder buy-in, with multiple trade-offs across parties. Collaboration and communication are core pillars, as demonstrated by the productive stakeholder workshop. We showed that the conceptual exposure model is effective for organizing technical data and anchoring stakeholder inputs across agencies, industry, academia, national laboratories, and NGOs. The RIPE framework will be linked with LCA tools and demonstrated with a case study. The anticipated outcome is new bioplastics that advance the bioplastics sector of the bioeconomy, and more broadly the circular economy, by strengthening bioproduct adoption and industry competitiveness while minimizing future environmental liabilities.



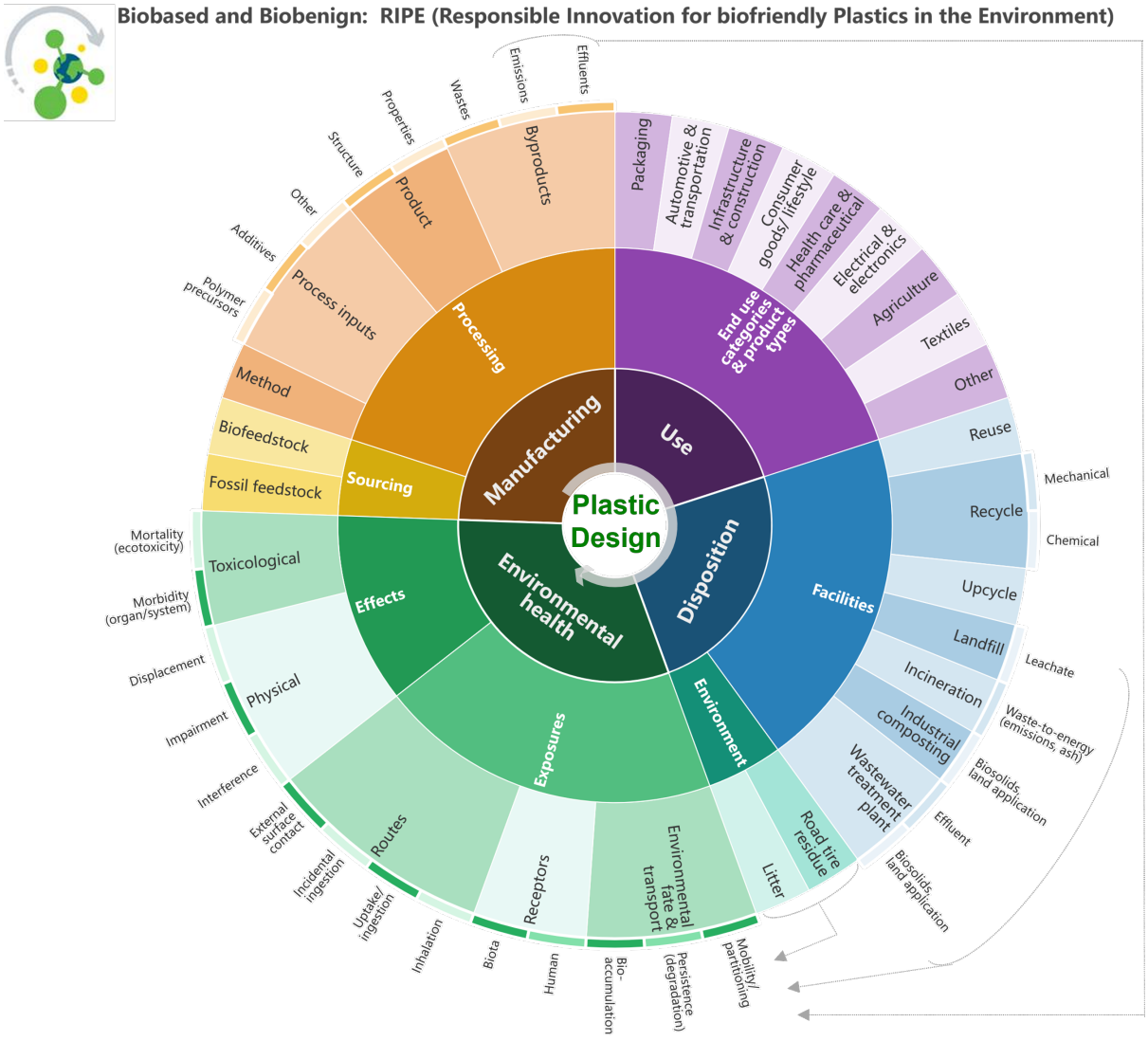



*Photo courtesy of ANL*

## COMMENTS

- It is encouraging to see BETO focusing its portfolio on emerging areas such as bioplastics, and we applaud this project's intent to incorporate end-of-life and toxics exposure considerations in the material design phase. This project is developing a useful framework provided there is sufficient interaction with material science teams in the BETO portfolio and outside DOE to make its framework useful. It is not immediately clear how the complex questions raised by this assessment are being quantified, given the point raised by the PI that literature values for these issues are all over the place and aren't generalizable. As a comparative tool, there's certainly value here, and I look forward to seeing how it evolves into application.

- The project's focus on the post-use fate of plastics at the design phase is a highly relevant research topic in the portfolio. The level of collaboration and communication was impressive. The RIPE stakeholder workshop seemed to have effectively built stakeholder buy-in from the beginning as well as offered the project performers important input for the conceptual structure. This early connection also likely secures more success for project deliverables because they will be more squarely tailored to the needs of stakeholders. Project performers clearly justified substantial merit to advance the SOA and innovation in

application, contributing, among other things, the chemical and structural change standards on recyclable plastics (versus mechanical changes currently used). In the Q&A, PI MacDonell elaborated on an upcoming spatial analysis component to the exposure risk aspect of the project, a fitting addition to the RIPE tool set. The project appears to be progressing on time.

- This is a very interesting project that fills a unique niche and appropriately expands the breadth of the office portfolio.

- This project attempts to address a critical challenge of reducing the impacts of the industrial production of plastics and addressing end-of-life considerations. The modeling approach seems reasonable, and the collaboration with other BETO projects will enhance the likelihood of this project being successful. The effort to compare and contrast this project with other BETO tools (e.g., LCAs, GREENSCOPE) is important to leverage lessons learned and avoid duplication. It seems like the biggest challenge for this model will be how to get such an approach adopted when disposal/recycling is an externality for anyone looking to commercialize a plastic product and for any industrial producer. Further, the development of the model is anticipated to precede the data that would populate it and make it usable; therefore, both utility and adoption are likely to be key issues for this project in the near term, despite the potential for high impact over time. In this regard, it will be critical to demonstrate the utility using suitable examples with sufficient data for a "backcasting" exercise to demonstrate that the tool could have predicted some of the "bad performers" of recent decades and provided a less detrimental alternative. This modeling approach seems applicable for novel fuels and other bioproducts as well; if successful with plastics, the team could consider expanding the approach to other chemicals.

- This project is very timely because it targets bioplastics, which other work in the program area suggests are an emerging technology with a high economic value. The approach is novel and incorporates a high degree of stakeholder input at multiple process stages, which is critical because the project team has identified data gaps and stakeholder buy-in as key risks. The conceptual model shared by the team would be very useful to the program area on several levels by identifying risks beyond the scope of other projects and guiding R&D toward those biomaterials with fewer post-use impacts; however, more real-world data collection may be necessary for this effort, particularly in cases where ASTM standards for material degradation and composting differ from real-world disposal.

- Your stakeholder engagement via the workshop seems like it yielded excellent results. When thinking about environmental fate and impacts, you should connect with EPA and especially their Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) team. You need to connect your model to the LCA impacts—LCA tools often attempt to quantify environmental indicators, and you need to think through how you're going to either replace or improve or update those. Otherwise, you risk having several DOE plastics tools that give very different environment results: your model and LCA models. Another challenge you should consider are the various ASTM standards for degradation; they do not often overlap well with what happens in reality with respect to biodegradation and composting. Which one(s) will/are you using? There are so many data here, it would be good to see a clearer description of how these data and models can interface and work together. How will results/databases that disagree be handled? How will the tool be validated or verified?

## PI RESPONSE TO REVIEWER COMMENTS

- The RIPE team deeply thanks our expert reviewers for their thoughtful, constructive comments and positive feedback. We heartily agree that collaborations with other BETO projects are highly valuable, as are efforts to compare and contrast with other BETO tools and related LCA and sustainability approaches (including GREENSCOPE) to leverage their lessons and avoid duplication. We likewise agree that utility and adoption are key near-term issues, given that the development of the framework precedes the availability of many data, and disposal/recycling is an externality for commercial developers and industrial producers. These two factors have driven our emphasis on stakeholder

involvement, and, in fact, they are also part of what makes the project so exciting for us: to be able to create a practical environmental reference framework with inputs from our stakeholders, so we can produce a working tool they can use in the near term, which can be built out as fuller data sets become available. We are enthusiastic about the excellent backcasting suggestion and are developing examples, with initial consideration of bisphenol A. We also greatly appreciate the recognition of the future potential for high impact from this work and the welcome encouragement to expand the modeling approach to applications beyond plastics.

- With sincere thanks for this thoughtful feedback, yes, the array of inputs from our stakeholders markedly advanced the RIPE concept, and we are very grateful for their engagement. We welcome the suggestion to connect with EPA, in particular the TRACI team, and we have initiated this connection; we anticipate shared technical discussions during the upcoming phase of the project. The health and environmental risk concepts in RIPE expand on those in TRACI and related models, and we concur with the importance of connecting with LCA tools as we advance the quantification of environmental indicators. We are coordinating with the GREET team to identify linkages, and we anticipate a similar connection for other tools because our risk aspects complement DOE LCA efforts that have focused on energy use, GHG emissions, criteria air pollutants, and water consumption. We anticipate providing updates for some indicators and more specific resolution for others as we incorporate additional features (such as degradation products and joint toxicity). Our approach is to develop linkage options so existing tools can augment existing characterizations of health and environmental impacts. We appreciate the challenge of various ASTM standards differing from actual situations, and we will pursue engagement related to standards development in light of current information. The first phase of RIPE has focused on assembling relevant information (including literature data, standards, and metrics) to frame the framework. As we progress to constructing the environmental reference framework in the next phase, we look forward to incorporating these helpful suggestions to describe how the data and models will interface, identify how discrepancies will be handled, and outline the verification and validation plan.

- We greatly appreciate this positive feedback, including regarding the project's role in the BETO portfolio. We very much agree with the importance of interacting with material science teams within and beyond BETO, and we will continue to pursue and incorporate their valuable inputs. One way in which we are addressing the disparate literature values is to develop groupings or bins to organize the data as we develop a structure for the comparative tool. We anticipate that active research programs in this area will produce scientific information that can begin to mitigate some of the current data challenges, and we are delighted by the opportunity BETO has provided to develop this tool now so a working framework can be available to incorporate more coherent data as they evolve.

- We sincerely appreciate these positive comments. We look forward to continuing the important stakeholder collaborations and advancing considerations for recycling, and we value the reviewer's encouragement of a spatial analysis component for the exposure risk aspect.

- The team gratefully acknowledges this positive feedback, including regarding the value of the conceptual model. We also appreciate the helpful comments and certainly agree that more real-world data would be valuable, including those relevant to selected ASTM standards. As the project proceeds, we will continue to pursue such data via scans of the scientific literature and online databases as well as through stakeholder collaboration opportunities and engagement with ASTM.

