DATA, MODELING, AND ANALYSIS

PROGRAM

CONTENTS

INTRODUCTION

The Data, Modeling, and Analysis (DMA) Technology Area is one of 12 technology areas reviewed during the 2023 Bioenergy Technologies Office (BETO) Project Peer Review, which took place April 3–7, 2023, in Denver, Colorado. A total of 26 presentations were reviewed in the DMA session by 6 external experts from industry, academia, nonprofit, 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 to the corresponding Program and Technology Area Overview presentation slide decks (https://www.energy.gov/eere/bioenergy/data-modeling-and-analysis-program).

This review addressed a total U.S. Department of Energy (DOE) investment value of approximately $33.6 million, which represents approximately 6% of the BETO portfolio reviewed during the 2023 Peer Review. During the Project Peer Review meeting, the presenter for each project was given 30 minutes to deliver a presentation and respond to questions from the review panel.

Projects were evaluated and scored for their 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 Peer Review, including scoring information for each project, comments from each reviewer, and the response provided by the project team.

BETO designated Andrea Bailey as the DMA Technology Area review lead, with contractor support from Bryce Finch of BCS, LLC. In this capacity, Andrea Bailey 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 continues to provide a vital and strategic portfolio to DOE, the bioeconomy industries, and wider national sustainability objectives. The 2023 Peer Review of the DMA program was conducted over 3 days, from April 3–5, 2023, in Denver, Colorado, featuring 26 principal investigators (PIs) who presented their research to a diverse 6-person review panel that included members from academia, the private sector, research organizations, and other federal agencies. This report consolidates the panel's perspectives on the program, focusing on strategic management, implementation, progress, and the pursuit of program goals. It concludes with three prioritized recommendations for future directions.

During the 2023 Peer Review of the DMA program, reviewers were presented with an array of projects that were shown to significantly contribute to BETO's program goals of decarbonizing the transportation, industrial, and agricultural sectors and developing cost-effective, sustainable biomass and waste utilization technologies. The DMA program's portfolio demonstrates a diverse range of feedstocks and technologies that carefully align with BETO's evolving strategic objectives. Many projects are at the cutting edge of their respective fields, including the Global Change Analysis Model (GCAM) Bioenergy and Land Use Modeling and Directed Research and Development (R&D); Bioeconomy Scenario Analysis and Modeling; Integrated Landscape Management; Life Cycle Analysis of Biofuels and Bioproducts and Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) Development; and the Net-Zero Carbon Fuels Technical Team (NZTT). These initiatives serve as crucial resources for an array of stakeholders in the U.S. bioeconomy and contribute valuable methodological rigor for policy and business applications across local and global scales. The program strategically adapts to the shifting priorities and needs in the bioeconomy, reflecting BETO's focus on low-carbon and net-zero-carbon fuels for the aviation; marine; rail; and heavy-duty, long-haul freight industries.

The review panel commended the DMA program for its innovative and pioneering work in advancing a sustainable bioeconomy while emphasizing the need for strategic alignment with BETO's objectives. The panel also underscored the importance of distributing the analysis portfolio across high-priority biomass use cases and balancing short- and long-term decarbonization strategies. Further, focusing on equity, addressing it early in the program's growth, developing concrete metrics, and ensuring consistency across the portfolio will enhance the DMA program's impact and contribute to a more equitable and sustainable bioeconomy.

STRATEGY

Overall, all reviewers found the DMA program to have a well-defined strategy that aligns with its mission, goals, and technical targets, considering relevant industry and stakeholder input. Reviewers were "impressed by the breadth and depth of BETO-funded projects." The program's ability to quickly adapt to emerging priorities, such as sustainable aviation fuels (SAFs), demonstrates its agility; however, some reviewers felt there is room for growth in ensuring sufficient coverage across relevant sectors, such as rail, marine, plastics, and chemicals. In contrast, another reviewer praised BETO for adequate coverage in these areas.

Reviewers found the DMA program's funding mechanisms, including funding opportunity announcements (FOAs) and annual operating plans, are well suited to the varying technical topics. Reviewers noted that the program should continue to balance near-term decarbonization through first-generation biofuels with long-term solutions involving advanced biofuels. One reviewer suggested, "Funding projects that are readily market competitive—though not aiming at direct production of biofuels or not highly innovative—might present as great opportunities to actualize the bioeconomy." DMA should consider funding projects that are market

competitive in the near term while maintaining focus on mid-/long-term goals. One reviewer suggested that supporting non-biofuel markets, such as animal bedding, could alleviate farmers' concerns about the lack of biomass buyers and lead to faster adoption of bioenergy crops. Such a strategy may contribute to the actualization of the bioeconomy and advance the adoption of sustainable practices. To address gaps in the current strategic vision, DMA should prioritize end use applications, incorporate economic considerations, support bioenergy pathways with the greatest potential for deep decarbonization, and lead BETO in developing environmental justice (EJ) and diversity, equity, and inclusion (DEI) efforts for bioenergy R&D.

Several reviewers noted that the DMA program could improve its strategic plan by designing a complementary portfolio of projects that address different aspects of the bioenergy value chain and support technology development and policy design. Increased inter-project communication and consistent approaches, assumptions, and platforms will help create a coherent model ecosystem to support BETO's mission. Ensuring transparency in models and methodologies will also enhance the program's effectiveness.

Last, incorporating social aspects—such as social acceptability, community impact, and EJ—is essential to the DMA program's success. Paty Romero Lankao and Rebecca Efroymson's work serves as an excellent starting point for integrating social considerations into BETO-funded research. To encourage collaboration, BETO should consider inclusion of review criteria that emphasizes iterative communication and collaboration with related projects, advisory boards, and impacted stakeholder groups.

STRATEGY IMPLEMENTATION AND PROGRESS

The Strategy Implementation and Progress section of this review analyzes the effectiveness of the DMA program's project funding and management, with specific attention to their alignment with strategic directions, innovation, progress toward set goals, and beneficial outcomes for both the performer and the government. The review panel assessed all projects on their implementation and development, identifying leading-edge work, evaluating whether goals are achievable, and evaluating how the technology area team is managing these projects.

The DMA program, as part of its strategic direction, is effectively funding various projects. Notably, projects such as the GREET model and GCAM have been highly significant, working at the forefront of their respective fields, and they are expected to make considerable impact. The GCAM Bioenergy and Land Use Modeling and Directed R&D project, for instance, offers a detailed economic and physical model that integrates global trade, energy, agriculture, and consumption, providing valuable insights into terrestrial carbon management practices. Similarly, the GREET project continually evolves its model, incorporating new methodologies, fuel pathways, and technologies, making it a valuable tool for academia, industry, and policymaking.

Projects like the Biofuels National Strategic Benefits Analysis (BNSBA) and the Biofuels Information Center (BIC) align well with BETO's strategic objectives. BIC provides a comprehensive resource for biofuel stakeholders, compiling and organizing information on biofuels and bioenergy-based chemicals and offering effective data visualization. This project has seen wide adoption among industry and policymakers, as reflected in its numerous page visits. One reviewer said, "This project fills an important niche, as the data is extremely challenging to collect and yet it is compiled in one convenient place with excellent organization and data visualization." Also, the BNSBA project focuses on understanding and enhancing the socioeconomic and environmental benefits of biofuels. It has made significant strides since 2021 by improving its existing model to address key interest areas, contributing to decision making and policy design. Despite being well aligned with objectives, reviewer drawbacks of the BNSBA framework included discussion about a lack of market response and land use change (LUC) considerations.

In terms of managing projects, the technology area team actively ensures beneficial outcomes for all involved parties; however, there are areas for improvement, such as enhancing communication, access to models, and

harmonization across projects. Also, there is a need for increased focus on version control, flexibility, and robust uncertainty and sensitivity analyses in models like GREET.

Reviewers felt encouraged to see BETO funding projects that incorporate DEI efforts in their scope. Aligning with the DOE Office of Energy Efficiency and Renewable Energy (EERE) mission, the DMA program can further contribute to the creation of a clean energy economy that benefits all Americans by addressing environmental injustices, fostering a diverse science, technology, engineering, and mathematics workforce, and developing robust workforce training opportunities. In the future, it would be beneficial to prioritize such projects and to broaden the focus to various transport sectors and generations of biofuels.

Last, although the program is on track to meet its near-term and midterm goals based on the current project portfolio, there are some gaps that need to be addressed. These include a stronger push toward decarbonization and more focus on the social dimension of projects, which is often overlooked despite its importance in project deployment and EJ. Additionally, one reviewer noted, "Another methodological area for improvement is to ensure that all modeling and analysis projects start to incorporate uncertainty analysis and sensitivity analysis into their approach as a standard practice." With these improvements, the DMA program can ensure more significant progress toward its strategic goals.

RECOMMENDATIONS

The DMA program has made significant strides in promoting a sustainable bioeconomy, evidenced by their innovative projects and strategic alignment with BETO's objectives; however, from the collective input of several reviewers and the robust discussions that ensued, the review panel identified three key recommendations to further bolster the portfolio in the near to medium term. These suggestions include enhancing stakeholder engagement, ensuring distribution of the analysis portfolio across high-priority biomass use cases, and placing a greater emphasis on equity.

Recommendation 1: Enhance stakeholder engagement and measure impact.

First, stakeholder engagement and measuring impact is crucial for directing the program and measuring success. The DMA PIs should provide an explanation of how stakeholder feedback will inform the model and research as well as emphasize validation and ground-truthing. This involves translating model data and output into real-world applications, fostering partnerships with other agencies, and improving communication, marketing, accessibility, and usability of tools. Additionally, the program should outline clear goals and designed use cases, ensuring that the portfolio addresses stakeholders' needs and expectations. Such a design element can be included as a required component of the study by BETO.

Recommendation 2: Align the analysis portfolio with high-priority biomass use cases.

Second, it is essential to distribute the analysis portfolio across high-priority biomass use cases, aligning with the EERE strategic vision and broader federal objectives. This requires clearer plans for distributing funding to cover the necessary scope/objectives, leveraging tools/resources to reduce duplicability, and balancing short- and long-term decarbonization strategies. By doing so, the DMA program can effectively address various aspects of the bioeconomy and accelerate progress toward sustainability goals.

Recommendation 3: Prioritize equity in projects and objectives.

Finally, the DMA program should prioritize equity in its projects and objectives. Recognizing the importance of this issue early in the program's growth can lead to significant long-term benefits. Instead of biomass projects solely focusing on "supporting rural economies," the program should develop concrete metrics for equity that can use both qualitative and quantitative data. Developing equity metrics can be achieved by enhancing stakeholder engagement (linking to the first recommendation), ground-truthing, and ensuring that models have the capability to investigate issues related to fairness and justice. By working with BETO's EJ office and achieving consistency across the portfolio, the DMA program can contribute to a more equitable and sustainable bioeconomy.

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 their careful review of the portfolio. Feedback on the overall program is especially valuable as DMA works to pivot to address new office and administration goals and priorities. The program also appreciates the comments on increasing the utility of existing models and tools for multiple audiences and recognizes the importance of incorporating better uncertainty and sensitivity analysis into results to the extent possible.

The full set of recommendations from the review panel will be discussed and considered when working on future project selection and program design, as future appropriations allow. Following are the responses to the three key recommendations identified by the review panel.

Recommendation 1: Enhance stakeholder engagement and measure impact.

The DMA team agrees with this recommendation to improve both the practice of engaging stakeholders across the bioenergy supply chain and measuring this impact to ensure that BETO-funded models and tools are reaching the intended audience. Many models presented in this review will finish internal development and scenario testing before the next review, and the DMA team plans to work with these groups to include metrics on engagement and actual model use in the next set of updates. Beginning with the annual Fiscal Year (FY) 2024 call for proposals to the national labs, DMA has also committed to including a metric for the planned publication of all relevant tools and models and tracking views/downloads and other relevant engagement metrics. In addition, for projects that are not working on a specific tool or model, the team is encouraging either stakeholder engagement sessions, where relevant, or partnering with relevant organizations that already specialize in stakeholder engagement, such as land trusts and farmer-led cooperatives. The team is also looking into providing training to lab staff on how to best engage stakeholders such as small landowners who may not be as familiar with all the variables that go into a bioenergy model but would still like to engage with the bioeconomy. By the FY 2025 review, DMA will produce a list of relevant metrics for different project types for reviewers to use as a benchmark for these projects.

Although stakeholder engagement is critical for most DMA-funded models, some economy-wide models are primarily aimed at internal-facing analytical and policy needs for DOE. These models may be good candidates to publish less complex public versions as funding allows. Part of following this recommendation will also be carefully working with PIs to determine the targeted end user of their model and the degree of engagement or tracking that is appropriate.

Summary of actions:

- Work with existing projects to include metrics on engagement and actual model use.
- In future project calls, include a metric for the planned publication of all relevant tools and models and tracking views/downloads and other relevant engagement metrics.
- Work with national laboratory partners to provide staff training for stakeholder engagement.

Recommendation 2: Align the analysis portfolio with high-priority biomass use cases.

The emphasis on decarbonization goals since the 2021 Project Peer Review has resulted in many changes across the DMA and larger BETO portfolio. The DMA team has worked to address as many administration

and office goals as possible and to prioritize analyses that cover an appropriate breadth of feedstocks and end use cases while emphasizing the areas in which biomass has the largest role to play in decarbonization.

Some projects that that were selected as part of competitive solicitations that had goals set at the time of publication may have stronger links to past office priorities than to the overall current office goals. Even so, the DMA team is committed to working with them to support these goals as much as possible within their existing work plan. The entire BETO program has also recently engaged in a larger internal portfolio analysis exercise that will attempt to better map how each program has structured its portfolio to address administration goals and the March 2023 Multi-Year Program Plan. As a part of this analysis, the DMA program will create a mapping of analysis projects in other program areas for the 2025 Project Peer Review and show their relationship to areas of strategic priority for the office.

In addition to internal BETO analyses, BETO is committed to working with other EERE offices on analysis related to how biomass can support decarbonization across the chemicals sector and for additional hard-to-decarbonize transportation sectors. Portions of this analysis should be available in more detail in time for the 2025 Project Peer Review. As the analysis related to these different sectors becomes available, the DMA team hopes to enhance the overall understanding of the best use of biomass to maximize the overall decarbonization potential of this resource.

Summary of actions:

- Assess the feasibility of providing an overview of various analysis projects throughout the entire BETO portfolio in terms of the highest-priority biomass use cases.
- Define with other EERE offices the highest-priority biomass use cases with updates available by the 2025 Project Peer Review.

Recommendation 3: Prioritize equity in projects and objectives.

DOE has increased the focus on incorporating DEI priorities into the research and application of technologies since the 2021 Project Peer Review, and BETO is no exception. The DMA team appreciates the reviewers' recognition that this is an important piece of any R&D program, and we will continue to commit to achieving a better understanding of these issues as they relate to bioenergy and prioritizing research that takes equity concerns into account. The DMA team also appreciates the recommendation to robustly use stakeholder engagement, particularly of people and groups from less consulted expertise and backgrounds; ground truth research on social, environmental, and equity considerations of bioenergy; and ensure that the research done in the DMA portfolio can be responsive to equity considerations where relevant. These steps are being enacted in parts of the DMA portfolio, and the team aims to support the expansion of this approach throughout the DMA and BETO portfolio in appropriate, impactful ways.

In the near term, DMA will focus on the research, analytic capabilities, and integration of equity considerations into biorefinery siting. DMA has begun work with different national lab analysts to better understand the sustainability impacts (both social and environmental) of full-scale biorefineries with the intent of promoting more equitable siting decisions for the refineries that will be necessary to reach BETO's long-term goals. In addition to this work, DMA plans to engage with energy equity and siting experts and stakeholders on the best metrics and areas for research for incorporating equity into not only DMA research but also research across the entire BETO portfolio.

Internally, BETO remains connected to larger DOE and EERE-wide efforts related to equity and is committed to contributing data and staff time to those efforts. This has included supporting the development of DEI plans and, more recently, community benefit plan language and requirements in an effort to make the research project process more equitable, and it has included devoting resources to research areas that improve understanding and enabling equity and social and environmental sustainability, such as the biorefinery siting work. Increasing the amount of work in the portfolio specifically funded by BETO is subject to future

appropriations, but the DMA team as well as representatives from other BETO technology areas are working to stay current on equity concerns surrounding bioenergy and continue to incorporate equity into existing projects as much as possible. In the near term, BETO aims to have more resources about applying to FOAs and drafting meaningful community benefit plans.

Summary of actions:

- Continue to support research on biorefinery siting, social considerations, and equity implications, and ground truth this research with methods such as engagement with equity experts and stakeholders and case studies.
- Identify two or three high-priority research areas for the bioenergy supply chain in terms of equity implications and social sustainability.
- In future calls, as appropriate, include requirements for projects to identify whether and how their models and analyses have capabilities to measure and examine equity implications and social considerations.

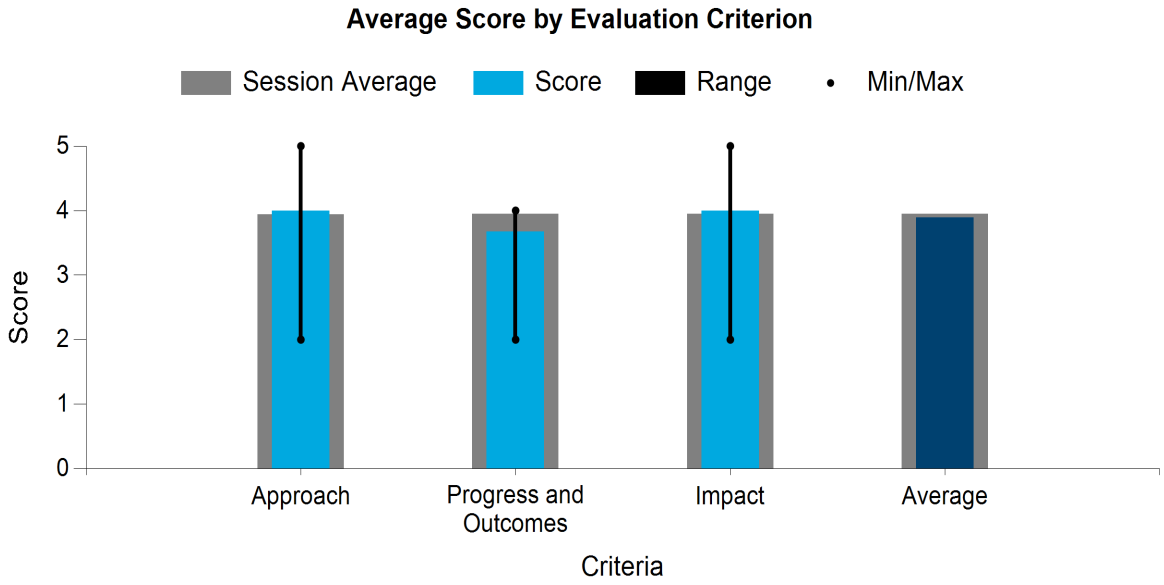
GCAM BIOENERGY AND LAND USE MODELING AND DIRECTED R&D

Pacific Northwest National Laboratory

PROJECT DESCRIPTION

WBS:	1.1.1.7
Presenter(s):	Marshall Wise
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$525,000

This project provides quantitative analysis of the potential scale and impact of bioenergy and land use in the integrated economic context of energy, agriculture, and carbon. The Pacific Northwest National Laboratory (PNNL) GCAM, a prominent model of long-term global energy and land use, has been widely used for DOE, the U.S. Environmental Protection Agency (EPA), and private industry. Using GCAM, we have published studies for BETO on biofuels, biopower with carbon capture and storage (CCS), resulting land use, and emissions impacts. The biggest challenge is to manage the complexity of modeling detailed bioenergy systems and terrestrial carbon strategies within the larger GCAM structure. For this FY 2022–2024 project, we are partnered with the National Renewable Energy Laboratory (NREL) (WBS 1.1.1.8) to study terrestrial carbon enhancement strategies in agriculture, including their impact on domestic and global land use and emissions. NREL performs biogeochemical modeling of physical parameters, including crop yields and soil carbon. PNNL uses these parameters to create crop practice options in GCAM and analyzes scenarios considering the economics of crop production under carbon incentive strategies. We have completed a study of biochar production and application to cropland, and we are currently developing scenarios for no-till practices and cover crops. In addition to terrestrial carbon, this BETO project is building GCAM capability to study the potential for alternative energy in the agricultural sector as well as the potential for renewable fuels for aviation demand.



COMMENTS

- Overall, this is a great project. GCAM is used by a wide variety of researchers and other stakeholders, demonstrating the value of the approach. I think the areas in which BETO is funding GCAM generally make sense, but I do see room for improvement.

Exploration of terrestrial carbon sequestration methods makes sense in general. But the focus on biochar is somewhat confusing to me. I agree that GCAM is a good approach for exploring the potential of this strategy, but there are other strategies being considered more widely in the near term that could benefit from analysis in GCAM. Examining no-till makes more sense to me, and I support the continuation of that line of research. I would encourage the researchers to consider other practices, such as nutrient management and conservation agriculture, which could yield DEI or sustainability cobenefits.

The work examining agricultural energy consumption is great and should continue. This is an under-researched area and a place where biofuels could play a strong role for decades to come. The forthcoming work on aviation is also very worthwhile. I do, however, think there is not enough emphasis here on the other BETO priority end uses of bioenergy. The use of biofuels for marine, rail, and off-road applications other than agriculture should be part of the scope as well as industrial chemicals and plastics. This is an area of suggested improvement for the project.

- Thank you for the opportunity to review the GCAM Bioenergy and Land Use Modeling and Directed R&D project. I am pleased to say that I believe the project is well aligned with BETO's goals, and I look forward to seeing how SAF is included in the framework and additional DEI metrics. The economic and physical model spanning until 2100 and covering domestic energy, agricultural production, consumption, and trade is an impressive undertaking. As most of the model parameters and assumptions are informed by other BETO research, the model is constantly evolving, and methods/data are somewhat crowdsourced and verified from an active community. The progress and outcomes of the project are also impressive, including completed biochar, current research on no-till and cover crops, and the expansion of the no-till option. I suggest providing more information on how the model decides between practices and the data or mechanism that defines the ultimate share. During the presentation, it was described that this was based on the input cost of the expected rate of return (output*price); however, there are other drivers controlling the share across production technologies/practices that should be included in this explanation. Overall, this is an excellent project that is making great strides toward its goals.

- GCAM is a valuable component of the technology area, providing a capable and publicly accessible open-source model for use by policymakers and researchers. This model balances both accessibility and flexibility to appeal to a wide array of stakeholders working on a variety of topics. This model is already extremely relevant in its current form, but the forthcoming updates to its analytical scope will further improve its usefulness. In particular, the integration of terrestrial carbon management technologies and the aviation sector will expand the range of analyses possible with the model.

  The progress toward incorporating terrestrial carbon management in the model underscores the model's utility as it combines detailed technology and physical data with economics to assess the trade-offs and net impacts of different approaches and policy incentives. The structure of the model also allowed for an evaluation of these management practices beyond a field level and their effects at a global level. It was clear from the presentation that these updates to the model will provide valuable insight on these land management practices and can inform policy.

- This is a very ambitious project. In striving to be a comprehensive model for all types of bioenergy for all regions for so many variables, a lot of important nuances and complexities are obscured. But, of course, that is the case with many models.

  When modeling inputs to agriculture, does the model account for fossil fuel inputs required to maintain certain biofuels, such as corn-based ethanol—greenhouse gas (GHG) emissions created through fertilizer manufacturing, etc.?

Land and water systems are highly vulnerable to current and future climate changes. How does the model account for climate change? Different regions—India, for example—are and will continue to experience different change trajectories. How are these accounted for?

How does the model account for issues of water quantity and water scarcity?

The DEI milestone mentioned hiring one high school student from Washington, D.C. This is a great first step, but more work could be done—if not in the models themselves, possibly in terms of the broader use and application of the model and related project artifacts and outreach activities.

Overall, this project strove to account for a wide range of variables in modeling land use as related to bioenergy, and it has the potential to advance the thoughtful implementation of bioenergy technologies. The project included a clear management plan and implementation strategy. I encourage the team to continue to consider how the project can address diversity and equity issues. The project has made progress toward its stated goals and has the potential to be useful to several different entities.

- While the inclusion of DEI in the internship program is appreciated, this type of modeling naturally lends itself to more informative diversity and EJ topics. EJ factors should be incorporated in future modeling.

  Calibration of the DayCent model is important and can substantially change soil carbon outcomes. Even with a robust literature review, it could be useful to include ground truth data on soil carbon. Adding sensitivity analysis or a range of outcomes to the permanence of sequestration would also likely make both pricing and climate outcomes more robust.

- The project has a broad and impactful goal, but it is unclear how the outcomes of this project have contributed to other BETO efforts. In particular, there do not seem to be many interactions with other models. A lot of previous/existing efforts seem to be on biochar, but this focus on biochar is not sufficiently justified. Admittedly, biochar has the potential for carbon sequestration, but it is not clear if and how biochar can achieve significant market penetration (and if this modeling effort complements other efforts on biochar). On the other hand, one strength of this project is that GCAM is publicly deposited on GitHub with good version control and a decent user basis.

PI RESPONSE TO REVIEWER COMMENTS

- Thank you to the review panel for your constructive and expert comments and suggestions for research directions on this project. Concerning the study on biochar, we put our initial focus there for two main reasons. First, there has been a growing interest for natural climate solutions in the international carbon dioxide removal community. Second, we believe we were well positioned with our GCAM modeling to provide integrated analyses of biochar in agriculture, energy, and carbon management that was missing in the literature; however, we agree that other conservation and terrestrial carbon practices may have more near-term impact and broader relevance, and we are currently performing modeling and analysis of no-till and cover cropping. In terms of the energy system aspects of this BETO project scope, we are planning on directly linking the fossil or other energy required for the agriculture sector in more technological detail. With that, the incremental energy to expand crops for bioenergy or other reasons is explicitly accounted for in some technological detail with feedback to the rest of the energy and agriculture systems. Also under the BETO scope, we are upgrading the GCAM refinery sector model structure and the technologies involved in the production of jet fuels and other liquids. The outcome of this effort will be to enable a robust economic and physical representation of the potential scale and impact of biojet and other low-carbon pathways for aviation energy. For other targeted uses of bioenergy, such as marine and off-road, improving these is not explicitly in our BETO project scope, but these demands are considered in GCAM generally. Finally, in terms of DEI, we were happy to have the chance to use this project as a vehicle for inclusiveness and provide some research experience to a local

high school student. This was a small step but hopefully one that makes some impact. In terms of the DEI impacts of terrestrial carbon management or conservation agriculture, those impacts are not something that we currently quantify as part of the economics of our modeling in GCAM. Impacts would have to be inferred using expert judgment, or they could be analyzed by a model that focuses on labor impacts and income distributions.

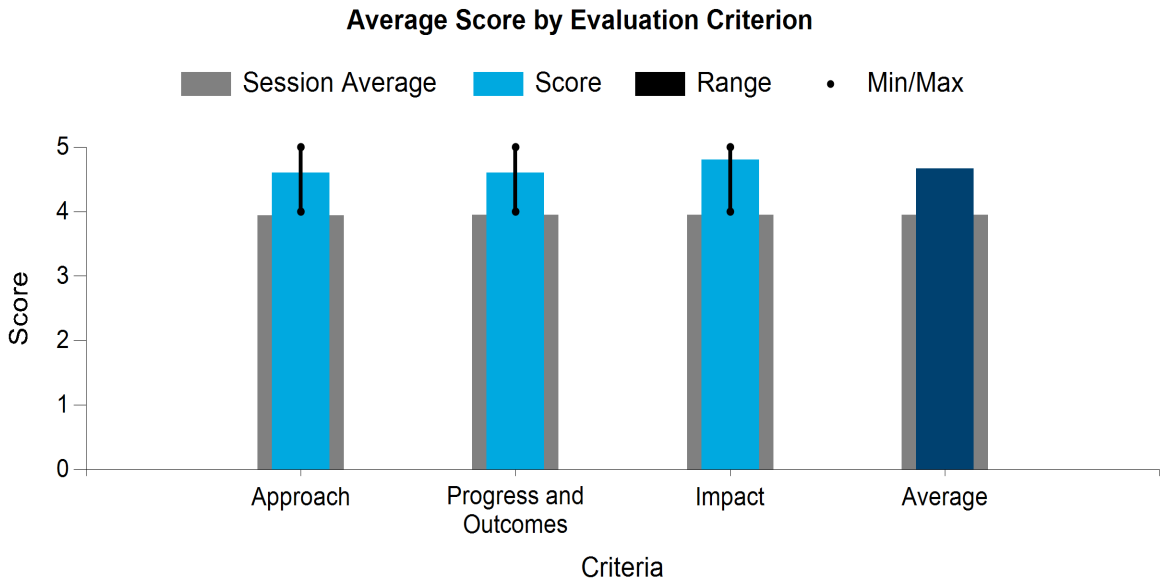
LIFE CYCLE ANALYSIS OF BIOFUELS AND BIOPRODUCTS AND GREET DEVELOPMENT

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 Funding:	$4,000,000

Argonne National Laboratory (ANL) has been developing and applying the GREET life cycle analysis (LCA) model to support the three EERE transportation offices, including BETO, for more than 25 years. This project for BETO continues to expand, update, and upgrade GREET to consistently and holistically address energy and environmental effects of bioenergy/bioproduct technologies and identify opportunities to improve their sustainability performance. With holistic LCA modeling of bioenergy technologies, ANL supports BETO R&D efforts across the entire biomass-to-bioenergy supply chain that encompasses terrestrial, aquatic, and waste feedstocks for SAF and road transportation fuel production. It addresses analytical challenges, such as data availability for bioenergy technologies, through national lab collaboration and industry engagement, and it examines important LCA system boundary issues, such as indirect effects of LUC of biofuels. Through this project, ANL releases an updated GREET model annually to benefit the bioeconomy community and the more than 50,000 registered GREET users globally. It dissimilates LCA results of biofuels/bioproducts via peer-reviewed publications and conference/workshop presentations. It provides credible, objective LCA results for R&D and other decision making at the federal, state, and international levels.



COMMENTS

- This is an excellent project with a strong approach and clear impact for stakeholders and the public. This is an excellent modeling framework, so my main area of focus as a reviewer was the selection of specific areas for expansion and analysis. Expanding GREET to include bioplastics and bioproducts is a great new feature. I also look forward to the new marine module, which seems highly valuable. The planned

future work to improve this module, develop an aviation module, and identify opportunities for deep decarbonization all seem worthy of pursuit.

- Thank you for the opportunity to review the Life Cycle Analysis of Biofuels and Bioproducts and GREET Development project. The project is well aligned with BETO's goals as it focuses on establishing LCA methodologies, developing reliable data, and maintaining model transparency for biofuel and conventional fuel pathways. The development of a feedstock analysis tool, carbon intensities for SAF pathways, and waste-to-energy conversion are important advancements in BETO's capabilities and are vital for achieving their stated goals. The project's regular communication and discussions with stakeholders and partners to mitigate data collection delays and obtain critical inputs are commendable. Overall, the project is on track, and the well-established tool that is heavily used in regulation and by commercial entities has significant impact. The project's engagement with stakeholders to improve the understanding and use of LCA results and its transparency make it a valuable resource. Kudos to all involved.

- This is a flagship project for BETO and for the technology area, with outsize influence among the policymaking community, academia, and industry. With a relatively small quantity of funding, this model has a tremendous impact and a wide audience. Within BETO, many other projects rely on the LCA estimates developed using the GREET framework. The project team has done an admirable job to continually update the model, with regular updates to improve the data quality referenced in the tool as well as to add additional fuel pathways and technologies to stay relevant, such as the recent addition of SAFs and e-fuels.

  Though the tool very much sets a standard for LCA for policymaking, there are some risks associated with its ubiquity. The increased recent political salience of the model, where significant quantities of policy support and investment may rest on minor assumptions and judgments within the modeling tool, greatly raises the stakes of results generated within the model. This may be particularly important in cases where the model combines attributional and consequential LCA (such as assumptions on induced land use change [ILUC] or counterfactual emissions for some fuel pathways) or for a handful of fuel pathways where long-term emissions assumptions are made based on expected future behavior and permanence (such as for soil carbon in the feedstock calculator). Though these are helpful and useful calculations, particularly for some academic and policy work, there may be issues with enshrining "one" GREET methodology in policy when the model mixes and matches emissions with differing degrees of certainty and verifiability or in cases where the model allows users to pick from different assumptions; thus, it may be helpful to break GREET out into policy-specific modules, as needed.

- The goal of this project is to quantify life cycle energy and environmental impacts of biofuels/bioproducts. GREET has been in development since 1995 and has 50,000 registered users. Clearly, the project has been developing, growing, and being refined for decades, and it has widespread impact. I am curious to know how the model adapted to changes in regulatory standards, such as criteria air pollutant emissions standards and others.

  How does GREET LCA address LUC for conversion to biofuels? Does the supply chain sustainability analysis include changes in labor, such as labor shortages and other social or economic barriers? If so, how are these changes reflected in the model?

  How has feedback from international, national, and state agencies helped to shape this project? Other stakeholders (researchers, industries)?

  One goal of the project was to identify key drivers affecting the sustainability of bioproduct and bioplastic technologies. Does GREET allow for comparison between biomass feedstocks for energy versus other bioproducts?

Another goal of the project is to facilitate discussions among government agencies and the private sector for opening low-carbon-intensity feedstock certification. Clearly, GREET has been used by many different entities, but what is the current status of those discussions? Have the ways in which agencies have used GREET changed over time?

The long and impressive list of project presentations includes ANL's Sept. 19, 2022, Energy Justice Webinar on GREET Bioenergy Life Cycle Analysis. How does GREET address energy equity? They have developed a concurrent mapping tool that shows data by zip code. This sounds like an incredibly helpful tool, and I will be curious to learn more about the linkages between the model and the mapping tool.

- GREET is a leading tool for LCA of a variety of bioenergy and biochemical products. It is transparent, well maintained, and continuously updated with user inputs. It also played a significant role in making policies at the state, federal, and international levels. It has accumulated a large user base, and the project team is consistently looking for ways to engage more users (e.g., through regular workshops). Within this GREET platform, a series of tools are also being developed with different focuses (e.g., Carbon Calculator for Land Use and Land Management [CCLUB], Feedstock Carbon Intensity Calculator [FD-CIC]), and different versions of GREET have been created to support different policies (e.g., CA-GREET). This is overall a very impactful project.

  But at the same time, both of the existing forms of GREET, Excel and .NET, are not built for version control, flexibility, and robust uncertainty and sensitivity analyses. Especially for the still more popular Excel form, it is hard for the users to track what changes have been made and quickly understand the implications of those changes. At the same time, the broad scope of GREET leads to (often necessary) a large number of default assumptions and model simplification. GREET is a great tool to get an out-of-the-box answer, though adjusting assumptions to tailor the answer to the specific application is also needed; therefore, balancing accessibility (on how easily a new user can learn and correctly use GREET) and model accuracy should be considered in future development plans.

PI RESPONSE TO REVIEWER COMMENTS

- Thank you for pointing out these important areas in the GREET LCA as related to policies and regulations. Since 2010, GREET, originally built as an attributional LCA model, has been expanded with consequential elements, such as ILUC effects of biofuels, coproduced animal feeds, and counterfactual scenario emissions of waste and residue feedstocks. This approach is similar to those in regulations such as the California Low-Carbon Fuel Standard and the International Civil Aviation Organization (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) program. It is widely recognized that ILUC GHG emissions and soil organic carbon (SOC) changes from different farming practices associated with biofuel feedstock production are important and unique analytical issues in bioenergy LCA. The bioenergy LCA community, including the GREET LCA team, has been adopting the consequential approach to addressing ILUC issues with economic models. The agro-ecological zone emission factor approach (originally developed by the Intergovernmental Panel on Climate Change) and the process-based simulation approach (such as the Century and DayCent models) are both used to address SOC changes. GREET has used both approaches. In particular, for domestic SOC changes, ANL has relied on the Century model, and for international SOC changes, GREET has used the emissions factor approach as used by the California Air Resources Board and the EPA. Despite the inherently greater uncertainty of the consequential LCA approach, data, and assumptions that are considered in addressing these consequential issues, the GREET LCA team has been engaging with the research community, agencies, and feedstock producers in the agricultural and forest sectors, among other stakeholders, to improve the data, assumptions, and modeling approaches in consequential LCA. Both ILUC and SOC issues are subject to great uncertainties in modeling and difficulties in verification. Advances in ILUC modeling have been made in the past 14 years, and ANL has benefited from the advances. There are ongoing efforts in the U.S. Department of Agriculture (USDA) and DOE Advanced

Research Projects Agency–Energy to develop better SOC inventory data and new sensor technologies to potentially economically measure SOC contents. ANL will continue to benefit from these efforts. The treatment of counterfactual scenario emissions reflects the belief of future, as well as current, treatments of wastes and residues. ANL will continue to examine these treatments and their effects on emissions. Further, the GREET model allows users to change the default assumptions and modeling options regarding these issues to reflect alternative approaches and data from the users and/or unique aspects of the user-specific technologies. The comment rightly identifies the difficulty of technical analyses versus policy considerations of fuel technologies, especially biofuel technologies. While the GREET model is developed to address technical/analytic issues as much as we can, policy considerations of energy technologies is different from technical analyses. We will continue to make GREET as comprehensive and flexible as we can so that policy considerations can benefit from the model. Given the unique analytical issues that may be relevant to different technology areas, ANL is currently working on specific modules that provide interactive features so that different technologies can be modeled separately but with a consistent, transparent LCA approach and background data for cross comparison.

