FEEDSTOCK TECHNOLOGIES PROGRAM

TECHNOLOGY AREA

CONTENTS

INTRODUCTION

The Feedstock Technologies (FT) program is one of 12 technology areas that were reviewed during the 2021 Bioenergy Technologies Office (BETO) Project Peer Review, which took place virtually March 8–12, 15–16, and 22–26, 2021. A total of 18 presentations were reviewed in the Feedstock Technologies session by six external experts from industry, academia, and other government agencies. For information about the structure, strategy, and implementation of the technology area and its relation to BETO's overall mission, please refer the corresponding program and technology area overview presentation slide decks, which can be accessed here: https://www.energy.gov/eere/bioenergy/2021-project-peer-review-feedstock-technologies.

This review addressed a total U.S. Department of Energy (DOE) investment value of approximately $39.5 million, which represents approximately 6.0% of the BETO portfolio reviewed during the 2021 Peer Review. During the Project Peer Review meeting, the presenter for each project was given 20 minutes to deliver a presentation and respond to questions from the Review Panel.

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

BETO designated Dr. Mark Elless and Dr. Elizabeth Burrows as the Feedstock Technologies Area Review Leads, with contractor support from Boston Government Services. In this capacity, Drs. Elless and Burrows were responsible for all aspects of review planning and implementation.

FEEDSTOCK TECHNOLOGIES REVIEW PANEL

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FEEDSTOCK TECHNOLOGIES PROGRAM REVIEW PANEL SUMMARY REPORT

Prepared by the Feedstock Technologies Review Panel

INTRODUCTION

The Feedstock Technologies area is an incredibly important part of the overall BETO portfolio of projects. It represents research and development of what is ultimately the lifeblood of any conversion project: its raw material. A robust industry creating advanced chemicals and fuels with biomass requires economical and quality feedstock production. This is the subject matter of this program area. The review panel for the FT program had a cross section of representatives with differing backgrounds and areas of expertise. Industry, government, and education perspectives were all represented and contributed strong and varied viewpoints, which became evident in the review comments and scoring, the ultimate deliverables for the review process. A selection of these scores and comments can be found later in this summary.

The peer-review process occurs every 2 years and is meant to address progress since the previous review; however, this program went through a significant change in approach since the peer review in 2019. During the 2019 review, BETO unveiled its plan to adopt a quality-by-design process for its projects. This is a process favored by the pharmaceutical industry. This approach will be discussed in more detail below.

The review panel evaluated 18 project presentations within the Feedstock Technologies program. Each of these projects is funded by BETO either by a funding opportunity announcement (FOA) (8 projects) or as part of BETO's annual operating plan (AOP) (10 projects). There were projects that were ending, ongoing, and in their beginning stages. Ongoing projects shifted their approach significantly since the review in 2019 due to BETO's adoption of the quality-by-design concept. Ending projects experienced little in the way of this change, and new projects have original designs accommodating the new approach.

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

1. Management: Have the principal investigators produced a management plan that includes
    A. A plan for communications among the project participants?
    B. Identification of project risks?
    C. Mitigation of those risks?
2. Approach: Did the project performers develop an approach that has
    A. Significant merit to advance the state of the art of technology?
    B. Relevance to BETO program and technology area goals?
    C. Significant potential for innovation in its application?
3. Impact: Does the project and its presentation
    A. Demonstrate a clear connection between the project approach and the potential for significant impact and outcomes?

   B. Have clear commercialization potential, or have they used or have plans to use industry engagement to guide project deliverables?

4. Progress and Outcomes: To what extent

   A. Has the project made appropriate progress addressing the project goal(s)?

   B. Have the accomplishments been completed on schedule with the planned approach, and if needed, have risk mitigation strategies have been employed to maintain project progress and schedule?

There is no doubt that the panel feels the FT program managed by BETO is an important area for BETO's involvement and support, and the peer-review process is an essential exercise to determine if the projects are both beneficial and addressing the problems that are blocking the success of the industry. Historically, the preprocessing and handling of biomass has been a chronic problem area, and the portfolio of BETO Feedstock Technologies projects is addressing a number of these. The following subsections are a collection of comments from the panel addressing several of the aforementioned areas.

STRATEGY

The panel was impressed by the projects in the BETO FT portfolio. BETO has set a clear pathway and goal of producing high-quality, economic 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 are supportive of the BETO goals and multiyear plan.

The panel agreed that to meet the goal of producing products for the national bioeconomy from renewable resources, we need a diverse supply of feedstocks. Just a few examples are feedstocks such as willow in the Northeast, energy cane along the Gulf Coast, *Miscanthus* in the upper Southeast and Midwest, pine forest residues or switchgrass in Tennessee, and clean corn stover all over the Midwest. Development of diverse feedstocks is supported by the portfolio funded through BETO and central to BETO's multiyear plan in support of a robust bioeconomy. In addition, the program has a clear strategy in support of 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 per gallon gasoline equivalent (GGE).

There are several themes that run throughout the BETO FT 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:

- Identification and characterization of feedstock supply sheds.
- Grower characterization and support.
- Feedstock logistics and storage.
- Feedstock handling and preprocessing.
- Feedstock quality.

To look at one of these areas in more detail, please consider the following: BETO shifted direction in 2019 to an approach pioneered by the pharmaceutical industry, quality by design. Biomass feedstock variability has been a chronic problem in the handling and preprocessing for biomass projects being developed that commercialize state-of-the-art conversion technologies. It is the opinion of all but one of the panel members that the shift to the quality-by-design process is a good move—that production of high-quality feedstocks to ensure production values and throughputs makes for a more efficient and economic outcome from conversion facilities. Investigating different aspects of this problem and discovering solutions is pervasive throughout the FT portfolio.

For example, pelletizing appears to be the predominant form of densification in the reviewed projects. The panel agrees with BETO that pelletization provides several advantages across many feedstock technologies and Feedstock-Conversion Interface Consortium (FCIC) projects, in addition to the advantages of densification, from understanding particle surface interactions to conversion-specific feedstock blending. Pelleting addresses many material-handling issues that arise when operating at commercial versus demonstration scale. Conversion facility efficiency places an emphasis on keeping the reactor up and running. Having a uniform blended product delivered that meets well-defined feedstock specifications has the potential to increase production efficiency and therefore project economic returns. This methodology also supports use of diverse feedstocks, as well as BETO's regional feedstock depot concept.

Some panel members believe that several projects might benefit from greater industry involvement. Some projects had excellent industry involvement with multiple industry partners, and others had just one industry representative. This latter scenario seems to be true mostly for AOP projects, where the main participants are the national laboratories and there is no industry cost share required. There is no information or discussion as to the process of how these AOP selections are made; therefore, it is difficult for the panel to make any comments in or not in support of the process. Another question the panel has is whether there are some industry groups or associations, such as the Renewable Fuels Association, that might get involved with the projects? Other choices might be forestry companies, forestland owners, power generators, and equipment manufacturers and suppliers.

It is apparent from the expansion of study and research into municipal solid waste (MSW) as a desirable feedstock that BETO has been listening to industry as well as state and local government entities as they seek to deal with an ever-mounting problem of MSW disposal. The panel sees this as a positive development and would be supportive of more funding in this area.

It would be useful if there was some study directed toward industry regarding the characteristics of the "ideal" biomass so work could be directed to achieving this ideal. One panelist finds there is an unresolved conflict in the objective for the overall program between achieving optimum yields of biomass versus fractionating and separating of components to make material more uniform and higher quality for the "next" processing step. The economic modeling should resolve this issue, and particular attention should be paid to this outcome. If not, this could create a significant gap in the work.

BETO has a biomass properties library at Idaho National Laboratory (INL). This is a significant resource and accomplishment. It is beneficial to all working in the field and much needed. The current harvest knowledge database has grown to the point where an "equipment cost library" is needed. The panel recommends a template with an agreed-upon standard for calculating dollar-per-hour operating cost and dollar-per-dry-ton unit cost for commercially available harvest machines. This template is used for the cost analysis required for all BETO projects. This would provide PIs and future reviewers with a common starting point for harvest activities, which are not always apparent in the presentations.

While not necessarily a gap, at least one panel member is not completely sold on the quality-by-design concept. Their view after the review process is that the variability in properties/characteristics of biomass are potentially better handled at the project level through learning how to accept this variability rather than by designing to eliminate it, and that biomass feedstocks may not have enough variability to warrant the resources being spent.

The panel believes that the roughly 50/50 mix of FOA funding versus AOP funding has been a good distribution of funds, and the overall funding level has grown appropriately. The panel would like to see more funding available, and potentially more through the FOA process, to create greater industry participation. While the panel knows this is up to the appropriations process, they are supportive of BETO seeking greater funding.

STRATEGY IMPLEMENTATION AND PROGRESS

The technology area is funding a wide range of projects addressing all areas of the supply chain and this problem area. A partial list of subjects investigated includes:

- Storage methodologies and logistics.
- Feedstock particle interaction.
- Present and next-generation supply chain logistics.
- Preprocessing and deconstruction of feedstock.
- Particle size reduction and densification.
- Risk and critical property analysis.

As previously stated, the panel believes that BETO is funding a strong portfolio of projects, supportive not only of BETO's objectives but also the needs of industry. Particular projects that impressed the panel and are providing strong support for this vision are:

- Tim Volk's project, "Improved Biomass Advanced Logistics Utilizing Woody Feedstocks in the Northeast and Pacific Northwest," which serves as a good model for an operational-scale trial. His field days and number of stakeholders were impressive and meaningful.
- DK Lee's project, "Next-Generation Feedstocks for the Emerging Bioeconomy," is an excellent project with good partnerships. The panel appreciated his work on evaluating ecosystem services. This novel approach should be considered for other applicable projects.
- Three projects that deal with different aspects of the supply chain as to moisture management, storage, quality creation, and preservation that advance and provide state-of-technology solutions are:
    - William Smith's project, "Feedstock Harvesting & Storage: Post-Harvest Management for Quality Preservation"
    - Lynn Wendt's project, "Value-Added Process Intensification in the Supply Chain"
    - Jaya Tumuluru's project, "Biomass Size Reduction, Drying, and Densification."

With the Feedstock Technologies portfolio, BETO is funding projects that are on the leading edge of many technology areas that could have far-reaching influence in several areas. For example, Lynn Wendt and Jaya Tumuluru's projects mentioned above could allow for the harvest of high-moisture feedstocks such as corn stover, which is high in moisture early in the harvest season. Being able to avoid time spent during the dry-down process could significantly lower cost, and these two methods can handle high-moisture materials in a manner that maintains quality. Maintaining quality and lowering cost are not normally two concepts accomplished simultaneously.

Although the panel is singling out the above projects, there are several others that could have been mentioned, and the reader is encouraged to review the entire portfolio. The BETO management team is clearly working and managing their portfolio of projects toward their near-term/mid-term and final goals of providing high-quality feedstock at an economical cost in support of existing and emerging conversion projects. The FT portfolio has moved the needle positively in knowledge, technology, data collection, and analysis in all areas of the supply chain, which over the long term should prove beneficial to a healthy and growing bioeconomy. However, as in most endeavors such as these, there is always more work to be done.

RECOMMENDATIONS

The panelists have several recommendations that could prove impactful to the FT portfolio. One high-priority target is the need for work in applying information technologies such as data warehousing and deep machine learning to the supply chain delivering feedstock for the biorefinery industry. It would involve taking an approach similar to the quality-by-design concept by using the industrial and systems engineering discipline, which has developed very sophisticated analysis tools to optimize the logistics system in other industries. It is essential to structure the emerging biorefinery industry such that these technologies can be applied. This could help make for a highly efficient logistics system and potentially help quality management as well.

It was mentioned by more than one panelist that investigation and research into feedstocks such as municipal solid waste is a welcome and important development for the FT portfolio. Another suggestion for new work in the portfolio would center around the abundant resource of forest residue. This feedstock suffers from a costly supply chain system. Future FOAs could focus on forest residue logistics and blending and utilization of both herbaceous and forest residue biomasses. Work in this area to reduce the cost for the collection and delivery of this resource direct to a biorefinery or to a depot for blending would provide at least two major benefits. First would be another economic feedstock to support continued growth of the bioeconomy, and second, this would provide an economic incentive and support for cleaning and reducing fuel loads of both public and private forestlands. This would make for healthier forests while also helping prevent natural disasters such as forest fires.

