FEEDSTOCK TECHNOLOGIES

TECHNOLOGY AREA

CONTENTS

INTRODUCTION

The Feedstock Technologies Program is one of 12 technology areas that were reviewed during the 2023 Bioenergy Technologies Office (BETO) Project Peer Review, which took place April 3–7, 2023, in Denver, Colorado. A total of 32 presentations were reviewed in the Feedstock Technologies session by 4–5 external experts from industry, academia, and other government agencies. Of the 32 projects reviewed, 26 were reviewed by the Feedstock Technologies panel and six were reviewed by the Feedstock-Conversion Interface Consortium (FCIC) panel. 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, which can be accessed at the Peer Review website: www.energy.gov/eere/bioenergy/2023-project-peer-review.

This review addressed a total U.S. Department of Energy (DOE) investment value of approximately $59.9 million, which represents approximately 11% 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 Review, including scoring information for each project, comments from each reviewer, and the response provided by the project team.

BETO designated Elizabeth Burrows as the Feedstock Technologies Technology Area review lead, with contractor support from Andrew Zimmerman of Lindahl Reed Inc. In this capacity, Elizabeth Burrows was responsible for all aspects of review planning and implementation.

FEEDSTOCK TECHNOLOGIES REVIEW PANEL

Name	Affiliation
Dr. Jingxin Wang*	West Virginia University
Dr. Sally Krigstin	University of Toronto
Dr. Bhima Vijayendran	Redwood Innovation Partners LLC
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FEEDSTOCK TECHNOLOGIES REVIEW PANEL SUMMARY REPORT

Prepared by the Feedstock Technologies Review Panel

INTRODUCTION

The Feedstock Technologies area is an integral component of the overall BETO portfolio of projects. It addresses the research and development (R&D) essentials of biomass feedstock development and establishes the foundation for the success of any biorefinery project. A robust industry producing advanced biofuels and bioproducts with biomass requires economical, high-quality feedstock with minimal variation in feedstock quality. This is the subject matter of this program area. The review panel for the Feedstock Technologies program had a cross section of representatives with diverse backgrounds and expertise. Industry, government, and academic perspectives were all represented. This made for strong and varied viewpoints, which became evident in the review comments and the numerical evaluations of the projects.

The Feedstock Technologies Peer Review process occurs every 2 years and addresses progress since the previous review. In the 2019 review, BETO unveiled its plan to adopt a quality-by-design process for its projects. This process is favored by the pharmaceutical industry. The 2021 review (in which 18 projects were reviewed) was conducted virtually due to the COVID-19 pandemic.

In 2023, the review panel evaluated 26 project presentations within the Feedstock Technologies program. Each of these projects is funded by BETO, either through a funding opportunity announcement (FOA) (nine projects) or as part of BETO's annual operating plan (AOP) (17 projects). Of these 26 projects, eight are on supply chains and process modeling, seven address municipal solid waste (MSW) processing and artificial intelligence (AI)/sensing technologies, three focus on cover crops, four are on carbon impact analysis, two concentrate on feedstock production, and two focus on value-added bioproducts. Nine projects were ending, 13 were ongoing, and four were in their beginning stages.

The review process was straightforward. The panel listened to an oral presentation by the principal investigator (PI) of the project. The presentation was accompanied by a slideshow, with a Q&A period following the presentation. Each project was allocated the same amount of time and used the same format for its presentation. Each individual on the panel rated the project numerically and made comments with their assessment based on the following criteria:

1. Approach – Did the project performers develop an approach that has:
    - Significant merit to advance the state of the art of technology, relevance to BETO program and technology area goals, and significant potential for innovation in its application?
    - A clear management plan and successful implementation strategies for identification of project risks and mitigation of those risks?
    - An adequate approach to address diversity, equity, and inclusion (DEI) in the project plan?
2. Progress and Outcomes – To what extent:
    - Has the project made appropriate progress toward addressing the project goal(s)?
    - Have the accomplishments been completed on schedule with the planned approach—and, if needed, have risk mitigation strategies been used to maintain project progress and schedule?
3. Impact – Does the project and its presentation:

- Demonstrate a clear connection between the project approach and the potential for significant impact and outcomes?
- Demonstrate a clear commercialization potential or use or have plans to use industry engagement to guide project deliverables?

Each of the panelists was also asked to provide a written assessment of each project based on the above criteria to rationalize the evaluations. There is no doubt that the panel feels that BETO's Feedstock Technologies program is an important area for their involvement and support. The Peer Review process is an essential step for determining whether the projects are beneficial and addressing the barriers to the industry's success. The biomass harvest, logistics, handling, preprocessing, techno-economic analysis (TEA), and life cycle analysis (LCA) have been problem areas, and the portfolio of BETO Feedstock Technologies projects is addressing a number of these. Below is a collection of comments from the panel addressing several of the areas above in terms of strategy, strategy implementation and progress, and recommendations.

STRATEGY

The program has a clear strategy, supporting the industry by setting a near-term cost target for biomass delivered to the throat of a conversion facility of $84/dry ton, or $3/gallon gasoline equivalent (GGE) for the sustainable aviation fuel (SAF) markets. In the 2023 BETO Multi-Year Program Plan (MYPP), BETO set six key performance goals to achieve by 2030, including enabling commercial production of SAF and renewable chemicals capable of >70% greenhouse gas (GHG) emission reduction. These goals will help researchers and developers from academia and industry work together to achieve the deliverables and generate long-term impacts.

The Feedstock Technologies program has been well managed. The panel was impressed by the projects in the BETO Feedstock Technologies portfolio. BETO has set a clear pathway and goal of producing high-quality, economical feedstocks to support the growth of a healthy bioeconomy. For the most part, the projects had clear targets and go/no-go decision points and were supportive of the BETO goals and MYPP.

The panel agreed that to meet the goal of producing biofuels and bioproducts for the national bioeconomy from sustainable feedstocks and renewable resources, we need a diverse supply of feedstocks, such as agricultural and forest residues, MSWs across the nation, willow and switchgrass in the Northeast, energy cane along the Gulf Coast, miscanthus in the upper Southeast and Midwest, and clean corn stover all over the Midwest. The development of diverse feedstocks is supported by the portfolio funded through BETO and is central to BETO's multiyear plan in support of a robust national bioeconomy.

The Feedstock Technologies program's priority topic areas were determined through extensive stakeholder input from groups such as industry stakeholders, federal advisory committees, interagency working groups, workshops, and professional organizations. Some of the projects reviewed have been in progress for over ten years, whereas others started just a few months ago. Some projects are led by scientists at national labs, others are led by private-sector entities, and still others are led by university scientists. There are several themes that run throughout the BETO Feedstock Technologies project portfolio. There are projects that are investigating and developing state-of-the-art methodologies and advancing the state of technology through the following areas:

- Feedstock handling and preprocessing
- Feedstock quality
- Renewable carbon resources
- MSW

- Coproducts and preprocessing
- Feedstock logistics and storage
- AI and sensing technologies
- Data, modeling, and analysis of the supply chain.

The related FOAs were published to address these topic areas and included several specific objectives within each of the above topics. For example, feedstock supply chain analysis includes the continued development of the *Billion-Ton Report*, DOE's Bioenergy Feedstock Library (BFL), and computational modeling and predictive systems. Additionally, the overall MSW portfolio includes projects that address characterization and MSW separation/sorting/decontamination/blending/processing to improve feedstock quality and consistency. The Feedstock Technologies portfolio also includes requirements for TEA, and more recent projects must include long-term DEI goals.

The panel believes that several projects, especially some MSW projects, could benefit more from stakeholder input, especially from industry involvement. Communications with MSW disposal professionals and agriculture and forestry practitioners seem essential for PIs to improve project performance. Important stakeholders that were notably absent included critical members of the local farming and forest community, including county extension agents and members of local governing boards. If involved in the early stages of a project, these groups might be able to help with advice, logistics, and local issues. Field practitioners are always known for their innovation and problem-solving skills. Although some projects had varied and meaningful stakeholder input, others seemed to be quite deficient in the Feedstock Technologies area. A number of presenters were asked to identify the "customers" for their projects. Often, the PI was not able to succinctly identify who would make use of their project results. It is important for all projects to have their end user in mind and to make sure they are connecting with these stakeholders throughout the project and even beyond.

The panel agreed that Idaho National Laboratory's (INL's) BFL and Oak Ridge National Laboratory's (ORNL's) *Billion-Ton Report* are significant resources and accomplishments. They are beneficial to all who are working in the field nationwide and are much needed. The panel recommends a general guideline for conducting TEA and LCA and calculating dollars-per-hour operating costs and dollars-per-dry-ton unit costs for commercially available biomass harvest or processing under certain site, machine, and feedstock species conditions. This guideline can be used for the cost analysis required for all BETO projects. This would provide PIs and future reviewers with a common starting point for cost analysis and comparisons.

The Feedstock Technologies gaps are well identified and are valid for increasing the mobilization of biomass resources. One panelist noted a lack of projects focused on the biomass depot idea and the biomass by design component in this review. If there has been a shift in direction away from these concepts, there could have been an explanation given in the overview presentation. Another panelist commented that the economic modeling on a few projects seemed unrealistic and not as well thought out as it should be. We hope that by the next review, PIs will have time to consider this and make suitable adjustments.

The Feedstock Technologies program's funding mechanism seems to be working well, although there might need to be an increase in the proportion of FOA projects or a shift in the mix of FOAs versus AOPs to roughly 50/50. Collaborations among academia, DOE labs, and industry could be further promoted through this innovative funding mechanism, especially through commercialization and scale-up programs and activities. Better and more effective communications between this program and the U.S. Department of Agriculture's (USDA's) National Institute of Food and Agriculture and DOE's Advanced Research Projects Agency–Energy through joint FOAs and workshops would be promising. The panel knows that this is up to the appropriations process, but they are supportive of BETO seeking greater funding.

STRATEGY IMPLEMENTATION AND PROGRESS

Overall, the programs are reasonably well structured to monitor progress. It may be helpful to further tighten the milestone deliverable metrics so they are more transparent to measure. In this review cycle, the Feedstock Technologies area funded a wide range of projects addressing all areas of the supply chain, from feedstock harvest and handling to processing to LCA and TEA. The topic areas investigated included:

- Feedstock supply chain analysis and modeling
- Cover crop valuation for biofuels
- AI and sensing technologies
- MSW characterization, decontamination, and processing
- Value-added bioproducts.

The panel believes that BETO is funding a strong portfolio of projects supportive of BETO's objectives. The projects that impressed the panel in providing strong support for this vision are:

- DoKyoung Lee's project, "Next-Generation Feedstocks for the Emerging Bioeconomy," is an excellent project with impactful results. The panel appreciated the project's work on evaluating ecosystem services with diverse field trials and machine learning (ML) modeling. Their approaches and findings can be considered for other applicable projects.
- Rachel Emerson's project, "Bioenergy Feedstock Library," hosts characteristic data from over 70,000 biomass samples representing over 90 crop types, providing tools to store, record, track, retrieve, and analyze data to help researchers and industry overcome challenges posed by biomass variability. It is an impactful project for a variety of audiences nationwide. DOE should continue to support this effort that will benefit the national biomass for energy strategy.
- Matt Langholtz' project, "Supply Scenario Analysis," updates the *Billion-Ton Report* with new additions, such as oilseed and cover crops. It is an impressive and impactful project with more than 4,000 citations of the report, providing important information to a wide variety of stakeholders. DOE should continue to invest in this effort to further improve the data accuracy, regional field data collection, and validation.

Although the panel has singled out the above projects, there are several others that could have been mentioned, and the readers are encouraged to review the entire portfolio. The BETO management team is clearly managing their portfolio of projects toward their near-term/mid-term and final goals of providing high-quality feedstock at an economical cost to support existing and emerging conversion projects.

The panel also noticed that there was a substantial number of projects focused on MSWs, especially on preprocessing (sorting). Although these MSW projects were well done, using different sensor technologies to measure critical characteristics, one panelist indicated that this focus may not be able to achieve cost-effective utilization of MSW biomass, and perhaps industry partners may be better suited to work in this area.

The panel also noticed that some of the legacy-type projects were still targeting chemical molecules such as levulinic acid that have shown very little commercial traction despite numerous attempts with significant venture capital funding. Projects of this nature need to clearly articulate why the particular molecule is being targeted and what the market justification is.

The panel agreed that the implementation of the project associated with the designated technology readiness level (TRL) at the beginning and the end of the project should be encouraged, while a graphical presentation of the project's progress with color coding would be helpful. The panel noticed that some of the projects need to proceed to the next TRL for scale-up or demonstration.

RECOMMENDATIONS

To further improve the impacts of the Feedstock Technologies portfolio, the panel thinks the following recommendations will be helpful for future reviews and funding cycles.

Recommendation 1: Integrate data from various projects and ensure accessibility.

There are a couple of excellent initiatives focused on data collection and cataloging. It would be helpful to all stakeholders in the field if easily deployable tools, such as AI/ML-driven ChatGPT search engines, could be implemented by integrating diverse data from various projects funded in this area.

Recommendation 2: Optimize Feedstock Technologies subprogram investment in computational modeling.

There are quite a few modeling and analytical-based projects in this review. Feedstock Technologies may be overinvested in computational modeling. Future solicitations may focus on data and model generation from lab and field studies that are the foundation of the modeling work. Some of the initiatives in this area seem to have the flavor of modeling for the sake of modeling with no clear path toward integrating the results with downstream tasks, such as pilot-scale demonstration and commercialization. Modeling can provide an acceptable range of production rates and costs, but some performance-related variables, such as equipment delays and utilization rates, are needed from actual studies. Some of the models are being field tested, but some are not. It should be a requirement that all models are field tested; this would give a higher confidence in their accuracy and results.

Recommendation 3: Develop general guidance for future TEAs and cost analyses.

Each of the projects reviewed has a TEA/cost component. There seems to be some inconsistency in these analyses, with some superficial and confusing results. General guidance is essential for future TEAs and cost analyses. Data sharing and uses among completed and ongoing projects could be further enhanced via ORNL's Knowledge Discovery Framework (KDF) and INL's BFL. More dissemination workshops should be conducted. It would be helpful to accelerate R&D and commercialization tasks in making funding decisions.

Recommendation 4: Expand focus on forest logging residues.

At least one panelist mentioned that research on diverse feedstocks, such as forest logging residue, should be considered in the Feedstock Technologies portfolio. Forest logging residue is abundant nationwide but suffers from a costly supply chain system. A key concern is the economics of logging residue collection and harvest. Future FOAs could focus on the logistics of forest residue and the blending and utilization of both agricultural and forest residue biomasses for the production of uniform feedstocks, development of emerging technologies, advancement of equipment, engagement with industry, and commercialization. Work in this area to reduce the cost of this resource's collection and delivery direct to a biorefinery or to a depot for blending would provide at least two major benefits: (1) providing another economical feedstock to support the continued growth of the bioeconomy, and (2) providing an economic incentive and support for cleaning and reducing fuel loads of both public and private forest lands, which would make for healthier forests while also helping prevent natural disasters such as forest fires.

Additional observations from the panel are as follows:

There is extensive investment in MSW characterization. Some projects also entail sorting, and yet others focus on final chemical characterization. As these projects conclude, the results need to be captured in the *Billion-Ton Report*. An important addition to the portfolio is the use of cover crops to enhance the sustainability of feedstock production systems. One panelist stated that these projects are among the best implemented.

The panel understood that DEI was introduced in this review cycle. There appear to be differences in DEI implementation among projects. There needs to be greater clarity on what the higher-level goals are for DEI in future reviews of projects. The involvement of students from underserved communities is laudable, but stakeholder input and direct benefits to the underserved communities should be considered.

To better understand the evolution of the Feedstock Technologies program and to strategize about the program's long-term impacts, the panel thinks that keeping a historical perspective on changing or introducing new goals and/or objectives in the Feedstock Technologies portfolio would be beneficial. It would be helpful to have a map of past goals and major findings followed by the evolution to new goals, whether determined through program results or political forces. It was positive to see a more holistic approach being taken for complete biomass utilization focused on achieving the best value for each material component. A more comprehensive and practical approach can be considered in future funding cycles with respect to carbon sequestration and decarbonization.

FEEDSTOCK TECHNOLOGIES PROGRAMMATIC RESPONSE

INTRODUCTION

BETO would like to thank the review panel for their careful evaluation of the Feedstock Technologies projects and subprogram overall. The panel's dedication to improving BETO is sincerely appreciated by both the Feedstock Technologies team and the broader stakeholder community. Recommendations by the Peer Review panel are referenced regularly when making decisions about the program.

The Feedstock Technologies team appreciates the positive comments made by the review panel regarding program management, strategy, goals, and implementation. We will continue to work to maintain a high level of success in these areas. The Feedstock Technologies team particularly appreciates the recommendations to improve the program. Our comments about these recommendations are as follows.

Recommendation 1: Integrate data from various projects and ensure accessibility.

Ensuring data availability is one of the most important ways to maximize the value of government-funded R&D. DOE already requires that all data collected through its projects be published on osti.gov, which is linked to data.gov, but we realize that this is not enough. We will leverage ORNL's Bioenergy KDF and INL's BFL to further integrate data from multiple projects, especially projects from the same funding opportunity. Special emphasis will be placed on integrating data from the MSW funding opportunities (see below) as well as data on purpose-grown energy crops. The review panel noted a lack of attention to the "customer" when considering the outcomes and impact of applied R&D projects, and this is especially important for data availability. When making integrated data available, we will ensure that the users of the data drive the content and format of the data provided.

Recommendation 2: Optimize Feedstock Technologies subprogram investment in computational modeling.

BETO researchers have developed many models. BETO recognizes that models are only as good as the data used to generate/validate them, and moreover, that models need to be used by stakeholders to realize their full benefits and to enable supply chain design and process equipment operation that do not rely on empiricism. We will focus more heavily on these aspects to increase the value of existing models. Our immediate plans for funding opportunities indeed focus on lab and field experimental data generation in the most promising areas identified by BETO-funded models, such as feedstock resource and supply chain analysis for deploying purpose-grown energy crops for SAF, as well as first-principles-based computational modeling of material handling and feedstock quality improvement for integration with downstream processes. BETO routinely uses sensitivity analysis (e.g., tornado charts) from supply chain modeling efforts to identify future R&D needs and topics for future FOAs, and we will pay special attention to making sure this link is apparent to external stakeholders. BETO models are continuously improved by leveraging new data from the lab and the field that can inform and validate the accuracy of models. BETO researchers have made progress by integrating industry data with the company name removed to protect proprietary information, and we will continue to encourage this type of information sharing while protecting the intellectual property of our project partners.

Recommendation 3: Develop general guidance for future TEAs and cost analyses.

BETO is committed to developing BETO-wide uniform TEA guidance. One of the first steps will be to host a workshop on the challenges of harmonizing these data before issuing standardized guidance; the Data, Modeling, and Analysis subprogram has made plans to hold this meeting. Additionally, as suggested, we will work to put integrated TEA data into the Bioenergy KDF. The idea to hold data dissemination workshops is a good one.

Recommendation 4: Expand focus on forest logging residues.

The subprogram agrees with this recommendation and acknowledges that a similar recommendation was made in the 2021 Project Peer Review summary report. In the past two years, BETO has:

- Funded at least three Small Business Innovation Research projects on forestry residues or woody biomass
- Coauthored a chapter on forest restoration in a report to Congress on carbon dioxide reduction
- Held a breakout session on forest management during BETO's workshop titled "Bioenergy's Role in Soil Carbon Storage"
- Included forest fire mitigation in BETO's MYPP, released in March 2023, and added salvaged material from natural disasters and invasive species as renewable carbon resources of interest
- Made a strategic hire with expertise in forest biomass logistics.

Additionally, thanks to a collaboration with the USDA Forest Service, the updated *Billion-Ton Report* will include estimates for biomass from fire reduction treatments. Projects reviewed by the FCIC review panel include forestry residues, but we agree that more emphasis is warranted, especially in the areas noted by the panel: logistics, equipment advancement, industry engagement, and commercialization. Forestry residues are listed second in the list of renewable carbon resources in the MYPP, and BETO will continue to support this important resource in coordination with the U.S. Forest Service.

Response to additional observations from the panel:

Regarding the suggestion to incorporate data from the MSW projects into the *Billion-Ton Report*: new data on wastes will be incorporated in the next *Billion-Ton Report*, including the addition of county-level fats, oils, and greases, and mature-market price competition will be accounted for. Furthermore, a nationwide MSW characteristics database will be created, focusing on quantity and quality and considering spatial and temporal variability. BETO's MYPP, released in March 2023, specifically mentions this effort, and a workshop is being planned for fall 2023 to discuss and coordinate the three cohorts of MSW funding opportunities and related national lab projects. As recommended in the strategy section of the panel's summary report, the workshop organizers will emphasize outreach to MSW industry stakeholders across the supply chain to inform database development.

The idea to create a map of historic goals and major findings followed by the evolution to new goals is a great one. We will keep this project in mind and ensure that it is accomplished prior to the next Peer Review. At a minimum, the map will be provided as a resource for the next Peer Review panel. Additionally, more clarity on DEI goals and implementation will be provided to the next panel; this is an ongoing DOE-wide effort, and much progress is being made.

Lastly, to address a comment in the panel summary's strategy section, we will emphasize engagement with members of the local farming and forest community, including county extension agents and members of local governing boards. BETO's Small Business Innovation Research program took initial steps in this direction by piloting a unique set of topics (fiscal year 2021 [FY21]–FY23) focused on community-driven bioenergy development. After the first pilot, eight other DOE applied offices adopted the idea. The BETO-funded projects include engagement with farmers, foresters, tribal nations, local community groups, and many others. Our upcoming efforts on deploying purpose-grown energy crops for SAF will also have a strong focus on farmer engagement.

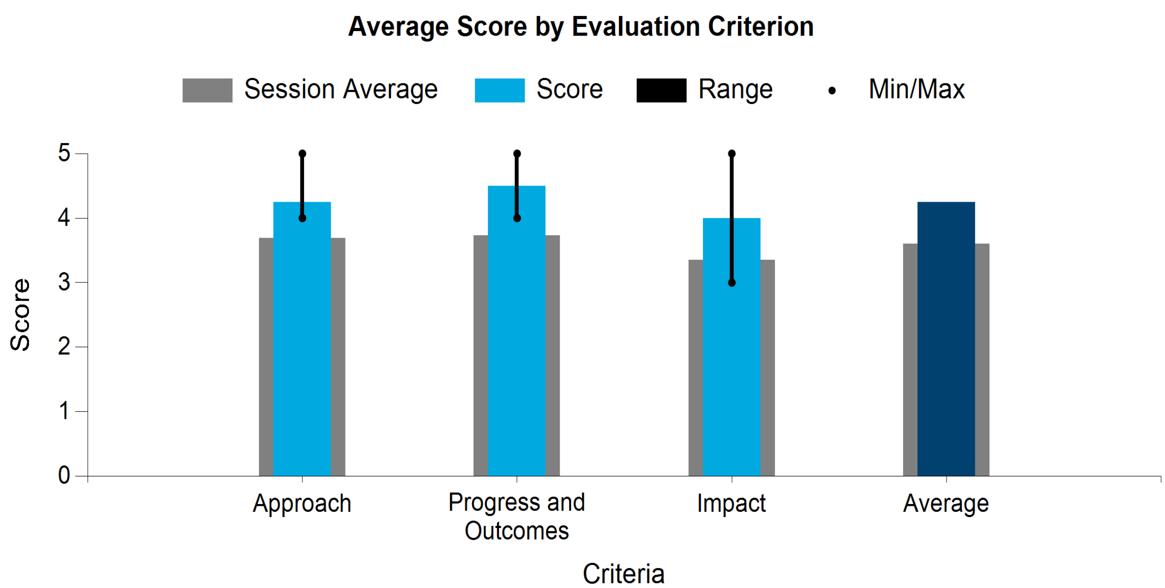
NEXT-GENERATION FEEDSTOCKS FOR THE EMERGING BIOECONOMY

University of Illinois at Urbana-Champaign

WBS:	1.1.1.105
Presenter(s):	DoKyoung Lee
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2024
Total Funding:	$6,251,399.00

PROJECT DESCRIPTION

Perennial bioenergy crops like switchgrass can supply feedstock for sustainable bioenergy production and improve ecosystem services on marginal croplands. Biomass and associated ecosystem services for high-yielding switchgrass cultivars (i.e., Liberty and Independence) were evaluated on marginal fields in Iowa, Illinois, Nebraska, and South Dakota. Biomass was determined by commercial harvesting and baling, and ecosystem services examined soil quality, GHG emissions, water quality and quantity, and biodiversity. In harvest years 2 and 3, new cultivars Liberty and Independence produced 13%–32% and 10%–36% more yield, respectively, depending on location, when compared to previous cultivars, and nitrogen fertilization was important for maintaining sustainable yields. Compared to corn, switchgrass had 15%–70% lower N_2O emissions and 4–10 times lower NO_3-N leaching, but higher water use due to higher total biomass. Bird diversity was greater in corn, but total bird number was higher in switchgrass. Feedstock composition differences were related to location and cultivar. This project provides a template for growing feedstocks that could lower biofuel cost by using detailed yield, harvest logistics, fuel use, and field capacity data to perform TEA. These results meet the BETO goal of developing productive, cost-effective, and sustainable bioenergy feedstock systems on marginally productive croplands across geographic locations in the U.S. Midwest.



COMMENTS

- This is a very strong team with a well-laid-out approach and execution of the tasks needed to meet the major milestones and deliverables. The project seems to have met the key milestone. I'm not clear on the commercialization path—who are the potential commercial partners? On Slide 6, some of the risks—weather, breakdown of machinery—are noted. These types of things are bound to happen. What is being done to estimate/project rolling average type data? Slide 7 shows variation of crops in different states, plots in a given state, a given year, and the results. Are the variations understood?

- This is a very good project with lots of results and accomplishments. On Slide 6, several challenges were discussed for the project. Some of them have already happened, whereas others are just potentials. It is not clear how the team has handled or mitigated these challenges. I'd like to revisit a couple of questions I raised in the previous review. First, best management practice (BMP) development is being used as a major success factor. It is not clear which BMPs will be developed. This may be planned in Budget Period 4 and 5. I think BMPs can be developed earlier, and the BMPs' application and effectiveness can be accessed in Budget Period 4 and 5. Has there been any progress on BMP implementation in the project? Second, there are many different ways to do the modeling work in ag/forest ecosystem services. Using ML is appropriate but challenging, especially in the algorithm selection and data set preparation, for consistency and robustness. Can you explain more about how the model has been trained for improvement and how tract size and machine type would affect the field harvest performance?
- Lignocellulosic feedstocks are gaining greater interest as a mechanism to fix atmospheric CO_2 to drive carbon sequestration in natural systems. The decades of bioenergy feedstock production research are foundational to catalyzing current research on atmospheric CO_2 removal, especially if lignocellulosic resources are to serve multiple purposes. This is a very expansive field-based research project on switchgrass and corn production systems in several Midwestern states. Their approach is to obtain extensive field data on switchgrass cultivars, nutrient management, and harvest management to develop carbon uptake models. An interesting, repeated observation was that switchgrass systems had considerably greater soil CO_2 efflux than corn systems. They attributed this to switchgrass having greater root mass and thereby greater production of CO_2 through root respiration. This observation calls for much greater investigation. This project will have a major impact on soil carbon sequestration research.
- This is a valuable and very well executed project. The data gathered is comprehensive and will lead to a much better understanding of switchgrass as a feedstock. This was one of my favorite presentations of the session. The presenter provided a lot of information, but the slides were well laid out and easy to see, and the whole presentation told a very meaningful story. One slide outlining the roles of the contributors would be beneficial.
    - Approach: The technical objectives are well laid out. The PI specified what they were going to do and accomplished what was set out. This project was well designed and has significant potential to develop BMPs for this application.
    - Progress and Outcomes (P&O): Even though a significant portion of this project was carried out through a difficult period (COVID), the team managed to keep the project on track. The challenges identified on Slide 6 are generally unpredictable and uncontrollable (i.e., weather-related). However, this provided an opportunity for real-life learning that can be applied to future work. Nice work on the modeling, especially the remote sensing models; this was novel and very useful.
    - Impact: There is a plethora of meaningful data that will continue to be synthesized to answer important questions related to switchgrass crops. This project is contributing to other BETO projects, such as the biomass sample library and Bioenergy KDF. The BMP guidelines and their introduction to local stakeholders will be a very important outcome of the project. Working with seed partners will improve biomass commercial opportunities. The largest question will be whether switchgrass makes sense in the long term when used as a large commercial crop.

PI RESPONSE TO REVIEWER COMMENTS

- Comments: This is a very strong team with a well-laid-out approach and execution of the tasks needed to meet the major milestones and deliverables. The project seems to have met the key milestone. I'm not clear on the commercialization path—who are the potential commercial partners? On Slide 6, some of the risks—weather, breakdown of machinery—are noted. These types of things are bound to happen. What is being done to estimate/project rolling average type data? Slide 7 shows variation of crops in different states, plots in a given state, a given year, and the results. Are the variations understood?

- Response: We thank the reviewer for the comments. The target market for the project is cellulosic ethanol producers and biorefineries, including stand-alone facilities and facilities co-located with grain ethanol production facilities situated across the country. Moreover, the target production market area for the switchgrass varieties is the marginally productive croplands in the Midwestern region. The regional farmers, who have marginally productive croplands and environmentally degradable lands, will have the greatest interest in adopting these new switchgrass varieties. The possible competitor crops will be corn, soybeans, and perennial forage crops, but the economic benefits from the higher yield potential of switchgrass compared to the low yield of these crops will mitigate the perceived barrier to market penetration. One of the biggest challenges with perennial energy crops is stand establishment under unfavorable weather conditions. Flooding delayed the stand establishment; however, all sites were successively established, and we did not have much problem with data collection even though biomass yields were low during the establishment year. Switchgrass cultivar and site differences influenced biomass yield for both the field-scale and small-scale field trials. Site differences at the field-scale level were evident with high biomass yields in Brighton, Illinois > Urbana, Illinois > Nebraska > Iowa > South Dakota for yields averaged over the three years (2020–2022). Biomass yield was marginal in the establishment year (2020) for all cultivars in the five sites, but the yield increased immensely in the second and third years after the establishment. Lower yields in 2022 in Urbana, Illinois; Iowa; and Nebraska are attributed to drought. The newly introduced Liberty and Independence cultivars produced higher biomass on average when compared to local cultivar Shawnee. Likewise, biomass yield of Carthage, a new cultivar, averaged 9% greater than Sunburst, despite the stand damage due to winter injury. Moreover, nitrogen fertilization with 50 pounds of nitrogen per acre increased biomass yield by 10%–15%.

- Comments: This is a very good project with lots of results and accomplishments. On Slide 6, several challenges were discussed for the project. Some of them have already happened, whereas others are just potentials. It is not clear how the team has handled or mitigated these challenges. I'd like to revisit a couple of questions I raised in the previous review. First, BMP development is being used as a major success factor. It is not clear which BMPs will be developed. This may be planned in Budget Period 4 and 5. I think BMPs can be developed earlier, and the BMPs' application and effectiveness can be accessed in Budget Period 4 and 5. Has there been any progress on BMP implementation in the project? Second, there are many different ways to do the modeling work in ag/forest ecosystem services. Using ML is appropriate but challenging, especially in the algorithm selection and data set preparation, for consistency and robustness. Can you explain more about how the model has been trained for improvement and how tract size and machine type would affect the field harvest performance?

- Response: We thank the reviewer for the insightful comments. The challenges faced in the project were mostly weather-related. Spring flooding resulted in establishment challenges during the first year and delayed weed control and fertilization. Cold winters in South Dakota during the second and third growing years caused stand damage (winter kill) and delayed harvesting, whereas drought in the third growing year in Illinois and Nebraska affected the biomass yield. Spring flooding was mitigated by replanting all affected plots, and harvesting (delayed due to early snowfall and cold) was performed in the early spring in South Dakota. The project evaluated biomass productivity under typical rainfed conditions; thus, irrigation was not included to mitigate the drought. The technical challenge encountered with machine breakdown, especially in Nebraska and Iowa, was mitigated by conducting prompt repairs and rescheduling operations. We have made progress in the field-scale feedstock production practices, including estimating feedstock chemical quality and mineral composition. We are now working to produce a switchgrass management guide summarizing the BMPs specific to the new high-yield bioenergy-type switchgrass cultivars produced on marginal lands to reduce variability in yield and quality, generate economic return for producers and processors, and provide environmental services. The BMPs being developed include establishment practices, weed control, fertilization regimes, and biomass harvest management and logistics, as well as storage systems and their economics and energetics. We hope to publish the BMPs in late 2023. The application of ML in predicting the agronomic and environmental attributes of perennial bioenergy crops grown on marginal croplands has not been widely explored. Thus, ML model development tasks for this project focus on foundational efforts, particularly finding (1) an algorithm or set of algorithms that are well suited to predict end-of-season biomass yield of multiple bioenergy switchgrass cultivars under U.S. Midwest conditions, and (2) the most important predictors or explanatory variables. Data used for training the model were collected as part of the study (yield, weather, and other publicly available data), which allows some control over the quality, quantity, and availability of the data. Using data from three cropping years (2020–2022), we evaluated a wide range of algorithms that have been applied for commodity crop production applications, including traditional (ordinary and partial least regression), ensemble (random forest, gradient boosting machines, and AdaBoost regressor), K-neighbors regressor, and artificial neural networks. We found that random forest and gradient boosting machines proved to be the most accurate algorithms, although artificial neural networks could be further tested as more data become available from upcoming growing seasons. We also found that the top predictors are climate and topographic variables. This particular work has been peer-reviewed and was recently accepted in the *Energies* journal. Factors that affect field harvester performance, such as tract size and machine type, are outside the scope of this current project, and thus are not included as part of the model capabilities. However, they can be included as part of future model capabilities funded by future projects and can build on the final model outcomes of the Affordable and Sustainable Energy Crops project.

- Comments: Lignocellulosic feedstocks are gaining greater interest as a mechanism to fix atmospheric CO_2 to drive carbon sequestration in natural systems. The decades of bioenergy feedstock production research are foundational to catalyzing current research on atmospheric CO_2 removal, especially if lignocellulosic resources are to serve multiple purposes. This is a very expansive field-based research project on switchgrass and corn production systems in several Midwestern states. Their approach is to obtain extensive field data on switchgrass cultivars, nutrient management, and harvest management to develop carbon uptake models. An interesting, repeated observation was that switchgrass systems had considerably greater soil CO_2 efflux than corn systems. They attributed this to switchgrass having greater root mass and thereby greater production of CO_2 through root respiration. This observation calls for much greater investigation. This project will have a major impact on soil carbon sequestration research.

- Response: We thank the reviewer for the insightful comments. We observed higher soil CO_2 flux from the switchgrass field in the second and third growing seasons compared to the corn fields. We have embarked on several studies to ascertain the CO_2 source, as the soil CO_2 flux is the sum of soil organic matter mineralization, heterotrophic respiration, and root respiration, as well as autotrophic root respiration. We hypothesized that the greater root mass of switchgrass contributes to the higher CO_2 flux under switchgrass production. We have already sampled 0–15 centimeters depth of root biomass to quantity the total root mass at this depth. We are also planning a more comprehensive root biomass sampling campaign up to 100 centimeters in autumn 2023. Moreover, a preliminary field study is underway to assess the root contribution to total CO_2 emissions.

- Comments: This is a valuable and very well-executed project. The data gathered is comprehensive and will lead to a much better understanding of switchgrass as a feedstock. This was one of my favorite presentations of the session. The presenter provided a lot of information, but the slides were well laid out and easy to see, and the whole presentation told a very meaningful story. One slide outlining the roles of the contributors would be beneficial.

- Approach: The technical objectives are well laid out. The PI specified what they were going to do and accomplished what was set out. This project was well designed and has significant potential to develop BMPs for this application.
- P&O: Even though a significant portion of this project was carried out through a difficult period (COVID), the team managed to keep the project on track. The challenges identified on Slide 6 are generally unpredictable and uncontrollable (i.e., weather-related). However, this provided an opportunity for real-life learning that can be applied to future work. Nice work on the modeling, especially the remote sensing models; this was novel and very useful.
- Impact: There is a plethora of meaningful data that will continue to be synthesized to answer important questions related to switchgrass crops. This project is contributing to other BETO projects, such as the biomass sample library and Bioenergy KDF. The BMP guidelines and their introduction to local stakeholders will be a very important outcome of the project. Working with seed partners will improve biomass commercial opportunities. The largest question will be whether switchgrass makes sense in the long term when used as a large commercial crop.

- Response: We thank the reviewer for the generous comments. The present project targets marginal lands. The viability of switchgrass as a commercial crop depends on the market demand for the biomass, ecosystem service benefits, and its profitability. Switchgrass biomass is primarily used for biofuel production and as a feedstock for bioproducts. We expect the market demand for biofuels to increase and stabilize and to provide long-term viability for expanded switchgrass cultivation. Moreover, switchgrass has potential ecosystem service benefits that include nutrient cycling, carbon sequestration, reducing soil GHG emissions, improving soil and water quality and quantity, and providing a habitat for birds and insects. The increased environmental concerns faced today will likely persuade policymakers to shift policy and encourage switchgrass cropping in large areas. For instance, the Conservation Reserve Program and related marginal lands are currently targeted for long-term switchgrass production. In addition, the release of groundbreaking research and technological advancements that can enhance switchgrass productivity, biomass quality, and processing efficiency, such as breeding (new high-yield switchgrass cultivars), improved agronomic practices (establishment, fertilization timing, harvest methods), and processing techniques, can contribute to making switchgrass a more attractive option for large-scale commercial cultivation. Whether a crop makes sense at the commercial scale depends on market availability and profitability. We evaluated the profitability of switchgrass in the project by comparing the farm-gate prices with corn and soybeans, and found that switchgrass competes favorably with soybeans at the high price of $88 per megagram and with corn at $66 per megagram. In addition, switchgrass had lower production costs (land preparation, seed acquisition, establishment, management, harvest, and transportation) but higher income compared to the row crops (https://doi.org/10.1002/glr2.12017).

SUSTAINABLE HERBACEOUS ENERGY CROP PRODUCTION IN THE SOUTHEAST UNITED STATES

Texas A&M AgriLife Research

WBS:	1.1.1.108
Presenter(s):	Ted Wilson
Project Start Date:	10/01/2018
Planned Project End Date:	03/31/2024
Total Funding:	$6,251,605.00

PROJECT DESCRIPTION

This project develops a comprehensive assessment of the economic viability and environmental sustainability of producing advanced energy cane and biomass sorghum in the Southeast United States. Field experiments are being conducted in seven sites for energy cane and six sites for biomass sorghum across five states (Texas, Louisiana, Mississippi, Georgia, and Florida), involving five institutions (Texas A&M University, USDA Agricultural Research Service [ARS], Mississippi State University, University of Florida, and Tennessee State University). Comprehensive data on agronomics, off-season storage, and sustainability have been collected from 2020–2022. Major findings include:

Agronomics:

- Stem and root biomass increase through the season, while leaf biomass decreases toward the middle of the season.
- Energy cane yielded more than biomass sorghum, and southern sites produced higher yields.
- There was almost linear biomass loss during storage, and higher biomass loss for aerobic storage.
- Cellulose, hemicellulose, lignin, and ash all increased during the first 3 months of storage.

Sustainability:

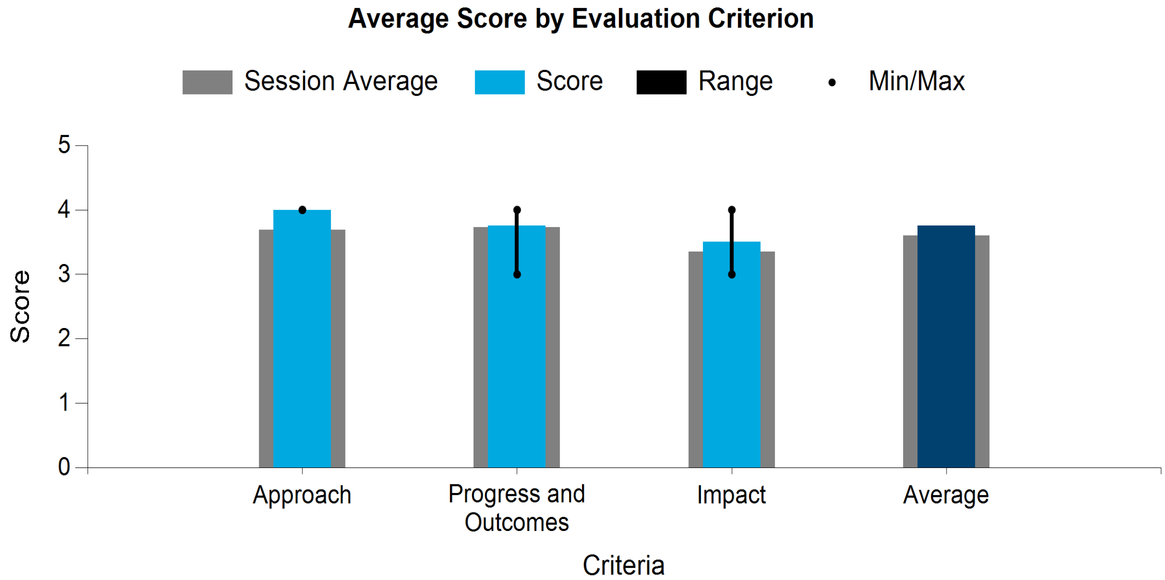
- Soil organic carbon (SOC) was, on average, higher post-harvest than pre-planting.
- Higher nitrogen rates had significantly greater N_2O emissions.
- Surface runoff water: Total nitrogen spiked after nitrogen application and decreased thereafter.
- Deep percolation water: Nitrogen application did not affect total nitrogen concentration.
- There was higher soil microbial diversity post-harvest compared to pre-planting.
- There was considerable variability in ground-active invertebrate diversity across sites and crops.