LUC emissions have been modeled for GREET biofuel LCA with two key steps: economic modeling of the types and magnitudes of LUC due to biofuel production and changes in GHG emissions, particularly in SOC changes associated with each LUC type, such as grassland conversion to cropland. ANL has relied on Purdue's Global Trade Analysis Project (GTAP) modeling to estimate the types and magnitudes of LUC of a given scale of biofuel production (a "shock"). This is the same approach used by California's Low-Carbon Fuel Standard and the ICAO CORSIA program. For SOC and other GHG emissions, such as N_2O emissions associated with specific LUCs, as stated in a previous response, GREET has relied on the Century model process-based SOC model and California Air Resource Board and EPA emissions factors of different land conversions. The Century model is coupled with U.S. statistics of long-term crop yield records. These two steps are combined organically in the CCLUB module (https://doi.org/10.1111/gcbb.12237; https://doi.org/10.1111/gcbb.12333; https://doi.org/10.5539/sar.v10n1p61) that was developed for GREET to generate LUC GHG emissions for biofuel production. The supply chain sustainability analysis, a significant GREET application task for BETO, does not include changes in labor or other social or economic barriers. It only addresses energy, GHG emissions, criteria air pollutant emissions, and water consumption. Some of these issues, such as economic barriers, are addressed in separate but linked techno-economic analysis (TEA) for BETO. Stakeholder engagement and interactions are an integral part of the GREET project. These activities have dual purposes. First, we want the GREET development to be relevant to the pursuit of energy and environmental sustainability of bioenergy technologies. The inclusion of relevant sustainability metrics and technology options are key to GREET. Second, technology advances are important to consider for addressing the potential of bioenergy technologies. Our engagement with technology developers helps us understand technology options and their advances over time for GREET considerations. We have interacted with agencies such as the ICAO, the International Energy Agency, the International Maritime Organization, U.S. federal agencies (DOE, USDA, U.S. Department of Transportation, and EPA), California, and several other states to ensure that GREET has broad coverage of energy technologies including bioenergy technologies. We have interactions with stakeholders from industry and academia who help us understand the current state of technology (SOT) and the potential directions. One example is the interaction with several chemical companies that helped us refine the steam cracking modeling by providing shares of feedstocks for the steam cracking process to reflect the current U.S. average shares of the production of major chemical building blocks used as the baselines for LCA comparison with bio-based chemicals. While GREET does not directly compare the use of biomass for the production of biofuels and bioproducts, such analyses have been done outside of GREET to determine the best use of biomass for the decarbonization of U.S. economy. Further, biofuels and bioproducts are sometimes coproduced. In such cases, both are evaluated in GREET LCA for their joint energy and environmental benefits. Such analyses are conducted with holistic LCA methodologies and consistent background data in GREET to address their life cycle sustainability effects. For example,

GREET simulates integrated biorefineries that produce both biofuels and bioproducts and addresses the synergies and trade-offs of producing biofuels and bioproducts together. Some of the work published in this area includes https://doi.org/10.1002/bbb.1893, and https://doi.org/10.1016/j.jclepro.2021.127653. For the energy justice issue, GREET LCA provides results for the regional use of biomass, regional environmental effects such as criteria air pollutant emissions, and water consumption. These results can shed light on opportunities to improve energy and environmental benefits to disadvantaged communities by promoting bioenergy development and deployment with data and science that are critical for stakeholders to make sound EJ and bioenergy investment decisions.

We appreciate the comment on the need to improve the tractability, enhance user accessibility, and enable more robust/interactive sensitivity/uncertainty analysis of the current GREET model platforms. In FY 2023, with support of the DOE Office of Technology Transitions, ANL began the effort to develop different modules (such as the SAF, marine, clean hydrogen, and battery modules) to make the Excel version of GREET with interactive user interfaces to help users clearly identify key input parameters for changes. Further, ANL will design a new GREET modeling platform to increase the functionality, traceability, expansion, and maintenance of GREET. The latter effort is anticipated to be completed in the next two years. (Related references: https://doi.org/10.1002/bbb.1893, https://doi.org/10.1016/j.jclepro.2021.127653 https://doi.org/10.1016/j.jclepro.2021.127431, https://doi.org/10.1111/gcbb.12237, https://doi.org/10.1111/gcbb.12333.)

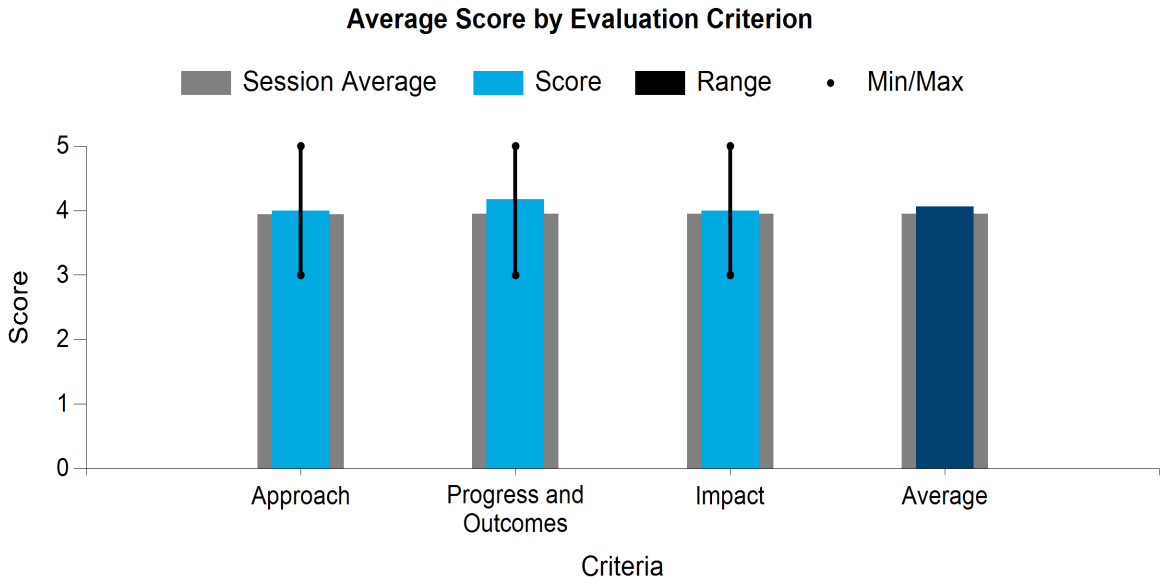
MULTI-INPUT, MULTI-OUTPUT BIOREFINERIES TO REDUCE GREENHOUSE GAS AND AIR POLLUTANT EMISSIONS

University of California, Berkeley

PROJECT DESCRIPTION

WBS:	4.1.1.100
Presenter(s):	Corinne Scown
Project Start Date:	10/01/2019
Planned Project End Date:	03/31/2023
Total 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. The resulting 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. The project has resulted in peer-reviewed publications on biogas yields from codigestion as well as cost, energy, and life cycle GHG impacts of biorefinery designs coproducing renewable natural gas (RNG), compostable plastics, and single-cell protein (SCP).



COMMENTS

- This is an excellent project. The environmental impacts of collecting biogas from manure digesters is a highly controversial question for many stakeholders in the bioenergy space. Assessing which livestock systems might be more or less suitable for manure collection and digestion and the potential economic viability of bio-compressed natural gas production from manure digesters are also worthy goals of

potential high impact to stakeholders. This project appears to have developed new tools and data and distributed them through an accessible web tool that seems likely to realize much of this impact. I encourage DOE to consider how platforms like the Bioenergy Knowledge Discovery Framework (KDF) could be used to inform potential users of these capabilities. Overall, I find nothing to criticize about this project, and I hope to see BETO continue to fund work like this in the future.

- Thank you for the opportunity to review the Multi-Input, Multi-Output Biorefineries to Reduce Greenhouse Gas and Air Pollutant Emissions project, which is somewhat aligned with BETO achieving their goals. The project is innovative in its approach to designing cost-competitive biorefineries that can process lignocellulosic biomass and organic waste, and the use of integrated models is commendable. The employment of a machine learning methodology is also impressive; however, an opportunity for improvement would be to couple this with more traditional methods to compare outcomes. Such a framework may ensure more confidence among industry. The project has a significant number of publications and has the potential to attract and support industry entrants.

- This project fits well with BETO's mission, and it is a good use of FOA funding to develop a targeted, short-term analysis. The focus on developing a flexible biorefinery that can use multiple inputs is unique across the projects studied, and the focus on identifying the optimal end product offers flexibility and could inform future biorefinery design and investment. The progress and outcomes also had compelling results about the cobenefits of the feedstock selection.

  It is a bit difficult to see how it is integrated with other projects at DMA. It is unclear if this approach to multi-input, multi-output biorefinery design and TEA is going to be incorporated into further analyses or if this is a one-off project.

- The goal of this project was to assess the economic and environmental performance of multi-input, multi-output biorefineries. Specifically, the project explored the question of whether or not lignocellulosic biorefineries could coprocess organic waste in rural communities at comparable or lower costs and environmental impacts relative to a conventional stand-alone design. The team sought to build and demonstrate integrated siting, TEA, and LCA models to simulate designs and explore trade-offs.

  As with all models, especially ambitious ones with many inputs and outputs, there were many forms of uncertainty embodied in this project. For example, the team noted that manure availability was a major source of uncertainty. What determines whether or not manures are collectable? How might the model seek to address those constraints and other uncertainties associated with the logistics of collecting a wide range of wastes, including poultry blood, lactose, sludge, etc.

  Project goals were clear, and activities supported the intended outcome. The team included a small business (Mango Materials) to build a launch-scale facility for lignocellulosic refining and worked with a local wastewater treatment plant. In the future, it would be good to continue to work with other labs and stakeholder groups that may add valuable feedback to the model and analysis. For example, the team plans to publish water and GHG results and post polyhydroxyalkanoate (PHA) and SCP scenarios on a web tool. Who are the intended audiences for these additions on the web tool? How might different groups benefit from these additions?

  I am also curious to see how the team plans to explore potential rural benefits such as improved wastewater treatment in building new biorefineries. This is an understudied area that would be interesting to explore further.

- Overall, the approach of this project is unique and important. The multi-input, multi-output approach allows for a more complex biorefinery to be conceived and a more diverse set of inputs to be consumed and products to be produced. This model also included comprehensive impact analysis in GHG, water quality, and air quality evaluations.

Excellent real-world experimentation with Mango Materials as an implementation partner. Would be great to have more partners documented using the system.

Manure's use as fertilizer is an important method to replace synthetic fertilizer and to decarbonize corn and wheat production. This model has a useful approach of identifying manure-saturated areas for siting using regional watershed loads as a guide for maximum manure applications.

- This project focuses on the biorefinery design with TEA and LCA. Its strengths include the close collaboration with industry partners, the consideration of multiple configurations for different emerging bioproducts (polyhydroxybutyrate [PHB], SCP), the rigor of analyses (sensitivity and uncertainty analyses), and the inclusion of biorefinery designs in web tools. It is a nicely executed project near completion, but it also only focuses on a few select products, and therefore the larger implication on the entire bioeconomy is limited.

PI RESPONSE TO REVIEWER COMMENTS

- We want to extend our thanks to the reviewers for their careful review of our progress, excellent discussion during the Project Peer Review, and thoughtful and encouraging written comments. It is true that this project is nearing completion, so we have limited flexibility to adjust or expand the scope based on the reviewers' comments; however, the feedback is still valuable for us as we finalize and disseminate our results, and it provides great direction as we think about potential follow-on work. The points raised about possible benefits of improved wastewater treatment in rural communities are excellent, and we agree that this is an interesting topic for further study. Manure management and septic waste treatment (which can include brown grease) is a challenge for small, rural, and tribal communities. The EPA has some great resources available on this subject. A key challenge is that it is difficult to collect reliable, comprehensive data on how this waste is managed across the United States, which is critical to prioritizing where diversion to bioenergy facilities can offer the greatest GHG, water quality, and air quality benefits. As noted in our presentation, it has been difficult to obtain manure management plans from some states, but we continue to make progress, and this is an area where follow-up work could be enormously valuable. Regarding the comments about the targeted set of products analyzed in this project—specifically, RNG, PHB, SCP, ethanol, and isoprenol—we hope and expect that our findings can be generalized to other products. In particular, we see great value in further exploring the potential for biorefineries to address the needs of historically underserved communities by providing additional options for treating wet organic waste in a manner that reduces emissions to air and nutrient runoff. Matching the available waste types with the most economically attractive end product(s) is essential to achieving that goal. In terms of integration with other DMA projects, our data and scenarios will be available on Bio-Cradle-to-Grave (BioC2G) (a tool supported through a DMA national lab project). We will continue to disseminate all our data sets in publicly available, web-based platforms so that national labs and universities can use our outputs for their own analyses and publications.

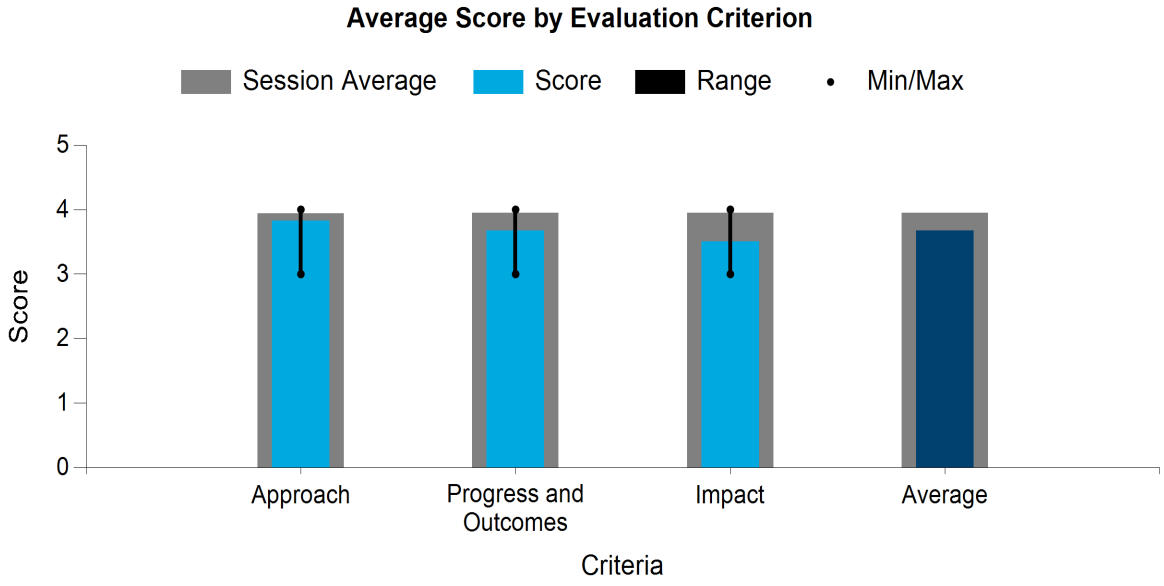
AGENT-BASED MODELING FOR THE MULTI-OBJECTIVE OPTIMIZATION OF ENERGY PRODUCTION PATHWAYS: INTEGRATED TECHNO-ECONOMICS AND LIFE CYCLE ASSESSMENT

Colorado State University

PROJECT DESCRIPTION

WBS:	4.1.1.101
Presenter(s):	Jason Quinn
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2024
Total Funding:	$1,000,000

A changing world is increasingly straining the precarious balance of energy and the environment. This strain has motivated researchers to search for long-term solutions that ensure the proper balance and use of limited resources. Concerns over depleting oil reserves and national security have spurred renewed vigor in developing bio-based products. A variety of feedstocks, conversion technologies, and bio-based refinery concepts have been proposed and are being investigated. The viability of these systems is typically quantified through sustainability assessments. Current work has focused on the assessment of technologies either based on economic viability or environmental impact but typically not concurrently. Further, there has been minimal work in the area of biorefining optimization. The proposed work will develop a unique tool set that is capable of identifying promising production pathways as well as performance targets for bio-based energy and coproduct systems. The foundation of the work is a modular engineering process model that captures the performance of various feedstock production systems, conversion technologies, and end use. This foundation is coupled with TEA, LCA, and resource demand modeling to understand the sustainability of the various production pathways. The work includes the novel coupling of economics and environmental impact through the integration of a social cost of carbon such that a more holistic assessment can be performed. A unique aspect of the work is the use of multi-objective optimization and agent-based modeling to evaluate the various production pathways. The development of foundational modeling work and results will include an external advisory board for feedback and research direction. The work will demonstrate the ability to evaluate new and emerging technologies and provide performance targets for specific pathways to meet sustainability criteria. Advantages of the proposed work include the ability to evaluate multiple production pathways, perform optimization across multiple sustainability metrics, identify areas for strategic investment at a system level and subprocess level, and decrease the risk associated with future technology investments by DOE.



COMMENTS

- I am supportive of BETO including this type of approach in the DMA portfolio. Optimization modeling and agent-based modeling are two potentially valuable techniques that seem underrepresented in the suite of tools attempting to understand biofuel producer decision making. I think the PI demonstrated the potential value of this project in that area.

  Overall, the project seems to be making good progress and appears to be on track to deliver the open-source tool set to DOE. One comment is that the scenario analyses and applications of the tool set to date seem a bit all over the place. I can see how these analyses may be useful for evaluating the potential for SAF production. But what was missing for me in the materials was a clear strategic vision for how all these pieces fit together to do that.

  Regardless, I think this tool set could have some impact. These are underrepresented perspectives in this area of modeling, and including them in the analytical conversations around SAF potential could be valuable. Releasing them as open-source tools should amplify that impact. I'm also encouraged to see that this framework will be capable of estimating particulate matter ($PM_{2.5}$) impacts and other metrics relevant to EJ considerations at a fairly fine spatial resolution.

- Thank you for the opportunity to review Agent-Based Modeling for the Multi-Objective Optimization of Energy Production Pathways: Integrated Techno-Economics and Life Cycle Assessment. I find that the project reasonably aligns with BETO's goals, using multi-objective optimization and agent-based modeling to integrate TEA and LCA. I appreciate the inclusion of equity as an objective and the integration of models to address inconsistencies. The open-source nature of the project, with peer-reviewed papers, can result in a community resource and help inform policy design. A suggestion for improvement would be to clarify the model components completed and those still under development. It is recommended that the model team explores the inconsistencies across the frameworks, understanding that each is solving a fundamentally different problem, and achieving the same results should not necessarily be a goal but rather to understand the differences and in what situations they are the same problem (removing what components from the objective functions). Overall, the project seems to be on schedule, and I wish the team all the best in future endeavors.

- This project is nicely designed and seeks to address one of the core risk areas of the technology area by integrating the results of some different modeling approaches across DOE. The PI was very clear on how they leverage the existing resources of DOE to build out the agent-based modeling approach and how they fit together. The outputs of the model are very clear and serve an important role in evaluating the feasibility of broader policy goals, such as the SAF Grand Challenge, and illustrating the pathways to reach them.

  The multi-objective optimization modeling approach is useful in that it allows the modeler to balance multiple competing priorities for a given agent. In particular, this approach does a good job of identifying potential equity risks with bioenergy policy via its spatial analysis. It may still be relatively early in the project to draw conclusions, but several key findings and progress presented still appear to be theoretical; it would be helpful to provide additional detail on exactly which policy or technology gaps this model can identify.

- The project's goal for a unified and multipurpose bioenergy-based tool set embodies a holistic approach that supports BETO's goals and objectives. The model uses county-level data, which is consistent with BETO's interest in regional data and understanding disparate impacts. For example, this county-level assessment could be useful in looking at equity in the siting of biorefining technologies.

  Like other models, however, some assumptions might be worth exploring a bit more. For example, one of the project goals is to determine land availability and total biomass that can be grown for bioenergy. What factors are used for determining land availability? There is well-developed literature that looks at the social availability, or willingness, of landowners/farmers to grow different crops. The project might benefit from more engagement with that literature to ground truth some model assumptions.

  The project addresses equity issues by including things like exposure to PM in the multi-objective optimization to measure system equity. This is a great start, but other EJ indicator systems have been developed to account for a wider range of variables. Here are a few of the different ways in which agencies have attempted to quantify and model concerns about equity as it relates to energy equity and environmental justice (EEEJ): https://screeningtool.geoplatform.gov/en/#3/33.47/-97.5, https://www.epa.gov/ejscreen. Several states have developed their own EJ mapping tools as well: https://cdphe.colorado.gov/enviroscreen, https://www.michigan.gov/egle/maps-data/miejscreen.

  The agent-based modeling example shows the miscanthus 100-mile radius familiarity expanding in California—is Miscanthus a fire-adapted grass? How is the team quantifying, addressing, and communicating about uncertainties in this model? Overall, the project models risks to the fuel supply chains and seeks to account for dynamic systems. The model could be of potential use to several different user groups and is worthy of funding.

- This project was strong overall but could improve in several key areas. Strengths of the approach include a robust inclusion of familiarity with new crops and agent modeling over time. Practice change in farming often includes a component of time that cannot be accelerated with incentives. The DEI approach was good with the inclusion of the $PM_{2.5}$ impact by county.

  The inclusion of the carbon pricing scenarios and tax incentive scenarios could improve comparisons and understanding of end product price points. It would also be good to document stakeholder use. In particular, including feedback from the Natural Resources Conservation Service (NRCS) and local agronomic nonprofits could help improve the modeling of familiarity. An important understanding extension of the agent model would be to include and model processing locations along with production areas. Often paths to market can limit grower crop selection. Finally, crop insurance is an important factor in the risk of switching crops, and crop failure with and without should be included both in financial and adoption curves.

- This project clearly identifies the gap in the current modeling efforts, and the goals of this project align well with BETO's priorities. The team uses multiple layers of modeling (TEA, LCA, geographic information system, multi-objective optimization, agent-based modeling) to consider land availability, spatial variation, multiple feedstocks, and fuel production pathways as well as the implications of stakeholder priorities (i.e., objectives). This approach also enables the explicit consideration of EJ and DEI in the optimization objectives. This is an impressive modeling undertaking with great impacts. Although this amount of modeling involves a great level of uncertainty that should be carefully evaluated, the project team acknowledges the existence of such uncertainties and has plans to characterize them. The team is also making the tool publicly available, and this transparency should help to address this issue (i.e., the users would be able to know/adjust the underlying assumptions); however, the agent-based modeling approach used in this project is purely based on rational decisions without actual inputs from agents (e.g., farmers, landowners), which may lead to significant deviation from reality and invalidate conclusions generated by the modeling system.

PI RESPONSE TO REVIEWER COMMENTS

- The project team is grateful for the positive feedback on our approach to date. We will make sure to clarify the strategic vision of the work to ensure that all components align toward evaluating SAF potential in the United States moving forward.

  At present, the process modeling and biofuel feedstocks are complete. This work was recently published in the *Journal of Cleaner Production*. Ongoing work is being done to finalize the geographic information system modeling and get accurate results for the total SAF production potential of the United States. It is expected that this work will be submitted for review during the summer. Multi-objective optimization and agent-based modeling work is ongoing, but publications related to each plan will be submitted during the fall. We will clarify the current progress of the work in future presentations/communications. The technology gaps that this model can identify are the large-scale resources required to meet DOE goals (SAF Grand Challenge, Renewable Fuel Standard [RFS], etc.), the geographically resolved deployment of technologies to meet the goals while optimizing for economics or environmental impact, and highlighting the impact of technology advances on achieving DOE goals such that DOE can focus its resources on critical pathways/technologies. We will review the referenced EEEJ work and ensure that our work aligns with previous work. In terms of land area under consideration, we have included nondeveloped marginal land classifications that are not protected according to the U.S. Geological Survey's Protected Areas Database of the United States 2.1 and Key Biodiversity Areas. Each feedstock has a limit on the maximum slope on which they can be cultivated, and each has a minimum yield required to ensure biofuel prices less than $20. This work uses the Parameter-elevation Regressions on Independent Slopes Model Environmental Limitation Model (PRISM-ELM) data set of predicted rain-fed yields of various bioenergy crops across the United States. The PRISM-ELM data set includes climate and soil data as inputs to their model, so our work has put no constraints on climate regions or soil quality required for biomass growth. Moving forward, we will be sure to include carbon pricing/tax scenarios in our simulations and evaluate the impact of crop insurance in financial and adoption analyses. As mentioned, there are uncertainties with all the inputs to the modeling effort. This tool set will be publicly available, so end users can adjust inputs and assumptions with new values as they become available. The project team will work to better understand the decision making of agents (farmers, landowners, biorefinery operators, etc.) through published survey data, journal articles, and interviews.

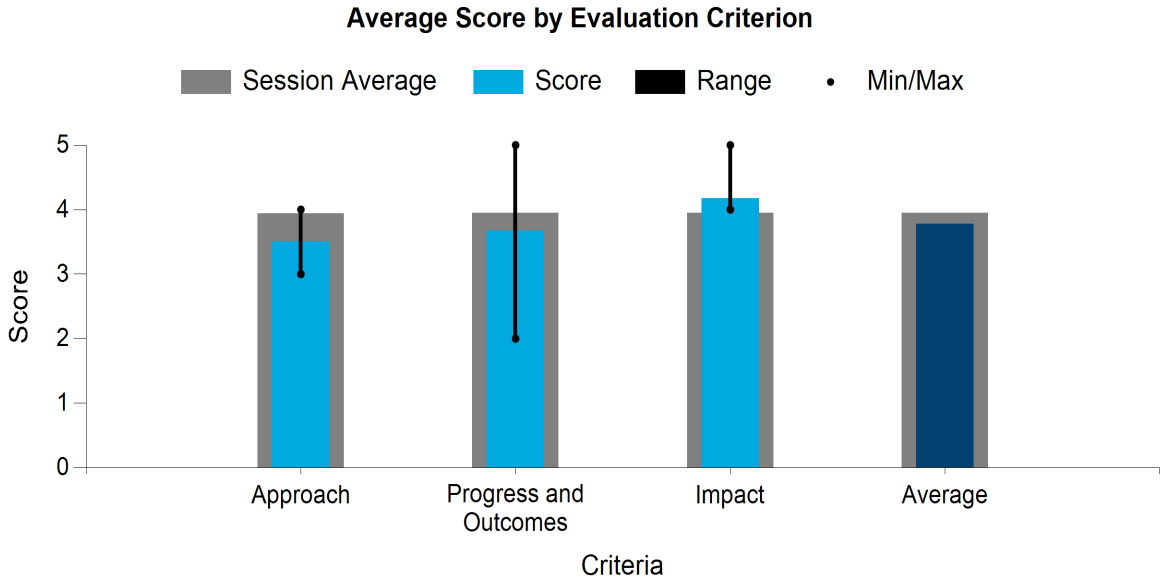
STRATEGIC ANALYSIS SUPPORT

National Renewable Energy Laboratory

PROJECT DESCRIPTION

WBS:	4.1.1.30
Presenter(s):	Ling Tao
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$2,000,000

The objective of the NREL strategic support project is to provide sound, unbiased, and consistent analyses to inform the strategic direction of BETO. This project addresses key technological questions, provides critical data needed to inform strategy, and highlights barriers, gaps, and data needs in support of BETO's mission to improve the affordability of bio-based fuels and products. This task employs various tools and analysis capabilities (TEA, Gauging Reaction Effectiveness for the eNvironmental Sustainability of Chemistries with a Multi-Objective Process Evaluator [GREENSCOPE]-process sustainability analysis, refinery integration and bioeconomy optimization, job analysis, EEEJ) to allow for direct comparisons of biomass conversion technologies across a wide slate of processing platforms, products, and impact categories. The project is tasked with evaluating drivers that support the growing bioeconomy. This project team supports the federal government goals of 3 billion gallons of SAF by 2030 and 35 billion gallons by 2050, and it has specifically supported the SAF Grand Challenge with pathway strategies and analysis insights. 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.



COMMENTS

- This is a project with many different elements. Each of the six major tasks seems like a worthwhile scope for BETO to be funding. And most of these tasks seem to be well scoped and showing good progress. I do, however, have some specific areas of criticism regarding some tasks.

The sustainability scope seems to be missing or underrepresenting some critical factors. Impacts on water quality do not appear to be considered directly. Possibly some of this impact is captured in the ecotoxicity metric, but that seems incomplete in a way that a broader measure of water quality would not be. LUC, particularly indirect LUC, is also conspicuously missing from the sustainability metrics. This is not simply an emissions metric. The impact of LUC on both terrestrial and aquatic species must also be considered. Finally, as a general methodological matter, it does not appear that the sustainability analysis includes any consequential LCA. The recent National Academy of Sciences study on biofuel LCA makes it clear that program-level impacts analysis of the type being conducted under this project are most appropriately conducted with consequential modeling rather than attributional modeling. This National Academy of Sciences study was only recently published, but future work under this project should heed its findings.

The sustainability scope appears to narrowly focus on processing plant sustainability. While this is an important subcomponent of biofuel sustainability, it is incomplete. Assessments of biofuel environmental, energy, economic, and efficiency impacts need to consider the full life cycle of the fuel, not just the processing plant. This appears to be a significant gap in the scope of the project and the overall assessment it is trying to achieve. The types of assessment being visualized on slide 18 are highly valuable, but the data going into them need to be more complete.

Finally, the focus of this project on corn alcohol to jet (ATJ) is out of step with most of BETO's feedstock analysis portfolio. This work needs to allow itself to be informed by other projects in the portfolio. BETO-funded work has already demonstrated the limited emissions benefits of corn ATJ barring substantial advances in carbon capture, utilization, and storage (CCUS). And the general focus of BETO seems to be on low-emissions feedstocks with substantial potential for knock-on ecosystem benefits. It would seem more in-line with this work to focus on pathways where the potential for sustainability benefits seems greater.

- Thank you for the opportunity to review the Strategic Analysis Support project. I am pleased to report that this project is well aligned with BETO's goals through developing and applying various analyses to support BETO's strategic direction and inform collaborations across EERE. I am particularly impressed with the project's use of a "meta-model"; however, the project could benefit from advancing the state-of-the-art (SOA) analysis in indirect economic impact analysis in other sectors, particularly with regard to jobs and indirect impacts. I don't believe the input-output approach applied should be referenced as SOA, as mentioned in the presentation. Overall, the project appears to be progressing well toward its goals, including identifying scenarios for achieving net-zero SAF and investigating farming practices with biochar options. The impact of the project, including the 11 peer-reviewed papers and book chapters and 7 conference and invited talks, is significant, and the project appears to be on schedule.
- This project is highly relevant and necessary to the portfolio by coordinating across multiple modeling teams and assessing a wide array of data and expertise to inform and respond to BETO's long-term goals. Particularly impressive is this group's ability to coordinate across BETO to iterate and improve different, disconnected modeling tools to contribute to broader strategic visions, particularly the recent focus on SAFs as part of the SAF Grand Challenge. The consolidation of the TEA database to the KDF was also a critical point of progress because it helps to improve transparency, access to, and relevance of BETO's analysis. There is a high degree of coordination with DOE and with other parts of government as well as industry, indicating high impact.

  In terms of strategic direction, the multidimensional analysis appears to undercut other priorities of BETO and the administration. For example, this presentation appears to emphasize existing or near-term biomass resources (e.g., the focus on hydroprocessed esters and fatty acids [HEFA] and corn ATJ) rather than those emphasized in most other presentations, as well as an emphasis on using existing refinery infrastructure.

This project also emphasizes Justice40 and equity goals while potentially undermining those goals with its recommendations. Specifically, this project emphasizes the importance of retrofitting existing refineries. This is a current flash point in the policy space in California, where the low-carbon fuel standard (LCFS) is prolonging the life of some refineries against the wishes of those located in nearby communities who have disproportionately borne the burden of the pollution; therefore, recommendations on refinery retrofits from this work group should take special care to consider this type of recommendation with respect to DOE and the administration's equity priorities.

- The goal of this project is to develop analyses that go beyond traditional biorefinery-focused TEA/LCA to identify both technical and nontechnical barriers, mitigation strategies, and R&D needs. One of the great strengths of this project is that it investigates EJ factors involved in biorefinery development. The project partners acknowledge that there is a lack of tools for understanding the socioeconomic impact of bioenergy technologies, and this project aims to fill that gap.

  To capture EJ impacts, they used NREL's Feedstock Production Emissions to Air Model (FPEAM). They note that most BETO models have native geospatial resolutions that are not sufficient to meet Justice40 requirements, which is census tract level. Downscaling is the process of estimating high-resolution values from low-resolution data and enables community-level analysis without alteration to existing models; however, downscaling introduces additional and unavoidable uncertainty. This is an important direction given Justice40 goals of 40% of the benefits of federal investments going to disadvantaged communities, but how will some of the uncertainties associated with downscaling be mitigated (changing census track data over time, alignment with air quality data, etc.)

  For the renewable chemical analysis, the project team narrowed 30 chemicals down to 15 to focus on energy intensity and GHG emissions connected to those 15 chemicals—what criteria were used in this narrowing selection process?

  For the SAF regionalization case study of O'Hare, the project examined the SAF potential of the surrounding region. It sounds like this study occurred before the EJ factors were developed, but this kind of regionalization study will be particularly useful in thinking about Justice40 and disparate impacts on communities.

  The project reached out to many stakeholders, including agencies outside BETO, such as the EPA, EERE Strategic Analysis, the Vehicle Technologies Office, the Fuel Cell Technologies Office, and several others. Were any EJ groups consulted? Or even the EPA's Office of Environmental Justice and External Civil Rights in the development of the new EJ analysis? This would be useful as the project continues tdevelop the EJ portion.

  The project goal is to understand and address rapidly changing externalities.

  Another important direction for developing socioeconomic indicators would be job analysis. This could be especially compelling for potential investors and local policymakers in decisions about the siting of biorefineries and other bioenergy technologies.

  It is fantastic that BETO is trying to find ways to integrate equity into analyses, and this spatial approach could be very helpful for understanding issues of distributive justice. That said, the analyses presented here do not necessarily get at issues of procedural justice: Who is involved with decision making? Who controls land and other forms of capital? This is an important next step, and working with other BETO-funded researchers to develop more sophisticated indicators on equity and justice would be an important direction forward for this team.

- This program performed very well in terms of engagement and accessibility. The model is published on KDF and has been cited in more than 50 publications. The model is also being used in complex industry partnerships, notably O'Hare and the Port Authority of New York.

  The updating of the model annually is an appropriate cadence and will help keep the model relevant and useful.

  The inclusion of farm-specific practices such as variable-rate N is an important inclusion. The model should also include opportunities to differentiate the type of fertilizer and allow for those types produced using renewable energy to be appropriately credited.

- This project takes a meta-model framework for TEA/LCA with job and EJ analyses. It also considers the integration of bio-feedstock/bio-derived crude products into existing chemical refineries throughout the analyses. The general approach is sound, and it is encouraging to see social factors being considered in the analyses, but the differentiation between this project and the U.S. Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability (DRIVE) project is unclear. It seems there are opportunities for the multiple pathways considered in the U.S. DRIVE project to be included here, and there are opportunities for the job and EJ analyses performed in this project to be included in other studies.

  Additionally, it is great that this project supports the SAF report, but the underlying Aspen model has not been released on NREL's Biorefinery Analysis Process Models page (https://www.nrel.gov/extranet/biorefinery/aspen-models/; the page has not been updated since 2018, but it is indeed challenging to keep the website current, and the team has made good efforts in setting up this page).

PI RESPONSE TO REVIEWER COMMENTS

- We appreciate the reviewers' recognition of the contribution of this NREL's strategic support to the BETO program and key accomplishments for this project over the last two years. We especially thank the reviewers for their helpful feedback and comments, which are helpful in shaping our analysis direction and ensuring we provide high-quality and timely strategic analysis support to the program in the future. Going forward, we will continue to publish TEA data via a KDF database so that valuable analysis research data are publicly accessible. Our goal for all our analyses is to develop defensible studies and tools in support of the strategic direction of BETO.

  In response to the reviewer's comments on the project being more focused on near-term pathways, we would like to clarify that we did include comprehensive biomass pathway strategies, including both near-term (e.g., HEFA and corn ATJ, as included in the presentation) and long-term opportunities (a variety of biomass carbon conversion as well as waste carbon utilization via electrochemical, biological, and thermochemical conversions). Due to time constraints, we presented only a few examples in the Project Peer Review, but our peer-reviewed publications provide more examples on our analysis covering as many carbon conversion pathways as possible. Also, U.S. DRIVE analysis is included in this strategic analysis support project as Task 7. Based on high interest from our funding agents, stakeholders, and industry collaborators, in addition to the significant amount of work and associated content, U.S. DRIVE analysis was presented as a separate project in the Project Peer Review.

  Thank you for the insightful question on the scope of our sustainability analysis and for suggesting additional critical factors to consider, such as impacts from direct and/or indirect LUC and water quality. Our sustainability analysis focuses on the process level and is complementary to other sustainability analyses funded by BETO, such as water analysis, GREET, and LUC analysis. It is important to integrate sustainability into process design early in the development stage and not at the end. By considering multiple metrics for evaluation when comparing technologies and design modifications, we

can make more informed decisions by looking at the design more holistically. We implemented the GREENSCOPE methodology, which is an effective tool for biomass-to-fuels/chemicals process sustainability evaluation and design. GREENSCOPE is able to capture the multidimensional aspect of the process design because making any design change to improve one aspect of the process sustainability may likely impact other aspects. Further, the GREENSCOPE gate-to-gate process sustainability assessment is not about replacing any effective frameworks (e.g., TEA and LCA) but complementing them. It synergistically associates with environmental LCA, and the combination of the two enables a more sustainable design and the development of bioenergy supply chains. Improving the sustainability of the biorefinery will also enhance the life cycle environmental impacts, which can be assessed through LCA. We hope that this explanation clarifies our approach to the sustainability analysis in our project.

Regarding the comments related to refinery integration, the scope of the refinery analysis within the Strategic Analysis Support task was originally developed to evaluate cost and operational efficiency benefits for biofuels production through the utilization of existing refining and ancillary infrastructure. The team has recently begun integrating carbon intensity calculations to enable both cost and decarbonization optimizations in response to DOE and industry needs. The team will continue to seek opportunities to further develop analysis approaches to meet the evolving priorities of DOE and society with specific considerations for justice and DEI.

We would also like to thank the reviewer for the comments about the input-output approach for the job analysis and indirect impacts. While the input-output model is not the only approach to estimate economic impacts from a change in demand for a given product, it is still one of the most commonly used methods by governmental agencies (e.g., U.S. Bureau of Economic Analysis, EPA, U.S. Bureau of Labor Statistics), academia, and consulting industry to quantify direct and indirect benefits or costs, such as impacts on jobs. We agree with the reviewer that this project could benefit from advancing the SOA analysis on indirect impact analysis. For example, using computable general equilibrium models could help quantify the nonlinear impacts on other sectors due to the change in demand for biofuels by a given policy. Because modifying and running computable general equilibrium models and partial equilibrium models requires significant efforts, our project will need a significant funding increase to advance such analysis. Going forward, we will work to adopt suggestions to advance our analysis by seeking opportunities to integrate with other DOE-funded (BETO or other offices) computable general equilibrium models.

We appreciate reviewers' comments on the Justice40 and EJ-related topics. It is critical to recognize the lived experience of residents surrounding biorefineries and how the perpetuation of their activities, and commitment air emissions, can affect them. While the current project does not explicitly address this issue, we have proposed to address this in future work.