# SCALING UP THE ECOSYSTEM SERVICES OF BIOENERGY LANDSCAPES

## Argonne National Laboratory

### PROJECT DESCRIPTION

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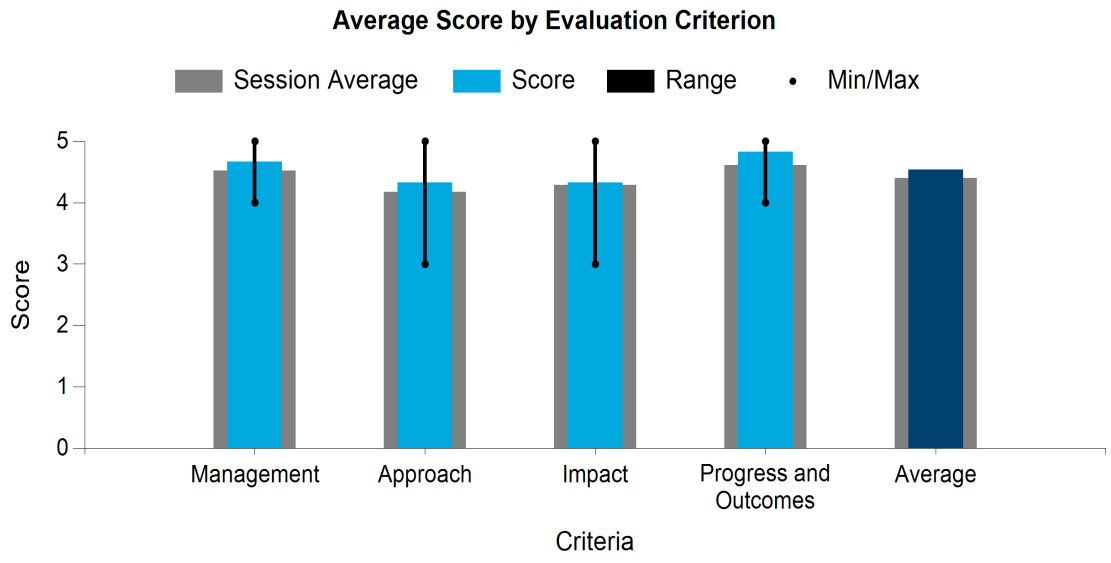
|---|---|
| WBS: | 4.2.2.12 |
| Presenter(s): | Cristina Negri; John Quinn |
| Project Start Date: | 10/01/2019 |
| Planned Project End Date: | 09/30/2022 |
| Total DOE Funding: | $1,950,000 |

Perennial bioenergy crops grown on marginal agricultural land can sustainably provide both biomass for the bioeconomy and significant ecosystem services, such as improved water quality, decreased GHG emissions, and enhanced biodiversity. Identifying marginal agricultural land for the placement of perennial bioenergy crops is a key step in designing profitable cropping systems that provide ecosystem services with quantifiable economic value. Building on a previous, successful effort, this project scales up a geospatial tool for a 12-state Midwest region. The tool's purpose is to (1) identify economically or environmentally marginal agricultural land at any scale, (2) determine the ecosystem services that are possible if the marginal agricultural land were converted to perennial bioenergy crops, and (3) estimate the net economic value of the combined production of biomass and ecosystem services. We will also conduct a demand analysis focused on the water quality aspect of the ecosystem services that could be offered to water treatment facilities. We are exploring remote sensing to determine economic marginality in irrigated regions where Soil Survey Geographic database (SSURGO) information is not applicable. In addition, we are continuing field research on long-term yields and carbon sequestration at our Illinois willow observatory. Altogether, our efforts are aimed at developing a tool and supporting information that can be used by producers, regulators, and researchers for the analysis and promotion of perennial bioenergy crops in a viable business model to improve the sustainability, both economic and environmental, of rural communities while reducing the cost of biofuels and bioproducts.



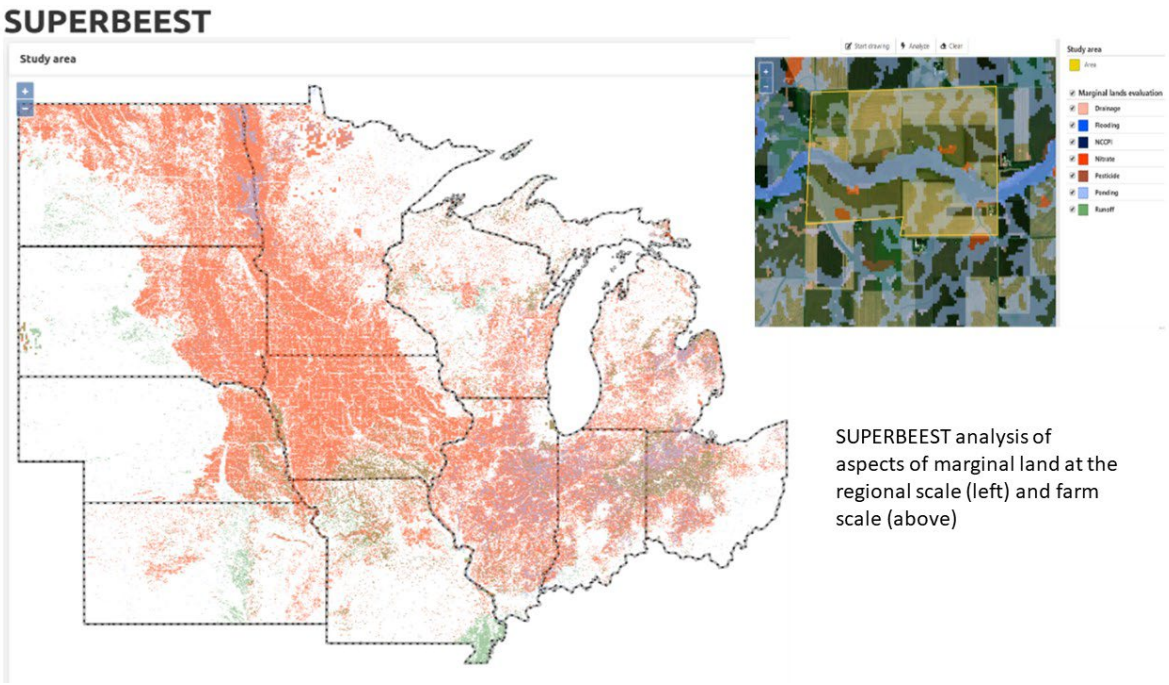



*Photo courtesy of ANL*

## COMMENTS

- This is a fantastic project. I would want to see this move in the direction of the measurement of additional sustainability indicators. It will also be important to work with the agricultural community to identify barriers to implementation and pathways to adoption.

- This is an impressive project with clearly articulated management and approach, focused on marginal lands for bioenergy crop production. This project complements other marginal land production projects in the portfolio, with its inclusion of biodiversity surveys and ecosystem services quantification and valuation. This aspect often gets relegated to the sidelines, but it has the potential to create important feedbacks that directly impact variables more commonly connected to farmers priorities (fertilizer and pesticide applications, for example). Likewise, these kinds of data will prove invaluable should PES schemes develop on a broader scale for application in agricultural settings. Much of the communication with intended end users of the SUPERBEEST tool so far seems to have been confined to the development phase, but it was good to hear mention of future plans to test and solicit feedback—an important step for gauging utility and impact.

- Integrating biomass crops on marginal farmland in the interest of improved economics and environmental performance is indeed an estimable goal. After more than a decade of promoting this, are we seeing uptake by farmers? The quantification of ecosystem services offered by these systems is an important component, though it does not alter the economics if markets for these services are not forthcoming. It is not immediately clear what is occurring under the umbrella of this project versus leveraging other work from within the BETO portfolio. This would be useful to better understand how this project is unique within the BETO program rather than duplicative of other efforts.

- The concept and potential impact of SUPERBEEST is exceptional; it may increase access to and use of lands for biofuels. Expanding this model from Illinois and the current 12 states included in the model to the United States is challenging but potentially high reward. It was not clear that any stakeholders have been engaged thus far. Potential users and partners should be engaged in order to determine the usability of the model and to improve its usability.

- This modeling project is an important extension of this team's previous work identifying methods for leveraging marginal lands in the farming landscape to provide ecosystem services. The explanation of the model itself is somewhat brief. This project uniquely combines field data collection and ground-truthing with the modeling work. The team has clearly resolved their go/no-go challenge of addressing leaching and aquifer susceptibility. There are incipient markets for ecosystem services, and this modeling would provide estimates for farmer monetization of such services; inclusion of actual payment programs into the modeling would help with the realism of the revenue potential. It appears that the user audience for the SUPERBEEST model is primarily planning organizations thinking about the allocation of marginal lands, utilities or others considering how to pay for ecosystem services versus other mitigation programs, or trading systems by which ecosystem services payments might be made; however, it is not clear how many of those users there might be and if those users would have the necessary technical knowledge to leverage such a model. Some additional thought should be given to user needs and capabilities. It would be great to see this model be deployed in a public version—for example, on the BioKDF, on the USDA Ag Data Commons, or other venue for researchers' and others' accessibility and use.

- This project is particularly useful within the project area because it incorporates ecosystem services into its geospatial analysis to identify the areas that are suitable for perennial energy crops using more than a simple yield and economic assessment. Though this project is relatively early in its cycle, the project team is already able to point to several promising areas of progress, including mapping low-yield areas and areas susceptible to nitrate leaching. One area that could use greater clarity is the methodology for determining and valuing biodiversity; although the project team is assessing the presence of unique species in areas, more detail is necessary to illustrate how this is to be done consistently across the area of study and how it will be valued as an ecosystem service.

## PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their attention to our project. They demonstrated, through their comments, a clear comprehension of what we are undertaking and why. We appreciate all their comments, some of which call for clarification, which we are glad to provide here. The intended users of SUPERBEEST include those identified by a reviewer (planners, utilities dealing with water quality or GHGs) but also farmers (who make the decisions regarding their marginal land), regulators, and researchers. The amount of usage of SUPERBEEST will depend on publicizing it after a future testing phase with input from a reviewer team representing the range of stakeholders. Their comments will inform of changes in design and capabilities. SUPERBEEST will be a public tool and suitable for use by a general audience, with training materials available to instruct users on its abilities and procedures. The tool will be modular, able to adapt to various sustainability indicators and their valuation. Our focus area for the current project remains on the 12 Midwest states that are most relevant to water quality issues in the Corn Belt, ranging from the local scale to regional problems (e.g., hypoxia in the Gulf of Mexico and Lake Erie). Future efforts may involve other geographic areas as we add more ecosystem services and other large-scale environmental problems. The concept of payments for ecosystem services has started, e.g., for water quality (Chesapeake Bay) and soil health and biodiversity (Conservation Reserve Program). Given the current national climate priorities, markets for carbon sequestration, water quality, GHG reduction, soil health, and biodiversity may realize growth, and SUPERBEEST will be a tool that is well positioned to aid decision makers in these new programs. We believe that major factors holding farmers from adopting perennial bioenergy crop production systems is the lack of a market for biomass from perennial crops for bioenergy, a working system for trading ecosystem services that is widely acceptable, and consistent government support; however, we expect this system to be widely adopted by farmers due to the convergence of catalysts, including federal government support under the current administration, maturing of relevant R&D technology, and a strong push for environment, social, and corporate governance criteria. In particular, the potential rise of carbon sequestration to fight climate change could give this concept a tremendous boost and enable the creation of an environmental trading industry that

would immensely benefit farming communities. BETO projects cover a wide range of areas under sustainability, broadly defined. We and our colleagues at other national labs and industry are aware of our respective efforts. This project alone is developing a geospatial tool to give a wide range of decision makers the ability to identify marginal land, determine the ecosystem services that could arise if the land were converted to bioenergy crops, and estimate the economic value of those ecosystem services.