Enterprise budgets of energy crop production:

- Field operations account for the largest cost component in enterprise budgets.
- The total cost for biomass sorghum is higher than for grain sorghum.
- The total cost for energy cane is higher than for biomass sorghum.

Comprehensive integrated analysis (field-fuel economic viability and sustainability, site-specific BMPs, and operational plans) will be carried out in 2023 to the end of the project.

The current project complements existing studies on energy crops and assesses the economic viability and sustainability of cellulosic energy crop production in the Southeast United States. Outcomes from the project will accelerate adoption of cellulosic bioenergy development in support of BETO's strategic goal to reduce the price of biofuels to <$3/GGE and reduce the cost of feedstock to less than $84/dry ton.



COMMENTS

- This is a well-laid-out and well-executed project. The team is strong and has a proven track record. The project appears to have met all major milestones. It is not clear what the next steps toward commercialization are. Slide 6 mentions organizational and operational risks. What are the proposed mitigation steps? On Slide 20, what is the unit on the y axis?

- (1) In addition to the organizational risks you identified, are there any technical risks you have encountered over the last two years, and what measures you have taken to mitigate them? (2) Why is the Weslaco site's yield significantly higher than other sites for biomass sorghum, or lower for energy cane? (3) I raised a similar question in the previous review. The data analysis and interpretation can be further enhanced and improved in the coming years based on more data collected, such as the number of observations for each measurement and the number of replications. Some details are also needed to explain analysis of variance (ANOVA) and principal component analysis (PCA) data and results. (4) It is not clear how labor cost was considered in the cost analysis, and how these cost factors will be able to achieve the target of <$84/dry ton or <$3/GGE. (5) Any BMPs will be helpful for farmers and practitioners.

- Lignocellulosic feedstocks are gaining greater interest as a mechanism to fix atmospheric CO_2 to drive carbon sequestration in natural systems. The decades of bioenergy feedstock production research are foundational to catalyzing current research on atmospheric CO_2 removal, especially if lignocellulosic resources are to serve multiple purposes. This project is evaluating energy cane and high-biomass sorghum as feedstocks in the Gulf Coast region and Southeastern states. The primary intent of the work is to provide production information for siting biorefineries. They have made excellent progress on the production aspects of the project and have reinforced that these two species can reliably produce very high yields of biomass. The project also revealed, however, that no significant increases in SOC occurred. Although these species are excellent candidates to support biorefining, they do not seem to have great potential for soil carbon sequestration in production systems that remove all of the herbage.

Determination of dry matter losses associated with harvest timing and storage was listed as an objective; however, no results were presented.

- Presentation comments: Black font and standard font type would improve the presentation.
    - Approach: There was a clear definition of objectives, and an excellent slide (4) showing the roles of the collaborating team members. The project shows links with other BETO projects. Only two operational risks were mentioned. I'm sure there are many more; however, if these were the most severe, then the project has good prospects to proceed with little difficulty. Slide 7 was very helpful in understanding the technological approach used. This project is nearing its end date of 2024 and is a long-term, 5–6-year project.
    - P&O: On Slide 7, I have a question about the dry biomass loss chart. It shows dry biomass loss for sorghum at 25% in storage for 3 months, and 50% at 6 months. If this is the case, then how can it possibly be economical? What is the field of storage losses? It seems like this system would not be practical. The energy cane shows a similar trend, but storage losses are a little lower. On Slide 15, you should use percent increase or decrease of carbon so scales are comparable. On Slide 20, a stacked bar chart for each site would be better for comparison. The project shows some good data but is not presented in a way that would provide uptake for stakeholders.
    - Impact: The impact slide (21) is good, but I didn't see the metrics presented in such a way that it would be easy for a farmer to decide whether this would benefit their land and practices. I think what I am missing is a deliverable for 2023—the integrated analysis, as mentioned on Slide 22. I would have expected, with less than a year left in the project, to see some of this important analysis. The plan for disseminating results was not clear.

PI RESPONSE TO REVIEWER COMMENTS

- Comments: This is a well-laid-out and well-executed project. The team is strong and has a proven track record. The project appears to have met all major milestones. It is not clear what the next steps toward commercialization are. Slide 6 mentions organizational and operational risks. What are the proposed mitigation steps? On Slide 20, what is the unit on the y axis?
- Response: Steps for commercialization will include (1) potential biorefinery site selection based on a comprehensive analysis of land availability, biomass productivity, and environmental sustainability; (2) identification of BMPs for growing bioenergy crops that optimize profit and environmental benefits; (3) development of year-round biomass supply plans; and (4) provision of large-scale funding from DOE to (a) create a minimum of three biorefineries and associated storage facilities and transportation equipment for the Southeastern United States; (b) fund low-cost loans to support farm land purchases, equipment for bioenergy crop production and harvesting, and buildings for feedstock storage to support the production of a year-round feedstock supply sufficient to meet the needs of a biorefinery; and (c) establish a bioenergy commodity check-off system to ensure a research infrastructure to support necessary genetic, agronomic, insect, weed, and disease management research improvements to address evolving production and management needs. Wide-scale establishment of the bioenergy industry will rely on government incentives to promote commercialization of biomass sorghum and energy cane and national networks of biorefineries. Number 4 is beyond the scope of the current project, but our team would very likely play a major role in its implementation. Mitigation steps for organizational risk include (1) development of detailed sampling schedules for individual tasks; (2) monthly project updates on task implementation status; (3) frequent communication via email, phone, and video to resolve emerging issues; and (4) cross-training of project personnel for potential staff changes. Mitigation steps for operational risk include (1) production of biomass sorghum seed or energy cane stalks for commercial-scale planting/replanting; (2) appropriate seed bed preparation to minimize excessive moisture caused by

poor drainage in some soils to promote an aerobic environment for root health; and (3) sufficient land and equipment preparation to guarantee smooth and timely field operations. On Slide 20, the y-axis unit should be dollars/acre.

- Comments: (1) In addition to the organizational risks you identified, are there any technical risks you have encountered over the last two years, and what measures you have taken to mitigate them? (2) Why is the Weslaco site's yield significantly higher than other sites for biomass sorghum, or lower for energy cane? (3) I raised a similar question in the previous review. The data analysis and interpretation can be further enhanced and improved in the coming years based on more data collected, such as the number of observations for each measurement and the number of replications. Some details are also needed to explain ANOVA and PCA data and results. (4) It is not clear how labor cost was considered in the cost analysis, and how these cost factors will be able to achieve the target of <$84/dry ton or <$3/GGE. (5) Any BMPs will be helpful for farmers and practitioners.
- Response: Technical risks: Please see response above on "mitigation steps for operational risk." Weslaco's yield: Welasco's higher biomass sorghum yield is thought to be due to double-row beds (two rows per 40-inch bed instead of one row per 30-inch bed for other sites) and the use of drip irrigation (most other sites did not apply irrigation). We mistakenly used the average of low and optimal nitrogen levels for Beaumont and Starkville, which lowered the yield for the two sites. The low yield for Tifton was due to damage from nematodes. A main factor in lower energy cane yield is probably the very late harvest (early March instead of December) due to a combination of equipment breakdown and wet weather. We are also examining other factors that might have contributed to differences in yield among different sites. A comprehensive analysis of the factors impacting biomass yield across sites and years will be included in the final report. Data analysis and interpretation: We are in the process of integrating data from multiple years and sites and will provide improved comprehensive analysis, including ANOVAs and multivariate analyses (PCAs and others). Labor cost and target yield: An enterprise budget for each crop was built based on variable costs (material costs, labor costs, custom service costs, etc.) and fixed costs (machinery depreciation, equipment investment, management fees, land charge, etc.). Comprehensive economic analysis through enterprise budget, biomass yield, transportation logistics, and conversion processing will determine whether the target of <$84/dry ton or <$3/GGE can be achieved under different biomass pricing and biorefinery-scale scenarios. BMPs: Please see response above on "steps for commercialization."
- Comments: Lignocellulosic feedstocks are gaining greater interest as a mechanism to fix atmospheric CO_2 to drive carbon sequestration in natural systems. The decades of bioenergy feedstock production research are foundational to catalyzing current research on atmospheric CO_2 removal, especially if lignocellulosic resources are to serve multiple purposes. This project is evaluating energy cane and high-biomass sorghum as feedstocks in the Gulf Coast region and Southeastern states. The primary intent of the work is to provide production information for siting biorefineries. They have made excellent progress on the production aspects of the project and have reinforced that these two species can reliably produce very high yields of biomass. The project also revealed, however, that no significant increases in SOC occurred. Although these species are excellent candidates to support biorefining, they do not seem to have great potential for soil carbon sequestration in production systems that remove all of the herbage. Determination of dry matter losses associated with harvest timing and storage was listed as an objective; however, no results were presented.
- Response: Lignocellulosic feedstocks have two potential ways to reduce atmospheric CO_2: through soil carbon sequestration and as a renewable and replacement resource for fossil fuels. Soil carbon sequestration is a relatively slow but very important process. A small change in the percent carbon concentration equates to a very large change in terms of megagrams/hectare. Soil to a depth of 15 centimeters has an average mass of 2,260 megagrams/hectare. One tenth of a percent increase of soil carbon sequestration is equal to 1.13 megagrams/hectare. We expect to see a significant increase in soil

carbon with additional growing seasons for the energy cane. Because biomass sorghum is a rotational crop, its rate of increase of soil carbon will be less. The other benefit of lignocellulosic feedstock is its renewable nature. Atmospheric CO_2 is captured by plants through photosynthesis, released through biofuel combustion, and then captured again in a cyclic renewal way. Burning fossil fuel is a one-way release of CO_2 into the atmosphere. Our scheduled LCA will quantitatively address this topic. Biomass loss during storage is included on Slide 13 in the BETO review presentation. Biomass loss from harvest timing will be assessed through seasonal biomass as early harvest penalty and as standing biomass loss post maturity.

- Comments: Presentation comments: Black font and standard font type would improve the presentation.
    - Approach: There was a clear definition of objectives, and an excellent slide (4) showing the roles of the collaborating team members. The project shows links with other BETO projects. Only two operational risks were mentioned. I'm sure there are many more; however, if these were the most severe, then the project has good prospects to proceed with little difficulty. Slide 7 was very helpful in understanding the technological approach used. This project is nearing its end date of 2024 and is a long-term, 5–6-year project.
    - P&O: On Slide 7, I have a question about the dry biomass loss chart. It shows dry biomass loss for sorghum at 25% in storage for 3 months, and 50% at 6 months. If this is the case, then how can it possibly be economical? What is the field of storage losses? It seems like this system would not be practical. The energy cane shows a similar trend, but storage losses are a little lower. On Slide 15, you should use percent increase or decrease of carbon so scales are comparable. On Slide 20, a stacked bar chart for each site would be better for comparison. The project shows some good data but is not presented in a way that would provide uptake for stakeholders.
    - Impact: The impact slide (21) is good, but I didn't see the metrics presented in such a way that it would be easy for a farmer to decide whether this would benefit their land and practices. I think what I am missing is a deliverable for 2023—the integrated analysis, as mentioned on Slide 22. I would have expected, with less than a year left in the project, to see some of this important analysis. The plan for disseminating results was not clear.
- Response: The results on biomass storage loss from seven study sites consistently indicate high biomass loss during both aerobic and anaerobic storage. This poses a major challenge for year-round biomass supply, and the reviewer's concern about the practicality of off-season storage is well justified. This is an area that is understudied but critical to the economic viability of a biorefinery operation. Our integrated analysis in Budget Period 4 will examine best options to address the year-round biomass supply challenge. Regarding Slide 15, we will include the percent change in the final report. On the stacked bar chart: A stacked bar chart would make it difficult to visualize different cost components for each site. In terms of information for stakeholders: Please see the response under "steps for commercialization." Deliverables for 2023 were included on Slide 22: Comprehensive integrated analysis (field-fuel economic viability and sustainability, site-specific BMPs, and operational plans) will contribute to accelerating cellulosic bioenergy development in the Southeast United States. In terms of disseminating results: We have established an effective and well-attended outreach program in conjunction with the annual rice field day at the Texas A&M AgriLife Research Center in Beaumont. On the field day in 2022, we had a tour of our energy crop field experiment in Beaumont. We have also presented our results in the annual meetings of The American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America International Annual Meeting in 2021 and 2022. Manuscripts are being prepared for publication in bioenergy-related journals. Results will also be provided to DOE's Bioenergy KDF.

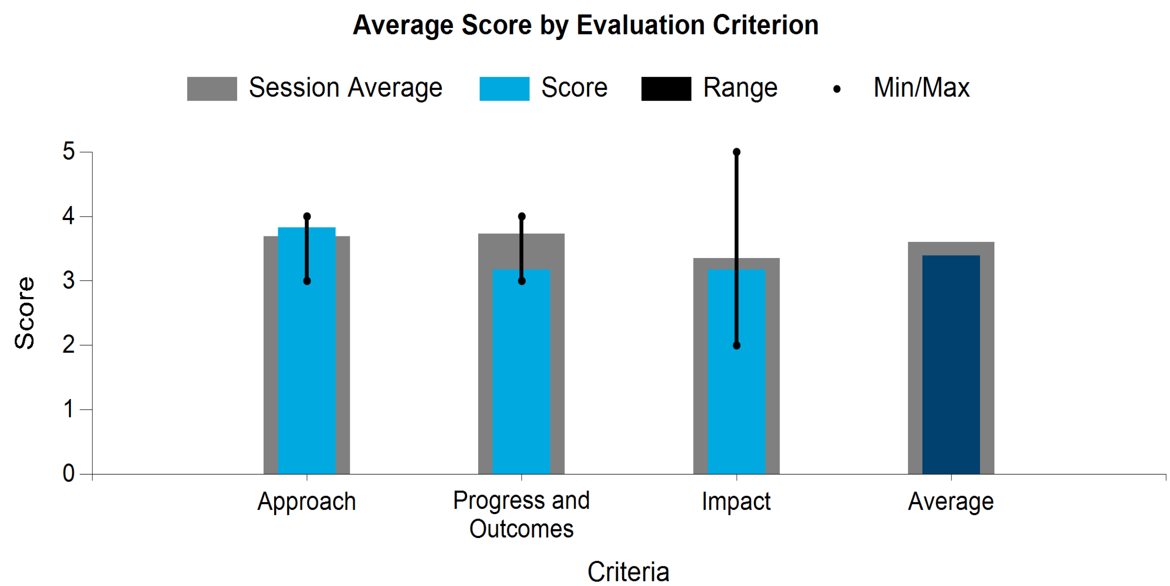
CHARACTERIZATION OF MECHANICAL BIOMASS PARTICLE-PARTICLE AND PARTICLE-WALL INTERACTIONS

Pennsylvania State University - University Park

PROJECT DESCRIPTION

WBS:	1.1.1.114
Presenter(s):	Hojae Yi
Project Start Date:	10/01/2019
Planned Project End Date:	03/31/2024
Total Funding:	$907,658.00

Forest residue feedstocks include a mix of particles from bole wood, bark, needles, twigs, etc. Similarly, corn stover is a complex bulk material with properties influenced by anatomical content such as cob, husk, leaf, and stalk. The resulting feedstock flow behavior varies due to differences in the anatomical origin and percentage of each fraction in the bulk feedstock. It is because the bulk feedstock behavior is the manifestation of responses of particles and their interactions at the underlying scale. Friction and adhesion are thought to be the two dominant interactions between biomass particles or particle-wall surfaces affecting the flow, which is a key mechanical phenomenon describing feedstock handling. This project aims to develop micro-mechanical test devices and protocols to characterize biomass particle and interparticle properties that are sub-millimeter to several millimeters in size typical to ground biomass. Upon successful completion, this project will result in a novel knowledge of values and variabilities in the friction and adhesion between (1) biomass particles and (2) biomass particles and a common wall material in biomass handling systems. This novel knowledge will enable innovative design and manufacturing of engineered biomass supply systems to handle, store, and deliver conversion-ready feedstocks consistently through innovative biomass handling modeling such as discrete element modeling (DEM).



COMMENTS

- The feedstock tested with the device has been particularly limited. Southern pine from a single location and time is not likely representative of the feedstock in question. As other projects noted, there are differences between years, ages of trees, harvest locations, etc. There was a broad statement made that this information could impact biomass handling, including modeling. However, no information is provided on *how* this will be accomplished. Will the PI be working with modelers, equipment designers, etc.? The impacts that are outlined are largely qualitative. A significant amount of data is being generated as a part of this work, but it's not clear where it's going and how it will ultimately be used. I agree with risk #4 as listed (limited day-to-day applicability). Risks and mitigations were laid out and realistic but did not include impacts or likelihoods. The validation and reproducibility of this novel piece of equipment was not clearly laid out. In terms of progress, a nice Gantt chart was provided, but it does not align with the dates on the quad chart.

- The team seems to have made good progress toward developing a characterization device with unique and important applications in feedstock handling. Their industry partnership with Forest Concepts indicates that there is a need for this device; however, the presentation did not clearly articulate any specific use cases, so it is difficult to evaluate the potential for impact on industry. I would recommend asking the following question: "If this device worked perfectly, what would that look like, and how could one quantify the potential benefit to industrial practice?"

- The slides are well organized, detailed, and adequately explained. The strength of this project is academia partnering with a private-sector industry company that has strong expertise in feedstock issues. It wasn't clear from the presentation why the given particle size was chosen and what specific commercial applications would benefit from a better understanding of characteristics at that size. The live presentation explained size selection. How this project advances feedstock handling beyond the status quo for commercial applications is general but not specific. The project will need to validate the reliability of the tester devices with an acceptable test standard. Graduate student recruiting efforts toward DEI are not explained, nor is any success toward achieving that intended outcome demonstrated.

- The approach of first-principles measurement of fundamental biomass mechanical properties (particle-particle and particle-wall interactions) is intriguing; however, the PI seems to be fundamentally developing a novel mechanical apparatus ("interparticle mechanics tester") and using results from this novel tester to correlate to observed bulk behavior. However, the novel mechanical device has not been tested against materials with known properties (elastic modulus, friction, adhesion) to calibrate or test the validity of the device. I suggest that the PIs test the device against polymer samples of the correct size and shape where these properties are well established. For instance, one can use polymer nibs from acetal polymers, atactic or syndiotactic polypropylene, polybutylenes, polyesters, etc. Because these materials are well characterized with known properties, one could calibrate the instrument and validate the measurement capabilities of the device. Additionally, the bulk handling characteristics of these materials are well-studied; how they behave in screw extruders and other flow characteristics is well known. One could develop and test the bulk property correlations of a model on simplified systems prior to tackling the models on biomass materials. Because of the lack of calibration and testing against known standards, I don't feel that one can claim the interparticle test has been successfully developed. That remains to be seen. Additionally, it is claimed that the device is "quick and accurate"—quick is a relative term, and listing a more precise cycle time for measurement is preferred. The "error bars" around the measurements presented are quite large, and I can't tell if that is due to mechanical property variation or measurement variation by the instrument, or even operator dependence. I think the approach has great promise, but the mechanical device development has not been demonstrated. Once it is calibrated against known standards, it could be useful in determining other material handling challenges, such as the influence of particle shape and entanglement of particles on flowability characteristics.

- The interparticle mechanics tester is a novel device with potential for patentability. The statistical approach and consideration of appropriate sample size and environmental controlled testing mitigate the identified risks. The project has met its milestones for Budget Period 2. The project has potential to provide impact in the flow of materials in hoppers, screw conveyors, and other material handling devices. However, the current testing to correlate the friction and adhesion of particles to wall material may not be sufficient to determine the performance in material handling equipment. Also, the review does not discuss the FOA metric of achieving an R-squared value of >80% relating the characteristics to feedstock handling. Adding a partner to evaluate material handling process performance as a function of particle-wall and interparticle properties would provide further verification of the correlation to bulk material handling as well as the commercialization potential of the interparticle mechanics tester.
- In terms of approach: The team has a well-thought-out approach to begin to characterize particle-level interactions of biomass, and they provided a nice outline of mitigation strategies as well as implementing feedback from previous peer reviews. The team does not currently have estimating impact in their plan, but are looking to do this in the future, which would be excellent. A full TEA is not required, but some estimate of impact would be beneficial. Specifics of the involvement and integration of forest products into the project were not presented. In terms of P&O: The team exceeded their initial mechanical property milestone with 20 replications rather than the requisite five, and so the subsequent milestone was increased in difficulty to 20. One significant issue is that the system has no reference materials for the equipment and correlation development. A reviewer suggested using plastic polymers, as they have extensive data and correlations. While this may help address this issue, plastic is not the same as biomass, and the researchers should have identified potential remedies for this issue. In terms of impact: A potential patent and commercialization of the interparticle tester would be a significant achievement and a real help to all solids industries, not just biomass. The ability to evaluate data on the particle level when other research is only on bulk and/or numerical modeling/analysis without aid of data will be especially helpful. The team has already started on patenting and commercialization of the tester.

PI RESPONSE TO REVIEWER COMMENTS

- Many thanks to the reviewers for their time and effort in evaluating various projects and providing insightful comments. We firmly believe that incorporating your comments strengthens this project and broadens its impact. In terms of project impact: This project has designed and constructed a novel first-principals-based interparticle mechanics test. The friction and adhesion between particles have long been hypothesized to be fundamental mechanisms of particulate materials' mechanical behavior. As pointed out by the comments, issues in biomass handling include the large variability in flow behavior and the lack of understanding of the cause of such variability. Significant portions of the FCIC and BETO FOAs on biomass handling have produced knowledge and tools to address these issues. Most notably, DEM is a promising computational tool to investigate and predict particulate material handling, including milled biomass. For example, the INL group has active research programs on developing and using DEM. However, no existing experimental device or protocol exists to measure the parameters of the DEM framework, forcing fields to rely on secondary measurement protocols. The device and experimental protocol developed under this project produce key parameters of DEM at the particle scale, which provides a pathway to understanding the cause and magnitude of the variability in biomass handling. Therefore, the immediate use of the product of this project is to advance the understanding and prediction power of biomass handling through computational simulation. To this end, we are actively working on follow-up collaborations with the INL group. The limited number of sample species and batches of biomass feedstocks in this project was set to keep the number of experiments achievable with the given resources and timeframe. While the representativeness of species and batches is bounded, this project includes four different tissue types and two different moisture content levels. The friction and adhesion measurements between particles of different tissue types demonstrate different variabilities between species and anatomical origins. These findings can be readily used in developing fractionation strategies for improved biomass handling for southern pine residue and corn stover. We are looking into collaboration opportunities with FCIC to this end as well as disseminating the findings to the field. We particularly appreciate the suggestion on validation. Because there is no referential material, experimental device, or standard to determine friction and adhesion between particles, the appropriate validation of this novel device is a crucial component. Following up on the suggestion, we are identifying and procuring appropriate polymer materials to conduct the validation experiments. In the meantime, we have acquired a precision steel ball bearing with a known surface specification and experimental measurements of friction coefficients using a conventional tribometer. The validation test with the metallic surface compared to the tribometer resulted in a negligible magnitude of variation between measurements. This validation result indicates that the observed variations of biomass particles are innate to biomass particles. We will include further validation of the device in the remainder of the project. We aim to achieve an R-squared value greater than 80% relating to the characteristics of feedstock handling, based on the bulk mechanical property measurement carried by Forest Concepts with the Cubical Triaxial Tester, which is another novel analytical device developed through a BETO-sponsored project. Comingled corn stover (4 millimeters) is one of the feedstocks that Forest Concepts routinely processes, and we do have data on handling with an industrial-scale hopper, which we will use in validation of the established correlations between friction/adhesion and bulk scale biomass handling.

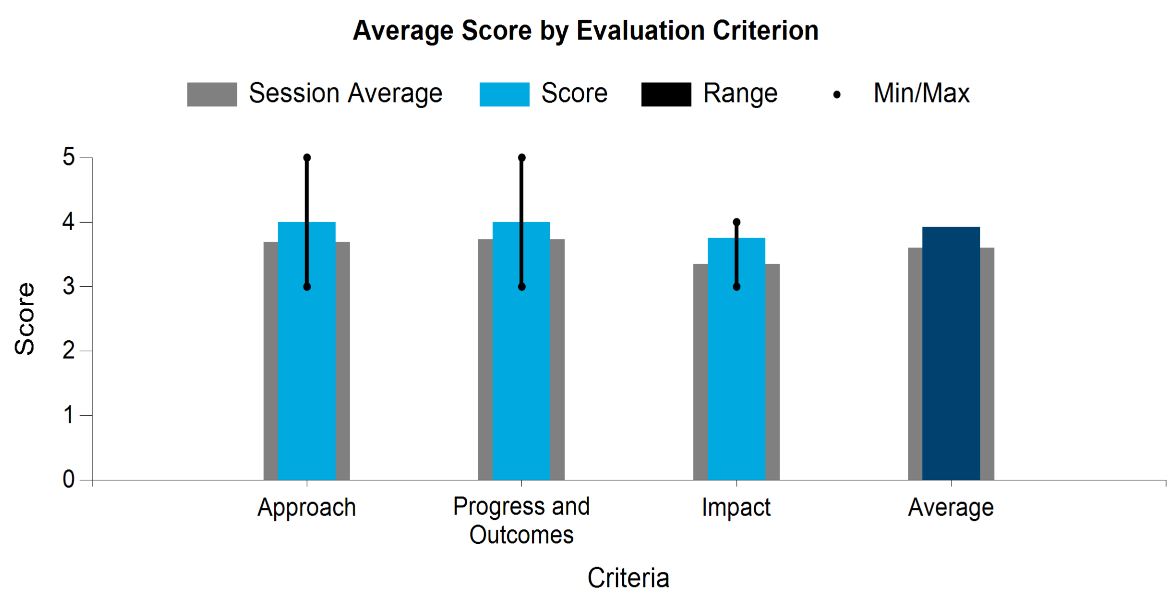
FEEDSTOCK SUPPLY CHAIN ANALYSIS

Idaho National Laboratory

WBS:	1.1.1.2
Presenter(s):	David Thompson
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023
Total Funding:	$3,000,000.00

PROJECT DESCRIPTION

The geographic distribution, low bulk density, and wide variability of biomass types, moisture levels, and compositions making up the billion tons of biomass potentially available for bioenergy create a unique challenge to the development of reliable, cost-effective biorefineries to provide low-cost, high-volume biofuels that can compete with petroleum-based fuels. This foundational project led the development of the pathway to the 2022 MYPP targets for development and verification of feedstock supply and logistics systems that can economically and sustainably supply industrially relevant quantities of herbaceous feedstocks for biochemical conversion at a delivered cost no higher than $85.51/dry ton (2016 dollars). The project also contributes to meeting a delivered feedstock cost target of $71.26/dry ton, in support of achieving the $2.50/GGE minimum fuel selling price (MFSP) target for 2030. This project investigates both conventional feedstock supply systems and a number of advanced (active quality management) feedstock supply system strategies, including blending and commoditization of biomass to meet the modeled cost, quantity, and quality specifications required to meet long-term BETO targets for biofuels production, cost, and volume. Beyond design case development and annual state of technology (SOT) tracking, this project performs high-impact forward-looking analyses toward enabling the development of an advanced feedstock supply system. The project was last merit reviewed in FY20, and its current 3-year cycle runs through FY23.



COMMENTS

- The team is strong and has the proven experience and track record in the needed skill sets to execute the work plan. The project seems to have met the deliverables. The team needs to articulate the results delivered versus the original plan more clearly. Slide 16 shows that overall operating effectiveness value increased steeply from 2019 to 2021, then declined in 2022? Why? Is this projected trend moving forward? Was there any feedback from Exxon/Shell on the report presented to them?

- The project was initiated in 2006 and has evolved over the last several years, including the addition of advanced supply chain management in FY14 and the design of the n^{th} plant in FY18. A major piece of supply chain resilience can be considered in the future study. In terms of approach, the number of milestones was mentioned. However, they need to be clearly defined. Two major project risks were discussed. However, their mitigation plans are not convincing. In terms of P&O, it is not clear how to estimate downtime on Slide 14. Furthermore, more explanation is needed on how this analysis can help real production for industry partners. In terms of impact, there are good results and publications. Any outreach and commercialization efforts would further enhance the project's impact. Specifically, the lessons you have learned since 2006 should be able to help for scale-up of the project.

- Computational modeling is important for conducting foundational analysis and forecasting the costs, availability, and characteristics of biomass feedstocks. The feedstocks are also expected to complement existing crop and livestock production systems. Projections need to support production goals for sustainable, climate-smart systems. Modeling systems are necessary to predict feedstock variability, illuminate management options for risk mitigation, and understand feedstock fractionation, separation, sorting, and blending.

- This is a very important project, as it attempts to answer economic feasibility questions surrounding fractionated biomass. The methodology and approach allow for testing of permutations related to the amount of biomass recovered versus the amount of fractionation and resulting quality. These are very important questions that can help optimize the resource but also balance processing costs. I hadn't seen failure and downtime considered in operations prior to this presentation, and thought it ties the feedstock quality to mill operation. The costs and efficiencies can now be balanced. I have had reservations about the value added by fractionated materials, and this model should hopefully help elucidate the value through the whole supply chain and bioconversion process. The presentation contained a lot of information in a short time. It is difficult to fully comprehend all aspects of the project.

PI RESPONSE TO REVIEWER COMMENTS

- This project has a very diverse work scope. In previous BETO Peer Reviews, this led to confusing the reviewers by presenting multiple accomplishments in a very short presentation. Those reviewers indicated a pressing need to understand how we accomplished the analyses and used the results to advance the feedstock supply system SOT, rather than outlining individual analysis accomplishments toward project milestones. Hence, for this review, we focused on analysis approach, methodology, and how the results are used to advance the SOT. We developed new analysis tools and carried out the annual SOT assessments. The results presented for this review covered SOT assessments for FY21 and FY22; during late FY22, BETO announced a shift of program focus to carbon intensity and SAF volume targets rather than delivered feedstock cost. Accordingly, we have adjusted the focus of our future assessments to region-specific analyses that identify available supplies of individual conversion-ready feedstocks based on regional characteristics that impact feedstock quality and carbon intensity. The utility of the first-plant analysis to industry is in identifying the feedstock properties that have the most significant impacts on preprocessing operation and ultimate product yields from the conversion. We showed total operating time and total downtime as well as the percentages of downtime occurring due to the various biomass properties, which can be used with the total downtime to estimate downtime attributable to individual properties over the course of a year of operation. We compared first-plant and

n^{th}-plant costs for the volume of biomass preprocessed; the difference is the cost incurred by decreases or interruptions of system throughput due to biomass properties and losses of biomass from the system. We showed a comparison of the first-plant time on stream and the assumed n^{th}-plant time on stream. Finally, we provided comparisons of total delivered cost due to the enforcement of compositional specifications, as well as overall operating effectiveness for supply logistics (harvest through storage) and preprocessing systems. This clearly identified losses of convertible organics during storage as a significant underlying issue that must be solved for the supply system to consistently meet yield requirements. Finally, with regard to risks, as an analysis project that projects performance for large-scale systems, our primary risks are a lack of sufficient scale-relevant data to adequately model the systems and understanding cost/quality trade-offs between aspirational n^{th}-plant assessments and the realities seen in first-plant projects. In the absence of large-scale data, we align with BETO feedstock R&D projects, utilize industry outreach and stakeholder engagement, and, when possible, utilize experiential information from industry preprocessing operators to inform the economics for larger-scale systems.

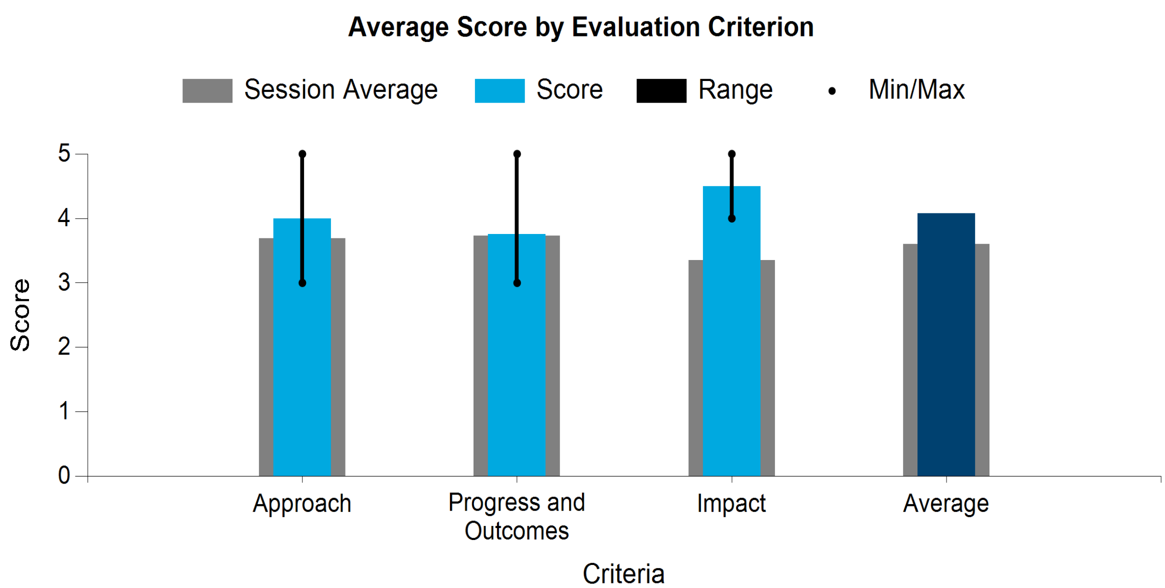
SUPPLY SCENARIO ANALYSIS

Oak Ridge National Laboratory

WBS:	1.1.1.3
Presenter(s):	Matt Langholtz
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023
Total Funding:	$2,025,000.00

PROJECT DESCRIPTION

The goal of this project is (1) to provide DOE and bioeconomy stakeholders with the biomass feedstock data needed to develop strategies to grow the bioeconomy (2023 *Billion-Ton Report*), and (2) to determine the optimal allocation of national biomass resources for decarbonization (best use of biomass [BUoB]). This project provides data including biomass feedstock quantity, cost, and spatial distribution. Previous *Billion-Ton Reports* (e.g., https://www.energy.gov/eere/bioenergy/2016-billion-ton-report; https://www.energy.gov/sites/prod/files/2015/01/f19/billion_ton_update_0.pdf) have identified ~1.2–1.5 billion tons of biomass potentially available annually in the United States in a base-case scenario. However, changing economic conditions, updated data, and interest in new feedstocks warrant an updated analysis, expected to be completed in 2023. *Billion-Ton Reports* and associated data support and inform government, research, and industry. Data from the *Billion-Ton Reports* are being used in a spatially explicit analysis of bioproduct pathways, including pyrolysis, Fischer-Tropsch, fermentation, and alcohol-to-jet, to assess BUoB for decarbonization based on minimization of carbon abatement cost.



COMMENTS

- This program is highly relevant and potentially impactful by advancing the prior pioneering work in the field. The team is very strong and has a proven track record and credentials. The proposed plan and milestones are well discussed. The project seems to be on track, and the 2023 report is expected shortly. The team has addressed the suggestions/comments raised in the previous Peer Review. It looks like a fair amount of emphasis is placed on energy crops like camelina. The cost is estimated at $0.15/pound. Is this the final cost delivered to the seed crushing plant? Is there enough infrastructure for harvesting, processing, etc.? As the team knows, the USDA has done some extensive work in this area. Is there much coordination between these efforts?

- This is a good project, with two tasks focusing on the billion-ton study and BUoB. DOE should continue to invest in this effort. To further improve data accuracy, regional field data collection and validation can be considered. In terms of the approach, I did not see that mill residue was considered as a part of forest biomass. Regional variation in logging residue tonnes per acre, the available amount of logging residue, and quality degradation over 1–3 years after harvest can be considered in the future report. Input-optimization-output was discussed in the modeling process. However, exactly what and where optimization was employed is unclear. In terms of P&O, results were good. In terms of impact, the number of citations of the *Billion-Ton Report* is very impressive. I look forward to reading the upcoming 2023 *Billion-Ton Report*.

- Computational modeling is important for conducting foundational analysis and forecasting the costs, availability, and characteristics of biomass feedstocks. The feedstocks are also expected to complement existing crop and livestock production systems. Projections need to support production goals for sustainable, climate-smart systems. Modeling systems are necessary to predict feedstock variability, illuminate management options for risk mitigation, and understand feedstock fractionation, separation, sorting, and blending. The project leader described the objective of this project as pushing the frontier of feedstock R&D. This team has led the production of two *Billion-Ton Reports*, with the second edition occurring in 2016. They are now concluding work on the *Billion-Ton Report* for 2023 and have added other feedstocks, including oilseed crops, forest thinnings, macro-algae, and CO_2 to e-fuels. I don't understand the addition of the latter, as CO_2 is not a biological feedstock. The group has expanded to also develop a decision tool on BUoB; however, this effort has had difficulty because of the absence of clear markets for feedstocks. I recommend that valorized ecosystem services be included as a considered BUoB.

- This is a very good project. The approach for the *Billion-Ton Report* is tried and tested. Additional feedstocks have been added to the report, which looks at future biomass resources. Progress is on track. The impact is very high, as this is a widely used and cited report. The information in this report is used extensively by those involved in the biorefinery industry, and as long as the intent of the report and the availability of biomass are clearly stated, this is an excellent, impactful project. It should be noted that on all presentations, there should be a minimum font size. The charts and tables pasted into the PowerPoint often have very small font, and at times this makes following the presentation difficult. Questions: Is there thought given to mapping other related production facilities (i.e., chemical/materials/pulp mill, etc.) in the biorefinery mapping? Also, are biomass depots being considered in the mapping for the BUoB?

PI RESPONSE TO REVIEWER COMMENTS

- Regional field data collection and input data are based on the Regional Feedstock Partnership (https://www.energy.gov/sites/default/files/2016/07/f33/regional_feedstock_partnership_summary_report.pdf). Mill residues are included in the analysis but are largely in use for hog fuel and may provide limited additional resource potential in a national context. Regional variation in logging residue and potential quality degradation will be considered. CO_2 is a non-biomass resource of interest to BETO. We agree that ecosystem services should be considered in downstream analyses. We agree that mapping of existing production facilities should be considered. Biomass depots have been and should continue to be considered in modeling and mapping of biomass resource use. The Biomass Supply Analysis Team thanks the reviewers for their comments and constructive feedback.

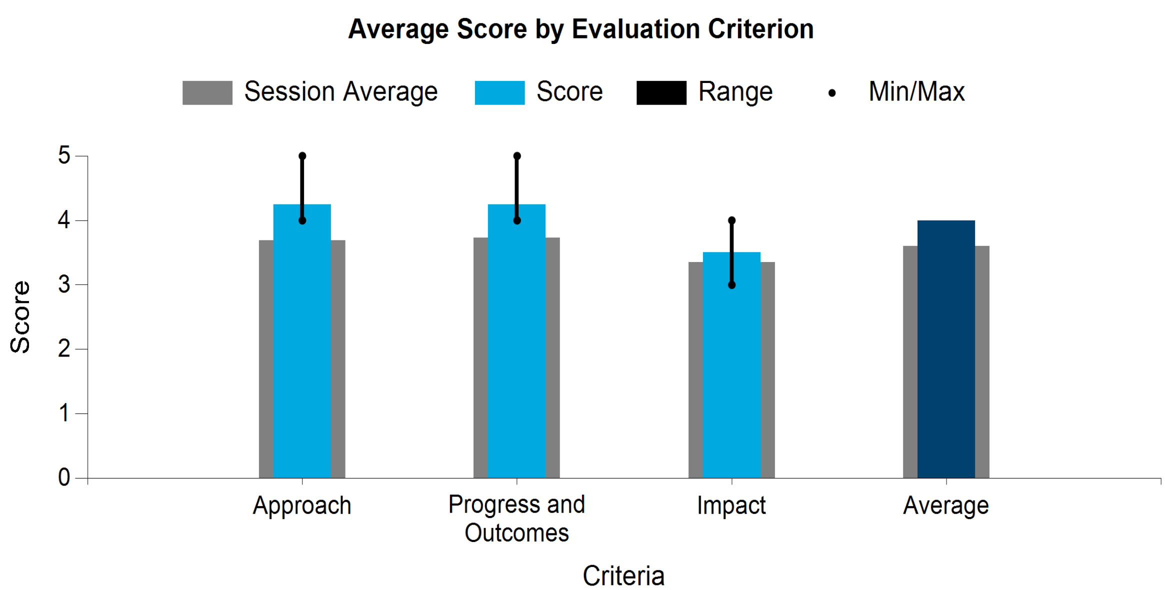
TRIPLE BOTTOM LINE SUSTAINABILITY INDICATORS FOR SPATIALLY EXPLICIT, MULTI-FEEDSTOCK, MULTI-TECHNOLOGY WASTE-TO-ENERGY SUPPLY CHAINS

Pacific Northwest National Laboratory

WBS:	1.1.1.6
Presenter(s):	Andre Coleman
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$1,125,000.00

PROJECT DESCRIPTION

There is broad public support for sustainability concepts, but defining and tracking progress toward multi-objective sustainability goals has proven to be challenging amid complex social, environmental, and economic interactions across geographic and jurisdictional boundaries. To address these gaps, Pacific Northwest National Laboratory (PNNL) is coupling state-of-the-art analytical methods (e.g., resource assessment, TEA, and trade-off analysis) with novel research in sustainability accounting to develop new standardized tools for the public that provide credible guidance to the waste community in support of regional waste-to-energy planning. PNNL is developing a unified sustainability assessment methodology to define, measure, and track sustainability goals for waste resource supply chains and evaluate the long-term trade-offs of different waste conversion strategies. Importantly, these tools will ultimately consider the local waste "diet," community goals, and nontraditional benefits (e.g., health, environment, equity). Stakeholder engagement is explicitly integrated into all aspects of the project. The completed sustainability framework could be used by federal, state, and municipal decision makers to identify and compare regionally relevant waste conversion pathways in a transparent and consistent manner.