We thank the reviewer for the recognition of the importance of EJ to the future success of the bioeconomy and in particular the model downscaling to spatial resolutions compatible with Justice40 evaluation. It is important to note in the context of the suggestions for the future direction of this component of the project—which were all valuable—that the funding level supporting this component is a small fraction of the total project funding, and thus there are significant limitations to how far and fast we can progress. Through other funded work, we are aware of the significant challenges to the durability of Justice40 evaluations owing to changes in census tract boundaries, population demographics, and Justice40 constituent metric scores that can then affect Justice40 designation (e.g., disadvantaged community status). We have looked at this in the context of California, and we are eager to expand our analysis nationally, should there be funding support, and consider implications of how model downscaling uncertainty interacts with underlying census variability. Indeed, the O'Hare regionalization case study occurred before the EJ component was completed but would be an interesting follow-on application of the model downscaling work should funds be available. The purpose of the model downscaling effort, especially in the context of the funding made available to it, was to preliminarily

explore quantitative approaches to transforming BETO-supported models to Justice40-appropriate resolutions. A natural step after this exploration would be to socialize the approach with DOE's and the EPA's EJ offices and EJ groups. We are actively looking for opportunities in the future to carry it forward.

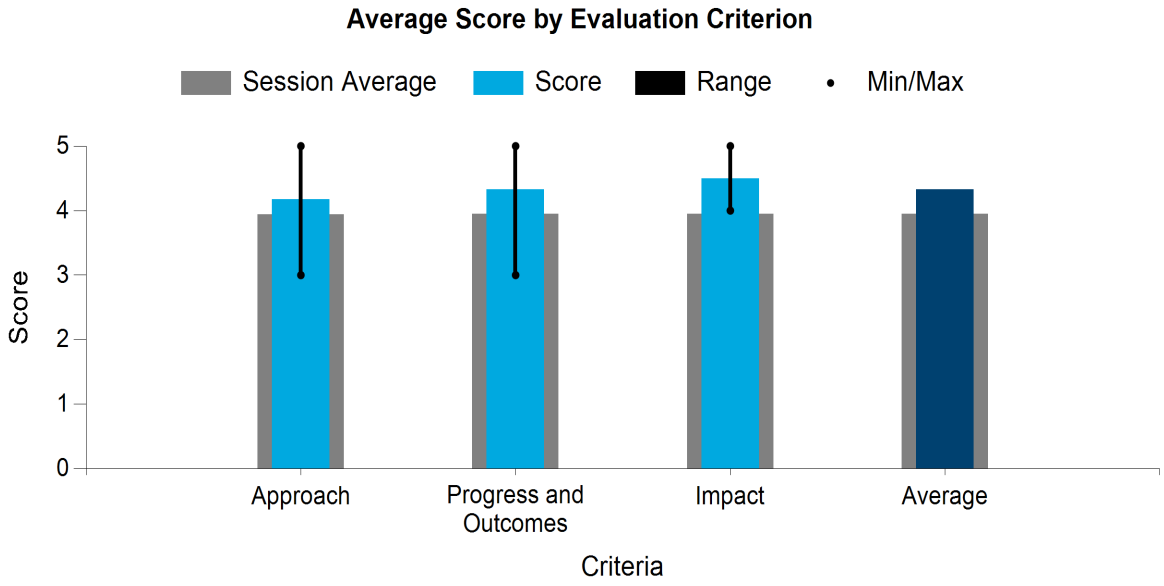
A FRAMEWORK FOR EVALUATING JUSTICE AND EQUITY IN THE TRANSITION TO RENEWABLES: THE BIOENERGY CASE

Oak Ridge National Laboratory, National Renewable Energy Laboratory

PROJECT DESCRIPTION

WBS:	4.1.1.40
Presenter(s):	Patti Romero Lankao; Rebecca Efroymson
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2023
Total Funding:	$500,000

This project provides BETO with tools to analyze and address equity (justice) in the energy transition. The project has three tasks: (1) development of equity indicators for measuring or modeling progress, (2) inventory of current BETO activities that support equity, and (3) options and best practices for community engagement. A framework was adopted that includes distributional, procedural, and recognition justice. A diverse stakeholder advisory committee was assembled to codevelop distributional and procedural justice indicators to be used and modified by communities for bioenergy facility siting processes. Committee members are from industry; a historically Black college; a labor union; environmental, agricultural, and energy nonprofits; the U.S. Forest Service (USFS); a utility; and a state EJ department. Distributional justice indicators include social, economic, and environmental metrics. Procedural justice indicators are a significant advancement over the SOA. A review of justice tasks in the BETO portfolio identifies research gaps. A review of best practices for community engagement and energy equity is under development. Energy transitions can perpetuate, aggravate, or mitigate historic inequities. The project is responsive to Justice40 (requirement that 40% of the benefits of clean energy flow to disadvantaged communities) and executive orders related to energy and racial equity, underserved communities, and well-paying union jobs.



COMMENTS

- This project is an excellent addition to BETO's portfolio. I find nothing significant to criticize in the approach, current progress, or impact. The list of new research directions on Slide 20 is excellent, and I look forward to seeing progress in some of these areas.

- Thank you for the opportunity to review A Framework for Evaluating Justice and Equity in the Transition to Renewables: The Bioenergy Case. This project is well aligned with BETO achieving its goals, particularly those surrounding DEI. The tools proposed to evaluate equity and diversity in BETO R&D are thorough, and the portfolio analysis identifies gaps and tasks that need attention. The project's focus on incorporating impact on underserved communities is commendable. Additionally, the effort put forth on both the literature review and the construction of the expert panel shows the significant progress on this project. One opportunity for improvement could be to engage with BETO projects and teams at the design phase. Overall, this project has the potential to significantly impact the bioenergy industry's transition to renewables in an equitable manner.

- It is great to see this project added to DMA based on feedback from the last Project Peer Review and the administration's increased focus on equity issues. This project fills a clear role, and the managers have developed a well-structured plan to develop DEI metrics and evaluate opportunities to assess BETO's work with an equity lens. The gathering of a group of outside stakeholders is also helpful to add perspectives from outside BETO. Because this process is still in its early stages, it is difficult to evaluate, but at this stage, I think that this fits well within the DMA Technology Area and would align well with many of the projects here. The development of indicators can be a critical piece of tools that optimize scenarios based on multiple metrics. In particular, it is extremely helpful to make sure that projects with a broader scope do not offer recommendations that exacerbate existing historical inequities (see refinery retrofits) or offer opportunities to redress those wrongs.

- The goal of this project was to develop metrics to assess DEI, conduct an inventory of BETO R&D that supports DEI, and make suggestions for how DEI could be incorporated into existing work or new activities at BETO that could improve DEI.

  This is very exciting to see a BETO-funded project that focuses squarely on evaluating justice and equity in the context of bioenergy. There is a dearth of work in this area in terms of both research and, until recently, policy. Many of the projects reviewed are attempting to incorporate energy equity into their analyses, which is great, but it seems many engineers, scientists, and modelers do not have the language or examples of how to do this kind of work. This project will help address the gap between the urgent need for addressing historical inequalities in the shift to the low-carbon economy and the ability of modelers and researchers to account for these often hidden, complex human dynamics.

  The project partners explain that distributive and procedural justice are likely to be the easiest factors to measure, while recognition justice is more difficult because it deals with understanding how the past shapes the present. I understand the relative ease of distributive justice, but what examples and metrics have been used to account for procedural justice? Are there any examples of recognition justice?

  For distributive justice, the project partners discuss ways in which BETO-funded researchers have started to account for disparate impacts in terms of air quality data (often focused on PM) or siting issues. There is an exciting array of composite EJ health indicators developed by other entities, like the EPA's Environmental Justice Screening and Mapping Tool (EJScreen), the Climate and Economic Justice Screening Tool (CEJST), and many states now have tools such as Michigan's EJ screening tool that will help understand distributive justice factors. These tools allow researchers to focus on different aspects of EJ. Are there particular EJ issues around bioenergy development that require greater attention in terms of distributive justice? This might be an interesting and important line of further research.

  In terms of procedural justice, the project team worked with an advisory group to come up with key metrics, including the percentage of key organizations and communities providing input and the percentage of decisions on which stakeholders feel they had real input. I like the effort to break this down into tangible metrics, but how would this data be gathered? By emphasizing percentage, that implies you can determine total number of people providing input or total number of decisions?

It appears indicators for distributive (bioenergy) siting and procedural justice (good practices for community engagement in energy projects) are coming along nicely, but what to do about recognition (or restorative) justice? That is, what kinds of indicators can be developed to understand how the past shapes the present?

In the strategic literature search, project partners used terms such as *engagement*, *energy equity*, *transitions*, *social acceptance*. One thing I am currently exploring is the relationship between social acceptance and EJ in the context of bioenergy development. I think these things are slightly different, as famously revealed in the 1984 Cerrill report on waste-to-energy siting in California. Both concepts may be useful in planning and siting of bioenergy technologies, but there are some important nuances that need to be carefully examined.

The project team's collaborative work was impressive, including the cultivation of a stakeholder advisory committee and work with EERE, the DOE Office of Economic Impact and Diversity, the Energy Futures Initiative, Resources for the Future, the Sloan Foundation, the Deep South Center for Environmental Justice, the University of Michigan Energy Equity Project, and the Initiative for Energy Justice. This kind of collaborative approach can serve as a model for other BETO-funded projects looking to authentically address equity and diversity issues.

One particularly interesting finding was that engagement does not necessarily improve equity. Understanding the nuances of what forms of engagement lend themselves to equity outcomes is an important direction for researchers.

Also, moving forward, the project will provide and implement ways to measure the progress of research portfolios toward Justice40, and it will work to develop a community of practice for BETO justice-focused projects with bimonthly meetings. This project is essential to achieving the goals of the Justice40 initiative—and, more fundamentally, to ensuring that the path to a lower-carbon economy does not reproduce the inequalities established in the era of fossil fuels. Keep up the excellent work.

- This is a crucial part of the BETO portfolio and should be perennially funded. Progress in the first year has been impressive and the literature review and stakeholders convened substantial.

  Providing BETO methods and metrics to measure the progress of the research portfolio toward Justice40 is one of the most important next steps, and the project is wise to focus on that as one of its top priorities.

  It was not clear from the presentation how indigenous lands and peoples are being included in this work. If they are not, please include this perspective in future efforts.

- This is a very important and impactful project on DEI and EJ. The review of existing literature and the profiling of BETO projects delineates the current status of EEEJ and points to future priorities. The development of bioenergy justice indicators would also assist the integration of social considerations in BETO's modeling work. It would be very beneficial to disseminate the outcomes of this study to the public and leverage this project to develop a DEI guideline for future BETO FOAs (e.g., example tasks PIs can integrate into their projects to promote DEI).

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their valuable and enthusiastic comments that suggest the project is headed in the right direction to meet needs of BETO, underserved communities, and industry. We also agree with the reviewers that much work remains to be done. Reviewers recommended that we "engage with BETO projects and teams at the design phase"; we will work to learn more about new projects at BETO and their potential equity or justice implications. One reviewer suggested that future work be designed to help redress past wrongs. We plan to pay special attention to recognize justice in all activities, including any case studies where industrial facilities are repurposed for renewable energy. This project direction

also responds to a separate reviewer recommendation to develop indicators that help convey how the past shapes the present. Regarding the question about which metrics are used for procedural justice, we have worked with the stakeholder advisory committee to develop a broad first cut at candidate metrics that can be modified by communities where bioenergy projects may be sited. We will soon submit a manuscript for publication that includes these indicators. We will also submit a review paper examining the nature and links between energy equity and community engagement—an essential means to operationalize procedural justice. As recommended, we will consider forms of engagement that are associated with improvements in equity outcomes. Finally, we will try to incorporate indigenous perspectives into future work, as recommended by a reviewer.

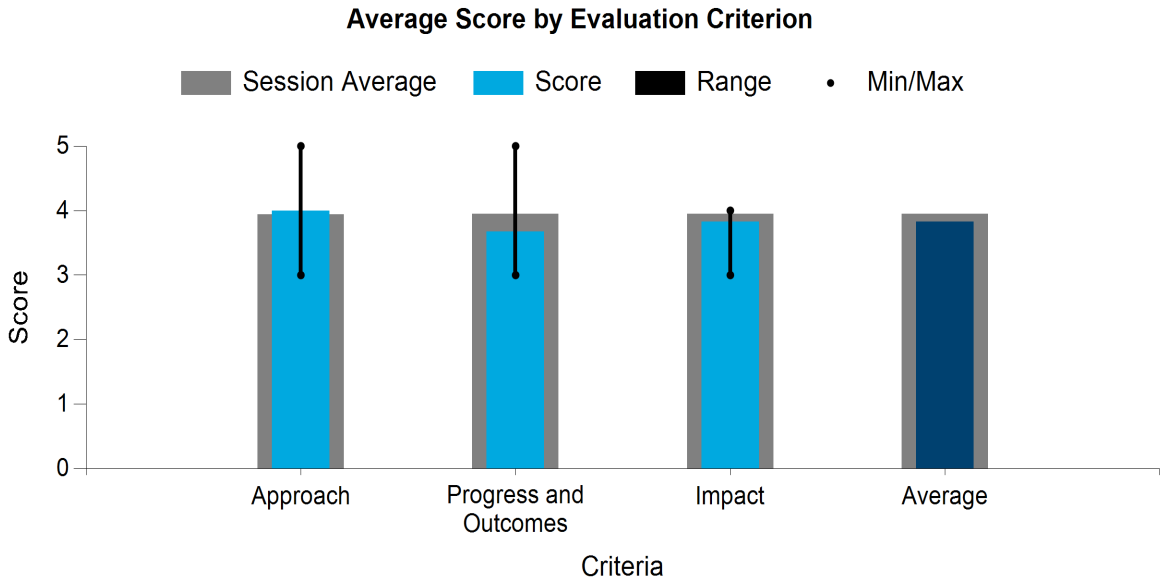
SUSTAINABLE BIOMASS THROUGH FOREST RESTORATION

Pacific Northwest National Laboratory

PROJECT DESCRIPTION

WBS:	4.1.1.52
Presenter(s):	Mark Wigmosta; Zhuoran Duan
Project Start Date:	10/01/2022
Planned Project End Date:	09/30/2025
Total Funding:	$750,000

In 2022, 68,988 wildfires burned more than 7.5 million acres, with 6 fires each requiring more than $90,000,000 in suppression costs alone. Climate change and poor forest management practices contributed to the severity of the wildfires. 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 USFS 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 used it in a 100-year simulation of the Wenatchee basin (historical climate) for multi-objective trade-off analysis considering vegetation regrowth, biomass, carbon, wildfire and smoke emissions, snowpack/streamflow, and economics. This work has resulted in significant two-way knowledge and technology transfer through follow-on federal and state funding for six projects.



COMMENTS

- In general, this is a well-developed project. Developing tools to aid targeted forest restoration and fire mitigation is a scope that is both timely and likely to be of strong interest to stakeholders. The modeling approaches appear sound, and progress to date shows a lot of promise for this work to benefit decision making. I also appreciate the plans to consider the impacts of climate change on these physical systems. This is an area where more work is generally needed.

One area of project weakness is in the scenario design. To date, all the scenarios assume the use of sustainable harvest practices. While these are excellent scenarios, to fully quantify the impact of these practices, the modelers must also produce scenarios where the model solution is not constrained in this way. It is certainly possible that harvesters in the real world will not fully adhere to sustainable practices. Part of the value of this work will be to articulate the economic and ecosystem benefits of sticking to those practices. To do that, a counterfactual scenario set where sustainable harvest constraints are relaxed is needed. The project team should incorporate these scenarios into their future research plan.

- Thank you for the opportunity to review the Sustainable Biomass Through Forest Restoration project. I believe the project is reasonably aligned with BETO achieving their goals. The project has made great use of spatial and biophysical models to prioritize and target forest restoration to address multiple objectives, and I appreciate the good use of LANDIS-II, the presented visual representations, and the use of different general circulation models. While there are opportunities for improvement in clarifying how follow-on tasks mentioned in the presentation are related to project goals, I'm pleased to see that progress is being made toward the goals and the project is on schedule. The significance of impact is noteworthy, and the continued engagement with Blue Forest is encouraging for potential commercialization. Additional commendation for the five publications.

- The opportunity to implement forest management practices that would reduce wildfire risk, generate a stream of sustainable biomass, and other cobenefits is very promising. The scope of the project and its plan appear very clear and well defined, though one important question to determine is how well integrated and consistent the approach here on management practices is with forest biomass updates to the integrated landscape management tool. The analytical tool appears robust and nicely incorporates a mix of ecological functioning, community needs, and economic viability to inform the model recommendations. Further, the collaboration with multiple outside groups—nonprofit, Native American communities, industry, and local government—illustrates the impact of the project.

- This project simulates vegetation regrowth to better estimate long-term biomass supply and impacts to wildfire intensity and streamflow. The project partners aim to estimate the scale of spatially explicit, time-dependent forest treatments required (over decades) to stabilize landscapes, their carbon, burned area, smoke emissions, water resources, and biomass.

  One main assumption of the project is that they only consider biomass for energy associated with commercial activities. Are there sufficient markets to sustain biomass for energy?

  What does the Roundtable on Sustainable Biomaterials (RSB) think about forest residuals being used for energy as opposed to other biomaterials?

  The goal of this project seems to be to improve USFS decision-making software to target forest restoration in fire-prone areas in Washington. What kinds of outreach activities have been done to other academic researchers, agencies, industry, and (especially) policymakers?

  There is a lot going on with this project, and while the goals support BETO's primary objectives, it is not always clear how all the pieces fit together.

- The partnership with LanzaTech, collaboration with the USFS, and the inclusion of indigenous tribes make this program clearly relevant to and inclusive of many diverse stakeholders.

  One project goal for the future is continued outreach to the science, policy, and industry communities. It would be helpful to quantify this with both measurable outcomes and timelines.

- This project focuses on forest restoration through sustainable management strategies. The project team developed the LANDIS-II model to simulate the impacts of different events on the ecosystem. The team

has regular communications with collaborators and stakeholders, and this project has led to multiple follow-up projects. But it would be good if the team could explore and discuss the broader implications of this project. For example, the team mentioned that they are engaging with private equity on a pilot project—what are the investors attitudes toward the management strategies considered in the project? Are these strategies financially viable or are incentives required? Addressing questions like these would help the project move to the next stage.

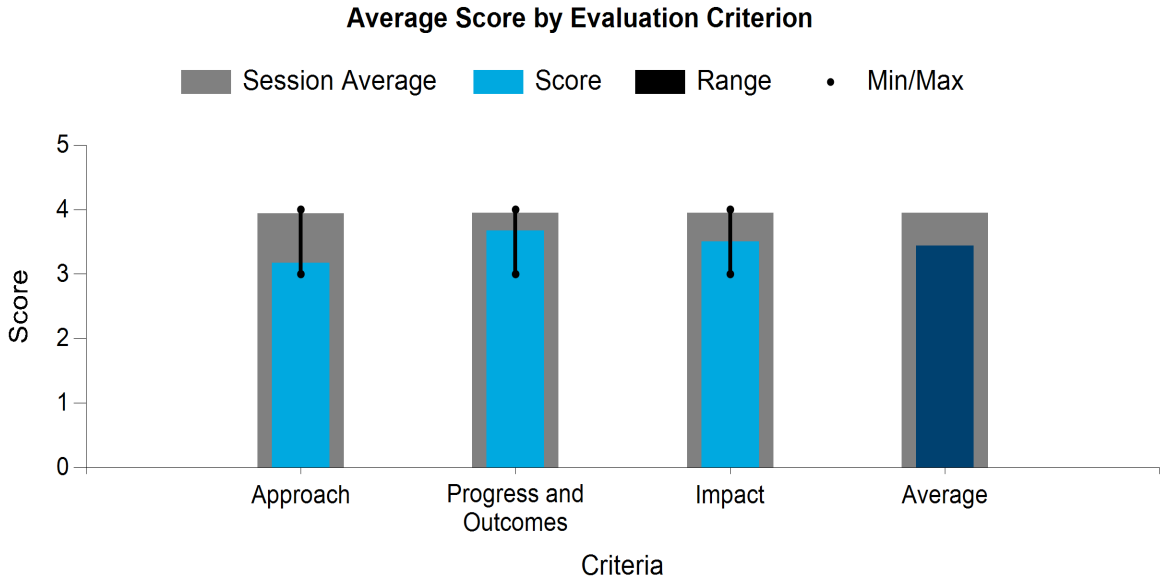
PI RESPONSE TO REVIEWER COMMENTS

- 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, developing tools to aid targeted forest restoration and fire mitigation is a scope that is both timely and likely to be of strong interest to stakeholders as wildfires pose greater threats to society and are being exacerbated by climate change. A decision support tool is vital for weighing the trade-offs of biomass harvests for wildfire reduction. Our management scenarios currently span a range from minimal intervention to full intervention through varying levels of prescribed fire, wildland fire use, restorative thinning, and commercial thinning. We appreciate the comment that we should simulate a more intensive harvest. Although it may not have been clear in our presentation, the current scenarios do just that. We are applying heavy commercial harvest in parts of the landscape where this is likely to occur. We are also actively working with stakeholders on the management side (federal, state, and tribal) to develop scenarios that align with their anticipated management activities (in terms of treatment type and treatment rate). Given the computational resources required to run the model, we are not able to run scenarios that are too far departed from reality. We currently assume that biomass for energy is only associated with commercial activities; however, as increased public funding is being directed toward fuel reduction programs to mitigate the risk of extreme wildfires, there will likely be opportunities for additional biomass for energy beyond commercial activities. For example, the USFS Central Washington Initiative, encompassing most of the project study area, is an all-hands, all-lands effort to implement the national Wildfire Crisis Strategy, the Bipartisan Infrastructure Law, and Washington House Bill 1168 to promote resilient landscapes and resilient communities that are adapted to changing wildfire conditions through targeted fuels reduction. A significant portion of our outreach has been through close collaboration with academic researchers, nongovernmental organizations (NGOs), and local, state, and federal agencies (including policymakers) through follow-on funding external to BETO. These collaborations provide not only provide a means of technology transfer from our BETO project to application but also important information on the needs and constraints of a broad range of land managers, stakeholders, and policymakers to develop scenarios that align with their anticipated management activities. Our recently funded collaboration with LanzaTech will provide a valuable industry perspective as well. As part of our BETO annual operating plan, we specify priority outreach activities for the upcoming year and provide outcomes in our quarterly progress reports. Our engagement with Blue Forest continues as they grow their Forest Resilience Bond footprint in eastern Washington state. The Forest Resilience Bond funds the upfront costs of restoration that are covered by returns from fiber recovery. The strategies we are advised (by Blue Forest) are financially viable because the avoided costs outweigh the restoration costs. As the total forest biomass calculations and trade-offs are better understood, our work with a range of stakeholders will continue to incorporate these values and improve our understanding of how these values trade off with others in management scenarios via the decision support models. Already, we have begun developing management-grade tools from the research findings that can be incorporated into land management planning and decision making. A first such investment by the Washington state Department of Natural Resources has already occurred, and we have an expectation of continued interest and support in this area.

MAXIMIZING CO-BENEFITS OF CARBON REMOVAL AND SUSTAINABLE AVIATION FUELS PRODUCTION

Lawrence Livermore National Laboratory

WBS:	4.1.1.80
Presenter(s):	Wenqin Li
Project Start Date:	10/01/2022
Planned Project End Date:	09/30/2025
Total Funding:	$450,000



COMMENTS

- Based on the initial TEA and LCA, the researchers have identified bioenergy CO_2 capture technology that seems to work well theoretically. The next step of conducting more detailed process design and modeling makes sense generally. And the project is focused on SAF, giving it a chance to deliver insights of significant impact.

  The critical element that seems to be missing from the current approach is consideration of the practical technical and economic barriers. This project has demonstrated on paper that carbon-neutral corn ethanol should be economical under currently available incentives. But, as discussed in the Q&A, significant technological risk remains in areas such as carbon supply chain logistics, retrofitting downtime, and the availability of RNG. I have no doubt that the researchers can model a process design that should work out from a theoretical TEA and LCA perspective in this next phase. But what will be just as valuable, if not more so, is if they can model the technological risks of project failure that a plant constructor would face, quantify those technical risks and the associated economic risks, and compare that to what investors might be willing to bear.

  This and other projects have demonstrated that ethanol with carbon capture should be feasible from a technical perspective and that it should be possible economically. But, to date, that has not occurred, and

there are real technological and financial difficulties that have prevented it. What is sorely needed along with process modeling, TEA modeling, and LCA modeling is an understanding of these risks and an assessment of where they are greatest. This type of assessment does not appear in the current description of the research plan.

- Thank you for the opportunity to review the project Maximizing Co-Benefits of Carbon Removal and Sustainable Aviation Fuels Production. The project is well aligned with BETO achieving their goals given its focus on SAF. The project showcases the advance of science and innovation through multi-pathway research and the incorporation of uncertainty, which is commendable. I appreciate that policies and their interactions were investigated, and costs were incorporated in the analysis. The project's risk identification and mitigation strategies are well outlined, and the advisory board and DEI were well considered. Despite some issues with the suitability of strategies given the small economies of scale, the project shows great ambition and progress toward its goals. Two publications and collaborations with other research groups also indicate significant impact. Discussions with industry could also help in identifying a feasible project size.

- With an increased focus on net-zero targets, this project is both timely and relevant. This seems to be very close to the design of the NZTT project but with a greater emphasis on negative carbon intensity pathways and a spatially explicit analysis. Because the two projects are coordinating, there is less risk of redundancy. This project also draws on other models in the portfolio to develop TEA and LCA expertise to inform the project design and model emissions reductions. There is immediate policy relevance, as indicated by the potential value of LCFS and 45Q tax credits.

  I have concerns similar to those for the NZTT project. In contrast to most other projects in this technology area, this work appears to be largely focused on incremental changes and benefits for existing, commercialized technologies (at least based on the initial progress) rather than the wastes or cellulosic energy crops emphasized in BETO's mission; however, this project manages that risk by focusing on a small-scale biomass gasification project, which would align with many feedstocks emphasized in other DMA projects.

- This project seeks to quantify the technical and economic potential of multiple, diverse bioeconomy pathways that draw down carbon dioxide from the atmosphere. The project partners acknowledge that CO_2, biopolymer, wood products, and biochar have different projected end states and wide bounds of uncertainty, and some of this uncertainty seems worth exploring in greater detail.

  For example, they argue that corn ethanol could be considered carbon-negative, but does the model account for LUC for conversion for the expansion of corn ethanol and the increased inputs/fertilizer of that converted land?

  I am very curious to see if their plans to see if a small-scale biorefinery with carbon capture could be both economically and practically feasible. Presently, it is not entirely clear what small-scale biorefining could look like and what the implications would be. This project's focus on distributed, decentralized, small-scale production is an interesting approach. I wonder how small they consider small-scale. Can bioenergy with CCS or biomass carbon removal and storage work on a small scale?

- The focus of this project is excellent as much near-term progress can be made on decarbonizing Tier 1 biofuels. Please include industry feedback on these decisions and evaluations.

  Reducing carbon intensity in feedstock production through the adoption of low-carbon and regenerative practices is an important potential path toward net-neutral corn ethanol production and should be considered in future modeling.

It is currently unclear how engaged industry is in adopting these outlined opportunities. It would be helpful to document industry conversations and evaluate the interest in each aspect of decarbonization outlined. For example, how many ethanol facilities are currently under contract for CCS given the current price points of both the Inflation Reduction Act incentive and LCFS.

- This project is unique in the sense that it is looking at more readily implementable strategies for decarbonization. Although this project does not involve innovative technologies, it has the potential for substantial impacts in the near future. For example, given the large number of 1G corn ethanol biorefineries in the United States, switching to oxyfuel boiler (a mature technology) might be more easily accepted by the industry. Similarly, analyzing the economics of a small-scale biorefinery-based CCS system, while not having the economies of scale as a 2,000-tons-per-day (TPD) cellulosic ethanol plant, could be more relevant to near-term deployment. The team solicited certain inputs from industry, but more efforts can be made (e.g., are current corn ethanol plants on board to switch to oxyfuel boiler? If not, what needs to be done to get them on board?).

  One limitation of the presented results is that uncertainties are completely missing in the results (a few scenarios are considered, but they are far from enough), and the presenter acknowledged that assumptions were made in the analyses that might be debatable. Future work should address the main sources and the level of uncertainties.

PI RESPONSE TO REVIEWER COMMENTS

- Assessing the risks associated with integrating carbon capture with fermentation to ethanol plants may not perfectly align with the scope of our current project; however, we recognize the importance of understanding industry concerns and risks, and we have plans to continue interacting with more biorefineries to gather further insights. By engaging with biorefineries and incorporating their concerns and risks into our modeling design and writings, we are ensuring that our research remains relevant and valuable to the industry. This iterative approach of learning from industry stakeholders and incorporating their feedback will contribute to provide a more comprehensive and practical understanding of the challenges and opportunities associated with carbon capture integration in biorefineries. A 2,000-TPD-scale biorefinery is great to achieve higher economic viability; however, it is important to consider the potential challenges associated with selecting refinery locations, such as biomass density, logistics, and traffic considerations. In light of these factors, we propose two representative scenarios with smaller-scale biorefineries: 1,000 TPD and 500 TPD on a wet basis. These choices were made in consultation with companies in the gasification field considering practical considerations and the ability to maintain economic value. By focusing on these smaller-scale refinery scenarios, our research aims to address the challenges of biomass logistics and other constraints while still ensuring economic feasibility.

  Our project aims to conduct an in-depth design and analysis specifically targeting the integration of carbon capture and sequestration in a small-scale gasification-to-SAF refinery. By focusing on this specific context, we aim to maximize the potential for carbon removal by capturing both post-combustion flue gas and high-purity CO_2 from syngas cleanup. One significant aspect of our research is recognizing that the integration of carbon capture on biorefineries is often assumed to follow the design and cost estimation of large-scale power plant capture systems; however, we have identified that at smaller scales, the design and costs of the capture systems could significantly differ from those at larger scales. Therefore, our project proposes a bottom-up study approach to estimate the costs associated with carbon capture in small-scale refineries accounting for the unique considerations and potential differences compared to large-scale capture systems. Note that while the previous project focused on maximizing carbon removal potential in the existing corn ethanol industry (which concluded at the beginning of this fiscal year), our new proposed project (commencing this fiscal year) will shift its focus to the gasification-to-SAF system. This shift allows for the utilization of a wide variety of cellulosic biomass, aligning with the emphasis on such biomass in BETO's mission.

We appreciate your clarification on the consideration of LUC emissions for corn feedstock in our LCA. It is indeed a critical factor that affects the carbon neutrality of corn ethanol as the significant LUC emissions impose a penalty on its overall carbon footprint. In light of this, our research proposes the integration of carbon capture technologies, including high-purity CO_2 capture during fermentation and low-concentration, post-combustion capture. Additionally, we explore the synergistic effects of renewable electricity and RNG integration. Theoretically, these measures have the potential to reduce the carbon intensity of the process to achieve net-zero or even negative emissions. Regarding the small-scale refinery aspect, we have proactively engaged with various biorefinery industry stakeholders to determine a feasible and practical size for small-scale operations. Through our outreach efforts, we identified two representative scenarios: a biorefinery scale of 1,000 TPD and 500 TPD on a wet basis. These scale choices were determined after consulting companies in the gasification field. While it is common for TEA studies to primarily focus on larger scales, such as 2,000 TPD, due to the economic advantages of scale, we acknowledge the challenges associated with large-scale biorefineries, such as biomass logistics and high risks of capital investment; therefore, we believe that investigating the business potential of smaller-scale biorefineries holds significant value.

We deeply appreciate the insightful feedback received from industry stakeholders, and we are actively engaged in ongoing dialogues with them. These discussions provide us with a comprehensive understanding of their challenges, practical concerns, and ideas for potential collaborations aimed at accelerating the deployment of the bioeconomy. We believe that the proposed study on small-scale biorefinery capture is a compelling demonstration of our commitment to conducting research that directly benefits the industry. Given the limited number of large-scale biorefineries currently in operation—primarily due to practical challenges in the biomass supply chain, substantial financial investments, and uncertainties surrounding incentives—we have recognized the increasing trend of smaller-scale refinery startups in the field; therefore, our research aims to assess the technical feasibility of integrating carbon capture and sequestration systems into these smaller-scale refineries. By doing so, we hope to provide our industry partners with valuable insights into the economic investment and potential returns associated with carbon removal in their small-scale refineries. Regarding the uncertainties surrounding the analysis, we have conducted an in-depth investigation of various key parameters and have included a sensitivity study in the published paper. We have taken note of your suggestion and will continue to incorporate uncertainty quantifications throughout our system analysis. By doing so, we aim to provide a comprehensive assessment that accounts for the potential variations and uncertainties associated with the studied variables.

ECOSYSTEM SERVICES ENTREPRENEURSHIP TECHNICAL ASSISTANCE

Argonne National Laboratory

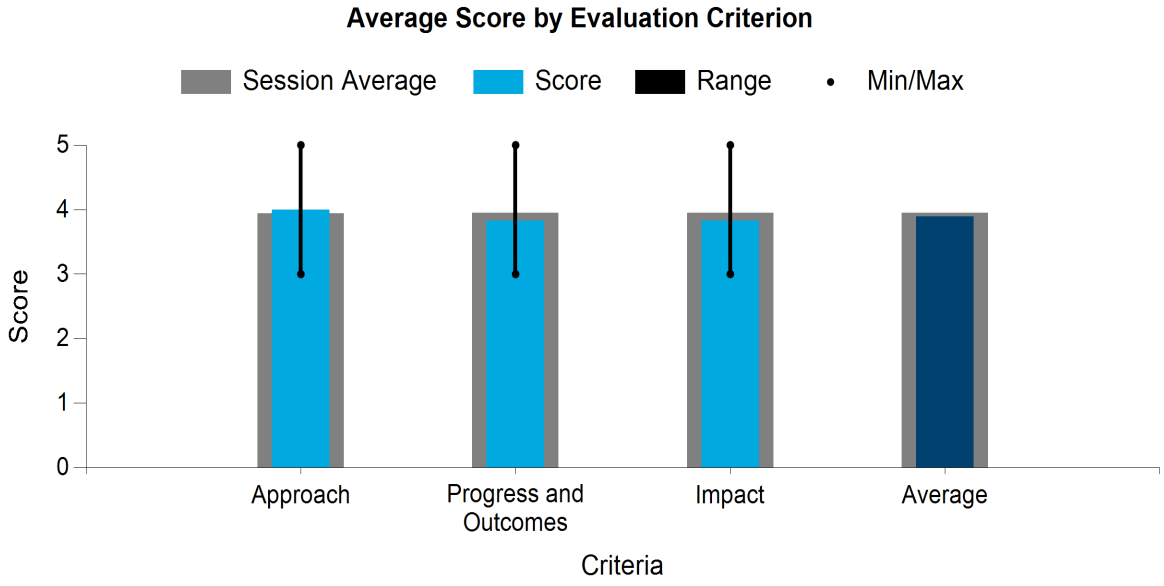
PROJECT DESCRIPTION

WBS:	4.1.2.11
Presenter(s):	John Quinn
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$1,350,000

As a significant outreach effort, ANL and our nonprofit partner, American Farmland Trust (AFT), are collaborating to provide technical assistance to farmers in matters related to bioenergy crops. Specifically, we are reaching out to farmers/landowners through surveys, listening sessions, public events, and the formation of the Midwest Bioenergy Crop Coalition. We are educating participants on perennial bioenergy crops (crop types, equipment needs, and the ecosystem services they provide, including carbon sequestration) and on approaches for using biomass to generate on-farm energy needs in place of propane in off-grid locations. In addition, we are demonstrating our Scaling Up PERennial Bioenergy Economics and Ecosystem Services Tool (SUPERBEEST) and its use assisting in decision making for the optimal placement of perennials in marginal farmland subfields and the net economic estimate of strategically located perennials in place of row crops.

The connections that AFT has with Illinois farmers have been invaluable in reaching a large number of stakeholders through our outreach events. Women landowners were the invitees to one listening session because women are generally receptive to matters related to conservation agriculture. In addition to farmers, we have specifically met with members of the Association of Illinois Soil and Water Conservation Districts and with industry representatives (e.g., wood chip, carbon credits, biochar, biofuels).

Response to the technical assistance project has been strongly favorable, including comments on SUPERBEEST. Suggestions for changes or additions to SUPERBEEST are added to our list of intended refinements. With AFT, we will continue to work toward offering technical assistance, gathering input on the attractiveness of or barriers against perennials, and informing BETO of our findings. Altogether, this project's diverse team and partnership aims to explore avenues for the adoption of perennials for biomass, reducing the cost to produce biofuels while assisting underserved rural communities and improving environmental conditions.



COMMENTS

- This is an excellent project. Direct outreach to potential growers of biomass crops is critical, as is documenting their perspectives and preferences. This project is doing that important work. The use of SUPERBEEST to assist decision making in crop planting also appears highly promising. I hope to see this project continue and expand beyond Illinois.

- Thank you for the opportunity to review the Ecosystem Services Entrepreneurship Technical Assistance project for farmers in Illinois. The project is well aligned with BETO's goals and has the potential to support disadvantaged rural communities. The efforts promoting and disseminating the SUPERBEEST framework are also commendable. It seems the project has made good progress toward its goals and has received positive feedback both for the modeling tool and with community outreach. It would be helpful to explore ways to target disadvantaged individuals directly rather than just reaching out to landowners. Also, obtaining characteristics of survey respondents—such as finance, farm size, type, age, ownership, and land characteristics—can aid in understanding the heterogeneity in decision making. Last, there may be benefits of collaborating with additional partner agencies or groups that engage with Illinois farmers to gain a broader perspective.

- Projects like this are critical to the success of BETO's wider mission because it is important to translate the theoretical benefits demonstrated by TEAs and LCAs into practical action. Because the uptake of some feedstocks and cropping practices has struggled in practice, it is very important to solicit perspectives from industry and farmers to understand the disconnect between theory and practice. This project could go further to understand farmers' perspectives and develop a more comprehensive assessment of their opinions. For example, the surveys conducted so far have not yet reached very many farmers, and it is insufficient to break down into meaningful subgroups. Further, some questions/answers are vague (e.g., on-farm energy) and may not be giving meaningful results. I suggest expanding the surveys to reach a wider audience of farmers and, if possible, additional research to measure and observe farming practices to better understand stated versus revealed preferences in these groups.