- Several comments dealt with detailed aspects of SUPERBEEST. Regarding biodiversity, our current approach includes relying on a national spatial database for value per unit area for wildlife viewing and hunting, with an option for user-specified values based on local studies. Our past research indicates that these aspects, although important, are relatively minor in economic value compared to other ecosystem services. Regarding National Commodity Crop Productivity Index data, yes, that data set is important for delineating marginality on an economic basis. We are exploring the use of remote sensing technology to assess crop yield in irrigated farmland where Crop Productivity Index data are not available. Other factors, which may overlap, determine marginality based on environmental susceptibility. Our marginality analysis incorporates all the factors, identifying fields or subfields of optimal potential for conversion from commodity crops to perennial bioenergy crops. Again, we thank the reviewers for their comments and their careful consideration of this project. We hope these comment responses will provide clarification.

# QUANTIFYING AND VISUALIZING PROGRESS TOWARD SUSTAINABILITY

## Oak Ridge National Laboratory

### PROJECT DESCRIPTION

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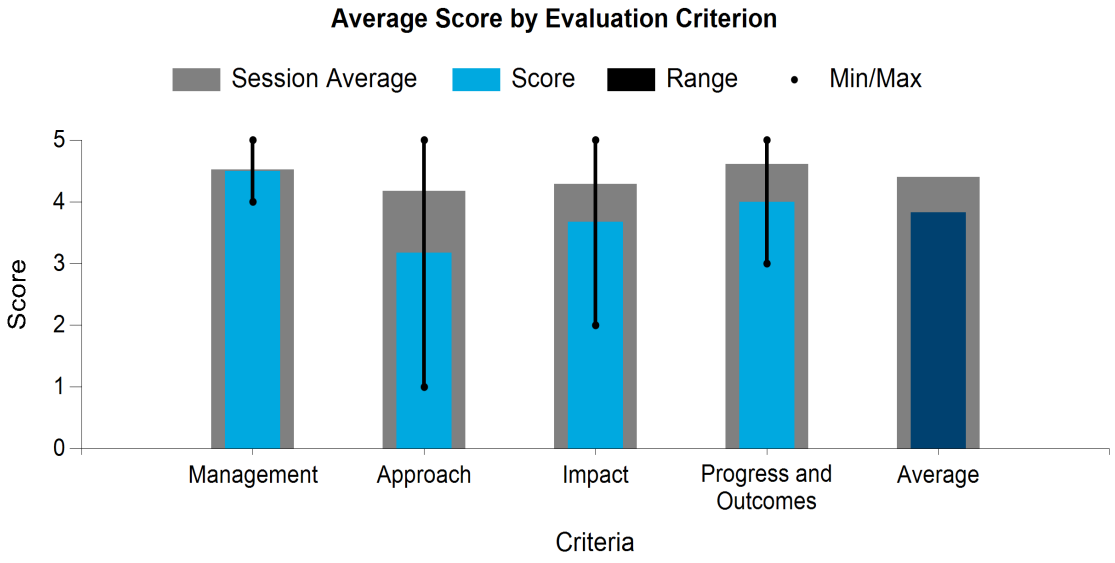
|---|---|
| WBS: | 4.2.2.40 |
| Presenter(s): | Esther Parish |
| Project Start Date: | 10/01/2018 |
| Planned Project End Date: | 09/30/2021 |
| Total DOE Funding: | $1,800,000 |

This ongoing project has been developing and testing an indicator-based sustainability assessment approach to quantify environmental and socioeconomic benefits and costs of bioenergy production at landscape scales. Case studies of cellulosic bioenergy production in several different geographic contexts are being used as the foundation for developing methods and tools that will be interactively shared with the public through a new web-based tool called BioSTAR. BioSTAR is being developed in collaboration with industry and research universities to enable stakeholders to evaluate, visualize, and compare sustainability synergies and trade-offs in real-world situations. In this way, environmental and socioeconomic benefits can be enhanced through bioenergy production while negative impacts are avoided.



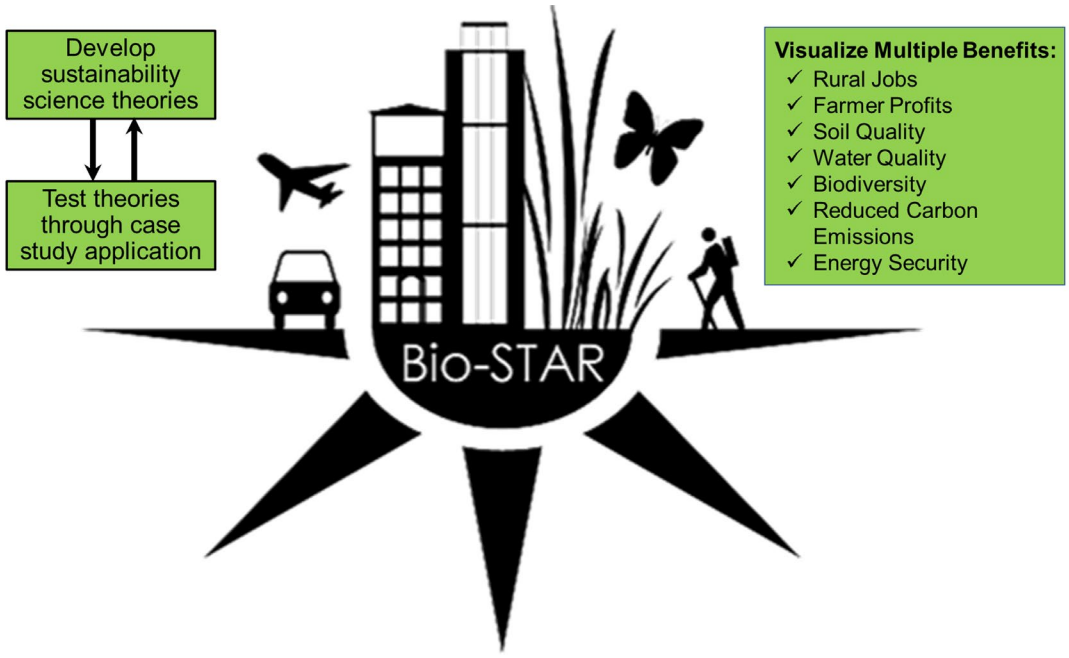



*Photo courtesy of ORNL*

## COMMENTS

- The management and approach to the development of the BioSTAR tool were all clearly communicated, and the challenges of reconciling the priorities of partners and integrating diverse data sets across multiple scales were articulated well. BioSTAR presents a great opportunity for end users to enter preferences and priorities into the visualization tool to better understand potential synergies and trade-offs in various scenarios. The progress thus far appears appropriate and on time, though the schedule seems tight for a launch in September 2021, given the remaining tasks on hand. One issue not mentioned in the presentation was the extent to which the visualization tool would suggest priorities that end users were perhaps not considering. Such suggestions could lead to more innovative land management practices that increase synergies and reduce inefficiencies in production and conservation potentials, among other impacts.

- Consistent and quantifiable ways of measuring sustainability are very important, and this project attempts to address this with the quantification of sustainability benefits and trade-offs as well as by providing a web-based tool for visualizing those trade-offs. The evaluation of synergies and trade-offs is important and not readily available elsewhere. Significant progress has been made both on analysis (e.g., comparing among landscape design approaches) and outreach (e.g., book chapter, progress toward public versions). The reviewers adjusted their approach to BioSTAR based on comments from the previous Peer Review, narrowing the focus from 35 indicators to "key indicators" and allowing users to select them. Although this is useful to enable focus on the driving concerns in a location, it does mean that the sustainability comparisons using BioSTAR are (1) not comprehensive and (2) not comparable except within a given project context (e.g., the Iowa example), so a researcher studying a different system or different location could not compare their sustainability performance to one from the Iowa project. It is important to be very clear when presenting results/visualization that this is not an approach for systematic comparisons across projects/geographies, etc., and treating a subset of indicators as a representation of overall "sustainability" for a given project/site is a bit misleading. A single "sustainability" value suggests a comprehensive evaluation that is comparable whenever used. Further, the indicators described in Parish et al. (2016) suggest that the evaluation of performance is primarily focused on year-over-year improvement, but not the actual value of the indicator metric. So, for example, if you reduce nitrate concentration in streams year over year, you would get a "high"

sustainability ranking for that indicator, and it appears that for this evaluation scheme, it does not matter if the actual nitrate concentration for a given land management case study is extremely high, whereas in reality the actual amount of nitrogen (for example) is very important for assessing environmental performance.

- It is great to see this project utilize stakeholder feedback as well as consider the environmental and social elements of sustainability. The regional differences of sustainability are both a risk factor, because the indicators can vary by location, and a strength of this project, given the regionally tailored analyses.

- The quantification and visualization of key environmental and socioeconomic indicators combined with a tool (BioSTAR) to streamline and make consistent stakeholder engagement has significant potential for DOE and other federal projects. The methods used to facilitate stakeholder engagement were not clearly outlined; this is important social science work, and it should not be left to engineers or chance. The team should use evidence-based best practices and experts in stakeholder engagement. It appears as though a large number of stakeholders have been engaged throughout the project, which is commendable.

- This project both quantifies sustainability and socioeconomic trade-offs of bioenergy and helps communicate those findings to relevant stakeholders. The project team has built the BioSTAR tool so that outside stakeholders can successfully input their own data into the draft tool; this project has also solicited feedback from the public on usability. These factors could be crucial to ensuring this project's wider impact. Given the extensive set of indicators and the wide geographic variation in possible impacts, it would be helpful if the project team provided more detail on the applicability of the BioSTAR model to other regions. Further, it would be useful to understand the data needs for stakeholders to successfully run the model and the risks inherent to partial data collection.

- This project is framed and described well. Its intent to quantify landscape-scale environmental and socioeconomic benefits and costs of bioenergy using indicators to evaluate trends and trade-offs in sustainability is useful. Moreover, it appears to be well integrated with other BETO efforts; however, it is not immediately clear, perhaps because of the difficulties of communicating via webinar, exactly how they are going about this goal. Sustainability analyses appear to be done on a one-off basis for each study. Does a user of the tool need to bring to it all of their own data and analysis? If so, is it mainly a framework for assessment and visualization? Some clarity on these points would enable BETO to leverage the strengths this project may offer.