COMMENTS

- This is a strong team with a proven record in the field through prior BETO-funded projects. The skill sets and organization of the team members are well articulated. The team has proactively reached out to potential end users and has started work with one of them. The project has made good progress against milestones. It looks like municipal waste is ubiquitous and well dispersed across the United States. How consistent in quality/supply is this source? Are there any synergies/economies of scale to treat this as one and develop the required quality, conversion, and equipment metrics? The project needs to address the lack of interest risk with stakeholders.
- This is a good waste-to-energy project. In terms of approach, the top potential project risks were well identified. However, the corresponding risk mitigations need to be clearly addressed. The roles and responsibilities of each project participant are not clear. In terms of P&O, good progress has been made. In terms of impact, the project mentions that social equity and environmental justice are a centerpiece of the model implementation. It is not clear how they have been implemented in the model applications.
- Computational modeling is important for conducting foundational analysis and forecasting the costs, availability, and characteristics of biomass feedstocks. The feedstocks are also expected to complement existing crop and livestock production systems. Projections need to support production goals for sustainable, climate-smart systems. Modeling systems are necessary to predict feedstock variability, illuminate management options for risk mitigation, and understand feedstock fractionation, separation, sorting, and blending. The project leaders pointed out that local governments and community leaders have difficulty understanding the organic waste streams in their communities, and even more difficulty understanding how to capture value from these wastes. This project has built significant momentum in meaningful stakeholder engagement, and I encourage them to continue with more outreach to rural, underserved communities. The project's geospatial analysis of underutilized waste streams is excellent. This project provides the strongest work reported for ongoing biomass R&D to achieve environmental justice in addition to circular bioeconomies. I recommend that they partner with other federal agencies to build awareness and build partnerships with minority-serving institutions.
- As far as the approach, there is significant merit to this project. Often, these models are for larger jurisdictions, but are equally or more important for assisting municipalities with decision-making, because they may have ownership of the waste. The communication routes could be improved by increasing the number of collaborators on the project. The presenter stated that they will be looking to link with more partners in the future. This is a vital component of the project that can affect success, but I didn't see risk mitigation outlined. Inclusion of environmental justice metrics is to be commended. Slide 4 is very informative; it shows who is doing what and points to a clear implementation strategy. There was a thoughtful analysis of challenges. Municipalities are motivated by ratepayers and their priorities, and it is difficult to get them to understand and plan for the future (outside of politicians' terms of office). In terms of P&O, excellent progress has been made to date. The project is midway and has already made some very good progress and produced some valuable results. Slide 9 gives a snapshot of indicators and an idea of the template. This will be easy to expand as new indicators come to light. Slide 12 breaks down the waste producers to the region—this is very nice information. As far as impact, risks to this project may be large. However, the project is still extremely valuable, as this will become a priority sometime in the future—even with disinterested stakeholders and short-term thinking by politicians.

PI RESPONSE TO REVIEWER COMMENTS

- Reviewer 1 Response: In terms of feedstock supply variability, because most markets and waste management services in the United States are highly consolidated and specialized, the wet organic wastes they ultimately produce are reasonably consistent in quantity and quality (including contamination). Some wastes, like wastewater solids and food waste, are steady year-round and correlate well with population growth. Depending on geographic region and animal type, manure supplies can be highly seasonal or year-round. Despite careful farm product price management, manure supplies are sensitive to market conditions, as animal herds are actively managed to address supply and demand (e.g., culling when prices crash). Similarly, depending on the region and crop, agricultural residues may be seasonal or year-round, and despite careful management of the food supply, crop harvest, and subsequent crop residue, supplies are often impacted by rising costs (especially fertilizer), severe weather, or drought, or all three, as was the case with historically low crop harvests in 2022. Historical variability is not always a good predictor for future conditions, but we can learn the key drivers that impact feedstock supply and enable the model to represent changes over time. Currently, the model evaluates average annual conditions to maximize profit for an average year. This approach meets our current need for rapid analysis. However, as a future development option, modulating waste flows, prices, and performance variables can improve our ability to model realistic impacts from population growth, waste policies, market dynamics, climate, risk management, etc. Also, there are several ways we can address input variability in the future, but they will require additional investigation and testing. In terms of economies of scale, the model does indeed account for economies of scale in relation to the total capital investment and annual operating expenses. An important feature of the model is the ability to model blended waste scenarios to achieve larger facility capacity. To accomplish this, we rely on scaled cost data provided by industry and experimental analysis teams modeling emerging technologies. We can quickly update our cost data as the TRL improves, providing better cost estimates. Additionally, as new technologies or processes become available, these can also be incorporated. As far as stakeholder interest—the involvement of stakeholders has been a key pillar in the project design to (1) understand the current gaps, challenges, practices, and aspirations from the perspective of multiple entities; (2) provide the foundation for case study design; and (3) provide a critical review and understand the practicality of sustainability metrics and measures and the modeling process as a whole. A key objective of this work is to build a capability that is useful, insightful, and impactful at the community, city, county, and state level. Building out stakeholder groups is a lengthy and involved process. The messaging in the presentation wasn't intended to convey that there is no interest, but rather that there is significant work involved. The process our team has used to establish stakeholder interest has been effective, receiving official endorsement of the work. Through our stakeholder interactions, our team has also realized that there is a significant lack of knowledge in new technology options for waste-to-energy conversion. Thus, an education component is advocated for, but there is much more that needs to be done that will need to happen at more programmatic levels.

- Reviewer 2 Response: In terms of risk mitigation, we apologize for not clearly summarizing our major risks and mitigation strategies. This information is presented below.
    - Price and policy uncertainty: We cannot accurately predict future market or policy conditions, and emerging technology cost and performance data are experimental. We mitigate this by (1) using the best available data; (2) applying sensitivity analysis to model a range of market and policy futures; (3) using statistical methods to assess long-term historical market and policy behaviors; and (4) eliciting external review.
    - Stakeholder interest: Municipalities may not have the policies, budget, or expertise to initially engage with a Waste to X (W2X) platform for trade-off analysis in this opportunity space. We mitigate this with direct stakeholder interaction, development of technology education materials, and demonstration of the modeling platform.
    - Unknown rate of technology adoption: We cannot predict technology readiness (commercialization) timelines or municipal/industry interest in new technologies. We mitigate this by adopting an enabling assumption that emerging technologies become commercially available in <10 years and are socially acceptable.

- Roles and responsibilities: We apologize for not clearly communicating the individual contributions of our team members beyond a high-level role/title. The following summarizes the roles and responsibilities of each team member. Andre Coleman and Timothy Seiple serve as the PIs, project managers, and task leads for the project. They also perform all the data management and spatial analysis. Craig Bakker provides operations research support and is responsible for selecting and implementing the optimization approach. Chrissi Antonopoulos serves as the lead economist to guide implementation of the sustainability indicators. Saurabh Biswas serves as an expert in sustainability science to provide a sound theoretical foundation for framework design and indicator design and interpretation, including potential feedback and bias. Michael Walsh and Dallase Scott are key performers for our subcontractor responsible for managing and facilitating stakeholder engagement. Andrew White serves as an expert in environmental, social, and governance; energy equity and environmental justice policy; and practice for energy systems. Bethel Tarekegne is an internal project reviewer with experience in policy research on building equitable, sustainable distributed energy systems.

- Indicator implementation: Given the limited presentation time, it was not possible to go into depth about how sustainability indicators are implemented in the model, so we appreciate the comment and opportunity to explain! The W2X Pathways model is designed to rapidly simulate and compare impacts from various waste management strategies. It is essentially a two-step process. First, we use a techno-economic optimization model to partition available waste resources among competing technologies for conversion to various energy endpoints (i.e., electricity, biofuels, biogas, etc.). The optimizer seeks the "best" overall waste utilization strategy by maximizing the systemwide net present value—profit. The siting game can be controlled to represent a wide range of scenarios. Second, based on the proposed optimal mix of technology locations, types, scales, and feedstocks, we can calculate various economic, social, and environmental impacts as the basis for performing trade-off analysis to understand the pros and cons of each waste strategy from a sustainability perspective. In other words, the impacts are calculated after the W2X facility siting process. Depending on how we run the model, we can evaluate the impacts of just the winning technology at a given location, and/or we can compare the relative impacts of building different technologies at the same location. In our software, sustainability indicators are represented as formulas or functions that accept input about relevant facility properties to calculate the magnitude of a particular impact. For example, based on the size of a facility, we can estimate the required number of employees, which is used to estimate economic impacts, but also safety-related impacts, such as injury and illness rates and total incidents per year. The facility size also gives us enough information to estimate air quality impacts such as GHG emissions, and even total residuals and effluent. The most difficult part of the project is developing a formula and gathering supporting data to adequately represent an impact indicator in a model with the appropriate units of measure that are relevant to stakeholders. The inclusion of sustainability scientists and human geographers on the team helps define metrics, measures, and supporting data related to social aspects, such as energy equity, environmental justice and health exposure, and social vulnerability, providing a critical component beyond the more traditional economic and environmental sustainability. Additionally, working with and eliciting feedback from community-level environmental justice stakeholders is key in this process. Even after this current project concludes, indicator development and interpretation will remain an active area of research within sustainability science. Our hope and objective is that the work completed under this project helps provide a foundation for future development in this space.

- Reviewer 3 Response: We are grateful for the positive comments, but also for raising several points of action beyond what our team has been discussing. In terms of supporting climate-smart systems, a major project objective is to perform and produce actionable analytics to generate multiple possible solutions that are possible within a defined geographic area. This will provide leaders with salient information to make informed decisions on further investigation, policy development, planning, investment, and actions beyond the status quo. We recognize that every community and jurisdiction will have a differing set of priorities, which the model supports. We further recognize that most leaders and decision makers will not have the capabilities to self-perform this type of multi-objective optimization analysis for current conditions, let alone quantify how a given scenario could impact/contribute to state or local-level climate goals, social sustainability, and economies. Driving toward climate-smart systems requires an adaptation to the business-as-usual process, and the utilization and conversion of wastes to numerous possible energy products is part of the solution. In terms of feedstock variability and blending, we agree that the inclusion of feedstock variability is a necessary part of the modeling process. We have several options for representing variability in the model. Please refer to our previous response on feedstock supply variability. We also address feedstock blending, a process that we believe helps stabilize variability, in the previous response on economies of scale. As far as stakeholder engagement, outreach, and coordination, with the help of our subcontractor who specializes in stakeholder engagement, we have successfully developed and maintained a focused partnership with the Boston metro area, including representatives of the various cities, nongovernmental organizations, and public advocacy groups, totaling ~30 different entities. We acknowledge that Boston represents a limited range of perspectives, and we plan to expand our outreach in the future. Our experience with the Boston stakeholder group has allowed us to build a process and gather lessons learned, and we will bring these experiences to future stakeholder groups. Our current level of stakeholder engagement is deliberately limited to be consistent with our project goals and available resources. For us, Boston serves as an incubator to help us learn how to adapt and tune our national-scale modeling techniques and deliverables to regional and local contexts, which admittedly is new for us. We view our work under the current project to be an important stepping stone to expanding the work in the future. Moving forward, we plan to complete the development and documentation of a robust functional prototype that can represent a broad range of pathways and impact quantifications. Once we accomplish this, we will be better positioned to present the concept to many more stakeholder groups and more effectively incorporate their feedback to operationalize the model. We also intend for future engagement to focus on rural and underserved communities and will look for alignment between this effort and the recently announced Empowering Rural America and Powering Affordable Clean Energy programs. Another BETO project (WBS 2.1.0.113) is planning to perform analysis specifically designed to characterize waste impact on underserved communities to identify synergistic opportunities for waste conversion, energy equity, and environmental health. We intend to use the results of that analysis to directly influence our future outreach and model development activities, which will certainly involve partnering with minority-serving research institutions. We also plan to expand our federal and nongovernmental organization partnerships and awareness, but again, we don't feel ready to advertise yet. After the sustainability model is published and operational, we plan to work with entities such as the BETO Technical Assistance Program to deploy the methods for the public.

- Reviewer 4 Response: We thank the reviewer for their insightful comments and recommendations. Regarding increasing communication and collaboration, please see our previous response on stakeholder engagement, outreach, and coordination. Another reviewer also noted the lack of risk and risk mitigation elements in the presentation. Please refer to our previous response on risk mitigation.

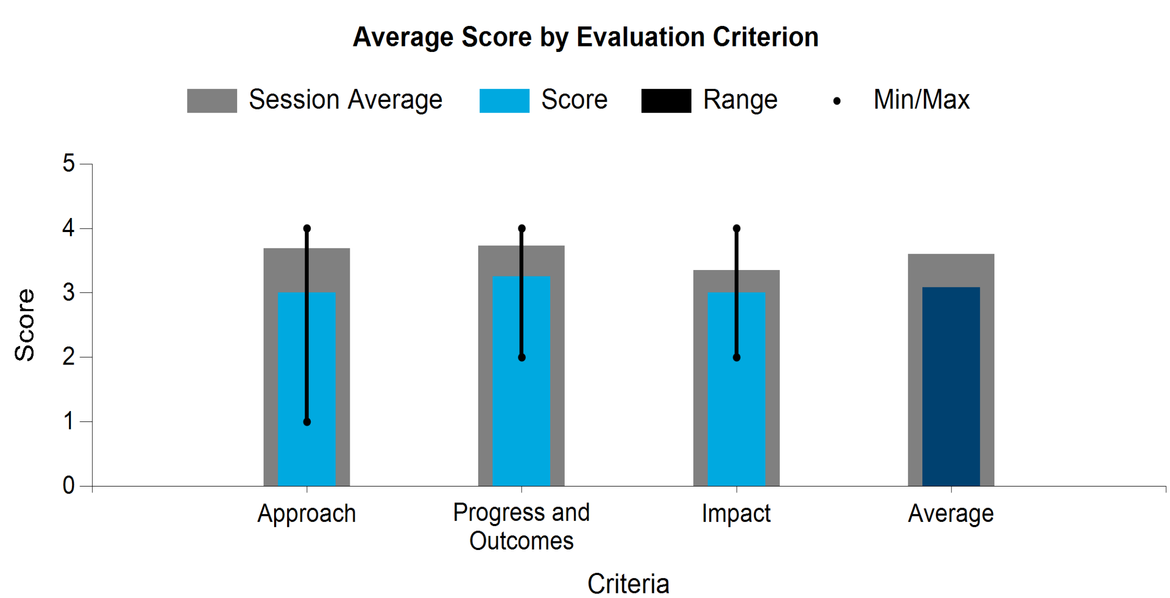
GLOBAL IMPACTS OF ENHANCING DOMESTIC ECOSYSTEM CARBON SINKS

National Renewable Energy Laboratory

WBS:	1.1.1.7/1.1.1.8
Presenter(s):	Patrick Lamers
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2023
Total Funding:	$1,450,000.00

PROJECT DESCRIPTION

The United States has set a target to accomplish a net-zero carbon economy, including a net-zero agriculture sector, by 2050. Initial assessments suggest that 30%–50% of the carbon removals required to achieve this target may (need to) come from terrestrial carbon sinks. The expansion of terrestrial ecosystem carbon sinks aboveground and belowground will inevitably result in resource competition, including for land. Land competition might reduce U.S. commodity outputs (e.g., corn, wheat, lumber), and, given the global trade balance of such commodities, might shift global production to other world regions. Thus, the potential expansion of U.S. carbon banking strategies needs to be assessed in a global, multisector context to quantify potential leakage and land use change effects, which may dampen the domestic efforts from a net global carbon perspective. Here, we use a biogeochemical model to quantify the net GHG and yield effects of terrestrial carbon banking strategies, including no-till agriculture, cover cropping, and biochar application on U.S. cropland, to parameterize respective options in a global, multisector carbon model, the Global Change Analysis Model (GCAM). GCAM will quantify the potential impacts on global agriculture production, land use, and emissions. This supports decision-making at the federal level, e.g., the viability of a net-zero 2050 U.S. economy, potential domestic feedstock competition to support the SAF production target, and the Office of Energy Efficiency and Renewable Energy decarbonization of agriculture pillar. It also advances the state of science in modeling carbon dioxide removal strategies in integrated assessment models.



COMMENTS

- The project plan is well documented, with detailed tasks, deliverables, and go/no-go milestones. The team is well rounded and has a proven track record and capabilities in the field. The team has addressed the comments/suggestions from the last review. The project is on track.
- This is a good project and is worthy of more investment for further investigation. In terms of approach, the project uses DayCent, Daymet, GCAM, and other models for analysis. However, the model integration and the inconsistency of data from different sources need to be addressed. In terms of P&O, the project needs to explain biochar application more, especially the two biochar app rates, three carbon prices, and any interaction between them. As far as impact, substantial efforts are needed for the project to deliver more impact. Some analyses are domestic, while others are global. They should be consistent.
- Computational modeling is important for conducting foundational analysis and forecasting the costs, availability, and characteristics of biomass feedstocks. The feedstocks are also expected to complement existing crop and livestock production systems. Projections need to support production goals for sustainable, climate-smart systems. Modeling systems are necessary to predict feedstock variability, illuminate management options for risk mitigation, and understand feedstock fractionation, separation, sorting, and blending. This project uses DayCent as a modeling platform to predict carbon sequestration rates in agricultural soils and production systems. I believe this project would benefit from increased collaboration with the USDA Office of the Chief Economist or the USDA Natural Resources Conservation Service. In the presentation, the team used a comment in a webinar from the USDA Office of the Chief Economist as their strongest example of stakeholder input, indicating a weak approach to stakeholder input.
- The slides for this presentation were not adequate for proper review. The font size was very small on some slides, and the addition of tiny figures where neither the data, axis, nor title could be seen just detracted from the project, rather than helping explain it. There was too much information on a number of the slides. See Slide 7 and Slide 4 as an example. In terms of approach, the roles of the seven people listed on the project were not clear. I didn’t see a risk analysis or mitigation strategy. The internship program to target DEI is commendable. As far as impact, no clear communication paths to the stakeholders were identified on the slides. There are only two project partners mentioned on Slide 17. The practical benefit of this project is difficult for me to determine. The PI should consider how this can be synthesized to be useful for policymakers. This needs a story that can be relayed to the layman. It was difficult to evaluate this project.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their constructive feedback. The project team plans to reevaluate the biochar treatment analysis in FY24 using new insights from ongoing literature review and meta-level analyses. The project performs national-level analyses in the context of global developments, all modeled in a single, integrated framework (GCAM). Thus, there is no disconnection between the geographic regions. Rather, U.S. practices are put in context of global commodity markets, and our results thus account for potential indirect effects. Feedstock variability is acknowledged but impossible to address at the level of resolution and aggregation of industries and supply chains in our model. We appreciate the suggestions of additional stakeholder input and plan to seek input from other federal offices in future efforts. We refer to the appendix/additional materials provided in the slide deck for roles and responsibilities within the project teams, stakeholder input and outreach plans, and risks and mitigation plans.

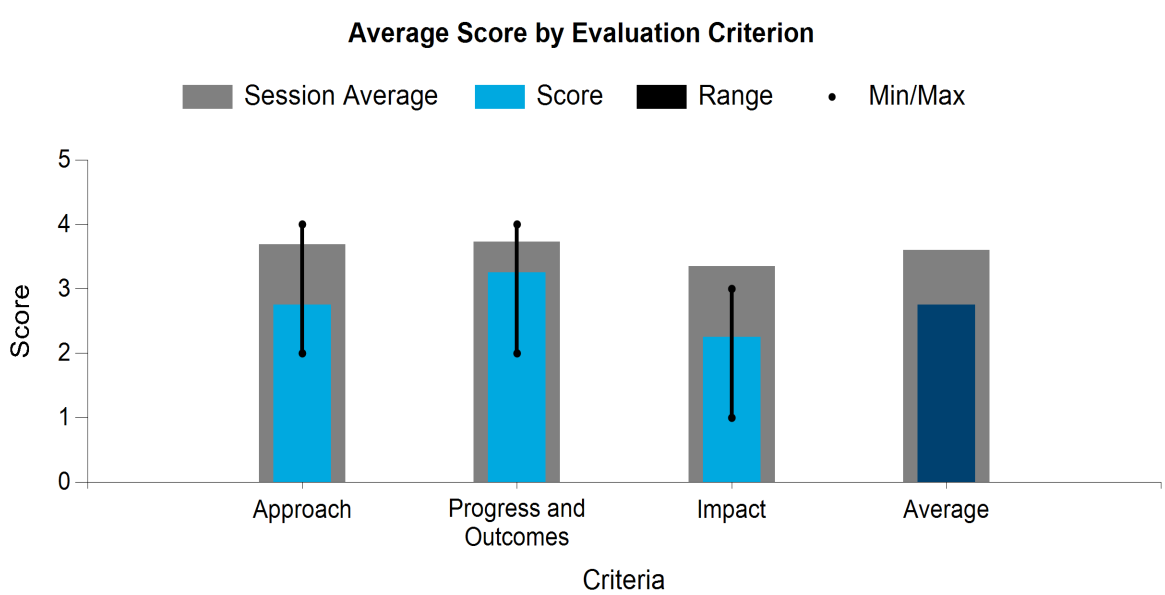
BENEFITS AND LAND USE EFFECTS OF U.S. ENERGY CROP-BASED CARBON BANKING

Oak Ridge National Laboratory

PROJECT DESCRIPTION

WBS:	1.1.1.9
Presenter(s):	Debo Oladosu
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$1,398,000.00

Carbon banking can help accelerate the production of energy crops in the United States by valuing the associated increases in SOC. Although SOC sequestration has received significant attention, details of national land transitions, potential land use changes (LUCs), and other effects are not yet well understood. However, these are essential to energy crop carbon banking. These LUCs and other “off-farm” impacts have already been identified as potentially limiting the role of carbon sequestration in agricultural soils for reducing GHG. Therefore, as with using food crops to produce biofuels, LUCs and other effects must be addressed when transitioning U.S. soils to energy crop carbon banks. In addition, SOC is highly dynamic and spatially heterogeneous, requiring detailed assessments to reduce uncertainties and carbon banking risks. This project supports DOE, BETO, and private industry by providing national/global-level information and analyses to address these issues to enable energy crop carbon banking in the United States. The project will examine scenarios for SOC sequestration, the national benefits, and the LUC effects of global interactions in the economy’s agricultural, energy, and other sectors. The project will seek to identify opportunities to maximize the complementary benefits of land use for agricultural production and energy crop carbon banking in the United States, as measured through environmental, social, economic, and equity sustainability indicators.



COMMENTS

- The project objectives, work plan, and deliverables are well documented. The team is well balanced and has the needed skill sets and capabilities to deliver the results. The project is on track. The required infrastructure to plant, harvest, and crush the seeds needs to be developed to have the projected impact on SAF. Slide 12 on economic analysis is not clear and needs further explanation.

- In terms of the approach, the challenges and risk mitigations are not clearly defined, and the data from many different sources and the conditions of the model development need to be further addressed. The project includes an analysis of growing energy crops for carbon banking versus growing forests of shorter rotation. In terms of P&O, the land use types range from existing cropland pasture (cotton crop) to miscanthus and sorghum, but other land types may be considered, such as marginal land and abandoned mine land. Analytical results from the three scenarios are confusing and inconsistent. In terms of impact, the project needs to address how its findings can help farmers implement more climate-smart agricultural practices.

- Computational modeling is important for conducting foundational analysis and forecasting the costs, availability, and characteristics of biomass feedstocks. The feedstocks are also expected to complement existing crop and livestock production systems. Projections need to support production goals for sustainable, climate-smart systems. Modeling systems are necessary to predict feedstock variability, illuminate management options for risk mitigation, and understand feedstock fractionation, separation, sorting, and blending. This project examined carbon banking for prospective cropping systems in Georgia. The project employed computational models aided by AI and ML. Satisfactory progress has been made with respect to AI development; however, a lack of understanding of agriculture became evident in the presentation. The project would benefit from increased collaboration with cropping systems experts in USDA ARS or a regional land-grant university.

- I find it difficult as a reviewer to grasp some of the project information when the slides are overloaded and the fonts are very small, i.e., Slides 4, 6, 7, 10, etc. This is a fairly high-level project that uses a number of models to arrive at some predictions for carbon soil banking. I am not clear on the project's approach, progress, or impacts. There were many terms and acronyms that I was not familiar with, and I didn't feel that an adequate explanation was given to help non-expert-level reviewers. There were a number of significant risks, including scarcity of data and the dynamic nature of soil carbon. I'm also not sure how impactful the large-scale predictions will be; it is more important to have more spatially explicit information for landholders to apply. The uptake of this project will be very difficult unless the results are translated into a more common language that a farmer or landholder could easily understand.

PI RESPONSE TO REVIEWER COMMENTS

- Comments 1: The project objectives, work plan, and deliverables are well documented. The team is well balanced and has the needed skill sets and capabilities to deliver the results. The project is on track. The required infrastructure to plant, harvest, and crush the seeds needs to be developed to have the projected impact on SAF. Slide 12 on economic analysis is not clear and needs further explanation.

- Response 1: Many thanks for your comments. Slide 12 presented key scenarios highlighting the main results of our simulations on the effect of SOC incentives on carinata adoption. We are preparing a paper that presents the other scenarios and puts the key scenarios in context with a more detailed discussion.

- Comments 2: In terms of the approach, the challenges and risk mitigations are not clearly defined, and the data from many different sources and the conditions of the model development need to be further addressed. The project includes an analysis of growing energy crops for carbon banking versus growing forests of shorter rotation. In terms of P&O, the land use types range from existing cropland pasture (cotton crop) to miscanthus and sorghum, but other land types may be considered, such as marginal land and abandoned mine land. Analytical results from the three scenarios are confusing and inconsistent. In terms of impact, the project needs to address how its findings can help farmers implement more climate-smart agricultural practices.

- Response 2: Thanks for your comments. Given that this is an analytical project, the challenges and risks are mainly related to data availability, tools, and personnel. The presentation highlighted the complexity of estimating SOC changes and efforts under the project to address the associated issues. We will examine the role of different land types in SOC accumulation with energy crops more closely. The three scenarios discussed during the short presentation highlighted the key results of evaluating SOC incentives for carinata production. We are preparing a paper that presents the other scenarios and puts the key scenarios in context with a more detailed discussion. We also plan to work with stakeholders to present these results and to better understand their perspectives on climate-smart agricultural practices for SOC accumulation.

- Comments 3: Computational modeling is important for conducting foundational analysis and forecasting the costs, availability, and characteristics of biomass feedstocks. The feedstocks are also expected to complement existing crop and livestock production systems. Projections need to support production goals for sustainable, climate-smart systems. Modeling systems are necessary to predict feedstock variability, illuminate management options for risk mitigation, and understand feedstock fractionation, separation, sorting, and blending. This project examined carbon banking for prospective cropping systems in Georgia. The project employed computational models aided by AI and ML. Satisfactory progress has been made with respect to AI development; however, a lack of understanding of agriculture became evident in the presentation. The project would benefit from increased collaboration with cropping systems experts in USDA ARS or a regional land-grant university.

- Response 3: Many thanks for your comments. We have made some progress under this effort, but there is much to do. In this context, we appreciate the suggestion to collaborate with USDA ARS or land-grant universities and plan to pursue this as part of our stakeholder engagement.

- Comments 4: I find it difficult as a reviewer to grasp some of the project information when the slides are overloaded and the fonts are very small, i.e., Slides 4, 6, 7, 10, etc. This is a fairly high-level project that uses a number of models to arrive at some predictions for carbon soil banking. I am not clear on the project’s approach, progress, or impacts. There were many terms and acronyms that I was not familiar with, and I didn’t feel that an adequate explanation was given to help non-expert-level reviewers. There were a number of significant risks, including scarcity of data and the dynamic nature of soil carbon. I’m also not sure how impactful the large-scale predictions will be; it is more important to have more spatially explicit information for landholders to apply. The uptake of this project will be very difficult unless the results are translated into a more common language that a farmer or landholder could easily understand.

- Response 4: Thanks for your comments. Yes, the dynamic nature of SOC, the scarcity of data, and the lack of a standard model present significant risks to this analytical effort. We have made some progress in addressing these issues, but much remains to be done. Although the preliminary results of the SOC simulations we presented were at the state level, the simulations were performed at the soil map unit/cropland use level—the most detailed level available from different data sources. Additional results of our efforts will be presented as maps at this more granular level. Yes, it is important as suggested for farmers and landholders to understand our results, and we plan to engage with these stakeholders as part of the project.

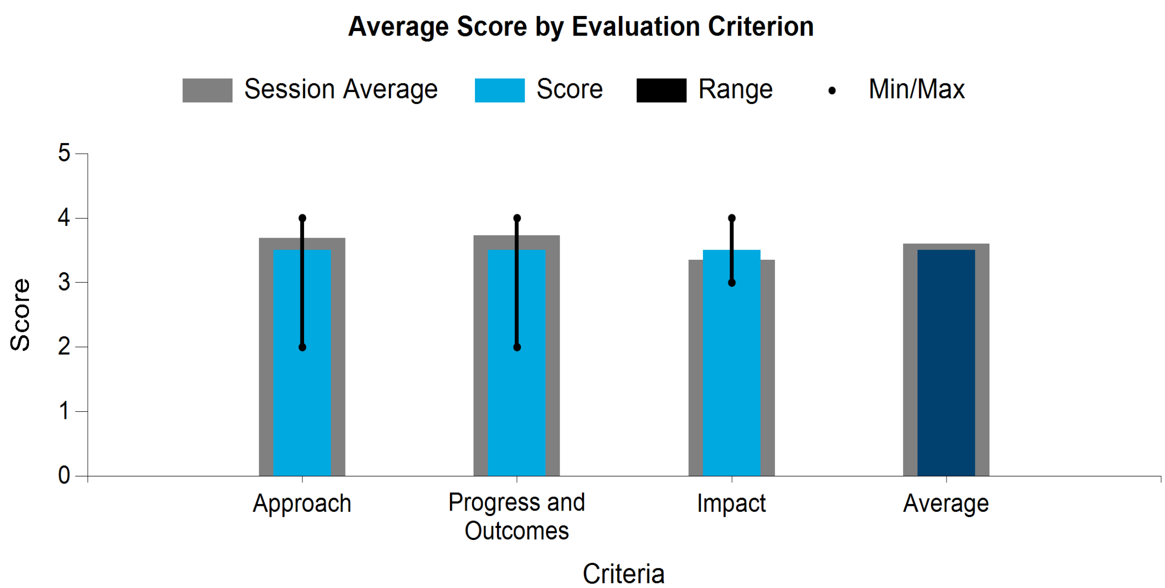
COVER CROP VALORIZATION FOR BIOFUELS AND PRODUCTS

Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	1.1.2.1
Presenter(s):	William Smith
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$2,250,000.00

This task identifies technically feasible but currently underutilized cover cropping systems with the potential to decarbonize agricultural activities associated with corn stover harvest as a feedstock for conversion to sustainable fuels. The project focuses on the economics, biogenic carbon use, and biomass quality impacts of using cover crops where the stover residues are used as feedstock for fuel production. The novelty of this work is that it goes beyond traditional ecosystem services and uses existing consensus values of those services as a baseline monetary value from which to measure success. Objectives include (1) economic evaluation of combining cover crops with agricultural residues to improve on-farm economics with and without cover crops, (2) decarbonization potential of combining cover crops with residue removal relative to conventional agrichemical application and field operations, (3) laboratory-scale evaluation of cover crop materials, (4) evaluation of economically advantaged biochar to modify soil carbon, and (5) testing of INL's bale probe to measure soil carbon. Results will be used to populate and expand INL's feedstock logistics models. The outputs will be used to show how cover cropping, residue removal, and integrated land management have the potential to provide growers with a sustainable additional income stream and supply biorefineries with a high-quality and sustainable biomass resource.



COMMENTS

- This relatively new 3-year project is making good progress in the area of GHG emissions, which are a serious problem associated with farming. The team is well balanced with active participation from industry. The potential partner companies are good and active. Slides 11–13 have interesting data on zeta potential for the heavy and light fractions. It looks like the light faction is better suited for biochar. Are there any estimates on the contribution to reduction in GHG emissions from this use?

- This is a good project involving collaboration with Antares Group and Continuum Ag. On Slide 7, how do you plan to mitigate and handle these uncertainties in the coming year? The diversity, equity, and inclusion plan (DEIP) can be further developed to serve underserved communities. Cost analysis can be incorporated into biochar applications. BMPs can also be developed for farmers for cover crop practices.
- Lignocellulosic feedstocks are gaining greater interest as a mechanism to fix atmospheric CO_2 to drive carbon sequestration in natural systems. The decades of bioenergy feedstock production research are foundational to catalyzing current research on atmospheric CO_2 removal, especially if lignocellulosic resources are to serve multiple purposes. The focus of this project is on examining trade-offs between cover crop management decisions and the inclusion of biochar. The work includes significant involvement of subcontractors for field demonstrations and stakeholder input. The highlight of the project in 2022 was participation in a field day event near Washington, Iowa. The necessity of measuring grain yield was emphasized as a key finding; however, that is already known for cropping systems R&D. They also reported results showing the benefits of using biochar, but no results were obtained or reported. No publications were reported, but the project is early in its implementation.
- Liked the use of the "farm budget" as the metric for measuring success, as the decision to carry out this practice will be based on specific farm operational costs and trade-offs with soil carbon. Because yield is the key variable for good farming profits, this should be a priority of the measurements. For better uptake by farmers (removal of corn stover for biomass), the questions posed in this project need to be answered. Relating to farmer operations is key information that will be needed by farmers to make the best decision. Chart 2 is not an adequate size to view the labels, etc. The font on many slides is very small and difficult to read. The blue color is also not ideal. In terms of approach, the study involves a case study of one farm. It will provide insights into what should be considered in an assessment, but the results themselves are of limited value. The questions asked (3) are highly relevant and need to be answered in order to make this a relevant and impactful process to allow for better utilization of corn stover residues. Modeling, while identified as challenging, is important for the real-life application of these findings. The partnerships with agricultural companies were good. In terms of P&O, the section on biochar was not well presented. Nothing about the costs/supply/sustainability of biochar—or the carbon footprint of biochar itself—was mentioned. Is it locally supplied? How is it brought to the site, spread, etc.? I don't fully understand the supply chain for the product and therefore whether it might make sense. In terms of impact, I have concerns about the limited number of sites/systems that will be analyzed in this project. Should preliminary BMP be included in this project?

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their positive and productive comments regarding the scope and progress that we've made thus far. The reviewers have recognized that our approach of using producers' on-farm budgets as our economic target comes with certain challenges and opportunities. Opportunities include analyses showing the potential revenue stream generated by stover residue removal and sale, which can offset the additional operational costs incurred by cover cropping, especially when working with a single producer over several years. Challenges—as specifically noted by our reviewers—include showing how those site-specific budgets can be extrapolated to other producers' conditions. Multiple reviewers reminded us that as we learn more about cover cropping and biochar application for sustainable residue removal, we need to distill our knowledge into BMPs that we can share with our collaborators for broader dissemination among producers. We believe that this communications strategy is important, as it also addresses a DEI concern: that the products of our research enable economic opportunities for rural economies as bioconversion technologies scale up. We have much to learn about the uncertainties surrounding soil carbon, the role of cover crops as a replacement for organic carbon removed during stover removal, and whether cover crops positively or negatively impact grain yield. First, although cover cropping and grain yield have been described in the literature—as stated by a reviewer—the added factor of residue removal is a relative unknown. We view cover cropping as a soil carbon replacement strategy with the potential to increase the amount of stover that can be removed sustainably. However, as we showed in our presentation, grain yield plays a larger role in producer profitability than either residue value or carbon credits. There is uncertainty in the literature about whether cover cropping and reduced tillage practices have a positive, negative, or neutral impact on long-term grain yields. We can make assumptions about how residue removal may impact the producers' budgets based on a range of modeled removal rates and sales values, but we need to understand how this additional operation impacts the row crops' yields to have a clear picture of whether residue removal is sustainable to the grower.

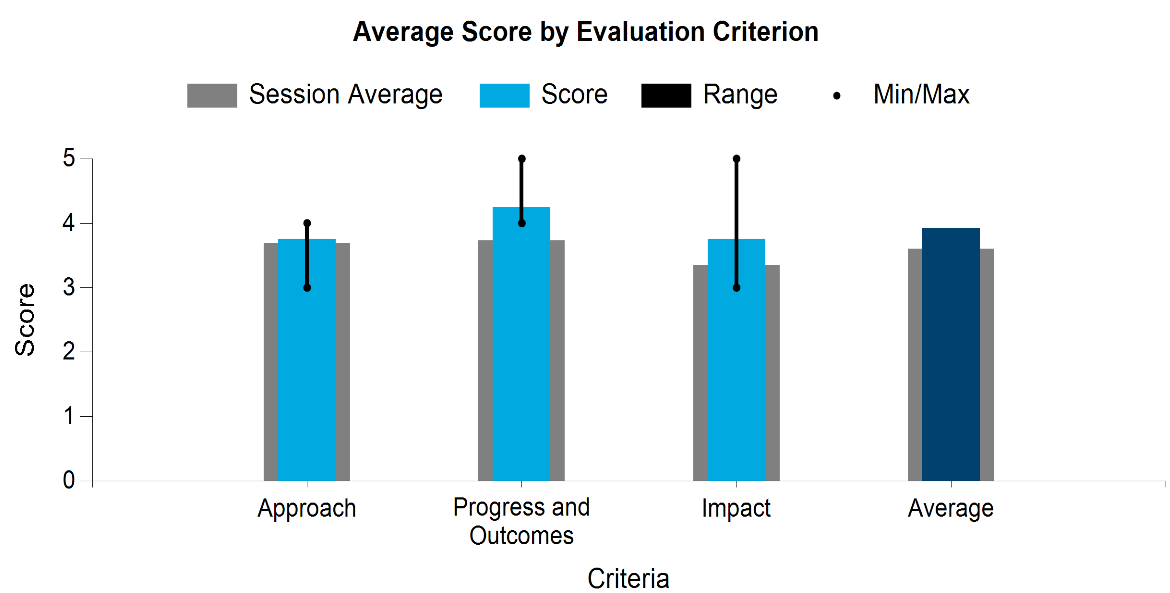
MAXIMIZING THE VALUE OF LATE YEAR COVER CROPS IN THE PACIFIC NORTHWEST

Pacific Northwest National Laboratory

WBS:	1.1.2.2
Presenter(s):	Daniel Santosa
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$1,470,000.00

PROJECT DESCRIPTION

This work highlights the potential of cover crops for use in biofuels from the perspective of the whole supply chain and life cycle to benefit farmers, biofuel producers, and the overall bioeconomy. In terms of utilization, cover crops equaled only 3.9% of all U.S. cropland in 2017. In addition, in Washington state, cover crop utilization is even lower, at <1%. Increased usage of cover crops provides an opportunity for producing biofuels and improving agricultural sustainability by improving soil health, thus enabling decarbonization efforts for both the agricultural and transportation sectors. The project objective is to provide a deeper understanding of the wide variation in cover crop use—in particular, the relative roles of climate, soil type, production practices, and application of cover crops as a feedstock for biofuels production. Typically, cover crops are grown for soil health only; however, biofuels production requires understanding trade-offs of harvesting optimal levels of cover crops to understand the impacts on soil quality. The first-year experimentation demonstrated promising results for the overall net benefit of cover crops in three different weather systems (wetland, irrigated, and dryland). We observed a net revenue due to the cash crop yield gain, with no observed loss of or impact on soil health. Moreover, improved revenue and sustainability is achieved when cover crops are blended with other wet waste, such as sewage sludge. The outcomes of this work are a deeper understanding of (1) an underutilized feedstock for fuel and (2) how to improve agricultural and agronomic practices, achieve biofuel production at a modeled cost target of $3.15/GGE, and achieve >70% GHG reduction by 2030.



COMMENTS

- This is a well-structured project with clear and specific, measurable, achievable, relevant, and time-bound milestones. The team is strong, with a proven track record and credentials. The focus on quantifying minimum technical achievements at this early stage is highly relevant and useful. I am wondering, with several projects funded by BETO, whether there are reliable guidelines/metrics for what minimum technical achievements are needed for operations like high-temperature air, gasification, Fischer-Tropsch, etc. (i.e., operations that are needed for biofuel and high-value chemical production). Such a guideline would be useful in focusing on early promising candidates.

- It is not clear how these three locations were selected and whether soil type was considered. DEI needs to be implemented in underserved communities. It is not clear whether any pretreatment was done on wastewater sludge for contamination. The cost of decontamination should be factored into the cost analysis.

- Lignocellulosic feedstocks are gaining greater interest as a mechanism to fix atmospheric CO_2 to drive carbon sequestration in natural systems. The decades of bioenergy feedstock production research are foundational to catalyzing current research on atmospheric CO_2 removal, especially if lignocellulosic resources are to serve multiple purposes. This project is early in its implementation, but is perhaps the best executed of the cover crop projects. It has a diversity of three locations in Washington state, several cover crop types, and several primary crops that are appropriate for the Pacific Northwest region. The team is obtaining data to conduct LCAs for the various cropping systems. The PNNL team is collaborating with research and extension staff at Washington State University. Excellent impactful work is underway, and they have yet another growing season to obtain data.