- The goal of this project was to provide farm holders—in particular, disadvantaged ones—the opportunity to be valued stakeholders in a bioeconomy that leverages marginal land for the creation of biomass and ecosystem services. The project team provided technical assistance for switchgrass varieties, miscanthus,

mixed prairie grasses, energy sorghum, and short-rotation woody crops, particularly on economically and/or environmentally marginal farmland. A related goal was to provide on-farm energy independence.

I was very curious to know more about how the concept of marginality was defined and used by different groups. It looks like the scale of cumulative marginalities (slide 5) focused on biophysical factors, but there was also a survey of landowners that indicated that 54% of respondents identified having marginal lands on their farms. How do farmer perceptions of marginal lands match with biophysical characteristics? How do particular land use legacies affect marginality? Is there a way to account for the past when modeling current and future conditions?

It sounds like the project team is considering a related topic for future research. They ask: Do lower income levels in some rural areas relate to the prevalence of marginal soil and therefore an optimal place for perennials and a biorefinery? This would be an interesting direction for future research to look at how land use histories shape current conditions both in terms of degraded/marginal land and the socioeconomic status of the farmers on those lands. How did land become degraded or marginal?

The project team is well positioned to put SUPERBEEST to use. They collaborated with AFT and the University of Illinois Urbana-Champaign Extension on an outreach plan for a wide range of stakeholders. This included listening sessions with diverse groups that resulted in useful feedback that the project then incorporated in its project direction. This is an excellent example of an iterative approach to stakeholder engagement in bioenergy R&D.

One important thing the team learned from their outreach and engagement efforts is that farmers consider a lack of biomass buyers to be a primary barrier to the adoption of bioenergy crops. What can be learned from SUPERBEEST about how to develop markets for biofuels?

Farmers were curious about how payments for ecosystem services and nutrient trading schemes may develop. How does the model account for these and other regulatory changes?

How does the project team define disadvantaged farming groups? I like the direction SUPERBEEST is going by adding biorefinery locations and spatial EJ information.

- This is an absolutely crucial program for DOE. Funding for technical assistance not only allows growers to connect modeled outcomes and practice recommendations but also creates a unique feedback opportunity to improve models through capturing implementation challenges.

  The survey associated with this program was a great start but could improve. It is interesting to know that growers perceive they have marginal acres, but this would have been made much stronger if the results were compared to marginal acres identified by SUPERBEEST. This would add insight to either the accuracy or the perceived accuracy of the model—both of which are important to grower practice change. It would be nice to have a summary of all engagement across partnerships, etc.

  I recommend the exploration of USDA partnership for several reasons. First, NRCS offices regularly interact with growers who are seeking information on how to improve marginal land. They are well positioned to use the model and recommend improvements to growers. Second, Conservation Reserve Program applications not funded by the NRCS could potentially be good candidates for planting perennial bioenergy crops on land that did not score high enough to win Conservation Reserve Program money. Finally, an understanding of how crop insurance could reinforce the adoption of perennial crops would be an important inclusion in outreach efforts.

- This is a unique project because it is akin to an extension effort with the main scope providing technical assistance to farmers (on perennial grasses, energy independence, and the use of SUPERBEEST). The project team partnered with a nonprofit organization, a university extension, and ANL to solicit inputs

from farmers on bioenergy issues. The listening sessions and surveys organized by the project team offer valuable insights on topics including farmers' attitudes toward energy independence and concerns over the adoption of bioenergy crops. To a degree, this project seems to be farmers providing assistance to the project team/BETO on how they should prioritize future R&D, demonstration, and deployment efforts to actualize the bioeconomy (e.g., how can we alleviate farmers' concerns over bioenergy feedstock adoption?), which, although different from the stated goal, nonetheless provides helpful insight that should be reviewed by BETO, and such efforts should be encouraged in the future.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the panelists for their attentiveness, their numerous positive comments, and their helpful suggestions on this outreach project. As summarized in the comments, the project focuses on providing a variety of information to—and receiving feedback from—farmers, landowners, and industry representatives on perennial bioenergy crops, on-farm energy independence, and the use SUPERBEEST. This project greatly benefits from our main collaborator, AFT, a nonprofit organization specializing in conservation agriculture with a strong influence in Illinois and throughout the United States. Through our outreach efforts, we are receiving valuable information regarding farmers' perspectives on the topic areas. We are also learning, as noted in the comments, how to recast the questionnaire content to broaden our reach and obtain more detailed, accurate information. As noted in the presentation, we have collaborated with various relevant organizations (University of Illinois Urbana-Champaign Extension, Association of Illinois Soil and Water Conservation Districts, Savannah Institute, Illinois Stewardship Alliance, Sierraview Systems), and we will continue to connect with others to broaden our outreach and obtain numerous perspectives. This will include the USDA NRCS and disadvantaged rural communities identified jointly with AFT. We will target disadvantaged communities coinciding with the marginal lands identified by SUPERBEEST that could have the greatest potential to benefit from bioenergy crop production. We have upcoming events to provide direct technical assistance to farmers, and these will be opportunities for us to gather information on how farmers' perceptions of their own marginal land compares with the results from SUPERBEEST. Preliminary conversations have shown that some farmers may focus solely on crop productivity. SUPERBEEST uses crop productivity in its analysis as well as six other marginalities dealing with soil health and environmental factors. The feedback received from the surveys, individual meetings, webinars, workshops, etc., that have taken place during the last several months has shaped how we will go about providing technical assistance to farmers. They have provided information regarding producers' knowledge of perennial bioenergy crops and on-farm energy production systems as well as what information/guidance producers would like to have before considering the adoption of perennial crops. With this information, we have already started to develop grower guides and personalized production plans to transition into a more applied direction. This includes considerations such as the size, shape, and location of perennial areas within a larger field, a topic that has already been discussed in listening sessions. We are also completing a market analysis to help us understand and eventually incorporate some current policies and market opportunities into SUPERBEEST and other educational materials.

  SUPERBEEST technical development continues under WBS 4.2.2.12, Scaling Up Decarbonization and Sustainability. Insights from this outreach project provide a basis for changes in SUPERBEEST capabilities. As planned, we are adding biorefinery locations to SUPERBEEST to identify potential biomass buyers to drive the conversion of marginal cropland to perennials and overcome a barrier to their adoption. As noted in the comment responses to WBS 4.2.2.12, SUPERBEEST will need to be continually updated in response to changing economic factors pertaining to biomass value and payments for ecosystem services, including aspects such as water quality trading schemes, carbon sequestration, and GHG emissions reductions. The ever-changing governmental and corporate incentives for these key ecosystem services are of great importance to SUPERBEEST's future relevance and usage. Incorporating the presumably favorable crop insurance aspect is a good suggestion for inclusion to complete the economic analysis for farmers. Incorporating spatial EEEJ information in SUPERBEEST

will assist in the project's goal of providing an economically viable, environmentally friendly, and socially equitable alternative to traditional row crops in regions with underperforming farmland and associated relatively low farm income.

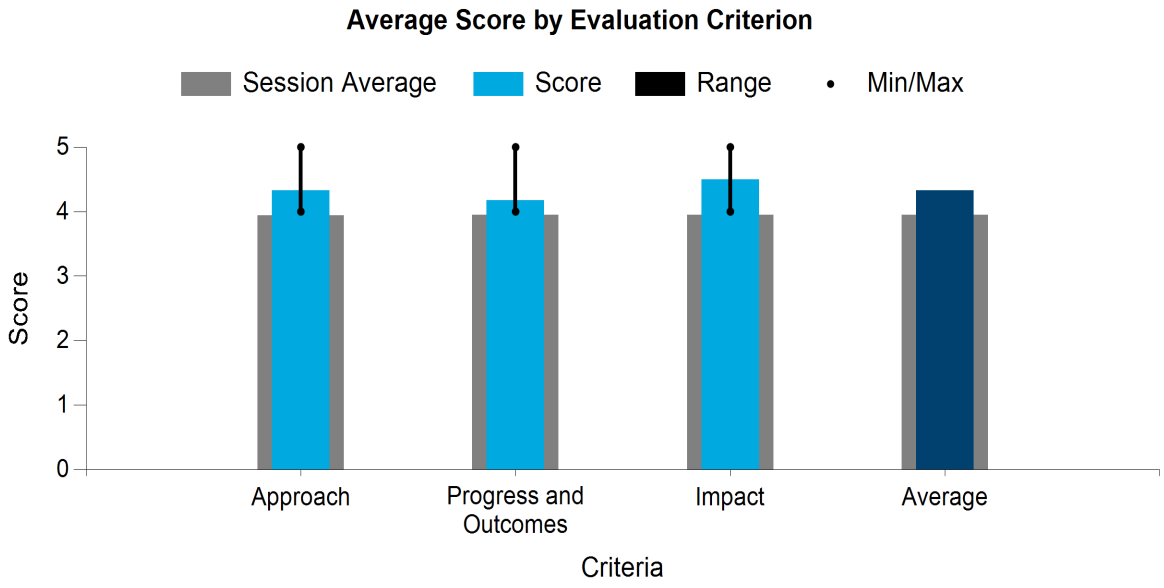
BIOECONOMY SCENARIO ANALYSIS AND MODELING

National Renewable Energy Laboratory

PROJECT DESCRIPTION

WBS:	4.1.2.32
Presenter(s):	Emily Newes
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023
Total Funding:	$1,505,000

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. Results from this project include the identification of opportunities and constraints to industrial development and the quantification of multiple metrics (energy, economic, environmental) to inform 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 by identifying policy actions; (2) improving the industry's understanding of the industry's growth potential under different 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 tool used in this project, the Biomass Scenario Model (BSM), is a publicly available, unique, validated, SOA, award-winning, fourth-generation model of the domestic biofuel 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.



COMMENTS

- Great project. It provides a rigorous systems modeling approach that makes unique contributions to biofuel modeling. The project has clearly had a strong impact as well. The fact that it is frequently used in policy-relevant contexts speaks to this. The project team has done an excellent job of finding use cases for this tool, and I hope to see that continue.

In terms of recent progress, I particularly applaud the linkage with GCAM. This seems to take advantage of the resolution of each framework in complementary ways. I would encourage both modeling teams to use this collaboration as a platform for future work. One significant weakness of BSM when it comes to analyzing SAF is the lack of detailed trade representation. This will be critical to looking at popular near-term SAF feedstocks, such as canola oil. It is understandable that BSM has been domestically focused to date, and I do not see this as a flaw in progress so far. But this is an area where near-term future work should make improvements. Linking to other models like GCAM that already have detailed commodity trade representation could be an elegant solution.

- Thank you for the opportunity to review the Bioeconomy Scenario Analysis and Modeling project. Based on the information provided, the project is well aligned with BETO achieving their goals. I am impressed by the use of system dynamics and the incorporation of inputs from seven BETO models to create a comprehensive model. The plan to include reduced-form representation and a repository of recreatable results is also a positive step forward. While the project lacks economic relationships and the ability to incorporate inventive policies, it has contributed to the EPA's *Third Triennial Report to Congress* and supported analysis of proposed policies in Congress, which demonstrates its real-world impact and impact. Overall, this project is on schedule and has the potential to support stakeholders in identifying bottlenecks and designing bioeconomy strategies.

- BSM is a long-standing DOE tool that has been extensively used and is publicly available. The project addresses a clear need by assessing biomass supply and associated risks across different scenarios and has a well-documented history of use by policymakers. It has newfound relevance with the SAF Grand Challenge and DOE's recent focus on aviation, illustrating how long-term SAF targets could theoretically be met with biomass. In terms of integration with other tools and research areas within DOE, the presentation very clearly communicated the project's purpose and role and how it interacts with other models to avoid redundancy.

  The project does a good job of communicating its risks and the steps taken to stay focused on the core project objectives and identify and fill data gaps when necessary. The model is also regularly validated against historical data to build confidence in the approach. To stay relevant, there is a good track record of adding TEAs of new fuel pathways to match the aims of broader policy goals.

  My primary recommendation would be to demonstrate, or perhaps to more clearly communicate, how the BSM approach aligns with ground truth data on aspects of the bioeconomy on the availability of wastes and residues as well as on expected yields for energy crops. Can this information go through a validation process as well?

- This project aims to encourage the bioenergy industry by providing data-based scenarios that can help guide decision making. The project team has worked with different stakeholder groups, and they have actively worked to contribute to policy formation. The PIs might look to European examples to see how different carbon pricing tools have influenced different types of biofuels overseas. The project has made progress toward addressing the project goals because the integrated assessment model shows the different commercialization potential of different policy choices. This work could be of great use to industry, investors, and policymakers.

- BSM has been a successful and useful model for many years and is highly accurate in forecasting markets with robust historical information. Modeling with data for markets that do not yet exist or have limited performance, such as carbon markets, poses several challenges that can make it difficult to create accurate and reliable models. One main difficulty is the lack of historical data on which to train the model, which is essential for ensuring the model's accuracy. Additionally, without existing markets, it can be challenging to identify the relevant variables to include in the model because the factors that will drive market behavior are not yet known.

To mitigate these challenges, holding stakeholder workshops can be a valuable tool. Eliciting feedback from industry experts and policymakers can help to identify potential market trends and relevant variables that should be considered in the model. These workshops can also help to identify potential biases or assumptions that may need to be challenged in the model development process. Documenting the breadth and depth of these workshops would also be an important measure in communicating the extent to which this mitigating step has been deployed.

- This project is clearly impactful through its collaboration with/support for multiple other modeling efforts and contributions to BETO's missions. The team is forthcoming with the potential limitations of the approach and takes proactive measures to mitigate the risks. The team also places a big emphasis on increasing the accessibility of the models. The model is publicly available and evolves with the current and future needs, the team leverages a variety of data deposit services to keep good records of the data/assumptions used for each analysis, and the team makes efforts to increase the accessibility of the models through visualization, etc. The team is also planning to move to platforms such as R or Python to increase the adoptability of the model. A regional version of the model (Regional BioEconomy Model [RBEM]) has also been developed for a targeted industry or a local area. One suggestion is to tie the scenarios considered in this project to the specific policy decisions it contributes to.

PI RESPONSE TO REVIEWER COMMENTS

- Thank you for the insightful comments on the Bioeconomy Scenario Analysis and Modeling project. We were encouraged by the comments relating to the strengths of the project, and we appreciate the thoughtful suggestions regarding future directions for the project. Here, we respond to those suggestions.

  GCAM, canola, trade, SAF: We are delighted with, and share your enthusiasm for, continued collaboration with the GCAM team, particularly as we create a reduced-form version of BSM. We envision that this reduced-form model will be easier to integrate with models such as GCAM. It will enable us to improve our representation of trade issues around fuels and feedstocks. We are in communication with PNNL and believe that this will make a useful future case study.

  Economic relationships, policies, real-world impact: Thank you for the comments relating to the real-world contribution of this project to policy analysis, including the EPA's *Third Triennial Report to Congress* and analysis of proposed policies for Congress. While the model contains simplified logic of economic drivers and incentives associated with the agricultural system, with bioenergy conversion investments and operations, and with "downstream" operations, the peer review of the model is an opportunity to revisit those relationships. We plan to use a portion of a workshop, planned for August 2023, to review key economic relationships in BSM.

  Alignment of BSM with ground truth data for wastes, residues, and yields: BSM uses data from multiple sources to populate its supply structures for wastes and residues. These sources include inputs from the Policy Analysis Systems Model (POLYSYS) from Oak Ridge National Laboratory (ORNL) (crop residues, forest residues, dedicated energy crop yields), the Biomass Logistics Model from Idaho National Laboratory (INL) (logistics), and available wet waste information from NREL and PNNL. We plan to revisit these data sources and to cross-check the data used in BSM against other sources as part of our FY 2023 scheduled public update to the model.

  Biofuel policy in the United States and European Union: Because the focus of BSM has been on the contiguous United States, we have not directly incorporated international policies. That said, we recognize the importance of international policies and the increased efforts being placed on global decarbonization. This is an area of potential future exploration that we will consider going forward. As for specific policy in the United States, BSM already has representations of many policies either implemented or considered by Congress, and we are currently working on a journal article that will present a review of these policies and how they may influence biofuel production.

Workshops: We agree that workshops are essential as a mechanism to vet and improve model data, model assumptions, and model logic. We have held many workshops during the past 15 years (in 2022, 2016, 2014, 2012, 2010) with varying degrees of public documentation. We are encouraged to hear that workshop documentation will be helpful, and we will be sure to release results from our workshop that will be held in August 2023.

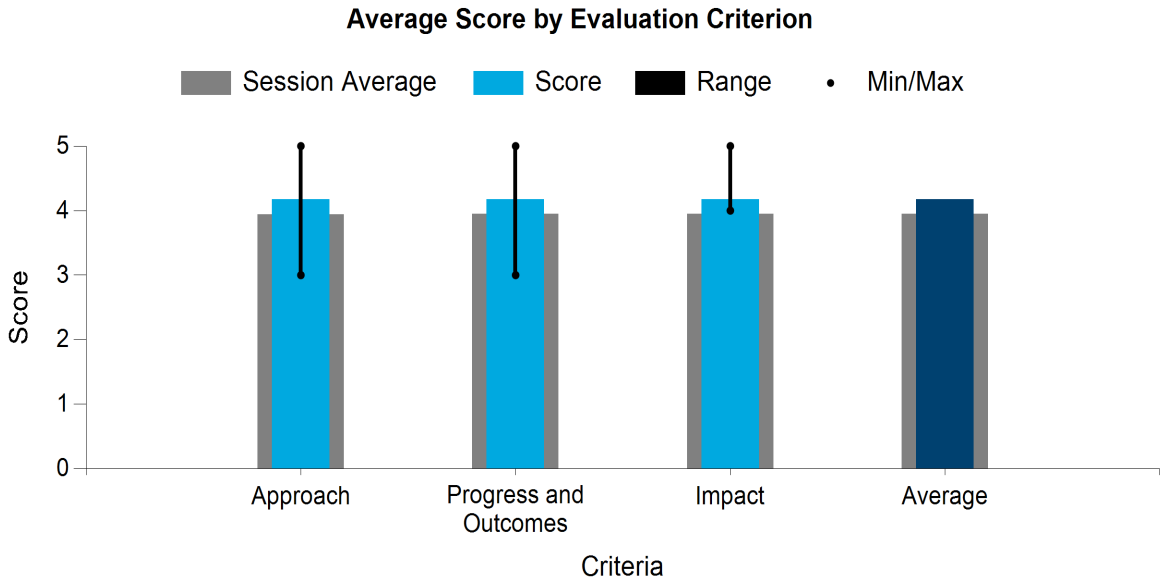
ALTERNATIVE MARINE FUEL PRICING, SUPPLY, AND DEMAND

National Renewable Energy Laboratory

PROJECT DESCRIPTION

WBS:	4.1.2.33
Presenter(s):	Emily Newes
Project Start Date:	10/01/2020
Planned Project End Date:	09/03/2023
Total Funding:	$750,000

The International Maritime Organization low-sulfur fuel rules and GHG-reduction strategy may significantly perturb global refinery operations, impacting the volumes and prices of marine fuel globally and within the United States and incentivizing the transition to alternative fuel use. The goals of this project are to (1) enhance the understanding of how very low-sulfur fuel—primarily fuel oil and diesel—and low-carbon fuel requirements and promising biofuel processes will affect the marine fuel supply chain; (2) explore how these perturbations interact with and impact indicators, such as pricing, number of trips, and demand behavior, along with the potential to meet low-sulfur and low-carbon fuel demand with biofuel supply chains; and (3) merge innovative thinking in the area of marine fuels within the research centers of DOE (NREL) and the U.S. Department of Transportation (The John A. Volpe National Transportation Systems Center (Volpe Center)). These goals will be accomplished through the combination of detailed refinery, marine fuel burn, system dynamics, and geospatially explicit linear programming models.



COMMENTS

- This is an exciting project with substantial potential value for stakeholders. The marine sector is understudied in the bioenergy space. This project fills a significant gap by helping to quantify the financial and environmental impacts that bioenergy could have in this sector. The initial progress on logistical modeling, refinery modeling, and supply chain modeling were all well selected, and progress appears to be solid.

  In general, I think this project is on a good track. But I do have two recommendations: First, the project should integrate vessel idling and hoteling loads into the fuel burn modeling. This will make the tool more valuable to federal, state, and local environmental organizations and communities. Second, the

supply chain modeling tool should be expanded to support the estimation of cosolutions for multiple ports within a given region. For example, the logistical network displayed on slide 17 should ideally also be able to incorporate the needs of other regional ports in the northwest (Tacoma, Portland, etc.).

- Thank you for the opportunity to review the Alternative Marine Fuel Pricing, Supply, and Demand project. This project is well aligned with BETO's goals to develop sustainable and renewable energy sources for marine fuels. The use of a collaborative modeling framework and proprietary data access in the first-of-its-kind analysis with the Volpe Center is impressive. The progress toward goals is impressive, and the project is on schedule. The significance of impact is high (interactions with Maersk Mc-Kinney Moller); however, the potential for the commercialization of this work is low due to the data confidentiality and nature of the research partner. Additional outreach to industry stakeholders, particularly for more fuel use data for additional ports, could be beneficial for the project's future success.

- This project fills a growing need to evaluate biofuels in the marine context as there is growing pressure to address maritime emissions but insufficient understanding of which biofuels to use and where to deploy them. This project nicely addresses those questions by developing a regional analysis for biofuel deployment in the marine sector, focusing on the needs of an individual port and the supply chains necessary to provide it with advanced biofuels. This project used resources from BETO on biomass supply and economics in conjunction with marine sector expertise from the U.S. Department of Transportation on fuel burn and logistics, and the project team showed good coordination and project design to ensure that the results were relevant to key stakeholders, such as the Maritime Administration.

  The progress so far suggests that the analysis is novel—giving the really valuable granular analysis that is necessary to understand how the Port of Seattle could be supplied with regional biomass suitable for coprocessing. One note of caution, however, is that while the data are granular enough to allow for equity impact analysis, the project does seem to imply that that local existing refineries will be used, so this recommendation must be taken with care to ensure that equity concerns are addressed.

- The goal of this project is to develop a tool for decision makers to assess scenarios for marine biofuels.

  The RBEM shows how different variables produce regional impacts, but what about the ways in which particular regions (i.e., particular landscapes and particular communities) impact biofuel production? If the goal is to understand which conditions are necessary and sufficient for investment, it seems that a better understanding of social acceptability and biofuel availability would be relevant. A regional-level analysis, such as the Port of Seattle example, has great potential to examine local socioeconomic and environmental variability.

  The project emphasizes the need for collaboration. The project partners have done a nice job collaborating with other agencies and entities working in this relatively new marine space. How has feedback from different groups been incorporated into the analysis? Specifically, it sounds like feedback from industry representatives indicated that regulatory uncertainty was the biggest barrier to development—how does the model take this into account?

  The project's preliminary results show that 100% of the projected 2040 marine fuel demand at the ports of Seattle and Tacoma could be satisfied with regionally produced biofuels, largely derived from wood residues. Does the model consider competition for feedstocks for other forms of bioenergy (biopower) or other bioproducts (cross-laminated/mass timber, traditional forest products, paper/pulp, etc.)?

  The project proposes eight new biorefineries for the Seattle area. An important next step for this project could be to incorporate EJ mapping tools to assess how these new biorefineries might contribute to or help address energy equity issues. EJ tools could include CEJST or the EPA's EJ tools.

- The intention of this project is strong and clearly impactful with ports and regions like Seattle that have available data to contribute. The focus on marine needs and uses of biofuels is of substantial importance to BETO's mission and requires separate modeling and infrastructure than SAF or even traditional biofuels required.

  There are substantial challenges to scale beyond ports where data on fuel consumption are available, which may limit the applicability of the project if this continues to be an issue.

- This project looks at the hard-to-decarbonize marine sector with specific focuses on select areas. The collaboration between NREL and the Volpe Center has been smooth, and the team has clearly identified potential risks and made plans to mitigate them. Aside from conducting a first-of-its-kind analysis, another impactful outcome from this project is the collaboration with partners on the feasibility study of a green corridor from Seattle to South Korea.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their thoughtful comments and enthusiasm for our project. We hope that the following responses address the major comments raised during the review.

  Fuel burn model: We agree that there are various additions to the model that would greatly enhance its value to stakeholders. An updated version of the fuel burn model will include the characterization of ship operating mode, including accounting for differences in the calculation of fuel burn that occur at berth as well as at anchorage, following the EPA's Port Emissions Inventory Guidance. These modeling improvements will impact fuel usage for future work on auxiliary engines and boilers.

  The Freight and Fuel Transportation Optimization Tool (FTOT): The FTOT modeling tool can easily handle additional ports up to the national scale. When provided with this additional demand data, the tool will adjust its routing solution to maximize the demand fulfilled across all ports in the region while minimizing transportation costs; however, the initial case study focused on the Port of Seattle due to the availability of data on fuel demand at the port; future iterations of the modeling scenarios may include additional ports in the region if fuel demand data can be acquired or if fuel demand at ports can be estimated from the fuel burn model component of this project. We would like additional data from ports on fuel demand that can be used to expand the FTOT supply chain analyses. Proposed future work will address additional ports as well as work more closely with industry and port partners.

  External release of information and engagement: Although the Volpe Center cannot release the data behind the fuel burn model, we can use aggregated data and share the source code used for converting vessel movement and characteristic data into fuel burn. The FTOT model is publicly available. In addition, we can share much of the information from the refinery modeling with the public, but they would need to have a license to the Aspen PIMS software to run the model. There will be published technical reports and journal articles on both topics to disseminate information to a broader audience. In summary, some of the knowledge gained and nonspecific data can be shared with the public. We have already received some feedback on aspects of our project as the fuel burn model approach was discussed with various groups (EPA, Maritime Administration), and their feedback was incorporated into the methodology to align with existing analyses, such as the EPA's National Emissions Inventory Guidance and Port Emissions Inventory Guidance. Future work is intended to address additional ports and to work more closely with industry partners (e.g., refinery owners and port authorities).

  Equity analysis/energy justice: The fuel burn model component is anticipated to support equity analysis. The first step is to complete an inventory of emissions related to current fuel usage, then build scenarios of alternative fuel usage, and finally incorporate dispersion modeling. In terms of FTOT, we can, at a minimum, overlay an equity metric on the outputs of the FTOT scenario runs once finalized to look at how proposed sites and transportation routes intersect with equity emphasis areas/EJ communities as

represented in tools such as CEJST and EJScreen. NREL leads a project for BETO on local air quality and EJ impacts of biorefineries. This project has explored emissions from different conversion processes and could assess changes in emissions with coprocessing and related air quality and EJ impacts. We plan to collaborate with them to assess the potential benefits from refinery coprocessing.

Modeling topics: The analysis to date using the Volpe Center's FTOT focuses on available feedstocks that could be leveraged to supply alternative fuels to the Port of Seattle and the associated transportation costs and emissions with a supply chain based on those feedstocks. Complementary work under this project using NREL's RBEM will take policy constraints and opportunities further into account to assess the potential for deployment in the region. Regulatory uncertainty will be addressed by running a sensitivity analysis around policy timing, duration, and magnitude. Feedstock competition with other possible end uses is not addressed in our current analysis. The currently defined scenarios focus on waste materials not used for primary bioproduct production, but they do not consider potential future competition with other end uses outside of biofuels. FTOT is a scenario exploration and analysis tool, so subsequent analyses representing different levels of competition with other forms of bioenergy can be modeled. In addition, what was presented at the BETO Project Peer Review was an interim analysis; we do not expect the final analysis with techno-economic alignment to propose the same number of biorefineries as was presented. There is a definite risk to modeling because marine data are sparse. Having a fuel demand value at the port is important to define the supply chain; however, if those data are not available, we may be able to estimate a first-order approximation of fuel demand at specific ports from the fuel burn model to facilitate continued expansion of the analyses across different ports and regions.

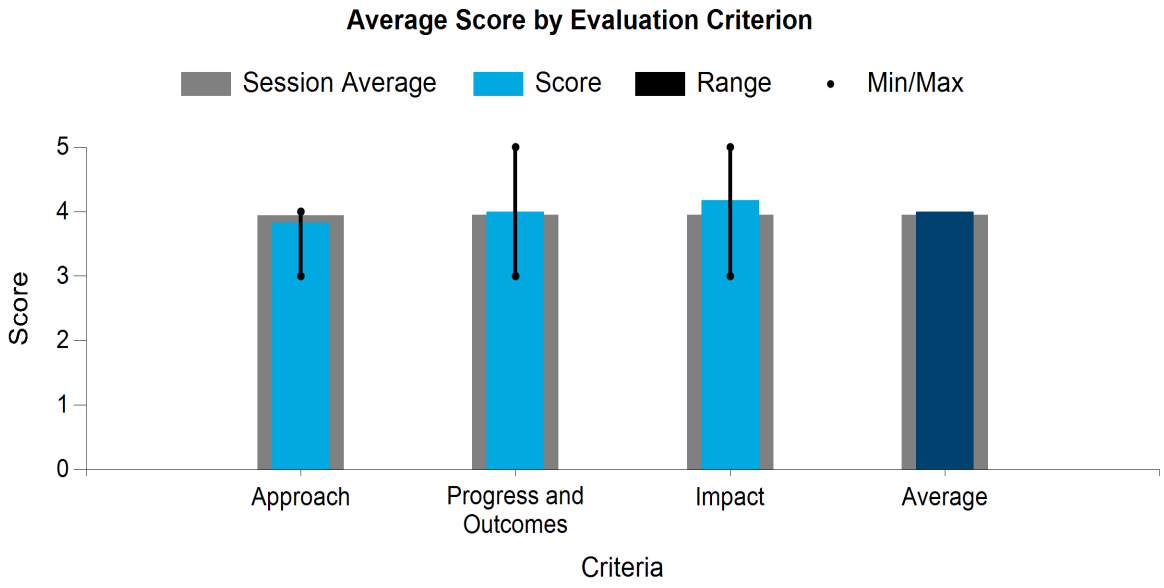
BIOFUELS NATIONAL STRATEGIC BENEFITS ANALYSIS

Oak Ridge National Laboratory

PROJECT DESCRIPTION

WBS:	4.1.2.41
Presenter(s):	Rocio Uria-Martinez
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$750,000

This project contributes to understanding and enhancing the socioeconomic and environmental benefits of bioenergy through economic and policy analysis/modeling of the effect of prices and policy incentives on fuel markets for hard-to-decarbonize transportation sectors, particularly aviation and marine. The analysis pays attention to potential synergies or competition for the use of biomass among different transportation segments while modeling the competition from incumbent petroleum-based fuels. The technical approach builds on the Biofuels National Strategic Benefit Analysis project previously funded by BETO. The market equilibrium model developed for that project (BioTrans) has been expanded and revised to depict the aviation and marine transportation fuel segments. New model features include (1) a new set of feedstocks, conversion pathways, and biofuels; (2) tracking the life cycle GHG emissions for each fuel depicted; and (3) finer spatial disaggregation. Additionally, the analysis approach includes an exploration of the economic equity of model results by linking them to socioeconomic and demographic data. FY 2022 work focused on adding those features and gathering insights from an initial no-policy baseline set of cases. In FY 2023, the policies and incentives affecting the use of biofuels in the aviation and marine sectors will be included in the model. The FY 2024 objective will be to publish the model and results and disseminate them among the target audiences.



COMMENTS

- This is an excellent methodological approach with significant potential to assist stakeholder decision making. I think that the areas of model development in year one of the project were generally well chosen. Overall, this is a worthwhile project, and I look forward to seeing it progress further.

  I do have some specific directions for future development and a couple notes on the results presented to the reviewers.

First, to realize the potential of the model, it will need to endogenously include legacy petroleum systems. Improving energy sector representation in this way would lead to more credible economic and GHG emissions estimates for bioenergy. It would also enable EJ analysis to include impacts on petroleum refining.

Second, biodiesel from waste fats, oils, and greases needs to be included, at least as some kind of aggregate pathway. A substantial share of historical and near-future biodiesel production comes from this pathway, and including it will better reflect the historical baseline.

Finally, a note on the results: The 2020 production volume estimates shown on slides 9 and 10 seem to underestimate the volumes of HEFA-RD and vegetable oil-based fuels in general. It is one thing for a scenario to not find growth from this historical baseline over time. But these fuels seem to simply be missing in the volumes they are currently produced.

- Thank you for the opportunity to review the Biofuels National Strategic Benefits Analysis project. I am pleased to report that this project is well aligned with BETO's goals. The project's approach to understanding and enhancing the socioeconomic and environmental benefits of biofuels is commendable, particularly with regard to modeling the effect of prices and policy incentives on fuel markets for hard-to-decarbonize transportation sectors. The project's progress toward its goals is commendable, including the work on policy and incentives and its state-level supply aggregation from BT16. The impact of the project, including the public DOE BETO Biofuels TEA Database and outreach to industry, is also significant. The project appears to be on schedule, and appropriate risk strategies, such as collaboration and check-ins with PIs and advanced analyses R&D, have been employed. Understanding the constraints of relying on BT16 inputs should be explored, particularly with scenarios that are likely to have large price signals or cause LUC, extensification/intensification, or incentivize the adoption of conservation practices.

- This project very nicely expanded and improved upon an existing model to improve its relevance and focus on specific interest areas for BETO. Particularly given some 2021 feedback that this project did not have a clear target audience, I think that the progress since 2021 has addressed those concerns. The updates make the model well suited to evaluate the SAF Grand Challenge, its impact on SAF production, and the associated economic and equity impacts. In particular, the updated BioTrans can assess the policy implications of SAF deployment in response to different policy designs, but, critically, it can inform the economic and equity implications of SAF deployment. Though the key output of this project is a model, it is not clear if the model will be publicly available, despite its obvious utility.

- I also think it is important to highlight that this project is unique in tackling the cross-sectoral pressures of competing biomass demand for transportation, which is critical for policy design but was not addressed much in the other projects. Particularly given the technology changes across sectors (e.g., electrification in light-duty vehicles), sector-specific policies (e.g., sulfur limits in marine), blending limits, and resource-constrained sources of biomass, assessing how these different transport sectors interact is critical for informing policy design.

- The goal of this project is to understand and enhance the socioeconomic and environmental benefits of biofuels through modeling the effect of prices and policy incentives on fuel markets for hard-to-decarbonize transportation sectors. It is good that this project is now working to account for socioeconomic as well as environmental benefits, and it is also good to consider the distribution of socioeconomic and environmental burdens. This focus on potential burdens as well as potential benefits will be a more nuanced and potentially comprehensive way to think about equity issues.

  That said, the project partners state that land allocation decisions are exogenous to the model. That is a major limitation when thinking about equity issues.

Also, to get at these equity issues, the project team decided to change the spatial units from census divisions to states. Most equity analyses try to get as granular as the data will allow, and census track level-data are becoming more common for this type of analysis. Breaking the data down even further in this way could be an important next step for this project. It appears that a past reviewer suggested scaling up as a means for national-level policy analysis, but for the new equity indicators, scaling up would obscure important nuances. Is there a way to do both?

The project found that 37% of herbaceous energy crops come from economically disadvantaged communities. What are the policy implications of this? What does the model tell us about how to incentivize the benefits of bioenergy development without creating burdens? The project seeks to find which communities could especially benefit from workforce development/financial incentives to participate in the SAF industry as biomass feedstock providers. Are these the same communities that will endure the burden of biorefineries? Who is involved in making these decisions? How do these models address issues of procedural justice? That is, how do the models account for complex decision-making processes?

One goal of the project is to produce maps to visualize disadvantaged counties with potential, economic feedstock supplies. How will they be used? To what extent were representatives of those disadvantaged groups involved in the process of developing this analysis or in discussions of potential uses of the project outputs?

Four states (Texas, Nebraska, Illinois, Iowa) provide 45% of the total biomass feedstock dedicated to biofuel supply in the high oil price with aviation emissions limit scenario in 2050. What are the socioeconomic implications of concentrating production in these four states?

The project identifies other sensitivities, such as biomass use for non-transportation purposes (biopower, bioproducts). This seems to an issue across most bioenergy models, especially for wood-based biofuels. What is the best use of forest residuals and other forms of woody biomass? Does the model account for potential competing uses of feedstocks?

- This project enables granular evaluations of the impact of biofuel policy at the county level. A great example of the usefulness was the evaluation of the potential of herbaceous energy crop production to overlap with disadvantaged communities. A nice step further would be to include other EJ and equity components in that kind of evaluation.

  The spatial distribution of soybean production did not align with current production nor with the supply shed that will feed the new processing capacity coming online in the next 5 years to serve renewable diesel demand. On a related note, the growing seasons and ranges of products are forecasted to change over the next 30 years as a result of climate change. An example is the soybeans being planted farther north in North Dakota every year. The model should consider forecast climate volatility changes in feedstock production, yield, and crop mix if they are not already included.

- The project aims to understand the socioeconomic and environmental implications of biofuels for the hard-to-decarbonize transportation sectors through the BioTrans model, with emphasis on the effects of prices and policy incentives; however, some approaches can be improved. For example, the team shows that there is great potential for disadvantaged communities to grow bioenergy feedstocks for economic growth, but the uncertainty in the profitability from bioenergy feedstock (there is no existing market) may hurt these communities. Future research should consider the opportunity cost of the land and other market factors in the analyses.

  Additionally, the project team is migrating the model to Julia, but the optimization part remains on the General Algebraic Modeling System (GAMS) (commercial software) due to the uncertainty of the open-source solver's performance. The team is encouraged to work with other labs to identify the optimal

language and potentially leverage existing work (e.g., Sandia National Laboratories developed the optimization package Pyomo in Python, http://www.pyomo.org/).

Finally, this project is heavily focused on SAF, but alternative clean fuel sources, such as H_2, should also be considered (if within the scope of BETO).