Feedstock storage and processing depots are an interesting concept. They can quickly respond to market demands. By mixing and merchandising delivered material, conversion facilities can improve efficiencies and produce high-quality products from each material. Many aspects of the work on depots have been examined and provide input for the BETO modeling efforts; however, one area of work that is still needed involves understanding machine interactions to optimize which tasks should be performed at the depot and which should be performed in the field. Likewise, for conversion facilities that require a blended product, more information is needed to determine where that blending should occur. Modeling can provide an acceptable range of depot costs, but some performance-related variables, such as equipment delays and utilization rates, are needed from actual studies. For larger depots, transportation alternatives to trucking may also need consideration. Many of the models are being field-tested, but some are not. It should be a requirement that all models are field-tested, which would give higher confidence in their accuracy and results.

When appropriate to the project, critical members of the local farming and forest community, including county extension agents and members of local governing boards, should be participants. If involved at early stages of a project, these groups might be able to help with advice, logistics, and local issues. Farmers and foresters will be a critically important part of the bioeconomy because they will be producing most of the feedstocks for conversion to fuels, chemicals, and other products. Farmers are also known for their innovation and problem-solving skills. Greater support for and acceptance of what the bioeconomy will be asking of these communities would be achieved if these community members had direct involvement in projects where assumptions or characterizations of the farming and forest community are the subject of investigation.

FEEDSTOCK TECHNOLOGIES PROGRAMMATIC RESPONSE

INTRODUCTION

The Feedstock Technologies team appreciates the Peer Review Panel statements affirming that FT is funding a strong portfolio of projects across the supply chain and supportive of industry needs with no notable gaps. FT further acknowledges the recommendations to:

- Apply information technologies such as data warehousing and deep machine learning to the delivery of feedstocks to biorefineries.
- Continue work of municipal solid waste and center new work on forest residues logistics, as its supply chain is still very costly.
- Expand work on feedstock storage and depots, including blending and modeling efforts that are field-tested to provide accurate costs.

RESPONSES TO PANEL RECOMMENDATIONS

Recommendation 1: Apply Information Technologies to the Delivery of Feedstocks to Biorefineries

The FT team recognizes that further improvements in supply chain logistics, including transportation, are needed to deliver conversion-ready feedstocks to biorefineries. The Supply Characterization Model was used in the *2016 Billion-Ton Report* (https://doi.org/10.2172/1271651) to calculate delivered costs that include production, logistics, and transportation costs. This holistic viewpoint is central to the industrial and systems engineering framework, as recommended by the reviewers. Incorporation of industrial and systems engineering concepts, such as needing the context of the whole system to understand the importance of each component part, and industrial and systems engineering technologies, such as data warehousing and deep machine learning, will be included with the quality-by-design approach in future projects.

Recommendation 2: Continue Work on Municipal Solid Waste and Center New Work on Forest Residues Logistics

The FT team appreciates the support of the review panel for our recent efforts to include cost-advantaged feedstocks, such as municipal solid waste, in our feedstock portfolio. Such feedstocks, we feel, are central to meeting our out-year cost goals of $2.50/GGE by 2030. Forest residues have been a focus of three past FOA projects in the FT portfolio and one current AOP project in the Analysis & Sustainability portfolio. All address the logistics of collecting, handling, and transporting these residues for bioenergy applications. FT will seek future opportunities to revisit forest residues to help meet FT or BETO goals.

Recommendation 3: Expand Work on Feedstock Storage and Depots, Including Blending and Modeling Efforts

The FT team appreciates and shares the review panel's interest in feedstock storage and depots. Maintaining feedstock quality through storage is key to meeting our delivered cost goals and ensuring delivery of conversion-ready feedstocks. As competition for feedstock increases due to the establishment of additional biorefineries, depots will be necessary to preprocess the biomass into conversion-ready feedstocks. FT will seek future opportunities for funding depot concepts as the bioenergy sector expands, including blending and identification of tasks to be performed at the depot versus the field.

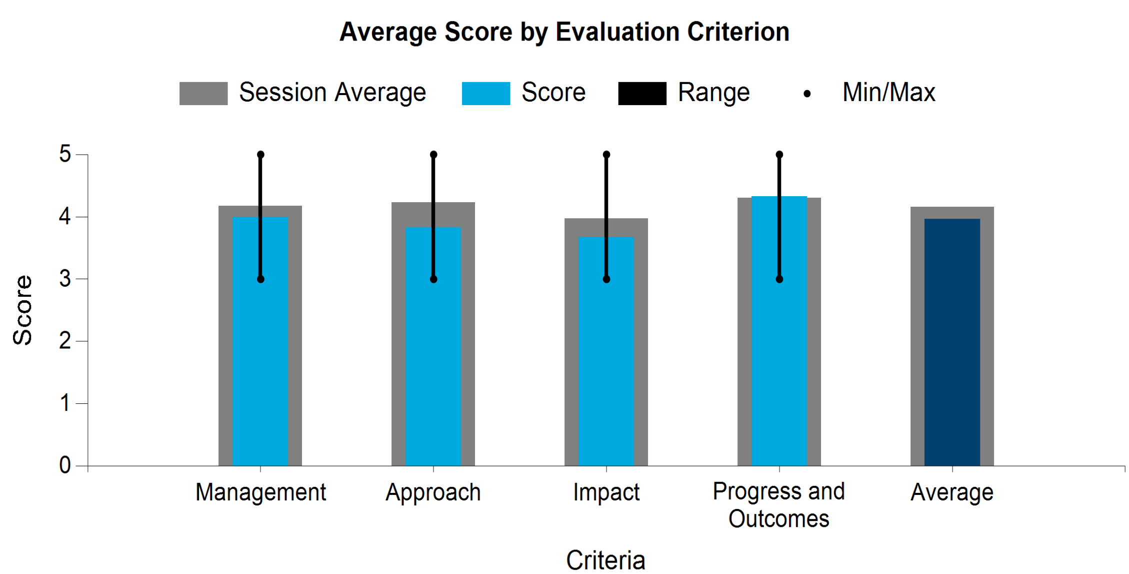
NEXT-GENERATION FEEDSTOCKS FOR THE EMERGING BIOECONOMY

University of Illinois Urbana-Champaign

PROJECT DESCRIPTION

WBS:	1.1.1.105
Presenter(s):	DK Lee
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2024
Total DOE Funding:	$5,000,000

Perennial bioenergy crops (e.g., switchgrass) have shown a great potential to improve ecosystem services with higher biomass production on marginally productive croplands compared to the traditional row crops (e.g., corn/soybean). This field-scale study focused on new high-yielding switchgrass cultivars for improving biomass yield/bioenergy production and ecosystem services on marginal lands across the Midwest (Illinois, Iowa, Nebraska, and South Dakota). Biomass yield was evaluated using commercial-scale production practices, and the ecosystem services provisions included soil quality, greenhouse gas emissions, water quality and quantity, and biodiversity. In general, the preliminary results showed that the new switchgrass cultivars ("Liberty" and "Independence") increased biomass yields by 25% and 50%, respectively, compared to the predecessor cultivar ("Shawnee") in the first harvest year. Compared to the corn production system, switchgrass production improved the system's ecosystem services with an approximate fivefold mitigation of N_2O emissions, ~30% reduction in NO_3^- leaching, and an increase in crop water use efficiency. Furthermore, this project is exploring the use of remote sensing and machine-learning modeling for ecosystem services and biomass yield estimation for future bioenergy crop production scale-up. So far, this study has shown promising results in meeting the BETO goal of producing feedstock for <$84/ton with >6-ton/acre yield, to develop productive, cost-effective, and sustainable bioenergy feedstock production systems on marginally productive croplands across geographic locations in the Midwest.



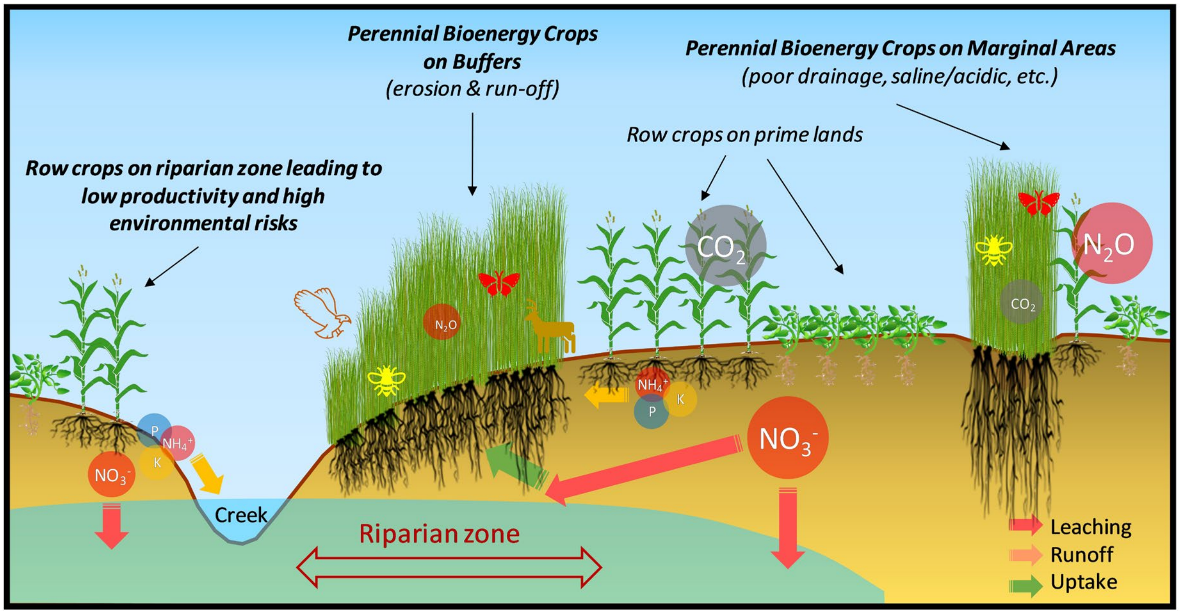


Photo courtesy of the University of Illinois Urbana-Champaign

COMMENTS

- The report of progress on the introduction of new switchgrass varieties is impressive. This project has a very impressive team assembled to address the crop production and ecosystem services questions. I believe much will be learned about switchgrass production on this marginal land. I have some questions about the project that caused me to choose a lower "impact" rating. If I have misinterpreted, I apologize to the project participants in advance.

  1. BETO wants to talk about a 2,000-dry-ton/day plant. For a plant this size to locate in the region being studied, the feedstock from the marginal lands will not be sufficient to supply the plant year-round. Presumably it will need to be supplemented with corn stover from additional land. What is available within a 30-mi radius, 50-mi radius, etc.? Maybe a depot (400 dry tons/day) can locate in the region and ship to the 2,000-dry-ton/day plant. I hope a scenario will be selected (as agreed to by BETO) and delivery cost analysis done based on this scenario.

  2. I think I have interpreted the slide 9 data correctly. For example, $44/Mg × 10.5 Mg/ha = $462/ha gross income. The graph shows $100/ha net income. The cost is then $462 – $100 = $362/ha. I interpret this to mean the payment to the farmer to grow crop, harvest (large rectangular bales), and place in roadside storage. The $100/ha is then the profit (return to land and labor). Is this correct? How does this cost compare to the payment to a custom harvest contractor to collect corn stover in large rectangular bales and store them in roadside storage? How does the $100/h compare to the current payment for corn stover lying on the ground after grain harvest? These data are available from the biorefinery operation in Iowa and should be available for comparison from BETO.

  3. Can switchgrass at 6-ton/acre yield be dried sufficiently (<20%) to bale into large bales and stored in a stack? Does this require delayed harvest with a partial dry-down before harvest? This project is well positioned to answer these questions if it falls within the scope of work.

- Best management practice development is being used as a major success factor. It is not clear what best management practices will be developed. It may be planned in budget periods 4 and 5. I think best management practices can be developed earlier and their application and effectiveness can be accessed in budget periods 4 and 5. There are many ways to do the modeling work in ag/forest ecosystem services.

Using machine learning is very appropriate and challenging, especially on the algorithm's selection and data set preparation for consistency and robustness. How do you decide the size of both the training and testing data sets to optimize the outputs of desired results, and what are the major factors affecting uncertainty of the machine-learning modeling? How do you evaluate the machine-learning models in terms of basic criteria such as R^2, root-mean-square error, p-values, and model validation? Does the machine-learning model necessarily perform better than traditional statistical models? The study layout is good. However, its scale is still small to indicate or imply the major benefits of ecosystem services.