- The project has valuable objectives: to produce information on the costs and benefits of using cover crops directly as a fuel source, which also reduces the overall carbon intensity of agronomic practices. In terms of the approach, there was a good slide (4) showing the partners and their role in the project. However, the slide is very wordy and was hard to read or absorb during the presentation. The project is sound and has a good chance of being very successful. There was good identification of risks and mitigation strategies built into the project. Missing from the project structure is who will be doing the outreach to the farming community. As far as P&O, there were some good initial findings related to the association between cover crops and the improved yield of a main cash crop. How will the information be shared and in what form? Is the intent to write scientific papers and/or extension bulletins? In terms of impact, is there sufficient market demand for the residue to warrant this extra step? The regionality of biomass energy plants would limit the viability to specific areas. Field demonstration days and feedback are very important for future implementation.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for taking their time and providing their thoughtful and insightful comments. We agree that the effort to quantify the critical material attribute (CMA) of the biomass is critical for the relevance and usefulness of cover crops and other feedstocks. We used a yield predictive model to estimate biofuel yields based on the hydrothermal liquefaction (HTL) feed compositions (carbohydrate, lipid, protein, ash, and lignin contents). The yield predictive model was developed from an experimental data set generated from the HTL flow reactor systems at PNNL. Examples of HTL yield predictive models can be found in recent PNNL publications, such as https://doi.org/10.1016/j.jece.2023.109706, https://doi.org/10.1016/j.apenergy.2020.116340, and https://doi.org/10.1016/j.algal.2019.101450. We would also like to clarify that the crop locations, soil types, and cover crops were chosen to represent the diversity of farming practices that are amenable to cover cropping in Washington state. The cover crops were selected to represent the varietals of legumes and grasses that are considered the best fit to the crop rotations and that will support the subsequent growth of primary crops that are appropriate for the Pacific Northwest. In addition, soil type is one of many factors that differ among sites, among which are climate and access to water. The aim is to consider different growing regions to inform which cover crops and regions might produce sufficient cover crop biomass and composition for biofuels. This knowledge can be used to incentivize adoption of cover cropping. We also appreciate the comments with regard to sewage sludge pretreatment. The HTL team at PNNL has been collaborating with multiple wastewater treatment facilities and waste management entities. We learned that any additional pretreatment step or decontamination effort for the wet waste feedstock is not necessary. However, a simple dewatering or dilution step may be required to control the viscosity and pumpability of the HTL feed. This is also consistent with the latest PNNL conceptual process design of a wet waste HTL pathway that was extensively reviewed by internal and external experts (https://doi.org/10.2172/1897670). In terms of outreach to underserved communities, we agree with the reviewers on how important this effort is. This project focuses on serving both rural and underrepresented communities across the state of Washington, in partnership with the Washington State University (WSU) Center for Sustaining Agriculture and Natural Resources, by holding annual field days in three farming locations. This is our primary way of demonstrating the growth and economic potential of cover crops for cash crop production alongside a presentation of sustainable agriculture practices. We have conducted outreach in the WSU Puyallup Research and Extension Center Cover Crop Field Day on May 1, 2023, and the field day in 2022. There is another upcoming field day in June 2023 at the WSU Research and Extension Centers across three sites in Washington state. Additionally, WSU will be presenting findings to diverse audiences, including underrepresented farmers, at annual meetings like the Tilth and Hay Growers Association. In terms of publications, we presented our first-year results at the American Chemical Society Spring 2023 meeting in April, and we will be presenting our TEA and LCA methodology and preliminary results at the 2023 American Society of Agricultural and Biological Engineers annual meeting in July. After our third growing cycle in 2024, we will have additional data on seasonal and climate variability, which will impact the overall cover crop production. We will present the results in journals. In addition, there is demand for economically advantaged residues from cover crops, which would not lead to additional land use change—one of the key factors in determining a biofuel's percent GHG emissions reduction. With the cover crops in the off season, the feedstock logistics are enhanced relative to just corn residues, which are harvested solely in August–October. It is clear that the price of cover crops for biofuels would have to be better than the price of using the cover crops as fodder or bedding.

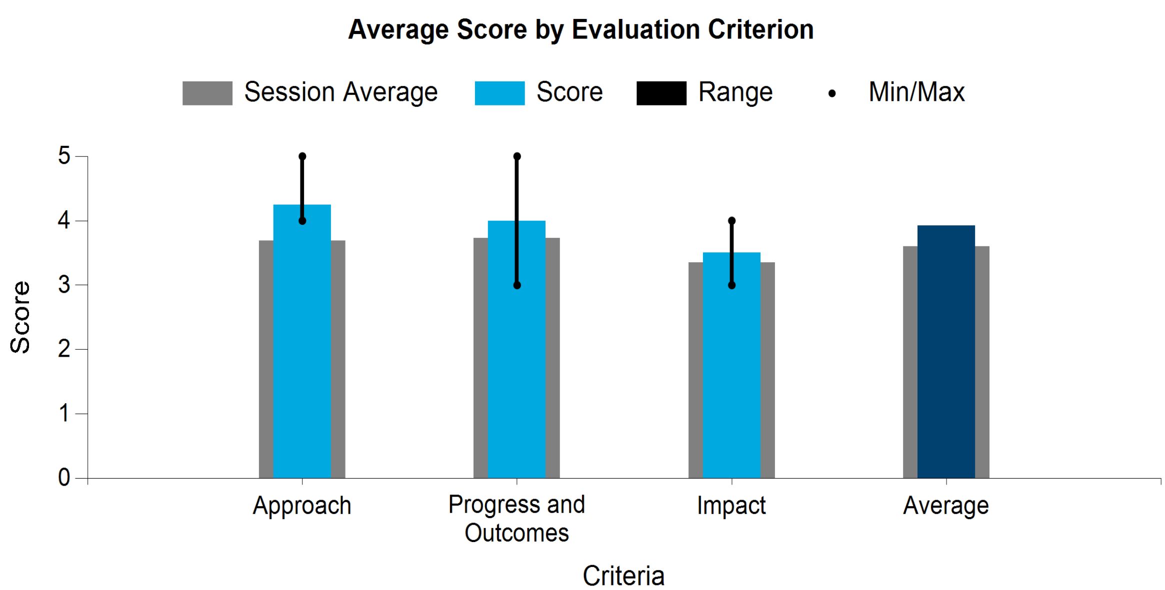
NATIONAL AVAILABILITY AND COSTS OF COVER CROPS MANAGED AS BIOFUEL FEEDSTOCKS

Oak Ridge National Laboratory

PROJECT DESCRIPTION

WBS:	1.1.2.3
Presenter(s):	Esther Parish
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$1,740,000.00

Cover crops—grasses, legumes, or small grains grown between the harvest and planting seasons of cash crops—offer many ecosystem benefits, including reduced soil erosion and increased soil organic matter. These benefits of planting cover crops during the off season help improve the conditions of the primary crop. More importantly to farmers, these cover crops may be harvested and utilized as biofuel feedstocks. Early studies suggest that cover crops could produce 2–3 tons/acre of biomass, comparable to higher-producing corn stover collection rates, or up to 65 gallons/acre of oil for oilseed crops. This is not always the case, however, as there may not be adequate time between the desired harvest and planting dates of the primary crop for the cover crop to reach maturity and viability as a biofuel/bioproduct feedstock. The feasibility of creating a double cropping system depends on the selection of appropriate cover crops, the determination of optimal harvest/planting dates, and the weather during the cover crop growing season. Because the maximum environmental benefit from cover crops comes when the biomass is not harvested, missed opportunities for ecosystem services must also be considered. Currently, cover crops of any type have very low adoption rates. However, adding a revenue stream for these secondary crops will incentivize adoption of cover cropping systems and could significantly expand adoption of this conservation practice. This project will elucidate the environmental and economic competitiveness of cover crops compared to other cropping options. This information will contribute to an understanding of potential cover crop adoption and oilseed crop production at a national scale with relevance for the potential development of renewable aviation fuels.



COMMENTS

- This is a well-laid-out project focused on secondary oilseed-based cover plants. Progress to date seems to be on track. The price/cost projected in one of the slides seems to be optimistic. Does this include collection/crushing costs of the seed oil? Compared to soybean/palm, the yield per acre is quite low, and hence the cost of crushed oil from these sources could be higher. Some of the oils, such as camelina, have fairly high omega 3 fatty acid content and other beneficial constituents and will have higher value in nutraceutical and pet food applications. It is worth focusing more on these higher-value products than on SAF. A Canadian startup has some interesting camelina-based products. The project needs to engage potential industry stakeholders.

- As far as approach, the project addresses the use of cover crops for SAF. Specific pathways from cover crops to SAF should be considered for analysis. In terms of P&O, on Slide 9, there may not be sufficient data points to develop a model in that case. In terms of impact, the income from ecosystem service benefits is not clear. Some field trials would be helpful and beneficial to the project. We encourage the team to continue and enhance its collaboration with the University of Maryland Eastern Shore.

- Lignocellulosic feedstocks are gaining greater interest as a mechanism to fix atmospheric CO_2 to drive carbon sequestration in natural systems. The decades of bioenergy feedstock production research are foundational to catalyzing current research on atmospheric CO_2 removal, especially if lignocellulosic resources are to serve multiple purposes. This project is early in its implementation and was recently modified to include oilseed cover crops, including pennycress, carinata, and camelina. These crops were included in addition to rye, winter wheat, and hairy vetch. Results from this project will be included in the forthcoming *Billion-Ton Report*, and this work will obtain information on cover crop ecosystem services such as soil health, pollinator habitat, and synergies with cash crops. The project will support a student intern from an 1890 land-grant institution. A significant impact is anticipated from this project.

- In terms of approach, the project shows a clear understanding of the criteria for success on Slide 2. The approach is well laid out and makes sense. As far as P&O, this is early-stage research for mobilizing a new biomass feedstock, either oil crop or herbaceous. This work is needed to justify the concept of cover crops on a national basis. The preliminary results are good. The impact of the project is well laid out on Slide 15. This will lend information to potential commercialization efforts in the future.

PI RESPONSE TO REVIEWER COMMENTS

- Thank you to the reviewers for this constructive feedback. Our project is new, but we have already been able to make significant progress by incorporating oilseed cover crop production into Policy Analysis System Model (POLYSYS) modeling runs for the forthcoming national bioenergy resource assessment (aka the *Billion-Ton* 2023 report). Our preliminary results indicate that incorporating carinata, camelina, and pennycress cover crops into traditional crop rotations could provide ~22 million tons of oilseeds from across the eastern United States that could be used to produce ~3 billion gallons of SAF. The POLYSYS oilseed price of $0.15 per pound reflects the price of harvesting the seeds but not the cost of crushing or transporting the seeds. We also acknowledge that oilseed crops may be used for a variety of end products that may prove more lucrative than SAF. However, this modeling work shows that there is significant potential for cover crops to contribute toward the SAF Grand Challenge.

- Over the coming years, we will engage with industry through the Commercial Aviation Alternative Fuels Initiative to better understand the information needed to make cover crops a commercial reality without unintended consequences. We will continue to collaborate with the University of Maryland Eastern Shore regarding herbaceous cover crop potential, and we look forward to hosting one of their undergraduate students at ORNL from May–July 2023 through the Undergraduate Research Student Internship program. The scope of this project does not include field trial installation and sampling. However, we will reach out to researchers at other labs and universities to see if data from their ongoing field trials can used to model the potential ecosystem benefits and trade-offs associated with harvesting cover crops for bioenergy production at regional and national scales.

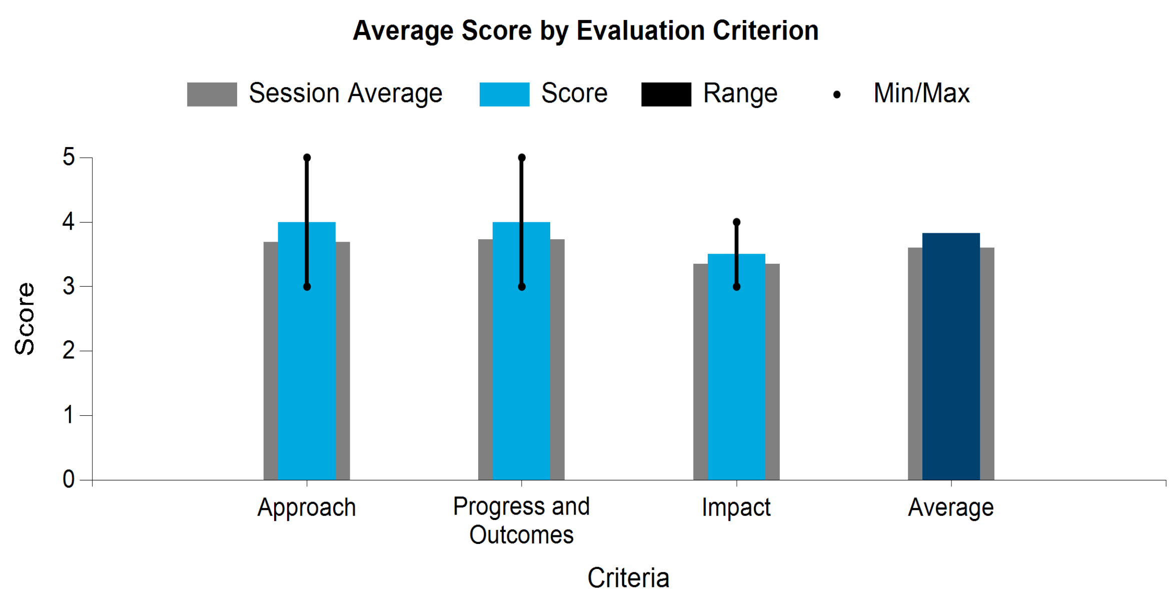
VALUE-ADDED PROCESS INTENSIFICATION IN THE SUPPLY CHAIN

Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.1.1000
Presenter(s):	Bradley Wahlen
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023
Total Funding:	$1,755,000.00

This project utilizes the necessary unit operation of storage and queuing to address feedstock challenges and add value by reducing downstream chemical and energy input. The long residence time of storage or queuing is used to achieve this through low-severity treatments. Microscale changes to biomass that occur over time in storage lead to macromolecular and tissue-level impacts during deconstruction, fractionation, and conversion. Using in-storage treatment, this project demonstrated a reduction in alkali and alkaline earth metals in a bark fraction from forest product residues, reducing a contaminant that limits its suitability for conversion. In-storage treatment of corn stover with formic acid led to partial breakdown of lignin, observed as a higher pyrolytic efficiency of lignols in pyrolysis gas chromatography/mass spectrometry. These molecular changes led to a lower activation energy required to initiate pyrolysis. Additionally, corn stalk consists of disparate materials—pith and rind—that are tightly bound, and their physiochemical differences reduce pretreatment efficiency. In-storage treatment targeting pectic polymers enabled the separation of pith and rind and the recovery of intact vascular bundles, improving corn stalk processability and enabling the recovery of potentially valuable coproducts. These principles of low-severity treatment over long periods of time to enable molecular changes to impact feedstock performance are being implemented with industrial partners at field scale.



COMMENTS

- This is a very impactful project with a clearly stated work plan, objectives, and deliverables. The team is well seasoned in the field and has very credible experience, a proven record, and strong capabilities. The team also has a good connection for implementation. The project is on track and is expected to focus on further larger-scale demonstration and TEA. Slide 12 shows the pH dropping to 3.2 from 5.3—is there any potential impact on materials of construction in downstream conversion steps from corrosion issues?

On Slide 14, is there any estimate of energy savings based on increased conversion? What is the impact on operating expenditures (OpEx) in downstream operations?
On Slide 16, we see reduced minerals—what is the impact on any catalyst poisoning?

- (1) This is a good project with clearly defined goals and methods. It addresses the value-added opportunities versus reducing costs of process components along the supply chain. However, it should clearly address where and when these value-added and cost-reduction activities should take place along the entire supply chain. (2) I agree that bark biochar is good for soil amendment and carbon sequestration. However, some comparisons are needed for bark char with biochar derived from wood. (3) In terms of impact, POET is a major industry partner for this project. It is not clear whether any major findings from this project have been applied in their production processes, such as storage and pretreatment to improve conversions. Future work can focus on the consistency of TEA data as well as large-scale storage and preprocessing of multiple feedstocks.
- BETO investments in feedstock pretreatment are important for optimization of the use of off-spec materials, stabilization during storage, and preparation for conversion processes toward specific products, such as SAFs, composite materials, or high-value chemicals. Companies that are scaling up the use of lignocellulosic resources for biofuel production often store feedstocks in piles that are exposed to the elements. They have experienced occasional spontaneous fires in these piles, similar to what can occur with silage and hay for animal feeding operations. Fire risks are enhanced with certain combinations of water concentration, such that heating results from anaerobic fermentation. A rapid influx of oxygen can cause a fire or even an explosion. This project is examining the use of acid treatments as an approach to pile management to both reduce the risk of fire and support pretreatment to reduce the recalcitrance of corn stover. Thus far, the team has observed that formic acid treatment achieves these goals and eases separation of stem rind and pith tissues. The industry partner in this project is POET. This project is on track and will be impactful for improved corn stover management.
- This project aims to use long-term (or short-term) storage to positively impact downstream processes through the use of low-severity treatments. The approach is well thought out. The opportunities on page 6 are valid and well defined. In terms of P&O, the results at the lab scale are very promising, and the analysis of the impacts is thorough and valuable. As far as impact, the main concern is the scale-up phase, where you are dealing with large industrial piles with dynamic moisture content/oxygen/temp conditions. It would be good to test a range of conditions for your pretreatments to see what the efficiencies of the treatments are at less-than-optimal conditions. These conditions can be derived from the literature, on testing and modeling done on large storage piles. It isn't clear what the subject matter of the patent or intellectual property (IP) would encompass. How does the PI see the rollout of this to the industry? Are there scale-up projects planned? This is good preliminary work, but it is a long way from commercial implementation.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their time and thoughtful comments. We agree that this project has the potential to positively impact industry and address storage challenges at scale. This project is currently collaborating with POET to study storage stability in large-scale storage piles. Additionally, progress toward commercialization of process intensification in storage can be achieved in the next cycle of the project through a combination of monitoring the storage conditions (temperature, moisture, dry matter loss) of commercial-scale piles and demonstrating mitigation strategies in the laboratory that will result in the desired critical quality attributes under a range of conditions observed at scale. TEA will be used to inform treatment strategies and determine costs. This project has sought to take advantage of the long residence time in storage to perform low-severity pretreatments to biomass that improve critical quality attributes, enable tissue separations, and reduce recalcitrance in conversion. TEA will be used to understand treatment costs and positive benefits to downstream operations. Questions related to the corrosivity of treated biomass, impacts to energy utilization in conversion or OpEx, and the effect of mineral reduction on catalyst poisoning might be best answered through collaborative research with other BETO-funded projects. This project will seek opportunities to work with others to better understand the impact of process intensification in the supply chain on downstream unit operations.

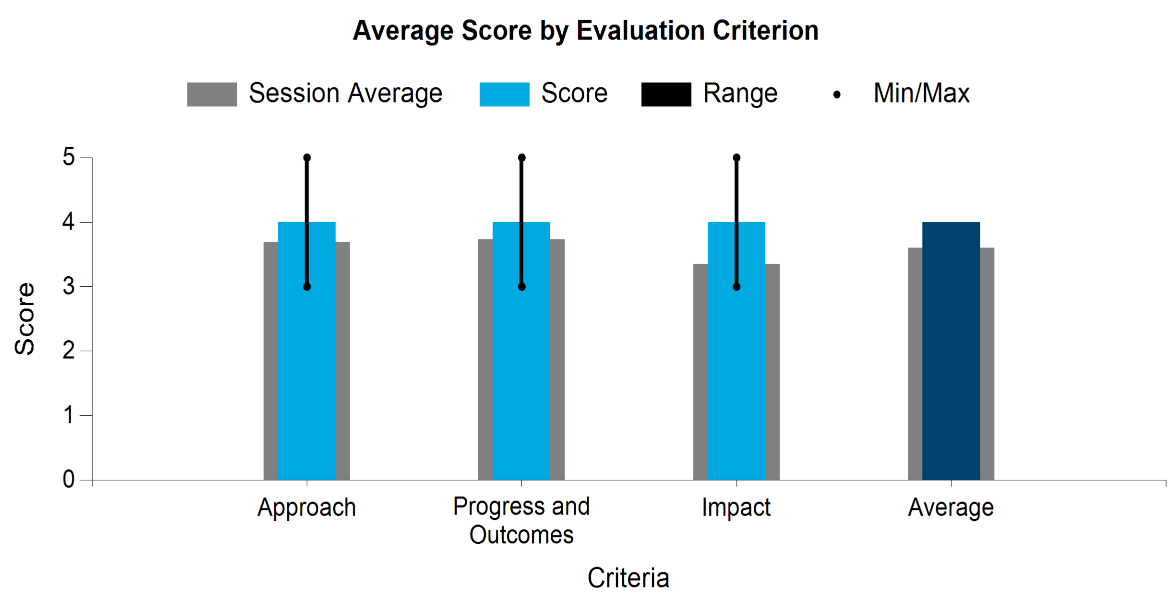
BIOMASS SIZE REDUCTION, DRYING AND DENSIFICATION

Idaho National Laboratory

WBS:	1.2.1.2
Presenter(s):	Neal Yancey
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023
Total Funding:	$1,922,194.00

PROJECT DESCRIPTION

Variability in feedstocks leads to significant downtime, low production rates, and poor-quality feedstocks. The goal of the project is to understand how process variables for preprocessing unit operations (i.e., milling, drying and dewatering, densification) impact the critical quality attributes of low-value carbon resources and how variables and material properties interact within and impact processes to produce products with the desired critical quality attributes using a quality-by-design approach. The specific objectives of the project are to: (a) take advantage of the Biomass Feedstock National User Facility (BFNUF) process development unit upgrade and grinding process for MSW fractions to understand its impact on the CMAs; (b) identify the impact of shearing process conditions on mechanical dewatering of forest residue fractions, as well as its impact on quality attributes; (c) create at least three MSW blends that meet moisture content, porosity, and density specifications by optimizing process conditions; (d) develop a densification model based on the compression characteristics; (e) analyze the processes tested for TEA to understand the energy and cost savings for high-moisture forest residue and MSW fraction processing; and (f) work with FCIC Task 5 on developing the discrete element method models for the grinding process. This project was successful at developing methods to achieve the required CMAs, including moisture content, porosity, and density. The TEA developed showed that a cost of $16.35/dry ton can be achieved using screening, advanced milling, and high-moisture densification. The resultant feedstock has lower-ash, high-durability pellets, which increase flowability and reduce downtime.



COMMENTS

- This is a well-laid-out project with a clear work plan, objectives, and deliverables. The team is experienced in the field and is working closely with other BETO-funded project teams working on similar topics. It looks like the project is on track. It would be helpful to clearly show the current status versus milestones and what is planned for the remaining performance period. What is the commercialization path? Slide 17 shows a 50% reduction in cost. Is this for a full-scale plant? What is the confidence level?

- (1) No details are provided on the approach. (2) Pellets were made separately from leaf, cob, stalk, and husk for testing. In reality, they can be mixed. It is not clear how pellets made from a mixture of leaf, cob, stalk, and husk affect the pelletizing process and fine reduction. (3) In terms of P&O, it is not clear what moisture content was used for making the pellets. Particle size, moisture content, and temperature will all affect the pellets' formation and properties. (4) On Slide 17, it is confusing how the cost was improved from 2019 to 2020 and 2022. It seems that the comparisons are not based on the same categories each year. (5) As far as impact, in addition to testing advanced preprocessing, a potential commercialization plan should be explored. (6) It is not clear what specific future work on forest residue will be conducted for later budget periods in this project.

- BETO investments in feedstock pretreatment are important for optimization of the use of off-spec materials, stabilization during storage, and preparation for conversion processes toward specific products, such as SAFs, composite materials, or high-value chemicals. This project represents essential continuous improvement for feedstock handling. Typically, feedstocks are ground rapidly in high-horsepower grinders to rapidly reduce particle size, and afterward, high-temperature drying is used. This high-throughput processing often causes systems to be plugged, and equipment damage can cause failure and stoppage, resulting in excessive opportunity costs. This project aims to redesign feedstock preparation by optimizing grinding through milling technologies and using chemical and low-heat drying. The project's initial TEA shows a reduction in prep costs from $33.64 to $16.35 per dry ton. Additionally, feedstock consistency is improved, and ash concentration is reduced. This work will help establish specification standards for biomass and nonrecyclable municipal solid waste (NMSW) feedstocks.

- In terms of approach, the responsibilities of the team were well laid out in the table on page 4. I appreciated that all biomass fractionation was considered, but the focus of the presentation was on MSW. The team demonstrated out-of-the-box thinking. This project was well presented. All slides could easily be read, and the charts were well presented. As far as P&O, the team did nice work on the three milling technologies. The comparison of the technologies for the same MSW produced results beneficial to the processing at the next step. The project looked at challenges in the physical/chemical variability in biomass and how to process efficiently. The actual densification trials look promising. Pellets are a good form for conventional equipment and can be delivered to a process efficiently and at a consistent feed rate; this is a promising direction. Low-temperature drying was out-of-the-box thinking, which is needed in this industry. Forced air ambient drying as a pretreatment may also show promise. We did work in this area for drying woody biomass with good results. Online sensor development should be continued. This gives real-time information and allows for diversion or better process control in subsequent processes. In terms of impact, this project has come a long way through really thoughtful process work and applying real-time monitoring to affect process control. Real-time process monitoring will be very useful for scale-up operations. This information will be very good for decision-making at the mill gate or biomass depot, but it is unclear how the technology transfer will take place. It isn't clear how the project will be commercialized, or what the plans are for industry uptake of the outcomes.

PI RESPONSE TO REVIEWER COMMENTS

- We want to thank the reviewers for their thoughtful comments and assistance in reviewing this project. It is important, as was noted, that the data from projects like this are effectively disseminated to industry as they work through the same types of issues. Just last week, INL hosted a ribbon cutting ceremony to highlight recent additions to the BFNUF capabilities. This ceremony, attendance at conferences, publications, and other outreach efforts are just some of the ways data is shared with industry. In this project, the focus was on fractionation/sorting followed by downstream milling and densification as needed for the individual fractions. Processing of the bulk material has been investigated and will likely continue for some time, but the need to fractionate and clean up feedstocks is becoming more apparent as a necessary approach to control variability in the feedstocks. Regarding the comment on Slide 17, the comparison was made by changing the fundamental approach each year to improve the overall outcome. The original baseline included drying using a rotary drier, hammer milling, and densifying. The next year included high-moisture size reduction and densification. The final approach included fractional milling, high-moisture milling, and high-moisture densification. Although corn stover has long been a major focus of our research, other feedstocks, like forest residues, will continue to be a fundamental part of our research as well. However, there is a growing need for research in other areas, including MSW, waste plastics, e-waste, and others.

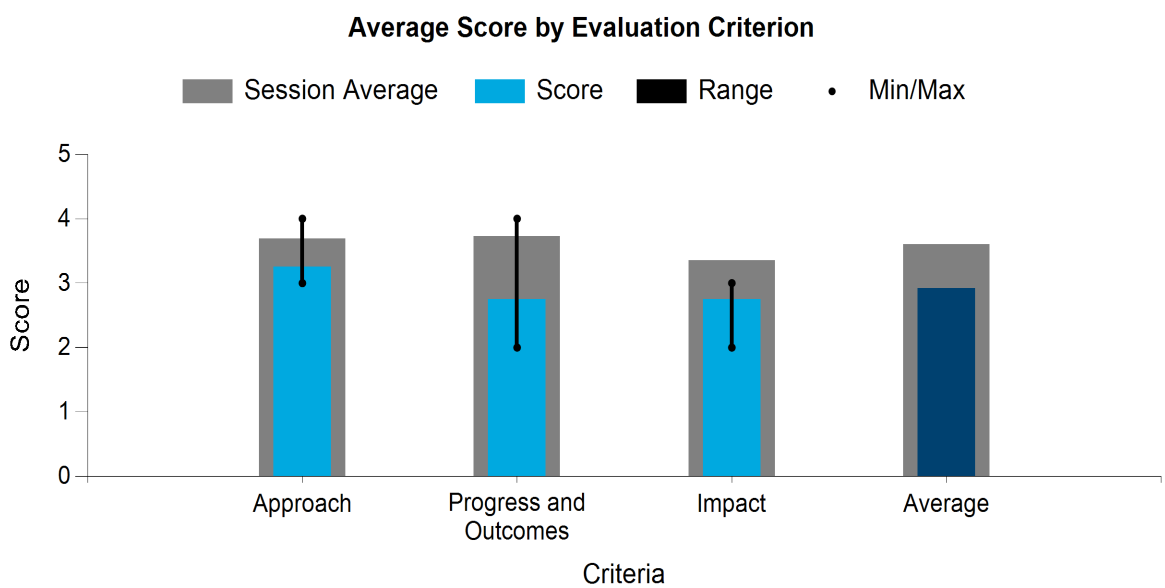
THERMAL CONDITIONING FOR DEVELOPMENT OF CO-PRODUCTS FOR CARBON CYCLE SEQUESTRATION

Idaho National Laboratory

WBS:	1.2.1.4
Presenter(s):	Jordan Klinger
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$1,800,000.00

PROJECT DESCRIPTION

This project explores pathways to generate coproducts from nonrecycled wastes that are not suitable for SAF production. Materials diverted to such support schemes are not of sufficient quality, are unable to be decontaminated, or have nonbiogenic carbon origins. The goal is to lock this carbon into long-lived goods for sequestration, while simultaneously generating additional carbon offsets and revenue to support SAF generation. Doing so would enable and develop new feedstock streams for commercial products, such as building materials (thermal and acoustic insulation), composites, lightweighting components, and carbon-dense materials, all with potentially lower carbon intensity compared to market alternatives. The main challenges arise from the heterogenous nature of wastes, the degraded quality of materials, and the nature of complex mixtures. To overcome this, the project is structured to investigate the hyperspectral characterization of wastes, including biogenic carbon detection, to direct unsuitable material to a preferred coproduct. In addition, several experimental tasks look at thermal, mechanical, and chemical modification of properties and component formulation. Overarching techno-economic and life cycle assessments are guiding the project through regular milestones, the go/no-go decision gate, and final recommendations. To date, one of the coproducts—building insulation—has been shown to have near-performance parity to commercial products and beneficial economics compared to market prices.



COMMENTS

- This is a well-conceived project to find new value-added uses for municipal waste components that do not meet SAF requirements. The team is well balanced and has the required skill sets and capabilities to carry out the project tasks and milestone deliverables. Work to date has identified and reached the preliminary proof-of-concept stage for developing insulation mats to compete with existing paper and cellulose ones. It isn't clear how and when this opportunity will be handed over to a potential commercialization partner. On Slide 7, it isn't clear what the insert at the bottom left is. On Slide 8/9, it looks like biogenic carbon and total carbon are used interchangeably. It is noted that the experimental insulation mat is within 10% of market value, but it isn't clear what this means. The slide on cost has units in dollars/ton, and the current products are in dollars/square foot. It isn't clear how to compare the two.

- (1) In terms of approach, the go/no-go decision points are not clearly defined, and they do not make a lot of sense. It is not clear whether contamination removal is considered in the analysis. (2) As far as P&O, the project makes progress. However, more explanations on the progress and outcomes will be needed for the coming years' reporting. Unsorted MSWs contain 68% biogenic carbon. It is not clear whether your analysis considers this carbon. (3) In terms of impact, commercialization of this material for residential housing insulation could be significant. The DEIP should be addressed.

- BETO investments in feedstock pretreatment are important for optimization of the use of off-spec materials, stabilization during storage, and preparation for conversion processes toward specific products such as SAFs, composite materials, or high-value chemicals. The potential exists to produce low-carbon-intensity products from thermal conditioned NMSW. Feedstock characterization for carbon isotopic composition will be necessary for products to enter low-carbon-intensity bioproduct markets. This project is developing hyperspectral carbon isotopic analysis of NMSW feedstocks and assessing the effects of thermal and mechanical modification. Coproducts, such as household thermal insulation, are also being examined. Progress has been satisfactory with carbon isotopic analysis of NMSW separated components. Testing for thermal insulation has been done for physical biological composites. The TEA based on the retail process of incumbent products seems unrealistic, however. Outputs include publication manuscripts, an invention disclosure, and a demonstration of home insulation.

- In terms of approach, using radiocarbon analysis for determining biogenic carbon seems like a complicated methodology for determining bio-based carbon content. The waste materials that are made from biogenic carbon are common knowledge. In terms of P&O, on page 8, I didn't see anything surprising in this table, and it could have been estimated without radiocarbon analysis. The difficult materials are those that contain various layers or plies, similar to juice boxes, but I didn't see that in the list. I cannot read the table on page 9. The cost comparison on page 14 was the processing cost of the MSW versus the retail sales price of the competing materials. This needs to be better thought out for a fair comparison. It is unclear what the three columns of "energy usage," "purchase price," and "throughput" represent on the MSW processing. In terms of impact, the IP on page 15 looks interesting but was not discussed in the presentation. Will this project reach a TRL of 5? This project deals with a small component of MSW, which will at best compete with very low-value materials. The TEA should consider the products currently used for these applications for meaningful comparisons.

PI RESPONSE TO REVIEWER COMMENTS

- We appreciate the reviewers' expertise, time, and thoughtful comments during this review process. Below are comments and additional details on the common feedback topics of TEA and the development of bio-based carbon detection methods. TEA is an invaluable tool to help guide process optimization and determine economically viable processes. During the BETO Peer Review preparation, we sought to compare the TEA of producing building insulation from MSW to other commercial alternatives. Because the economic details of the commercial products were not known, we compared the production cost of the MSW insulation (including packaging, delivery, etc.) directly, and determined a potential markup/profit from that comparison. The 18-month go/no-go milestone for this project was to demonstrate that, at a minimum, one of the projected coproduct pathways could be produced at comparable (±10%) costs to that of the sales price for market alternatives. Following the Peer Review preparations, we completed the economic analysis for the MSW insulation pathway. This analysis showed that the total cost to producing the product was $16.30/dry ton of product, excluding the addition of chemicals as flame retardants and biological activity inhibitors. This is only a fraction (<1.4%) of the cost of commercial products, such as cellulose insulation, which had a retail price of nearly $1,200/dry ton at the time of the analysis. Although the final insulation cost is dominated by the chemical additives, loadings of up to 10% by mass for each of the compounds still enabled an economic MSW insulation pathway with a production cost more than a factor of four smaller than the alternative product price. The presentation outlined one invention disclosure related to this project, although another patent application is under review at INL related to this concept of MSW insulation. The translation of such a product to market could follow well-known pathways of patent IP licensing from INL, for example. Team members involved in this work are/have identified and engaged potential partners/licensees, pending IP review. The rapid detection and measurement of bio-based carbon in waste materials will be critical for enabling certification or documentation of feedstock streams. These could be advantageous for fuel production pathways such as SAF, or for estimating the bio-based carbon being sequestered into coproduct pathways. Particularly in the case of displaced fossil resources where the carbon is stable and otherwise unsuitable for fuel production, any reduction in GHG emissions (or economic benefit) substantially benefits the primary objective of fuel production toward meeting BETO programmatic targets. Although the proposed hyperspectral methods can be complicated and require large upfront data sets and validation, they are a prime example of how the national laboratories support industrial development. As a near-term target, as a review indicated, categorical labeling as demonstrated in the presentation slides can be used as a proxy for bio-based carbon analysis. Indeed, the challenges will arise from multilayer packaging and more complex composite materials. Future work will drive the incorporation of these materials in rapid assessment techniques.

RESOURCE MOBILIZATION

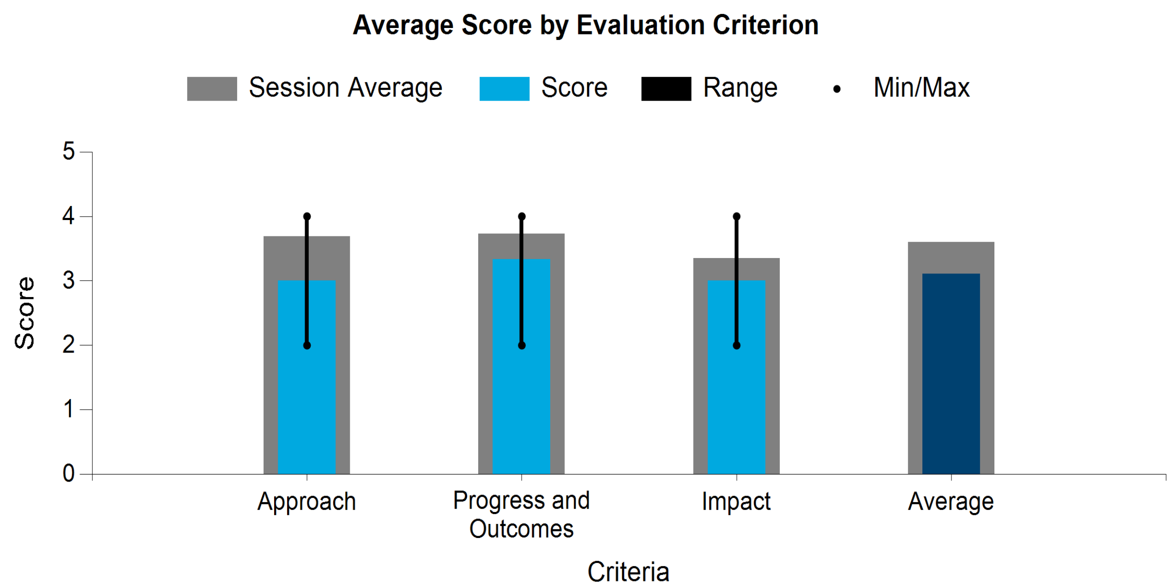
Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.1.5
Presenter(s):	Pralhad Burli
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023
Total Funding:	$765,000.00

The future of the bioenergy industry is linked to the willingness of farmers to participate in the biomass supply chain and supply feedstocks to the market. However, variability in the physical and chemical properties of biomass can be detrimental for conversion processes. Thus, strategies to fractionate the biomass and use it either as blended feedstocks or in alternate bio-based markets can improve the economic viability of the biorefinery. This project focuses on identifying strategies that can lead to higher adoption in the production of herbaceous biomass feedstocks and that use materials that are not suitable for biochemical conversion in alternate midstream markets.

We used agent-based models to simulate interactions between stakeholders to understand prospective trajectories of biomass mobilization and evolution of the supply chain. This modeling approach helps increase our understanding of systems in which the behavior of agents is not known with complete certainty, but is instead dictated by probabilistic decision rules. We developed integrated models to demonstrate the potential for using biomass fractions in value-added markets to increase the use of biomass fractions, identify drivers of increased adoption, and reduce the risk of participation in the biomass supply chain.



COMMENTS

- This is a useful economic-based diffusion model to better understand the practical viability of crop-residue-centric biomass feedstock. It seems to have made good progress in biochar applications. Is this a viable opportunity? Why has the biomass collection area decreased? (Slide 6.) How will buy-in from farmers be secured for the output results for filed implementations?

- Computational modeling is important for conducting foundational analysis and forecasting the costs, availability, and characteristics of biomass feedstocks. The feedstocks are also expected to complement existing crop and livestock production systems. Projections need to support production goals for sustainable climate-smart systems. Modeling systems are necessary to predict feedstock variability, illuminate management options for risk mitigation, and understand feedstock fractionation, separation, sorting, and blending. This modeling project is studying how to upgrade off-spec feedstocks through material fractionation and subsequent blending with corn stover. The team noted that corn leaves are a least-favored component of corn stover because of their high ash concentration and low density. They examined the use of blended materials in the production of biochar; however, like most biochar projects, no consideration was given toward the development of the coproduct pyrolysis oil. This project has produced only limited publications, and the team's external outreach needs to be improved to make the work more relevant to industry needs.

- This was a good presentation. However, I'm not sure I could completely wrap my head around what the project goal was and whether this was a meaningful or useful goal. The idea of a biorefinery is to take biomass and convert it into multiple product streams. The biorefinery could potentially separate the material streams ahead of or at any time during the process. The idea is that the most suitable material goes to the most value-added option for it. There should be nothing labeled as "off-spec" material; this should be "on spec" for the alternative product stream. I think that choosing one or two alternative markets is a very limited approach, yet there seems to be a lot of detail around the one alternative "biochar." How and why did the investigators decide this was a viable market alternative over other thermal technologies? It wasn't clear how they developed this approach. I can't join the dots between this work and industry uptake. The flowchart is so small I can't even read it on my computer (white font on green background).

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their feedback on our modeling approach and analysis to evaluate potential pathways for supply chain evolution and biomass resource mobilization. Our model is designed for a representative supply shed, and in its current version, it evaluates the supply requirements and biomass use for a representative biorefinery served by two preprocessing depots. The model demonstrates that the biomass collection area decreases over time in response to increased farmer adoption, whereby the biorefinery agents can contract with farmers located closest to the depots to minimize transportation costs. We agree that choosing one or two alternate markets is a limited approach; however, our intention was to demonstrate different modeling frameworks as a proof of concept that can show how some of the biomass that is not suitable for conversion to biofuels can be utilized in alternate markets. To evaluate the specific viability for biochar adoption, we identified the requirement on farms by developing an index using soil pH, water holding, and cation exchange capacity as indicators and incorporating the associated costs of biochar application and potential yield benefits. The model determined that only some of the farmers in the study region are potential biochar adopters, as the benefits on each farm might vary depending on a variety of underlying factors, and biochar application might not be economically beneficial for all. From an industry perspective, our end-of-project goal is to demonstrate how an integrated supply chain can support the biomass needs of a biorefinery and utilize fractions that are not suitable for conversion to fuels in alternate markets that can help the overall economic viability of the biorefinery by reducing biomass loss. Since the previous Peer Review, we have published one journal article. One manuscript is under review, and one manuscript is in preparation and is scheduled to be presented at the Association of Environmental and Resource Economists 2023 Summer Conference. Research in this project has also contributed to reports published by the International Energy Agency Task 40. We will increase our external outreach efforts and will continue to engage with industry participants to make our insights relevant for their uptake.