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their helpful comments. Some suggestions involve expanding the model scope (e.g., including an endogenous representation of petroleum refineries and an endogenous representation of land allocation decisions). We are exploring the possibility of collaborating with NREL on refinery modeling. For land allocation, building a representation of the U.S. agricultural sector is outside the scope of this project; however, some biomass feedstock supply response to biofuel policy incentives can be captured using *Billion-Ton Report* supply data for various biomass price assumptions. Two reviewers pointed out divergences between the simulated and actual activity levels and locations for soybean-based biodiesel production in 2020. The presented simulated results are from a no-policy baseline scenario; therefore, the biodiesel tax credit is not included, which partly explains the lower volume of biodiesel production. Several comments point to the importance of accounting for competing uses of feedstocks. We confirm that the model currently accounts for non-biofuel biomass uses by treating them as exogenous demands based on data from the USDA and U.S. Energy Information Administration. The effect of variations in the volume of these exogenous demands will be considered through scenario analysis. As for the public availability of the model, the goal is to make it public by the end of FY 2024. We appreciate the suggestion to continue exploring open-source solver options to enable users who do not have access to the commercial solver we are currently using to also run BioTrans. We appreciate the feedback regarding the approach developed to discuss EJ implications of biomass supply activities in the BioTrans model runs. We consider that the maps showing the overlap between biomass feedstock supply and economically disadvantaged communities provide useful information, but we also acknowledge that they need to be complemented by analyses of both potential economic and environmental benefits and burdens from activities along the entire biofuel supply chain. Much of that work requires more spatial granularity than what the BioTrans model provides.

OPTIMIZING BIO-JET FUEL BLENDS WITH THE FEEDSTOCK TO FUNCTION TOOL

Lawrence Berkeley National Laboratory

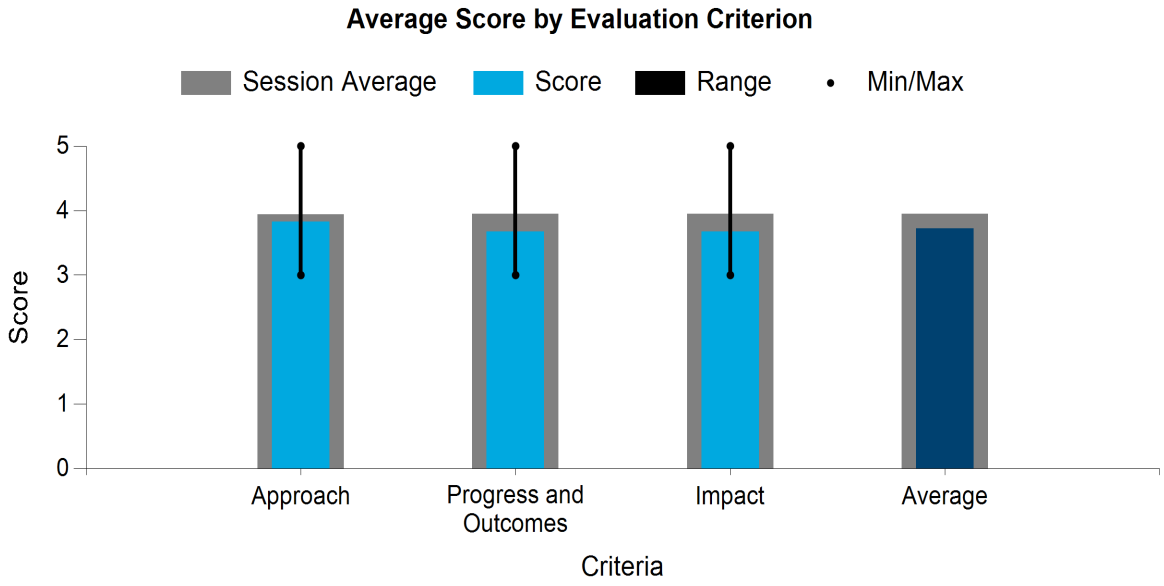
PROJECT DESCRIPTION

WBS:	4.1.3.60
Presenter(s):	Vi Rapp
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$1,275,000

Biological routes offer unparalleled flexibility when developing novel molecules tailored for high-performance applications (e.g., fuels and products). Due to high costs or high-volume requirements, experimental property testing of these molecules is usually conducted years after initial bench-scale experiments are completed. Kinetic models may be used to compute properties if experimental methods are unavailable, but these models take a significant amount of time to develop and require domain expertise. Regardless, neglecting to conduct property testing early in the development cycle can lead to investments spent on scaling up the production of biofuels and bioproducts that do not perform as well as expected.

Feedstock to Function is the first comprehensive web tool that enables scientists and companies to explore viable bio-based fuels and products without spending time and money testing in the lab (feedstock-to-function.lbl.gov). The web tool leverages machine learning and experimental data to predict high-throughput aviation fuel properties of more than 10,000 molecules, and it links to a separate tool for cost and emissions estimates. By predicting properties, costs, benefits, and risks of promising biomass-derived molecules, this open-source tool will facilitate faster, less expensive bioprocess optimization and the scale-up of SAF.

The goal of this project is to support the optimization and deployment of SAF by expanding Feedstock to Function's capabilities for fuel blends. The new capabilities will include (1) a fuel-blend property prediction model that includes fossil-based jet fuels blended with bio-derived molecules and (2) a fuel-blend design feature that enables users to identify bio-based blends within targeted aviation property values.



COMMENTS

- This project has a well-defined and logical approach, it seems to be exceeding progress benchmarks, and it could have significant impact for stakeholders. I find very little to criticize about this work. I look forward to seeing it progress further.

  One small suggestion: This project seems well placed to develop several EJ-relevant metrics for various fuel blends that could be useful to researchers and other stakeholders. These include estimating the ecotoxicity, sulfur content, and PM emissions associated with different blends. Such information could aid the selection of specific blends in the future.

- Thank you for the opportunity to review the Optimizing Bio-Jet Fuel Blends with the Feedstock to Function Tool project. I am pleased to report that this project is well aligned with BETO's goals given the SAF focus. The project's approach to developing the first comprehensive web tool that predicts promising molecule properties and evaluates the costs, benefits, and risks for bioprocess optimization, certification, and scale-up is impressive. The project's use of a machine learning approach and diverse optimization methods is also innovative. The project has made good progress toward its goals, including surpassing the fuel-blend property prediction model's ability to predict properties of fuel blends at different blend ratios to within 15% of published experimental values. The project appears to be on schedule and could benefit from improved model access and impact metrics. As with the other LBNL tools, the reviewers were unable to access and assess the tools directly. Additionally, there was no available information on who or how many users have been utilizing the tool. Future efforts to gauge the effectiveness of the outreach activities would be helpful in gauging the project impact.

- Due to the relatively narrow scope of this project and its focus on predicting molecules, it is difficult to compare it to the bulk of the projects within this technology area. This is very much at the frontier of feedstock selection, long before the implications of developing LCAs and TEAs or modeling the broader bioeconomy come into play. This project appears to be well designed and managed and is making meaningful progress relative to its goal. The web tool format should be very accessible and easy to use for its end audience, and it could be a good candidate for posting on KDF or another easily accessible portal. The audience and potential impact of this tool are readily apparent, and it clearly addresses a stakeholder need by de-risking R&D for SAF.

- This project acknowledges that the development of SAFs is limited by significant technical, social, and regulatory barriers. To address these issues, the project team developed the first comprehensive web tool, Feedstock to Function, that predicts promising molecule properties and evaluates the costs, benefits, and risks for faster, less expensive bioprocess optimization, certification, and scale-up.

- This seems to have great impact as a potential tool that could be of use to a range of users. Who has been the primary audience for this web tool—industry, investors, researchers? What kind of feedback has been received from users, and how has that feedback been incorporated into more recent iterations of the web tool?

- The availability, accessibility, and accuracy of this tool allows for experimentation, R&D, and innovation for biofuel blends. The project has successfully surpassed its error target and appears to be further than expected in accuracy. Having a free, responsive web tool strongly achieves the goal of availability. It is difficult to judge the accessibility because measurements on users and use is not presented. If they are not being collected, it is important to understand the number of unique users, page views, user queries, or other quantifiable actions, user demographics, and customer satisfaction scores.

  Because information dissemination is a stated goal of the project, it is also important to set measurable goals on what it would mean to achieve this bar.

- This is a straightforward project that aims to develop a machine learning-based model to predict the properties for fuel blends. It also interacts with the BioC2G model and is available on the web. The accuracy of the model is high, although comparisons to alternative methods (e.g., weighted average of individual pure compounds) would be able to further support this. Because this is a machine learning model, the integration of mechanistic insights could be helpful in understanding and improving the trained model.

  Additionally, it would be good to have experimental data for validation (could just validate for the most promising blends) and also work with industry partners on how this can be used in developing fuels that comply with ASTM standards.

PI RESPONSE TO REVIEWER COMMENTS

- Thank you so much for the feedback and comments from all the reviewers. We, too, are excited about the prospects and potential of this tool. We agree about the potential for developing EJ-relevant metrics, and we will explore options for predicting additional metrics, such as ecotoxicity, sulfur content, and PM emissions associated with different blends. We also agree about tracking the tool use to better understand outreach effectiveness and impact. We have recorded the number of users and just started tracking how frequently they use the tool. We really appreciate the suggestion to post the tool on KDF or another easily accessible portal, and we will look into this option. Also, to clarify, the tool predicts properties of individual molecules and blends of molecules. It is also connected to a lightweight LCA/TEA tool to support initial feedstock selection and explore scale-up options. The primary audiences for this web tool are industry and researchers. So far, the feedback has been positive, and it has helped guide user interface and property predictions. For example, researchers have requested that we expand property prediction to include viscosity and density, so we identified reliable experimental data sources for these properties and developed new models. Additionally, we received a request to search for molecules using specific property ranges instead of molecule name or Chemical Abstracts Service number, and the tool was updated accordingly. We also expect to solicit feedback for the blend design tool after the first release to better meet users' needs. We do collect information about the number of unique users, and we have just started logging page views, time on pages, and queries. Demographics are inferred by email address. Adding a satisfaction score and feedback form is a great suggestion, and we will explore options for adding this to the tool. We will also consider reasonable metrics and goals to use with the satisfaction and feedback data. Experimental data are used for developing the blend prediction tool and validating the predictions. We also plan to collect more experimental data for further validation. Additionally, we aim to integrate mechanistic insights and model overviews after we have finalized the models and looked more at how the Fourier transform infrared spectra features are weighted for property prediction. We appreciate the suggestion about working with industry and exploring how this tool could be used to support fuel development to comply with ASTM standards.

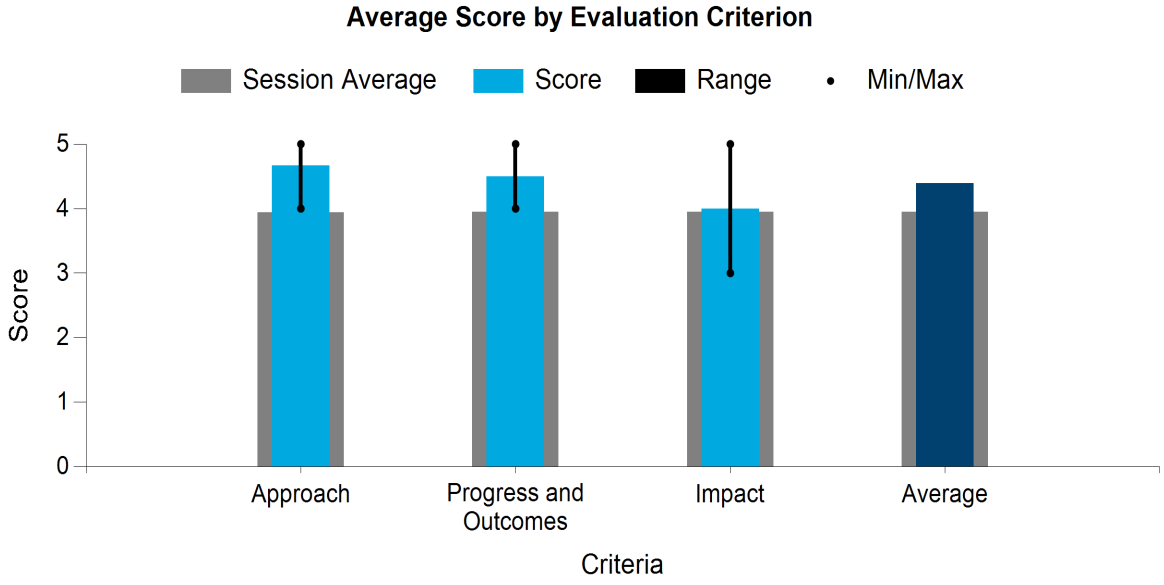
BIOC2G MODEL FOR RAPID, AGILE ASSESSMENT OF BIOFUEL AND CO-PRODUCT ROUTES

Lawrence Berkeley National Laboratory

PROJECT DESCRIPTION

WBS:	4.1.3.61
Presenter(s):	Corinne Scown
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$1,200,000

The objective of this project is to make rigorous TEA and LCA of biorefinery technologies accessible, flexible, and transparent to a wide range of researchers and industry decision makers. The current project substantially expands the scope and capabilities of BioC2G in response to an increasing emphasis on biojet fuels, net carbon-negative bioenergy, the utilization of waste feedstocks, and EJ. The web-based model has three primary components: (1) a geospatial biorefinery siting and resource filtering tool that leverages a combination of county-level biomass availability projections with location-specific and fine-resolution satellite data to provide detailed feedstock availability across the entire United States; (2) a Python-based process model that enables users to adjust a wide variety of feedstock, scale, and operating conditions to produce customized cost, mass, and energy balance results for different bio-based diesel and jet fuel blendstocks; and (3) a physical units-based input-output model for translating feedstock inputs and biorefinery mass/energy balances into cradle-to-gate environmental metrics, including life cycle GHG emissions. Users to date have included researchers, consultants, bioenergy production companies, venture capitalists seeking to evaluate new projects, and startups seeking basic information on key cost and emissions drivers. The model is publicly available at lead.jbei.org.



COMMENTS

- I found this to be an excellent project. The goal of democratizing both the data and assessment capabilities for biofuel economic analysis and LCA is an outstanding one, and I am happy to see BETO supporting this work. Progress to date appears very strong, and the potential impact of the tool is quite large given the significant potential user base.

One suggestion I have for an area of future work would be to develop methods for characterizing the uncertainty in results. Both LCA and TEA carry inherent uncertainty that nonexperts in particular may not be aware of. Because this tool is designed to be public-facing, it is all the more important to characterize what is uncertain. I strongly encourage the project team to consider how this information can be communicated to users through data visualizations and other means.

- Thank you for the opportunity to review the Bio-C2G Model for Rapid, Agile Assessment of Biofuel and Co-Product Routes. This project is well aligned with BETO achieving its goals. The democratization of feedstock/site assessment, TEA, and LCA through web-based tools is a highlight of this project, and the downscaled results leveraging satellite data are impressive. The project has employed risk identification and mitigation strategies well and has integrated local impacts and disadvantaged community indicators, demonstrating a commitment to DEI. Although the model is deterministic and does not incorporate parameter uncertainty, the project is on track, and the progress toward the goals is commendable. The commercialization potential of the integrated web tool, along with the good outreach to industry, is significant and shows impact. Also, the flexibility in the tool will broaden its usefulness. Overall, this is an excellent project, and I commend the team's efforts.

  Disclaimer: I have still not gained access to verify the tool's features and performance (after the time period stated on the website). The presentation and the website stresses its accessibility, and I have found the opposite to be the case. During the next review, the team must create a working log-in for reviewers to access and assess the tool if it is claimed to be available.

- This project is an exciting addition to the technology area that draws upon a lot of existing expertise and previous work and makes significant progress in making that work accessible for researchers and the public. Further, it is a very flexible tool that allows users to input their own assumptions to develop analyses that fit their own needs. This project looks to be well run and designed, and it could have a lot of impact for a relatively low level of spending.

  The current, in-progress version of the tool already illustrates the potential of this project, and it offers a robust set of parameters to adjust. It will be helpful to evaluate at a later date when more pathways, particularly those with fewer major uncertainties in their TEAs and that are further from commercialization, are incorporated. To ensure the project's success, it would be helpful to develop a plan to make the tool easier for users to access (for example, could it be prominently featured on the KDF?) and to keep it regularly updated.

- The goal of this project is to democratize feedstock/site assessment, TEA, and LCA through web-based tools to help researchers and startups prioritize efforts and speed up the time to deployment for biofuels and bioproducts. Democratizing information and data in this way is essential in meeting BETO's goals and the deployment of different types of bioenergy technologies.

  The project has harmonized with others where appropriate (*Billion-Ton Report*, GREET, NREL grid scenarios), and a bit more information on what that looked like would make an even stronger case for the collaborative nature of this work.

  The project partners acknowledge that one of the risks involved is that availability does not match on-the-ground experience. To account for this risk, the team proposes to leverage deep-dive feedstock availability analyses in this and complementary projects. What does that feedstock availability analysis look like, and how is that incorporated in the model?

  Slide 7 is very helpful to show different types of feedstocks, end uses, and how they are modeled.

  The model is in a new phase that now includes EJ indicators; this is a very exciting and important direction. But it was not totally clear which variables are included in defining disadvantaged community

status. The project partners are working to see if the EPA's Justice40 indicators of disadvantaged/not disadvantaged work for this application. Are there factors that shape disadvantages that are specific to bioenergy and land/use? The project team is working with other groups to determine what works best for this project.

Will these EJ factors be as accessible to users as the feedstock data? As a tool to help guide the siting of different types of bioenergy facilities, this model could be helpful. It is great to have this on an easily accessible public platform.

County-level data will allow for a granular analysis that will be useful for assessing both feedstock data and EJ indicators.

The project team says that their next steps are to work closely with key stakeholders to design tools and resources that de-risk deployment and ensure that facilities are good neighbors. The team plans to add location-specific information for bioenergy siting on preexisting environmental/health burdens and preexisting resource constraints (e.g., water). This is an excellent direction that attempts to consider how inequities from the past shape current conditions. This future research may shed light on how new bioenergy technologies interact with existing land use and socioeconomic histories. This is a very exciting next step.

As the project team may have already discovered, different EJ indicators and different ways of thinking about EJ can have very different outcomes, so it is good that they are considering which specific considerations might apply to bioenergy siting in this context.

- The approach of this project is excellent. The user interface is readily available and easy to use in a way that creates access to bioenergy data for non-power users of LCA/TEA models. The inclusion of EJ components are valuable and insightful.

  The road map for including location-specific parameters and local impacts will be useful in evaluating and understanding siting externalities.

  A couple of components would improve the impact of this project. Automating user account creation will speed access and usability. The PI should also measure and set goals for tool engagement, including page visits, account creations, tool use, and user demographic information. It is also important to implement user feedback mechanisms and a methodology for collecting a net promoter score to determine the overall satisfaction users have.

  This project should be awarded resources to fully fund the computational requirements for a growing user base with standard requests. While being scrappy is laudable, the tool will likely not achieve much use without standard uptime and responsiveness.

- The project team has done stellar work in making the BETO models more accessible to the public. The web tool is constantly being updated and clearly attracting interest, although the registration process can be made more straightforward (the project team cited security concerns). The team is encouraged to publicize the tool and further broaden its user base as well as collect more experimental data to validate/support the separation strategy tool.

PI RESPONSE TO REVIEWER COMMENTS

- We extend our thanks to the reviewers for their excellent questions during the review as well as the encouraging and constructive written comments. We agree that BioC2G offers unique flexibility and democratized access to feedstock and process simulation data that users can leverage to answer questions about feedstock availability, conversion costs, life cycle GHG emissions, and water use without having deep modeling expertise. Several comments centered around accessibility—namely, that the site requires

new users to create an account before proceeding to use the tool. It has historically been our understanding that this was a cybersecurity requirement based on how we were hosting the site. While creating an account is free and should be fast, we recognize that this is an extra hurdle for new users. In addition to creating guest accounts to avoid future issues in the very near term, we are excited to say that we are planning to eliminate the account creation requirement, ideally within days or weeks. This will ensure accessibility and further expand our impact. In parallel, we will expand the set of user engagement metrics to track, and we will also communicate with BETO management about the possibility of linking to BioC2G from the KDF. Another important point raised by reviewers is the need to continually update feedstock availability in the bioenergy siting portion of the tool. One example of how this might look in the near term is the incorporation of updated manure availability based on a complementary deep-dive analysis that is ongoing at the University of California Berkeley. Another example is the potential inclusion of updated data from the forthcoming updated *Billion-Ton Report* and the *Roads to Removal* report. In all these cases, feedstock availability is either tied to a specific facility (e.g., a confined animal feeding operation or a materials recovery facility) or assigned to a county, at which point we can use satellite land cover data to approximate where it is located within that county (e.g., for crop residues such as corn stover or wheat straw). We provide a detailed table citing all the sources for our feedstock data on the website, with links to the original reports or data sets. Finally, we are glad to hear that the reviewers see value in our planned efforts to incorporate EJ. This is an exciting new direction for us, and we look forward to receiving feedback as these features and data sets become publicly available.

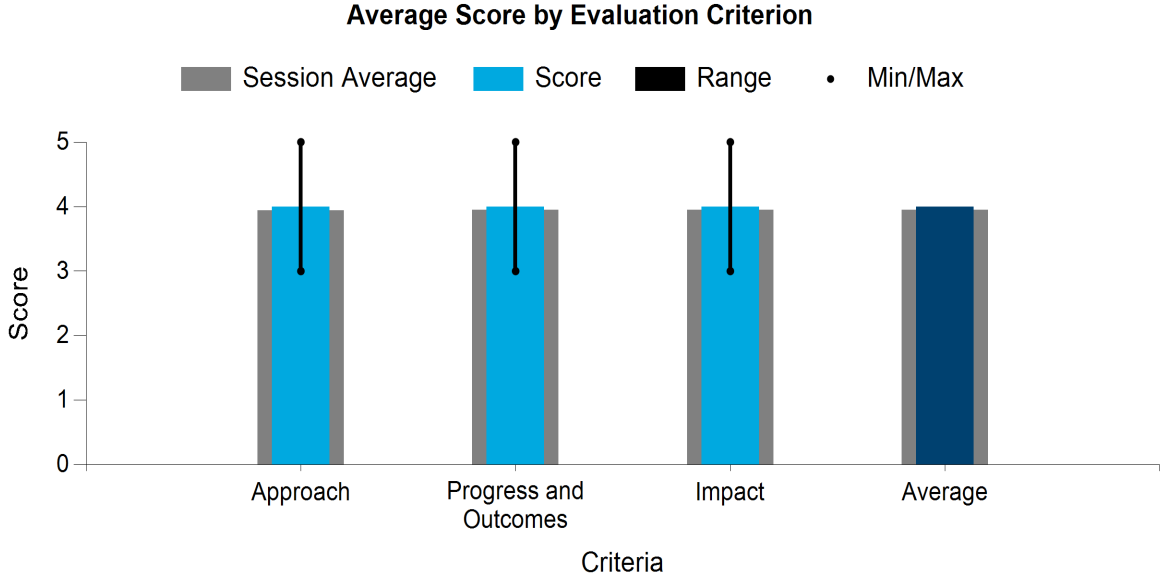
VALUATION AND VISUALIZATION OF WATER SUSTAINABILITY

Argonne National Laboratory

PROJECT DESCRIPTION

WBS:	4.2.1.10
Presenter(s):	May Wu
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$1,450,000

This project aims to develop science-based tools and metrics to understand the relationships between bioenergy production and water intensity, regional freshwater availability, water quality, carbon, the implication of alternative water use, and trade-offs. We develop models to characterize the interactions of carbon and water quality at the watershed scale; survey practices of water reuse in the United States; and identify gaps and opportunities of reclaimed water for bioenergy. The project delivers a set of analyses and data inventory to illustrate the impacts of water use and availability under future bioenergy scenarios using the spatially explicit Water Analysis Tool for Energy Resources (WATER) model. This work develops a new capability of the Soil and Water Assessment Tool – Carbon (SWAT-C) modeling, and a watershed LCA framework builds on SWAT-C, the FD-CIC tool, and GREET. The project's milestones and outcomes address EERE's decarbonization pillars in transportation and agriculture by identifying opportunities to reduce freshwater use and improve nutrient efficiency in low-carbon fuel production through enhanced conservation practices and the use of nontraditional water resources.



COMMENTS

- The approach of this project is well planned and excellent overall. The attention paid to building a strong network of collaborators is especially laudable. The project team appears to be making excellent use of the expertise of partners. The core aim of this work to create tools for integrating water quantity and quality into the LCA of bioenergy crops is an important research question deserving of support. This work could become critical to fully understanding the environmental impacts of bioenergy. This project has strong potential for policy impact. The results to date appear valuable to the regions that have been analyzed.

I am confused about why the capabilities being developed under this project are not being used in the current *Billion-Ton Report* update work. Water sustainability is firmly within the scope of the 2023 *Billion-Ton Report*, and this would seem like a significant missed opportunity. These capabilities seem well suited to evaluating where water sustainability constraints may bind biomass production potential as well as where there may be substantial cobenefits. I would encourage ANL and DOE to consider making use of these capabilities in the context of the 2023 *Billion-Ton Report*.

- Thank you for allowing me to review the Valuation and Visualization of Water Sustainability project. I believe this project is somewhat aligned with BETO's goals. I am impressed by the innovative approach of leveraging geospatial and other data sources to address the issues of nutrient, carbon, hydrology, and climate. Your investigation of operational changes for municipal water users given changes in water quality is very important. The progress toward goals is impressive, and the SWAT-C model seems to be performing well. The project's schedule is on track, and the team has completed several surveys and assessments. The findings on the impact of three conservation practices on SOC change, nutrient release, and GHG emissions are of significant value to bioenergy stakeholders; however, I recommend providing more information on the infrastructure investment required to use reclaimed water. The significance of the project is high in areas with a water deficit; however, I see the commercialization potential as low. I suggest packaging and providing management data sets from the project to stakeholders and reaching out to other water-interested agencies (EPA Office of Water) for possible collaborations/data.

- This project stands out from the rest of the projects in the technology area for its world-leading, extensive modeling of the water cycle and watersheds. The team's analysis of the water footprint and water availability appears to be well regarded and used by partners in government agencies, academia, and NGOs, particularly those concerned with water reuse. The team has also made meaningful progress across multiple fronts since 2021, particularly on water reuse and soil carbon. This project could also take on additional salience in the future as it is a key resource for DOE and BETO to evaluate the role of water impacts in equity concerns in some regions and identify strategies to mitigate those impacts. I was also impressed with the team's efforts to calibrate and validate the modeled findings with real-world data.

  One note of caution, however: From the presentation, I was concerned about the potential for scope creep and an expansion of the modeling capability from a dedicated water cycle tool to greater work on soil carbon flux, and it was not necessarily clear to this peer reviewer how SWAT-C was a natural extension of the modeling capabilities in SWAT. This could be expanded upon or better explained to make the connection, and better explain why this aspect of the analysis fits within this project.

- This project explores how to produce bioenergy in a manner that reduces impacts on regional water stress and water quality. The project connects to the decarbonization of the agricultural industry and feedstock production while also addressing an important aspect of any land-based energy system: water quality and quantity.

  In a case study of three land use practices in the Raccoon River Watershed-no-till, riparian buffer, and stover harvest with cover crops, the project team found that stover harvests at a 30% rate would lead to a decrease in SOC, and this reduction could be up to 12% in this watershed, but growing cover crops could recover SOC to a certain degree. These kinds of nuanced results are essential to understanding the full picture of the ecosystem dynamics involved in different kinds of bioenergy feedstocks.

  The next step for the project is to develop another SWAT-C analysis of another watershed. This will be helpful to compare the model outputs and functionality.

  The project also assessed the potential of using untapped reclaimed municipal water for bioenergy feedstock and agricultural crops in six states at the county level. The project seemed to incorporate

information from large-scale survey work with municipal water treatment plants, but it could have been a bit clearer where this data came from and how it was integrated.

Modeling land, feedstock, water resource, and climate in a single framework is an ambitious goal, but what is obscured in this big picture approach? Case studies such as the Raccoon River Watershed allow for researchers to consider place-based dynamics that can contribute to various types of uncertainty embodied in abstract models.

The project involved strong stakeholder engagement through collaboration with water and agriculture agencies, public and private sectors, NGOs, and academia. Continuing this collaborative approach will help ensure the utility of this work.

- The research question is excellent. Understanding and minimizing the water stress and water quality implications of biofuels are key to the feedstock's usefulness and long-term availability.

  The link to Des Moines Water Works on an economic understanding of water impacts is a useful component of this program.

  Modeling SOC permanence has been somewhat difficult. The model could be improved with consistent ground truth data over time. While likely already partially addressed by the model, a deep exploration of cover crop impacts on water and carbon would greatly benefit growers, watersheds, and supply chains as they make decisions about practice changes.

- This project investigates the important but often overlooked water resource issue for the bioeconomy. It is exciting to see that the project team considers the water needed for the entire value chain, is working with a lot of water/wastewater utilities, and makes the models/tools accessible. But existing work still seems very much focused on traditional feedstocks, such as corn and soybean, and water constraints developed from this project do not seem to be incorporated in the upcoming *Billion-Ton Report*. The team should start exploring work for new feedstocks, such as perennial grasses, and BETO should consider water resource limitations when presenting the potential feedstock availability.

PI RESPONSE TO REVIEWER COMMENTS

- We express our gratitude to the reviewers for their positive comments and words of encouragement. We are delighted to learn that our project's approach, particularly the establishment of a network of collaborators, has yielded positive outcomes. We fully agree with the reviewer that conducting a water sustainability assessment for the 2023 *Billion-Ton Report* falls within the purview of sustainable feedstock resource development. Moving forward, we remain committed to enhancing our modeling and analysis capabilities and to actively seeking feedback from industry and federal agency partners. Our aim is to effectively address crucial water resource challenges, contribute to policy studies, and facilitate decision-making processes in the field of bioenergy and bioproducts. We acknowledge the importance of including information on the infrastructure investment required for utilizing reclaimed water. In fact, we have dedicated a subtask within our project specifically aimed at analyzing the transport logistics of water resources considering the potential challenges associated with supplying reclaimed water for biofuels. Further, we fully recognize the significance of effective communication with stakeholders and the necessity of collaborating with the EPA Office of Water. We understand that their expertise and involvement are vital to the success of implementing reclaimed water applications in the field of bioenergy. To ensure the broad dissemination of our study and to engage with a wider audience in the water sector, we plan to release our findings through a water reuse symposium platform, thereby reaching various stakeholders in the water industry.

  Note that our current engagement with the EPA's National Water Reuse Action Plan lays a solid foundation for fostering increased collaboration. By sharing the synthesized information from our

project, we believe that our work can effectively benefit the ongoing efforts of the EPA's National Water Reuse Action Plan initiative and support their endeavors in promoting water reuse. Again, we appreciate the reviewer's valuable feedback, and we are committed to incorporating these suggestions into our project to enhance its overall impact and success. It brings us great satisfaction to know that our analysis and modeling work has made a meaningful contribution to the field of water sustainability in bioenergy development and has reached a wide range of audiences and stakeholders. We fully concur with your perspective that the water analysis capacity developed through this project is well equipped to explore the role of water impacts in equity concerns within specific regions. Further, we recognize the importance of identifying strategies to mitigate these impacts in the context of bioenergy production. We remain committed to advancing our understanding in these areas and working toward sustainable solutions.

The reviewer's comment regarding the inclusion of SWAT-C as a natural extension of the modeling capabilities in SWAT and its alignment with the project is highly insightful. SWAT is a process-based watershed model that effectively considers nitrogen, phosphorus, and hydrological cycles to characterize land, water, land covers (such as crops, grasslands, and forests), and urban areas within a watershed. While SWAT already incorporates carbon elements in plant growth and N_2O emissions, the carbon cycle was not exclusively simulated because the primary purpose of the SWAT model was nutrient loss modeling in agriculture; however, recognizing the significance of carbon in plant growth and the potential implications of land use for feedstock production on the life cycle carbon intensity of biofuels, researchers have increasingly acknowledged the need to integrate carbon dynamics into models that assess carbon, nutrient, sediment, and water interactions at the watershed scale. Unfortunately, such comprehensive models with extensive U.S. agricultural data were previously unavailable. In recent years, the USDA has expanded the capabilities of SWAT by incorporating the carbon cycle, thus enabling the model to account for carbon, nitrogen, phosphorus, water, and soil loss in the context of bioenergy and agricultural crops. By utilizing SWAT-C, the project aims to provide BETO with a comprehensive understanding of the impact of bioenergy at the watershed scale, thereby adding a new capability to BETO's portfolio. The information generated through the examination of various management practices and landscape designs will offer valuable insights to support decision-making processes for growers, regional watershed management, and conservation groups. While the inclusion of soil carbon and GHG emissions analysis represents additional benefits to BETO, it is important to emphasize that the project's primary focus remains on water quality and water resource assessment. The integration of carbon capacity into the watershed modeling framework serves as a complementary aspect that enriches the project's overall scope and objectives.

We acknowledge that strong engagement with stakeholders throughout this project has been instrumental in grounding our assumptions and research plan in practical experiences. We appreciate the opportunity to provide clarification on the data sources and integration process for the water reuse survey. It was indeed a complex undertaking due to the variations in data collection practices among wastewater districts and individual facilities, both at the state level and within each state. Because there is no comprehensive county-level database available for the entire United States, we approached each party individually, considering the availability and storage methods of their data. Additionally, during further analysis, volumes of stormwater direct reuse were excluded from the reuse data because these volumes are not part of publicly owned treatment works effluent. The annual facility reuse data were aggregated at the county level. By subtracting the reuse flow from the total publicly owned treatment works effluent flow, we obtained the net available reclaimed water flow for a specific year and county. The resulting flow data from recent years (2019–2021) were used for the bioenergy analysis. We hope this clarification provides a better understanding of the data collection and integration process for the water reuse survey. The water framework primarily focuses on environmental and land management factors, which are interconnected (e.g., climate, soil, water, land covers, land use, and practices) because it is essential to consider these factors holistically. Assessing one factor without considering the others would not provide

an accurate understanding; however, the framework does not emphasize economics and social factors because several other projects within BETO address these aspects. Note that social and economic factors are influenced by environmental factors and land use practices; therefore, the outputs from this project provide highly relevant information for the work undertaken by BETO and other stakeholders in these areas.

With regard to the comments on model uncertainty, we completely agree that all models, regardless of the scale, contain uncertainties. To address this, the SWAT-C model includes a model quality evaluation step during calibration and validation, which allows for the assessment. We value the reviewer's feedback and have taken it into account to ensure the accuracy and reliability of our findings. Our objective was to develop high-resolution, meaningful, and practical results that can effectively support decision-making processes for producers operating in regions with specific climate, soil, and water conditions. We fully agree that ground-truthing the model is crucial for verifying the accuracy of soil and water quality simulations, and we have actively sought multiyear measurements to achieve this. We have collaborated with the USDA Agricultural Research Services, the U.S. Geological Survey, the EPA, as well as regional and local soil and water conservation groups in the watershed to gather field-monitoring data over time. Further, we share your view on the significant benefits of cover crops. Our watershed modeling work for the Raccoon River Watershed, South Fork of the Iowa River, and the Iowa River basin during the past decade has consistently demonstrated the excellent performance of cover crops in reducing soil loss as well as nitrogen and phosphorus runoff at the watershed scale. We agree that further understanding the impacts of cover crops on water and carbon interactions will provide valuable insights for farmers when making practical decisions. Thank you for highlighting these important aspects, and we remain committed to incorporating field-monitoring data and evaluating the benefits of the best management practices in our project to ensure its relevance and applicability in bioenergy production.

We would like to clarify that while this particular review emphasizes our efforts during the past three years, our team has been actively involved in water analysis for cellulosic feedstocks since 2007 with the support of BETO. We have conducted extensive research on the water footprint and water availability of various cellulosic feedstocks, including corn stover, wheat straw, perennial grasses such as switchgrass and miscanthus, forest wood residues (both hardwood and softwood), woody crops, and algae. Further, we have assessed water sustainability for the second *Billion-Ton Report* scenario in 2011 (BT2) and the third *Billion-Ton Report* scenario in 2017 (BT16). The results of these county-level analyses are accessible on the WATER model website (http://water.es.anl.gov). We fully agree that considering water resource limitations is crucial when evaluating the potential feedstock availability for biofuel production. Looking ahead, we are actively considering the development of water assessments for the 2023 *Billion-Ton Report* update scenario in our upcoming project cycle. Your feedback aligns with our goals, and we appreciate your acknowledgment of the importance of water resource analysis in biofuel development. We remain committed to advancing our understanding of water sustainability and its implications for bioenergy feedstocks.

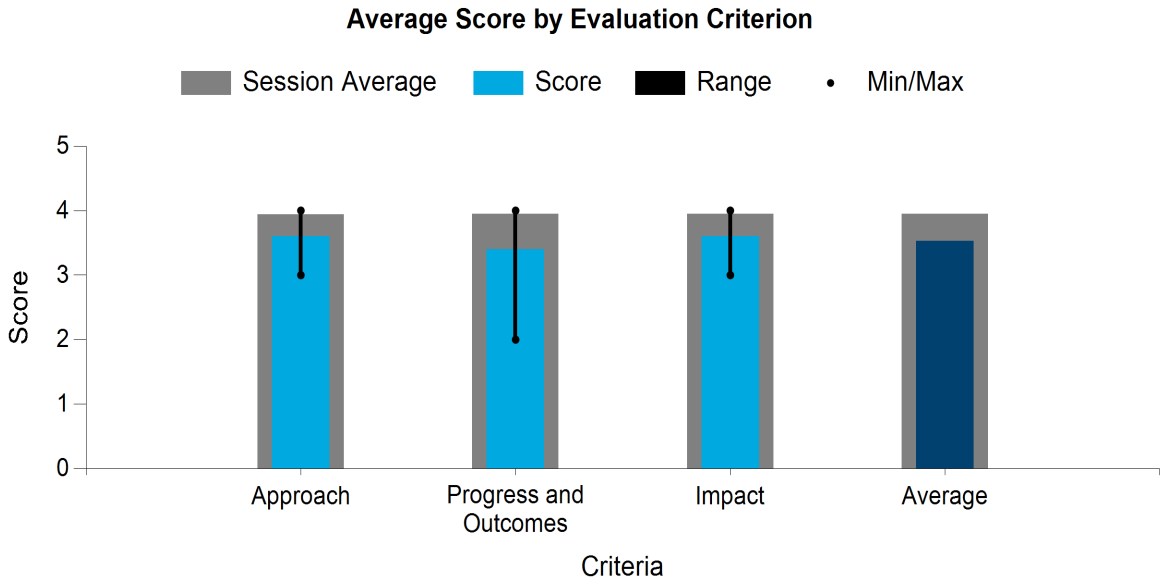
INTEGRATED LANDSCAPE MANAGEMENT

Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	4.2.1.20
Presenter(s):	Damon Hartley
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023
Total 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. The Integrated Landscape Management project was initially focused on the utilization of modeling to show that a viable strategy may be to integrate lignocellulosic biomass production practices into agricultural production fields via sustainable crop residue harvest, collection, and dedicated energy crop cultivation in suitable field areas. For the last two years, the Integrated Landscape Management project has focused on extending beyond the production of herbaceous feedstocks to include woody resources. The extension began with integrating short-rotation woody crops into agricultural production systems that are near areas of high concentrations of forest and forest operations. Short-rotation woody crop materials would likely more easily integrate into systems developed to use the forest resources, extending further beyond the farm and into the forest. The project examined using a landscape management approach to evaluate management strategies that can be used to maintain forest health and productivity. The Integrated Landscape Management project was last merit-reviewed in 2020 and is entering its last year of the current three-year cycle and will be merit-reviewed again in FY 2023.