- Management: Longer-term project, still lots of time to complete. The project is quite all-encompassing for determining overall viability of switchgrass. I assume that the PI has looked at other regions (international) for their experience with this crop. This is a large project and will require a focused approach to the project management aspect alone. Very impressive mix of collaborators covering the various aspects of the supply chain. The use of measurable critical success factors is an innovative method to manage a research project. I personally have not seen it used this way. This will help to keep the project focused and on track. I am wondering if the PI has also developed key performance indicators for each of the critical success factors. This would help to make the progress measurement highly relevant to the critical success factors. There is not much emphasis on identifying risks to implementing the strategy, which would be helpful to think about. There would be a lot of information from other jurisdictions about this crop that could be used to determine some risks and mitigation strategies, especially on the technical side of the project.

  Approach: This is a very hands-on project, with the need to collect a lot of field data. This type of project requires a great deal of coordination. There is a risk that data do not get collected (e.g., failure of measurement devices). I'm not sure the redundancy built into the study will ensure the measurements and data will be collected as required. This project has a component to evaluate and compare ecosystem services on different crops. There is a value to this that should be incorporated into all life cycle assessments (LCAs) and techno-economic analyses (TEAs). Very innovative approach! This project will serve to demonstrate the applicability and benefit to this specific biomass crop. Uptake by industry will depend on their results. The methodologies to evaluate ecosystem services is valuable for future work of researchers in this area.

  Impact: Thought has been given to being inclusive with the information. Excellent proposal for the on-site field visits to demonstrate best management practices. In addition, the public data repositories are beneficial for making the extensive demonstration information available to a wide range of stakeholders. It might be important to put a focus on farmer associations. The practitioners can assist in the project development stage and will be in a more favorable position for uptake, as they will learn as the project goes.

  Progress/Outcomes: Development of tools that can be applied to other trials and biomass, such as the artificial intelligence and remote sensing model, is very valuable. There is a good deal of evaluation that has taken place. Congrats, nice work.

- Management: Team members include specialists from all areas to be addressed by the tasks. The strategic plan does not specify determining harvesting production rates and costs. It is not clear whether the harvesting costs are included in the regional feedstock cost-rate model, or if that only includes crop production. Feedstock quality is addressed in Objectives 1 and 2 but was not further addressed in the slides. Risk identification and mitigation strategies are not outlined. It is not clear if there will be risks associated with harvesting in riparian zones or in poorly drained marginal areas. The impact of the project may be further clarified if an estimate was provided of the number of acres that could be potentially produce switchgrass. Riparian and poorly drained marginal sites often have accessibility issues for transport; this could be a risk that should be identified to further clarify which lands would be suitable for switchgrass production.

Approach: The approach addresses delays related to spring flooding impacting field preparation. This is a project on marginal land, and flooding should have been addressed as a risk. It does not address any weather-related issues with harvesting in November/December. Harvesting when wet may impact feedstock quality, such as ash content and/or moisture content, potentially resulting in storage issues.

Impact: The project clearly describes the field data collection process and outreach activities. New decision-making tools may help farmers decide whether to plan perennial energy crops. Site data go beyond the expected information and include avian acoustic monitoring and a survey of insects and pollinators. Collaboration with biorefineries is included to provide critical access to conversion technology insights with produced feedstock. However, feedstock quality and characterization are not addressed as part of the project; they are mentioned in Objectives 1 and 2. Feedstock chemical composition is noted on slide 15 but was not included in the approach.

Progress and Outcomes: The project is showing positive results related to yield of the various cultivars. Field data collection has continued through fiscal years (FY) 2019 and 2020. Ecosystem services impact assessment is making progress through remote sensing and field data collection. Nitrate leaching is being compared between switchgrass and corn.

Overall Impressions: This presentation did not address harvest logistics or feedstock quality in any meaningful detail. This information is crucial for stream-side management zone buffer or wet site operations. Avian acoustics data collection is interesting, as are some of the other environmental services included in this project. There may be a loss of observational data to inform commercialization of harvesting when using machine-generated production rates.

- The management team is strong with an excellent cross section of national laboratory, university, and industry partners. There is a strong communications plan that includes the farming community, which is an added plus that too often is not included in BETO projects. The strategy has clear, well-defined quantitative goals for their go/no-go decision-making, and risks with mitigation plans have been developed. The project approach should, if successful, advance BETO's Multi-Year Program Plan (MYPP) and will provide a useful tool. One significant drawback is that I believe this model, with the comprehensive inputs that it has, appears to me to be applicable to any geography, not just the Midwest as advertised. I would urge BETO to consider additional project work to test this model in other areas of the country. The approach is linked to the outcomes, which have had significant communication of their results through local stakeholder outreach, industry partners, publications, and a webpage. It appears all the project goals were met. Risk mitigation strategies were employed, such as replanting when some plots suffered due to weather complications. I do like that the model was developed with field-tested data, and this can give one great confidence in the model's results. One weakness is the lack of inclusion from the farming community on their view of the benefits of using these plants in their operations.
- There is a good management plan for the project, noting the risks. The project approach is clear and relates to the goals and desired outcomes with clear potential for planting switchgrass on lower-performing land. The pursuit of yield data is clear and very well articulated; the cost of the operation is not yet defined. It could be beneficial to establish predicted costs and costs goals early in the project so the project plan can be nimble and adapt to meet both goals, yield and cost. What input costs are predicted year over year to sustain yield? With a few updates to the project management plan to focus on cost, this project is very exciting, as the core yield looks to be promising.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their constructive comments and suggestions for the summaries of theswitchgrass project selected from the FY18 Affordable and Sustainable Energy Crops Funding Opportunity. As we are starting the third year of the 5-year project and the second growing season, we are accumulating the information that directly answers the questions posed by the reviewers. We understand the importance of a sufficient supply of feedstock for a large-scale commercial biorefinery, the availability of marginal lands, and the quantification of feedstock supply from marginal lands. To help address this question, this project focuses on the TEA of the new high-yielding switchgrass cultivars with best management practices and feedstock logistics based on the data we will collect from the field-scale operation, including input costs during the project period. The results will provide key information to quantify the regional availability of marginal lands and the associated feedstock production potential to provide tools to help local producers to make decisions for converting marginal lands to switchgrass feedstock production. To increase the impacts of this project, we are planning to have on-site field days and stakeholder meetings and develop outreach educational materials to demonstrate the benefits of new switchgrass cultivars for sustainable biomass production for the region. We also agree with the reviewer's comment that the TEA results from this project could be applicable to the geographic regions beyond the Midwest, which will require further testing of our model.

We appreciate the reviewer's comment on reemphasizing the importance of the best management practices for switchgrass feedstock production and feedstock quality. One of the main objectives is developing best management practices for switchgrass feedstock production on marginal lands in conjunction with the determination of feedstock quality. As we are currently making progress in the field-scale feedstock production practices, we will summarize the best management practices specific to high-yielding bioenergy-type switchgrasses on marginal lands, including establishment, post-establishment management practices, and harvest management and logistics. For all feedstocks, we produce each growing season across all locations. We will estimate the feedstock chemical composition, potential ethanol yield using saccharification and fermentation, and mineral composition.

We appreciate the reviewer's comment on ecosystem services. Ecosystem services are very important components of bioenergy feedstock production, especially on marginally productive croplands, and this project will continue to demonstrate the ecosystem services benefits of switchgrass production such as improving soil carbon sequestration and health, reducing nutrient loss, and improving biodiversity. We believe that our experimental design with field-scale practices is adequate to measure such ecosystem services. The inclusion of the machine-learning aspect has the potential to further increase prediction across these field-scale studies by the inclusion of other explanatory variables that can affect ecosystem service provisioning. Studying biomass yield and ecosystem services at the field scale is important, as this is the level in which the potential payment of ecosystem services is targeted, based on current ecosystem service market programs in the United States.

We appreciate the reviewer's comment on machine learning. We will conduct a sensitivity analysis on a range of training-testing data set splits, starting with the standard 70–30, then the lower (50–50) and upper (80–20) ranges, respectively, to determine an optimum value for each cultivar across geographic locations. The difficulty of generating large volumes of quality data is a major factor affecting the uncertainty of the machine-learning modeling task, which is particularly true for greenhouse gas emissions data where we are dealing with hot moments (i.e., times during the growing season when fluxes are relatively more intense) and may not be captured with a sparse temporal sampling scheme. We will consider a machine-learning model to be robust if it has an R^2 of 0.75 across the target parameters of interest (e.g., biomass yield, greenhouse gas emissions) and least values of root-mean-square error and mean absolute error between measured and predicted values at the testing phase. Machine learning is suited for multi-/hyperparameter problems (where traditional statistical models do not perform well) such as predicting biomass yield and peak evapotranspiration as a function of a plethora of explanatory variables including land marginality, crop management, soil properties, topographic factors, and climate without necessarily knowing the governing structural functions (linear, nonlinear, mixed, etc.) and satisfying certain assumptions (linearity, normality, etc.).

SUSTAINABLE HERBACEOUS ENERGY CROP PRODUCTION IN THE SOUTHEAST UNITED STATES

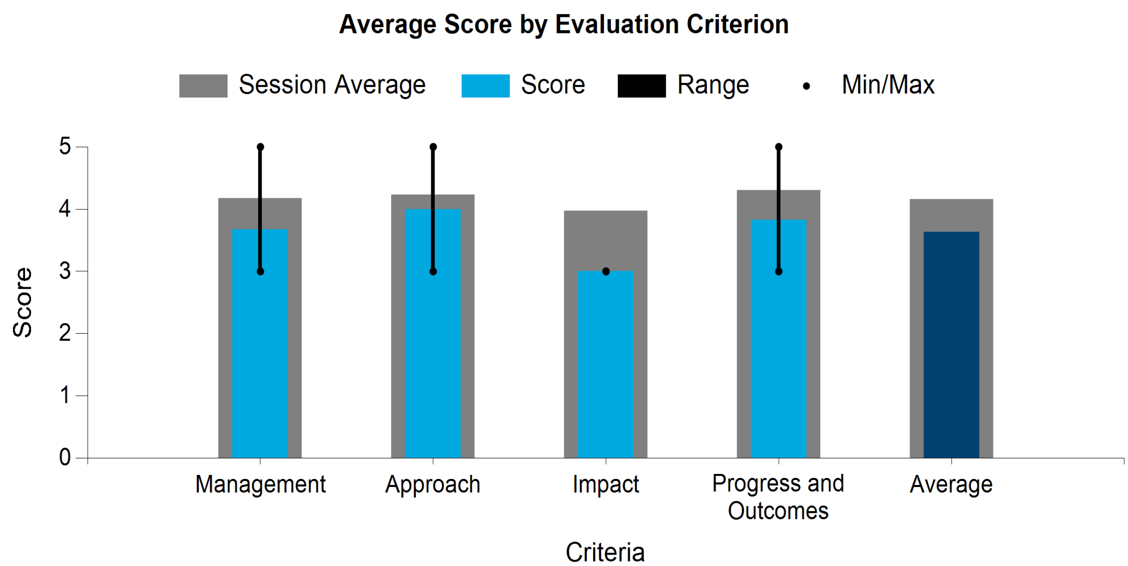
Texas A&M University

PROJECT DESCRIPTION

WBS:	1.1.1.108
Presenter(s):	Ted Wilson
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2023
Total DOE Funding:	$4,999,539

This proposal assesses the economic viability and environmental sustainability of producing advanced energy cane and biomass sorghum in the southeast United States. Its overall goal is to optimize sustainable biomass supply from energy cane and biomass sorghum over the diverse edaphic and climatic environments in the southeast United States through implementation of three major objectives: (1) characterize the seasonal dynamics of biomass production of energy crops in multiple edaphic and climatic environments, (2) quantify the impact of energy crop production on environmental sustainability, and (3) develop site-specific best management practices to optimize biomass production, harvest, and storage. Field experiments using three genotypes of energy cane and biomass sorghum each are being conducted at seven sites (three in Texas and one each in Louisiana, Mississippi, Georgia, and Florida). Data collection includes biomass yield and quality, carbon footprints, biodiversity, and other environment data. Integrated analysis on economic viability and environmental sustainability will be conducted to determine the best management practices on biomass production, harvest, and storage and to develop site-specific year-round biomass supply plans. We have successfully established energy cane experiment plots in all seven sites and collected biomass sorghum in 2020.

Outcomes from the proposed project will support the Bioenergy Technologies Office's main strategic goal of reducing the price of biofuels to less than $3/gasoline gallon equivalent, reducing the cost of feedstock delivered to the conversion reactor throat to less than $84/dry ton, and increasing the availability and affordability of biomass-derived transportation fuels and bioproducts.