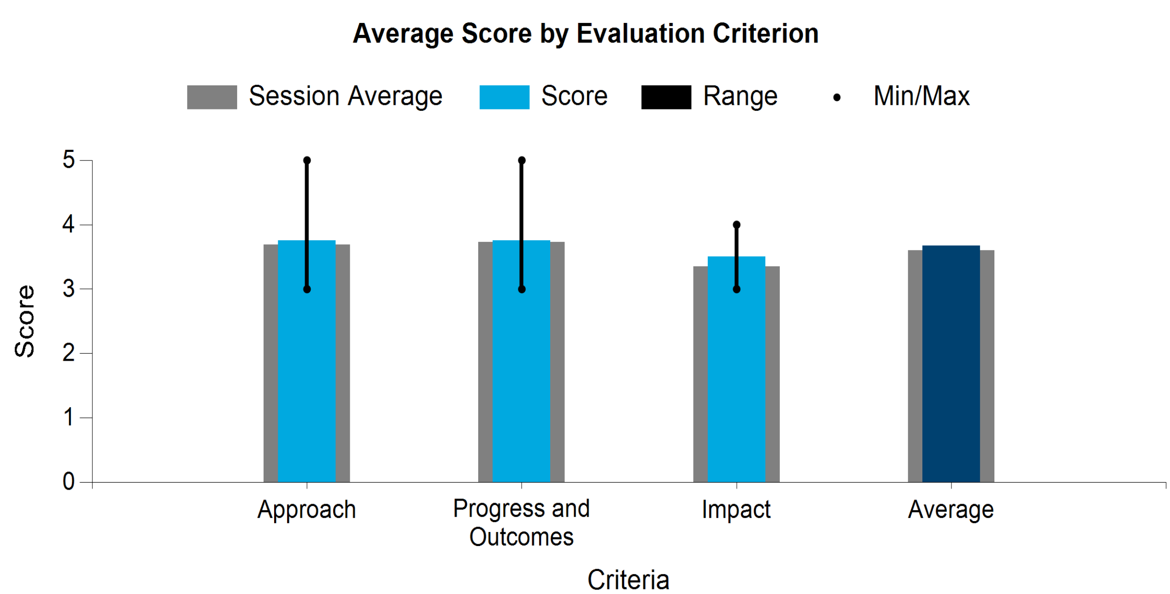
MUNICIPAL SOLID WASTE PREPROCESSING AND DECONTAMINATION

Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.1.7
Presenter(s):	Vicki Thompson
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$2,850,000.00

This project is developing a suite of preprocessing tools to reduce the variability and improve the quality of the biogenic organic fraction of MSW (excluding wet food waste), either by itself or as a blendstock for conversion to SAFs. The project is working with underserved and rural communities to source MSW streams and characterize the percentage of each MSW fraction and the types of contaminants present. The team is assessing preprocessing tools that can produce consistent feedstocks that meet conversion specifications and remove problematic contaminants. TEAs are conducted in parallel to select the most economic technologies. The project end goal will be preprocessing decision matrices to process and decontaminate MSW streams for fermentation and pyrolysis pathways to aviation fuels. These decision matrices will allow users to develop processes targeted for their waste streams.



COMMENTS

- The full project started recently and has made good progress. The team is well organized and has the necessary expertise, including local municipal waste handling organizations. Slide 6 mentions hazardous waste. What are the key components/their hazards/mitigation? Could this be a showstopper? Slide 8 shows various decontaminating agents. How are they disposed of safely?
- (1) This is a sound project. Some details on the approach should be provided to strengthen the project. (2) In terms of P&O, the project has made some good progress since the last review. The analysis, such as linear regression, could be further improved. (3) The decontamination strategies are not clear. If chemicals are used for decontamination, how will these chemicals be handled after the treatment? (4)

Mitigation strategies for some of the identified risks are not clear. (5) A DEIP needs to be specified to serve the underserved communities.

- Land use change and competition with food production are often cited as concerns for lignocellulosic feedstock production. Development of NMSW as a feedstock is warranted because it does not compete with agriculture for food production, and because the use of NMSW will offset the flow of waste into landfills and mitigate landfill methane emissions. Conversion of wastes into useful products and services is a basic aspect of circular economies. BETO has made significant investments into NMSW research, including the projects reviewed in this report. Some of the challenges of developing NMSW as an economic resource include (1) the extreme heterogeneity of NMSW, and (2) the presence of toxic and undesirable constituents. Therefore, BETO has made significant investments into NMSW characterization, sorting, blending, and milling to overcome these challenges. This project is evaluating (1) four decontamination strategies for NMSW, (2) blending NMSW with corn stover and pine, and (3) feedstock storage. The intent is to develop a consistent in-spec feedstock for SAF and chemicals. The team has made significant progress and has made a good effort on publishing the results. They have also filed one patent application.

- In terms of approach, there is a clear focus on diversity and inclusion, with a focus on underserved communities and rural communities without curbside recycling access. Priority is given to understanding the contamination issues for the material and developing safety procedures for handling. Project goals are very relevant to improving the feedstock and are also relevant to SAF. The presentation should include a slide showing member involvement. One consulting company is mentioned on the quad slide, but I'm unsure of their role in the project. In terms of P&O, the rapid change in the market from plastic (expanded polystyrene) to fiber-based packaging with various additives or layers is obviously changing the characteristics of MSW. It is difficult to keep up as these new materials come online and infiltrate the market. This will be a challenge going forward, as noted by the PI. Storage is an important aspect of the feedstock quality for this type of material. I noted that this milestone was delayed. Contaminants are related to the process. Contaminants for enzymatic hydrolysis/pyrolysis/SAF may be quite different, and perhaps a table showing which contaminants affect which conversion pathways would be valuable and would help target the correct contaminant based on the conversion. Slide 9 is very informative. All the relevant information is presented clearly in one slide! MSW quality mapping shows promising results that will be very valuable for planning by local municipalities and potential MSW users. For MSW storage, do you monitor microbe populations, especially for hazardous bacteria? As far as impact, this is a well-designed project with excellent progress over the last review. The PI presented the results in a clear, concise manner. The information generated in this report will help direct the potential of MSW feedstock.

- This project appears to be well positioned to fill in many questions about handling and preprocessing of MSW. I hope that there are plans for dissemination of the information to relevant stakeholders.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their positive comments on this project. We believe that this project has the potential for strong impact in the waste industry and will contribute to the goal of a circular economy. The reviewers had comments on decontamination strategies and the wastes that would be generated. Our TEA/LCA does include the wastewater treatment required to mitigate those wastes and models industry standard waste treatments. Other technologies that we are considering include solvent extraction, where the solvent is recovered with very high efficiency. The hazard identified by the reviewer was not hazardous waste, but rather hazardous biological organisms that might be encountered during MSW storage. This will be important for the waste industry to understand the risks of storing MSW for longer periods of time. A DEIP has been developed for working with the Shoshone-Bannock Tribes in Idaho, and an agreement was signed with them recently. INL will work with the tribes to characterize their waste streams and give recommendations for recycling and converting their wastes into fuels and chemicals. Part of our dissemination plan for our MSW capabilities was demonstrated during a ribbon cutting event on May 24 and 25, which introduced government, academia, and industry to the upgraded capabilities of INL's BFNUF. Several demonstrations on handling, processing, and decontamination of MSW were provided to attendees. A number of contacts were made during this event, and we will follow up on these. We also plan to work with Resource Recycling Systems to disseminate our results further.

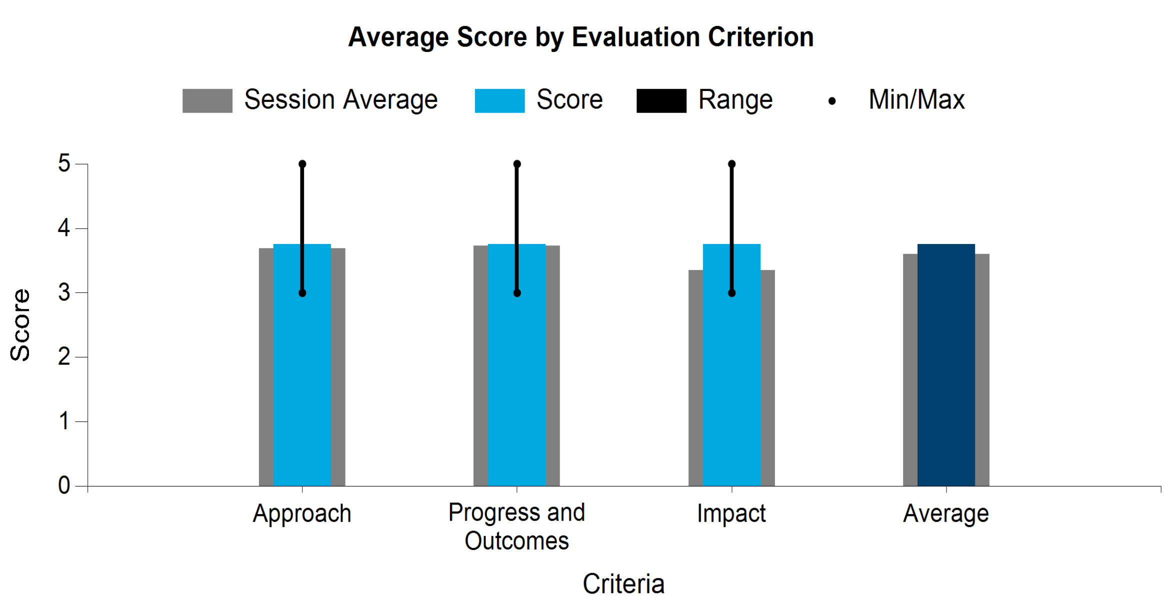
VALUE-ADDED BIOCOMPOSITE PRODUCTION USING OFF-SPEC BIOMASS FROM MECHANICAL FRACTIONATION

Oak Ridge National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.1.9
Presenter(s):	Erin Webb
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$2,100,000.00

Mechanical fractionation of biomass (e.g., particle size/shape/density separation by air classification) to select the portions that are easiest to handle and most convertible has emerged as a promising strategy to manage variability and reduce biofuel feedstock cost. This approach requires that the remaining biomass be sold to a separate nonfuel market to maintain economic viability. Biocomposite materials could provide such a market. In this project, we aim to better understand how typical characteristics of off-spec biofuel feedstocks—fines, high ash—impact biocomposite performance. We expect this understanding to enable the development of specific application areas for biocomposite based on the attributes of the biomass fiber and extrinsic ash particles and the thermo-mechanical properties of the resulting biocomposite. The proposed project will also identify and optimize surface treatments to improve biocomposite. Thus far, in small-scale screening tests, we have demonstrated strong performance of composites for a wide range of moisture, ash, and particle sizes, indicating broad opportunities for aligning biocomposite applications with biomass feedstock characteristics. In the coming months, we will apply the knowledge gained in small-scale testing to larger-scale printing demonstration(s).



COMMENTS

- This is a worthwhile effort to find high-value applications and markets for biomass waste that is not intended for SAF and thus to improve the overall economic returns for a biorefinery. The target chosen in the project is biocomposites with biofiber reinforcement for use in 3D printing applications. The project plan, approach, and tasks/milestones are well laid out. The team has the necessary technical expertise, skill sets, and capabilities to meet the deliverables. It is not clear what the commercialization path is and who the potential commercialization partners are.

- This is a good project and is worthy of more investment for further investigation. Collaborations among national labs, universities, and industry would help generate more impactful outcomes. Particle size and associated surface area need to be further investigated. The mixture of multiple feedstocks could be a concern in 3D printing due to their heterogeneity. A list of detailed cost components, including logistical and processing costs of multiple feedstocks, should be considered in future TEA.
- BETO investments in feedstock pretreatment are important for optimization of the use of off-spec materials, stabilization during storage, and preparation for conversion processes toward specific products such as SAFs, composite materials, or high-value chemicals. This project is developing value-added biocomposites from off-spec materials. The composites being developed are based on (1) raw off-spec biomass that is not suitable for biofuel production (e.g., corn stover fines and pine), and (2) polylactic acid. Also, 3D printing is being used to produce demonstration products from composites. Observations thus far include the following: (1) Fines from corn stover are preferrable to biomass with relatively long fibers. (2) Ash concentration can be a factor that impacts 3D printer head performance. (3) Switchgrass fiber results in desirable product stiffness. (4) The water concentration tolerance is relatively high at 5%–15%. This work will be impactful to the circular bioeconomy by developing bio-based construction and consumer products from otherwise low-value feedstocks.
- This project uses low-quality biomass from other processes for composite production in a 3D printing application. This was one of the best projects in terms of approach, outcomes, and impact. Some of the charts pasted in the presentations had fonts that were difficult to read. In terms of approach, the roles of the various members were not clear. The approach was well thought out and can be achieved. Some additional effort should be put into identifying products/markets for the material and specifying the quality required for the products. This would ensure uptake once the research proves successful. In terms of P&O, this was a nice research project. It would be nice to see a profile of the ideal properties of the material for the application(s), i.e., the range of important characteristics for 3D printing (e.g., viscosity, ash, modulus of elasticity). Some of the properties tested may not be that important (i.e., tensile strength), but a range for each property would be useful. This is an innovative and cool project! As far as impact, scale-up should be considered at this time. The project is not intended to be a demonstration project, but the next steps for larger production should be identified during this phase.

PI RESPONSE TO REVIEWER COMMENTS

- The project team would like to thank the reviewers for their encouraging and constructive comments. We appreciate the reviewers acknowledging our goals to use “off-spec” biomass (from a biofuel conversion perspective) for biomaterials to create a value-added coproduct for the biofuel value chain. While we are excited about the progress we’ve made to date, reviewers made astute and useful observations and suggestions for the remainder of our project. We agree that it is time to apply the insights we’ve gained in understanding how the properties of biomass particles impact biocomposite preparation and performance to designing large-scale systems. As noted by a reviewer, this is not a demonstration-scale project, but we can begin to consider the steps to scaling up these systems. This should include TEAs and industry engagement, as encouraged by multiple reviewers. Specifically, in the next phase of this project, we will focus on identifying and testing products and markets to better define ranges of acceptable biomass quality and evaluate potential commercialization paths. A reviewer noted challenges associated with mixtures of multiple feedstocks. We haven’t tested mixtures in our experiments so far (we’ve compared batches of different feedstocks, but not mixtures), but this is an interesting idea and one we might try if time allows. Being able to utilize feedstock mixtures, though challenging, would create a very robust coproduct pathway.

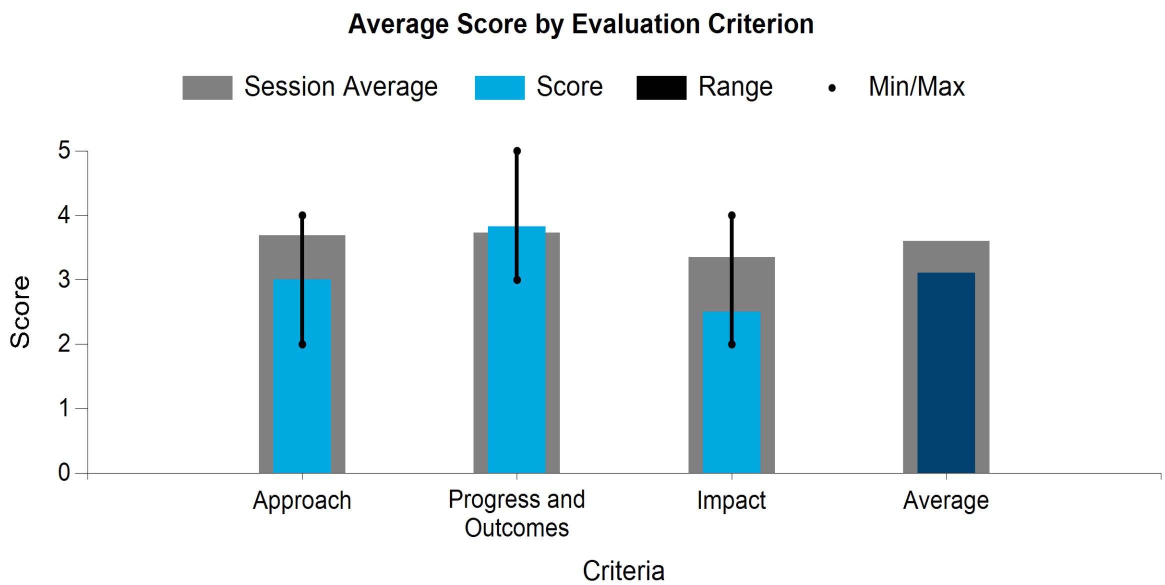
ENHANCED FEEDSTOCK CHARACTERIZATION AND MODELING TO FACILITATE OPTIMAL PREPROCESSING AND DECONSTRUCTION OF CORN STOVER

Montana State University

WBS:	1.2.2.100
Presenter(s):	David Hodge
Project Start Date:	10/01/2019
Planned Project End Date:	03/31/2023
Total Funding:	$1,625,000.00

PROJECT DESCRIPTION

This project addresses the challenge of processing compositionally and structurally heterogeneous corn stover through physical fractionation to both streamline processing and generate new potential coproducts. We developed new, field-deployable analytical tools that are coupled with empirical models that can be used to predict feedstock properties and processing performance. The overall scope of this project is to (1) identify conditions for optimal corn stover fractionation using a two-stage physical fractionation; (2) assess how physical fractionation impacts properties, partitioning of biomass, and response to processing; (3) further adapt, develop, and validate several advanced characterization tools for assessing biomass properties that can be linked to processing behavior; and (4) develop and validate predictive models based on measurements that can be performed in the field or at the biorefinery gate to predict feedstock processing behavior (preprocessing and deconstruction). The first objective will employ pre-separation processing (size reduction) of corn stover, which is next subjected to enhanced separations to yield fractions enriched or depleted in select compositional components or properties. For the second objective, fractions will be screened for their response to post-separation processing (pretreatment and enzymatic hydrolysis), and detailed characterization profiles will be developed, employing at least two techniques to assess the state of water association with the biomass (water retention value and low-field, nuclear magnetic resonance [NMR] relaxometry) and dynamic image analysis to assess distribution of particle size and morphology. For the final objective, we will utilize these tools to develop empirical models. These models will enable us to assess the relative abundance of tissue type in order to assess fractionation efficacy and predict fraction performance during pretreatment and enzymatic hydrolysis. A key impact of this project will be the development of the capability to tailor feedstock properties to the conversion process, allowing for more streamlined processing. Another important impact will be the ability to generate lignocellulose fractions enriched or depleted in select properties that could be used in other applications as coproducts. This is an important component of enabling the economics of cellulosic biofuels processes. This technology also has the potential to be employed at the regional depot scale, which addresses the critical challenge of feedstock logistics for low bulk density herbaceous feedstocks such as corn stover. Finally, this project will generate new, industry-relevant knowledge on biomass processing, providing value to industry and enabling commercialization of technologies for the conversion of biomass to biofuels and bioproducts.



COMMENTS

- The work is largely complete; however, no timeline was provided. The implementation strategy and risks were lacking. Any real and measurable impact of this work is unclear. New analytical tools are noted, but who is going to be using them, and how will they obtain them? Given what was learned, how can this benefit the process? Where are the cost savings and/or increased efficiencies?

- The team has used a robust approach to developing a variety of interesting analytical methods, but the real-world use and impact of these methods is not given adequate attention. Previous reviewers have also commented on this point. The analytical methods may indeed be very relevant industrially, and surely some more than others, but this research comes across as a random exploration of potential ways to characterize biomass. In my opinion, it probably doesn't make sense for these researchers to be responsible for developing their own techno-economic models, but their efforts might still be informed by the TEA of others. It would be useful to know which industrially relevant problems these analytical methods are aimed at solving, how big those problems are, and how much improvement they might expect.

- The project seemed to spend more time on physical processing of the feedstock and less on developing models to better predict and process feedstock to desired conditions. The project implies that it would develop technologies, but that does not seem to be the case, especially as explained in the live presentation. Extensive analyses were conducted, but there does not seem to be a cohesive overarching strategy to integrate the various analyses to reveal broader and practical findings. There is strong communication of results to the research community. The entire Montana State University and INL team (>12 people) appears to have 100% gender homogeneity.

- The objective of investigating fractionation methods was accomplished in a thorough manner. Estimating the power required (per kilogram or tonne) to accomplish this separation (power draw by fans at various speeds for biomass throughput) would have been informative. The overall use of multiple biomass analysis/characterization techniques on classified anatomic fractions helped in developing improved biomass handling and conversions of these fractions. I found the low-field NMR and fiber image analysis particularly informative. One of the primary goals is to develop analytical techniques that can distinguish the various anatomical fractions in a mixed sample. The fiber image analysis seemed to accomplish this very well. The low-field NMR data and usage seemed very promising, and how that might be converted to an online technique is worthy of exploration. I would have liked to see a PCA of the near-infrared (NIR) spectra data with loadings plots to determine the weighting factors to predicted values. Some of the prediction plots showed higher variation in prediction than one might expect. For example, in the stalk/pith weight fraction graph on Slide 22, at zero measured weight fraction, there are a great number of data points that skew widely from the predicted values from >−0.1 to 0.2. The cluster of data points around 0.18 and 0.33 measured weight fractions show similar behavior. A good PCA analysis with a vector loading plot could help narrow this. Finally, although outside of the scope of the project, how fractionation can help capture value in the conversion of biomass to products is difficult to imagine. I don’t feel that fractionation results in “streamlining” the process.

- The project has demonstrated the ability to effectively fractionate corn stover using multiple stages of air classification and sieving. The project has applied multiple analytical methods to characterize corn stover fractions and predict the performance in preprocessing and enzymatic hydrolysis. Most of the tasks discussed are shown as complete, although the presentation does not discuss the number of milestones outstanding. I assume that the project is on track to be completed by September 30, 2023. It is not clear that the analytical techniques can effectively predict performance in preprocessing or handling processes. The presentation cited some laboratory work by the team but did not present any verification demonstrating commercialization potential. The presentation mentioned that the new technologies could replace current methods but did not identify the performance or cost advantages for replacing the current technologies.
- The overall approach of the project was a bit hard to follow. The team explained that they would develop/adapt technologies for corn stover fractionation and tools for characterizing the stover, but it was hard to see how all of the tasks and their results fit together. Clear evaluation criteria were provided for each milestone, but it would have been helpful if the context for the evaluation criteria were provided. TEA was suggested by previous reviews but was not implemented. Although a full TEA or LCA is not required, some evaluation of impact (e.g., referencing a publication showing that achievement of 75% yield and purity of stems would decrease costs or improve pretreatment severity by X%) would be helpful to include in the approach. In terms of progress, the team has consistently met all milestones and deliverables. They have developed reference materials from the fractions, which can be used to develop standards for measurement. The team provided many examples of data and innovative and interesting measurement methods. In terms of impact, the team has published three papers and has three that are in development or have been submitted. They have also presented results at 10 national conferences. The overall impact of the work was difficult to determine, and although this may be due to its fundamental nature, some assessment of the significance of any of the results would be helpful. Understanding and communicating the potential impact of this work is critical so that it does not appear to be disconnected experiments rather than a well-thought-out project with the potential for improving biomass handling and conversion.

PI RESPONSE TO REVIEWER COMMENTS

- Comment: The team has used a robust approach to developing a variety of interesting analytical methods, but the real-world use and impact of these methods is not given adequate attention. Previous reviewers have also commented on this point. The analytical methods may indeed be very relevant industrially, and surely some more than others, but this research comes across as a random exploration of potential ways to characterize biomass. In my opinion, it probably doesn’t make sense for these researchers to be responsible for developing their own techno-economic models, but their efforts might still be informed by the TEA of others. It would be useful to know which industrially relevant problems these analytical methods are aimed at solving, how big those problems are, and how much improvement they might expect.

- Response: We are planning on working with the analysis team at INL to perform TEA on select fractionation scenarios during the remainder of the project.
- Comment: The project seemed to spend more time on physical processing of the feedstock and less on developing models to better predict and process feedstock to desired conditions. The project implies that it would develop technologies, but that does not seem to be the case, especially as explained in the live presentation.
- Response: Due to the limitations of the BETO Peer Review presentation format, we could not present in detail all the work performed for this project. The presentation focused on demonstrating how we achieved project milestones, but the current and pending publications provide significantly more detail on both the models developed and the fractionation performance at the pilot scale.
- Comment: The objective of investigating fractionation methods was accomplished in a thorough manner. Estimating the power required (per kilogram or tonne) to accomplish this separation (power draw by fans at various speeds for biomass throughput) would have been informative. The overall use of multiple biomass analysis/characterization techniques on classified anatomic fractions helped in developing improved biomass handling and conversions of these fractions. I found the low-field NMR and fiber image analysis particularly informative. One of the primary goals is to develop analytical techniques that can distinguish the various anatomical fractions in a mixed sample. The fiber image analysis seemed to accomplish this very well. The low-field NMR data and usage seemed very promising, and how that might be converted to an online technique is worthy of exploration. I would have liked to see a PCA of the NIR spectra data with loadings plots to determine the weighting factors to predicted values.
- Response: Due to the space and time constraints of the Peer Review format, we did not present the loading plots for the PCA work. These are in our publication: https://doi.org/10.3389/fenrg.2022.836690.
- Comment: The overall approach of the project was a bit hard to follow. The team explained that they would develop/adapt technologies for corn stover fractionation and tools for characterizing the stover, but it was hard to see how all of the tasks and their results fit together. Clear evaluation criteria were provided for each milestone, but it would have been helpful if the context for the evaluation criteria were provided. TEA was suggested by previous reviews but was not implemented. Although a full TEA or LCA is not required, some evaluation of impact (e.g., referencing a publication showing that achievement of 75% yield and purity of stems would decrease costs or improve pretreatment severity by X%) would be helpful to include in the approach. In terms of progress, the team has consistently met all milestones and deliverables. They have developed reference materials from the fractions, which can be used to develop standards for measurement. The team provided many examples of data and innovative and interesting measurement methods. In terms of impact, the team has published three papers and has three that are in development or have been submitted. They have also presented results at 10 national conferences.
- Response: All the previous DOE BETO projects I've been involved with have had an LCA and/or TEA component. However, this was not required for this FOA and, consequently, we did not budget personnel time to do this work. During the no-cost extension for this project, we will commit to performing a TEA comparison of several fractionation approaches performed in this work.
- Comment: The overall impact of the work was difficult to determine, and although this may be due to its fundamental nature, some assessment of the significance of any of the results would be helpful. Understanding and communicating the potential impact of this work is critical so that it does not appear to be disconnected experiments rather than a well-thought-out project with the potential for improving biomass handling and conversion.

- Response: The major contributions were (1) development of new characterization tools to predict anatomical fraction abundance (NIR and image analysis models) and physics-based air classification performance validated with experimental data, and (2) identification of fractionation strategies to yield target separations for ash removal, cob separation, stem separation, and pith/rind separation.

SWIFT: SINGLE-PASS, WEATHER INDEPENDENT FRACTIONATION TECHNOLOGY FOR IMPROVED PROPERTY CONTROL OF CORN STOVER FEEDSTOCK

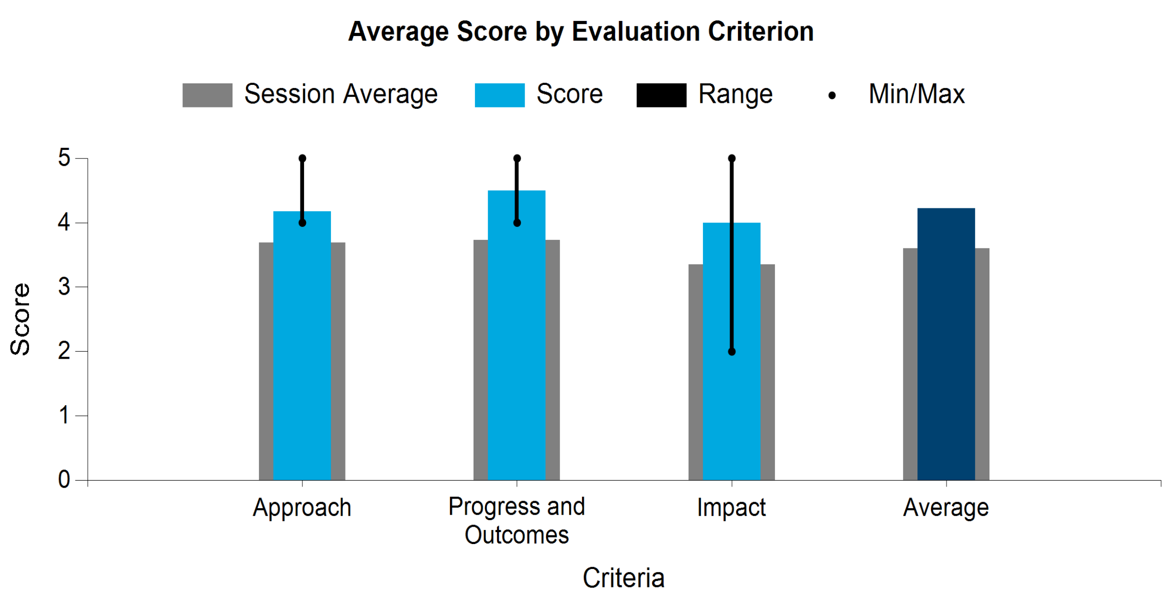
University Of Wisconsin

PROJECT DESCRIPTION

WBS:	1.2.2.101
Presenter(s):	Kevin Shinners
Project Start Date:	10/01/2019
Planned Project End Date:	06/30/2023
Total Funding:	$1,565,400.00

Corn stover is an abundant source of biomass that can be utilized for bioenergy production. It represents 70% of the available crop residues in the United States. However, recent projections estimate that over 60% of corn stover will be collected at moisture levels that exceed 20%. This is incompatible with conventional baled logistics systems due to unwanted microbial degradation. For the 40% of the stover that could be utilized with current technology, multiple other technical challenges exist. The result is a persistent inability to produce a reliable feedstock. Consequently, there are no real existing markets into which this potentially valuable cellulosic material can enter.

To solve this biomass challenge, we propose a paradigm-shifting technology: Single-Pass, Weather Independent Fractionation Technology (SWIFT). SWIFT streamlines collection by eliminating multiple time-consuming, costly, non-value-added, field- and weather-dependent steps that comprise the current technology in corn stover harvest. The novel approach employs four basic operations: whole-plant harvest, distributed anaerobic storage, cotransport of grain and stover, and fractionation at the biorefinery. SWIFT allows unprecedented control of the physical and chemical characteristics of corn stover biomass, enabling a reliable commodity market for corn stover.



COMMENTS

- The harvesting piece of this project is the most valuable and appears to provide a cost benefit. The TEA was provided but stopped at the feedstock collection. The TEA should be expanded to cover the other aspects of the project to provide real insights into any benefits to storage techniques and pretreatment costs (e.g., if washing is needed due to lactic acid buildup over time, this is likely not economical and also not ideal from an LCA standpoint). More work needs to be done from this aspect. Additionally, if the mechanical fractionation process is necessary to separate husks and stalks, this is an additional process cost. The management plan and risk identification were not included in the presentation. The work is mostly complete, but no timeline was provided.

- The researchers clearly identified and articulated challenges associated with the present state of corn stover harvest and storage systems. In developing SWIFT, they leveraged both scientific methodology and practical field experience/experimentation. They also published a strong paper examining the economics of the SWIFT process relative to the state of the art. The presentation could have spent more time on the TEA, however. The published paper has many interesting and important graphs showing the impact of process parameters on cost. A good sequence for the presentation (and R&D in general) might be: (1) start with a TEA of the current state of the art, (2) examine graphs of how various process parameters affect costs, (3) explain why and how particular process parameters were targeted for R&D, and (4) show how R&D efforts have improved those parameters and the impact on cost. Separately, the team's current TEA does not take into consideration the downstream impact of SWIFT-processed corn being slightly fermented. To provide a more equivalent comparison to the current SOT, they should add this to the TEA.

- This is an excellent real-world project that also addresses three significant feedstock challenges—transportation, handling, and cost. The principal lead has strong industry connections that offer future synergistic opportunities for the project. The project had the excellent outcome of achieving a better cost benefit than the current SOT by using a single pass rather than the current bale system. Unlike most of the other projects, this project is dealing with in-the-field applications and tiering the project focus to a total feedstock cost. Adjustments of different harvesting/processing equipment, especially when harvesting the grain and stover together without soil contamination, is highly beneficial to industry. The presentation mentions students trained, but no other DEI efforts. However, striving to reduce costs is an equalizing factor for farmers.

- The modified silage-style collection, transport, and storage of corn stover, cobs, and kernels developed and demonstrated here shows an alternative approach to the typical collection of corn kernels and stover in a separate manner. It has the potential to reduce the collection/transportation and storage costs, and the mechanics have been well demonstrated. I don't need to be convinced that the storage of stover in bales is at the very least problematic—large fires at all of the pioneer cellulosic ethanol plant storage yards as well as bale degradation demonstrate this. However, given that no current facility takes both the stover and the kernels, I wonder if this is a viable business approach. The fractionation methods and developed device show it is viable (facile?) to separate the kernels and the various anatomic fractions of the stover. However, the kernel gains moisture during storage. This may affect the value of the kernel, which is the primary economic driver for the farmer. The presenter stated that combining the leaves and stalk reduces severity, and that processing separately reduces pretreatment severity by 30% on 40% of the biomass. As one can't possibly afford to reject 60% of the biomass, it is hard to imagine how savings could be realized from this approach. Processing different fractions in separate campaigns is complicated and costly. Multiple processing trains would require a great deal of capital expenditure (CapEx). Finally, managing multiple streams in a plant is logistically very difficult. The SWIFT approach would be very valuable if combined kernel/stover processing could be envisioned, but I am not aware of such a plant. Past studies have shown that a certain percentage of stover must be left on the field from year to year. If the fractionation method used in SWIFT (which looks portable) could be used to collect/transport and store only the more valuable fractions and leave the most recalcitrant fractions in the field, this method would be a real success.

- The project has modified a combine harvester to harvest the grain and stover simultaneously and store it under anaerobic conditions. The project has demonstrated more consistent control of the physical properties of the stover and improved TEA compared to conventional harvest methods. The team has made excellent progress but did not include a milestone table or a Gantt chart, so it is not possible to determine whether the accomplishments were achieved on schedule. To verify the commercialization potential, the team needs an industrial partner committed to manufacturing the modified harvester. Industry partners should be engaged to verify the reduction in pretreatment costs and ash material in a biorefinery.
- The approach is well thought out and attempts to address the issues of minimizing feedstock variability and improving the cost-effectiveness of harvesting by developing single-pass harvest technologies with anaerobic digestion and simple processing at industry-relevant scales. The approach developed for the harvesting technology was especially intriguing. Implementation of the approach appears to be on schedule and achieving the expected results. It is not clear whether or how the measurement of physical properties will be used to improve any of the stages of the technology and/or downstream processing. This effort seemed to be disconnected from the rest of the project, even though it appears that this is a central tenet of the FOA (Area of Interest 2A: Relating Biomass Physical and Chemical Characteristics to Feedstock Performance in Handling and Conversion Operations). Collaboration with industry was not addressed in the presentation. The team has made great progress and has met the BETO goals of developing a feedstock technology with a cost of <$70 per dry ton (2016 dollars).

PI RESPONSE TO REVIEWER COMMENTS

- The reviewers recognized SWIFT's potential to improve the cost efficiency and practicality of corn stover biomass harvesting and storage. Appreciating its real-world applicability, they noted that the technology simplifies the process by allowing the simultaneous harvest of grain and stover, mitigating transportation, handling, and cost challenges. They also highlighted the SWIFT project's unique approach to storage and its potential to reduce feedstock loss and risk of fire. The reviewers found promise in the use of fractionation methods to separate kernels and stover anatomical fractions while expressing concerns about logistical feasibility. They recognized the SWIFT process' weather-independent nature and utility for reducing ash contamination for their potential to significantly impact commercial viability. Lastly, the reviewers saw the TEA demonstrated by the project as indicative of possible reductions in pretreatment costs in a biorefinery setting. However, the reviewers also identified areas for improvement, including the need for more comprehensive TEA, stronger DEI efforts, verification of results and commercialization potential, and exploration of the downstream impacts of SWIFT-processed corn fermentation. We agree about the need to expand the TEA beyond the feedstock collection phase to provide more insight into the potential benefits from SWIFT. We are working on a more comprehensive TEA for our final project report (Task 10). This analysis will be expanded to cover additional processes, such as fractionation, washing, pretreatment, and hydrolysis of the feedstock. The primary reason for this staged approach was to first determine the extent of the reduction in pretreatment severity that could be attained by adopting a fractional approach through Task 3 that would offset those costs. Regarding the team's DEI efforts, the reviewer's comment on our work's potential equalizing effect for farmers by striving to reduce costs is well taken. We see this as a critical aspect of our mission and will continue to focus on it in our ongoing and future projects. Additionally, we want to highlight that a female graduate student has been trained on this project. Given the underrepresentation of women in the machinery systems specialization of biological systems engineering, we believe this is significant. Moreover, the current student on the project is a first-generation college student. We will continue to foster a diverse and inclusive environment in our future work, as we understand its crucial role in fostering innovation and ensuring the broad applicability of our research. The concern about the viability of a business approach where no current facility accepts stover and kernels is valid. This project demonstrates a potential shift in industry practice, which is warranted given the current SOT limitations and the benefits demonstrated in our field to biorefinery gate TEA. We understand that the logistics of managing multiple streams and the associated costs are significant considerations. With this in mind, our final TEA (Task 10) will compare two scenarios: one where the two stover fractions (cob and leaf, stalk, and husk) are run in separate campaigns through the same processing equipment, and another where they are processed in parallel. This comparative analysis will clarify our approach's potential cost savings and practicality. Concerning commercialization, industry engagement, and third-party verification: We are working with John Deere as an industry partner on the machinery aspects of the project. John Deere has contributed significantly to the cost share in this project, donating capital equipment and engineering support. The Deere team has attended regular meetings and has visited the field site to optimize the equipment. Given our anatomical groupings and pretreatment severity, we also planned to work with POET on hydrolysis yields. However, due to a change in their company's focus during our project, we had to seek alternate external validation for our pretreatment and hydrolysis yields elsewhere. To that end, we have engaged with the Sustainable Bioprocessing and Bioproducts Lab at the State University of New York College of Environmental Science and Forestry. Finally, regarding the grain feedstock, we have presented data in our quarterly reports that will also be part of our final technical summary demonstrating the grain's utility for fermentation to ethanol. Further, there is a significant body of knowledge on using fermented grain, commonly called high-moisture corn, for livestock feed. We recognize that this limits the marketability of the grain fraction, but there are documented benefits in starch availability in ruminant nutrition. Additionally, we have a manuscript in preparation that documents reduced grinding energy of fermented corn kernels. However, after washing the former, our ethanol yields were similar between fermented and unfermented grain. Additionally, our team just published a paper on the physical properties of the grain fraction that will be useful for those handling and processing grain derived from the SWIFT process. We thank the review panel for their time and thoughtful review of our project and the SWIFT process. We hope our responses address your concerns and reassure you of our commitment to delivering a comprehensive and impactful project.

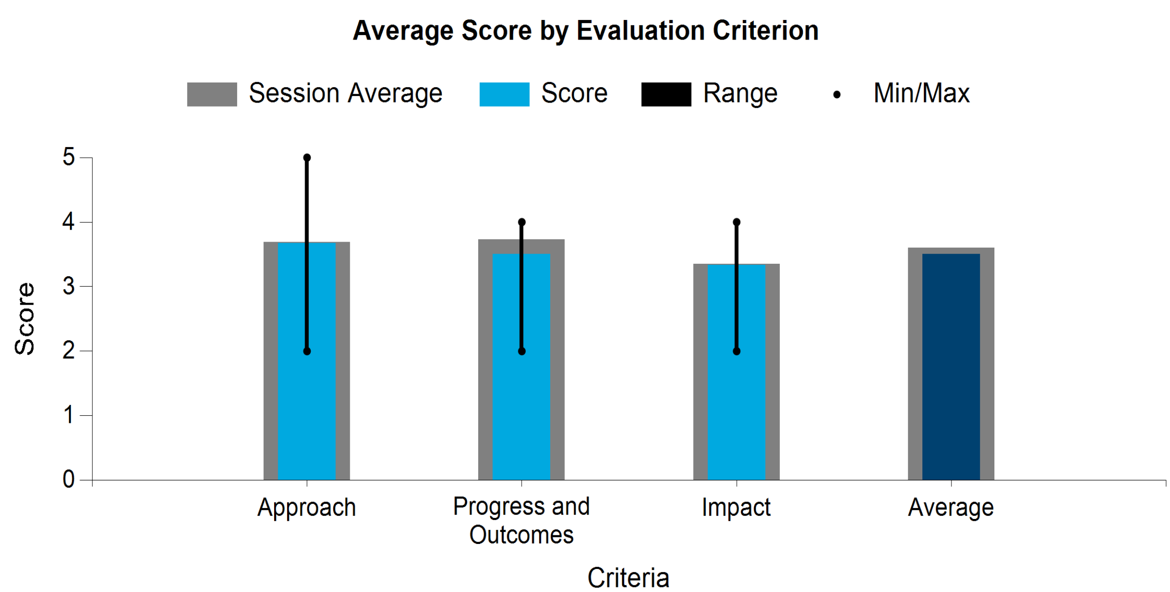
SULFUR PROFILING IN PINE RESIDUES AND ITS IMPACT ON THERMOCHEMICAL CONVERSION

University of Kentucky

WBS:	1.2.2.102
Presenter(s):	Jian Shi
Project Start Date:	10/01/2019
Planned Project End Date:	01/31/2025
Total Funding:	$2,056,352.00

PROJECT DESCRIPTION

Sulfur content varies widely depending on the biomass type, growth conditions (e.g., soil, weather, and age), and harvesting practices. It represents an important concern to thermochemical conversion platforms due to its effects of catalyst deactivation (e.g., in the Fischer-Tropsch reaction), equipment wear, and air pollution. Results from surveying 18 pine residue samples (including 87 fractions) suggest that precommercial thinning and logging residues collected near the coastal regions appear to have higher sulfur-containing fractions than samples from piedmont and sandhill regions. Air classification and bioleaching were shown to be effective in removing sulfur-/ash-rich fractions and producing a cleaner and more consistent feedstock for thermochemical conversions such as fast pyrolysis and gasification. Preliminary TEAs suggest a 5%–10% reduction of the MFSP with the implementation of low-cost sulfur mitigation/preprocessing strategies such as air classification in a biorefinery. An LCA was also performed to evaluate the global warming potential of the conversion processes. This study provides a better understanding of sulfur variability and the form and fate of sulfur during thermochemical conversion, facilitating the development of effective feedstock preprocessing and sulfur mitigation strategies.