## PI RESPONSE TO REVIEWER COMMENTS

- Our intentional stakeholder engagement efforts using evidence-based practices, facilitated discussions, and interactive posters have been detailed in several publications that predate the March 2019 to March 2021 project assessment period. For more information about these efforts, we suggest consulting our publications via the ORNL Center for BioEnergy Sustainability (CBES) website at https://cbes.ornl.gov/publications/. We hope that creating visualizations within BioSTAR using combinations of the 35 environmental and socioeconomic indicators provided in our starting checklist will get users to think about potential landscape-scale synergies and trade-offs that they may not have otherwise considered. These considerations can help users choose bioenergy feedstocks and/or develop land management plans that can provide multiple benefits. BioSTAR is designed to provide a consistent framework for evaluating and visualizing the sustainability of alternative feedstocks and management plans for cellulosic bioenergy production. The tool walks users through the six-step process of selecting and evaluating indicators. Although we are currently pulling together national-scale data sets that can be used to characterize starting values for many of the 35 indicators presented in BioSTAR's starting checklist, future values for most of the indicators compared under each plan will need to be modeled and/or measured outside of BioSTAR by the individual project. In order to use BioSTAR successfully, users will first need to work with their project stakeholders to choose a set of environmental and socioeconomic indicators that can be used to characterize progress toward collective goals. Users will

then need to set baseline and target values for each selected indicator (as either fuel shed-aggregated values or as county-specific values). They will then need to model or measure the trend of each indicator relative to the target under each plan outside of BioSTAR. By entering the measured and/or expected indicator trend values into BioSTAR, users will be able to visualize the sustainability synergies and trade-offs that can help them pick the feedstock and/or management plan that will provide the greatest number of benefits with the fewest adverse consequences. Partial data collection will make the visualization of project results within BioSTAR less helpful for decision making. BioSTAR is intended to help users evaluate the relative sustainability of alternative plans (i.e., feedstock choices and/or management practices) for their own project using a consistent methodology. This sustainability assessment approach was first demonstrated through a case study of East Tennessee switchgrass-to-ethanol production that compared measured and expected indicator trends for each of the 35 indicators under three alternative land use scenarios: annual tilled corn production, unmanaged pasture, and perennial switchgrass production. Although it is true that allowing users to narrow and refine the starting checklist of 35 indicators to a more manageable number of "key indicators" could make it more difficult to compare the sustainability of different bioenergy feedstocks and practices across the country, BioSTAR can still be valuable in helping users plan their own projects to provide multiple benefits to their local communities. And as more users share their project information in BioSTAR, we will grow our understanding of bioenergy stakeholder priorities across geographically diverse regions of the continental United States.

# SPATIALLY RESOLVED MEASUREMENTS OF WATER QUALITY INDICATORS WITHIN A BIOENERGY LANDSCAPE

## Oak Ridge National Laboratory

### PROJECT DESCRIPTION

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|---|---|
| WBS: | 4.2.2.44 |
| Presenter(s): | Natalie Griffiths |
| Project Start Date: | 10/01/2018 |
| Planned Project End Date: | 09/30/2021 |
| Total DOE Funding: | $1,020,000 |

Field studies are critical to assess the environmental effects of bioenergy feedstock production, but measurements are often time and labor intensive, thus limiting understanding of environmental responses. Coupling environmental sensors with drones can allow for improved monitoring across larger spatial scales, in a more timely manner, and at a cost comparable to current approaches. Our objective is to advance understanding of water quality indicators for bioenergy through the development, testing, and deployment of a novel drone-sensor platform, AquaBOT. In FY 2019, we designed and tested the AquaBOT. Using an iterative approach, we overcame the challenge of assembling a system small enough to access streams but large enough to carry the sensor payload. In FY 2020, we used the AquaBOT to map water quality in streams draining an agricultural-bioenergy landscape in Iowa; progress was somewhat hampered by COVID-19. The AquaBOT revealed meter-scale variation in water quality, and it provided higher-resolution data than manual sampling for less effort and at a comparable cost. In FY 2021, we will continue to evaluate the AquaBOT versus traditional sampling, and we will use the AquaBOT to examine the efficacy of saturated buffers at reducing nutrient losses. Drone-sensors systems will likely revolutionize environmental monitoring, and high-resolution data collected by the AquaBOT can help identify where bioenergy plantings and conservation practices can be implemented to improve water quality.

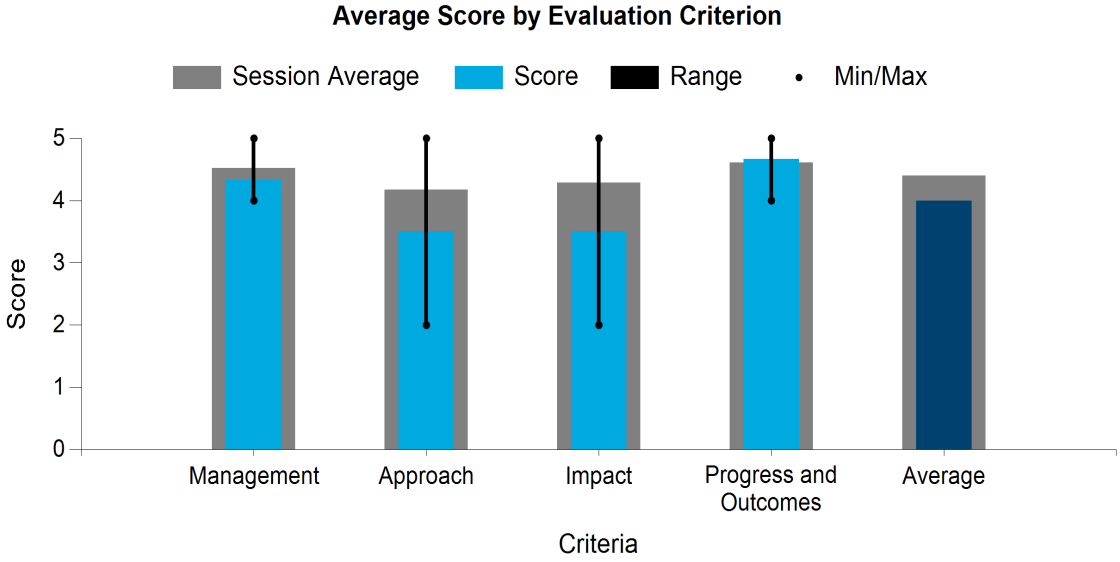


*Photo courtesy of ORNL*

## COMMENTS

- The improvement of water quality measurements to better inform water quality indicators and impacts from bioenergy crops, with a focus on N, has the potential to greatly improve our understanding and support for water sustainability. This is a really cool and fun project. The PIs really need to investigate other aquatic systems that are very similar; it is not clear that this work is at all novel because others have developed similar technologies in the past. In fact, you can purchase a commercial water quality testing boat online already. It would be helpful for the project team to justify the need to build something custom. The presentation keeps noting that this system is lower cost, but no cost comparisons were presented. This analysis should be conducted and presented. Although this project is clearly in the nascent stages of development, integrating outreach and engagement of key stakeholders could prepare potential users to adopt the product. Stakeholder engagement can also help gather feedback to improve the system and the user experience during development.

- The potential impact, if widely adopted, is high, although the point was raised that there are other options that exist for remote-controlled water quality sampling; given this, the team should emphasize in the approach section why this option is unique from technical, cost, or other perspectives. The potential for uses outside of the bioenergy realm would enhance the value/utility. The team has fully developed and tested the sensor since the last Peer Review. The ability to view data in real time is very useful for troubleshooting and field testing, and it is not always available from such sensors. The researchers identified an important measurement challenge: Because the AquaBOT cannot sample in more than one place at a time, temporal variations (e.g., diurnal patterns) become very important. The suggested approach of having limited stationary samplers and performing temporal measurements to adjust the drone data makes sense from a technical perspective, but it is not clear to what extent having to do this type of analysis would reduce the cost-effectiveness of the drone-boat approach. The program is well integrated with other BETO projects for field testing/validation (e.g., ANTARES, the tile drain work with the Negri group). The tile drain work is a great example of an application for this work.

- This application of an unmanned surface vehicle for high-resolution spatial mapping of nutrient pollution offers strong potential. I encourage the PIs and BETO to leverage this platform to support the efforts of other teams because this sort of detailed water quality mapping would provide valuable data for field trials as well as spatial modeling of pollution flows. A key challenge is that the spatial resolution comes at the expense of the temporal resolution offered by static testing stations. The project seems to be responding to this, and further development of hybrid sampling protocols as well as algorithms to correct drone data for changes over time would allow the interpolation necessary to map the pollution accurately.

- This project has clear tasks and objectives, and the progress to date was impressive, despite the setbacks of COVID-19 and the extreme drought conditions inhibiting the field season. It was helpful to hear about the challenges of the AquaBOT development as well as subsequent data collection. As this project develops, it would be helpful to hear how the AquaBOT compares to other, similar drone technologies developed elsewhere and if the team has considered supplemental technologies (e.g., aerial drones) during drought conditions in the future. The project appears to be progressing on time.

- This project utilizes emerging unmanned surface vehicle technology to collect what is normally difficult field-level data to collect, and it fills an important data gap on water nitrate data for some bioenergy pathways. The site assessments are coordinated with BETO's separate efforts on integrated landscape management. Although the early results suggest that this new approach allows for cost savings and overcomes previous temporal limitations for data collection, additional details would be helpful to evaluate the effectiveness of this approach, including (1) a closer comparison to existing data collection methods and (2) more defined plans to scale the approach beyond the current small stream test sites.

- Water quality issues are a key vulnerability for the bioenergy industry, so this work is important. If the research is indeed duplicative of existing research, as one reviewer suggested, it is critical that the office brainstorm how to advance this work. By bringing together government, research, and NGO stakeholders, BETO could evaluate where the gaps in research hinder progress as well as set goals and strategies to achieve real-world improvements in water quality. Real-world progress cannot be made without industry/agricultural buy-in. Creative solutions are drastically needed to achieve measurable water quality improvements, and the project should help guide how tangible accomplishments can be garnered.

## PI RESPONSE TO REVIEWER COMMENTS

- Thank you very much to the review committee for their time and their helpful and insightful comments. Here, we address the five questions/concerns that the reviewers brought up in their written comments: (1) the novelty of the AquaBOT system and comparison to similar technologies, (2) a cost comparison, (3) the challenge of identifying spatial versus temporal variation in AquaBOT measurements, (4) scalability, and (5) outreach.

  (1) The novelty of our AquaBOT system is based on two key characteristics: (i) the integration of a nitrate sensor; and (ii) the use of a small, unmanned surface vehicle to map water quality in small streams. The reviewers are correct that there are other similar technologies (i.e., drone water quality measurement systems) that have been developed. Systems have been developed to measure water quality using unmanned aerial vehicles equipped with sampling equipment and unmanned aerial vehicles or unmanned surface vehicles equipped with sensors (e.g., temperature, conductivity, dissolved oxygen). Further, studies have examined spatial patterning in nitrate concentrations in larger river systems (e.g., Mississippi River, Upper Colorado River) using nitrate sensors mounted to boats; however, we are not aware of any studies that have developed an unmanned surface vehicle sensor platform equipped with a nitrate sensor and that can access small streams. By measuring nitrate in small streams, the AquaBOT fills an important gap in drone-sensor technologies and is directly relevant for addressing water quality issues in high-nitrate, headwater streams, such as those draining agricultural-bioenergy landscapes.