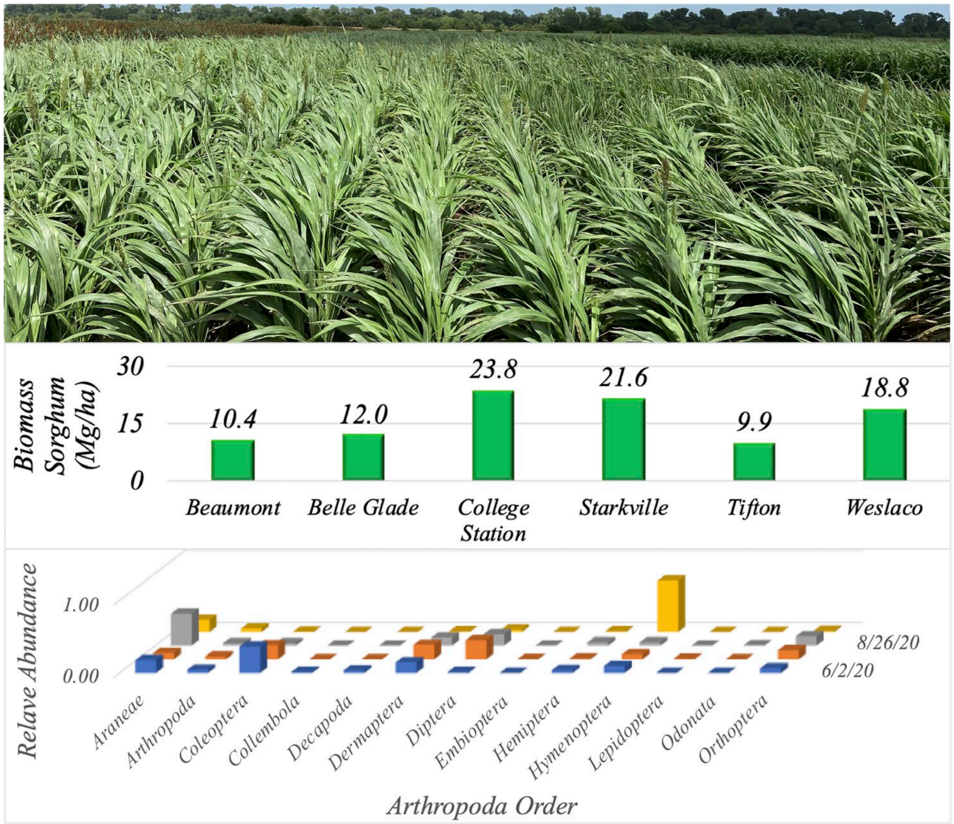


Photo courtesy of Texas A&M University

COMMENTS

- The team members and their responsibilities need to be presented to help monitor the project's progress. It is not clear how to optimize the sustainable energy cane and sorghum production among different states in the study area while land uses, stewardship, and landowner participation must be considered. I understand the progress and outcomes are pretty much based on only 1-year data and results. However, the data analysis and interpretation need to be improved in the coming years, such as the number of observations for each measurement and number of replications. Some details are also needed to explain analysis of variance and principal component analysis data and results.

- Management: PI has shown groups that will participate in the project, but it would be helpful to understand who exactly oversees each aspect of the project. This is a large and complex project and involves a number of sites and a large amount of data collection. A lack of good project management is high risk to successful completion of the project. This project is in an early stage, and perhaps some of the management issues have not been fleshed out at this time. Some technical and project risks have been identified, but there is a lack of mitigation strategies.

  Approach: Comprehensive study. Not sure if there is an intention to scale up to commercial level, via best practices information for farmers beyond the site-specific management practices proposed. Would like to see some outreach to the farming community for feedback on the project and for early adoption if project proves successful. Also, not clear as to industry involvement for planting and harvesting equipment.

Impact: Good early-stage project for evaluating the feedstock establishment and growth. Hopefully it will identify where the roadblocks are for commercialization and larger field trials.

Progress/Outcomes: Some good initial results on the biomass growth. Project is proceeding as described.

- Management: Project team involves researchers from a variety of southeast U.S. universities and the U.S. Department of Agriculture (USDA) Agricultural Research Service. Team communication plans are presented. Collaborations with related projects are listed and indicate that the project will tier to other projects and INL. Industry and landowner partners are not listed but may be involved through the various team members. There is an industry partner (Verd) that is interested in taking both the sorghum and energy cane, but their role was not clearly defined. Risks are identified, but mitigation isn't clearly addressed.

  Approach: The approach is clearly communicated but could do a better job of tiering it to the BETO program and technology area goals.

  Impact: While the team is knowledgeable, outreach to stakeholders or growers is not addressed.

  Progress and Outcomes: Harvest yield, invertebrate study, nitrogen use, and soil information was presented. Although harvesting has occurred, there were no results for feedstock quality. The discussion on how to deliver material over the longest delivery window was interesting. The project examined the trade-offs for harvest timing versus yield that were interesting in relation to a typical focus of maximizing yield.

  Overall Impressions: This is a big project with biomass plantings across the southeast United States. The research team is strong, and the project will benefit from ties to other biomass programs. Much of the first 2 years was spent in growing and planting the experimental sites. The next steps are fairly well defined and will provide information on a variety of topics such as economic viability, environmental sustainability, best management practices, and operational plans for a year-round biomass supply.

- The management team has a clear plan, good communication, and cross-referencing with other projects and labs. I would have liked to have known who the individual project members are, and the risk identification and mitigation strategy was not clear to me in all cases. The approach's goals have been explained, such as addressing the economic viability, and will be impactful to BETO's goals of promotion of bioenergy crops, which will be required to meet strategic and production goals of a vibrant bioeconomy. What I did not see was: What is the approach or road map to achieve this result? It appears to be too early to judge the project impact in a broad manner; however, there was an opportunity to communicate how the work to date will contribute to end-of-project goals of ascertaining the economic viability of energy cane and biomass sorghum. Solid progress was made toward the project's goals. Overall, the schedule appears to have been maintained, but it is unclear whether the schedule was met or there was slippage because no clear monthly, quarterly, or annual schedules were presented. Even though the score may seem overly penal, this is mainly due to the presentation, not the project or its results. I feel this project is well worth the effort, and solid progress has been made, and herbaceous crops such as biomass sorghum and energy cane will become important not only to the bioeconomy, but to the farming communities of many areas of the country, especially the Southeast.

- The model for high-tonnage, high-moisture crops, like the crops being studied in this project, is sugar cane. The presenter did not discuss harvesting or storage. It will be interesting to learn if ensiling will be considered. I am glad it is not my job to supply a biorefinery year-round with energy cane—large challenge.

- This project is very interesting and supports the diversification and potential growth of feedstock commodities. In the end, all sources of biomass will be relied on to provide energy for society, as the only way to address potential climate change is to recycle carbon as opposed to using fossil fuels. This project is a great step in understanding the potential of energy cane. Great work, thank you.

PI RESPONSE TO REVIEWER COMMENTS

- The reviewer's comments on some aspects of our research are understandable given the multifaceted and highly integrated focus of our project and the presentation time constraint that limited the detail that can reasonably be presented during peer review. Our point-to-point responses are presented as following:

  Harvest and storage: The studies on feedstock quality and post-harvest biomass storage are integral parts of our sustainable herbaceous bioenergy feedstock production project. As described in our project proposal, post-harvest biomass storage will be conducted in Budget Periods 3 and 4. We will evaluate biomass loss and composition change 3, 6, and 9 months after harvest under both aerobic and anaerobic conditions. Analysis on year-round biomass supply for different harvesting options will be carried out in Budget Period 4 (years 4 and 5). Feedstock quality analysis is scheduled to be conducted in Budget Periods 3 and 4.

  Roles of industry partner and outreach to stakeholders or growers: Verd Company is our industrial partner and will analyze the industrial-level conversion of biomass sorghum and energy cane feedstock from our project into bioethanol through a process referred to as ethanol-ensiled technology. Verd aims to lower the complexity and number of operations, resulting in simplified fuel ethanol production. The key for lowering complexity, risks, and costs is the production and storage of target product molecules within silage piles. Verd will also provide an industrial perspective for the technology transfer and potential upgrades in biomass feedstocks for commercialization. Outreach to stakeholders will be achieved through field tours conducted across the seven experimental sites spanning from the southeastern border of Texas with Mexico, east-central Texas, mid- and upper Gulf Coast of Texas, southern Louisiana, north-central Mississippi, and southern Florida. The results from this project can be broadly categorized as addressing the economic viability and environmental sustainability of cellulosic crop production in the southeastern region of the United States and will be distributed via conference presentations, extension bulletins, and as online media.

  Risk mitigation: Risks were identified, and appropriate mitigation strategies were summarized during the presentation. If additional risks are identified, appropriate mitigation strategies will be developed. Regular team meetings are integral to the project's success. We have clearly defined responsibilities for individual PIs and maintain regular communications (emails, conference calls, and virtual meetings) regarding project status and upcoming plans to timely identify and mitigate any risks.

  Approach on optimizing the sustainable energy cane and sorghum production among different states: Biomass production and sustainability are impacted by site-specific weather and soil conditions, land use patterns, and production economics. This project is designed to collect critical data on biomass production and economic and environmental sustainability from seven representative sites across the southeast United States, which will be incorporated into an integrated analysis system to identify site-specific strategies for optimizing biomass production, increasing economic profitability and improving environment sustainability. Land use patterns, stewardship, and landowner participation will be key factors in the integrated analysis. Land parcels suitable and economically profitable for energy cane and biomass sorghum production will be identified across the southeast United States, and site-specific best management practices will be developed for sustainable biomass production. Enterprise budgets are built based on costs for commercial biomass feedstock production and management. We have thoroughly tested and perfected our integrated analysis approach, which will be carried out at a range of spatial scales from individual fields to farms and to the entire southeastern United States. The degree with which spatial variability in crop productivity and economic and environmental costs are captured by our project exceeds what is currently available for a very large majority of integrated analysis systems. This intrinsic component of our analysis system will greatly facilitate the scaling up of cellulosic production at commercial levels.

NEXT-GENERATION MISCANTHUS: HYBRID PERFORMANCE EVALUATION AND ENHANCED, SUSTAINABLE FEEDSTOCK PRODUCTION AND SUPPLY IN THE SOUTHEAST UNITED STATES FOR BIOFUELS AND BIOPRODUCTS

North Carolina State University

PROJECT DESCRIPTION

WBS:	1.1.1.109
Presenter(s):	Mari Chinn
Project Start Date:	10/01/2018
Planned Project End Date:	12/31/2022
Total DOE Funding:	$4,627,161

Giant miscanthus is a perennial grass with potential to meet the growing needs of a U.S. bioeconomy through high yield and positive environmental impacts as part of a suite of emerging regionally specific, diversified renewable feedstocks. Through a 10-year breeding program, 15 advanced, high-biomass-yielding triploid hybrids of giant miscanthus with increased dry matter yield and propagation capabilities over standard currently available commercial miscanthus lines have been developed. This project is progressing to exploit high-yielding characteristics of newly developed varieties, capture relevant data to address gaps in knowledge surrounding impacts on local- and watershed-scale soil and water ecosystems, and generate field data to address barriers in harvest operations, handling, and transportation options that affect affordability of giant miscanthus as a viable feedstock in different U.S. regions. The project team is taking an integrated, multidisciplinary approach to define crop production and management practices around a miscanthus cropping system, including decision-making opportunities in variety selection, land use, water use and quality, soil health impacts, harvest methods, storage, and siting. Findings will support the dissemination of miscanthus feedstock and supply chain parameters to databases serving advancement of a U.S. bioeconomy.