COMMENTS

- The timeline provided was extremely high level. No risks or mitigations were provided. There appeared to be several partners on the project, but how they worked together was not addressed. It's unclear why the PI chose to exclude the leaching data, as this would have been valuable information to present. Other areas of the presentation could/should have been reduced to allow for inclusion of this information. The assumptions made in the TEA for this piece were also unclear. It was nice to see even a high-level TEA and LCA.

- The researchers have taken a methodical approach to developing technology and data around sulfur profiling and have effectively made a case for its industrial relevance through TEA. It is excellent that they are leveraging tools like tornado diagrams and sensitivity analyses to understand the key factors. In this case, it seems that the TEA is actually independent of the R&D work. As such, it could have been performed prior to the R&D work, and then used to evaluate the potential impact of the work and to direct research efforts to target the highest-impact parameters. As mentioned above, the researchers made good choices for the sensitivity analyses. Tornado diagrams, however, are far more valuable if actual best/expected/worst case scenarios are used, rather than simple percentage deviations. Also, it would have been useful to see more process parameters in the tornado diagram, like the sulfur content of biomass. It is unclear how the tornado diagram, as shown, would be used to inform decision-making in this R&D effort.

- Comprehensive analyses, testing, and diverse subtasks are used to assess sulfur content and the impact on conversion to biofuel. One of the market benefits is the cost/benefit analysis of the sulfur reduced feedstock versus the status quo, especially on the projected fuel cost. The capital cost analysis and minimum fuel selling baseline on Slide 19 are very informative and daylight a comprehensive assessment of the costs of various processes associated with sulfur reduction. Strong collaboration with industry, which delivered the feedstock samples, and diverse partnering are attractive attributes of this project. The project funded several underrepresented graduate students, which demonstrates an effort toward DEI.

- The work that was done (18 pine residue samples/87 anatomical fractions) is extensive and thorough. However, as the authors point out, the impact of the sulfur and the various forms of sulfur on the downstream catalysts “is not well understood.” As this appears to be the driving force for the work, it would seem that this aspect (the effect of sulfur species on the catalyst) could be studied by just doping various sulfur species into the pyrolysis stream and measuring the effect so that the levels and species to avoid/eliminate could readily be focused on. From the work that has been done, it appears that the needle fraction is relatively small on a mass basis, and it seems that one would be better off rejecting this fraction. Finally, the driving force of this work is somewhat muted, as the catalyst industry has well-developed methods of handling sulfur in an economic manner.

- The project has identified the source of sulfur in several pine samples from different locations in the Southeast United States. They have examined two methods for reducing the sulfur content of the feedstock prior to entering the thermoconversion process: bioleaching and air classification. Higher sulfur fractions from air classification can then be discarded or sent to a bleaching step. Needle-rich fractions had the highest sulfur concentration. They are showing a 5% reduction in MFSP from a 30% reduction in sulfur. Slide 20 demonstrates the potential sources of sulfur impact but does not clearly discuss how this will be accomplished. For example, does this model include the increased cost of biomass from bioleaching or discarding a fraction(s) for the biomass? The project has not determined how sulfur is released during the thermochemical processes (Objective 3) or the impact of sulfur on the Fischer-Tropsch catalyst of choice. Without a milestone table or a Gantt chart, it is difficult to determine if the project is on schedule for meeting its project goal or end-of-project milestones.

- The team outlined an approach that outlined the issues with sulfur in biomass and identified a systematic series of interconnected tasks that addressed each. The team has several partners, and the approach does a good job of integrating each. The team did an excellent job of framing the problem they are addressing. The team clearly identified the methods to obtain representative and homogenous samples, which is critical to ensure a basis for comparison. DEI was adequately addressed in the presentation, and the project has included Red Rock Biofuels as a project partner as well as other industry advisors. In terms of progress, the team provided results and trends from their experiments in sulfur composition by anatomical fraction and correlation with other components, as well as the results of air classification to concentrate or remove the sulfur. It was difficult to determine whether the project was on target, as the results were not tied to specific milestones. In terms of impact, the team outlined the framework for TEA/LCA analyses and conducted preliminary analyses. The team did a nice job identifying which steps had the highest impact for global warming potential (GWP) and economics and providing boundaries for expected improvements. The tornado sensitivity study varied important factors by ±20% from baseline, including operating hours from a baseline of 8,000 hours. An increase of 20% in the operating hours would mean that the plant would operate for 9,600 hours, which is more than 8,760 hours per year. This is not possible unless the equipment can be pushed past its rated capacity. Because this was identified as the most important factor in reducing costs, it should be noted that not only do operating hours need to increase, but the equipment capacity would also need to increase. The economic sensitivity shows that the amine solution demand goes down with an increase in sulfur reduction. This is not intuitive and should have been explained; the presenter could not explain this. Assessing the impact would be strengthened by including some assessments of which technologies/pathways are currently hampered by high sulfur contents and how solving this would have an impact in the overall commercialization of biofuels. This is not critical, but it would help provide context. The team has made several presentations and an ArcGIS story map, and one manuscript has been submitted.

PI RESPONSE TO REVIEWER COMMENTS

- The project is currently in Budget Period 3. During the Peer Review meeting, we presented the progress from Budget Period 2 (12 months into the project). The Budget Period 2 go/no-go decision points are to (1) collect 15–20 pine residue samples and statistically analyze their sulfur content and anatomical fractions for significant differences using ANOVA; and (2) complete baseline TEA and demonstrate a 5% reduction of the minimum selling price of biofuels assuming an interim sulfur removal goal (30%) and associated ash removal goal are achieved. Both criteria have been met. Due to time constraints, we did not present data from the bioleaching test. However, we screened three candidate microorganisms and demonstrated Aspergillus niger NRRL 2001 as the most effective sulfur and metal element remover, with a maximum sulfur removal of 30% from certain pine residue samples. We have presented the research outcomes at professional conferences and recently published them in a reputable peer-reviewed journal. We have developed a vigorous risk management plan that allows continuous identification and logging of risks, development of mitigation strategies, and monitoring of risk resolution. The specific risks that we identified in Budget Period 2 include (1) lab safety issues associated with sulfurous gases; (2) not enough (or representative) pine residue samples collected from proposed suppliers; and (3) the uncertainty of techno-economic factors associated with the sulfur removal technologies being developed. We have taken actions to mitigate those potential risks. We have implemented standard operation protocols and lab safety measures for sulfur gases. The team identified four pine residue suppliers/sources and collected 18 pine residue samples and 87 anatomical fractions in total. The collected samples cover various ages, locations, harvesting practices, species/genetics, and anatomical fraction factors. As a major change to the initial statement of project objectives (SOPO), we added Task 3 into Budget Period 2 to build a baseline TEA model on biomass preprocessing and syngas sulfur removal operations. This allows us to identify uncertainty and risks associated with system integration and cost factors early on during the project. Regarding the reviewers' comments on TEA, we conducted initial sensitivity analysis during Budget Period 2 to help guide project efforts. Prior to the experimental data becoming available, it was not clear what the best- and worst-case scenarios would be for all parameters. For some parameters, best- and worst-case values can only be determined from an actual commercial project. Thus, we followed common TEA practices to select parameters based on literature values or assumptions to identify the most important factors. These parameters and parameter ranges will be updated to reflect an improved understanding gathered from the project. The model includes additional capital and operating costs associated with bioleaching and discarding fractions of biomass. Bioleaching and its associated equipment add $5.9 million in pretreatment capital costs and an increase in operating costs. However, an increase in the fraction sent to bioleaching slightly decreases biofuel costs. This indicates that the costs of reducing the sulfur content are less than the additional revenue generated. Increasing the fraction of biomass sent to the boiler increases the MFSP. Because bioleaching can increase the biomass fraction lost to the boiler, there is a trade-off to consider in this approach. The initial sensitivity analysis employs ±20% ranges to provide guidance on which parameters to focus on during the project. The ranges will be updated based on project findings with more realistic values. The amine solution demand is proportional to the hydrogen sulfide concentration in syngas. Increasing sulfur reduction decreases the hydrogen sulfide syngas concentration and amine solution demand. Sulfur is a well-known contaminant for Fischer-Tropsch synthesis (FTS) catalysts, so this technology has the potential to improve the reliability of biofuel production from sulfur-containing feedstock. Regarding the reviewers' comments on sulfur poisoning on FTS catalysis, during Budget Period 1, we showed, from pyrolysis-gas chromatography analysis of pine residues, that hydrogen sulfide and carbonyl sulfide are the dominant sulfur species present in the effluent. However, their impact on cobalt catalysts for syngas conversion during FTS must be tested individually to assess catalyst stability with respect to those sulfur species. Our preliminary investigation of carbonyl sulfide poisoning (500 parts per billion) on a manganese-modified cobalt Fischer-Tropsch catalyst suggests that adding manganese to the cobalt catalyst not only helps control the production of methane, but also improves both olefin and C5+ selectivity compared to an unmodified cobalt catalyst. The beneficial effect of manganese on catalyst tolerance toward carbonyl sulfide needs further investigation, given that the manganese-modified catalyst undergoes slower deactivation than the unmodified cobalt catalyst at low temperature (220°), while at higher temperature (230°), both catalysts exhibit similar deactivation rates. Finally, the project is engaged in ongoing pyrolysis-gas chromatography analysis of preprocessed pine residues, the results of which will guide us regarding exactly what types and concentrations of sulfur species should be tested in syngas conversion to determine catalyst activity, stability, and selectivity toward various FTS products.

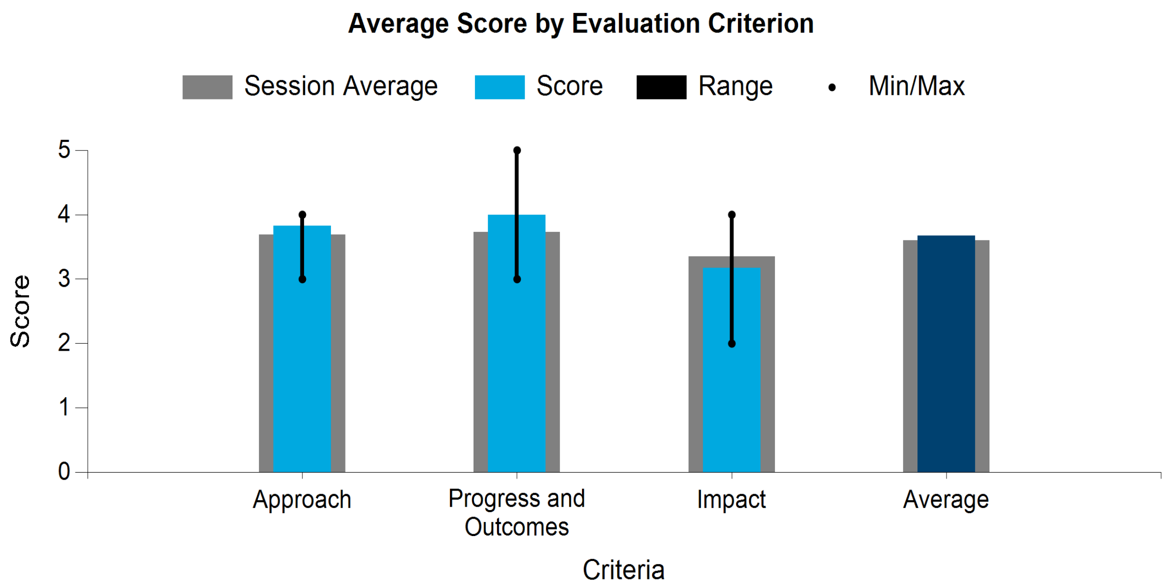
MODELING FEEDSTOCK PERFORMANCE AND CONVERSION OPERATIONS

Purdue University

PROJECT DESCRIPTION

WBS:	1.2.2.103
Presenter(s):	Michael Ladisch
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2023
Total Funding:	$1,724,750.00

Significant progress has been made in developing combined enzyme hydrolysis and fermentation technologies for transforming lignocellulosic feedstocks into ethanol and other bioproducts. Various routes described in the literature show that low-carbon-footprint processes efficiently convert the cellulose and hemicellulose fractions of pretreated corn stover, wood chips, and sugarcane bagasse to sugars and to ethanol. Combinations of different pretreatments at high or low pH or in liquid hot water, followed by enzyme hydrolysis and fermentation or direct conversion of cellulose to ethanol (i.e., by consolidated bioprocessing), have been demonstrated. These successes have brought the need to prepare the feedstock—before it enters the biorefinery—into focus. This report addresses developments in liquefying corn stover before pretreatment so that slurries with yield stresses below 200 pascals are obtained and a "pumpable" corn stover slurry is obtained for initial solids loadings of 200–300 g/L. Results to date address modeling of conditions and the experimental determination and validation of parameters that lead to formation of aqueous slurries at high solids loadings, and corn stover that has been fractionated by air classification.



COMMENTS

- The overall approach is sound and well laid out, though it was missing risks. Understanding the overall impact of the preprocessing on the economics, particularly the hydrolysis step, will be important in assessing the industrial viability of the process.

- The researchers made progress toward characterizing and improving the properties of biomass feedstock slurries. While they are probably correct that corn stover will be easier to handle as a slurry than as a solid, they did not quantify the potential benefit as well as they could have. The researchers are using TEA retrospectively to see "how well they did." It would have been better if they had built a techno-economic model at the beginning. Then, they would have been able to use it to understand the key factors driving the economics of their envisioned process and focus their R&D to address them. The researchers might also consider using Microsoft Excel instead of Aspen for modeling this process. The accessibility, transparency, and flexibility of Excel tend to make it a better option for modeling early-stage technologies that do not require the advanced capabilities of process simulation.

- Producing a slurry is a strong opportunity to facilitate feedstock compatibility for higher-value end products. This project adequately assesses the feedstock characteristics associated with generating a slurry, but fails to forecast the next steps needed to generate practical opportunities for industry in real-world applications. The project implied that costs were to be explored, but it ultimately did not quantify real-world costs. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model analysis seems out of scope in relative importance but might have been required. The project leads conducted stakeholder meetings despite the pandemic to communicate results. Based on the written presentation, the project appears to be delayed in meeting some objectives on the designated timeline.

- This project has made good progress in investigating the separation of four anatomical components of corn stover (cob/stalk/husk/leaf) by air fractionation. It is of particular note that the comminution energy of the various fractions was measured and recorded, with cob apparently having the highest specific energy. Note that the final ground size was very small (2 millimeters), which appears to be smaller than needed for commercial applications. It was implied that pelletization was done on the separated anatomic fractions, but no data were presented on the pelletization process of the various fractions. The authors are in the process of performing an LCA/TEA on the method of preprocessing a corn stover stream from pelletized materials for introduction into a pretreatment section. It is noted that water absorption of feedstock is a "key indicator" for ready slurry formation—further elaboration on this observation is desired. A TEA/LCA on pelletization is desirable, and it is unclear if this is part of the planned LCA/TEA. The authors claim that using enzyme-treated slurries can avoid the solid handling challenges experienced in pioneer biorefineries. These challenges were encountered when trying to add materials into processes at elevated pressures. The presentation didn't mention the pressures they were attempting to pump against and thus didn't clearly demonstrate overcoming this hurdle. Finally, there is currently no supply chain laid out in which pelletization of corn stover would/could be broadly accomplished. This limits the clear commercialization potential of the discoveries presented.

- This project focuses on creating an aqueous slurry with a high loading of corn stover fractions that can be pumped into a biorefinery instead of conveying solid, dry material to the pretreatment step of the biorefinery. The team has been able to demonstrate high solids loading using pellets created using different corn stover fractions. They have created rheological models of a highly solids-loaded slurry and verified the models experimentally. They have completed a preliminary TEA/LCA. The project is on schedule, as demonstrated by the Table of Tasks from the SOPO as well as the timeline/Gantt chart. They have involved partners from national labs and industry. The presentation indicates that corn stover must be pelletized in order to create a high-solids slurry. The pelletizing process should be included in both the TEA and LCA calculations. The benefits of pumping a high-solids slurry versus solids conveyance should be verified in a pilot or demonstration biorefinery. Without this experimental comparison, it will not be possible to determine commercialization potential or verify the TEA. The team should identify a partner with a pilot or demonstration-scale biorefinery.

- In terms of approach, the team did a good job of framing the magnitude of the biomass solids handling issue and how their approach for tackling it would look. The team developed a nice approach to assessing biomass and feedstock characteristics and the impacts of bioprocessing. The diagrams showing the processing steps as well as how they integrate with laboratory project partners was especially helpful. The integration of the industrial partners, Forest Concepts and AdvanceBio Systems LLC, was not clear, and I could not determine how they were providing input. The team has made excellent progress in meeting project milestones, and the presentation outlined this well. As far as impact, the team has published numerous articles on their work and has included their data in the Materials Property Database. The validated shear stress model will be extremely helpful for the bioprocessing industries. The summary of the overall impact of the project could have been stronger if the team had provided preliminary estimates of the GWP, cost reductions from the impact of slurry formation, or other achievements, and/or framed this in terms of the wider biofuels processing industry.

PI RESPONSE TO REVIEWER COMMENTS

- Comment: They did not quantify the potential benefit as well as they could have.
- Response: The reviewer is correct that the potential (and actual) benefits need to be further defined, although the major effect shown in Slide 4 (of the Peer Review presentation) clearly shows the impact (increase in productivity by a factor of >3). We plan to continue this work to address these and other questions, although they are not part of the approved SOPO and the budget allotted.
- Comment: The researchers might also consider using Microsoft Excel instead of Aspen for modeling this process.
- Response: Indeed, we are considering Microsoft Excel as well as Aspen. Excel tracks material balance, and the material type or behavior is irrelevant. Excel does not depend on software versions for use and is more user friendly. Aspen dynamically updates and propagates changes downstream and is designed to handle processes at scale. Costs are tracked and updated as changes are made. However, Aspen is not easily updated as software versions change, and does not easily handle biomass (cellulosic materials). Forecasting of next steps was not part of this project's SOPO. It is important, and will be pursued.
- Comment: This project fails to forecast the next steps needed to generate practical opportunities for industry in real-world applications.
- Response: This is a work in progress. A key is also to test concepts at pilot scale in an operating biorefinery or a test facility, based on selected corn stover fractions, fermentation of the resulting slurries, and estimates of the costs and potential cost benefits.
- Comment: It is noted that water absorption of feedstock is a "key indicator" for ready slurry formation—further elaboration on this observation is desired.
- Response: We agree and will continue to work on this.
- Comment: The presentation didn't mention the pressures they were attempting to pump against and thus didn't clearly demonstrate overcoming this hurdle.
- Response: This is addressed by yield stress criteria. This project measured and developed predictive models, validated with data, of the slurry rheology, which in turn define "pumpability" or the ability to mix slurry in terms of shear stress as a function of shear rate, as well as yield stress (determines energy needed to initiate mixing). The overall impacts were presented in Slide 21, although the yield stress curve was not discussed in detail. We agree that the benefits of pumping should be vetted, and this will likely be part of future proposals if the FOA addresses this topic. The current scope of work (and resources) does not include pumping tests.

- Comment: The pelletizing process should be included in both the TEA and LCA calculations. The benefits of pumping a high-solids slurry versus solids conveyance should be verified in a pilot or demonstration biorefinery.
- Response: The TEA for the pelleting process was determined previously and is not part of the scope of this work. This is available from INL and was addressed at Argonne National Laboratory, with results being reported by INL. The effect of pelleting on overall LCA is small.
- Comment: The integration of the industrial partners, Forest Concepts and AdvanceBio Systems LLC, was not clear, and I could not determine how they were providing input.
- Response: The roles of Forest Concepts (feedstock acquisition and crumbling) and AdvanceBio (reactor design for introducing feed into process) were addressed in graphics in Slides 7, 14, and 19.
- Comment: The summary of the overall impact of the project could have been stronger if the team had provided preliminary estimates of the GWP, cost reductions from the impact of slurry formation, or other achievements, and/or framed this in terms of the wider biofuels processing industry.
- Response: The reviewer is correct. Nonetheless, the SOPO/resources did not extend to the overall biorefinery, although impact is given in Slides 4 and 19. We thank the reviewer for an excellent suggestion for future work.

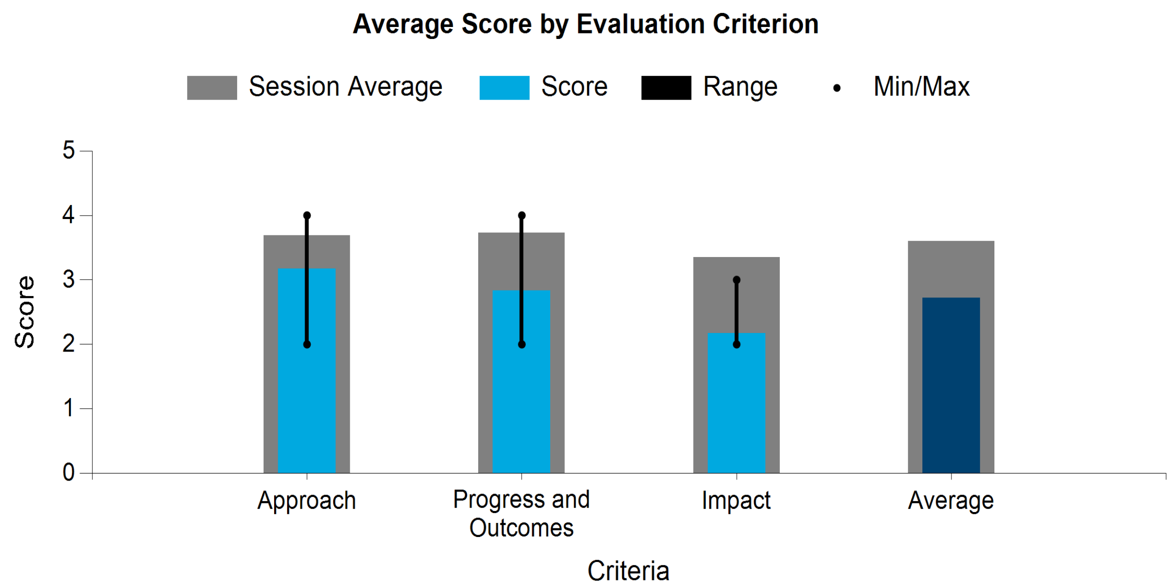
MACHINE LEARNING BASED MODELING FRAMEWORK TO RELATE BIOMASS TISSUE PROPERTIES WITH HANDLING AND CONVERSION PERFORMANCES

University of Georgia Research Foundation Inc.

PROJECT DESCRIPTION

WBS:	1.2.2.104
Presenter(s):	Sudhagar Mani
Project Start Date:	10/01/2019
Planned Project End Date:	03/31/2024
Total Funding:	$1,814,678.00

The project is aimed at developing a robust ML modeling framework to relate biomass tissue properties to feedstock handling and conversion performance using ML techniques such as artificial neural networks. Two biomass types—corn stover and southern pine forest residues—were selected and sourced to capture biomass variations. About 60 samples of corn stover bales collected from three different harvest methods and two different locations and years (2018 and 2020) were manually separated into four tissue fractions (cob, husk, leaves, and stalk) along with bulk fractions to determine chemical and physical properties and to develop an NIR-based hyperspectral imaging (HSI) instrument. Then, the tissue fractions were treated with the enzymatic hydrolysis method to determine hydrolysis performance. Similarly, five different samples of southern pine forest residues were sourced, collected, and manually sorted into four tissue fractions (juvenile wood, branch wood, bark, and needles) and were scanned using NIR-based HSI models to predict physical and chemical properties. The forest residue tissue fractions were used to carry out the fast pyrolysis performances using pyro-gas chromatography with a mass spectrometer (pyro-gas chromatography–mass spectrometry instrument. The ongoing research includes studying the grinding and bulk handling performances of both biomass samples and developing predictive models using ML tools. Preliminary ML modeling activities are carried out with existing data from the literature, and the developed framework will be adapted to the project results to evaluate prediction performance metrics ($R^2 > 0.8$). The developed ML models will guide selective preprocessing operations to produce highly flowable and conversion-specific feedstock for the smooth operation of a biorefinery. They can also be used to design modern biomass depots aimed at manufacturing uniform and standardized feedstock for a specific conversion while developing optimal strategies to monitor, manage, and control powder flowability during handling and storage and thus improve the operational reliability of a biorefinery. The successful completion of the project will not only meet BETO's feedstock-conversion interface goals, but will also deliver science-based strategies to preprocess biomass at the tissue level to unlock the feedstock-conversion interface challenges and flowability issues for a biorefinery.



COMMENTS

- An interesting approach is provided, but the long-term significant impact is not well defined. This appears to be largely academic work. It is unclear whether the models are actually being made publicly available. The cost and potential cost benefit of this work are not described. This was not a FOA requirement, but it would have been a measurable metric for this project. No other real measurable impacts were defined; all were qualitative. A metric will need to be defined just to determine when the models would be considered reliable.

- This work may have important implications for industrial feedstock handling, but it was difficult to discern from the presentation. I would have liked to see more content on how these software tools would be used in industry and what benefit they might have. It is also critical for the researchers to understand these factors so that they have the necessary context for decision-making.

- The ML aspect of the project appears to be largely based on literature review and not on more rigorous ML software or analyses that can analyze the feedstock characteristics that correlate with bio-pyrolysis. The project fails to accomplish a primary objective to achieve a novel ML tool. This project would benefit from forestry and biofuel industry partnerships. Extensive forestry feedstock analyses have been done, yet this project implies that much is unknown. However, the live presenter pointed out that it is the particle-level characteristics that are widely unknown. The presenter said that the ML tools can be used to help prioritize feedstock from biomass depots, but in doing so, failed to recognize that forest biomass depots do not segregate feedstock to an ultra-refined level for that to apply. The weakness of this project is the lack of industry engagement and strong connections to market or industry needs.

- This is an ambitious study in which NIR HSI will be used to correlate with the processability of both (1) corn stover lignocellulosic conversion using dilute acid pretreatment/enzymatic hydrolysis/fermentation to ethanol and (2) pine component conversion with pyrolytic conversion. Tackling one of these areas would be ambitious, and I don’t know the benefit of tackling both objectives when only the analytical method is common. As a result, the effort seemed unfocused. Currently, the corn stover method wet conversion appears to be based on a meta study of previous acid pretreatment and enzymatic hydrolysis, dividing the samples into "seven features." However, as none of the actual samples analyzed were converted, there appears to be a disconnect between the imaging/modeling and analysis (unchecked assumptions). This may be more misleading in criteria selection than beneficial to related criteria selection. The predictive abilities of the NIR models for handleability are "underway" and are unable to be evaluated. The pyrolysis prediction model seems more advanced than the corn stover predictions, although there is still some of the meta-analysis disconnect that the corn stover model appears to suffer from. The relationship of pyro/gas chromatography/mass spectrometry to commercial pyrolytic conversion remains to be proven in relationship to commercial unit operations—it is indicative, but gaps exist.

- The project has developed a rapid analysis technique for using NIR with HSI to determine the chemical composition of the anatomical fractions of both corn stover and pine forest residue. Using ML technology, the team is training the software to predict conversion in both enzymatic hydrolysis and fast pyrolysis. If successful, the application will advance the state of the art for predicting the yield of feedstocks in the conversion processes. In parallel, the team is evaluating physical properties and utilizing ML to predict grinding performance and flowability in the biorefinery processes. Based on the project schedule for Budget Period 2, the team has a strong likelihood of achieving Budget Period 2 goals. The presentation does not describe the tasks intended for Budget Period 3, which would help in determining the probability of achieving the end-of-project goal. The project is designed to demonstrate the potential for significant impact in both a low-temperature and a high-temperature environment using lab and pilot equipment. Engaging partners to evaluate the effectiveness of the NIR/HSI technology in both high- and low-temperature pilot conversion as well as preprocessing equipment are needed to verify the technology and increase the probability of commercialization.
- In terms of approach, the team outlined the issue of feedstock variability and the need for being able to predict the composition well. The outlined approach was difficult to understand; the roles of the various partners and a list of tasks, milestones, and goals were not provided. It is not clear how the team will solve this issue. It does not look like the team has any industrial partners, coalitions, etc. to provide feedback. In terms of progress, the team provided results, but it was unclear how the results will be used, and the ranking of the most important features seemed trivial, as most would be apparent. No discussion was provided on whether the project was on target, other than the fact that a task was completed. That is, no information on the attainment of specific milestones was provided. Also, some tasks are complete for the fourth quarter, but others are not. Is this because the project is ahead, behind, or on target? In terms of impacts, the team has published and/or presented five publications on this work. An ML model would be of great benefit to the biomass processing industry. However, it was unclear how predictive the model is and where the project goes from here. There was no assessment of the economic, GWP, or other impacts.

PI RESPONSE TO REVIEWER COMMENTS

- Thank you for the feedback and comments on this project. The project team agrees that the project is very ambitious. The project is intended to understand the variability of biomass at the tissue component level while evaluating its impact on conversion and handling properties. This is the first fundamental study that is focused on the heterogeneity of biomass physical and chemical properties impacting conversion performance. In addition, we will develop physical and chemical property prediction models based on the HSI spectra method, a nondestructive approach to rapidly determine biomass properties. Unlike other R&D projects evaluated during this Peer Review, this project is not intended to develop new technologies or provide a cost estimation; instead, we are building an ML modeling framework to relate biomass tissue properties to conversion and handling performance. The ML modeling approach will be of great benefit to the biomass industry, as confirmed by our project advisory board, which represents the biomass processing industry. ML models can advance agricultural and industrial practices and predict biofuel yields, leading to significant improvements in prediction and process control of conversion technologies. In addition to determining the conversion potential of various tissue fractions (e.g., pyro-GCMS technique), we are also collecting conversion data in the published literature to augment biomass variability and its relation to conversion performances to develop robust ML models. Access to ML models is typically given by providing the code and models upon request or through repositories like GitHub or public web servers. The feature ranking methodology will evaluate the influence of each feature on the model's final prediction by implementing a game theory approach. This leads to the identification of the key factors involved in the conversion of biomass into biofuels, providing invaluable insights for future R&D in this field. For example, if the biomass industry is willing to share its biomass input properties and its basic conversion process conditions, the ML model can instantly predict the conversion yields during commercial operations.

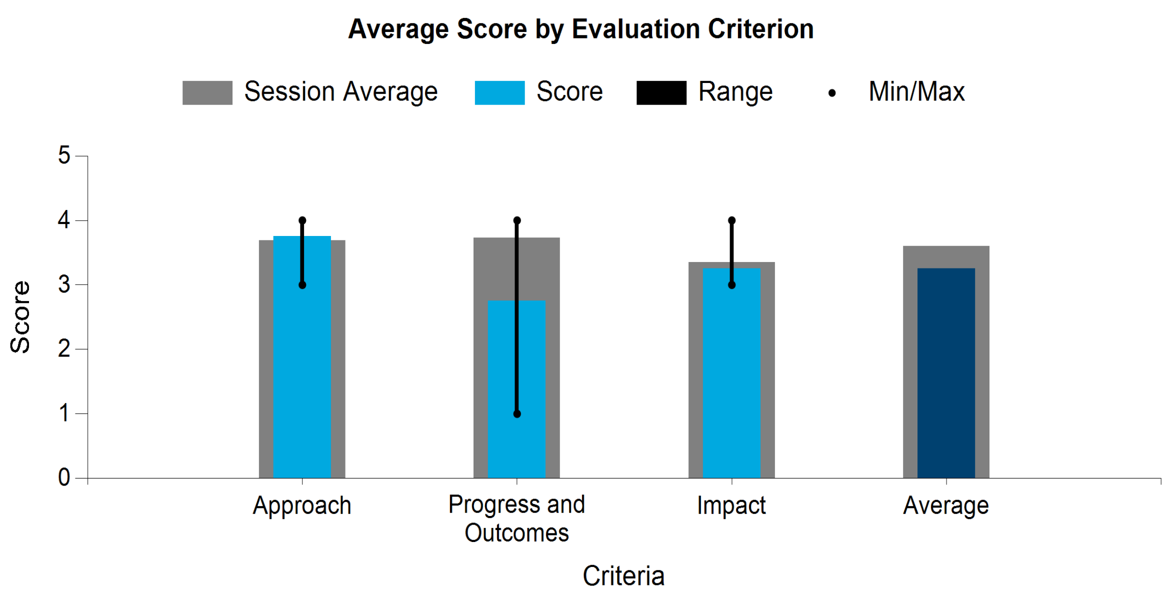
ARTIFICIAL NEURAL NETWORK FOR MSW CHARACTERIZATION

AMP Robotics

WBS:	1.2.2.105
Presenter(s):	Carson Potter
Project Start Date:	10/01/2020
Planned Project End Date:	03/31/2024
Total Funding:	$2,538,653.00

PROJECT DESCRIPTION

AMP Robotics' project "Artificial Neural Network for MSW Characterization" is an effort to model out a cost-benefit analysis of different sensor packages for characterization of MSW. By modeling sensor performance across a range of multimodal inputs, and utilizing deep learning techniques to fuse the sensor data, AMP hopes to produce a state-of-the-art tool for MSW characterization. The work includes profiling which sensors are the most impactful and economically viable for long-term characterization and chemical control of MSW for the production of low-carbon fuels and feedstocks, and will enable future research on efficient separation of critical fractions such as pyrolysis and bioenergy feedstocks.



COMMENTS

- The project is about 75% behind schedule (Slide 11) due to vendor issues, and UV/X-ray fluorescent (XRF) will not be carried out as planned. Question: What is the impact of these on the overall fidelity of the proposed approach and expected outcomes? The TRL was expected to go from TRL 3 to 5 after the completion of the project. Is that still the case with the mentioned issues/compromises? It would be useful to hear about the team's experience and track record in carrying out a project of such complexity and variability in a closely related application. It would also be good to have industrial partners.

- This is a good project with some details on the approach being used. More explanation is needed to address the strategies for mitigating the project's risks. In terms of P&O, although the project has had delays due to third-party sensor array procurement, it is making progress. The project needs to address the inconsistency of the AI training data from different sources. As far as impact, the cost/benefit of this robotic sorting system compared to a mechanical/manual system is not clear. A commercialization plan with clearly defined customers is needed.

- Land use change and competition with food production are often cited as concerns for lignocellulosic feedstock production. Development of NMSW as a feedstock is warranted because it does not compete with agriculture for food production, and because the use of NMSW will offset the flow of waste into landfills and mitigate landfill methane emissions. Conversion of wastes into useful products and services is a basic aspect of circular economies. BETO has made significant investments into NMSW research, including the projects reviewed in this report. Some of the challenges of developing NMSW as an economic resource include (1) the extreme heterogeneity of NMSW, and (2) the presence of toxic and undesirable constituents. Therefore, BETO has made significant investments into NMSW characterization, sorting, blending, and milling to overcome these challenges. The objective of this project is to develop an AI system to characterize NMSW using NIR reflectance data and Red-Blue-Green imagery. The investigator mentioned that the project is about 9 months behind schedule and noted some significant challenges due to the difficult environment of working with NMSW and material heterogeneity. Nevertheless, this project warrants continuation. I will note that on-board NIR analysis has been developed for grain harvest combines, which are also a difficult environment, albeit the material is more consistent than NMSW.

- In terms of approach, it was an excellent idea to include the first chart, which shows “short forms.” This was especially helpful, and thought should be given to including this in all presentations. Including roles of the project team would be very helpful. There are realistic challenges that may be very difficult to overcome for successful implementation of this technology. This is a novel and interesting approach for classifying MSW. As far as P&O, the project has gotten slightly off track with sensor delays. However, other work is proceeding well. The team can always look at the two missing sensors if time/funds allow at the end of the study and the PIs feel that they would contribute to better classification. In terms of impact, the project has the potential to be impactful if it is successful in characterizing feedstocks. A collaborator on the gasification end would be helpful to the team, as would a collaborator in the waste management industry.

PI RESPONSE TO REVIEWER COMMENTS

- In response to the first comment: I believe there are some misunderstandings from the presentation material. The project is not 75% behind schedule; we are 75% of the way through the second budget period, which was a total of 9 months behind schedule. That 9-month delay was driven by a third-party vendor chosen by INL to construct a sensor array at the BFNUF for use in this project and others. The delay was in no way driven by AMP’s participation in this project. AMP is our industrial partner, and has extensive partnership with Waste Connections, Casella, and many other leading industry processors. On top of that, AMP has over 300 robotics and AI systems deployed across 14 countries, making it the leading industrial provider of waste AI and robotics. The TRL will still progress from 3 to 5, just with the exclusion of some initial modalities from which we were hoping to gather additional data on chemical control. For the key performance parameters of this grant, we do not anticipate needing XRF or UV to fulfill the accuracy desired by BETO.

- In response to the second comment: It would help to clarify the nature of the inconsistencies the reviewer is concerned about. Bias in training sets is consistently a problem when developing large-scale AI models, and for the BETO grant in particular, we are definitely concerned about overfitting to the sample material provided. However, that material was sourced from landfills across the western United States, and should be fairly representative within the U.S. waste stream. Any production-ready version of this technology that AMP deploys will likely benefit from a mix of training data across more than 100 U.S. sites, with an emphasis on regional MSW recorded from robots deployed in our fleet. This is a common practice for us to ensure the robustness of the data and, ultimately, the performance of the model.

- Regarding points 3 and 4, we agree! We will produce a cost/benefit analysis of this use of a sensor; however, this project is not tied to a specific sorting mechanism, so it could be paired with almost any common mechanical approach. Wherever that sorting mechanism or energy conversion process will benefit from a better understanding of composition and an ability to track specific items as they move across the conveyance of the process (for the purposes of chemical control), this sensor will certainly provide a unique and cost-justified advantage.
- Regarding the fourth comment: Agreed! We have leveraged BETO's extensive network to have conversations with Gas Technology Institute (GTI) and a few other gasifiers, and we are exploring partnership with Fulcrum for future infrastructure funding opportunities through DOE. If we took a future iteration of this project to the stage where we were designing full-fledged sorting systems, it would be invaluable to partner with a gasifier and a waste processor (such as Waste Connections or Waste Management) for process flow optimization. AMP has experience and partnerships here, but nothing expressly directed at the ultimate realization of this specific award's focus, in a production environment, for gasification preprocessing of MSW.

DECONTAMINATION OF NON-RECYCLABLE MSW AND PREPROCESSING FOR CONVERSION TO JET FUEL

Gas Technology Institute

PROJECT DESCRIPTION

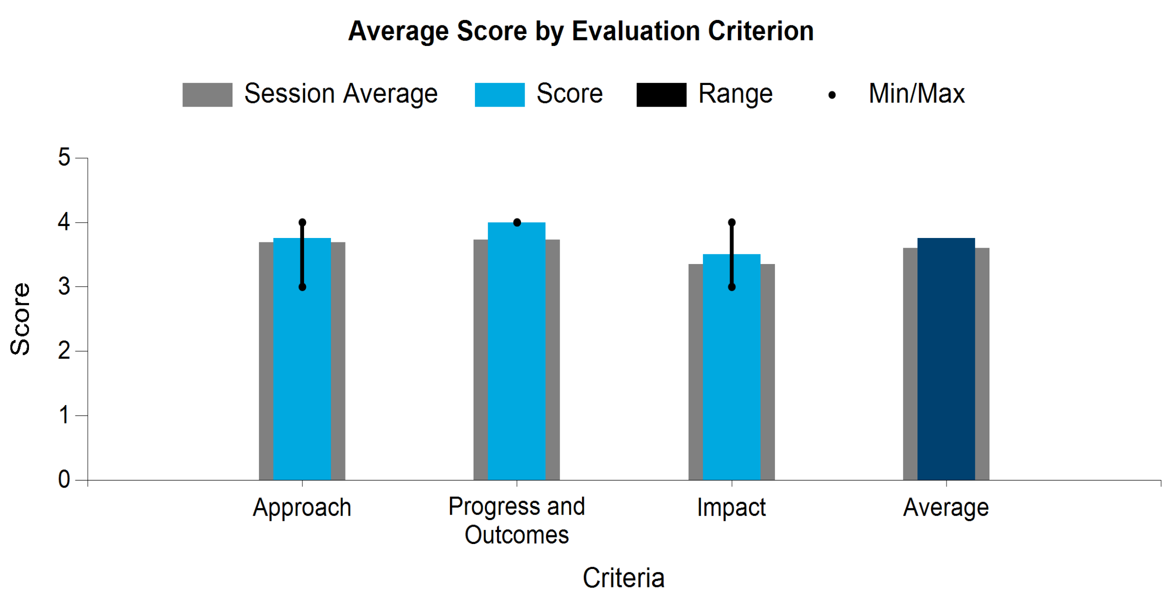
WBS:	1.2.2.106
Presenter(s):	Timothy Saunders
Project Start Date:	10/01/2020
Planned Project End Date:	05/31/2024
Total Funding:	$3,128,383.00

The project goal is to create a new path for NMSW to produce jet fuel, capture secondary value streams, and minimize landfill.