Nitrate sensor technology has advanced rapidly in the past few years. Specifically, UV nitrate sensors, which are much more accurate and stable than ion-selective sensors, are typically large (8–11 lbs.) and costly. The UV nitrate sensor used on the AquaBOT was just released at the start of our project (there was a several month delay in receiving these sensors from the vendor due to the high demand for this smaller, cheaper sensor). The lower cost (approximately half the cost of other UV-based nitrate sensors) and especially its smaller size (6.6 lbs) allowed us to mount this sensor to a small, unmanned surface vehicle for measurement in small streams (without exceeding the payload of the small, unmanned surface vehicle). To highlight that sensor technologies are advancing quickly, another UV nitrate sensor was released on the market a few months ago that can be integrated onto a multiparameter sonde (instead of a stand-alone nitrate sensor); therefore, an even smaller AquaBOT could be designed today than the one we designed 2 years ago, which could access even smaller streams. This highlights the dynamism of the drone-sensor field and the incremental advances that allow for newer unmanned surface vehicle sensor systems to continue to be developed. We also note that within the past few months, a commercially available unmanned surface vehicle sensor system was released (YSI's HYCAT) that is similar to our AquaBOT system (e.g., measurement of multiple water quality parameters including nitrate); however, this system is still larger than the AquaBOT (1.8 m x 0.86 m compared to 1.16 m x 0.73 m) and much heavier (120 lbs. versus 58 lbs.), making it challenging to deploy in small streams, which was the focus of our study.

(2) We apologize for not including details of the cost comparison in our presentation. A thorough cost-comparison report was completed for our FY 2019 Q4 milestone and submitted to BETO. Because similar technologies (e.g., drone water quality measurement systems) are primarily described in the literature (journal publications, reports), and they are not commercially available, a cost comparison with these systems was not possible. Instead, we focused our cost comparison between the AquaBOT system and the manual sampling approach, which is the equivalent approach for conducting longitudinal water quality surveys in small streams. We synthesized costs to analyze the five water quality parameters measured by the AquaBOT (turbidity, conductivity, and nitrate, dissolved oxygen, and chlorophyll a concentration) at 15 analytical laboratories across the United States. Based on the average per sample cost, we estimated that ~425 water quality samples could be analyzed for the cost of the AquaBOT. If one were to manually collect water samples at the same spatial resolution as measured along the 2.3-km reach of Alleman Creek using the AquaBOT (i.e., every 9 m), the sample analysis cost would exceed the AquaBOT cost after less than two sampling events. There are additional costs associated with these measurement methods that were discussed in the report but not included in the overall cost analysis because they depend strongly on the user's needs (e.g., how frequently samples are collected, how many sites are sampled). The report also details additional factors (e.g., personnel time for fieldwork and lab work, calibrants, analyzing samples in one's own laboratory) and nonquantifiable benefits and limitations (e.g., longevity of sensor systems, accuracy/precision of sensors versus analytical techniques, data and sample availability) to take into account when selecting a water quality measurement approach. Overall, measuring water quality at a high spatial resolution is more cost-effective using the AquaBOT than via manual water quality sampling/analysis, but we were not able to compare the AquaBOT cost to similar drone-sensor technologies because the latter costs are typically not available for comparison.

(3) A key challenge of the AquaBOT is that measurements integrate both spatial and temporal variation in water quality parameters. We note, however, that this challenge is not unique to the AquaBOT because water quality data collected by most measurement approaches integrate spatial and temporal variation to various degrees. For instance, the equivalent conventional measurement approach to the AquaBOT involves collecting multiple measurements (i.e., manual grab samples) along a river network. Similar to the AquaBOT, these longitudinal, manual collection surveys can reveal spatial patterns in water quality, but the data also reflect temporal variation unless all measurements are collected at the exact same time. To identify temporal versus spatial controls, we are collecting water quality data from fixed sensor stations so that the predominantly temporal changes measured via fixed sensors could be

"subtracted" from the AquaBOT data to reveal the predominantly spatial signal. A reviewer makes an excellent point that this would reduce the cost-effectiveness of the AquaBOT approach; however, because a fixed sensor station would be needed to account for temporal variation in manually collected samples from longitudinal surveys, this additional cost would be applied to both approaches, not only the AquaBOT.

(4) Our focal site for AquaBOT measurements is Alleman Creek, in part to test the AquaBOT approach, but primarily to evaluate the efficacy of saturated buffers at reducing nutrient loads to streams (this site will be receiving saturated buffers along the ~2-km reach in summer 2021); however, our overall research plan also includes conducting longer AquaBOT runs along stream and river networks to examine how spatial patterning of water quality varies from small to larger streams. For example, we planned on conducting measurements along a 50-km reach of the Southfork River, Iowa, and have identified various launch sites and worked with the local watershed alliance for site access. Although these measurements were put on hold in FY 2020 due to COVID-19, we plan to conduct AquaBOT runs along the Southfork or similar nearby river networks in FY 2021.

(5) We agree with a reviewer comment that outreach and engagement of stakeholders is an important aspect of this project. We have actively been presenting on the AquaBOT system and initial results to a variety of stakeholders. To date, this has included presentations to local watershed management authorities and watershed alliances (Southfork Watershed Alliance, Raccoon River Watershed Association) in Iowa; groups focused on stream management, restoration, and monitoring (Soil and Water Conservation Society, Upper Midwestern Stream Restoration Symposium); and scientists interested in nutrient biogeochemistry (Society for Freshwater Science, the American Geophysical Union). We have received considerable interest in the AquaBOT system and its application to better understanding water quality dynamics, especially from the local watershed management authorities, and we are working together with the Polk County Watershed Management Authority (Iowa) to use the AquaBOT to assess saturated buffer efficacy.

# ENABLING SUSTAINABLE LANDSCAPE DESIGN FOR CONTINUAL IMPROVEMENT OF OPERATING BIOENERGY SUPPLY SYSTEMS

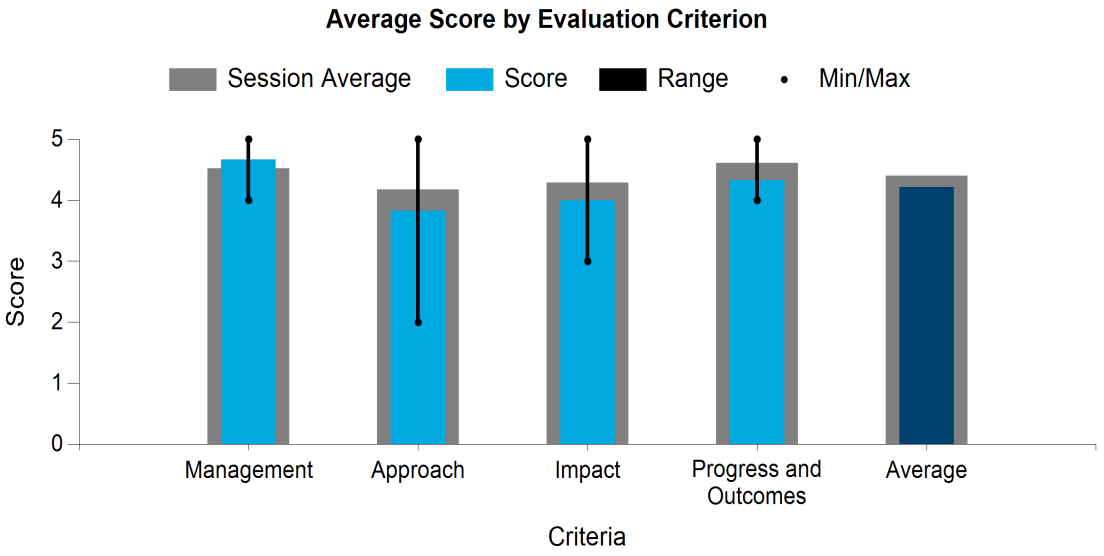
## ANTARES

### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 4.2.2.60 |
| Presenter(s): | Kevin Comer |
| Project Start Date: | 04/01/2016 |
| Planned Project End Date: | 03/31/2021 |
| Total DOE Funding: | $9,000,000 |

When fully developed, documented, and demonstrated in three commercially relevant bioenergy supply sheds, the landscape-design activities, associated enabling tools and practices, and the field-level sustainability and logistics system results will advance the SOA of sustainable bioenergy landscape design processes that will support current and future cellulosic biorefineries and the emerging bioenergy and bioproducts industries. Through outreach and information resources developed by the project team, the template created by this project can be adapted and implemented elsewhere and will offer a path to shared benefits for a broad range of federal, state, local, and industrial stakeholders. This project will utilize new and emerging subfield analytical software that will enable management decisions via precision agronomics. This will allow the identification of optimum areas to incorporate perennial energy crops and conservation practices into corn and soybean producing fields in a manner that is both economically and environmentally beneficial. The foundation of the project's multistage stakeholder outreach plan is to leverage existing federal, state, and local conservation programs, coupled with a transformative approach of integrating herbaceous energy crops into the bioenergy supply mix to supplement agricultural residues. The project team will fully monitor harvested acres of agricultural residues and warm season grass energy crops. The project team implemented a modified conservation grasslands approach on a pilot program basis to allow the establishment of approximately 2,000 acres of warm season grass energy crops that allows landowners to retain their conservation program benefits. Additional conservation practices have been implemented and monitored by team members, including the establishment of more than 15,000 acres of cover crops. A multiyear comprehensive field research, testing, and monitoring program has been conducted on targeted fields within the project's activities.

The best and most immediately relevant opportunities to develop and demonstrate innovative and impactful landscape design practices for bioenergy systems exist within the feedstock supply sheds of operating bioenergy projects. This project has been primarily focused on the biomass feedstock supply sheds serving POET-DSM's Project LIBERTY biorefinery in Emmetsburg, Iowa, and DuPont Cellulosic's biorefinery in Nevada, Iowa (plant recently sold to VerBio for renewable natural gas production from herbaceous biomass feedstocks). These are areas where land use change is already underway but is still early in its evolution in supporting the supply chains of groundbreaking cellulosic biorefineries. The project has built on information available from these operating bioenergy systems and collected additional data necessary for addressing barriers and stakeholders' objectives. The project's activities are also coordinated with the Iowa Department of Agriculture and Land Stewardship, and they are aligned with their aggressive efforts through the Iowa Nutrient Reduction Strategy to reduce nutrient runoff that contributes to Gulf hypoxia and other negative impacts to water quality. The project team is also implementing precision-agriculture strategies to improve the profitability and sustainability of biomass harvest operations and decision-making processes.



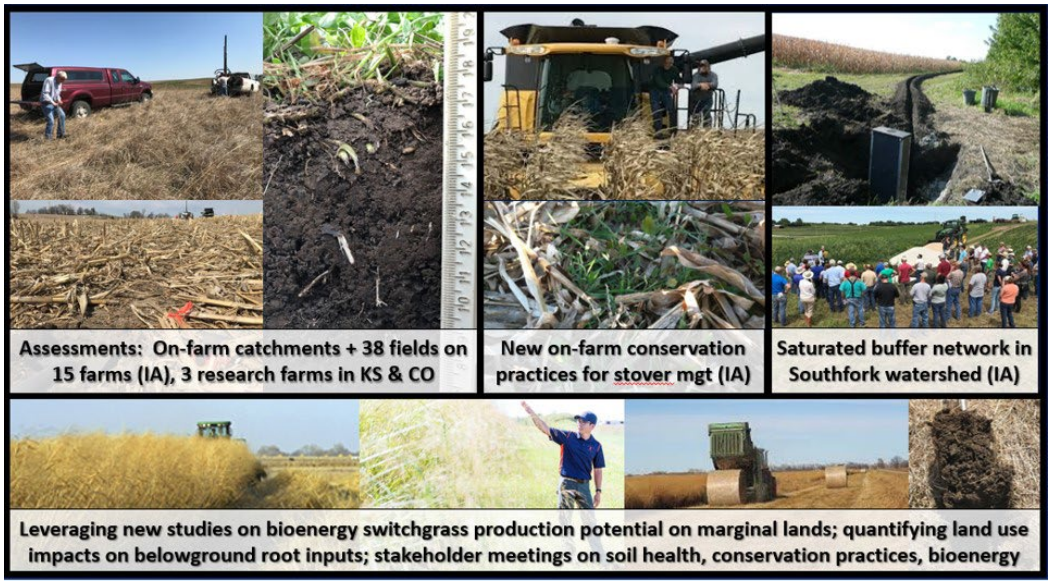




*Photo courtesy of ANTARES*

## COMMENTS

- The project contributes an important perspective in the bioenergy production conversation, focusing on energy crop production in marginal lands, and specifically an analysis at the subfield scale. It seems like a viable alternative crop opportunity for farmers. Still, one could imagine that farmers with a higher relative proportion of marginal lands on their property would potentially benefit the most from the technologies developed in this project but might also be less likely to participate due to risk aversion or lack of minimum required resources (access to appropriate harvesting machinery, etc.). It seems if the technology is developed with those farmers in mind, all farmers might benefit. Otherwise, those who already have access to resources and capacity to try something new on their land might be the only end users who participate and therefore benefit.