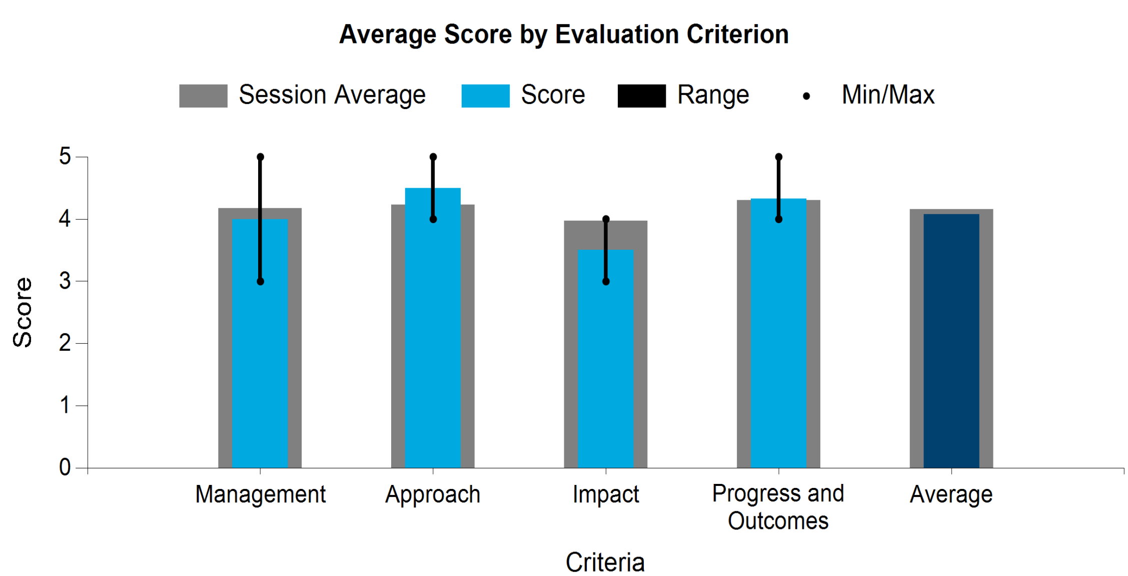


Photo courtesy of North Carolina State University

COMMENTS

- Because of the high yield, I understand the need to fund a project on *Miscanthus*. The project team has the expertise and organization for a successful project. Little detail was given in the presentation concerning harvest and storage; I will make some comments here that I hope will be helpful. The challenge is year-round supply of the biorefinery. I hope that there is an opportunity to "campaign" feedstocks, meaning that *Miscanthus* will be supplied part of the year and another feedstock (or feedstocks) will be supplied for the remainder of the year. Winter harvest will be possible in eastern North Carolina. (Wet fields will limit the days harvest can proceed.) Extending the harvest season provides an opportunity for harvest and direct shipment. Getting *Miscanthus* dry enough for storage in bales is problematic. Ensiling is an option—costs are well known—in bunker silos or silage bags. Another option is wrapping high-moisture round bales to achieve the "ensiling." These options are higher-cost options. One question of interest to me, can we harvest *Miscanthus* and deliver direct 4 months of the year in eastern North Carolina? If so, what is the average delivered cost?

- The team has collected hand/manual harvest data and will provide these data for Oak Ridge National Laboratory to use the Integrated Biomass Supply Analysis and Logistics (IBSAL) model to conduct supply chain analysis. These data may not be representative of the commercial-scale harvest for IBSAL to simulate. Best management practices will be developed in years 4–5. They can be developed earlier in year 3 and implemented in years 4–5 to assess their effectiveness. It is also not clear what specific best management practices will be developed. In the summary slide, what specific "interesting data sets" will be generated to evaluate supply chain functional efforts?

- Management: Diverse project team comprising North Carolina State researchers. There are limited external collaborators. This project might benefit from involvement from some other stakeholders, such as farmers, to assist with concept verification and farming practices. Good identification of project management objectives for the three groups.

  Approach: A lesson learned during the development of short-rotation hardwoods was that marginal land gave marginal productivity. Has work been done on these hybrid *Miscanthus* in various regions to demonstrate their potential yield? I don't have enough background on the project to provide a meaningful comment.

  Impact: Might be helpful to identify roadblocks to scale-up of the crop as the project evolves. Even if some of the project objectives are met, this may not lead to high uptake or commercialization. Personally don't understand the DNA work, but hopefully this is addressing more fundamental science questions. These are fairly small trials, so there is a fear that the chemical testing will not demonstrate variability in properties that would help to define the suitability of this crop. See slide on compositional analysis. Can't see rejecting or really favoring any of those materials, yet testing is quite burdensome. This is also the quality of fresh biomass, so how meaningful is that to what goes into the gates of the biorefinery? Storage is such an important step affecting quality.

Progress/Outcomes: Early results are not that indicative of success of the approach; difficult to evaluate.

- Management: The project team includes researchers from various departments at North Carolina State University, a national lab, and two industry partners. Project risks are identified, and mitigation measures addressed. There is a risk that there won't be a measurable difference between varieties, but that information also adds to the knowledge base.

  Approach: The approach is detailed for site selection and crop productivity on the replicated trials and describes what is to be sampled and analyzed. The plots are 8 m × 8 m (26.24 ft × 26.24 ft). This plot size seems too small for a harvesting trial. There seems to be a disconnect between the individual plots and the harvesting diagram. The various approaches include a schedule of accomplished and continuing activities.

  Impact: The project clearly connects the various activities to each other. This project also has a regional scale, which furthers the potential for significant impact and outcomes for these newly developed varieties of miscanthus.

  Progress and Outcomes: Initial results on survivability, yield, and compositional analysis have been presented. The schedules provided for each approach clearly indicate that progress is being made.

  Overall Impressions: The scope of this project is regional, and as such, provides broad knowledge for growing miscanthus as an energy crop in North Carolina. From site selection to growing, harvesting, feedstock analysis, and storage, this robust project addresses interesting gaps in the knowledge base.

- This project has a strong project team with recognized industry leaders and well-stated goals. This project will help advance BETO's MYPP through informing industry with solid information about the use of the *Miscanthus* hybrids studies. The management plan as presented doesn't have a communications strategy, which would seem to be important with three distinct teams looking at three diverse issues, or a strategy about how project results will be communicated to industry. While project risks and mitigation strategies did not appear in the project management section, they were addressed in the section on project approach. The project approach is comprehensive and will provide valuable data to any project developer wishing to explore the use of *Miscanthus* as a feedstock. The results will also inform models that will be useful to developers and farmers alike, and the project will advance the BETO goal of promoting the use of herbaceous energy crops. The project's impact can be recognized in the approach; the approach is clearly geared toward development of models and information to support advancement of its impact. The project's impact statements fell short by one step: What plans are being developed to not only add information to the database and tools for developers to use, but also to make this known to industry? There has been clear progress addressing project goals and a clear timeline has been presented, delineating not only the task and goal, but also the percentage of completion. Progress has been less than 100% realized on many tasks based upon the timeline presented. More explanation of why goals in the timeline are behind and necessary mitigation steps, if applicable, need to be presented in more detail. The project is well on its way to producing the goals as outlined, and it will advance BETO's goals for energy cropping systems. Strengths outweigh weaknesses, which can be addressed with minor changes.

- Well-managed project with some risks identified. This project is certainly raising the bar on state-of-the-art varieties of *Miscanthus*. The project potential for impact and outcomes is pretty high in my opinion, with clear commercialization potential. Certainly a lot of impressive science being performed as well. It's encouraging to see that we have biomass options, as I feel we will depend on the land to supply us in the future. Well done.

PI RESPONSE TO REVIEWER COMMENTS

- Thank you to the reviewers for providing comments and feedback on our project. During the presentation and in the written comments, it is encouraging that the work we are doing is stimulating conversation and interesting research questions around miscanthus as a cropping system. The variety (Yr1) and agronomic trials (Yr3) are being completed in the smaller plots as described at three different site locations across the state to evaluate productivity on marginal soils/fields for 5 of the 15 advanced miscanthus hybrids developed. These are referenced as standard sites for the project. The harvest experiments and the hydrologic modeling efforts are being completed on 8 acres of an established miscanthus crop that is in a separate field from a standard site on the same farm. This space is referenced as the harvest site and the watershed site for the project, and activities are coordinated between the project team members. The project supports the research of three primary areas—crop performance, sustainability, and supply chain—and while the objectives of the project are divided in this manner, the research efforts are highly integrated in decision-making, material sourcing, and data interpretation. This is possible because the teams working on these three areas have members that cross over into one or more of the other two areas. The advanced miscanthus hybrids are the technology for this project, and the North Carolina State University breeder is continuously in communication with interested parties about material use and licensing. Aside from working with Iogen and Novozymes North America to demonstrate that the crop produced meets industry specifications, the project team has several extension specialists and is accustomed to sharing data and technology developments with stakeholders at field days, workshops, and other organized events. As the project progresses and restrictions from COVID-19 are removed, these types of outreach activities are likely to take place. Progress on the timeline presented was adjusted to reflect the 6-month no-cost extension approved for budget period 1 based on the university's response to COVID-19, research and travel restrictions, service lab closures, limited equipment availability, and back-ordered reagents and DNA/RNA kits. The manual harvest data that the team is collecting will quantify the biomass being produced, especially at times when there may be considerable leaf drop, so that we can determine how efficient the mechanical harvest operations being studied are at collecting the miscanthus material (e.g., how much material is being left behind with each operation/pass). These data, in addition to the machine data, can be incorporated into the modified IBSAL model for analysis of our defined scenarios. We are collecting miscanthus harvest data in October/November and February/March in the harvest site, which will provide useful information surrounding supply, composition, and machinery efficiencies. The team has also related storage feasibility data for annual and perennial biomass crops that can support addressing storage and composition quality questions that arise from this project for year-round supply of diversified biomass sources, including miscanthus. DOE support has allowed the experience of our team members who have worked with miscanthus over the last decade in the different project areas to effectively integrate so we can define more meaningful outputs and practices around this emerging energy crop.

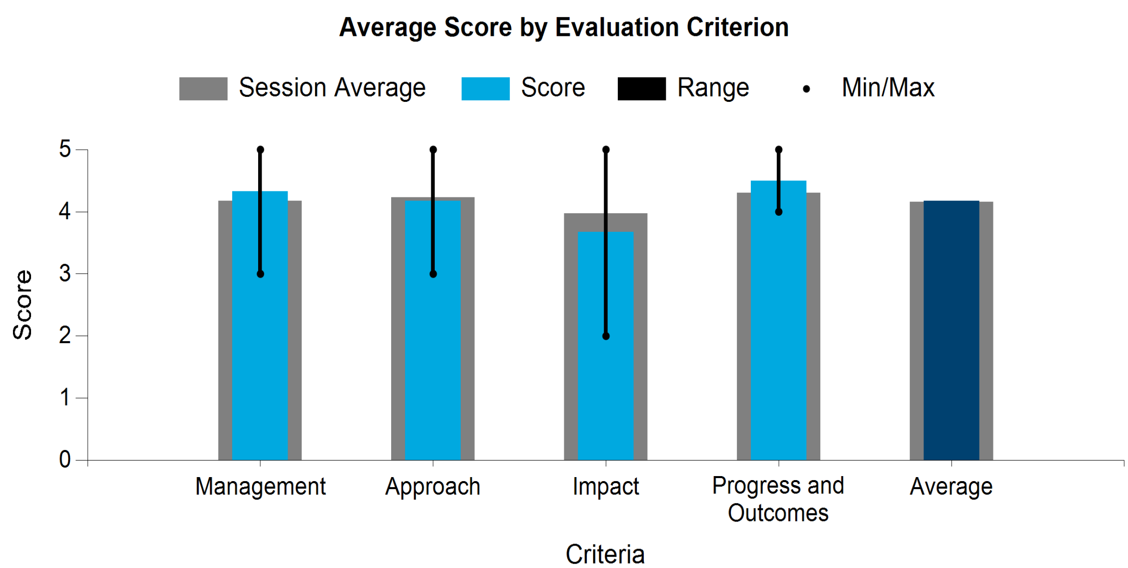
CHARACTERIZATION OF MECHANICAL BIOMASS PARTICLE-PARTICLE AND PARTICLE-WALL INTERACTIONS

Pennsylvania State University

PROJECT DESCRIPTION

WBS:	1.1.1.114
Presenter(s):	Hojae Yi
Project Start Date:	10/01/2019
Planned Project End Date:	03/31/2023
Total DOE Funding:	$707,323

Forest residue feedstocks include a mix of particles including bole wood, bark, needles, and twigs. Similarly, corn stover is a complex bulk material with properties influenced by anatomical content such as rind, pith, nodes, leaves, and cobs. 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 particles. Upon successful completion, this project will result in the 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 engineered biomass supply systems to handle, store, and deliver conversion-ready feedstocks consistently through innovative biomass handling modeling, such as discrete element modeling.