GTI has demonstrated U-GAS, a single-stage fluidized bed gasifier applicable for converting biofuels and NMSW, which has been selected as an applicable baseline technology for converting NMSW to jet fuel. The project will develop a novel AI sorting algorithm to produce high-purity feedstock from NMSW and will enhance physical methods for fractionation of NMSW. The AI algorithm will be tested on a commercial-scale sorter machine. The commercial conversion process will utilize a novel solids pump that injects the processed NMSW directly into gasification pressure for conversion.

Specifically, the project will:

1. Develop a novel AI sorting algorithm for increasing the purity and efficiency of fractionation and decontamination of NMSW.
2. Undertake physical and chemical characterization of NMSW.
3. Develop fundamental numerical models to predict plug formation of NMSW fractions and blends and validate in an adapted solids pump.
4. Test an adapted semi-scale solids pump for homogenous feedstock injection at pressure.
5. Undertake a commercial TEA and LCA showing viability and impact of integrated process from NMSW receipt through conversion to jet fuel.



COMMENTS

- This is a well-balanced team with the necessary expertise in waste collection, sorting, separation, characterization, and AI-based data analysis and informatics. Active participation from Waste Management is a plus. The project seems to be on track and has met key metrics and go/no-go decision stages. Slide 8 clearly details the risks and their mitigation steps. It is not quite clear how the project would be transitioned into a field trail. Slides 5 and 7 detail the proposed approach. It looks like it mostly addresses the solid components of the waste stream. What about chemical contaminants, such as forever chemicals?
- This is a sound project with some details on the approach being used. More explanations could be used to further address the strategies for mitigating the project's risks. In terms of P&O, substantial progress is needed to address the association of decontamination with the yield of jet fuel relative to specific conversion pathways. It is not clear how AI can help remove the contaminants. Will AI detect other contaminants besides chlorine? As far as impact, there are no touchable impacts reported at this phase of the project.
- Land use change and competition with food production are often cited as concerns for lignocellulosic feedstock production. The development of NMSW as a feedstock is warranted because it does not compete with agriculture for food production, and because the use of NMSW will offset the flow of wastes into landfills and mitigate landfill methane emissions. Conversion of wastes into useful products and services is a basic aspect of circular economies. BETO has made significant investments into NMSW research, including the projects reviewed in this report. Some of the challenges of developing NMSW as an economic resource include (1) the extreme heterogeneity of NMSW, and (2) the presence of toxic and undesirable constituents. Therefore, BETO has made significant investments into NMSW characterization, sorting, blending, and milling to overcome these challenges. This project is developing NMSW as a feedstock for SAF through Fischer-Tropsch/gasification. The team's approach is to remove harmful constituents, such as polyvinyl chloride (PVC), from the feedstock by developing AI-based characterization. They are also developing a continuous-feed dry solids pump to feed decontaminated NMSW into the gasifier. This project appears to be on track, and the team is gaining basic experience with the safety and physical risks encountered with NMSW.
- In terms of approach, using black instead of grey font would be helpful. Slide 3 was good; it attempted to show the involvement of the collaborators. I appreciated the definition of the TEA and LCA on page 6. Regarding the <$30/ton add-on cost for processing above the $86/ton delivered cost: How does that apply to this project, where the anticipated cost of NMSW would be lower than better feedstocks at $86/ton? Some of the slides in this presentation were impossible to see and also contained far too much information to comprehend in a short amount of time, i.e., Slide 8. The 15 key performance parameters are an excellent way to track the project. This system could be utilized by a number of projects to make the success criteria clear and tracking more direct. (I only wish I could read the slide.) P&O seems to be on target and progressing well. In terms of impact, the commercialization potential is not very clear. The TEA and LCA will determine commercial feasibility. The next steps to commercialization were not mentioned—i.e., who would be the customer for this application, and has the group been in communication with the intended SAF manufacturer to understand feed systems and feedstock requirements?

PI RESPONSE TO REVIEWER COMMENTS

- GTI is currently considering a commercialization plan that incorporates testing of the feed system to be developed. Initial testing will most likely be at a gasifier test site at a GTI facility where the feed system will be used to inject NMSW into an operating U-GAS gasifier. Field testing of the NMSW preparation process will be undertaken in conjunction with INL and suppliers of the process equipment. We envision asking Waste Management to support on-site testing of such processing equipment for validation at actual materials recovery facilities.

- GTI is confident that the project risks can be managed by the team, as the key deliverable is a feed system able to deliver into 150 psi—a pressure that the team has successfully achieved with other materials. The process equipment for the NMSW preparation being used by INL is all commercially available except the AI system; consequently, risks related to performance are very low. The AI system will need training, but the narrow focus for the material target simplifies the process objective.
- The AI system to be developed for the project will target a single contaminant: chlorine compounds, primarily PVC. The number of specific targets in the as-received NMSW containing PVC are relatively small, and so far, they appear easily identifiable by the sensor suite employed, offering a high confidence of successful performance. The project will use AI for PVC targeting only, and there are no plans to expand this requirement.
- The program commercialization steps are in development by GTI, as mentioned in the response above. The TEA and LCA will define the cost parameters for both the processes being developed in the project and the larger plant-scale economics. Once these are defined, the best approach for commercialization can be developed. Having the nation’s largest waste handler as a partner opens many opportunities for process applications, operations, and locations. The team will expand contact with municipal operators as the project develops and expects to have additional interested parties joining the evaluation process as a first step to identifying test targets. Included in this process will be manufacturing companies for process equipment development and future sales to interested markets. It should be noted that the feed system will have many applications in addition to NMSW—biomass, for example—so there will be parallel commercial opportunities to take advantage of upon success in meting operating targets.

ADVANCED SENSING FOR CHARACTERIZATION AND SORTING OF NON-RECYCLABLE PLASTICS USING SENSOR FUSION WITH ARTIFICIAL INTELLIGENCE

UHV Technologies

PROJECT DESCRIPTION

WBS:	1.2.2.107
Presenter(s):	Nalin Kumar
Project Start Date:	10/01/2020
Planned Project End Date:	03/31/2025
Total Funding:	$3,125,000.00

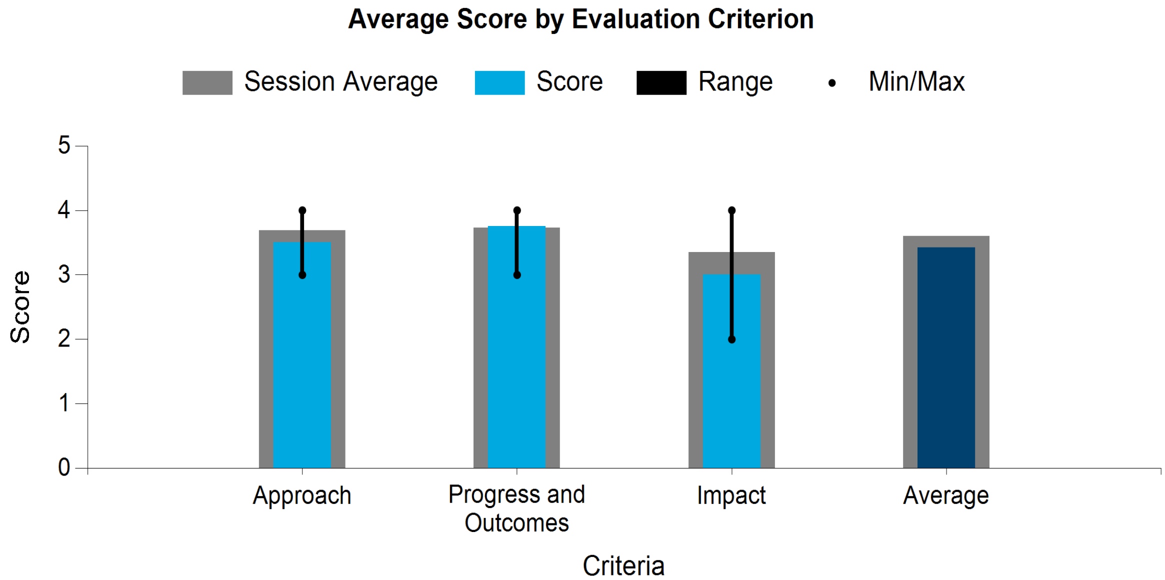
Objectives: The first objective is to develop an instrument that can quantify individual pieces of plastic with multiple sensors and assign a unique fingerprint, containing organic and inorganic data, to each piece. The second objective is to create a novel classification system for polymer and multilayer polymers in this stream with deep learning and AI algorithms. The third objective is to develop three different products with catalytic pyrolysis to determine which of the novel sorted fractions are most viable for the creation of products. The fourth objective is to perform end-to-end TEA and LCA to ensure economic viability of the sorting technology.

Description: The project goal is to advance state-of-the-art plastic sorting capabilities by employing cutting-edge technologies such as sensor fusion and AI-based deep learning algorithms. The proposed technology will develop advanced and techno-economically viable sorting and preprocessing methods tailored to MSW. To this end, an existing stream of nonrecyclable MSW plastics such as #3–#7, which is currently produced at an existing material recovery facility from NIR sorters, will be investigated to divert from disposal for conversion to fuels and products.

Methods: Deep learning neural networks will be developed to perform chemical-based classification of components found in the nonrecyclable plastic waste stream. An experimental apparatus will be developed that uses air nozzle jets to perform sorting, fractionation, and decontamination of this waste stream. Pyrolysis testing will be used to evaluate the viability of the novel fractions to produce new products.

Potential Impact: Novel fractions from this waste stream have the potential to become a valuable feedstock for the production of gases and fuels. These 1,200-pound bales created from this plastic waste stream sell for $6–$10 in current open-market conditions. This sorting technology potentially enables a new low-cost feedstock for the creation of new products.

Major Participants: UHV Technologies Inc., INL, the University of Illinois Urbana-Champaign, Penn State University, and Palm Beach Solid Waste Authority.



COMMENTS

- This is a well-articulated project with clear objectives, approaches, necessary tools/capabilities, and go/no-go metrics. The team has the necessary skill sets and capabilities to carry out the tasks outlined in the project. Are there any concerns about additives such plasticizers and perfluoro compounds in the plastic waste stream? How will they be handled? It would be helpful to have an industrial partner on the team. Slide 7 shows 70% conversion. What is the other 30%? How is that handled? On Slide 11, is the initial weight given dry weight? In the run with the catalyst, dry conversion is shown as 64.41% and liquid is shown as 31.96%. I do not quite follow this. Slide 13 claims a plant cost (CapEx?) of $12 million–$15 million for a 60,000ton/year facility. Is the product bio-oil or a further upgraded one?

- This is a sound project with some details on the approach being used. In terms of P&O, the project is making progress. A baseline was created in Budget Period 1. It is not clear whether decontamination is considered. The calculation of the MSW cost of $20–30 per ton needs to be further refined and clarified to achieve the target of $3/GGE. For example, how is the logistical cost or transportation cost considered in the process? As far as impact, there are no touchable impacts reported at this phase of the project. In the coming years, dissemination of the project findings and commercialization will help generate substantial project impacts. The TEA and LCA also need to be further improved, especially through clarification of data sources (lab work, existing literature).

- Land use change and competition with food production are often cited as concerns for lignocellulosic feedstock production. Development of NMSW as a feedstock is warranted because it does not compete with agriculture for food production, and because the use of NMSW will offset the flow of wastes into landfills and mitigate landfill methane emissions. Conversion of wastes into useful products and services is a basic aspect of circular economies. BETO has made significant investments into NMSW research, including the projects reviewed in this report. Some of the challenges of developing NMSW as an economic resource include (1) the extreme heterogeneity of NMSW, and (2) the presence of toxic and undesirable constituents. Therefore, BETO has made significant investments into NMSW characterization, sorting, blending, and milling to overcome these challenges. This project aims to develop systems to characterize NMSW constituents and sort out undesired constituents. The team is developing a complicated system of Visible, NIR, XRF, and Mid Infrared Range sensors to drive AI-enabled characterization and sorting. Their current goal is to obtain one million images to train the system. Obtaining and characterizing this number of images is daunting; however, the results will lead to a robust calibration set for the system. This work is on track and will have a significant impact on NMSW processing irrespective of the biofuel conversion system.

- In terms of approach, more specificity on the project goal and specific aims (Slide 2) would help situate the project within the BETO portfolio. I don't see an alignment with the BETO objectives. Collaborators are listed on page 3, but there are no details on how each is involved in the project. It is unclear whether a value of inorganic/organic content is generated by the sensors, or how this information will be used. The project will take the sensor footprints and relate them to a camera image, but the classification of the material is not clear to me. In terms of P&O, for the proof of concept through the lab-scale pyrolysis system: What type of fuel is it, and where can it be used? I don't understand the costs on Slide 7. On Slide 11, highlighting the meaning of the important results in this table would be helpful. It would be helpful to have both the plastic type and the classification number on the same slide (Slide 8). How much of 4, 5, and 6 are available in the marketplace? As far as impact, it is not clear how this fits with the BETO objectives. Details on the revenue slide (Slide 12) would be helpful. I'm not sure what this slide is showing. My thoughts are that this system would need to ensure that markets already exist for the #1, #2, and aluminum in an area. Otherwise, this would significantly affect project feasibility. A comparison with the use of this material in a waste-to-energy conversion plant should be considered. It seems like a high cost for processing a low-value material that may not have a high value-added application as a liquid fuel of some sort. What is the application of the fuel? Does the cost target of $30/tonne for sorting include all handling, waste disposal, etc.? Is it the entire plant cost?

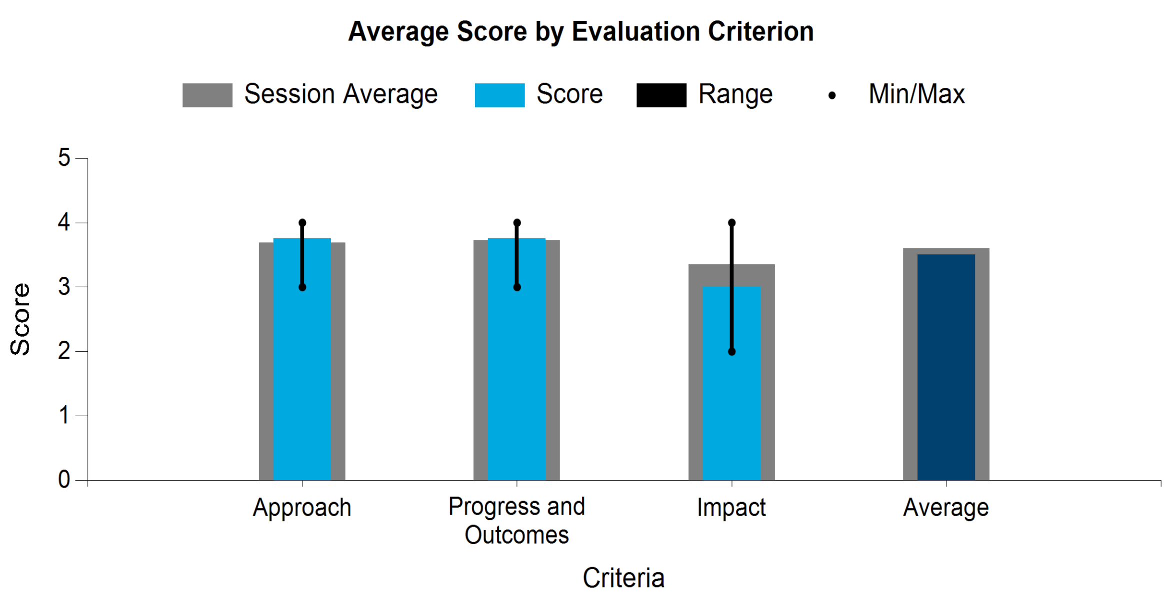
HIGH PRECISION SORTING, FRACTIONATION, AND FORMULATION OF MUNICIPAL SOLID WASTE FOR BIOCHEMICAL CONVERSION

University of Cincinnati

PROJECT DESCRIPTION

WBS:	1.2.2.108
Presenter(s):	Maobing Tu
Project Start Date:	10/01/2020
Planned Project End Date:	03/31/2025
Total Funding:	$2,651,991.00

MSW represents a valuable source of low-cost feedstock for the production of biofuels, biochemicals, and bioenergy. However, most MSW is generally destined for landfills. The heterogeneity and variability of MSW due to the presence of plastics, metals, and other impurities are the major bottlenecks for biochemical conversion, and only the organic fraction can be used. Significant gaps exist in understanding the heterogeneity of MSW and effective mitigation strategies for managing MSW to improve its cost-effective utilization and maximize valorization. Moreover, the initial baseline evaluation of the traditional screening and sorting processes, i.e., vibratory and trommel screening with nonrecyclable MSW, resulted in an organic fraction with a limited purity of only 50%–70% in this project. Therefore, the main goal of this project is to develop advanced sorting and fractionation technology to separate the organic fraction from the MSW and blend and formulate the organic waste (>95% purity) with lignocellulosic biomass for biochemical conversion. This project will employ the integration of dynamic disc screening, mechanical milling, and ballistic screening as an innovative approach to address MSW heterogeneity and facilitate effective separation of the organic fraction. Subsequently, blending and formulation of the sorted organic fraction with lignocellulosic biomass will be carried out to reduce feedstock variability. Finally, the TEA and LCA will be performed to evaluate the technical and economic feasibility of the proposed novel MSW sorting, fractionation, and blending pathways. The successful implementation of the current project will result in producing conversion-ready feedstock in support of the BETO cost target of $73/dry ton and will have a great impact on MSW management and waste-to-energy industries by developing a new sorting and milling technology.



COMMENTS

- This is a well-detailed project with objectives, an approach, relevant tasks, and milestones. The team is well rounded and has the necessary skill sets and capabilities. The project has met the milestone goals and is on track. In terms of impact, the project has the potential to be significant and to meet BETO goals.

- Who is the ultimate customer for the finished product—equipment/process, etc.? Slide 13 shows an efficiency in the 85%–90% range. What are the components—metals and others that are not removed? Could they have a negative impact on downstream conversion processes such as catalyst poisoning? Are there any concerns about residual hazardous chemicals such as forever chemicals?

- In terms of approach, on Slide 5, two challenges were discussed: shredder breaking glasses and disc screening issues. It is not clear how the team has handled or will handle and mitigate these risks. Regarding challenges for TEA and LCA, rather than boundary or scope, I like to say that data consistency and accuracy would be a major challenge to TEA and LCA. In terms of P&O, the project is making good progress. Regarding target performance metrics, for operating cost, the project needs more data support to address where it will achieve this target of <$30/ton for MSWs. As far as impact, it needs to be specific, especially on industry collaboration and engagement, and scale-up of the system. The decontamination work is not clear in the project, which needs to be a part of the total cost. It is not clear if contaminants of MSWs were removed before they were considered to be blended with biomass.

- Land use change and competition with food production are often cited as concerns for lignocellulosic feedstock production. Development of NMSW as a feedstock is warranted because it does not compete with agriculture for food production, and because the use of NMSW will offset the flow of wastes into landfills and mitigate landfill methane emissions. The conversion of wastes into useful products and services is a basic aspect of circular economies. BETO has made significant investments into NMSW research, including the projects reviewed in this report. Some of the challenges of developing NMSW as an economic resource include (1) the extreme heterogeneity of NMSW, and (2) the presence of toxic and undesirable constituents. Therefore, BETO has made significant investments into NMSW characterization, sorting, blending, and milling to overcome these challenges. Rather than employing AI-enabled characterization and sorting systems for NMSW, this project is developing milling as a means of improving the homogeneity of NMSW feedstocks and as an approach to blending NMSW with lignocellulosic feedstocks. The team has made good progress by procuring a disc mill, and installation of a test bed is currently underway. They are also collaborating with the Tuskegee Institute to elevate DEI as an objective in this project. This project will establish important capabilities at the University of Cincinnati, and the collaboration with INL reinforces the impact of the national lab.

- In terms of approach, the use of the term "organic fraction" is very confusing, as plastic (hydrocarbons) are organic molecules. Is the project referencing the separation of the bio-based organic fraction? If the end use of the material is to direct combustion/gasification, then it may not be desirable to remove the plastics. The prescreening stage (removing ferrous metals) must be commercially established already. How is this being designed in this project? The concept of grinding and then separating is a novel approach. This seems to be a high preprocessing cost for such a low-value feedstock. The team should mention the industrial collaborators by name in the presentation. It would be helpful to know what industries they are associated with. I appreciate the detailed investigation of equipment for new applications. In terms of P&O, what will be the start and end of the process for the LCA? How will the TEA show the benefit of this technology? It isn't clear how the technology will integrate with a biorefinery process in the LCA and TEA. As far as impact, no industrial partners are mentioned in the quad chart. This may make commercialization more difficult. What is the intended conversion pathway? Sugar conversion may not be the most favorable use. The material may be too contaminated for biochemical conversion pathways, and prove too costly to process. The team should maybe consider a gasification pathway.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their encouragement and constructive comments. We appreciate the positive feedback regarding our progress and outcomes, team skill sets and capacities, and milestone goals. We will address key questions raised by the reviewers below.
- Comment: Who is the ultimate customer for the finished product—equipment/process, etc.?
- Response: The goal of this project is to develop advanced sorting and fractionation processes that can separate the bio-based organic fraction from MSW to achieve a high-purity byproduct for blending with lignocellulosic biomass in a biochemical conversion process. The ultimate customer will be MSW handling companies and feedstock production companies.
- Comment: Slide 13 shows an efficiency in the 85%–90% range. What are the components—metals and others that are not removed? Could they have a negative impact on downstream conversion processes such as catalyst poisoning?
- Response: Depending on their size, some of the metal, glass, textile, and plastic will not be removed in the screening process and will end up in the organic matter fraction. These contaminants might have a negative impact on the downstream biochemical conversion process, but their impact is expected to be minimal. This potential impact will be evaluated in Budget Periods 2 and 3.
- Comment: Are there any concerns about residual hazardous chemicals such as forever chemicals?
- Response: We do have some concerns about forever chemicals such as perfluorooctane sulfonate and perfluorooctanoic acid in the bio-based organic fraction due to their presence in plastics and textiles. However, these materials will mostly be removed from the bio-organic fraction, and their contamination is expected to be minimal.
- Comment: In terms of approach, on Slide 5, two challenges were discussed: shredder breaking glasses and disc screening issues. It is not clear how the team has handled or will handle and mitigate these risks.
- Response: The shredder breaking glass could potentially be an issue. We plan to mitigate this risk by developing a presorting process without shredding and comparing the decontamination efficiency to the process with shredding.
- Comment: Regarding challenges for TEA and LCA, rather than boundary or scope, I like to say that data consistency and accuracy would be a major challenge to TEA and LCA.
- Response: We agree that data consistency and accuracy could be a key challenge to TEA and LCA. We will increase the sample size and the number of replicates to improve the data accuracy and consistency.
- Comment: In terms of P&O, the project is making good progress. Regarding target performance metrics, for operating cost, the project needs more data support to address where it will achieve this target of <$30/ton for MSWs.
- Response: We agree that more data support is needed to address the final target performance metrics; this will be addressed in Budget Periods 2 and 3.
- Comment: The impact needs to be specific, especially on industry collaboration and engagement and scale-up of the system.
- Response: Industrial collaboration and engagement and scale-up of the system will be specified in Budget Periods 2 and 3.

- Comment: The decontamination work is not clear in the project, but it needs to be a part of the total cost. It is not clear whether MSW contaminants were removed before they were considered to be blended with biomass.
- Response: Decontamination of the bio-organic fraction is defined as the removal of metal, glass, textile, and plastic in this project. Thus, the goal is to remove these contaminants as much as possible before blending the bio-organic fraction with biomass.
- Comment: In terms of approach, the use of the term "organic fraction" is very confusing, as plastic (hydrocarbons) are organic molecules. Is the project referencing the separation of the bio-based organic fraction?
- Response: We will use the term bio-organic fraction in future project reports. Yes, it is referencing the separation of bio-based organic fraction.
- Comment: If the end use of the material is to direct combustion/gasification, then it may not be desirable to remove the plastics.
- Response: The end use of bio-organic fraction is biochemical conversion, so plastic removal is desirable.
- Comment: The prescreening stage (removing ferrous metals) must be commercially established already. How is this being designed in this project?
- Response: The removal of ferrous metals will take place in the prescreening stage using a magnetic apparatus, as has been established by industry.
- Comment: The concept of grinding and then separating is a novel approach. This seems to be a high preprocessing cost for such a low-value feedstock.
- Response: The cost of preprocessing will be evaluated by TEA, which will assess if the process is cost-effective in producing conversion-ready feedstock.
- Comment: The team should mention the industrial collaborators by name in the presentation. It would be helpful to know what industries they are associated with.
- Response: The industrial collaborators include TORXX Kinetic Pulverizer and GoForward Solutions. Their associated industries may be found on their websites.
- Comment: I appreciate the detailed investigation of equipment for new applications.
- Response: We thank the reviewer for the positive comment.
- Comment: In terms of P&O, what will be the start and end of the process for the LCA?
- Response: The LCA will start from MSW preprocessing and will end with biofuels production and usage, composting, and refuse-derived fuel utilization.
- Comment: How will the TEA show the benefit of this technology? It isn't clear how the technology will integrate with a biorefinery process in the LCA and TEA.
- Response: The TEA will help optimize the prescreening, fine-tune the screening/sorting processes, and identify which products/processes are more valuable for MSW utilization.
- Comment: As far as impact, no industrial partners are mentioned in the quad chart. This may make commercialization more difficult.

- Response: The industrial collaborators are TORXX Kinetic Pulverizer and GoForward Solutions. They will be mentioned in future reports.
- Comment: What is the intended conversion pathway? Sugar conversion may not be the most favorable use. The material may be too contaminated for biochemical conversion pathways, and prove too costly to process. The team should maybe consider a gasification pathway.
- Response: The intended conversion pathway will be biochemical conversion to useful end products. We believe that if the contaminants can be removed, the sorted bio-organic MSW fraction will be suitable for biochemical conversion. The recovered plastics could be used for refuse-derived fuel and potentially for gasification as well if such facilities are near the MSW sorting process.

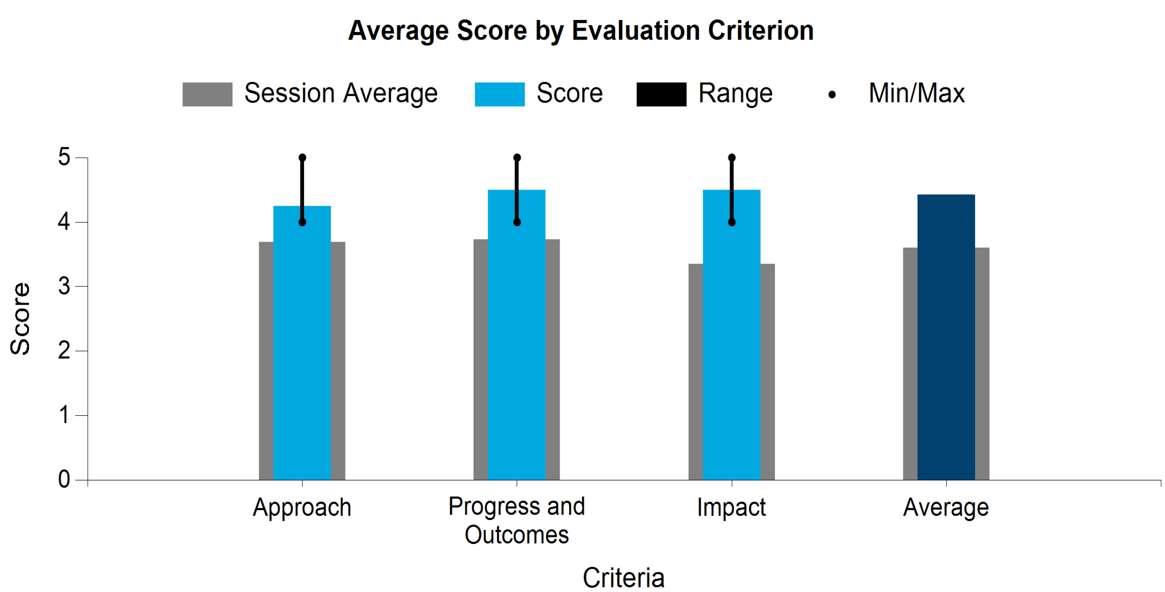
BIOENERGY FEEDSTOCK LIBRARY

Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.2.2
Presenter(s):	Rachel Emerson
Project Start Date:	10/01/2021
Planned Project End Date:	09/30/2024
Total Funding:	$750,000.00

Variability in bioenergy feedstock properties continues to be a primary challenge to integrated biorefineries achieving continuous operation and meeting the yield requirements necessary for commercial-scale production of biofuels and chemicals. The BFL is an important resource for understanding biomass variability; it provides a centralized location that is readily and easily accessible and understandable to bioenergy researchers and industry stakeholders. The objectives of this project include using the existing functionality already developed for the BFL to: (1) archive samples, metadata, and analytical data as necessary in a standardized way for BETO's FOAs and other BETO-funded projects; (2) develop sample and data management plans to provide policies for physical sample archival and disposal, data sharing, and pathways for eventual public release; (3) facilitate easy access to data and sample sets; and (4) maintain the BFL database through necessary software updates to ensure consistent access to samples, data, and results by bioenergy stakeholders. These objectives will be met through two tasks. Task 1 ensures that the samples and data generated through BETO's FOA projects are archived. Task 2 provides management and maintenance of the BFL samples, data, and database overall.



COMMENTS

- This is a very important initiative to collect, organize, and disseminate relevant feedstock information to meet BETO's overall goals. It looks like most of the users of the data/website are academics/national labs, with about 20% of users from industry. How can we get more industry participation? On Slide 11, are some of the tasks behind schedule?

- This is a good and useful project for a variety of audiences nationwide. DOE should continue to support this effort, which will benefit the national strategy on biomass for energy. The approach is good. In terms of P&O, the collaboration with the Bioeconomy Development Opportunity Zone Initiative was discussed. It is not clear how exactly the team associated the feedstock characteristics and quality variation with the Bioeconomy Development Opportunity Zone's regional, spatial, and temporal variability. As far as impact, this is a great project. More outreach may be needed to promote and disseminate the use of BFL.
- Computational modeling is important for conducting foundational analysis and forecasting the costs, availability, and characteristics of biomass feedstocks. The feedstocks are also expected to complement existing crop and livestock production systems. Projections need to support production goals for sustainable climate-smart systems. Modeling systems are necessary to predict feedstock variability, illuminate management options for risk mitigation, and understand feedstock fractionation, separation, sorting, and blending. This project is providing outstanding service to the biomass industry and is an essential resource for the pending circular bioeconomy. They have archived more than 60,000 biomass feedstock samples, of which over 30,000 have associated constituent data available for public use. This work has been well executed by INL and will have a significant impact for many years ahead.
- This is a very worthwhile and impactful project. The size of the data bank and its accessibility are to be commended. There is lots of important information on biomass variability that can help address questions about various aspects of biomass quality. The regionality aspect of the data is also very useful. The database has strong potential for use by academics/scientists. It is a good example of the impact of data synthesis to answer questions. The project has an extensive list of collaborators. In my opinion, the sample storage, while nice to have, is not as important as the characterization and database. Because samples are stored dry and may be kept for prolonged periods of time, they do not represent the biomass that a biorefinery would receive. Ideally, the greatest benefit of the samples would be for use in testing/designing for a biorefinery. Rachel did mention that the samples can provide a bridge for scientists from disciplines outside forestry to access biomass. This is an important use of the samples. As far as concerns, the characterization work may consider using the same procedures for at least a subset of the testing so that it is highly comparable. In the presentation, the pasted charts were very difficult to read, and there was too much information on each slide. This may not be the fault of the presenters, as they have a lot of information to present in a short time. Some thought should be given to the presentation format—maybe it could be more focused around the questions that reviewers are asked to evaluate.

PI RESPONSE TO REVIEWER COMMENTS

- We appreciate the reviewers' unanimous support of the BFL as a publicly available resource for bioenergy feedstock data and information. We agree with the reviewer's thoughts on the physical samples that are stored in the BFL. Many of the dried samples stored for prolonged periods in the BFL do not exactly represent the fresh or stored biomass a biorefinery might see; however, these samples can represent other types of chemical and physical variability that are useful to understand. The BFL has supported hundreds of requests for these physical samples. We will work on making the value of these physical samples clearer and better incorporating the additional data that is generated from meeting the requests for physical samples in the future. The reviewers noted that this project needs to continue focusing on outreach and dissemination strategies to engage with industry and build industry participation. We completely agree with this assessment. This project has a multifaceted dissemination strategy that we will continue to modify as necessary to increase the impact. Currently, this project publishes an end-of-year summary report highlighting the availability of samples, data, tools, and knowledge; has a yearly presence at industry-relevant conferences as part of INL's BFNUF; and is planning to have at least one webinar as part of the end-of-project milestone in FY24. The opportunity to present at events like BETO's Project Peer Review has also led to a noticeable increase in industry membership in the BFL. Additionally, the reviewers identified the need for modeling and projections using the BFL database resource. Although this project does not currently have the scope to develop these models, it does support other BETO projects, both at INL and other institutions, focusing on this type of work by providing relevant curated data sets. In FY23, projects including INL's Feedstock Supply Chain Analysis project (1.1.1.2) and ORNL's Supply Scenario Analysis project (1.1.1.3), which are responsible for the research supporting the *Billion-Ton Report*, were given large data sets representing variability in biomass characteristics to support various feedstock models. The continuous communication between modeling projects and the BFL team since the conception of the BFL has been important in generating and reinforcing the development of comparable data sets.

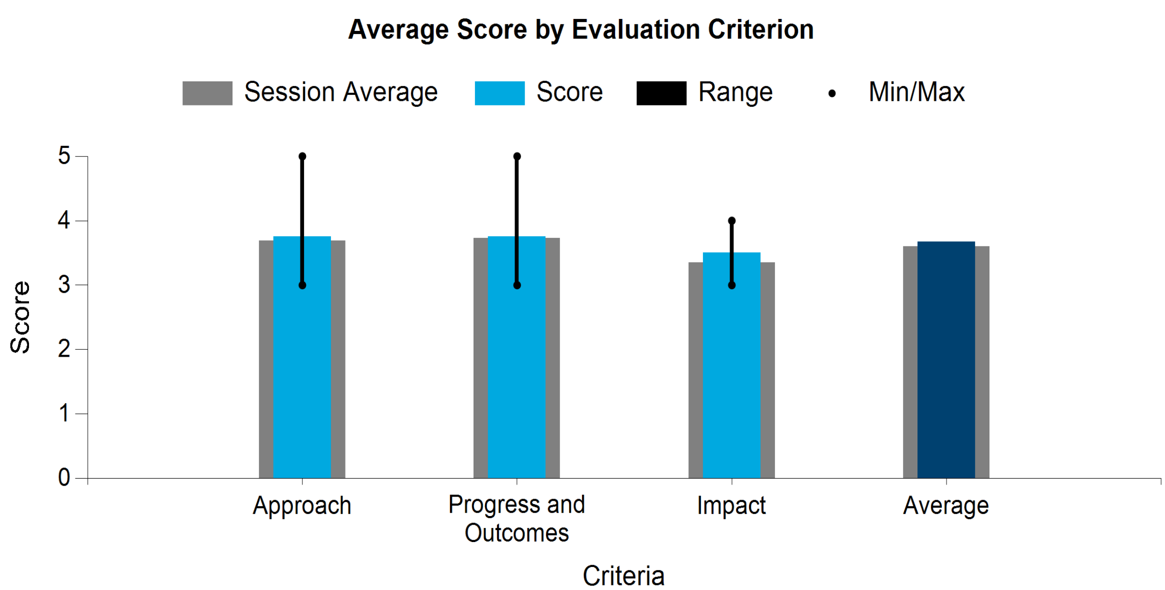
AI-ENABLED HYPERSPECTRAL IMAGING AUGMENTED WITH MULTI-SENSORY INFORMATION FOR RAPID/REAL-TIME ANALYSIS OF NON-RECYCLABLE HETEROGENOUS MSW FOR CONVERSION TO ENERGY

North Carolina State University

PROJECT DESCRIPTION

WBS:	1.2.2.203
Presenter(s):	Lokendra Pal
Project Start Date:	10/01/2021
Planned Project End Date:	12/31/2024
Total Funding:	$3,557,339.00

MSW is a potential low-cost abundant feedstock that can be used to produce fuels and products, but its heterogeneous nature causes significant hurdles that must be addressed for efficient valorization to fuel and products. We have proposed the use of AI-driven real-time characterization to enhance separation and preprocessing at different MSW facilities to enable efficient and economic valorization of MSW. Our project aims to tackle this valorization of MSW by building (1) an ML visual imaging model to conduct front-end discrimination of a broader classification of the materials based on shape and color, and (2) an ML hyperspectral imaging model to identify materials through being trained on specific material spectral signatures to obtain intelligently labeled hyperspectral images, augmented by multisensory information. We will present recent progress made in this project by demonstrating MSW identification and characterization, data gathering for hyperspectral imaging, visible camera ML models, and development of cloud-based data repository systems.



COMMENTS

- This is a good, solid project to better quantify the “quality” of a complex mixture in a typical municipal waste stream by using known analytical tools and metadata analysis with AI and imaging. The team is well qualified and has the required skill set and capabilities. The project seems to be on track, with about 25% completed. Would the proposed approach detect hazardous chemicals such as perfluoro compounds? There are other projects in the BETO portfolio addressing closely related areas. It isn’t clear if this effort is coordinated with those projects. Who is the ultimate customer? Would your approach lead to a certification-type outcome for a given downstream end use? What is the industry participation?

- This is a good project with sound approaches being used to achieve the project goals. In terms of approach, I agree that the preexisting availability of relevant data is a key challenge. What about the consistency of AI training data from different sources? Some loops need to be defined in the AI pipeline to improve the AI modeling process. As far as P&O, the project is making good progress with results. In terms of impact, I am curious how this project will be used in a real-world application. The future plan needs to be specific, especially on industry collaboration and engagement and scale-up of the system. LCA and TEA scope should be clearly defined with essential cost components.

- Land use change and competition with food production are often cited as concerns for lignocellulosic feedstock production. Development of NMSW as a feedstock is warranted because it does not compete with agriculture for food production, and because the use of NMSW will offset the flow of wastes into landfills and mitigate landfill methane emissions. Conversion of wastes into useful products and services is a basic aspect of circular economies. BETO has made significant investments into NMSW research, including the projects reviewed in this report. Some of the challenges of developing NMSW as an economic resource include (1) the extreme heterogeneity of NMSW, and (2) the presence of toxic and undesirable constituents. Therefore, BETO has made significant investments into NMSW characterization, sorting, blending, and milling to overcome these challenges. This project is using hyperspectral image analysis to develop an AI-enabled system for NMSW characterization. The team is composed of experts from North Carolina State University, the National Renewable Energy Laboratory (NREL), INL, IBM, and the town of Cary, North Carolina. Their primary progress has been on establishing data input, storage, and training for real-time analysis while materials are in motion on the conveyor. They have also had significant outreach accomplishments through a workshop, meeting presentations, publications, and a provisional patent disclosure.

- In terms of approach, there is a good focus on the characterization of NMSW. Effort is not wasted on material that can already be sorted and recycled. There is some emphasis on sharing the data set and models through the web platform. Not being in this field, I'm wondering who would want to use this data set. Is there a large demand for this type of data? On Slide 13, what about multilayer packaging—how is that optically different than some other paper grades (i.e., how will you detect that visually)? What about additives in the paper, i.e., chlorine or fluorine chemicals? Will it be possible to identify them? In terms of P&O, there has been much progress with this project. Over 80,000 images of waste have been collected. On Slide 10, what type of composition analysis will be done? The characterization should be aligned with the potential conversion process. I'm not sure what end use is intended in this case. As far as impact, for TEA and LCA, where will the start and end of the process go, and how will this work account for changes to an LCA for biofuel conversion? It's not clear how the results of this project can be incorporated. I would like to see more explanation about who the collaborators are and who the end user of the technology would be. Has a commercialization plan been developed that would take place after the pilot facility is successful?

PI RESPONSE TO REVIEWER COMMENTS

- Dear BETO and Peer Review panel members: Thank you very much for your time and effort in providing valuable comments from the Peer Review meeting for this project. We have carefully reviewed the comments and have added our responses below for major comments. We don't anticipate any impact on scope, schedule, or budget due to these comments.

- Comments: This is a good, solid project to better quantify the "quality" of a complex mixture in a typical municipal waste stream by using known analytical tools and metadata analysis with AI and imaging. The team is well qualified and has the required skill set and capabilities. The project seems to be on track, with about 25% completed. Would the proposed approach detect hazardous chemicals such as perfluoro compounds? There are other projects in the BETO portfolio addressing closely related areas. It isn't clear if this effort is coordinated with those projects. Who is the ultimate customer? Would your approach lead to a certification-type outcome for a given downstream end use? What is the industry participation?

- Response: Thank you for your comments. We agree with the reviewers that our project team has made significant progress toward meeting/exceeding the SOPO goals. HSI is a very adaptable technology that can detect hazardous chemicals, as documented in the literature. This feature played a significant role in the decision to utilize HSI for NMSW characterization, given its ability to detect a wide range of chemicals. However, perfluoro compound detection is not currently within the scope of this project. Our SOPO goals include a demonstration of the viability of identifying and characterizing major fractions of NMSW (i.e., paper and paperboard, plastics, food waste, textiles) with at least 50% accuracy at varying conveyor speeds. However, our system is scalable; we can incorporate additional data into our model to predict polyfluoroalkyl substances and other hazardous contamination. In addition, we are closely working with the DOE-BETO team to leverage other projects that are also focusing on NMSW spatial/temporal data collection, including polyfluoroalkyl substances and other hazardous contaminant issues, which could be combined with our system to tackle grand challenges of deeply characterizing the NMSW. Our ultimate customers are municipalities, waste management companies, dirty materials recycling facilities, materials recycling facilities, waste management companies, recyclers, biorefineries, equipment suppliers, technology developers, researchers, educators, etc. We envision these partners would be the primary users of this technology with the following immediate use cases:
    - Use case 1: Raw and labeled data sets available for research use
    - Use case 2: Raw and labeled data sets available for commercial use via licensing
    - Use case 3: Materials recycling facilities (MRFs) for improved detection and sorting
    - Use case 4: Conversion-ready feedstocks from nonrecyclable MSW for various industry segments.