COMMENTS

- The expansion of this project into woody feedstocks has led to some good research. Developing tools suited to evaluating site suitability for short-rotation crops fills a significant research need. The work to estimate ideal depot locations also seems to have strong potential impact. In particular, though, the work to estimate the impact of biomass removal for fire mitigation seems both timely and of great interest to stakeholders and decision makers. If the project staff can succeed in getting these tools into the hands of

stakeholders (as their presentation suggests they are trying to do), this project could prove highly influential in the development of biomass production systems that are coupled with fire mitigation efforts. I also applaud the planned steps to next assess the carbon impacts of woody and herbaceous systems.

- This project has a very clear purpose in its current iteration—to expand on an existing modeling framework for herbaceous feedstocks and apply it to woody biomass and wastes. The project looks like it is making important progress incorporating many woody biomass-specific dynamics into its framework, particularly wildfire mitigation, illustrating the potential to develop a valuable method of determining where it would be most effective to collect woody biomass and implement forest management practices that would simultaneously reduce fire risk.

  There is already good progress on the project, with promising results on shifts in fire risk based on implementing practices. As with other projects of this type, I would recommend additional efforts to ground truth and validate the modeling outcomes. This project also appears to have had some impact already, with two industry partners interested in using the model.

- This project seeks to maximize feedstock production in diverse landscapes, municipal solid waste, woody material, and agriculture. The project team first focused on cultivated perennial energy crops, such as switchgrass and miscanthus. In FY 2021, they shifted to expand beyond agriculture and herbaceous feedstocks to include additional feedstocks, such as woody material, which is what is being reviewed here. The project developed a modeling framework that can simulate forest and biomass supply impacts from the application of management activities. I am curious to know more about how these modeling efforts account for different silvicultural applications. Also, what scale of analysis was used?

  To what extent, if at all, might the use of forest residues compete with other forest product industries, such as pulp and paper markets, pellet markets, or emerging markets for biomaterials, cross-laminated timber/mass timber?

  The project partners state that DEI was not a formal goal of this project, but success in this project will help rural businesses and increase the wealth in rural communities. This seems intuitively true, but what metrics support this?

  Site suitability focuses on biophysical constraints—what about social availability? Who owns the land, and how willing are they to grow cultivated perennial energy crops or supply forest residuals?

  Making these models accessible and useable for stakeholders seems particularly relevant and important given the project's objectives.

- The approach in this project is thorough and thoughtful. The idea that biorefineries would be somewhat biomass agnostic and would need tools to identify what is available, environmentally useful, and economically viable is an interesting future posit. Detailing the connection and collaboration with industry to confirm that they find this tool robust and useful would be a great next step.

  The patent and potential licensing of CropAIQ is tangible indication of the usefulness of the model.

  The inclusion of the proximity to transportation nodes and clusters of suitable fields makes the output of this program more likely to reflect on-farm realities and will likely help to overcome logistical complications a plant may experience in implementation.

- Despite the project name (Integrated Landscape Management), this project seems to focus only on woody biomass without considering other feedstocks (e.g., grasses), and the discussion was mostly about fire management. The PI did mention a larger project that will look at a portfolio of feedstocks to

maximize the energy yield from a unit of land and other related projects that will work with stakeholders such as farmers, but those projects could not justify the significance and impacts of this project, and the current progress and outcomes are not impressive. Additionally, it seems that the main route for this project's impacts is through publications and software repositories, which is very focused on academia despite the potential of this project's impacts on a larger scale; therefore, the team is encouraged to design future activities that can be applied to broader areas and to get more stakeholders involved.

PI RESPONSE TO REVIEWER COMMENTS

- The Integrated Landscape Management project has been actively working on the concept of incorporating the production of biomass into traditional management practices for nine years, with the first eight years of the project working in the area of developing strategies to incorporate dedicated energy crops into agricultural landscapes, and seven of those years focused on establishing perennial grasses in agricultural settings in addition to collecting crop residue. Because of the heavy focus on perennial grasses and crop residues in the early stages of this project, to become a truly integrated landscape management project, we needed to expand beyond agriculture, perennial grasses, and crop residues into other landscapes and feedstocks. As we begin to expand into the forestry area, we must develop a new set of tools to be used for analysis and design, and for this reason, the project does not currently have outputs that are at the same level as the outputs we previously had in the agricultural space, such as CropAIQ, which was awarded a patent in 2020; however, we aim to match the significance of the work that we have done in the agricultural domain with our forestry work. The planned focus of this work is to understand how management activities within the forest can be used not only to manage fire risk but also to contribute to carbon sequestration. Within this work will be the evaluation of different silvicultural systems based on current and future stand conditions, which will include the impact of markets on the products produced and an accounting of carbon that is sequestered in long-lived forest products. Our interest is to have tools that we can use to examine large regions and potentially national-level potentials of biomass production and carbon sequestration, but the tools that we are developing are modeling forests at the stand level and will ultimately be useful to forest landowners and managers to design management strategies for their landholdings.

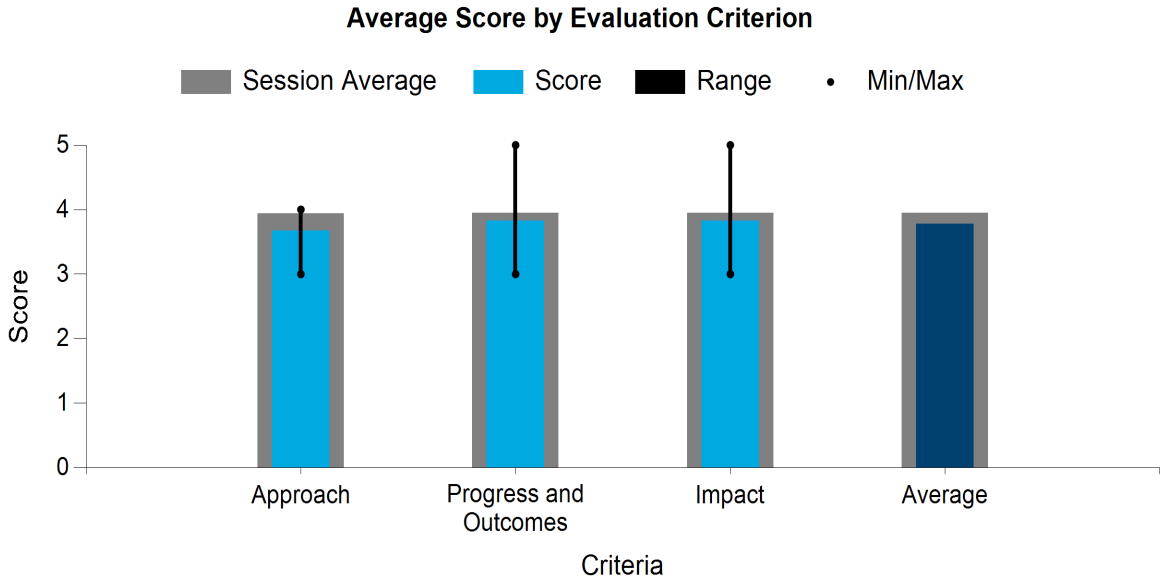
BIOFUELS AIR EMISSIONS ANALYSIS

National Renewable Energy Laboratory

PROJECT DESCRIPTION

WBS:	4.2.1.30
Presenter(s):	Vikram Ravi
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$600,000

The United States has goals to produce 3 billion gallons of SAF annually by 2030, increasing to 35 billion gallons by 2050 to decarbonize the aviation sector. Meeting these production targets will require setting up large numbers of biorefineries; however, the ability to comply with federal air quality standards is a prerequisite to being issued a construction permit. Negotiating the permitting process for a new biorefinery can be quite onerous and cost the investors significant time and money. Although there can be numerous reasons for delayed biorefinery construction, air permitting is fraught with pitfalls because the permitting process relies on precedence, which the future SAF biorefineries lack. NREL's Biofuel Air Emissions Analysis project is unique and innovative in terms of the tools, approaches, and analyses provided. NREL is the only national laboratory that is actively working at the intersection of federal air quality regulations and emissions and air quality analysis across the supply chain, including process design cases. This project is focused on providing much-needed data and analyses that address biorefinery air permitting. This project develops models and quantitative analyses, and it measures progress toward meeting air quality regulatory requirements. These models and methods have been applied to analyze the air permitting process related to wastewater sludge-to-biofuel conversion pathways using hydrothermal liquefaction (HTL) and study the impacts of the HTL pathway on local and regional air quality, including an assessment of health and equity impacts. In addition to filling research gaps, this project disseminates the findings to the relevant stakeholders at BETO, other national labs, and regulatory agencies.



COMMENTS

- The motivation for this research—helping biorefineries demonstrate compliance with federal air quality regulations—is laudable. I agree with the project team that such analysis would be highly useful for future biorefineries. The potential for impact is significant. Overall, I think the approach and progress to date are also good. One area where I would like to see more thought is regarding how biorefineries might

be able to use these tools in conversations with federal air quality regulators. As the presenter said during the question-and-answer period, it is still unclear how results from this modeling workflow could be used in regulatory applications. I strongly encourage the researchers to continue engagement with the EPA's air quality and health effects modeling efforts to think through this important question.

- Thank you for the opportunity to review the Biofuels Air Emissions Analysis project. The project is reasonably aligned with BETO achieving its goals by providing data and information for the biorefinery air permitting process and helping the industry design processes that minimize impacts on the environment and communities. The project also includes important DEI considerations, and the advisory board is well connected with industry and regulators, including both Exon and the California Air Resources Board. The project's opportunity for improvement lies in updating FPEAM data inputs to make them more current (or allow for other sources of these model inputs). This would enable the assessment of the air impacts of other model results. Also, the PIs could consider more discussions with staff from the regulatory agencies to ensure that what is recommended to stakeholders would fulfil requirements. Thanks, and all the best going forward with this important project.

- This project nicely complements BETO's increased focus on equity by evaluating the potential risks of the bioeconomy to local air quality in finer detail and evaluating mitigation strategies. The modeling framework presented here was well designed and showed flexibility to evaluate different processing technologies. This has natural potential to integrate with any of BETO's work focused on new refinery siting.

  This project points to a potentially significant equity issue—that existing, centralized upgrading points would not be subject to air quality permitting. It would be helpful if, beyond siting new facilities, this work could be coordinated to identify mitigation strategies and opportunities for existing biomass processing.

- The goal of this project was to create industry design processes that minimize impacts to the environment and communities in the development of future biorefineries with an emphasis on air quality permitting. The project partners mentioned informing the stakeholders—are there ways in which feedback from the stakeholders has been incorporated into modeling and analysis?

  One reviewer mentioned that the project could include a more robust approach to stakeholder engagement and connections across other DOE modeling efforts. The project team has continued to communicate with teams at other national labs, but what about other affected stakeholder groups outside of research teams? This still seems like an important direction for the project.

  The breakdown of health impacts by race in different regions is helpful in showing disparate impacts. The project team should continue to work on developing these kinds of equity metrics related to air quality as it relates to distributive justice. It would also be interesting to look into procedural justice issues (decision-making process issues) and recognition justice issues (how past conditions inform the future).

- This project is important to the BETO portfolio because it works on the permitting pathway for the construction of biofuel facilities. This work is scaffolding that enables the faster implementation and production of low-carbon fuels.

  This work can be made more accurate and inclusive by allowing for variable feedstock scoring dependent on actual recorded farm practices, not regional or county averages. This is important for two reasons: First, farm practices can widely vary between farms, and by allowing for actuals, it can incentivize the adoption of better-than-average practices. Second, this can allow for farmers to be participatory in the evaluation and understanding of the models that are assigning them environmental

impact metrics. This type of ground-truthing can end up improving and extending the models to be more representative.

- This project considers the impacts of on-site air pollutant emissions from biorefineries. The outcomes from this project include the open-source FPEAM (already publicly available) and contributions to other federal agencies or industries on the health impacts of biorefineries. It is meaningful work to provide inputs on the overlooked health impacts of the bioeconomy, especially for disadvantaged communities. But better approaches can be used for more accurate and impactful results (e.g., measuring the actual air emissions from pilot facilities rather than modeling using literature data, engaging with permitting agencies on the types and methods of pollutant tracking).

PI RESPONSE TO REVIEWER COMMENTS

- While not all tools and analyses developed as part of this project are designed for a regulatory application, we can explore ways to more effectively communicate how findings from the project can be used in a more suitable manner by the industry to lessen the permitting burden. We will continue to engage with the EPA's air quality and health modeling efforts.

  The logistics modeling component of FPEAM was recently updated to the most recent version of the EPA's Motor Vehicle Emission Simulator (MOVES) model, and we plan to update some underlying FPEAM data based on scenarios for the next *Billion-Ton Report*. We will continue to engage with various stakeholders on how our data, tools, and analysis can be made more robust.

  Regarding the concerns about "potentially significant equity issues" at centralized upgrading points, there will be permitting requirements for these sources per the prevailing regulatory environment as prescribed by the permitting agency. Analysis only suggests that no major source permitting is required unless the facility is located in a serious, severe, or extreme area of nonattainment for ozone.

  Thank you for the valuable comments and feedback. We will explore ways to further improve stakeholder engagement. Thank you for highlighting the value of distributional justice analysis, which aligns with the prospective analysis done as part of this project. Other projects have engaged in procedural and recognition issues, and we can explore how our work aligns with their analysis.

  We use the best available data within the project's constraints, and we will continue to improve our data as suggested by the reviewer. We agree with the reviewer that a local scale analysis (not the focus of the project's presentation during the Project Peer Review) can be improved by accounting for local farming practices that can influence analysis outcomes, although it can be a very resource and time-intensive exercise.

  The HTL analysis presented for the Project Peer Review does not have any measured emissions data available as of now, and most specific pathways we analyze have no real-world examples available that will be applicable at the same size and scale of the facilities for which we perform analysis. For these reasons, we use the best available estimates based on modeling and literature estimates, and we perform an evaluation of our emissions estimates where possible (and will continue to do so, as suggested by the reviewer).

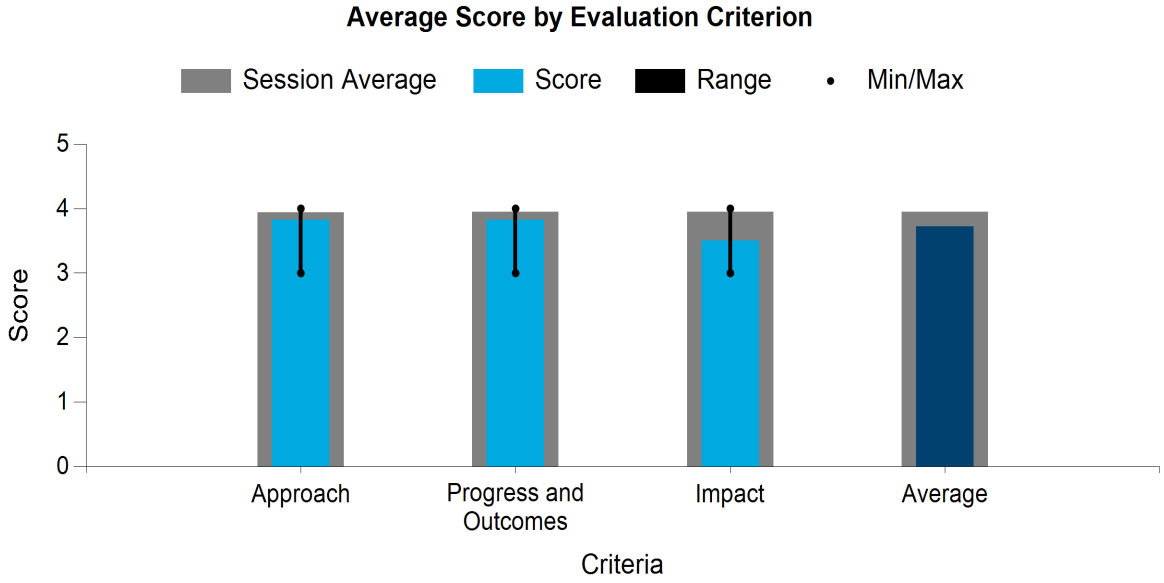
ENVIRONMENTALLY EXTENDED MULTI-REGIONAL PROJECTION OF LIFECYCLE AND OCCUPATIONAL ENERGY FUTURES (EMPLOY)

National Renewable Energy Laboratory

PROJECT DESCRIPTION

WBS:	4.2.1.31
Presenter(s):	Andre Fernandes Tomon Avelino
Project Start Date:	10/01/2022
Planned Project End Date:	09/30/2025
Total Funding:	$1,200,000

This project provides BETO with strategic decision support for the evaluation of its R&D portfolio and future decarbonization scenarios by developing, validating, and applying a coherent methodology and consistent economy-wide model framework to quantify the net effects of an expanding U.S. bioeconomy. The framework fills an analysis gap previously identified by the Project Peer Review and supports a related milestone in BETO's Multi-Year Program Plan. The model complements pathway-specific TEA and LCA using a top-down framework to compute environmental, resource use, socioeconomic, and occupation metrics, and it provides retrospective (2002–2017) and prospective (2020–2050) economy-wide assessments for individual technologies or technology portfolios with regional-level detail to determine the trade-offs between deployment strategies for bioeconomy commodities. Presently, EMPLOY covers several commercial and near-commercial biofuel routes, including SAF, and an emerging pathway for plastics upcycling. EMPLOY has provided analyses for the *Third Triennial Report to Congress* on the environmental effects of the RFS, its results have been cited by the EPA's regulatory impact analysis for a proposed rule change in the RFS 2023–2025, and its capabilities have been presented to members of the aviation industry.



COMMENTS

- Economy-wide modeling perspectives on U.S. bioenergy are few and far between. It is a gap that needs to be filled, and I applaud DOE for funding research in this area. I think the model is choosing appropriate areas for development, expanding biofuel pathway representation and improving geographic resolution. Including a rest-of-world aggregate will also be an improvement. There are clearly areas where this model could be used for DEI-relevant work through the analysis of socioeconomic impacts, as

shown in slide 9 of the presentation. The project does appear to have a very broad scope. Attempting to cover economic and workforce impacts at the same time the researchers are building out a biophysical representation of environmental impacts is a lot; however, I am encouraged that the researchers are linking to bottom-up models rather than trying to endogenously incorporate so much scope. I would encourage them to think about where their value add lies and not try to take on more than that.

- Thank you for the opportunity to review the EMPLOY project. This modeling project is reasonably aligned with BETO achieving its goals, particularly with expanding U.S. bioenergy and investigating the impacts on the economy. The plans for the incorporation of state-level energy policies and dynamic consumption structure/relationship to socioeconomic forecast assumptions are positive aspects of the project. The model's consistency across input sources is a critical issue that the project has addressed well with consistent assumptions in the baseline. Although the project plans to achieve DOE goals, the scale may have issues for incorporating different EJ analyses. Also, the mix of GAMS and R programming language makes it difficult to disseminate and could have accessibility issues; however, the project is an ambitious and useful tool that takes advantage of BETO's available models and data sources.

- This project is well timed and well suited to the priorities of BETO because it connects the bioeconomy to the recent focus on the socioeconomic risks and opportunities of the bioeconomy. The authors have focused on providing critical information to guide policymakers and has already been used in high-profile applications, such as the EPA's RFS *Triennial Report to Congress*. The key outputs that are particularly compelling include employment impacts and spatial trade-offs for pollution.

  One area of concern is the sheer complexity of the model and the risk of overreaching, particularly as the model tries to balance a complex set of economic and physiochemical processes. It would be helpful to more clearly demonstrate where the model is filling in new gaps and where the model outputs may be redundant with separate models, particularly on pollution estimates. Ideally, the model could be aligned with or integrate the results of those outside models and can focus on its key strengths and added value to the program on social and economic indicators.

- This is an ambitious project that covers multiple sectors to assess environmental and economic impacts. I agree with the 2021 reviewer that if the goal is to capture socioeconomic effects, a more diverse range of indicators could be incorporated. Adding labor and workforce metrics was a good initial step to understanding the potential economic benefits; I wonder if there are other metrics to address equity impacts in terms of workforce issues.

  Expanding the spatial dimension from the national to the state level to highlight regional trade-offs of specific pathways and decarbonization strategies is good, but it would be interesting to break that down into even finer-grain analysis to look at local impacts. Census track data are readily available, or county-level analysis could be useful. This seems especially important given the initial findings that discuss rural versus urban differences, and it is consistent with BETO's goal to increase regional studies and regional data. This would also allow for a better understanding of disparate impacts.

  It would be good to get the EMPLOY model in an accessible form that could be useful for decision makers and also to account for climate change and potential policy changes.

- Overall, this project is ambitious in scope and impactful in use. It has a strong connection to supporting policy decisioning and impact with the EPA and SAF Grand Challenge connections.

  The difficulty of modeling the Inflation Reduction Act policy was acknowledged in the presentation because of the way it impacts supply shock as opposed to demand shock. If possible, the model's accuracy should be tested against historical data on supply shocks to determine its ability to predict the effects of supply shocks on the economy.

The use of future models that incorporate climate change should be explored as this will provide policymakers with a more accurate picture of the future economic landscape. It is recommended that the model be updated when new climate change models become available and that its performance be tested against real-world data.

- The project has clearly defined goals, intermediate targets, and expected outcomes. It leverages process-based models and includes retrospective (with validation through back-casting and comparison with historic data) and prospective analyses. It considers multiple environmental impact categories (i.e., not only limited to GHG emissions); however, the use of the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) also leads to potential inconsistency/incomparability with other models, such as GREET (e.g., GREET updates the N_2O- and CH_4-to-CO_2 with Intergovernmental Panel on Climate Change reports, whereas TRACI has not been updated for a long time). The project team also considers multiple scenarios based on the *Annual Energy Outlook* report. One strength of this project is the consideration of workforce development, which enables the model to consider how the expansion of the bioeconomy would affect urban and rural communities and contribute to EJ and DEI. One major caveat of this project is that the model is not publicly available (and the model uses GAMS, a commercial tool that requires a commercial license to use), which greatly limits the user basis, makes it very hard to assess the underlying assumptions and approaches, and creates difficulties in gathering constructive comments and feedback.

PI RESPONSE TO REVIEWER COMMENTS

- The EMPLOY team thanks the reviewers for their time, constructive comments, and suggestions provided during and after the presentation. EMPLOY aims to provide an economy-wide perspective to the introduction of new energy technologies in the United States, thus revealing indirect impacts and their trade-offs across sectors and regions in terms of economic, environmental, and resource use and workforce metrics. These results can then be used to study strategies to mitigate negative effects and increase positive ones. EMPLOY models the interactions between all sectors of the economy, and therefore its complexity and data requirements significantly increase at finer spatial scales. Primarily due to public data availability, the model is being developed at the state level. The team understands that to better highlight EJ implications, a finer spatial scale (such as at the census tract level) is essential. EMPLOY's EJ goal is to provide initial insights in terms of direct and especially indirect EJ effects across sectors throughout the United States, whereas most EJ models focus on localized direct effects. Due to the spatial scale of the model, equity metrics besides workforce ones might be difficult to evaluate. Nonetheless, we will explore the possibility of adding additional EJ metrics or linking EMPLOY's output to finer-scale NREL models, such as InMap. As part of the calibration process for EMPLOY, we perform a back-casting estimation against historic economic data to check for model fitness. Future shocks are based on external models, such as the BSM, which is also validated against real-world data; hence, this process is used to measure the degree of confidence in our estimates. Nonetheless, forecasted results from EMPLOY in FY 2024 will also include a sensitivity analysis across inputs to create ranges around our estimates. In FY 2025, the model will be expanded to account for international trade, thus revealing the importance of global supply chains to the growth of a domestic bioeconomy. At that stage, we will explore the possibility of connecting to a climate change model to create external supply shocks. Additionally, although the model currently uses TRACI characterization factors, those can be updated by incorporating other data sets, depending on DOE's preference. Due to the complexity of EMPLOY as well as data requirements and connections to other NREL models, currently, the model is not designed to be publicly available but to be used internally by DOE and NREL. Nonetheless, the team is always improving the model's codes, and we will explore the possibility of having our optimization routines in the same coding language as the rest of the model (R language) for efficiency and better workflow. Additionally, the team is currently drafting a manuscript with EMPLOY's modeling framework for submission in a peer-reviewed journal, and we will publish additional peer-reviewed papers with future model developments and results.

VISUALIZING 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 Funding:	$1,250,000

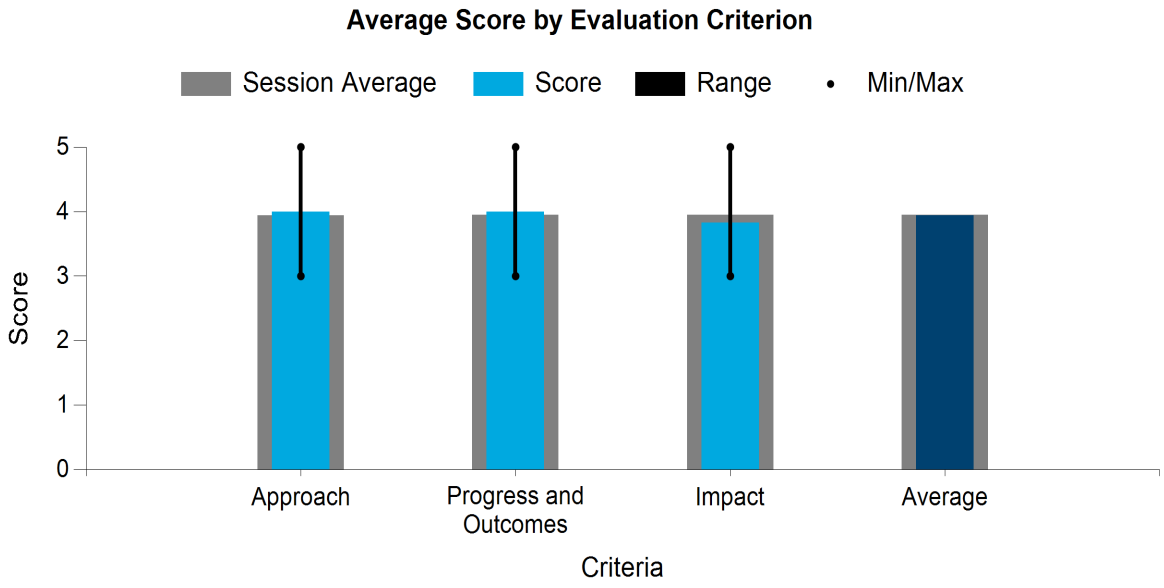
Our project seeks to quantify pathways to producing biomass feedstocks with high potential value for producing ecosystem services. We met our go/no-go milestone by determining that the value of ecosystem services in riparian buffers of the Mid-Atlantic region converted from growing annual crops to switchgrass and coppice willow exceeded 25% of fixed production costs. We modeled ecosystem services, including increased SOC, reduced N_2O emissions, and reduced runoff of total nitrogen and phosphorus. The Biofuel Infrastructure, Logistics, and Transportation (BILT) model optimized ethanol refinery locations for these feedstocks, supplemented by forest residues. Our analysis suggests that 90% of carbon (19.4 Mt CO_2) could be avoided by using high-ecosystem services-value feedstocks while avoiding sensitive areas where air pollution concerns are high. ANL used these inputs to conduct an LCA using GREET in which ethanol achieved >82% GHG reductions compared to gasoline.

Beyond the results associated with key project milestones, we have produced the following results:

1. In the Arkansas-White-Red basin, we estimated that water quality improvements exceeded production costs for nearly half the cellulosic biomass supply, offsetting more than 20% of the 3-billion-gallon target for SAF.

2. A preliminary assessment of animal wastes showed that on average 18% of total nitrogen (20,859 Mg) and 21% of total phosphorus (2,276 Mg) could be removed if all manure were collected to produce RNG.

3. We completed climate flood risk modeling and used it to assess avoided insurance costs when planting perennial feedstocks. Preliminary estimates suggest an increase in average avoided costs from approximately $48,000 (current) to $54,000/county/year due to increased flooding under future climate conditions.



COMMENTS

- Tools to assess and monetize the potential ecosystem service benefits of biomass production and tools to help site future biorefineries in light of the potential positive and negative impacts seem like worthy scopes. Quantifying the potential revenue and impacts of riparian buffers and flood management could both provide strong value to stakeholders.

  The planned next steps for this project seem logical and potentially highly impactful. I especially applaud the efforts to make these tools publicly available. Because the researchers are seeking feedback on potential continuations, I will offer two. Further analysis of the potential impacts of producing RNG from manure digesters on water quality is extremely timely given public debates in this area, and it could have a strong impact. The ability to provide inputs to EJ decision tools for evaluating biorefinery siting may also be impactful. Providing stakeholders with tools and insights in both areas would be excellent for further work.

- Thank you for the opportunity to review the Visualizing Ecosystem Service Portfolios of Agricultural and Forestry Biomass Production project. Based on the information provided, the project is well aligned with BETO's goals. I was impressed with the progress made thus far, particularly on the development of BioVEST and the creation of geospatial maps. The web tool for stakeholders, BioVEST, hosted on the Posit platform, is an excellent impact outcome. It was easy to use and was very accessible. One area for potential improvement is to consider focusing outreach efforts on bioenergy companies in addition to landowners to increase impact. Overall, the project appears to be on schedule and has made significant progress toward achieving its objectives.

- This project provides a very valuable theoretical component to drive the use of cellulosic energy crops, assessing their suitability for ecosystem services and assessing the value of those benefits. This complements the objectives of BETO well because it could help to improve the cost-benefit calculus for one of the most abundant sources of biomass necessary for broader DOE objectives, such as the SAF Grand Challenge. The approach used here was both regionally and technically well differentiated from other projects to reduce redundancy with other projects within the technology area, and it provided a comprehensive basis to inform potential producers of the value of energy crops and the siting of potential biorefineries.

As with other projects of this type, the theoretical results are very exciting. I would say that the main way to improve the impact and relevance of this project would be to build upon this valuable conceptual work to better understand farmers' perspectives and openness to these techniques. This could better inform the types of policies necessary to capture these cobenefits.

- This project focuses on demand for biomass feedstocks and argues that nutrient credits and ecosystem service credits/payments can offset 25% of biomass production, and 10% of fuel cost. The visualizations the team have created have the potential to contribute to the profitability of perennial and waste feedstocks, which are, as they note, barriers to development.

  The project used six indicators related to air pollution from the EPA's EJ screening tool to also consider equity issues in locating potential biorefinery sites. It was great to see this understudied dimension of bioenergy sustainability addressed, and I wonder if the project team can consider other factors outside of air pollution that might play into rural equity issues related to bioenergy.

  How are animal wastes used currently? Are these concentrated animal feeding operations where wastes are a nuisance byproduct? Do they serve as fertilizer? If the material is coming from concentrated animal feeding operations, how might incentives for bioenergy indirectly incentivize unsustainable farm practices?

  Analysis of ecosystem services tends to focus on SOC and nitrogen runoff. Are there other relevant ecosystem services that should be considered?

  The project team does a good job working with related models, tools, and projects to build understanding of the economic dimensions of bioenergy production (GREET).

- This project's inclusion of flood insurance analysis as a potential benefit to incentivize communities was innovative. A useful next step here would be to engage with the insurance industry as well as state-level governments to elicit feedback. Additionally, it would be good to include crop insurance implications because improved resilience and reduced crop failures would be very valuable.

  The EJ screening seemed strong for Task 4. This could be better by considering economic impacts, if they are not already included.

  I highly recommend developing a data source for keeping ecosystem payment data current. Several groups—including AFT, *Farm Journal*, and The Context Network—all produce regularly updated carbon market pricing for growers. NRCS programming could also be an important pricing indication. Because ecosystem services are a rapidly changing market, this model will need to be responsive to be useful. The model could also allow for user inputs for key pricing data as a flexible way to run economic scenarios.

- Despite some delays due to external factors, this project largely stays on track. It is encouraging to see that BioVEST is interacting with other BETO models, but the interactions seem superficial, and there are a lot of opportunities for improved accuracy/more considerations of uncertainties. For example, the manure-to-natural gas project seems to rely on a previous NREL analysis of natural gas production potential; SOCs used in the LCA analysis are fixed values, etc. The project team is recommended to focus more on the accuracy of the analysis. Additionally, with the new stakeholder-related capabilities added to BioVEST, it would be instrumental to have it tested by partners and the public for comments.

PI RESPONSE TO REVIEWER COMMENTS

- Generally, the reviewers found the project to be well aligned with BETO's goals. The development and deployment of BioVEST on the Posit platform was appreciated as a way to increase project impact. Progress toward the objectives of quantifying potential income from ecosystem services, including flood

insurance, was appreciated, as was the use of multiple models and the focus on the full life cycle. The reviewers suggested several future directions. (1) Allow users to provide input to EJ decision tools, and quantify the economic impacts of including them. (2) Focus on outreach efforts, including bioenergy companies in addition to landowners and farmers, and have partners test the tool. (3) Provide real-time data on ecosystem payments, incentives, and carbon prices. (4) Increase attention to accuracy and uncertainty analysis. (5) Perform further analysis on producing RNG from manure digesters, and address concerns that the use of these wastes for energy may incentivize unsustainable practices. Our proposed renewal of the project will seek to address the first four of these, with a significant focus on outreach, dissemination of results, user elicitation, scenario analysis to evaluate incentives, and the use of real-time price sources. Although we are interested in continuing our RNG research, the expansion of other parts of the project would make it difficult to address at the current funding level. We will also prioritize moving from Tier 1 to Tier 2 methods of modeling carbon sequestration, and we have recently conducted a sensitivity and uncertainty analysis of BioVEST.

SCALING UP DECARBONIZATION AND SUSTAINABILITY (SUDS)

Argonne National Laboratory

PROJECT DESCRIPTION

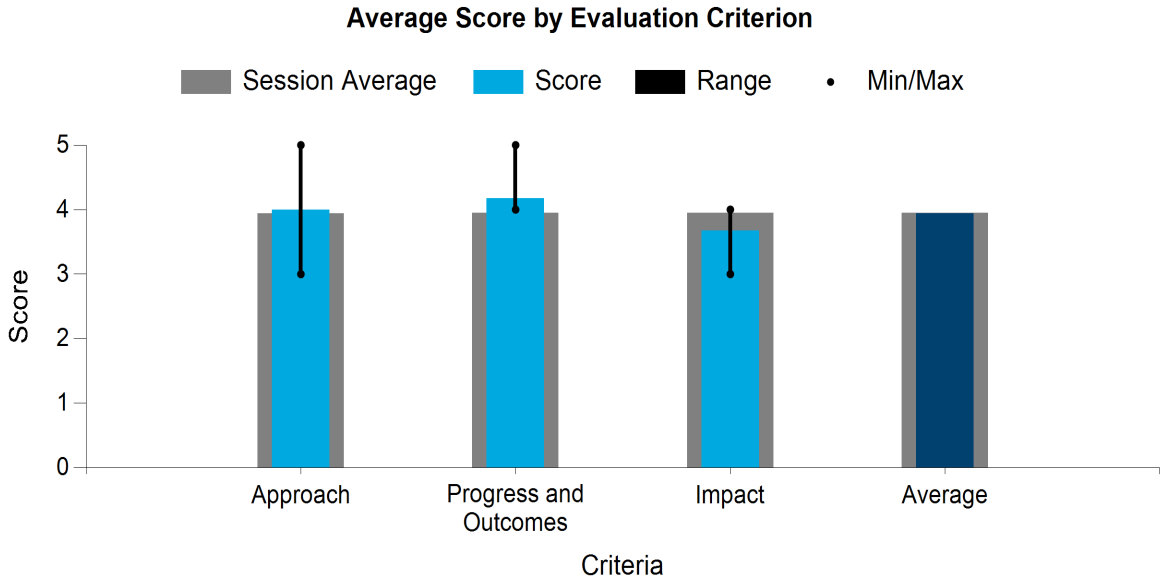
The sustainable generation of biomass can be achieved using perennial bioenergy crops to support the bioeconomy while providing a range of ecosystem services. Our group continues to explore the potential for farmer adoption of perennials through a combined effort of tool development, modeling, technology research, economic analysis, and field and lab work.

WBS:	4.2.2.12
Presenter(s):	Cristina Negri; John Quinn
Project Start Date:	10/01/2022
Planned Project End Date:	09/30/2025
Total Funding:	$1,605,000

Our new project builds on accomplishments in the prior project cycle and adds new directions. A key component of both projects is the creation and development of an online geospatial tool, SUPERBEEST. This tool is designed for a full range of users, with interests at scales ranging from the field level to one or more counties or watersheds. Its purpose is to assist with decision making regarding the conversion of row crops to perennials. It identifies economically and/or environmentally marginal farmland that is optimal for the change, providing users with the ability to explore different scenarios. It also identifies candidate locations for saturated bioenergy buffers to increase biomass production while reducing the loss of nutrients to surface water. Under development is the ability to determine the possible improved ecosystem services in a study area with integrated perennials relative to the business-as-usual scenario. The net economic impact of such a change will be estimated by relying on ever-changing valuations for ecosystem services, in particular, carbon sequestration, reduced GHG emissions, and nutrient trading schemes. Government and corporate programs will be evaluated for their relevance.

In addition, we will continue the development of a soil core scanner for the rapid estimation of SOC content, a project initiated with internal research funding (laboratory directed R&D) and important for verification of the carbon sequestration effects of deep-rooting perennials. We will assess root mass and SOC at our mature shrub willow research site in Illinois, perform baseline and future assessments of carbon sequestration and GHG emissions at a set of new switchgrass fields in marginal land in Iowa, and assess a saturated bioenergy buffer for its biomass generation and reduced nutrient loss.