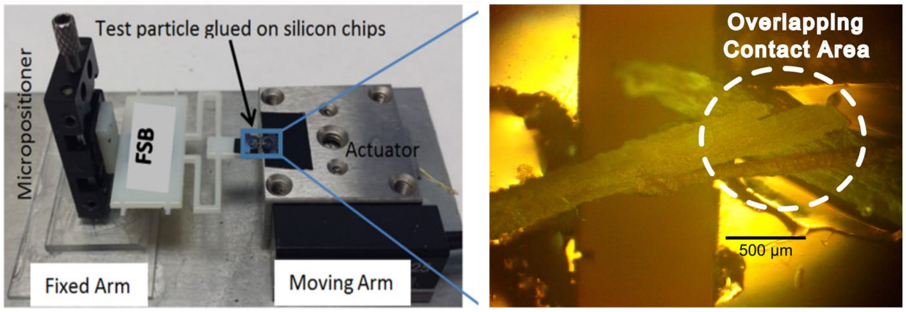


Photo courtesy of Pennsylvania State University

COMMENTS

- I classify the research funded by this project as the most basic of the several projects in the group being reviewed. It is in the "physical properties" subject area, which is not my area of expertise. I understand that the goal of the research is increased understanding that will ultimately lead to improvement in size reduction technology. The program at Penn State has long-standing expertise in the study of particle interactions, and Forest Concepts has an admirable, widely recognized reputation in the development and commissioning of size reduction technology. I expect impressive results from this project. One issue that is faced when particulate materials are transported is the influence of vibration. The particles tend to clump together and may bridge in such a way that it is difficult to get these materials to flow. An example is a truck on a truck dump being lifted to allow material to flow out the back. An example question is, do we know if a blended feedstock (25% switchgrass and 75% pine forest residue) will flow out of a chip van when it is dumped? If this project yields results that are applicable to this question, I hope this will be addressed in the final report.

- In addition to southern pine residue and corn stover, why was mixed hardwood residue not considered as a feedstock for experiments? Hardwood residue is abundant in the mid-Atlantic region and other parts of the country. Testing southern pine residue and corn stover particles separately are fine. In reality, we mix particles of multiple feedstocks. How will the mixture of multiple feedstocks affect the results and the test instrument design? A brief/plan is needed on how this extensometer can be commercialized for a broader application.

- I think it's important to gather a broad understanding of the physical characteristics of biomass at a micro level. This work could eventually help industry improve material-handling machines. To this point, biorefineries have struggled with material handling of corn stover feedstock. I think it would be beneficial to expand this project in two directions. First, how do harvest conditions including moisture, ash, and storage method affect the test results? Second, what do industrial machine providers need for data to improve machines? This work will be beneficial, and a little more work to consider and engage application upstream and downstream could help to improve the data set.

- Management: The team membership includes the knowledge and equipment necessary to see this project through to its completion. The communication plan described using Zoom and Microsoft Teams. The PI identified critical success criteria, but not in a risks and mitigation manner. He recognized that particle analysis sounds simple, but things can get complex quickly. Tasks and scheduling were identified.

  Approach: The PI gave a convincing presentation of why the micro scale of particles matters in biomass handling. Researchers have devised a method to modify a micro extensometer (elongation stress test) to characterize mechanical properties of two types of blended biomass (residues and corn stover). Small particles, 2 mm, will be tested using digital imagery. A risk was identified related to accurate measurement of the contact area; mitigation of that risk is not yet clear but will be incorporated into the project's implementation. The project is robust in that it will use residues that include stems, leaves, husks, and cobs from corn stover and wood chips, needles, bark, twigs, and small branches from logging residues.

Impact: The impact of the project will provide information on biomass handling, storage, and deliveries. Specifically, it could result in understanding whether further handling would be required to screen, debark, or further treat 2-mm delivered material. It takes energy, time, and money to grind material to a 2-mm size.

Progress and Outcomes: Progress was displayed on a Gantt chart. The project appears to be on track by budget periods. No roadblocks or delays have been identified in budget period 1 or with the initial tasks associated with budget period 2.

Overall Impressions: Feedstock rheology is an important but often overlooked characteristic for biomass handing. This $707,323 project will examine friction and adhesion properties of two common types of biomass. It is unclear whether the tested particle size, 2 mm, is representative of what markets will demand.

- Management: Very clear outline as to responsibilities. Is there a risk in depending on Forest Concepts for a lot of the work? If they are a for-profit organization, their priorities may change. There could be some additional thought given to risks. One risk may be that the measurement focus may not correlate to meaningful practical metrics. Small project team. Critical success criteria could be: (1) develop a means of measuring biomass particle interactions and (2) apply evaluation to corn stover and pine residues (friction and adhesion)

  Approach: Excellent fundamental research. The road to industrial utilization could be long-term, which doesn’t mean that this work is not valuable. Very impressed with the scaling of the nano equipment measurement for particle size. Would like to see a list of all characterization that will be done on the particles. At what stage in the process is this scale of particles important?

  Impact: At what stage in the industrial process is this scale of particles important? Need to scale the information to chips or ground material. This work is very relevant for composite materials, where very precise feed rate is very important. Is the PI working with a theoretical model that can be related to a practical measure such as flow or agglomeration propensity? I don’t see the path to practical application to this excellent research.

  Progress and Outcomes: Results thus far look to be on course with expectations.

- There is a good management team, communication plan, goals, and project timeline. I believe there needs to be more detail on potential risks and mitigations plans added. I would have liked to have seen what the basis of the go/no-go decision was or is. The project approach is solid and not only builds upon previous BETO work, but if successful in understanding the particle-to-particle and particle-to-wall interaction causing adhesion, the project conclusions could also help immensely in solving a serious handling problem for the industry. The project doesn't necessarily create innovation as much as it will develop information to make way for innovation. If the goal is met to enable engineering of successful preprocessing and handling systems to produce feedstocks that enable conversion systems to work reliably, there is no downside to this project. It could be significant in its impact. The project met its goals and timeline and employed mitigation where needed. It will be exciting to see the project as it moves into the future.

PI RESPONSE TO REVIEWER COMMENTS

- This project focuses on characterizing interparticle mechanics of milled corn stover and southern pine residue following the FOA requirement. Based on the correlation analysis between particle scale measurements and bulk scale flow properties, we expect to gain insights into the flow characteristics of anatomical fractions and blended samples of each species, which will be included in the final report. We are focusing on milled biomass passed through a 2-mm screen as the most widely used reactor-ready biomass feedstock for thermochemical conversion to liquid fuels and polymers. The choice of biomass particle size is intentional to impose better control over variability analysis. The main focus of this project is to quantify the variability of inter-biomass particle properties between different species (corn stover versus southern pine residue) or different anatomical origins at different moisture contents. To characterize milled biomass particles of multiple feedstocks, we are developing multiple force sensor beam designs with varying resolution and precision for varying mechanical properties expected from milled biomass particles of different species and anatomical origins. Another potential risk in the accurate estimation of contact area will be higher in the case where the biomass particle surface is excessively uneven. We have plans to mitigate this challenge, including microscopic imaging of surface or characterization of surface profile using a precision surface profilometer prior to the sample preparation. Also, the variability of inter-biomass particle properties may be more considerable than expected, which will require more extensive numbers of tests than planned. To mitigate this potential risk, we plan on using the Bayesian statistics approach, which will provide additional statistics on the variability and correlation with probability rather than a wide confidence interval. Also, we can consider adding the number of tests on biomass particles from more abundant and important anatomical origins to maximize the impact of the project with a higher confidence level.

Budget period 2 focuses on developing a micro-mechanical device appropriate for measuring the proposed inter-biomass particle properties, whereas budget period 3 focuses on the measurements. Naturally, the budget period 2 go/no-go decision criterion depends on the successful development of micro-mechanical devices for characterizing friction and adhesion between biomass particles and between a stainless-steel surface and biomass particle collected from different anatomical fractions of corn stover and southern pine. This project will be among the first efforts to produce direct knowledge on the expected variability of bulk biomass properties emerging from the particle-scale measurement. This project will produce critical and as-yet unavailable measurements for a discrete element modeling approach. An accurate discrete element modeling approach is expected to impact engineering practice to overcome the prevalent problem in handling biomass. We will explore patenting the developed design of a micro-mechanical biomass particle test device. Depending on the technical difficulty of developed test protocols, we will pursue commercialization of the test device or characterization services. More importantly, we will pursue developing test and data standards that the industry can adopt.

Based on the findings of this study, we expect that future research will explore a wider variety of biomass samples and conditions, including moisture, ash, storage method, and particle size. We also expect that experimentally determined particle-scale properties will advance the calibration of discrete element modeling by providing particle-level mechanical properties that must be inferred today.

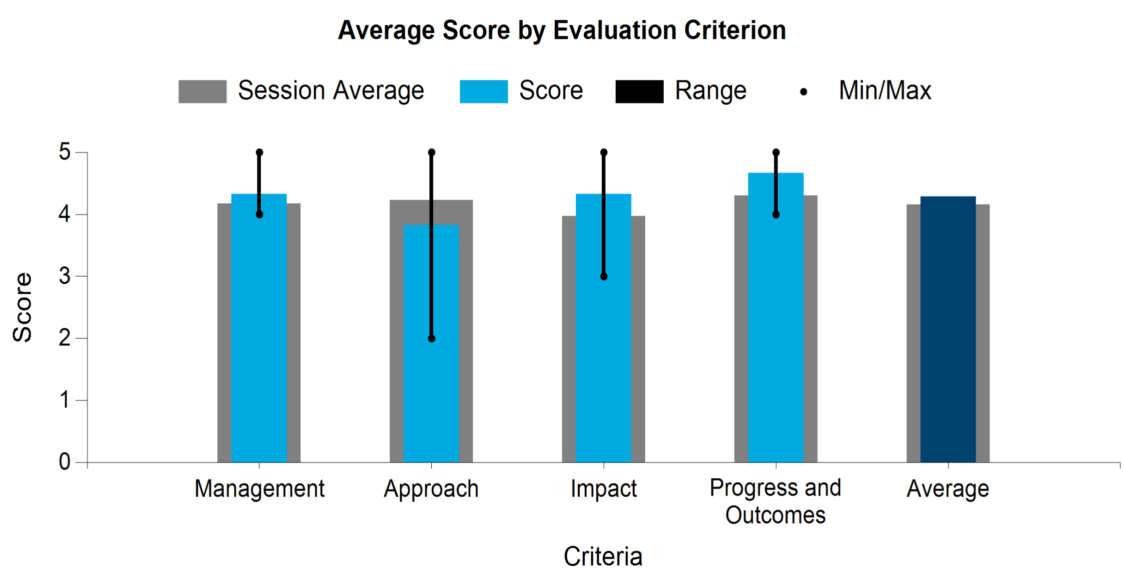
FEEDSTOCK SUPPLY CHAIN ANALYSIS

Idaho National Laboratory

PROJECT DESCRIPTION

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

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 creates 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 leads 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 $85.51/dry ton (2016$) and 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 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 modeled cost, quantity, and quality specifications required to meet long-term BETO biofuels production, cost, and volume targets. Beyond design case development and annual state-of-technology (SOT) tracking, this project performs high-impact forward-looking analyses toward enabling the development of advanced feedstock supply systems. The project was last merit reviewed during FY 2020, and its current 3-year cycle runs through FY 2023.