- It seems as though changes in the buyer (closure of Dupont and POET facilities) impaired this project's market to sell feedstock. This will likely continue to be a problem as the industry works to get off the

ground, but it emphasizes the need for versatility and that a single buyer is not reliable at this stage in the technology deployment. Nonetheless, the project did well to continue with the data collection.

- It is really important to watershed and ecosystem sustainability that you are including nitrogen and phosphorus impacts in this work; great job. The large acreage of land you've recruited to your project is impressive: 3,000 acres on marginal lands. It sounds like you've done a lot of work, but critical results related to the stakeholder engagement process and impact, the environmental sustainability indicators, and logistics were not described. How are you sharing/making public the data you've collected? The PI really should have a handle on the high-level activities and results from your team and overall project. As such, it was difficult to evaluate whether the approach has substantial merit to advance the SOA, is relevant to the Strategic Analysis Support BETO Program and Technology Area goals, and is innovative in its application. It is difficult to tell BETO if they should fund additional parts of this project given the PI's inability to discuss many of the impacts and results.

- This important project is attempting to identify strategies to improve farmer revenue, environmental performance, and biomass production in parallel, which would reduce trade-offs among performance metrics. The project team is extensive and leverages strengths from across the national labs, federal and state agencies, as well as academia and the private sector. The forward-looking effort to build a template for future biorefinery projects will be important for the development of cost-effective and successful bioenergy supply chains. The public release of the AgSolver Profit Zone Manager software (being incorporated into an existing software system) should provide direct access to the tool by farmers; however, there are still some questions about the scalability of these approaches and usability by the intended farmer audience. It would be valuable to pare down the range of treatments, etc., based on primary drivers of performance and identify best practices so that farmers would have a more tractable range of solutions to select from. It would be helpful to lay out the barriers and/or benefits to farmer adoption of methodologies as well as information on the likely cost to farmers of the Straeter Cornrower header.

- This is a strong effort, despite the difficulty of managing such an enormous undertaking with field and modeling elements. Its reach across 16 individual landowners, well-placed partners, and significant cost-share are impressive and support efficacy. I appreciate its focus improving the economic and environmental performance of agricultural land via biomass from cover cropping, perennial grasses, and buffer strips. I encourage an effort to further ground-truth the harvest and soil carbon projections modeled here.

- This project is highly relevant to this program area's efforts because it combines modeling with real-world field data. Its results could have substantial implications for the economic viability and scale of the bioeconomy. The project appears to be making substantial progress in implementing its recommendations and measuring results on its targeted land areas; however, it would be helpful to better understand the scalability of this approach and determine its cost-viability when applied to a broader area of study.

## PI RESPONSE TO REVIEWER COMMENTS

- We appreciate the reviewer's comments and time spent offering feedback on our project and presentation. We are confident that this project has provided a great deal of publicly available information and significantly advanced the SOA knowledge and analytical capabilities associated with the project's overall landscape design strategy. A software system for precision agricultural business analysis (developed by AgSolver, now available as part of EFC System's FieldAlytics software) was advanced and commercialized within the project period and is now available to an existing customer base that is managing tens of millions of acres. This was a significant step toward large-scale market deployment. The New Holland/Straeter Cornrower header for variable-rate sustainable removal of high-quality corn stover has been commercialized, and this project contributed to advanced control features

that link sustainability factors to biomass removal rates in real time. During harvest, this unique development provides a range of benefits to farm managers and biomass customers, including reduced harvest cost (up to $14/dry ton), improved biomass quality (low ash), and site-specific control capabilities to help ensure sustainable harvests under variable field conditions. Our project team has measured, modeled, and published results that demonstrate the strategies targeted in this project will sustain or improve soil carbon levels, significantly reduce nitrogen and phosphorus runoff, reduce soil loss, improve soil health, and improve farm profitability on marginal acres. More than 30 journal papers and reports associated with project activities have been published to date. At least four new (not yet commercialized) software tools for aiding decision making and information distribution for strategies considered have also been developed and demonstrated. Based on prior Peer Review feedback and our team's recognition of the importance of landowner feedback, communication, and information sharing, our team has published several papers that include feedback from stakeholders regarding their priorities for sustainability indicators. Perhaps the most significant of these efforts involved a series of structured one-on-one interviews with approximately 40 landowners representing different levels of experience and exposure to biomass supply issues (e.g., corn stover suppliers, conservation acre owners, switchgrass suppliers, row crop producers). Those interviews resulted in a +200-page Ph.D. thesis report, several publications, conference presentations, and a new decision support tool that incorporates landowner priorities into a decision-making framework. Those interviews and subsequent analysis verified this project's premise, that although environmental sustainability issues are important, farm profitability is a primary driver of land management decisions and strategies among producers.

- This project identified opportunities that will simultaneously improve farm profitability, environmental outcomes, and provide new, publicly available information and decision support tools that will more readily facilitate landscape design decisions and quantify impacts of those decisions from financial and environmental perspectives. Feedback provided by our cooperating landowners confirms the importance of our project vision and strategies. To further enhance communication between our team and participating landowners, USDA Agricultural Research Service has prepared individualized, detailed soil quality analysis reports for every field where we performed fieldwork and collected soil samples. By the end of this project, team members will have participated in more than 150 local stakeholder meetings, collaborated with many different groups on project activities, provided frequent updates to our stakeholders, and actively sought to gather ongoing input from local stakeholders who are engaged in project activities. This includes local watershed alliances, producers, conservation agencies, and the scientific community. Those collaborations have resulted in well-attended local field practice demonstrations and field days, and they have demonstrated several new technologies to a wide variety of stakeholders who have remained actively engaged throughout the project. We believe our team has demonstrated that landscape design for continual improvement of operating bioenergy supply systems can be compelling and advantageous from the perspectives of individual landowners/farm managers, commercial-scale biorefineries, and state/regional programs being designed to meet water quality objectives. Undoubtedly, market conditions and government policies will determine the extent to which this project's landscape design tools and strategies are financially attractive to landowners with regard to supplying sustainable biomass supplies from marginal acres (perennial crops) and/or harvesting crop residues (e.g., corn stover, cover crops). This project has made significant SOA contributions, but additional R&D is needed to enhance many of these tools and encourage the implementation of those strategies to more fully validate the sustainability benefits and impacts for a wide variety of field conditions.

- In summary, we believe this project has established a valuable portfolio of field-scale opportunities and built positive local stakeholder and landowner relationships that can be leveraged in future research and demonstration projects. It has also provided valuable field and model validation that will significantly advance sustainable bioenergy production by implementing landscape design strategies.

# BIOFUELS INFORMATION CENTER

## National Renewable Energy Laboratory

### PROJECT DESCRIPTION

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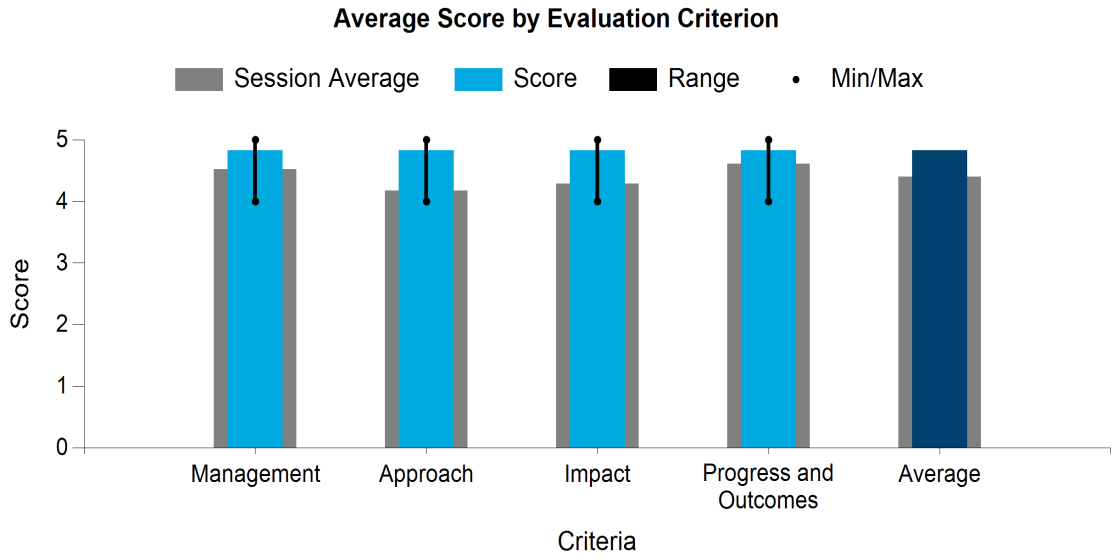
|---|---|
| WBS: | 6.3.0.1 |
| Presenter(s): | Kristi Moriarty |
| Project Start Date: | 10/01/2019 |
| Planned Project End Date: | 09/30/2022 |
| Total DOE Funding: | $660,000 |

The purpose of the Biofuels Information Center task is to provide relevant data, information, reports, and web-based tools to all bioenergy stakeholders. The Biofuels Information Center task began in FY 2008 to meet the requirement under Title II, Sec. 229 of the Energy Independence and Security Act of 2007 that requires DOE to develop a "Biofuels and Biorefinery Information Center."

The Biofuels Information Center task supports biofuels pages content on EERE's most visited website, the Alternative Fuels Data Center (http://www.afdc.energy.gov), and the Bioenergy Atlas tools (https://maps.nrel.gov). This task results in more than 1 million web page views (an instance of an internet user visiting a web page) per year. In FY 2017, the task expanded to include the USDA's Biofuels Infrastructure Partnership and the annual Bioenergy Industry Status Report. The USDA Biofuels Infrastructure Partnership expanded infrastructure for E15 and/or E85 to approximately 850 stations, and NREL reviews data for quality and analyzes all infrastructure and sales data collected by the USDA. Stations are privately held, and previously it was difficult to ascertain infrastructure and sales data. This unique data set allows insight into infrastructure data (number of pumps and tanks, costs to install new equipment) and sales data (price and volume for E10, E15, E85, and diesel by month). The 2019 USDA Biofuels Infrastructure Partnership National Summary Report is with DOE for review prior to publication. The Bioenergy Industry Status Report provides key bioenergy metrics in one place. Topics covered include biofuels (ethanol, both starch and cellulosic; biobutanol; biodiesel; and renewable hydrocarbons), renewable natural gas, biopower, and bioproducts. Reports were published for data years 2013, 2015, 2016, and 2017.