Altogether, our current and future activities have the goal of reducing the cost for biofuel production while providing quantifiable environmental benefits, such as carbon sequestration both locally and globally.



COMMENTS

- This is a good project with a solid approach and a great deal of progress to show for it. Geospatial tools to help farmers understand the value proposition of perennial bioenergy crops, both from a traditional revenue standpoint and from an ecosystem services payment standpoint, have a lot of potential for impact. The capability to assess land marginality is great. The coupling of these modeling capabilities with real-world data from the willow test plots would be a powerful combination. The work to understand the potential for bioenergy crops to aid nutrient runoff reduction is also great. Keep doing that work.

  One area I would encourage the project team to consider doing more is considering transition costs and barriers. It is encouraging that the project is thinking about which equipment options exist and do not exist. But the target audience here are potential growers of perennial bioenergy crops. These tools need to consider things such as access to infrastructure for processing feedstock and whether plots being analyzed are compatible with existing machinery. These considerations are important to the core question: Can I grow it?

  Another thing I would strongly recommend is the public release of SUPERBEEST. While I understand that is not always a fast thing to do, I think it should be an explicit milestone for this project.

- Thank you for the opportunity to review the Scaling Up Decarbonization and Sustainability project. I find that the project is well aligned with BETO's goals, and after evaluating it with the corresponding outreach project, this includes goals related to DEI. SUPERBEEST's identification of marginal land that is ideal for a change, watershed-specific SWAT modeling, and the benefit transfer methodology can all provide potential support tools for bioenergy stakeholders. Further, the project's focus on the increased adoption of perennials, reduced feedstock production costs, improved carbon sequestration, biodiversity, and water quality, and decreased GHG emissions and topsoil loss contribute to farmers' needs for optimal cropping systems, determining low-input cost strategies, and a resilient and stable rural economy as a result of bioenergy adoption. The project is progressing on schedule, and the identification of a cheap method of measuring soil carbon is a notable achievement; however, there are no data on the use or dissemination of the project's free online tool, SUPERBEEST, and a clearer plan to include policy or farmer learning would be beneficial. Nonetheless, the project shows promise in tying together various work streams, and its ongoing refinement through outreach efforts is commendable.

- This project has a very ambitious approach and could be very impactful. The modeling tool developed for this project has the potential to help deliver on BETO's goals of delivering large quantities of sustainable biomass and simultaneously creating additional farm income and ecosystem services. The initial results from the model are extremely impressive, drawing together a variety of data sources to evaluate the optimal locations for energy crops on a very granular basis.

  Given the impressive theoretical findings in this project, this project would benefit from efforts to ground truth and validate the findings, particularly on farmer willingness to implement the recommendations on planting and to incorporate feedback from farmers and industry into the approach. It is very promising that the PI is already coordinating with Antares and pursuing comments from stakeholders through a separate project.

- This project aims to foster bioenergy supply by identifying marginal land that can be converted to perennial bioenergy crops. SUPERBEEST (one of the best acronyms that I've come across in terms of data modeling systems) employs a county-level approach that allows for nuances and complexities of biophysical landscapes. The SUPERBEEST approach allows for multiple scales of analysis—from farm-level to watershed-level scales—which could potentially be useful to different users, including farmer or landowner groups, researchers, agencies, and biorefinery developers. Has SUPERBEEST been tested with farmers? Outreach seems particularly important for this project.

  I wonder if social factors could be considered alongside biophysical dimensions. For example, the authors note that values of ecosystem services are greater than the loss of corn/soybean revenue on marginal lands, but will landowners/farmers change practices? What are the actual (or perceived) impacts on agricultural producers? Who decides what is marginal agricultural land?

  In terms of EJ implications, has a relationship between marginal land and low-income farmers been established? How might this part of the analysis be developed?

  Exploring the relationship between marginal land and income will be interesting and could make significant contributions to the understanding of equity issues in rural communities.

  What are the implications of SUPERBEEST in terms of the incentives necessary to achieve wider-scale bioenergy crop adoption? The authors note that if on-farm reduction costs are more cost-effective than what treatment plants pay to reduce nitrogen, it may be advantageous for treatment plants to pay farmers a credit to grow bioenergy crops. This can provide an additional market incentive to transition to bioenergy crops. Are there examples of this? How would this work exactly?

  How will moving targets such as potential carbon policies and incentives for ecosystem services that could influence conversion to bioenergy crops be incorporated in the model?

- This project's inclusion of a nitrogen water trading scheme is an effective and useful exercise. Often water and climate goals are separated, which misses the economic opportunities of aligning carbon markets with watershed district priorities. It also fits much better with how growers think about their fields and farming practices.

  Siting biorefineries in specific communities that meet EJ requirements is a strong approach to DEI.

  SUPERBEEST excelled in both partnering with local farmer-focused groups as well as prioritizing the gathering of first-party data. The partnership with AFT will help ensure that the farmer voice is well represented, and the commitment to gathering soil samples will help ground truth nitrogen and carbon outcomes.

There are several areas this project could improve. While the idea of identifying marginalized land for conversion to perennial crops is strong, it is important to include the cost of management change, the availability of markets, and the minimum viable acreage a processing facility would require. Growers will also likely be interested in the crop insurance implications of switching crops.

- This project aims to develop an online geospatial tool for decision making on the conversion of row crops to perennials (SUPERBEEST). The tool considers multiple aspects (productivity, soil, nutrient leaching) for marginality, and it can be used at different scales. It is promising as described, though currently it is not yet available to the public (I recommend making it publicly available even during this initial stage).

  The project also includes other activities to support the development of SUPERBEEST or demonstrate the potential usage of the tool (e.g., fieldwork for soil carbon data collection, nutrient credit trading analysis). It would be very exciting if the project team can have more involve partners throughout the project (e.g., as described for the saturated bioenergy buffer siting task, collecting comments from both farmers and wastewater treatment plant managers on the nutrient trading schemes).

PI RESPONSE TO REVIEWER COMMENTS

- We thank the panelists for their contributions of many positive comments and useful suggestions related to this project. As summarized in the comments, this continuation project aims to drive a thriving bioeconomy while decarbonizing agriculture through the adoption of perennial bioenergy crops by exploring the combination of biomass revenue, ecosystem services payments (including water quality trading schemes), and support for underserved rural regions. Many comments focus on the geospatial tool SUPERBEEST, which continues to be developed. Its planned scope addresses many suggested ideas or concerns. As described in the presentation, SUPERBEEST is adding biorefinery locations to provide users with information on distance to buyers and adding spatial EEEJ information to examine differences in farm income related to farmland marginality. Outreach is important for the future impact of this tool, and, as mentioned in the presentation, we are working closely with the ideal partner, AFT, in a related project (WBS 4.1.2.11 Ecosystem Services Entrepreneurship Technical Assistance). Through that project, we are gathering important input from farmers and industry to inform the technical path for SUPERBEEST development as well as pathways for bioenergy crop adoption by developing educational material and partnerships to identify and overcome some technical challenges of adoption. SUPERBEEST has had a partial public release and will be fully public soon, with announcements made at many relevant conferences and workshops. As mentioned in the presentation, we anticipate that changes in how SUPERBEEST provides economic estimates of changes in cropping at the farm, watershed(s), or county(ies) scale will require continuous modifications to be current and relevant to federal, state, and local government policies and corporate sponsorships. These updates will be necessary because of constant changes in governmental or corporate support for key ecosystem services, such as the water quality trading schemes highlighted in our demand analysis and TEA and the evolving support for carbon sequestration and reduction in GHG emissions. Our efforts with shrub willow, new switchgrass study sites, saturated bioenergy buffers, and scanning technology for SOC will all contribute to the scientific literature to support ground-truthing and model validation, and they represent important partner collaborations. Through the related project WBS 4.1.2.11, we are examining the important topic of crop management change and the associated costs. Crop insurance is a helpful new suggestion that may improve the economic proposition for farmers. Altogether, our intention is to contribute to an economically viable, environmentally friendly, socially equitable future scenario of sustainable perennial bioenergy crops supplying biomass to a growing market and offering low-income farming regions a robust cropping alternative.

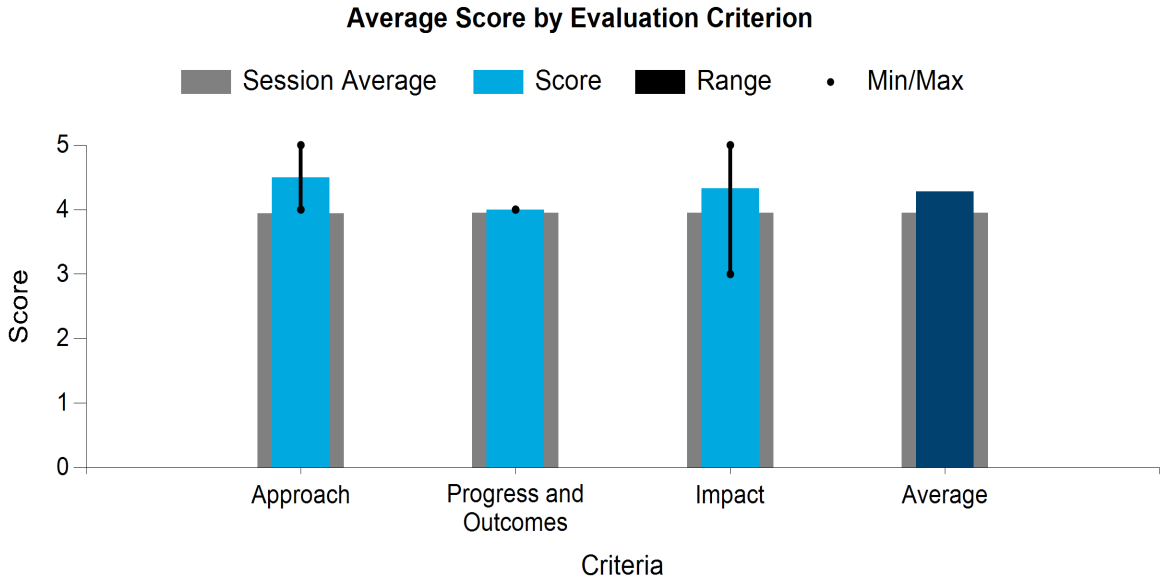
EXCHANGE: EXPANDING THE CONVERSION OF HABITAT IN THE NORTHERN GREAT PLAINS ECOSYSTEM

University of Nebraska – Lincoln

PROJECT DESCRIPTION

WBS:	4.6.1.10
Presenter(s):	Daren Redfearn
Project Start Date:	10/01/2021
Planned Project End Date:	03/31/2027
Total Funding:	$4,000,000

EXCHANGE quantifies and monetizes ecosystem services from the targeted deployment of perennial bioenergy grasses in semiarid, irrigated croplands. The selective return of native perennial grasses to irrigated landscapes fosters the diversification of row crops, livestock, and bioenergy production systems in water-scarce landscapes. This spatially directed innovation for integrating perennial and annual crops enhances climate resilience, sustainability, and security of domestic food and energy production. Expected impacts include improved (1) groundwater sustainability, water quantity, and quality; (2) nutrient retention; (3) pollinator/wildlife habitat to support increased biodiversity; (4) climate change mitigation through increased soil carbon storage and decreased agricultural GHG emissions; and (5) economic risk management by diversification of farm revenue streams. Soil sampling and water sensor installations were deferred due to the COVID-19 pandemic and project funding delays. EXCHANGE successfully established two small-plot trials and measured avian/arthropod populations at 10 paired grassland/cropland on-farm sites. Preliminary results show greater avian/arthropod populations in grasslands than croplands. The first perennial biomass harvests occurred in 2022. Soil GHG emissions summarization and biomass cell-wall parameter analyses are ongoing.



COMMENTS

- This project seems highly valuable, and I find little to criticize. Although the project seems to have gotten off to a slow start, the progress to date seems very promising. The scope of this project seems well suited to provide real-world data to address multiple important analytical needs for BETO. The data on energy grass cultivation seem likely to benefit efforts to develop those feedstocks and move them closer to commercialization. The quantification of ecosystem benefits from these cropping systems provides a

separate set of potentially impactful data. While it remains to be seen how much of this project's potential will be realized, I find little to criticize so far.

- Thank you for the opportunity to review the EXCHANGE project. Based on the information presented, the project appears reasonably aligned with BETO's goals. I appreciate the approach of assessing bioenergy grass production to increase biomass for the bioeconomy while also reducing unsustainable stress on the Ogallala Aquifer and providing ecosystem services. It is also great to see the progress made in tasks 1–4 and the use of SOC measurements at different depths to assess GHG emissions. One opportunity for improvement could be to provide more information on the preliminary data that will be presented to give a better understanding of the project's progress. Additionally, it may be useful to provide more information on the site that was unsuccessful to gain better knowledge of suitable switchgrass acreage and the plant's resilience. Overall, it seems like the project is on schedule and making good progress toward achieving its goals.

- This project uses FOA funding to pursue a more focused analysis of energy crop cobenefits in the Northern Great Plains. This project is very useful to the portfolio because it connects theoretical benefits to real-world practice and data collection. While it is still in its very early stages, this project appears to be making progress toward its intended goals, with the early data collection showing results on wildlife ecosystem services, soil carbon change, and reduced N_2O emissions. In addition to a comparison of impacts of biodiverse farming systems to business-as-usual farming, it could also be helpful to evaluate the trade-offs associated with the planting and harvesting phases to get a more holistic comparison and better understand barriers and challenges.

- This project seeks to improve decision making by quantifying ecosystem services and incentives to bioenergy crops. The project yielded promising preliminary results finding that avian biodiversity was greater in grassland than cropland, and more insect pollinators were observed in grassland than cropland. The project also included a water modeling tool (MODFLOW) to capture changes to the aquifer from bioenergy production. The team brought together a wide range of approaches and tools, from range ecology to remote sensing data, and it has great potential to inform other models and projects.

  In addition to measurements at the field stations that showed promising results, it would be interesting to explore why the High Plains Agricultural Lab fizzled? It would be useful to explore this to understand what factors contribute to resilient systems.

  The two test sites, Scottsbluff and North Platte, compared aboveground biomass for switchgrass planting versus a low-diversity mix of big bluestem and other grasses. It would be interesting to see how different kinds of ecosystem services might compare between different types of perennial bioenergy plantings.

  The project states that it has potential to support rural socioeconomics in the Northern Great Plains region, which seems intuitively true, but having metrics to support that could make this claim even stronger.

  Creating best management practices for perennial bioenergy crops would have high impact value to farmers, and the project team is well qualified to disseminate results to farmers through Extension work.

  This project is an important inclusion in DOE's portfolio. The ground-truthing data collected here will help to aid growers' understanding of how to be successful and build confidence in the ultimate planting of switchgrass. This project also had the foresight to highlight biodiversity improvements, which are likely to be a driver of future environmental credits alongside carbon payments.

  The project could be made stronger by including industry biofuel representatives. Documentation of test site visits plus testimonials from local ethanol producers would help to build confidence in Nebraska.

The inclusion of the impact on the Ogallala Reservoir through switchgrass will also aid in the generation of additional economic incentives.

- This is a rare and much-needed project that aims to collect ground truth data to quantify the ecosystem service values. A variety of techniques were used to collect data related to SOC, GHG emissions, biodiversity, evapotranspiration, etc. Multiple plots were established and monitored to compare various scenarios (switchgrass versus low-diversity mix versus no-till corn, rain-fed versus irrigated, different sites). Field data were also leveraged in multiple models to understand the larger implications through TEA (economic), LCA (environmental), and ecosystem services valuation. The project has clear goals, coherent tasks, and is expected to provide critical information related to the application of perennial grass toward improving ecosystem quality while contributing to the bioeconomy.

PI RESPONSE TO REVIEWER COMMENTS

- The EXCHANGE team expresses our appreciation for the reviewers' efforts and input. We realize the time commitment involved to conduct a thorough Project Peer Review process. The review team's compliments on the achievements and suggestions for improvements are greatly appreciated. These suggestions will be extremely valuable in guiding the project moving forward. Generally, our plan is to include metrics on ecosystem services, trade-offs, and industry needs once additional data are available. The EXCHANGE project will provide supplementary data that can be coupled with some of our existing data sets to confront some important challenges identified by the reviewers. Several reviewers requested additional insight on the site information that resulted in unsuccessful bioenergy grass stand development. Part of the general premise for the project was to determine if these bioenergy cultivars could be used outside the recommended region. We generally do not recommend planting switchgrass, big bluestem, and Indiangrass for bioenergy production west of the 100th meridian. Of the three sites selected for small-plot bioenergy grass evaluations, two were successfully established (Scottsbluff, Nebraska, and North Platte, Nebraska), and one was an establishment failure (Sidney, Nebraska, is more than 150 miles west of the 100th meridian). Both the Sidney and Scottsbluff locations are classified as having a semiarid climate. Supplemental irrigation was available at both Scottsbluff and North Platte, whereas the Sidney site was dryland and nonirrigated. We purposely included a dryland (nonirrigated) site to test the risks associated with establishing bioenergy grasses under extreme conditions in a dryland, semiarid environment. All three sites were planted in spring 2021. The two sites with supplemental irrigation were successfully established in spring 2022, with the first biomass production data from those two sites collected in 2023. For the Sidney location, grass emergence and establishment were hampered by significant drought in 2021, resulting in thin stands. We chose to replant for the second time in spring 2022, and we planted corn for the business-as-usual comparison. Severe drought conditions persisted throughout the 2022 growing season, and grassy weeds continued to be problematic due to poor grass stands. The corn grew to about 4 feet but never produced grain. The Sidney site experienced two consecutive years of drought, resulting in poor seedling emergence and failed stand establishment. In spring 2023, we chose to abandon the dryland site (Sidney) and focus resources on Scottsbluff and North Platte. Again, the EXCHANGE team greatly appreciates the positive comments and feedback for this project. We look forward to continuing the process of data collection to support the understanding of the larger economic, environmental, and ecosystem services implications of bioenergy perennial grass production systems affecting the Northern Great Plains Ogallala Aquifer.

EVALUATION OF ENERGYCANE FOR BIOENERGY AND SUSTAINABLE AGRICULTURAL SYSTEMS (EC-BIOSALTS)

University of Florida

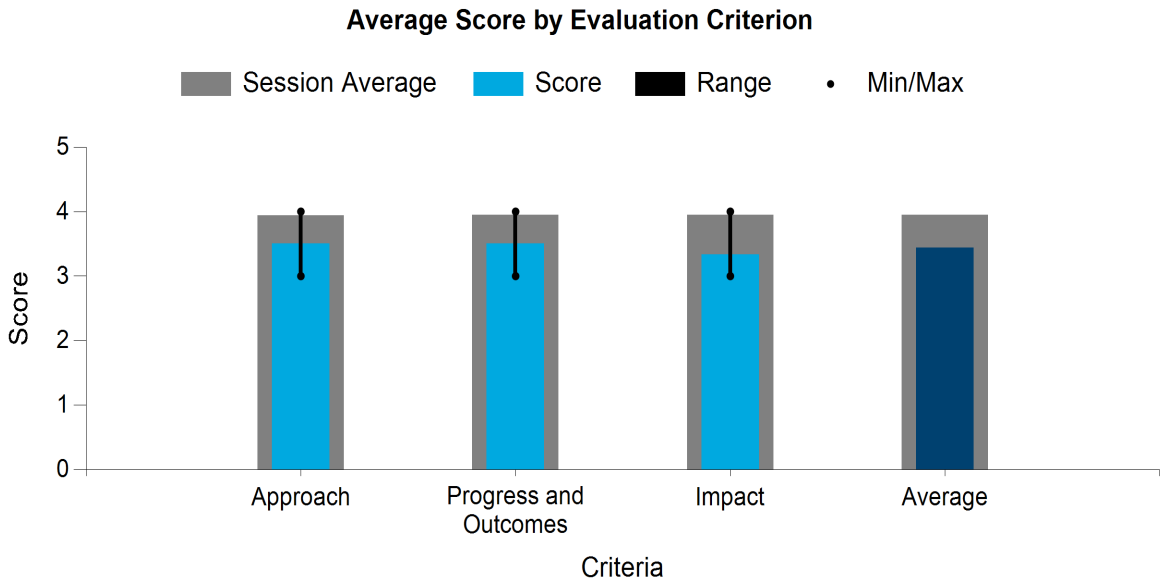
PROJECT DESCRIPTION

WBS:	4.6.1.20
Presenter(s):	Hardev Sandhu
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2025
Total Funding:	$4,991,921

Blue-green algal blooms and red tides are major environmental challenges in the U.S southeastern coastal plains, particularly in Florida, where they are a threat to public health and are affecting aquatic life, wetlands, and agriculture. Nitrogen (N) and phosphorus (P) runoff from agricultural fields are considered some of the major causes of blue-green algal blooms in rivers and lakes and red tides in the coastal waters. In this project, we are evaluating energy cane for ecosystem services, including reduced N and P losses and GHG emissions and improved soil carbon (C) storage and biodiversity in marginal agricultural lands of the U.S southeastern coastal plains. The overall goal of this project is to develop a bioenergy feedstock production system using an advanced energy cane cultivar (UFCP 84-1047) in marginal and fallow croplands of the U.S southeastern coastal plains. Specific objectives are to: (1) evaluate the yield and quality of currently available UFCP 84-1047 and advanced energy cane cultivar for bioenergy at the field scale in marginal and fallow croplands to predict biomass yield potential and determine suitable agronomic practices, (2) quantify the ecosystem services of UFCP 84-1047 compared to sugarcane and sweet corn cropping systems on marginal and fallow croplands, (3) test sensors for estimating environmental parameters and energy cane's agronomic attributes and ground truth information management platforms, (4) develop a machine learning-based model that can predict energy cane's agronomic attributes (yield and feedstock chemical composition) given a collection of environmental and crop management parameters, (5) use field-scale data to generate baseline and enhanced (with projected market values of ecosystem services) TEA to quantify opportunities to meet BETO's cost goal of <$3/gasoline gallon equivalent (GGE) with >4 ton per acre yield and a refinery delivery cost of <$84/ton, (6) develop an LCA, and (7) develop a market transformation plan. This project will enable the creation of a field-scale demonstration on how to sustainably embed bioenergy crops in marginally productive croplands of the U.S southeastern coastal plains, a region in the United States that could potentially supply large amounts of biomass for the bioeconomy. Field-scale production and demonstration will allow us to generate data of quality and quantity not achieved before for the proposed unique production system using one of the most productive bioenergy crops suitable for subtropical growing conditions. The expected multiple project outputs directly support the growing U.S. bioeconomy. These include remote sensing and modeling tools, high-resolution information on production, feedstock compositional characteristics, economic potential, LCA, a market transformation plan that specifies the path to the integration of biofuel and bioproduct production into the local and regional economic systems, and sustainability of energy cane in the U.S southeastern coastal plains. We anticipate being able to achieve BETO's biofuel price point goal of <$3/GGE. The development of remote sensing technology for the cost-effective and rapid data collection as well as machine learning model with agronomic predictive capabilities directly supports efforts toward using precision agriculture in bioenergy cropping systems. Additional impacts of this project are in the forms of field visits, training workshops, data dissemination through the KDF, peer-reviewed publications, and presentations at various national and international conferences.

Currently, we are in the 18th month of this project. Baseline data collection and energy cane seed cane propagation for field trials are successfully completed, which was required for our first go/no-go decision. The actual field trials are successfully planted at two locations: Everglades Research and Education Center in Belle Glade, Florida, and Indian River Research and Education Center in Fort Pierce, Florida. We are currently

collecting data on energy cane biomass and ecosystem services in plant cane. Data on two ratoon crops will be collected in the third and fourth budget periods.



COMMENTS

- The goals and approach for this project seem valuable. Though energy cane may have a smaller overall range than some other potential cellulosic feedstocks, feedstock diversity is valuable. And there do seem to be some significant opportunities and potential environmental cobenefits. That said, it is difficult to provide much assessment of the progress, outcome, and ultimate impact of this project given that its start has been significantly delayed. For now, I will just say that the potential for an excellent project seems to be there, and I look forward to seeing how it progresses.

- Thank you for the opportunity to review the EC-BioSALTS project. The project is reasonably aligned with BETO's goals, particularly in their consideration of SAF. I was impressed with the team's detailed and comprehensive approach, including the development of a machine learning model for yield and feedstock chemical composition. The progress and outcomes of the project are on schedule, with data collection ongoing and several milestones completed. I appreciate the focus on environmental and economic measurements as well as the potential impact of the project on reducing GHG emissions through the use of energy cane-derived SAF. One area of improvement could be to discuss the machine learning data sets in more detail and to ensure the results can be replicable.

- This project is very focused and builds out understanding of the potential for energy cane in the southeast. Beyond energy potential, this project also illustrates several cobenefits, such as improved water quality and soil quality improvements that are unique to the Florida region. Particularly compelling was the potential for energy cane to benefit from existing supply chains and practices applied to conventional sugar cane.

  The project is still in the relatively early stages due to a delay associated with the negotiation period, so its progress is difficult to evaluate. Early results suggest success in matching measured data with previous reports on GHG fluxes and soil quality improvements. It also appears that in an LCA sense, the project is well on its way of demonstrating the GHG benefits of energy cane systems; however, as noted as a trend with these projects, it would be helpful to integrate more farmer and industry perspectives on

the techniques implied by integrated land management and their feasibility. I think this would help to increase understanding beyond data collection, LCA, and TEA.

- This project seeks to quantify sustainability benefits such as GHG emissions reductions through LCA by evaluating supply chains in the production of energy cane. The project acknowledges that risks associated with energy cane production include prolonged drought, flooding, insect pests, and diseases. These seem like very real risks given current climate scenarios. The project aims to mitigate these risks through different genetic varieties of energy cane, but given the intensity and frequency of climate events in Florida, it seems worth exploring these risks a bit more.

  The project includes an advisory committee. What stakeholder groups are represented on this advisory committee, and how were different stakeholder perspectives integrated into the project development?

  The project claims to contribute to BETO's goals of DEI and workforce development by involving students from diverse backgrounds in research project activities. What did this look like? How many students were involved? What did they do on the project?

  How are the social dimensions of sustainability addressed? For example, how does the project address things outside of traditional LCA, such as access to land, land ownership and use, decision making about land, land ownership, workforce? How does the supply chain analysis account for labor issues, particularly given that citrus growers rely on migrant labor? What kinds of human capital (i.e., labor) are required for the production of energy cane? Perhaps this is something the project could consider in future iterations of this work.

- Overall, the opportunity for energy cane as a feedstock was not clear. The presentation identified major changes in orange production, but it was not clear if and why energy cane would be a suitable substitute. An evaluation of total addressable acres likely to adopt based on agronomic or land quality factors is required to better evaluate the importance of this potential feedstock. It would also be useful to evaluate how available land suitability and availability may change due to climate volatility.

- The partnership with LanzaTech is a nice connection with industry, and it would be helpful to include the parameters by which they evaluate the viability and competitiveness of a feedstock. Extension of stakeholder connections to environmental groups and growers would strengthen this project.

- This project focuses on the development of energy cane as a new bioenergy feedstock for the southeastern United States. It is meaningful in diversifying the portfolio of bioenergy feedstocks with options that might be more appropriate for a certain region, and a series of field and modeling activities have been performed/are planned.

  However, the research team did not fully justify the motivations/contributions of this project, especially given that the application of energy cane (although it is more cold-tolerate than sugarcane) is likely to be limited to a few states in the United States, and it is unclear if energy cane will be more beneficial for the ecosystem than perennial grass. Additionally, the team proposed to incorporate energy cane in conventional sugarcane and sweet corn cropping systems, but this will add non-negligible risk for farmers as they shift from established crops with a mature market to new feedstocks without potential buyers; therefore, the project team is encouraged to answer these questions through research activities in the future.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the panelists for their helpful feedback and suggestions. As reiterated in the comments, the overall aim of the project is to drive the adoption of a thriving and sustainable bioeconomy through the adoption of high-yielding energy cane cultivars in the fallow and marginal croplands of the U.S. southeastern coastal plains to produce SAF and coproducts. We intend to better demonstrate regional

yield potentials and identify how to best transform the market in the region to support a thriving market for SAF and coproducts while providing improved ecosystem services and multiple income streams (e.g., biomass revenue and ecosystem service payments) for farmers/producers.

An important comment touched on the clarity and replicability of our machine learning model development process. In response, this process will be further laid out in progress reports and in our findings. The data sets needed for training and testing machine learning algorithms include energy cane biomass yield and quality, weather parameters, topographic features, and soil properties, which will be generated from field data and online databases. Weather parameters (air temperature, precipitation, etc.) will be generated from databases associated with nearby weather stations maintained by the USDA NRCS, National Oceanic and Atmospheric Administration, etc. Topographic features (elevation, slope, etc.) will be derived from the 3-m digital elevation model of the U.S. Geological Survey National Elevation Dataset. The rest of the data sets will be generated from data collected from the field site. Energy cane biomass yield and quality data will be generated from the outputs of the remote sensing task (using drones). Expected outputs from the remote sensing task are heat maps of the end-of-season biomass yield and quality at 1- to 3-m spatial resolution, which will be validated by actual biomass collected from each plot using 3 x 3-m quadrats throughout the growing season. Heat maps of 8–10 soil parameters will be generated from point sample measurements conducted as part of the study site characterization. The key is to create a gridded data set of the response variables (biomass yield and quality) and all the predictors or explanatory variables (climate, soil, topography, etc.) at a common horizontal spatial resolution for each experimental plot. The final choice of horizontal spatial resolution will be dictated by the spatial resolution of the biomass yield and quality maps produced from the remote sensing task, which is expected to be 3 m. We will follow a similar modeling framework from our work in the U.S. Midwest on the application of machine learning in predicting biomass yield, which has been published (https://doi.org/10.3390/en16104168).

Other comments touched on the LCA process. There is an emphasis on analyzing an LCA focused on life cycle GHG emissions, which aligns with DOE's priorities. The results of the TEA and LCA will provide valuable insights into the major factors that contribute to both cost and GHG emissions of the project. These factors primarily stem from energy consumption and chemical usage (e.g., fertilizers) during farming as well as fuel production. The TEA and LCA team will conduct a thorough assessment to identify potential opportunities for achieving further cost and emissions reductions through various activities across farming and fuel production stages. Further, the team will explore innovative farming techniques, such as a reduction in nitrogen application within marginal lands and crop diversification strategies for soil and water management, that could contribute to these objectives. Additionally, the team will address the feasibility of implementing these techniques and consider their practicality in our operations. By integrating these findings and discussions, we aim to optimize our practices, reduce costs, and minimize our environmental impact. The social LCA, which examines the social dimensions of the pathway, is currently not within the scope of this project; however, we recognize that the inputs and outcomes from the current study can be used for future social LCA efforts. By using harmonized conditions, these analyses can effectively identify trade-offs between environmental and social impacts. Although it is outside the immediate scope, the findings of the present study can serve as a foundation for conducting comprehensive assessments that encompass both environmental and social aspects in the future.

As to the suitability and applicability of energy cane within the region, we will ensure that the following information is clear throughout our upcoming reports. High-yielding (advanced) energy cane cultivar production is a desirable substitute for fallow citrus lands for several reasons, primarily because our initial assessment showed that most lands that are ideal for advanced energy cane feedstock production for SAF and coproducts in Florida are fallow lands that used to be under citrus production. Except for a very small portion enrolled in the water farming program administered by the South Florida Water Management district, these fallow lands are mostly left unused, leaving landowners and farmers

incomeless. Previous evaluation of energy cane in Central and South Florida showed high biomass yields (30–34 Mg/ha) on marginal sandy soils, which were under most of the citrus production in Florida. In addition, a more extensive deep-rooting system of energy cane than sugarcane and some other perennial grasses makes it more efficient in soil carbon sequestration and the use of water and nutrients, which can reduce nutrient runoff to water bodies. Energy cane cultivation is very similar to sugarcane, which is mostly mechanized and needs minimum human labor. Converting these fallow and/or marginal lands into sustainable energy cane feedstock production systems will boost the rural economy. Sales from energy cane biomass will provide income to landowners and farmers. Additionally, payment for ecosystem services (especially subsoil carbon sequestration because citrus fallow lands in this region primarily comprise sandy soils) will provide more income to landowners and farmers, providing further economic incentive for this diversification of crops. We are, in fact, conducting a formal analysis to assess the total addressable acreage of land in Florida that is likely going to adopt a sustainable energy cane feedstock production for SAF. The results of this analysis will be available by the end of this fiscal year, which are critical for our analyses to better understand the energy cane feedstock supply chain and impacts on ecosystem services.

We acknowledge the merits of the reviewer's suggestion to include climate change impacts on the land availability analysis. In this project, we are focused on the assessment and valuation of short-term carbon sequestration and other ecosystem service impacts at scale in Florida. Long-term impacts are beyond the scope of this project; however, inputs, process, and outcomes generated in this project when coupled with a downscaled climate data set at high horizontal spatial resolution can be used to determine long-term climate impacts. A downscaled climate data set at a high horizontal spatial resolution of 1 km could become available and accessible in a few years, particularly for North America, based on the work of climate scientists, including that of our colleagues at ANL. Future projects can leverage a downscaled climate data set of Florida at 1-km horizontal spatial resolution along with the foundational data sets and outcomes from this current project to better understand the long-term impacts of climate on the proposed energy cane feedstock production system in the U.S southeastern coastal plains region.

This project's focus on diversity and equity is primarily within diversifying the workforce development training for science, technology, engineering, and mathematics students. At national laboratories, DOE has a couple programs designed to provide a 10-week paid internship for talented students from academic institutions, including land grant universities, historically Black colleges and universities, and community colleges. Talented student research interns from diverse backgrounds and multiple academic institutions have been part of the ANL team since 2012 through the DOE's Science Undergraduate Laboratory Internship program. As part of the team, they are exposed to a wide range of activities geared toward building their professional and research skills during brainstorming and project planning meetings, teamwork activities (e.g., working in pairs during field data collection and laboratory experimental activities), literature reviews, technical report and journal paper writing, and data processing and analysis. Most importantly, each intern is required to work on a specific research problem (typically a subset of our BETO project deliverable) that could be done within the 10-week period. They will then present the results of their research as poster presentations in a laboratory-wide culmination activity for all student research interns. This summer, two student research interns (a male and a female) will join the ANL team for 10 weeks to work on not only the EC-BioSALTS project but also the other BETO-funded projects, such as the Affordable and Sustainable Energy Crops (ASEC) – Switchgrass and EXCHANGE.

Currently, the advisory panel includes members from the Florida Department of Agriculture and Consumer Services, South Florida Water Management District, Florida Department of Environment Protection, Florida Energy Systems Consortium, USDA Agricultural Research Service, University of South Florida, and LanzaTech. At present, there is no specific plan to target diverse stakeholders and other communities in the study area. Following the geospatial analysis of suitable agricultural lands for energy crop adoption, we can better understand the potential demographics of farmers and landowners.

Outreach is not built into this project, but the geospatial data derived from the project can provide context for future projects that will focus on outreach and education regarding these crops. We thank the reviewers for their feedback, and we look forward to working closely with BETO to maximize this project's potential during the next few years.

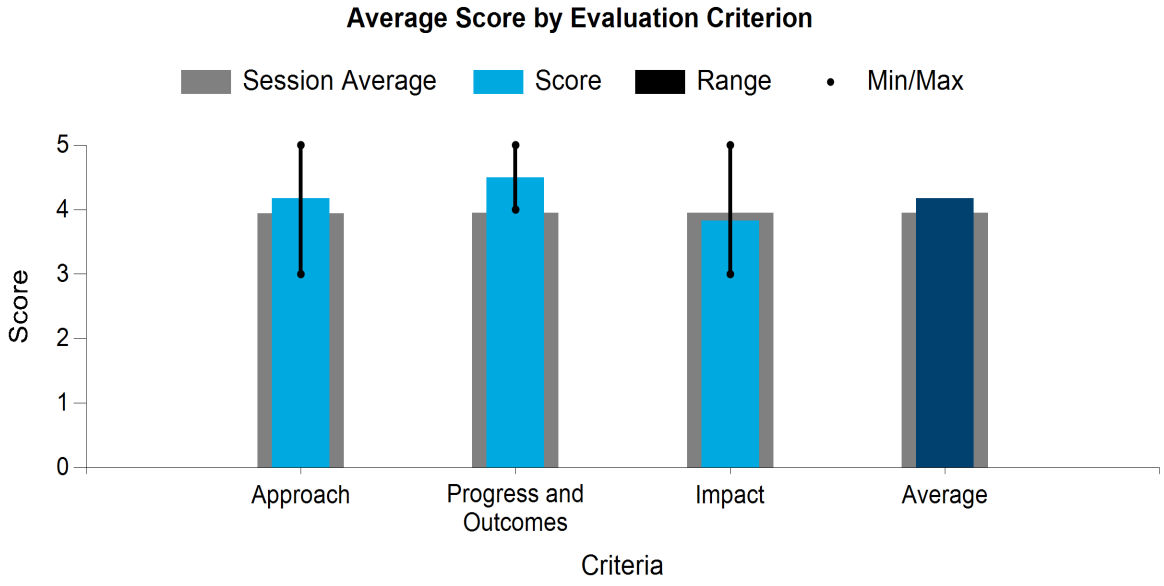
POSIES: POPULUS IN THE SOUTHEAST FOR INTEGRATED ECOSYSTEM SERVICES

Mississippi State University

PROJECT DESCRIPTION

WBS:	4.6.1.30
Presenter(s):	Heidi Renninger
Project Start Date:	10/01/2020
Planned Project End Date:	08/31/2023
Total Funding:	$2,544,896

The southeastern United States has great potential for growing poplar (*Populus spp.*) biomass, although costs are still higher than traditional fossil fuels. The incorporation and efficient quantification of ecosystem services may diversify income streams to reduce final costs, reduce market volatility risks, and provide additional benefits to society; therefore, our goal is to reduce the final cost of Populus feedstock production in the southeast by (1) enhancing productivity (through cultural planting practices and inoculation with endophytic bacteria), (2) quantifying ecosystem service provision (nitrogen mitigation and belowground carbon (C) storage), (3) developing remote sensing strategies to enable faster quantification of ecosystem services and productivity, and (4) integrating all findings into an updated TEA for short-rotation Populus plantations in the southeast. So far, we have identified Populus genotypes that exhibit biomass of more than 20 Mg/ha/yr on high-quality sites, increases of more than 91% with endophyte inoculation on poor sites, and increases of more than 30% based on cultural planting practices. Soil C in plantations increased by 13% and nitrate decreased by 20% compared with row crop agriculture. Near-infrared reflectance and LiDAR-predicted soil C and aboveground biomass with r2 of 0.73 and 0.97, respectively. In total, incorporating ecosystem services from Populus may be essential for meeting targets of $3/GGE for biofuels.