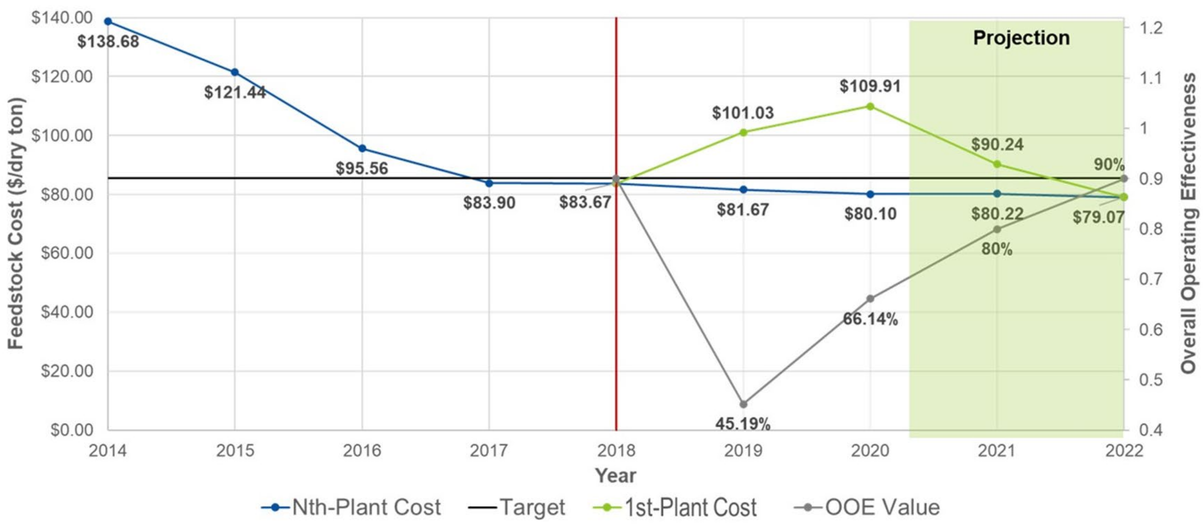


Photo courtesy of Idaho National Laboratory

COMMENTS

- This project presents the DOE goal of $85.51/dry ton. Analysis is presented for a 2,205-dry-ton/day plant. The analysis is put into perspective for me if I suppose the surrounding land area within a 30-mi radius is in feedstock production, and the average yield is 3 dry tons/acre. It will require 13.4% of the total land area to supply the 2,205-dry-ton/day plant. If the yield averages 1.5 dry tons/acre, the requirement is 26.8%. The key question is, how many locations in the United States could support this size biorefinery? If the analysis was done presuming that a series of depots would supply the large biorefinery, this was not explained in the presentation. Your analysis of the processing options is impressive. In order to properly evaluate the current biorefinery knowledge base, I need to know processing cost as a function of plant size. For example, suppose the processing cost for a 400-dry-ton/day plant is $3.00/GGE, as compared to $2.50/GGE for the 2,000-dry-ton/day plant. The feedstock cost at the 400-dry-ton/day location is $0.50/GGE, giving a total cost of $3.50/GGE. The feedstock cost at the 2,000-dry-ton/day location is $1.00/GGE, giving a total of $3.50/GGE. Both locations can compete in the market. At a higher level, why does BETO care if the cost is $3.53/GGE for blended feedstock in Tennessee, $3.74/GGE for energy cane along the Gulf Coast, and $4.00/GGE for willow in New York? (These figures are for discussion only.) Let the competition take place at the liquid fuel level. If a liquid fuel supplier has a demand for *x* million gallons of renewable fuel, they will buy $3.53 as long as it is available, then $3.74, then $4.00, if needed. The biorefinery industry will build out accordingly. The use of the $84/dry ton goal in the FOA implies that a project will be nonresponsive if the project team calculates a higher average delivered cost. I hope this is not the case. If I have misinterpreted, I hope the project manager will clarify. In order to realize the potential of the Billion-Ton study to meet the nation's renewable fuel needs, we will need a variety of feedstocks (all of the above). I am a firm supporter of the diversity of projects funded by BETO. By agreeing to be a reviewer, I hope I have helped move the biorefinery industry forward.

- In first-plant or nth-plant design, there are two major components of analysis for each equipment used in the block flow diagram: risk and cost. I understand scale-relevant data is a major challenge. In addition to that, what are the major risks considered in the analyses, and how can they help enhance the robustness of the analytical results? It seems preprocessing presented the highest greenhouse gas emissions compared to other processes. It was not mentioned how the technology advancement can help reduce the emissions. Cost progress has been discussed from 2018 SOT to 2019 SOT and beyond. Transportation cost was changed from $31.56/dry ton in SOT 2018 to $12.22/dry ton in SOT 2019. What was the major driver for that change? On the other hand, tech advancement was introduced in FY 2019–

2020 for preprocessing. However, preprocessing cost seems to increase steadily. It is not clear how this cost can be reduced as tech advancement being used in the future plant design.

- Management: Appreciated the clear description of the evolution of this project. Slide 3 was very helpful. The risk to the successful completion of the project is a major one (i.e., lack of sufficient scale relevant data). Detailed description of management structure provided.

  Approach: Level of detail presented is very helpful (i.e., top-three technical challenges).

  Impact: Excellent attempt to validate the work with presentations to Drax, ExxonMobil, and Shell, as well as at international meetings. This will obviously help to steer the project and make sure that it will be of high impact.

  Progress and Outcomes: The model will become more impactful as new technologies that may better homogenize the biomass can be included. Is its application also to predict the savings of applying these technologies before they go into full development—for example, if a new air classifier can produce a few streams with higher quality? I have some reservations about the value added to fractionated materials, and this model should hopefully help to elucidate their value through the whole supply chain and bioconversion process.

- Management: Management includes two teams with heavy representation by the national labs. Project management brings together other project managers and their research outcomes. There is a tightly structured communication plan. The schedule and progress are milestone-driven.

  Approach: The approach outlined is broad and incorporates research findings on growth, yield, harvesting, collection, and transport of biomass. Technical challenges (risks) are identified and address such topics as the lack of complete data sets for harvesting and preprocessing across multiple biomass resources.

  Impact: This project is a technical application of funded research. If a new approach requires new tools, this project develops ways to model it.

  Progress and Outcomes: Progress and outcomes are on target.

  Overall Impressions: This is a foundational project that relies on other BETO-funded projects for information to develop a supply chain analysis.

- This project coordinates and tracks progress across several BETO projects and seeks to develop and test veracity of the information and put in one place this information and tools to aid industry in the development and design of state-of-the-art supply chain and preprocessing systems for feedstocks for conversion across multiple conversion techniques. The team has an excellent communication plan and multiple annual milestones to keep the project on track. The project team has developed a solid approach from a technical standpoint that recognizes the challenges and has plans to meet them. I am again not sure what is included in the feedstock harvesting and delivery costs, and these seem to be higher than what industry is already doing. While the project in innovative and informative, I am unsure of what it does to drive innovation. The project has a very good plan, has made progress to inform industry where the SOT is, and has developed good analytical tools. To the extent the project addresses industry problems and is suggestive of solutions to these problems, the project will be impactful and advance the BETO MYPP. For example, if the project can provide a design basis addressing material bridging and plugging, then it will be very impactful to project developers. The project has made significant progress and has stayed on its timeline, adhered to the plan, and used mitigation techniques where needed. I find this project could be very informative and impactful for industry. However, I would like to see the results discussed with industry already performing on a commercial scale some of the processes being modeled.

- This project is well managed and very informative. I particularly appreciate the granularity and cost breakdown of feedstock costs. In time, these feedstock costs may stay the same as the quality of the preprocessed feedstock and the value climbs. I believe this work is a very real steppingstone for the advancement of corn stover and other biomass feedstocks. Impressive work, thank you.

PI RESPONSE TO REVIEWER COMMENTS

- Our role in the BETO FT platform is to develop supply system design cases to determine the research and development performance targets necessary to achieve BETO goals, as well as track research and development progress toward achieving those targets. Additionally, we help to develop innovative approaches that may not be obvious with forward-looking analyses that consider new equipment and system configurations that may be utilized. We have research and development projects looking at material bridging and plugging, as this project is focused on cost, quality, and operational impacts; when sufficient data/models have been collected/developed to include these impacts in our cost and operating effectiveness analyses, we will inform BETO and industry on their relative impacts to operability and cost. We have shared our results with industry and are continuously looking to them for at-scale information to better inform our stochastic models in regard to equipment performance and downtimes.

  For both first-plant and n^{th}-plant designs, the major risk in the analyses is the uncertainty in biomass composition and quality. For cost it is the uncertainty in biomass yield. Technology developments can help to reduce greenhouse gas emissions in preprocessing through looking for lower-energy-intensity equipment for comminution, looking for process efficiency, and ensuring that you have the right equipment for the different feedstock characteristics. Additionally, finding opportunities for process intensification can contribute to reducing greenhouse gases.

  The transportation cost change referenced is from the ex situ catalytic fast pyrolysis case in the supporting slides. The 2018 SOT for this case utilized 100% clean pine, whereas the 2019 SOT utilized 50% clean pine and 50% residues. Hence, the difference was due to increased resource density close to the biorefinery. Preprocessing costs projected for 2022 are higher, but this included leaching of a small fraction of the residues to reduce ash. Preprocessing costs through the 2020 SOT were decreasing due to the conversion process relaxing the ash specification from 1% to 1.75%. The ash specification for 2022 will be back to 1%, and so the high ash lights fraction, which will not be leached, will need to be repurposed for value-added applications in a different market with a value higher than their cost at the point of removal from the preprocessing system. A collaborative analysis among North Carolina State University, Oak Ridge National Laboratory, and INL performed during 2020 found that at the 2022 target delivered feedstock cost of $79.07/dry ton (2016$), 124 depots and 59 biorefineries of this scale could be supplied with 42.8 million dry tons of blended corn stover and switchgrass (blended to meet the carbohydrate specification). The manuscript for this work has been accepted for publication in *Applied Energy* and is in press.

  Regarding preprocessing cost as a function of plant size, we have done some sidebar analysis directed toward this question with the National Renewable Energy Laboratory to support one of their 2019 milestones for the herbaceous case. Because of economies-of-scale issues for the conversion process, 2,205 dry tons per day is about the smallest size that can be overall economically competitive. To support their milestone, we did an analysis looking at corn stover and switchgrass supply for biochemical biorefinery sizes ranging from 100,000–800,000 dry tons/year (304.9–2,439 dry tons/day) and delivered costs of $50–$85/dry ton. We presented those results at the 2019 AIChE Annual Meeting, but they are unpublished. We found that the maximum quantities of feedstocks delivered at smallest biorefinery size were 108 million dry tons of three-pass corn stover, 46.6 million dry tons of two-pass corn stover, and 32.8 million dry tons of switchgrass. As the size of the biorefinery increased, the quantity delivered decreased, highlighting the diseconomy of scale that is present in feedstocks. While not a part of this project, within the FCIC we are working with the biochemical conversion TEA group at the National Renewable Energy Laboratory to explore the cost trade-offs of improved conversion performance/lower costs of running the conversion in campaigns of individual stover tissues. We found an increase of \$0.01/GGE (2016\$) in the minimum fuel selling price due to the addition of air classification in preprocessing, while on the conversion side they found a reduction of \$0.31/GGE due to more efficient conversion.

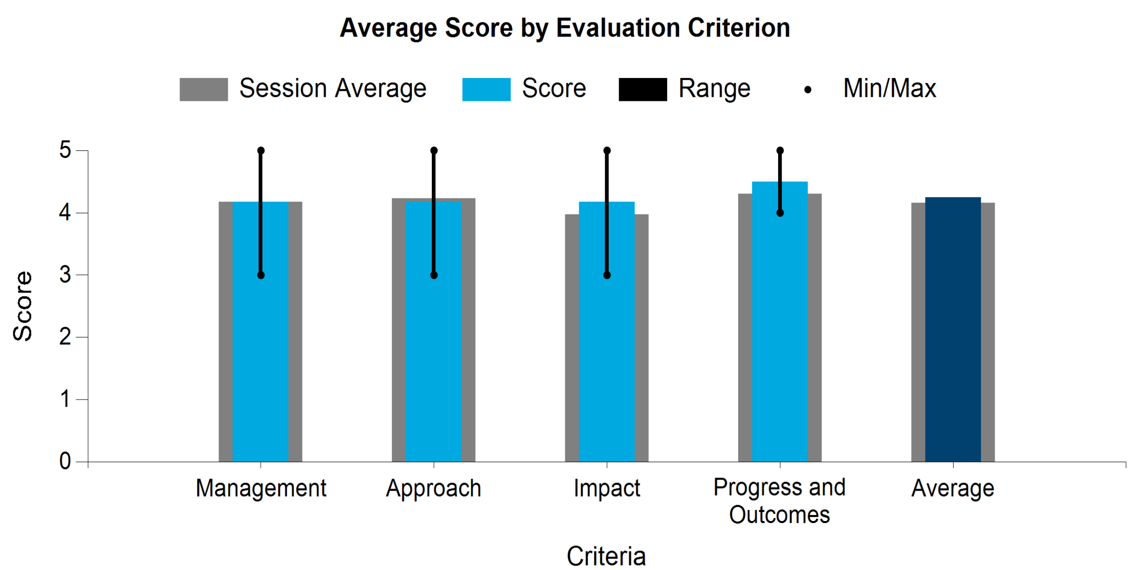
SUPPLY SCENARIO ANALYSIS

Oak Ridge National Laboratory

PROJECT DESCRIPTION

WBS:	1.1.1.3
Presenter(s):	Matthew Langholtz
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023
Total DOE Funding:	$1,125,000

The goal of the project is to provide DOE and bioeconomy stakeholders with biomass feedstock data needed to develop strategies to de-risk the biomass supply chain. These data include information regarding biomass feedstock quantity and cost, as well as environmental effects associated with producing, harvesting, and transporting biomass. Because these data can vary by feedstock type and spatial distribution, they should be generated under assumptions that reflect specified bioindustry scenarios. For example, biomass feedstock data should reflect the scenario-specific feedstock demand characteristics regarding type, quantity, and spatial distribution of feedstock required. Economies of scale from the position of the biorefinery, and "n^{th}-plant" mature-industry feedstock use, run counter to potential diseconomies of scale in feedstock supply. This project applies feedstock supply analytics to account for these scenario-specific feedstock supply attributes. Furthermore, understanding the environmental effects of marginal additions of biomass in the United States or in a region, as well as the intersection of cost and environmental effects, can help DOE and bioeconomy stakeholders identify feedstocks and regions that constitute the best opportunities to grow biomass. An additional objective is to examine trade-offs or synergies between price and environmental effects as biomass supply, especially energy crops and residues, increases across the United States.