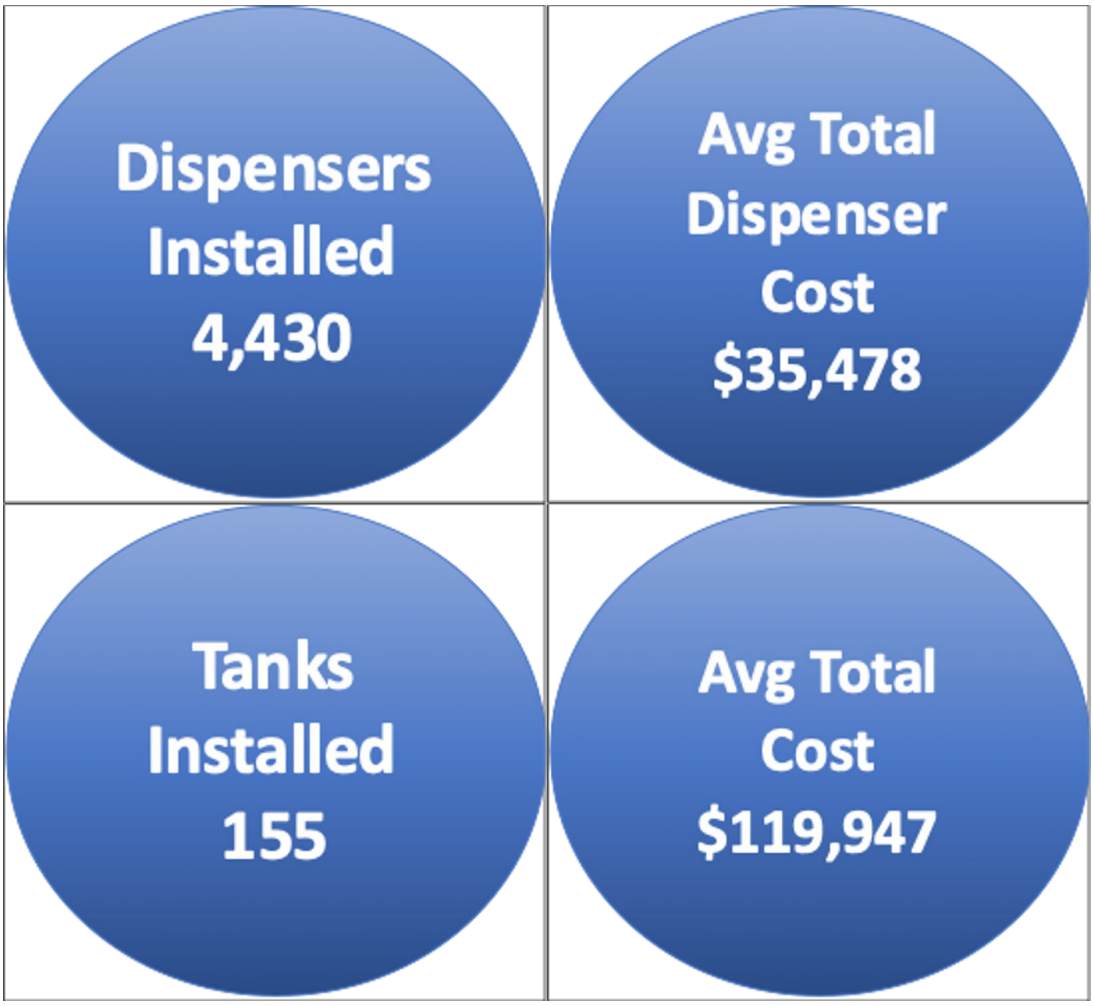



*Photo courtesy of NREL*

## COMMENTS

- The Biofuels Information Center platform represents an important contribution to the BETO portfolio, and the reported number of page views was impressive, especially given the volatility in the fuel market in 2020. It seems information beyond page views might be helpful to understand the extent to which the data are being utilized, through downloads or other tool engagements. This project has clear connection to the needs of stakeholders, especially industry partners, and is on time meeting project goals and deliverables.

- It is good to see this project working harmoniously with the Bioenergy KDF, such as being the central repository for geospatial information.

- The Biofuels Data Center provides a valuable service to DOE by organizing a wide array of data and web tools, and it makes them accessible to stakeholders and the public. This effort makes use of extensive coordination with other agencies as well as through contacts with industry. The project team has developed a thorough project management plan for collecting, verifying, and updating their data sets, showing continual improvement and expansion. The impact of the project is illustrated via Google Analytics, showing a high degree of engagement.

- The Biofuels Information Center continues to be an important component of BETO's data collation and outreach program. The impact of this center is evident—more than 1 million page views shows that

people are using it. The Bioenergy Atlas provides a venue for geospatial data on current and potential feedstocks and supply chain infrastructure for biofuels. The transfer of the Billion Ton Study information and other geospatial data formerly housed on the Bioenergy KDF to the Bioenergy Atlas is an important consolidation that will help interested parties find the data more efficiently. The Bioenergy Industry Status Report is a high-value publication of information not easily accessible elsewhere. The addition of renewable diesel, sustainable aviation fuel, and marine fuels would be very valuable to industry participants and would expand the impact of the Biofuels Information Center. One opportunity that was not discussed was the potential to study the USDA Biofuels Infrastructure Partnership information to generalize those real-world data into model inputs for other projects in BETO. This would be a helpful real-world validation of information going into BETO models and projects.

- This PI is an expert in the fuels distribution industry landscape and decision factors. In fact, it seems to be more integrated with industry than with colleagues at other national labs. This is useful in bringing new lenses to BETO's work as well as potential new partners and data, but it is also important to consider whether the effort could better support the broader BETO ecosystem. It is clearly filling an important niche, as illustrated by the large number of page views. Their approach to data vetting and visualization has created an impactful and credible source of information.

- This was clearly a complicated project, with numerous stakeholders and partners. Excellent job ensuring data quality and integrity. The Alternative Fuels Data Center is clearly an important data portal for the bioenergy community. The wide range of data visualization and analysis available within the site is commendable. You need to ensure that this database is collaborating with and not duplicating KDF.

## PI RESPONSE TO REVIEWER COMMENTS

- The PI thanks the reviewers for their insightful feedback. The Alternative Fuels Data Center is intended for a wider, general audience with less technical knowledge. The Bioenergy KDF is for engineers and scientists sharing their research among peers. The two projects will collaborate to ensure there is not duplication of effort. The USDA Biofuels Infrastructure Partnership data will be used as inputs into other BETO-funded tools and models, including the BSM.

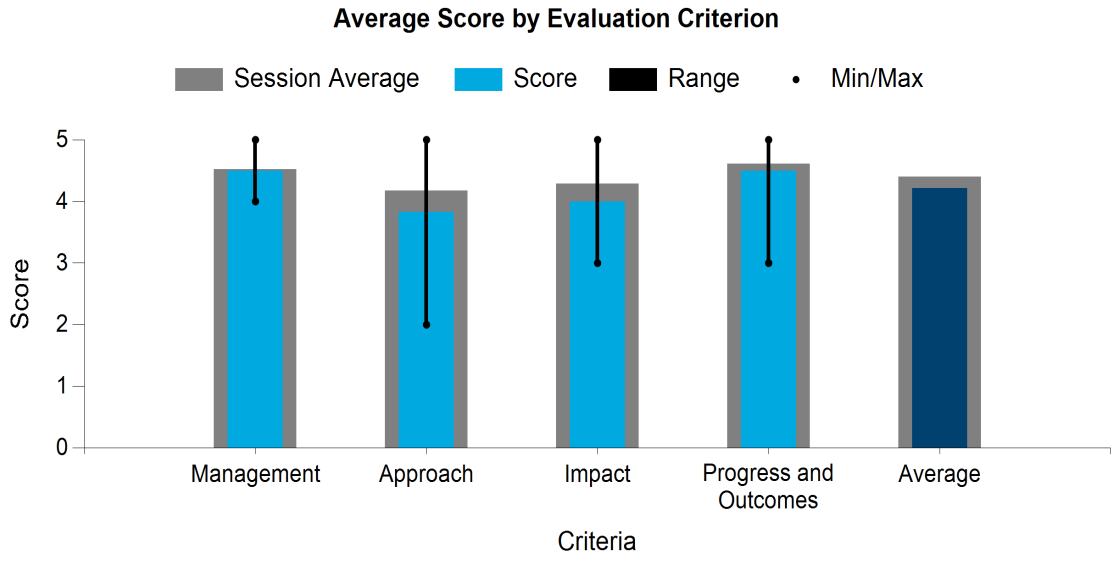
# BIOENERGY KNOWLEDGE DISCOVERY FRAMEWORK

## Oak Ridge National Laboratory

### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 6.3.0.2 |
| Presenter(s): | Aaron Myers |
| Project Start Date: | 10/01/2019 |
| Planned Project End Date: | 09/30/2022 |
| Total DOE Funding: | $450,000 |

There are many issues in the biofuel supply chain, from production to delivery, that must be addressed in order to foster a viable biofuel industry. Infrastructure issues related to the generation, distribution, and delivery of biofuels include finding the optimal locations to site a biorefinery to minimize cost with adequate availability of feedstock resources nearby. The Bioenergy Knowledge Discovery Framework (KDF) is a collaborative platform for knowledge collection, curation, and discovery to support DOE's effort to develop a sustainable biofuel industry. The Bioenergy KDF facilitates expanded research opportunities by providing a means to synthesize vast amounts of information from across the bioenergy supply chain. The Bioenergy KDF enables data harmonization from different sources, and it serves as a source of benchmark data sets and key topics. Recent updates to the Bioenergy KDF have been focused on migrating from an open community model, where any user with an account could contribute data, to a curated content model, where the KDF development team will work closely with national lab partners and BETO to create, edit, and maintain key content within the KDF. Improvement and updates to the underlying open-source technology supporting the KDF have helped to facilitate this transition.




### COMMENTS

- It was not clear how this project is different from or related to the Findability, Accessibility, Interoperability, and Reusability (FAIR) data project or the Alternative Fuels Data Center. This project seems to be primarily website upkeep and not research. In terms of impact, presenting the Google Analytics would be helpful, and making the site look aesthetically more like other DOE websites so that navigation is seamless. It seems that this project should be merged with the Alternative Fuels Data Center, using the Alternative Fuels Data Center format as lead. It is not clear why two separate data

access points need to exist for BETO. This particular project seems to be something that could be simply managed by DOE web services, rather than researchers.

- It is good to see the strategic pivots this project has taken. Given that the KDF is a key conduit to disseminate information, it is good to see the website reflect office priorities on the landing page, such as the marine and aviation fuel pages. The more the project can define its audience and hone interests/needs and barriers for its audience, the more likely that DOE-funded research will be disseminated to the right stakeholders. I see the project make tremendous strides in its data collection and presentation. It may be worthwhile to invest more in the front end of the website by bringing in third-party experts in data presentation to get an in-depth take on how the Bioenergy KDF can best suit the office's goals.