COMMENTS

- This project is doing highly valuable empirical work. Scaling up bioenergy crops cannot happen without work like this to test systems and growing strategies and gather data on the potential ecosystem benefits (and associated revenues). This approach will generate valuable data for other researchers and potential bioenergy crop growers. My only suggestion is that it seems like this project is an excellent context in

which to develop harvesting machinery and logistics for poplar cropping systems. I encourage the project team to not neglect this opportunity as they pursue the valuable work of assessing genotypes and environmental impacts.

- Thank you for the opportunity to review the PoSIES project. From my analysis, the project is reasonably aligned with BETO's goals. I appreciate the use of short-rotation woody crops like poplar to assess ecosystem services, productivity, and variability while considering cost-competitive measures. The incorporation of technology such as lidar/drones to quantify soil carbon and biodiversity is commendable. The preliminary financial estimates and the quantification of impacts for farmers are also innovative. Additionally, the 22% decrease in nitrate relative to the agricultural field shows significant progress toward sustainable agriculture. As an opportunity for improvement, the project should further develop ecosystem services and quantifying disservices with dynamic considerations because these are likely to be sensitive to time. Additionally, and as other researchers noted, it may be useful to include harvest time as an endogenous variable in the optimization considerations. From what I understand, the project is on schedule, and I look forward to further updates.

- This project is a good opportunity to use FOA funding to do more targeted work on a specific feedstock in a region of interest to generate real-world data. The outcome of this work has broader relevance to unlocking a large potential pool of sustainably available biomass with some ecosystem cobenefits, which aligns well with BETO's and DOE's goals. The project has a very clear focus, and the emphasis on assessing and improving productivity from poplar stands, particularly on more challenging sites, fills an important niche. It is not clear from the approach, however, to what degree this project is focused on using marginal lands unsuitable for conventional production or whether it is intended to be implemented at larger scales on more conventional land types.

  While it is still relatively early in the life of the project, the initial outcomes and progress appear promising—in particular, the use of bacteria to improve productivity at more challenging sites as well as demonstrating cropping with reduced inputs.

- This project takes an innovative approach to examining ecosystem services and potential ecosystem disservices from poplar plantations grown in the southeast, potentially feeding markets for SAF. The project has great potential for impact to farmers, researchers, and bioenergy investors. The project team talks about working with stakeholder groups from industry, nonprofits, government agencies, landowners, and farmer organizations in yearly meetings and semiannual email reports. I am curious to know how feedback from those groups has been incorporated into the project? What function does the stakeholder advisory panel play in project development?

  Another question I had but that was thoughtfully addressed at the review: Is there potential for competition with other markets for these feedstocks? The project team mentions that if there are insufficient bioenergy markets, the material could supply traditional hardwood markets. Is there any concern about competition with pulp and paper industries, pellet markets, or emerging biomaterials (cross-laminated/mass timber, etc.?)

  The project team notes that hybrid poplar genotypes outperformed older eastern cottonwood genotypes. How do potential ecosystem services and disservices compare across the different genotypes? Impacts on wildlife? GHG? Water? How do different types of ecosystem services compare to one another in terms of assigning value to water quality versus biodiversity for example? That may be beyond the scope of this project but is possibly something to consider for future work.

  Poplar clones were developed by the USFS for the pulp and paper industry back in the mid- to late 20th century. What can we learn about the long-term sustainability of poplar from past studies on USFS

efforts to pulp and paper production? Are there any long-term poplar study sites that have looked at some factors covered in this project?

Although it might be beyond the scope of this project, the team might want to check out the following to situate this project in the broader socioeconomic context: https://rowman.com/ISBN/9781793632357/Forests-as-Fuel-Energy-Landscape-Climate-and-Race-in-the-U-S-South.

Overall, this project had clear objectives and has made good progress on those goals. They have communicated and collaborated with other groups and partners from industry and NGOs. The project makes important contributions to understanding bioenergy production at a very practical, field-based level.

- This project adds important data to DOE's understanding of the cost, productivity, and agronomic viability of poplar. The improvements in predicting carbon sequestration and tree mass gain are exciting outcomes of the work to date. This project also excelled in stakeholder engagement. Pricing carbon payments with a carbon project developer, wood demand with a pellet facility, technical assistance with a conservation group, and direct feedback from growers all lead to better outcomes of the research and make it more likely that recommendations will be adopted.

  There are several risks with planting a harvested crop on marginal land that this program can address. First, having clear delineations between the characteristics of marginal land that can impact grower outcomes can help better inform expectations and decisions. Second, an economic analysis of minimum viable acres would be useful to understand how much land should be dedicated to the effort in a single operation to be financially viable. Finally, it would be good to understand whether it would negatively impact the productivity of the poplars if fertilization of the main cash crop were to change and nutrient runoff were be reduced through improved farming practices or a shift in synthetic fertilizer application.

- This project evaluates the use of poplar (new genotypes, use of endophytes, etc.) for biofuels while providing ecosystem services. Highlights of this project include the establishment of multiple research sites (with measurements on SOC, water, biodiversity), improvement on data collection approaches, and involvement of multiple stakeholders (advisory panel with regular meetings); however, a key caveat is that the industry advisors do not seem to be interested in the genotypes developed in this project, and it is highly recommended that the project team works with the advisors to pilot-test the genotypes or to understand what metrics the new genotypes should reach before industries are willing to test them.

PI RESPONSE TO REVIEWER COMMENTS

- Thank you for all the helpful suggestions and the time and effort you took to review our project. We agree that harvesting machinery and logistics will be important as more broad-scale production occurs, although our study plots are not large enough to adequately answer this question. While not the scope of our study, other researchers have evaluated harvesting systems and timing (see https://doi.org/10.1016/j.biombioe.2017.09.003 and https://doi.org/10.1016/j.biombioe.2021.106075). The most useful new research would probably be TEA and LCA comparisons between 2- to 3-year coppice cycles with single-pass cut-and-chip harvesting compared to 10- to 15-year single-stem rotations harvested and chipped with traditional logging equipment in the southeastern United States. This is beyond the scope of our study in space (our plots are all too small for operational comparisons) and time (we do not have 10- to 15-year-old trees to harvest), but it would be valuable information for landowners. Minimum viable acres would also be interesting to determine, but that is also beyond the scope of our study. Landowners potentially also have the potential to work with neighbors to coordinate the harvesting of individually smaller plots if they are on the same planting schedule.

While not presented at this year's Project Peer Review, we are quantifying potential ecosystem disservices of water use, wildlife biodiversity, and trace gas and carbon dioxide emissions through time at various field sites. These will be compared across genotypes and planting designs and their scale compared with one another. We will definitely check out Sarah Hitchner's book because it sounds like it will be useful in putting our research into a broader context.

In terms of marginal land, we have a range of sites based on availability of more or less "free" land that is likely all considered marginal, or it would be in agricultural production. Implications for different degrees of "marginal" versus conventional agricultural land are probably better addressed through modeling, which our field data can contribute to, and some of which has been done already for our target system (see https://doi.org/10.1016/j.biombioe.2015.05.004, https://www.fs.usda.gov/research/treesearch/54326, and https://doi.org/10.1016/j.biombioe.2010.01.012). But we agree that more data connecting land characteristics (i.e., how marginal is the land) with growth and productivity predictions will be useful to landowners.

This study is also collecting a large amount of physiological data that can be used to drive process-based models of poplar growth at the genotype level. Our study is able to look a bit at the effect of the nearby fertilization of agricultural fields on growth because most sites are near agricultural land on a rotation between corn and soybeans (with corn being fertilized with synthetic fertilizer and soybeans not receiving extra fertilizer). Although soybeans fix nitrogen and may contribute more nitrogen to our poplar trees, it is likely much less than during corn production. We also have other sites that are not in direct contact with agricultural fertilization, but they are growing very well (suggesting that an external fertilizer source is not essential for good growth but may help).

Our stakeholder advisory board provides feedback on our data and will likely provide valuable input as we begin the TEA. It would have been good to have stakeholder input for project development; however, due to the short-term nature of the study, we needed to get trees planted as soon as possible, which was before stakeholders could provide suggestions for experimental design, etc. We have stakeholders who were a part of the original USFS trials and others with decades of experience in Populus research, and their expertise has been useful. Most trials in the past have focused on growth, disease resistance, and survival, with few looking at ecosystem services and impacts and tree-level physiology. We have a few of the older USFS genotypes in our study as well to provide continuity with older studies. To our knowledge, the older trials have not been maintained and monitored beyond the initial studies that planted them. In terms of competition with other markets, the hardwood pulp market is generally oversupplied, with exceptions in some geographies close to specific mills, so there is likely not competition there. Poplar is not currently considered suitable for cross-laminated timber products that are more suited to softwood species (southern pine, Douglas fir, etc.). On longer rotations, poplar has potential for plywood applications and even dimensional lumber. Grown on short coppice rotations, poplar is most suited for bioenergy, pellet markets, and emerging biomaterials, including lignin-based bioproducts; however, these markets are either in their infancy (bioenergy, SAF, and bioproducts) or have other sources of material (wood from thinned pine stands that are overly abundant in the south) in terms of pellet markets. But it is likely that as bioenergy and bioproducts markets emerge, industry will become more interested in the new genotypes being tested in this study. From past experience and our stakeholder panel, we know in general what industry values for genotypes (productivity, survival, disease resistance, wood quality parameters), but the production of stool beds to provide material to establish large-scale plantations of these new genotypes also will needs to be developed before they can be implemented in large-scale production.

BIOFUELS INFORMATION CENTER (BIC)

National Renewable Energy Laboratory

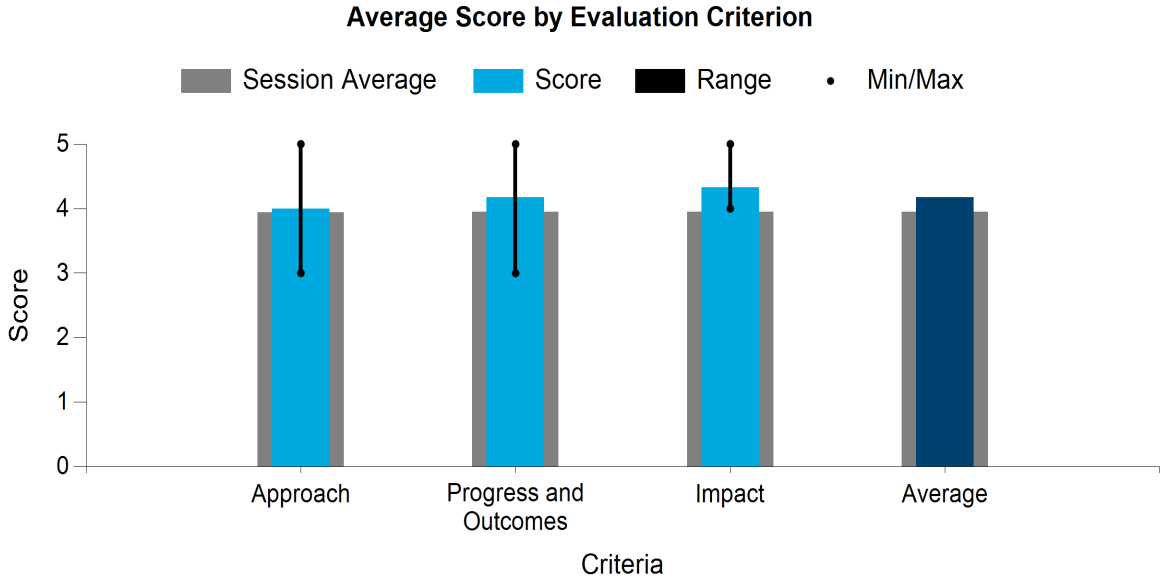
PROJECT DESCRIPTION

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

WBS:	6.3.0.1
Presenter(s):	Kristi Moriarty
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2025
Total Funding:	$1,060,000

The BIC 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 (currently archived; previous address https://maps.nrel.gov). This task results in more than 1.7 million webpage views per year. In FY 2022, the task completed the final year of the five-year USDA Biofuels Infrastructure Partnership (BIP). The BIP expanded infrastructure for E15 and/or E85 to approximately 850 stations, and NREL received and reviewed data for quality and analyzed all infrastructure and sales data collected by 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, cost to install new equipment) and sales data (price and volume for E10, E15, E85, and diesel by month). The 2021 BIP national summary report is with DOE for review prior to publication. Future work will include the biannual *Bioenergy Industry Status Report* (four previous versions have been published).

The task also supports the PI's time to engage stakeholders on infrastructure and the deployment of biofuels. This includes leading, membership, and participation in the following roles: member of the board of advisors at the Fuels Institute, voting member for multiple UL standards committees, co-chair of the Infrastructure Team at Agriculture/Auto/Ethanol, and member of the Coordination Research Council's ULSD Corrosion Committee. The PI routinely responds to industry inquires to assist in the regular deployment of biofuels.



COMMENTS

- The data products and visualizations generated by this project are important for a wide array of stakeholders. Overall, the BIC is a valuable public resource. I have no criticisms with regard to the approach and impact. My main suggestion is that the project team should consider how they might begin to provide information on biochemicals. It would be very valuable to visualize for the public where bio-based chemicals are being produced.

- Thank you for the opportunity to review the BIC, a project that is well aligned with BETO's goals. The BIC website provides comprehensive and valuable information on biofuels, and its progress and outcomes demonstrate that it is on schedule. The addition of bioenergy-based chemicals to the repository is a positive development, and efforts to improve data quality will be beneficial to all stakeholders. One opportunity for improvement is to better capture the impact of the project beyond page views, such as through user feedback or case studies. Additionally, it may be worth exploring the use of BIC as a tool for BETO modeling groups to better exchange and track various model output data streams. As many of the projects have shown, there is immense inter-dependability across frameworks, and it is difficult to keep data consistently updated, track which model output came from which run, and substitute models that become discontinued in such an interconnected framework. Overall, BIC is a valuable resource for stakeholders in the biofuels industry.

- This project has a very clear objective and role, and the relevance and importance of the project is underscored by its wide adoption, as measured in page views. This project fills an important niche because the data are extremely challenging to collect and yet they are compiled in one convenient place with excellent organization and data visualization. Beyond page views, it appears that this project has also attracted significant attention from industry and policymakers.

- This project is very helpful in maintaining an open and transparent information economy around bioenergy. The project team has clearly collaborated with related projects, advisory boards, and different agencies to provide data, information, reports, and web-based tools to a wide range of users. The project team has made progress toward addressing their goals. BIC will have immediate beneficial impacts to many people and organizations and is worthy of funding. I encourage the project team to consider how BIC can be used to further the understanding of diversity and equity issues related to bioenergy development. There are many ways in which these web tools are helpful in that regard, but emphasizing those more could help align this work with broader DOE goals.

- This project is crucial to bringing data from USDA's BIP to the public. Time spent cleaning and confirming the validity of data is valuable and will enhance the accuracy of all future modeling.

  The partnership between USDA and DOE for this program is an important one and is a strong component of this program. Stakeholder engagement with other agencies, industry, and academic institutions is comprehensive.

  The annual cadence of updating the model is appropriate and useful without being too frequent.

  Because public engagement and the usability of data are goals of this project, it is important to measure and report on the use in the form of page views, time spent on the website, downloads, etc. It would also be useful to measure user satisfaction and gather recommendations for improvements.

- Despite the limited budget, this project has curated a great number of easily accessible resources that have benefited a wide group of stakeholders (nearly 1.8 million page visits in FY 2022). The team is also adjusting/updating the information based on user inputs and trends (e.g., adding an SAF page). With the high level of interest in SAF, this project will likely have more users in the next few years, and some

platforms and data collection methods can be modernized to enable easier usage and improve efficiency. Other web portals (e.g., the Bioenergy KDF) could also include links to BIC to increase accessibility.

PI RESPONSE TO REVIEWER COMMENTS

- The PI thanks the reviewers for their comments. Biochemicals: The project will include biochemical data and information in the *Bioenergy Industry Status Report* (FY 2023) and the revived BioEnergy Atlas tools where possible (FY 2024). Diversity and equity: The project will include appropriate data layers in the revived BioEnergy Atlas tools. Stakeholder engagement: The project will seek input and recommendations from Alternative Fuels Data Center users. BETO modeling groups and outputs is appropriate for ORNL's KDF project rather than BIC.

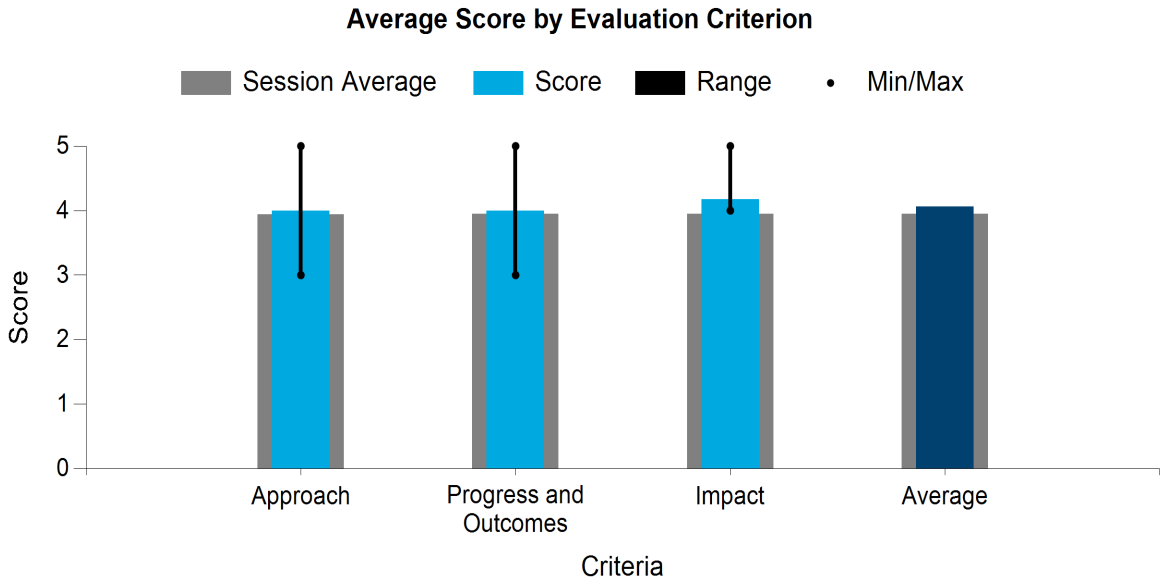
BIOENERGY KNOWLEDGE DISCOVERY FRAMEWORK

Oak Ridge National Laboratory

PROJECT DESCRIPTION

WBS:	6.3.0.2
Presenter(s):	Esther Parish
Project Start Date:	10/01/2022
Planned Project End Date:	09/30/2025
Total Funding:	$1,250,000

The purpose of this project is to develop and maintain a go-to web-based repository of BETO-funded data sets, reports, and publications for researchers proposing new projects needed to accelerate decarbonization and development of the U.S. bioeconomy. The Bioenergy KDF (https://bioenergykdf.net/) has been fundamental in the previous distribution of the *Billion-Ton Report* data sets and visualization tools, and the project is currently working to develop a new database and data download interface for the next *Billion-Ton Report* (expected to be released by the end of 2023). Last year, the project worked with BETO to gather SOT, LCA, and TEA reports and data sets from across the DOE labs and make them available to researchers through one central location. The project has also been working with the Biomass Feedstock Library at INL to align the information that recent BETO FOAs stipulate each awardee must provide to the Biomass Feedstock Library at INL and the KDF at ORNL. The project has also been working to incorporate findable, accessible, interoperable, and reusable (FAIR) data principles through showcasing previously unpublished biorefinery data sets gathered through the Data Valorization project and by developing a new workflow module to automatically generate DOE Office of Scientific and Technical Information digital object identifiers for user-contributed data sets and reports with a standard KDF prefix and a human-readable inset value (e.g., 10.23720/BT23/XXXXXX).



COMMENTS

- The recent progress toward developing new capabilities of the Bioenergy KDF has been highly encouraging. This is an excellent project with a good approach and strong potential for impact. The unknown factor has always been whether the project leads will be able to develop tools and resources that are sufficiently accessible and understandable to potential users. In many ways, the project is finding success here: The goal to make data and data sets FAIR is being realized. For example, the TEA

spreadsheet on the landing page synthesizes critical research that is useful to a wide array of stakeholders in an easily accessible way. Creating a tool to mint new digital object identifier numbers, and using a dedicated prefix, will also make research more easily discoverable. My main feedback is to keep seeking new ways to make more of these data FAIR.

- I appreciate the opportunity to review the Bioenergy KDF project. The project is well aligned with BETO achieving its goals, as an excellent repository of BETO-funded data sets, reports, and publications. The team has made significant progress in adding numerous features and tools, and they focused on researchers as the primary target user. The project could focus more or investigate the feasibility and usefulness of facilitating data exchange between BETO researchers. The project has excellent potential for impact, considering outreach to users; however, the team should consider including usability experience to improve user-friendliness and creating more opportunities for data sharing across tools and frameworks.

- This project has a very clear role in the portfolio and excels at it. It provides a comprehensive repository of BETO resources and makes them accessible for users. Recent updates to the website have improved the user interface and even consolidated complex TEA data to make it easier to cross-reference. The user data suggest that in terms of page views, the popularity of the portal is growing. It could be helpful to develop other metrics to track uptake.

- The goal of this project is to develop and maintain a go-to web-based repository of BETO-funded data sets, reports, and publications. One primary audience is researchers proposing new projects needed to accelerate the decarbonization and development of the U.S. bioeconomy.

  To date, the webpage reflects BETO's emphasis on the economic and environmental dimensions of sustainability. As DOE tries to engage more with questions about equity, socioeconomic impact, and access to decision making, BETO should also move in this direction, and the webpage should reflect these important aspects of sustainable technological development.

  I would love to see more of the platform's emphasis on EEEJ—either weaving it throughout by highlighting how the different databases and models speak to these issues or having a designated landing page. If the terms *energy equity* or *environmental justice* are too esoteric, maybe talk about impacted communities on a section of the outreach page? Maybe this could go under the sustainability tab on the webpage? Is this something the ASEC projects cover? What was the focus of those three projects?

- This project provides excellent access to data and improves the usability of research. The new Office of Scientific and Technical Information and DOI system appears to be useful categorical hygiene.

  While government and lab teams are likely to be aware that this resource exists, it would be good to have an outlined outreach plan to industry to use this system with documented results.

  Previous commenters have asked for site usage, and KDF is currently getting registered with appropriate security measures to allow for that reporting. These metrics are important but may not tell the whole story because value may come not only from the volume of use and number of users but also the quality of use as well. Please also include metrics on quality, such as demographics of users, data accessed, and user satisfaction.

- KDF is a good example of the FAIR principles and has the potential to be the centralized repository for BETO's DMA work. Visualization of the *Billion-Ton Report* has been of great help to researchers. Future work should consider consolidating BETO's models and databases (e.g., with INL's Bioenergy Feedstock Library) so that regular users can just use KDF to find and navigate the resources they want. Additionally, when presenting the *Billion-Ton Report*, it would be great if factors in addition to cost (e.g., GHG emissions, water availability) can be presented together with cost.

PI RESPONSE TO REVIEWER COMMENTS

- ORNL's Bioenergy KDF team would like to thank all the reviewers for their constructive feedback. We will continue to work on making the Bioenergy KDF data sets more FAIR. Google Analytics was deemed a security risk, but we have now installed a Siteimprove tool that will help us gather and track metrics associated with user demographics and interaction with the various pages and tools housed on the Bioenergy KDF. We have also arranged for a usability experience expert to help us design the new 2023 *Billion-Ton Report* data visualization and download tool that will be rolled out near the end of 2023. We will seek to facilitate ways to help BETO researchers exchange data sets with one another through this shared platform, and we will work with BETO to possibly design a landing page to reflect the new and ongoing efforts related to EEEJ. The focus of the three ASEC projects has been on gathering field measurements and environmental metrics associated with dedicated energy crop production: The ASEC project led by the University of Illinois is focused on advanced switchgrass cultivars, the ASEC project led by Texas A&M is working with three new genotypes of energy cane and three new genotypes of biomass sorghum, and the ASEC project led by North Carolina State University was focused on the production of miscanthus.

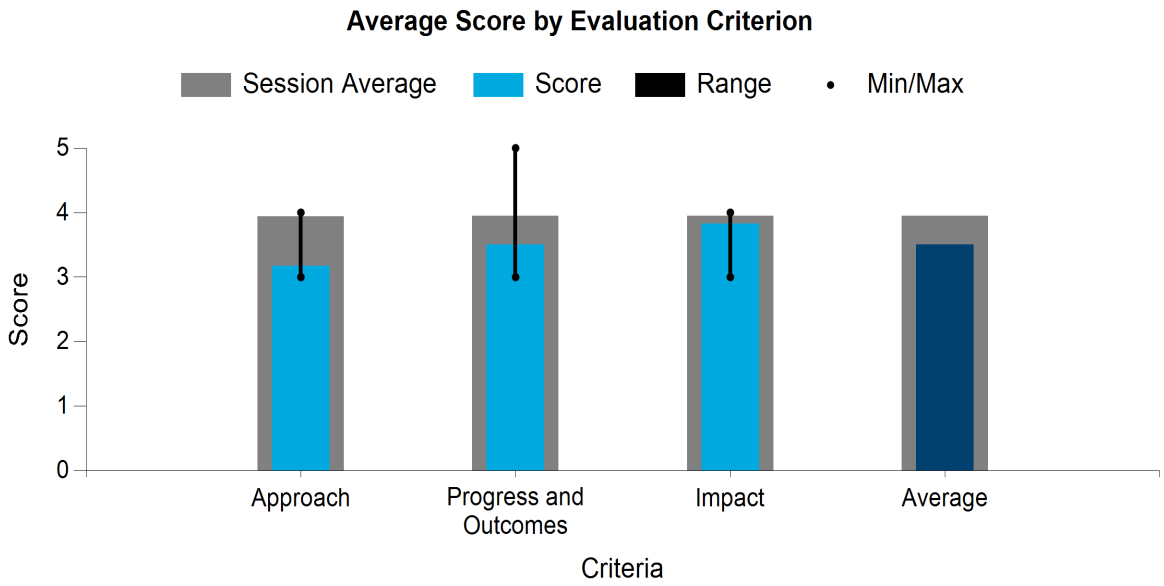
NET-ZERO CARBON TECH TEAM

National Renewable Energy Laboratory

PROJECT DESCRIPTION

WBS:	NetZero
Presenter(s):	Aye Meyer; Hannah Goldstein; Ling Tao; Michael Wang; Uisung Li
Project Start Date:	01/01/2020
Planned Project End Date:	09/30/2023
Total Funding:	$1,050,000

The NZTT is tasked with investigating the potential to generate carbon-based fuels with much lower carbon intensities compared to those of conventional fuels, approaching or exceeding net-zero GHG emissions. In this project, researchers from four national laboratories (ANL, Lawrence Livermore National Laboratory, NREL, and PNNL) have teamed up to evaluate carbon conversion pathways for their potential to produce net-zero carbon fuels. This project directly supports BETO's missions on carbon reduction and SAF conversion strategies by collaborating with the U.S. DRIVE NZTT formed by industry experts. In FY 2020–2021, four fuel pathways were selected for scrutiny to discern their costs and benefits and their ability to provide net-zero-carbon fuels. In FY 2021–2022, six more fuel pathways were selected for scrutiny to discern their costs and benefits and their ability to provide net-zero-carbon fuels. These pathways represent a diverse set of options for producing net-zero-carbon fuels, covering a range of feedstocks, process inputs, products, coproducts, environmental impacts, and technical maturities. The project team concludes that multiple pathways exist to produce commercial net-zero-carbon fuels. Most pathways require both technical maturation of core conversion processes and one or more process inputs (e.g., feedstock, electricity, process heat) to be substantially decarbonized to deliver a net-zero product. The uniqueness and key contribution of this study is that both sustainability constraints and cost perspectives are simultaneously investigated, so, consequently, this integrated study can quantify the impacts of a variety of economic and environmental metrics. Applying this simultaneous analysis approach to several highly varying technologies allows for the identification of overarching trends, such as those highlighted in previous sections. This current analysis, together with future studies, can inform strategic decisions for the development of future net-zero-carbon fuel production technologies.



COMMENTS

- Overall, this project makes a lot of sense. The identification of liquid fuel pathways that could approach net-zero carbon is a worthy goal with potentially substantial impacts. This project could make substantial contributions in that area. But I see two weaknesses in the approach that I am hoping the researchers can amend going forward.

  First, while the TEA modeling appears to consider financial uncertainty case by case, as shown in the error bars on slide 11 of the presentation, the LCA results for each case do not appear to consider uncertainty in emissions. When considering which liquid fuel pathways have the greatest chance of reaching carbon neutrality, one very significant consideration is which pathways start with greater or larger downside risk of emissions. The greater the risk of high emissions, the less attractive the pathway should be from a strategic perspective if the goal is carbon neutrality. Looking at the appendix slides, it appears that the various cases consider different sources of process energy, which is one source of uncertainty worth considering. But it does not appear that the upstream risk associated with feedstock cultivation/collection is considered. This risk exists to some extent for corn stover because too much removal may lead to a loss in soil C. But the risk is substantially greater for corn to ETOH. It also appears that the risk of carbon leakage is not being quantified in the scenarios. For CCUS pathways, these risks need to be quantified with appropriate methods, and it is strange to see them missing from slide 11. The recent National Academy of Sciences study on biofuel LCA methods provides a good guide to the key considerations for this type of methodology (https://doi.org/10.17226/26402). Future work in this area needs to make uncertainty analysis a core part of the LCA scope.

  Second, there appears to be a mismatch between the goals of the project and the downselection of pathways for deeper analysis. A large amount of the analysis presented to the reviewers focuses on corn ethanol to jet fuel pathways. Looking at slide 13, however, it appears that corn ATJ has some of the highest potential emissions and least potential for negative emissions. Focusing on corn ATJ over the stover, biomass gasification to Fischer Tropsch and wet waste HTL pathways does not seem to make sense from a deep decarbonization perspective. Perhaps this was simply a case where an odd example was selected to illustrate the larger project. But I would hope that in the final year of the project the researchers would narrow more of their focus to those pathways with greater potential for deep decarbonization rather than spending further resources quantifying the emissions of corn ATJ.

- Thank you for the opportunity to review the NZTT project. From my evaluation, the project is reasonably aligned with BETO achieving their goals. The team has made progress in investigating different pathways and feedstocks, adding decarbonization strategies and fuel pathways across a significant number of combinations. The project's impact is substantial, with outreach to the fuel industry, electric partners, and automobile sectors; however, the team should consider investigating methods to better show results across large numbers of fuel production pathways and better reflecting on uncertainty to more effectively communicate with stakeholders.

- The increased focus on net-zero goals makes this a very timely and relevant project. It nicely combines the technology area's existing research and expertise with TEA and LCA and puts it into a new perspective, evaluating all the different technology levers to reduce the GHG intensity of existing or future fuel pathways, and then estimating the incremental cost impact of those interventions. There is a natural synergy with the use of GREET to evaluate the LCA impacts of technology changes along the supply chain and NREL's TEA expertise. In terms of the project design and progress, I think the project has a very clear path forward. There is high relevance to the SAF Grand Challenge and very meaningful partnerships to be developed with industry groups.

  In terms of fitting within BETO's overall strategy, I do have some minor concerns. In contrast to most other projects in this technology area, this work appears to be largely focused on incremental changes and benefits for existing, commercialized technologies (at least based on the initial progress). While this

is laudable, I am wondering if the relatively low costs and high opportunities for incremental gains here may crowd out interest in some of the more challenging feedstocks. There also appears to be some optimism associated with CCS results versus real-world practices that may overstate the potential for CCS. It would be helpful to expand the analysis to more feedstocks emphasized in other DMA projects and to include error bars to show a wider, more realistic range of CCS outcomes for the selected fuel pathways.

- The NZTT seeks to investigate options for generating liquid carbon-based fuels with a reduced carbon intensity such that, from a life cycle carbon accounting standpoint, they have a net carbon emissions profile approaching zero. This goal requires more than 400 biorefineries, and 1 billion tons of biomass and/or gaseous carbon oxide feedstock will be needed to produce 35 billion gallons/year by 2050. Where will all of this take place? How will the siting of biorefineries occur? How can this team collaborate with other groups who are looking at the EJ implications of feedstock production and refining?

  Each different feedstock has its own set of supply chain challenges—how are these accounted for?

- This project has successfully demonstrated pathways to reach net-neutral liquid fuel biofuel production along with the costs and trade-offs of those options. While a national-only evaluation could result in overlooking regional drivers of decarbonization, the inclusion of regional complexities of CCS and CCU drivers help to mitigate that risk. Of particular note, this project has a comprehensive and clear engagement with many stakeholders across the academic, industry, and policy sectors that it touches.

  This project is missing an evaluation of EJ and could incorporate it to strengthen its outcomes.

- This is a multi-national lab effort that leverages various BETO models to examine the various technology pathways for sustainable bioenergy. It involves the federal government and various industry partners (electric utility, fuel, automobile) with regular meetings. Work on this scale is needed to leverage and synthesize BETO's DMA efforts and map out a blueprint for bioenergy decarbonization. The main recommendations are to rigorously consider uncertainties in the analyses (especially LCA) and to make the analyses (including underlying models, assumptions, etc.) and their results publicly available so that they can be used by other researchers and industries to tailor the analyses to their individual needs.

PI RESPONSE TO REVIEWER COMMENTS

- We sincerely appreciate the reviewers' recognition of the importance and contributions of this project's efforts for the last two years to the BETO program. The main objective of this project is to identify and evaluate the economic and environmental implications of various potential pathways for net-zero-carbon fuel production. The research scope and directions of this project have been actively discussed with the engaged industry stakeholders (U.S. DRIVE NZTT) and DOE to ensure the optimal utilization of available project resources and alignment with DOE's decarbonization strategies.

  Regarding the suggestion on performing more uncertainty analysis, our team has evaluated pathways for future fuel production instead of only analyzing existing fuel production pathways; thus, this analysis heavily relies on process modeling because industry data sets that illustrate the possible ranges of each parameter are currently unavailable. Consequently, conducting uncertainty analysis and generating error bars with limited information can potentially lead to misleading results. Even if there were available data sets, conducting uncertainty analysis (e.g., stochastic and/or sensitivity analysis) would require significant efforts to collect, process, and analyze the data. While we acknowledge the importance of analyzing uncertainties to provide valuable information about the risks associated with these pathways, it was not the primary focus of our analysis in this project. The project team has been focused on identification opportunities and challenges of various fuel production pathways under different low-

carbon technology options. To evaluate uncertainty and risks associated with these pathways, a separate and more dedicated effort would be necessary.

Certain other outstanding issues, such as the impact of SOC change resulting from corn stover removal and emissions leakage from carbon capture and sequestration, are being evaluated by other DOE projects and expected to be further assessed. Analyzing these specific impacts is beyond the scope of this project. The uncertainties associated with CCS significantly vary based on factors such as capture technologies, capture efficiencies, the volume of gas captured, geological locations, and storage efficiencies. Similarly, assessing the ranges of these parameters falls outside the scope of this project. Moving forward, the project team will provide qualitative assessments of uncertainties, risks, and associated implications in the technical reports. The primary focus was to determine the availability of low-carbon liquid fuel production options in the near future and assess the associated resource utilization, so we did have extensive discussion and considerations on pathway or feedstock choices.

In response to the reviewers' comments on the pathway selections and consideration of biomass feedstocks, the selection process for feedstocks, conversion technologies, and decarbonization options not only heavily relied on the feedback and input from these stakeholders but also was a result of extensive discussions among NZTT team and subject matter experts. One distinguishing factor of this project compared to others is its strong communication with industry stakeholders. In addition, the presentation of the corn ethanol-derived jet fuel production pathway among other evaluated pathways was not a random choice; it was intentionally included to showcase the potential of emission reductions through various options. It is also because the main goal of this project is to identify opportunities and challenges associated with various net-zero-carbon fuel production pathways rather than conduct a screening solely based on carbon intensity scores. To meet the U.S. SAF Grand Challenge volume targets of 3 billion gallons/year by 2030 and 35 billion gallons/year by 2050, all possible available low-carbon SAF production pathways will need to be used. As a result, we incorporated a variety of feedstocks (cellulosic biomass, wet waste, and waste CO_2) and a wide spectrum of conversion pathways, although we only presented the corn ethanol ATJ case during the BETO Project Peer Review. We do believe creating a balanced and comprehensive portfolio is crucial, so we plan to provide defensible analysis results to assist DOE and stakeholders in building a decarbonization road map.

We would like to thank the reviewers for their insightful questions on the siting of the future biorefineries and EJ-related complications. The analyses presented in the project encompass the initial two-year efforts primarily focusing on integrating TEA and LCA for decarbonization strategies. The team and our industry collaborators did recognize the importance of regional implications for future biorefineries, so the project has shifted its focus toward evaluating regional aspects that encompass factors such as feedstock availability, renewable electricity, water, and infrastructure in the third year as ongoing efforts. Similarly, related to the comments on CCS, our evaluation primarily accounted for the reduction in GHG emissions and the incremental cost associated with implementing CCS. Starting from the third year, our team began evaluating regional factors in various pathways to incorporate more realistic conditions, such as the transportation of CO_2 from the source to storage, to provide additional perspectives. This comprehensive evaluation aims to identify both the challenges and opportunities associated with the selected pathways, ultimately assisting in the strategic siting of biorefineries. While evaluating EJ falls outside the specific scope of this project, we believe that the project's outcomes can serve as inputs for assessing the EJ implications at a regional level. By considering the broader regional context and incorporating the findings of this project, stakeholders and BETO can gain insights into the potential EJ implications related to the implementation of the selected pathways. We recognize this is an important subject, and we will consider incorporating EJ with our analysis in the future.