  We plan to design various protocols, including new characterization techniques, homogenization/blending techniques, a raw and labeled data repository, ML models, and an end-to-end data and AI pipeline for system deployment. For example, we have developed a robust method for NMSW sampling, manual sorting, and imaging that could be leveraged as a standard across the waste industry. Our patent application focuses explicitly on the effective homogenization, densification, shipping, and storage of heterogeneous NMSW for accurate analysis of relevant chemical, compositional, and thermal characterization, and conversion to appropriate biofuels and bioproducts. This approach could allow for certification, as suggested by the reviewers. We have many industry partners, including one of the largest recycling facilities, which is a 15-minute drive from our North Carolina State campus. They have expressed a strong interest in our technology, as they would like to further automate their operations and enhance the quality of their final outputs. We are sampling their residual materials that are destined for landfill. Further, we are working directly with a municipality that continues to provide us NMSW samples. Finally, we have identified strategic partners for each waste stream, each of whom plan to evaluate the feasibility of the application of our technology. We will continue to engage them and others to promote our technology, and we can see a path to potential implementation. Our team will disseminate technology advancements through publications in peer-reviewed journals, conference presentations, and publications within the open-source environment. Public release of IP will only occur after the property is appropriately protected. Along with the IP from the deep learning portion of this project, the optimized wavelength for characterizing the MSW will be supplied to a hyperspectral camera manufactured in addition to the AI system.

- Comments: This is a good project with sound approaches being used to achieve the project goals. In terms of approach, I agree that the preexisting availability of relevant data is a key challenge. What about the consistency of AI training data from different sources? Some loops need to be defined in the AI pipeline to improve the AI modeling process. As far as P&O, the project is making good progress with results. In terms of impact, I am curious how this project will be used in a real-world application. The future plan needs to be specific, especially on industry collaboration and engagement and scale-up of the system. LCA and TEA scope should be clearly defined with essential cost components.

  Response: We agree with the review panel that data consistency is an important consideration when using AI for meaningful data interpretation, especially when training data is obtained from different sources. During the presentation, we mentioned that data sets are available for visual recognition of clean MSW, which can serve as training data for ML models in MSW object characterization. These images can be utilized alongside the data being collected as a part of our project. Basic object labeling is adequate for training ML models; however, the principal challenge lies in accurately labeling the data with relevant metadata, such as physical characteristics, process parameters, and radiometric information. Given the novelty of this research area, there is currently no universally established data labeling protocol. Therefore, part of our work aims to establish a comprehensive labeling protocol. This is crucial because the characteristics of NMSW are specific to each region, and for potential global deployment of this work, the existing ML models will need to be expanded and enhanced. Similar issues exist with existing HSI data sets; for example, there are companies working on HSI ML models for specific material within the MSW, but they are not consistent in their metadata. Therefore, we are developing a universal labeling protocol for HSI, visible color imagery, and other sensory data, which will be of universal value and appeal. This is an ancillary benefit from the execution of the current effort. Further, as discussed during the Peer Review meeting, our ML models will be updated with a primary focus on continuous improvement in a loop as we expand our database for scaling to industry standards. Our AI and data pipeline approach includes these circular steps: (1) data connections, (2) data preparation, (3) algorithm selection, (4) training infrastructure, (5) model deployment, and (6) continuous improvement. We envision the four immediate use cases listed above. As stated earlier, we have a robust plan for industry collaboration and engagement, with the implicit end goal being the final scale-up of the system. We have also clearly defined the LCA and TEA scope with essential cost components as we develop various use cases for this technology. For TEA/LCA, our baseline process includes the current practice of hauling the nonrecyclable (residual) MSW (NMSW) to landfill sites by trucks. The purpose of the TEA/LCA modeling is to clearly understand the valorization pathways of waste in the bioenergy relative to landfilling the waste in order to guide our research and process optimization. Biomass sources that need waste management, such as NMSW, have the highest potential for economic profitability and CO_2e emission reductions.

- Comments: In terms of approach, there is a good focus on the characterization of NMSW. Effort is not wasted on material that can already be sorted and recycled. There is some emphasis on sharing the data set and models through the web platform. Not being in this field, I'm wondering who would want to use this data set. Is there a large demand for this type of data? On Slide 13, what about multilayer packaging—how is that optically different than some other paper grades (i.e., how will you detect that visually)? What about additives in the paper, i.e., chlorine or fluorine chemicals? Will it be possible to identify them? In terms of P&O, there has been much progress with this project. Over 80,000 images of waste have been collected. On Slide 10, what type of composition analysis will be done? The characterization should be aligned with the potential conversion process. I'm not sure what end use is intended in this case. As far as impact, for TEA and LCA, where will the start and end of the process go, and how will this work account for changes to an LCA for biofuel conversion? It's not clear how the results of this project can be incorporated. I would like to see more explanation about who the collaborators are and who the end user of the technology would be. Has a commercialization plan been developed that would take place after the pilot facility is successful?

- Response: To tackle the grand challenge of valorization of NMSW, the development of a raw, labeled, and cleaned data set is critical for ML models to meet specific use cases, as described earlier. Further scalability of the data repository is important to continue in order to account for major input changes in materials composition, as NMSW is extremely heterogeneous. This is especially true as new product development continues. There is thus a real and significant demand for this type of data from municipalities, waste management companies, industry, equipment manufacturers, and many other stakeholders we have contacted. The HSI system does not have a deep penetrating depth and would have difficulty providing such detection if the object were multilayer packaging. Because of the limited ability to penetrate deeply into an object, we have coupled the system with an optical system that will have the ability to distinguish between multilayer packaging and other paper grades. As previously mentioned, HSI can detect hazardous chemicals, as has already been demonstrated in many publications. This feature played a significant role in the decision to utilize HSI for NMSW characterization, given its ability to detect an extensive range of chemicals. Based on our progress to date and the SOPO goals, we are now conducting the following analyses: (1) physical (proximate) analysis—moisture, density, total solids, ash content, chloride content, particle size distribution, etc.; (2) chemical (ultimate) analysis—elemental analysis (C, H, O, N, S, C/N ratio), Fourier-transform infrared spectroscopy; (3) compositional analysis—cellulose, hemicellulose, lignin, extractives, etc.; and 4) calorimetry—energy content/calorific values. We are targeting paper and board fractions/subclasses using existing conversion pathways such as mild mechanical/alkali pretreatments and enzymatic hydrolysis/catalytic upgrading to biofuels such as SAF, guided by TEA/LCA. Our simulation results will provide detailed process economics, material requirements (chemicals, water, etc.), and energy balances for a complete process under optimal conditions. Sensitivity analysis will be performed by varying the amount of usable major fractions, providing an estimate of potential benefits from residual MSW recovery. The TEA/LCA results will be used primarily to prioritize the characterization of specific materials based on their intrinsic economic benefits. For example, within paper and paperboard, how does fractionating corrugated only versus other paper products affect the global economics? The primary LCA input parameters that will be investigated will be characterization and separation efficiency, because these are critical measures of the success of our system. Additional exogenous input parameters will also be investigated to explore how they affect the potential performance of the system (e.g., waste composition, moisture content, carbon content, landfill, and anaerobic digestion operating parameters). Additional parametric sensitivity analyses will be performed on the most important input parameters to get a better evaluation of the direct relationship between the input and outputs. We have a diverse team of collaborators from academia (North Carolina State University), a national lab (NREL), industry (IBM), and a municipal corporation (the town of Cary) working hand-in-hand to develop this technology. Further, we have many potential commercialization partners, including one of the largest recycling facilities, which is a 15-minute drive from our North Carolina State campus. They have expressed a strong interest in our technology, as they would like to further automate their operations and enhance the quality of their final outputs. Additionally, we have identified strategic partners for each waste stream (paper, plastics, and food) to evaluate our technology. We will continue to engage them and other potential commercialization partners to promote it while ensuring compliance with the overall scope of our project.

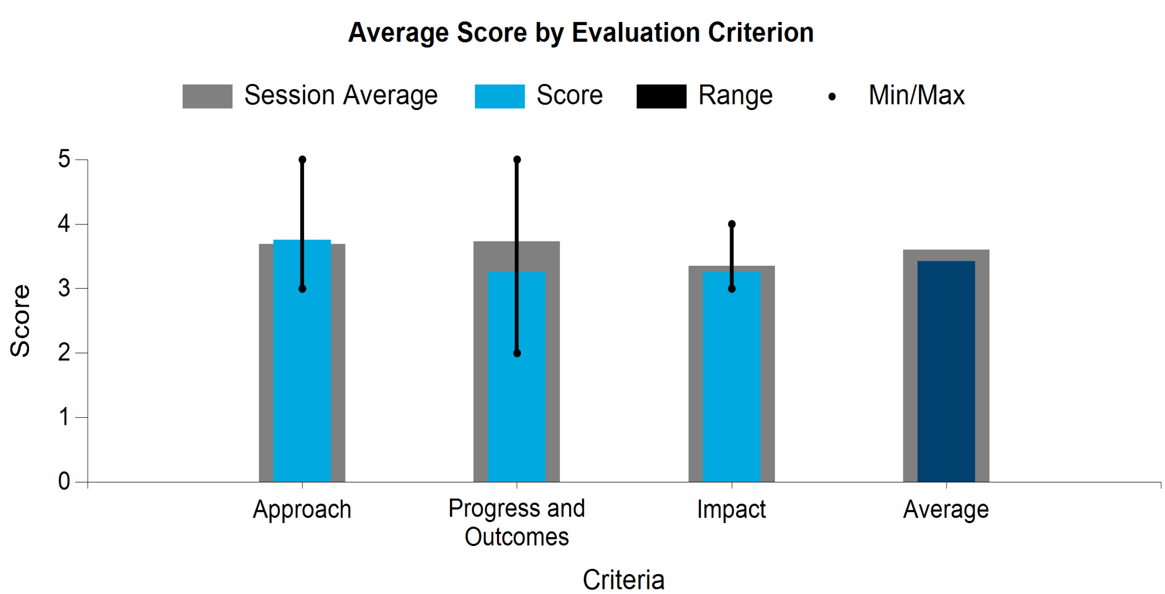
INTEGRATED LIBS-RAMAN-AI SYSTEM FOR REAL-TIME, IN-SITU CHEMICAL ANALYSIS OF MSW STREAMS

Lehigh University

PROJECT DESCRIPTION

WBS:	1.2.2.204
Presenter(s):	Zheng Yao
Project Start Date:	10/01/2021
Planned Project End Date:	01/31/2025
Total Funding:	$3,513,104.00

The overall goal of this project is to demonstrate a leap in developing measurement technology for application in MSW operation, particularly in the characterization of feedstock entering a biofuel reactor that would otherwise be going to a landfill. The end-of-project goal is to improve the throughput of the characterization technology, with a minimum target of 25% improvement over the baseline characterization technology. The proposed technology will allow rapid, in situ characterization of feedstock, providing critical characterization data in minutes for continuous confirmation of feedstock specifications and potential feed-forward process control of downstream biofuel production processes. This represents a hundredfold improvement over current methods of grab sampling, compositing, and costly laboratory analyses that, at a minimum, take several hours to obtain results at a cost of more than a thousand dollars per sampling event. This project targets overcoming challenges associated with packaging laser-induced breakdown spectroscopy (LIBS) and Raman spectroscopy together with AI/ML algorithms into a functional prototype for deployment and demonstration at a gasification process development unit. The project has been able to gather actual refuse-derived fuel, and it is in the process of conducting laboratory testing of material samples under static conditions, while meeting targets for measurement accuracy and precision.



COMMENTS

- The project objectives and approaches are sound and have many similarities to other BETO-funded projects in this area. It is not clear how well and closely these are coordinated. The team is very strong and has the needed skill sets, capabilities, and track record. The project has industrial participation. The project is in the second year of funding. It is not clear what has been accomplished against the milestones and the forward path for Year 3. It would be useful to have a slide showing this information clearly. Slide 7 has details and is not clearly explained. One of the deliverables is an improvement in the overall reliability of waste quality by >25% from the baseline. It isn't quite clear what this means from a practical implementation perspective. It would be better to have a minimum quality needed for gasification at TRL and judge the progress against this metric. Who is the customer for the product from the project at the end of Year 3? What is the expected TRL?

- In terms of approach, the perceived risks and associated mitigation strategies could be further improved. In terms of P&O, the project is making good progress. The development of new algorithms needs to be specific to compare and evaluate them. As far as impact, the presenter said that the project is close to downstream gasification, with TRL 2 to TRL 6. Therefore, its commercialization potential and details on the work plan with Energy Research Company need to be discussed and provided in the upcoming review.

- Land use change and competition with food production are often cited as concerns for lignocellulosic feedstock production. Development of NMSW as a feedstock is warranted because it does not compete with agriculture for food production, and because the use of NMSW will offset the flow of wastes into landfills and mitigate landfill methane emissions. Conversion of wastes into useful products and services is a basic aspect of circular economies. BETO has made significant investments into NMSW research, including the projects reviewed in this report. Some of the challenges of developing NMSW as an economic resource include (1) the extreme heterogeneity of NMSW, and (2) the presence of toxic and undesirable constituents. Therefore, BETO has made significant investments into NMSW characterization, sorting, blending, and milling to overcome these challenges. The other NMSW projects are focused on characterization and sorting at early stages of feedstock preprocessing. This project is developing an AI-enabled system for feedstock characterization immediately before entrainment into the gasifier. The team is using LIBS and Raman spectroscopy, both of which are appropriate for this work. This approach will conduct a chemical constituent analysis rather than looking at NMSW constituent types. The work is on track and is expected to be impactful. They expect a CapEx of $300,000–$500,000 for the system, which seems to be affordable.

- The approach is novel compared to other sensor technologies in that the sensors are positioned downstream, near the gasifier. The real-time data is intended for use in feed-forward process control and has the potential to significantly impact process efficiency. I appreciate the inclusion of the personnel and their roles in the project on page 5. In terms of P&O, good progress has been made. The combination of Raman spectroscopy and LIBS is very useful for characterizing some of the more fundamental chemical properties of the MSW. Comprehensive characterization is proposed, which will cover many applications. The AI model will allow for the identification of important chemical characteristics of variable materials. The aim is to eliminate the cost of sampling/compositing and lab analysis. However, I would expect that sensors would need calibration/verification on a continuing basis. In terms of impact, the team provided a clear evaluation of the value of this technology through operational and maintenance cost reductions yielding a 1-year payback on the instrument cost. The partnership with Covanta is excellent for making sure this will work and make sense in an industrial setting with MSW. This also provides a great opportunity for commercialization. Also, the partnership with ThermoChem Recovery International (TRI) is very helpful for understanding gasification requirements. Both organizations have widespread expertise in their fields.

PI RESPONSE TO REVIEWER COMMENTS

- Response to Comment 1: A slide with an updated report on the milestones has been included in a PowerPoint file uploaded in response to the Project Review comments. Slide 7 has been expanded to clarify it, as well as to explain the 25% improvement deliverable. Slide 7 is included in the uploaded PowerPoint file. TRI participates in the project as the customer for its process development unit. Potential customers of the technology include gasifier designers and operators, waste-to-energy plant operators, and operators of coal refuse circulating fluidized bed boilers. The expected TRL at the end of the project will be 6–7.
- Response to Comment 2: An updated list of risks and mitigation strategies has been included in the uploaded PowerPoint file. Progress on new algorithms is being reported with more detail in quarterly reports. Energy Research Company's LIBS instrument has an advanced TRL of at least 6. It has been used in multiple industrial applications. The commercialization potential for its use, coupled with Lehigh's AI and the National Energy Technology Laboratory's Raman instrument, is quite high, as it will have a payback of well under one year. This is based on its ability to optimize the gasification process. Specifically, it will reduce the oxygen use to its minimum value and increase the hydrogen or syngas production and its heating value.
- Response to Comment 3: No responses were required.
- Response to Comment 4: Concerning the calibration/verification on a continuing basis: That is correct. The instrument will first need to be calibrated, or, in terms of AI, will need to be trained. This is a requirement shared by all instruments if accurate quantitative results are required. The approach is straightforward. Samples of the MSW, in the form used by the customer, will be sent to a lab for analysis. The instrument will provide spectral data from these samples, which will then be processed by the AI models, along with the lab results, for its training. It is important that as wide a range of MSW properties as possible be provided in the customer's MSW feedstock. After the initial training, the instrument will need to be periodically drift corrected. This is still being considered by the team, and will likely entail periodically taking MSW samples, sending them to a lab, and then modifying the AI models.

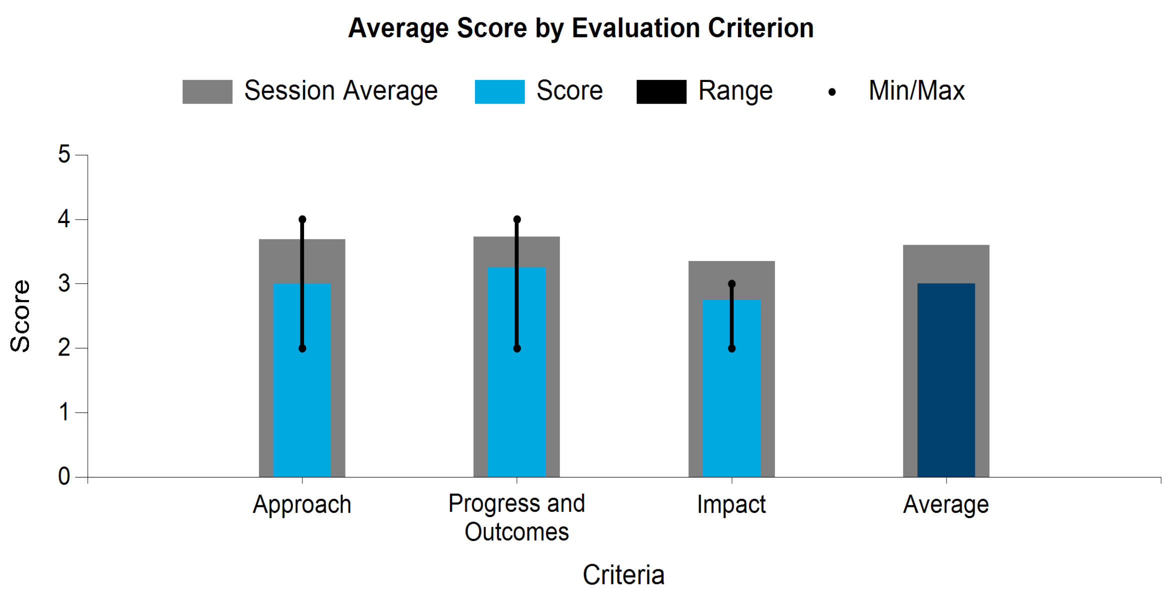
ADVANCING FOREST BIOREFINERIES TOWARDS COMMERCIAL APPLICATIONS THROUGH FRACTIONATION OF BIOMASS WASTES

Idaho National Laboratory

WBS:	1.2.2.3
Presenter(s):	Luke Williams
Project Start Date:	01/04/2022
Planned Project End Date:	12/31/2024
Total Funding:	$3,000,000.00

PROJECT DESCRIPTION

Currently, a significant number of pulp and paper mills in Maine are idle or underutilized, and these brownfield facilities could contribute to SAF production. Researchers from the Forest Bioproducts Research Institute at the University of Maine (UMaine) have been working to develop technologies to use these underutilized infrastructures, leading to the development of the thermal deoxygenation (TDO) pathway/technology to convert the cellulose fraction of woody feedstocks to fuels and chemicals. Technical R&D has progressed from market pulp as an ideal feedstock in the Biomass to Bioproducts Pilot Plant to more difficult feedstocks like sawmill residues (sawdust) and forest residues. These new woody feedstocks are presenting challenges due to the physical and compositional material attributes of these waste biomass sources. This project aims to identify the feedstock CMAs for the operational and yield performance of the TDO process and to quantify acceptable limits. Preprocessing strategies will be developed to meet these feedstock CMAs, utilizing the wide range of preprocessing equipment available in the BFNUF at INL. This project will determine the physical and compositional CMAs for the TDO process while also helping define optimal pilot plant operational parameters for improved reliability.



COMMENTS

- The project is primarily focused on improving flow, handling, and processing of woody biomass feedstock for conversion into fuel and chemicals in a TDO unit at UMaine. The approach outlined focuses on particle size, moisture, and grinding of woody biomass to produce a more uniform feedstock for subsequent treatment in a TDO unit. The experimental work is supported by modeling and data analytics. To date, the project has shown some encouraging results and seems to have met the interim milestone. The team is experienced in the technical aspects of the project tasks. The level of potential commercial partner engagement is not clear. What is the current TRL, and what is the projected TRL at the end of the project? Risks and their mitigations are discussed on Slides 10–12. It looks like there are some significant issues related to access of proprietary design data needed for planned activities that may lead to dropping (?) this task. I'm not sure what the impact of such a change would be on the overall outcome of the project. Also, there seem to be some staffing issues. The impact of this is not clear. It would be helpful to have a clear chart showing the expected outcomes, status, etc. in light of these issues. The project needs to have a credible partner and commercialization path. It appears that interaction with potential partners is limited. I recommend that this be given a high priority. The team should work closely with potential customer(s) of the product resulting from the project. Levulinic acid is one of the products targeted in the project. It isn't clear what the market justification for this is. To date, various attempts to commercialize levulinic acid have not been successful. It would be helpful to share some of the successful outcomes of the TDO technology in the field.

- This is a good project. It is not clear if it is an integrated pilot project of INL's pilot and UMaine's pilot plants. I am curious if this integration is the best for future commercialization. In terms of P&O, for char produced from the Biomass to Bioproducts Pilot Plant as a coproduct, it will be good to consider its potential application for future analysis. As far as impact, the pilots are the focus at this point. How far is it for this project to be commercialized with an industry partner?

- BETO investments in feedstock pretreatment are important for optimization of the use of off-spec materials, stabilization during storage, and preparation for conversion processes toward specific products such as SAFs, composite materials, or high-value chemicals. Maine has a successful history in wood product manufacturing and the pulp and paper sector. With the decline of the pulp and paper sector, however, many businesses have ceased operations. The state hosts many underutilized assets in this sector, driving interest in converting these plants for chemical production instead of paper production. This project team includes experts from UMaine, NREL, and the INL BFNUF. They are working to better characterize available feedstocks, reduce C5 sugars, improve the pathway, and reduce char formation. This project is in early stages of implementation and seems to be on track.

- In terms of approach, although this is a nice, detailed study of specific equipment for a specific purpose, it lacks broad application for biorefinery. I am not confident that the information developed within this project will get widespread use in the industry. The aim of uniform delivery of woody wastes is a huge problem and should be looked at, but I don't feel this project has the scope to solve the problem. When defining the contributors on Slide 6, it would be beneficial to identify their roles in the project. I don't see any industrial partners/equipment manufacturers on the collaborator list. Being limited by the IP rights of manufacturers really limits the project's ability to provide meaningful information on specific equipment. In terms of P&O, the progress of the project as designed seems to be on time and appropriate. I'm not sure about the applicability of the particles selected for the screw feeder. Are they a size commonly used by industry now? As far as impact, the project has limited impact for industrial applicability (see approach). The specific customer who could use the project outcomes should be clearly specified.

PI RESPONSE TO REVIEWER COMMENTS

- The overarching goal of this project is to define and meet the physical and chemical CMAs (particle size distribution, aspect ratio, and chemical composition) for biochemical conversion of waste woody biomass to levulinic acid. Biofine Developments Northeast is our commercial partner, and they are planning to build a commercial facility in Lincoln, Maine, to produce levulinic acid and ethyl levulinate from waste woody biomass. We expect that the ongoing project will address processing at the commercial scale with the conversion of waste woody biomass to levulinic acid at the commercial scale by successfully establishing physical and chemical CMAs for the waste woody biomass. As far as limitations/risks, the risks mentioned in the slides around equipment information and personnel have already been overcome by switching the flow system that is being addressed with fundamental models from the progressive cavity pump at Maine that was proprietary to the compression screw feeder at INL. Staff acquisition occurred on time, in part due to the offset start date for the project, and was also accomplished in a way that drastically increased the diversity on the project. Additionally, the limitation of obtaining proprietary information about the pumps will be addressed in the future by (1) experimentally measuring the flow patterns at the pilot scale, (2) exploring a relationship with another pump manufacturer, and (3) investigating smaller-scale pumps designated for research purposes. In terms of broader impacts, the current project findings are also applicable to any biorefinery pretreatment process that employs low-viscosity organic solvents and requires a woody biomass particle size of less than 10 millimeters. The following future work proposed in the new AOP will further broaden the application for biorefineries: (1) establish the physical and chemical CMAs for corn stover, switchgrass, and the biogenic fraction of MSWs; (2) determine the synergistic effects of blending various biomass feedstocks (e.g., corn stover and forest residues) on the performance of biochemical conversion; and (3) upgrade preprocessing rejects from different biomass feedstocks to biocomposites. Additionally, the pilot plants at INL and UMaine are not fully integrated, which leads to added steps around material handoff between the two facilities. This is being addressed with cold flow tests on identical feedstocks. In future research, we intend to look at feedstocks beyond woody material from the Northeast to broaden the applicability of feed handling knowledge to multiple geographic locations.

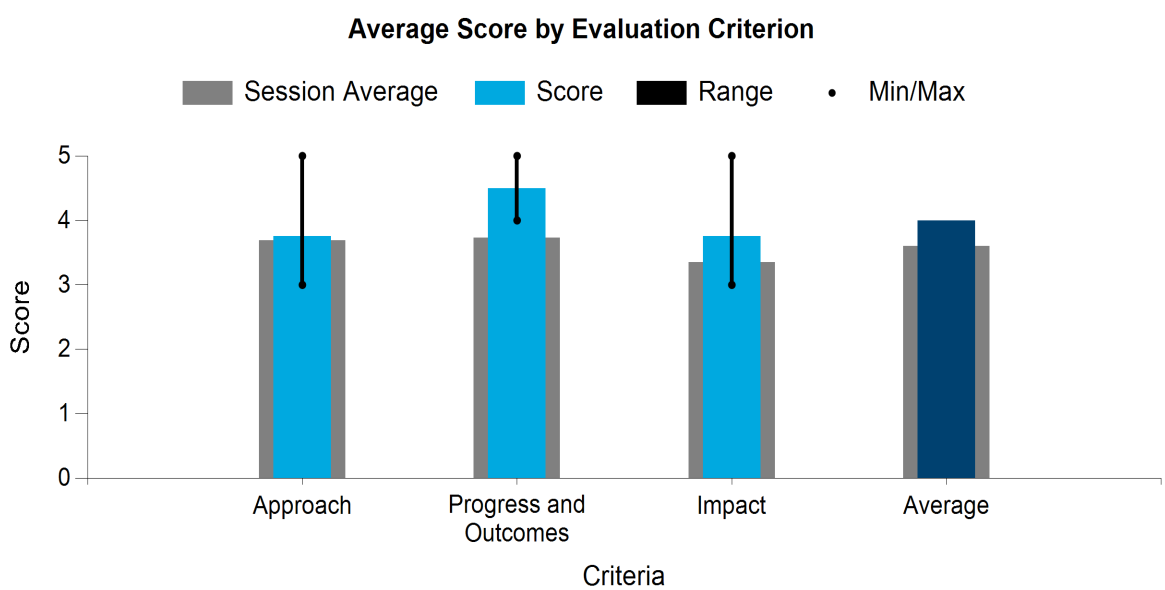
ROADS TO REMOVAL

Lawrence Livermore National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.2.302
Presenter(s):	Roger Aines
Project Start Date:	09/01/2021
Planned Project End Date:	09/01/2023
Total Funding:	$1,000,000.00

Our team is conducting the first economy-wide technical evaluation of CO_2 removal options for achieving net zero by 2050. We are evaluating feasibility, performance, and costs with county level resolution in the United States, considering all well-developed removal methods. We have identified methodology and system boundaries for: forest sequestration, soil sequestration, direct air capture and storage, and biomass carbon removal and storage (BiCRS), and are also evaluating geologic storage, resource availability, and environmental justice. Our initial findings show: (1) improved forest management practices like reducing stocking densities in high fire risk areas and lengthening rotations can increase forest C stocks and decrease forest C emissions. (2) Soil C storage can be increased most effectively by increasing the amount of year-round plant cover and root inputs. Converting low productivity corn/soy cropland to C-crops could lead to soil C increases on the order of 10-20 Mt CO_2 y-1. (3) Much of the United States has geologic storage availability, however some areas will require transport to adjacent areas. (4) We have developed in-depth TEA for 16 unique BiCRS pathways with TRL>8 and integrated these into a model for facility spatial optimization. Our analysis suggests BiCRS has capacity for 0.5 Gt CO_2/yr removals using multiple conversion technologies. (5) Priority regions for direct air capture must have both geologic storage and land for renewable energy.



COMMENTS

- This is a very strong team that has a well-laid-out approach with milestones. The metrics for deployment are not clear. It also isn't clear how much interaction has occurred with end users/commercial entities. On Slide 9, various approaches for mitigation are shown, the highest being converting to electricity followed by H_2 production. It would be helpful to estimate/project the probability for each outcome given the current state of technologies/deployment/TEA, etc.

- In terms of approach, "bioenergy carbon capture and storage" is a commonly used term. The project uses "biomass with carbon removal and storage" (BiCRS). The team needs to describe the difference between these two terms. We also need more details on the improved forest management used in the project, such as management plans and outcomes, especially on plantation, pulpwood, and mass timber production. In terms of P&O, the project needs to provide a little in-depth discussion on progress and outcomes in the next review. As far as impact, we need more details on economic assessments of the five pathways for carbon capture with sensitivity analysis. CO_2 reutilization should be considered. Logging residue for BiCRS in the Northeast should be further discussed.

- Lignocellulosic feedstocks are gaining greater interest as a mechanism to fix atmospheric CO_2 to drive carbon sequestration in natural systems. The decades of bioenergy feedstock production research are foundational to catalyzing current research on atmospheric CO_2 removal, especially if lignocellulosic resources are to serve multiple purposes. This project is very extensive and includes a comparative analysis of five CO_2 removal systems: forests, agricultural soils, BiCRS, direct air capture, and geologic storage. The team is developing a geospatial model, and publication of results is forthcoming, with the intended primary use being a policy development resource. This project has a strong environmental justice component; however, the project is encouraged to also consider transition periods in their timelines.

- This is a very comprehensive high-level project (WOW). It provides important national and regional information on CO_2 removal capacity and costs. This is an important project to better understand the potential of the various mechanisms for CO_2 removal. In terms of approach, the project has a diverse group of collaborators representing the whole nation. Even though the project dealt with five very different CO_2 removal strategies, it appeared that the team had a solid grasp of each. Implications for climate change and other future predictions were not mentioned. These might be significant, as the time frame for CO_2 removal is 2050. As far as P&O, the project end date is quickly approaching, and it appears that the project is on track for successful completion. A lot was accomplished in a short time. The project provided efficient and meaningful information. In terms of impact, the presentation noted that "each region has a story and opportunity"—practical information may be ascertained from this study! The county-by-county assessment brought high-level thinking to the level where it can impact the planning and implementation of some of the relevant strategies.

PI RESPONSE TO REVIEWER COMMENTS

- Comment 1: We appreciate the positive and constructive comments provided by our BETO peer reviewers. With regards to our engagement with "end users," our stated goal for our national carbon dioxide removal assessment was to remain entirely neutral and only engage with industry within limits. The technologies we are assessing are only those where there are "no miracles required"—meaning sufficient evidence of efficacy and broad-scale applicability was available to us as of March 2022. That said, the cost curves we are generating are real and reflect the investment we estimate will be needed in new approaches and technologies. We expect that there will always be unforeseen hurdles to carbon dioxide removal implementation, but we are looking at close-to-commercialization approaches.

- Comment 2: Our group coined (and published) the term "BiCRS" a couple of years ago with our *Getting to Neutral* report, and we feel it is more comprehensive than "bioenergy carbon capture and storage." For BiCRS, the biomass feedstock need not be purpose grown—indeed, in many cases it is literally garbage. Regarding improved forest management, we are certainly assessing specific silvicultural practices and appropriate practices for each of our regional case studies. We do not think that CO_2 reutilization (to fuel) is a type of true removal, and thus we consider it out of scope. If processes can lead to syngas, we would count the financial benefit. However, most CO_2 utilization avenues are not going to result in true CO_2 removals.

- Comment 3: We agree that transition periods are an important element of our national road to removing CO_2 from the atmosphere at scale. However, although timing is certainly important, assessing it was not part of our original mandate, and we feel that an analysis for transition timing would be out of scope. For example, although we are assessing impacts on jobs, we are not forecasting job losses and gains that would involve ramp-up for hiring.
- Comment 4: Regarding how we are considering implications for climate change, we are basing our projections on crop yields in light of climate change. Direct air capture also includes climate shifts, although it is a relatively small factor. For forestry, we are not including CO_2 fertilization effects in our assessment. However, many things that affect forests are projected to get worse (drought, fire, insects), so, while these are not forecastable in a meaningful way, we are assessing the management practices that are needed to deal with them. For soils, our team is including an uncertainty analysis from five different climate projections, because climate change is likely to change projected crop yields, which affects costs. We also have an analysis of transition periods (e.g., 2025 versus 2045).

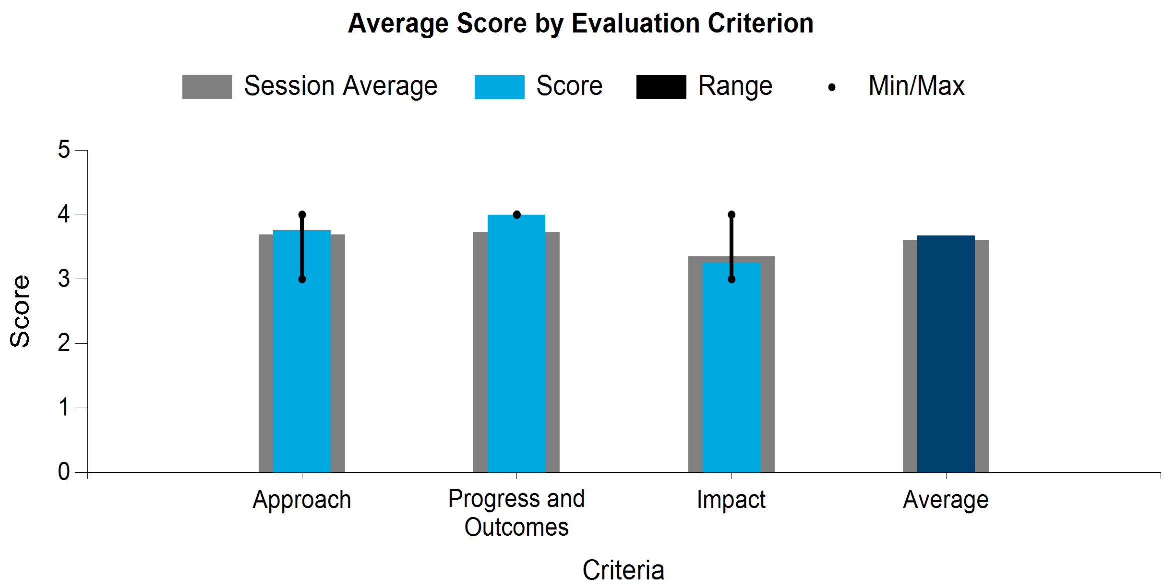
POLYMER PRODUCTS FROM LIGNIN THROUGH DE-AROMATIZATION AND COOH FUNCTIONALIZATION

University of South Carolina

PROJECT DESCRIPTION

WBS:	1.2.3.109
Presenter(s):	Michael Kent
Project Start Date:	10/01/2019
Planned Project End Date:	08/31/2024
Total Funding:	$1,129,722.00

The project focuses on a new method to convert lignin into valuable products. Currently, in the biofuels industry, lignin is burned for heating and therefore has a low economic value. We use a room-temperature oxidative process to open the aromatic rings within the lignin structure and generate a polymeric polyacid material that functions as a commercial agricultural dispersant, micronutrient complexation agent, or water-absorbent material. This project is a collaboration between Ingevity Corporation, the University of South Carolina, and Sandia National Laboratories.



COMMENTS

- This is a very challenging and potentially impactful project to valorize the ubiquitous low-cost supply of lignin. The proposed chemical modification schemes are fairly well known and are practiced to some degree in the industry. Working with an industry partner—Ingevity—to get product performance and cost requirements is a plus. The team has the needed chemical synthesis and characterization/formulation skills to carry out the proposed tasks and deliverables. The project seems to be on track. Some questions: Modified lignin-based formulations that have met the performance requirements seem to have the required cost limit. Does this estimate include the final, fully loaded manufactured cost for the product? Are there any details on the manufacturing process/CapEx/OpEx, etc.? For the hydrogel applications, it looks like the lignin-based carboxy compounds are blended with standard polyacrylic acid (PAA) and polyacrylamide (PAM) hydrogels. What is the swelling ratio of the pure polyacrylic acid (PAA/PAM) hydrogels, and what is it with various levels of the lignin compounds? What is the glass transition temperature (Tg) of the lignin compounds that have shown good swelling? Typically, higher-Tg polymers show lower swelling. Has there been any feedback from Ingevity?

- In terms of approach, more details are needed to explain how related tasks can be implemented. Who will do the field trials for hydrogels? Will it be at lab scale? In terms of P&O, the project is making progress. However, more explanations on the P&O will be needed for the coming year's reporting. Soil type should be considered if hydrogels are applied for soil amendment. The unit cost of hydrogels and the potential mix ratios with biochar need to be clearly addressed with cost/benefit analysis. In terms of impact, some kind of commercialization plan with industry should be addressed.

- BETO investments in feedstock pretreatment are important for optimization of the use of off-spec materials, stabilization during storage, and preparation for conversion processes toward specific products such as SAFs, composite materials, or high-value chemicals. This project focusses on the conversion of lignin to polymers that can be used for chemical dispersants, water purification, hydrogels, and delivery of nutrients in cropping systems. The team evaluated several approaches to cleaving aromatic rings and achieving stabilization via carboxylation. They have conducted informative TEAs on the various approaches and have chosen to emphasize further development of hydrogels for delivery of biochar onto agricultural soils. Field trials will begin in 2023. They have an industry partner to help further develop the products. Two papers have been published thus far.

- A more holistic approach taken by BETO is to be commended. The utilization of byproducts from energy utilization of biomass is important for the economic viability of all biorefinery processes. Lignin, as many know, has a lot of potential and may one day be readily available in the marketplace. Currently, it comes from pulp mills, but it could potentially be generated at a bioethanol refinery. In terms of approach, the team is small but seems to be highly focused. Intimate involvement with Ingevity has its pluses and minuses. They will be focused on current market demand (which is positive) but may miss important opportunities that have longer-term benefits. It may be a concern that Ingevity performs TEA for all samples—there may be some bias. In terms of P&O, lignin use for these applications shows promise. The TEA is not very clear. It produces the metric of $1.5/pound. I would like to see more detail on what is contributing to the TEA. Is this at lab scale, pilot scale, or full scale? As far as impact, this is a product development project that has clear market viability. Product development at the lab scale is demonstrated, but I found details of the TEA lacking and therefore not clear in terms of the viability. The project's success will depend solely on Ingevity commercializing the products, which are high risk. The IP will most likely belong to Ingevity, which limits its accessibility.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the review panel for their constructive feedback and positive comments on the Polymer Products From Lignin project. The TEA was performed by Ingevity to generate the dollars/pound values and included the final fully loaded manufactured cost for the product. The estimates are based on an OpEx model using existing facilities. The lignin hydrogels were generated by reacting oxidized lignins with PAM (not PAA), and the reaction scheme is reported in a publication and also included in one of the supporting slides. We appreciate the panel's question about the swelling ratio of the pure PAM hydrogels compared with that of the lignin-based hydrogels. That is one of the milestones for Budget Period 3. Regarding the Tg for the lignin compounds that have shown good swelling in water, we have not measured the Tg, but we expect it to be low. We note that the lignin is heavily oxidized prior to cross-linking. Although lignins have a range of Tg, it is not considered a performance metric for lignin derivatives used for dispersant applications. Regarding field trials for hydrogels, we apologize if this was not clear in the presentation, but field trials with hydrogels are beyond the scope of the current project. The current project will include measurement of the hydraulic properties of soils mixed with hydrogels as well as the biodegradability of the lignin-derived hydrogels. A follow-on proposal has been submitted to the "Reducing Agricultural Carbon Intensity and Protecting Algal Crops" FOA to perform field trials with lignin-derived hydrogels mixed with biochars. That proposal addresses soil types common in the

Southwest United States, includes a commercialization plan, and involves the agriculture department at New Mexico State University and BioChar Solutions Inc. Regarding the TEA, Ingevity uses the same model for all the samples in this project. Thus, the results can be used for benchmarking with existing product controls. Regarding the review panel's request for more information on the TEA, this is proprietary information that must be protected. We note that the work done within this project was performed at lab scale. Regarding IP, the process for oxidizing lignin and the method for cross-linking oxidized lignin were covered under IP filed prior to this project. Any IP related to formulations developed by Ingevity that include oxidized lignins will be owned by Ingevity.