- The management plan and implementation strategy are clearly identified in the presentation, and major risks/challenges are clarified during a Q&A follow-up. The KDF site and its recent platform changes are impressive, offering a wide array of resources to researchers and others. The site should clearly articulate connections and differences with other databases through the BETO portfolio to increase the impact of this and other associated projects. The project has made impressive strides since the last Peer Review and appears to be progressing on time. If possible, the KDF should consider incorporating a public-facing space for educational tools that engage with the database/current research to enhance K–12 and higher education curricula and encourage bioenergy literacy.

- The apparent shift from a user-updated model to curated content model is a worthwhile strategy because it can ensure that data sets are up to date, maintained, and high quality. In particular, this tool can serve a useful role as a geospatial data repository because a great deal of overhead in both compute resources and data management is involved in hosting geospatial data, making it difficult for smaller entities. It is not immediately clear how much interest or web traffic the KDF is attracting beyond the Billion Ton sites.

- The Bioenergy KDF is a useful tool for accessing bioenergy data, particularly for national lab data. The platform represents a substantive addition to the resources enabling bioenergy research and analysis. There is a risk that resources will not allow the data to be kept up to date. The project has progressed by transitioning to newer software and updating the user interface and curation approach. The move to consolidate the Bioenergy KDF focus on data and outputs from BETO and national laboratory researchers makes sense, as does the move to a more curated approach. One of the current challenges is there is no "one-stop-shop" to find all projects, data, etc., from bioenergy-related projects from BETO. The newly developed project-focused pages are a helpful addition to give people an entry point for particular areas of interest. Ensuring that the data are FAIR will advance the utility of the site. The team should consider whether/how the FAIR data repository concept being developed under another BETO project could be consolidated under the Bioenergy KDF. It would also be helpful to clarify the differences between the Bioenergy KDF, the Biofuels Information Center, and the Bioenergy Atlas Tool. It appears these are intended to serve different audiences, but ensuring that the distinctions are clear and ensuring relevant cross-linking is used are important. The renewal cycle for data should be clarified as to whether there is there a process for culling old data or reaching out for updates. It makes sense to talk with other agencies, such as the USDA, regarding their National Agricultural Library/Ag Data Commons on approaches and best practices for data curation, refresh, and management.

- The KDF provides a valuable service to the general public by compiling resources and making them available. This effort has a clear, well-defined objective and lays out its impacts via page views to illustrate its usage. In response to previous feedback, the project team is improving the database to enhance content curation, update the software, and improve the data organization.

## PI RESPONSE TO REVIEWER COMMENTS

- Thank you for the feedback. We are working closely to determine and communicate the differences and similarities between the KDF and other funded efforts to reduce redundancy but promote collaboration and cross-capability data sharing. As per the user interface design, we will work closely with BETO and other web designers to ensure we are following up-to-date web design standards. The KDF team will continue to work to bring the most relevant data and adapt to the changing requirements of the community.

# ACCELERATING BIOENERGY TECHNOLOGY ADVANCEMENT THROUGH FAIR DATA DELIVERY

## Oak Ridge National Laboratory

### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 6.3.0.9 |
| Presenter(s): | Bruce Wilson |
| Project Start Date: | 10/01/2020 |
| Planned Project End Date: | 09/30/2021 |
| Total DOE Funding: | $250,000 |

The purpose of this project is to assess whether bioenergy technology development can be accelerated by improving the Findability, Accessibility, Interoperability, and Reusability (FAIRness) of relevant data and information that are presently stranded, inaccessible, or otherwise underutilized. Examples of these data and information include material presently protected as proprietary, data from "failed" experiments, and data from companies or programs that are no longer operating. Data may also be effectively inaccessible where there are insufficient metadata for discovery, where the metadata are in an isolated repository known only to a particular group of people, or where the metadata are in nonstandard formats.

This project is a new start, beginning in mid-November 2020. To date, we have done an initial solicitation for leads on data that would be of value to the community, and we have done an initial evaluation of the data identified in the July 2020 BETO Leveraging Existing Bioenergy Data Workshop. We expect to identify one or two data sets where creating or improving access to the data would most benefit bioenergy processing technology, particularly process scale-up. We have a modest budget to acquire presently rights-restricted data. Key outputs from this project will be one or two data sets that are made substantially more accessible to the bioenergy community, an assessment of the value of those data to the community, and a list of other data sets that are of potentially significant value, along with the estimated costs to make the data available.

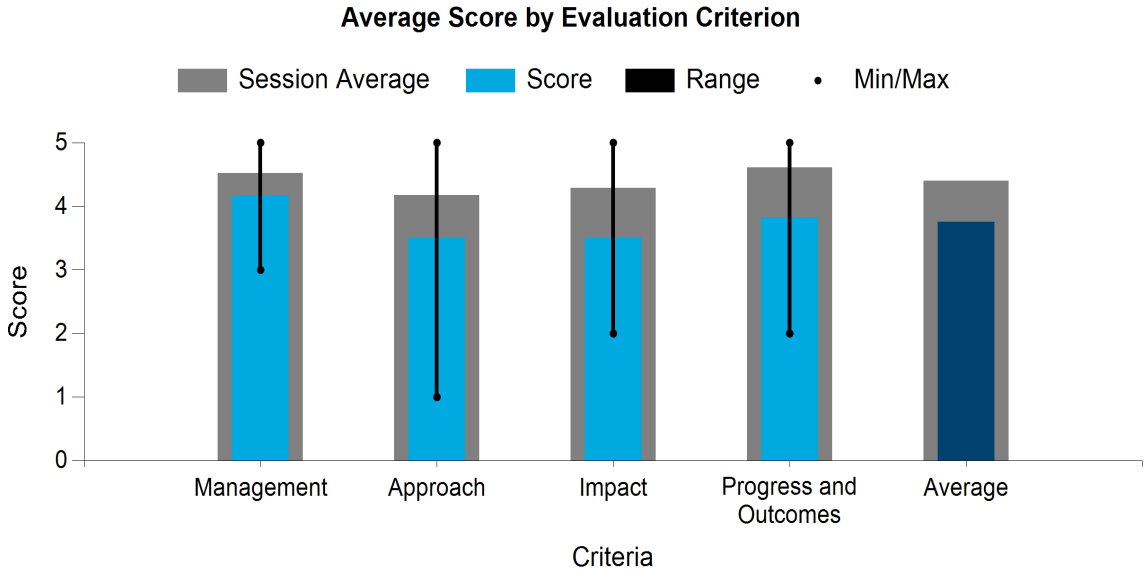


*Photo courtesy of ORNL*

## COMMENTS

- Improving data access is critical to achieving BETO's goals; the project team here has correctly identified several key barriers to accessing bioenergy technology data. Although this project is still early in its development, I see this as a very promising project. This project team has identified an opportunity to utilize the program area's community connections with industry players to access and organize failed experiment data and proprietary data, and make it available to researchers, which could greatly support the other parts of this project area. Key issues moving forward are how to protect proprietary or failed data while balancing the desire to improve access; is it possible to utilize such platforms as the KDF for less sensitive data?

- It is nice to see the office investing in the link between its research and the end users through data management.

- The management plan and implementation strategy are clearly communicated, though it is difficult to ascertain routes for collaboration and communication with all parties, given that some of the data sources remain unconfirmed and therefore were not disclosed for this review. The innovation here is avoiding duplication of efforts across multiple projects—a worthy task. The hang up may be a lack of interest or prohibitive (financial and labor) cost of acquiring data to reach the project goal. PI Wilson was transparent about this challenge of the project, but mitigation strategies were less clear. The project seems to be progressing on time, though it remains without a clear audience for the data gathered through this effort. This should be clarified soon in the approaching go/no-go point.

- The go/no-go will look at only one or two data sets; given the large amount of data and data sets that this program deals with, this seems like a really low number. There are so many data out there related to bioenergy. There was no list of data sets that will be evaluated or even a description of the type of data (e.g., LCI data, yield data, soil data, use data). Although, in theory, efforts to create a framework for

assessing the (re)usability of data and information is incredibly important, it is shocking that DOE does not already have data quality standards and that this project did not reference those standards. There was no discussion of the actual approach that would be used to evaluate data quality, integrity, fix/address data gaps, etc. It was incredibly difficult to determine whether the approach has substantial merit to advance the SOA or whether the approach has a clear connection to impacts and outcomes. It was not clear that the project has plans to engage stakeholders; the project claims to have developed this presentation with feedback from stakeholders, but they were not named, nor was the stakeholder engagement and data collection process clearly described. For example, it seems appropriate to collaborate with the Alternative Fuels Data Center, KDF, etc.

- The goal of the FAIR data repository is an estimable one. It is not, however, clear what novel value this project brings to the bioeconomy, and due to confidentiality concerns, the PI was unable to offer much detail. Insofar as this work indexing and making available targeted high-value data sets, it strikes me that this is the role of academic literature and that most PIs willing to share their database with this tool may also do so if contacted by an interested fellow researcher. The KDF struggled early with its role as an unfiltered data repository, and if this project seeks to be actively managed, then perhaps it should be merged with that effort?

- This is a new project, so review is based primarily on planned activities. The presentation provides a good outline of the approach, management, and key risks. The information about the value of ecological data over time versus changeable process data justifies the emphasis on recent process data. The group has made appropriate progress, given that the project started just 3 months ago. The BETO portfolio itself is an appropriate place to start with this effort to get researchers to consider the FAIR nature of their data at the beginning of projects. A key opportunity to be explored is whether/how to use the Bioenergy KDF to curate and store the data coming from this project or whether both the Bioenergy KDF and this database should be merged into something larger and more comprehensive for DOE-wide use. There are lessons to be learned from existing repositories of publicly available data (e.g., the National Agricultural Library's Ag Data Commons). A key challenge is making the barrier to entry on any FAIR repository low enough to encourage researchers to actually post data to it.

## PI RESPONSE TO REVIEWER COMMENTS

- The data that we are investigating are not public, and until the data transaction is complete, we do not yet have permission from the data owners to disclose the discussions in the public forum of this BETO Review. These discussions include industry scale-up data that have recently been highly confidential. In all cases, these are data sets for which no academic publication exists, so the academic literature is not a viable venue for making the data public, though it is possible that publishing these data may enable future review papers. Price discussions may prove successful, but if they do not, the data would not be released. The vast majority of the bioenergy data sets that the BETO program deals with are already being made public, as required by DOE policy, through tools like the Bioenergy KDF, and are therefore out of scope for this work. In fact, the majority of the data we are looking at were not funded by DOE at all, which we may not have made clear to the reviewers. Although all bioenergy data that would be useful to others are fully in scope, we are focusing on scale-up data from conversion (both high temperature and fermentation), as was discussed in the presentation, based on the input received at DOE's summer 2020 workshop: Leveraging Existing Bioenergy Data: Workshop Summary Report (https://www.energy.gov/eere/bioenergy/downloads/leveraging-existing-bioenergy-data-workshop-summary-report). The time limits for this presentation did not permit getting into the data quality assessment approach, which is primarily a qualitative assessment by subject matter experts, similar to manuscript peer reviews. Some BETO programs have specific quality standards, and we will consider those in our evaluation, but work beyond consulting existing standards is out of scope for this work. Thank you for the link to the Ag Data Commons. Their Data Submission Manual, Guidelines for Data Files, and clear statements of policy are additional useful examples. Note also that the ORNL Earth System Informatics and Data Discovery Section (https://www.ornl.gov/section/earth-system-informatics-

and-data-discovery), which is the home for this project, includes other projects that have been making research data publicly available and reusable for decades.