COMMENTS

- This is impressive work, and I hope my brief comments here can contribute. Feedstock costs do tend to come down (less haul distance, less haul cost) when the facility size is reduced. This was pointed out in the "biopower" slide. One issue, and I do not know if it falls within the scope of work for this project, is the competition than can develop between a biopower plant and a biorefinery. In Virginia, we have a wood-fired electric generating plant that competes with a paper mill for wood chips. At the time I studied this issue, the electric plant operated "spot market," which I found amazing. How can they do that and get 150 loads per day? The issue is this: How can a 2,000-dry-ton/day biorefinery compete with a series of small biopower plants scattered across their supply shed? Contract considerations become key in supply chain analysis. I mention two considerations from the standpoint of a feedstock contractor: (1) length of contract (multiyear), practically of concern if I plant switchgrass to get a contract, and (2) a contract rider tied to energy prices (if energy prices go up, I get to participate; I also take part of the hit if prices go down). I appreciate the "increasing nitrogen use study." Did not know that this work fell within the purview of BETO projects. I did not understand the "parallelization" slide. In general, most of the slides in all the national lab presentations had too much information. I understand the problem when you have a lot to cover.

- The Billion-Ton study/report is a great piece of work and has been cited and refenced by many researchers nationwide. As the PI mentioned, increased precision has not increased accuracy of the results/data. I am wondering if the models used in the Billion-Ton study could be validated with regional- or state-level results, given that many states do have relatively robust biomass production and availability data. The data by the Forest Service in *Forest Resources of the United States, 2017* (https://doi.org/10.2737/WO-GTR-97) could also be used to some extent for comparisons and validation purposes. The Forest Sustainable and Economic Analysis Model is used as the major tool to estimate forest biomass production/yield at a county level of a state. How is this model validated for applications nationwide? It is not clear what the major assumptions are in the model. The Forest Vegetation Simulator by the Forest Service is a good tool to project growth of biomass potential. PIs present impressive, refereed publications. Carbon sequestration of logging residue and whole trees were considered in the analysis. Mill residue should be also considered. I also assume whole trees here refer to entire trees harvested only for biomass. Some details are needed for future work of supply chain analytics.

- Management: The project team has a clearly defined management plan. Risks regarding attributes and the impact of those were acknowledged. A communication plan that includes interactions with BETO program managers and other working groups was also presented.

  Approach: The approach discusses current and future work that is relevant to the BETO program. The project performers are developing approaches to look at subcounty-level data. This change is significant because it changes the scope of the project from thousands of counties to millions of fields.

  Impact: This project is an integration of data into the Policy Analysis System Model (POLYSYS). It is closely connected to many other BETO portfolios and spans the full supply chain. The list of supply chain publications is evidence of the range and impact of this project.

  Progress and Outcomes: An analysis of how the supply response would change in response to market pull was just one example of the project's progress and outcomes. This project could examine future supply chain scenarios as future research results are added to POLYSYS.

  Overall Impressions: This project can examine future supply chain scenarios as future research results are added to POLYSYS. A strength of this project is the team membership. This team is able to pull together a variety of interrelated research results to examine the economic impacts of various supply chain scenarios.

- Management: Not a lot of detail provided. A plan for active dissemination to industry would be helpful in addition to the academic papers. Is there a website where this information is available to the public? Are there any risks or roadblocks to project implementation/completion?

  Approach: While the objective is obviously important, in that biomass supply/cost data need to be available for the development of the bioeconomy, I had a hard time following the technical side of the presentation. One aspect that was mentioned in a few presentations was the benefit to ecosystem services of certain crops. Is this incorporated in the model? Realize that there may not be enough data available to model this at this time. I didn't follow how the n^{th}-plant scenario was developed, but this is a useful process, as it will help to identify the areas where the most significant savings can be made to reduce the costs.

Impact: This project is obviously valuable, as this is information that is absolutely required for biorefinery development, especially on the regional basis.

Progress/Outcomes: From the presentation, I was not clear as to whether the information presented was done as part of this project or is information that had already been derived. It would be nice to see a clear picture of the expected deliverables for this project.

- The project has clear management plans and risks. The project has clear goals to maintain the current system and improve it to support DOE. There is less clarity on what data will be generated, but it appears the project goal is to generate data requested by others to support industry. It's unclear to me if the project intends to focus on what biomass is already out there currently or what is possible based on demand, or both. It appears that the project can generate data sets and manage data accuracy risk through peer review. It appears this project is a continuation of an already established modeling system, but it seems important to maintain and improve this model.

- There is a good project management team with an adequate communication plan that involves other BETO projects, as well as recognition of project risks. I am not sure that mitigation plans are adequate; for example, erroneous resource or supply cost data may not be mitigated with peer review, but certainly can be mitigated with field data gathering. I don't see the approach as innovative or necessarily providing for innovation. The future work to obtain subcounty (individual field/farm level) data would be valuable, but I am not sure how you would get these data. Individual farmers are very reluctant to share such information, and many are developing efforts to monetize these data. For these field-level data to be useful, one would have to not just gather field-level data on yield, but also agronomic and farming practice data; for example, what seeds did the farm use, how and what fertilizers were applied, and when? Then one might be able to model best management practices at the farm level that would be useful for interaction of developers with farmers. The models and information can inform and be of value to other projects. Project data can be used to benchmark other data sources and models to find gaps and/or discrepancies within each other. The project impact could be significant if the modeling was field-tested to ascertain its veracity and thereby build confidence in its use. The project has kept up with their timeline, and the proposed outcomes are interesting in the least. For example, there was more than one reference where large swings in supply were not represented by corresponding swings in price. It would be interesting to follow this to a conclusion. A question to be answered would be if this is because biomass doesn't travel well, meaning you cannot move it long distances economically. The project has a chance to have significant value across the BETO project chain by taking steps to field-test the model results. It would also be useful to go deeper to understand what affects yields and supply at the field level, such as best management practices at the field level.

PI RESPONSE TO REVIEWER COMMENTS

- We agree with the suggestion to mitigate resource supply and cost data uncertainty with field confirmation. County-level yields were derived from the Sun Grant Initiative Regional Feedstock Partnership field trials (https://doi.org/10.2172/1463330); the project would benefit from reviewing the crop budgets, which influence adoption production response. We agree that the subcounty field data would be an asset and may be difficult to collect, but we have found that the Gridded Soil Survey Geographic Database data combined with the Cropland Data Layer can provide subcounty crop and soil attributes, possibly also the Common Land Unit data set, all from USDA. We agree that simulations of best management practices would be an asset, and we are exploring options to quantify environmental effects of biomass production based on subcounty attributes (e.g., soil type, slope, and proximity to water). The PI should have clarified that the primary data generated is county-level biomass production (as a function of price, year, and scenario), available at https://www.energy.gov/eere/bioenergy/2016-billion-ton-report. These data are fairly static for resources that exist today (i.e., wastes, residues, and forestland resources); the energy crops are scarce today but have growth potential assuming adequate market demand.

We agree that USDA Forest Service data are useful for validation. Transportation cost is a factor that adds cost and is quantified in case studies in the latest Billion-Ton Report. The U.S. Forest Service Forest Vegetation Simulator was used in the 2011 Billion-Ton Report, and the U.S. Forest Service's Forest Inventory and Analysis data are inputs in the Forest Sustainability and Economic Assessment Model. Mill residues reported by USDA are included as secondary wastes in the biomass supply data.

We agree that competition for biomass resources among new end uses should be considered, and following Peer Review, BETO requests new emphasis on understanding market-based cost-minimizing biomass allocation for fuels, power, products, and decarbonization. Feedstock contracts that begin in a specified year are simulated in the POLYSYS, but question of a contract rider tied to energy prices has not been included. This is a good suggestion and should be explored. This could be simulated by varying offered feedstock price. We note that environmental externalities are not included in our supply analysis but strongly agree that they can and should be. We thank the reviewers for the constructive suggestions.

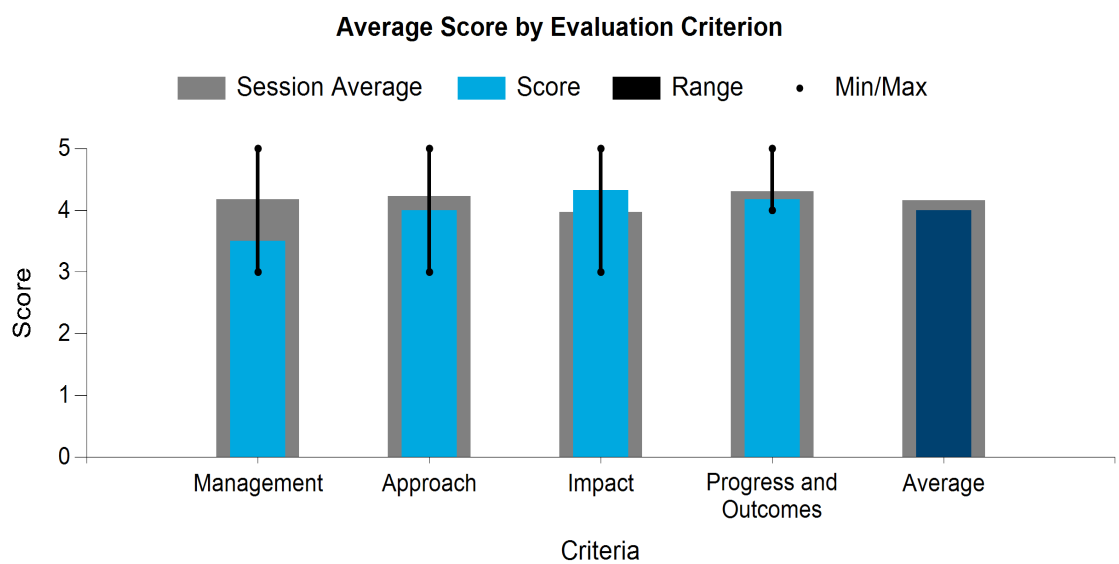
SEED PROJECT: CHANGES OF PRICE ELASTICITY OF SELECT WASTE FEEDSTOCK WITH INCREASED DEMAND

Oak Ridge National Laboratory

PROJECT DESCRIPTION

WBS:	1.1.1.5
Presenter(s):	Matthew Langholtz
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2021
Total DOE Funding:	$150,000

The objective of this project is to support the Waste-to-Energy platform and the Feedstock Technologies platform with projected feedstock cost assumptions. As the Feedstock Technologies platform explores “economically advantaged feedstocks,” it is currently unclear if low or negative prices will persist in a free market if demand for these feedstocks increases. Specifically, we will evaluate what may cause a shift in feedstock prices of organic wastes over time as demand increases. This will include a causal analysis of the change in market demand (i.e., what caused the change in demand over time, such as technical progress, regulatory changes, evolution in potential target markets, and shortages in existing supply chains). It is important to quantify the pattern of changes in the price elasticity of supply over time to understand the competitiveness of fuels produced from waste resources and their economic sustainability over time. Price elasticity of supply quantifies the change in the market value of a resource associated with a corresponding change in demand. This would support industry and government research and development planning and reduce uncertainties about the prospects of waste resources for fuel bioenergy uses.



COMMENTS

- The following statement is made by certain leaders in the environmental movement: "No U.S. city is sustainable." I agree with this statement. Food must be shipped in (unavoidable), and waste must be shipped out. This project addresses the utilization of waste to reduce landfilling, specifically the hauling of waste to a remote site outside the city. I agree with the decision to define the organic portion of MSW as a renewable energy feedstock, though this is not always done. The choice to use yellow grease and dried distillers’ grains as example markets makes sense to this relatively uninformed reviewer. (I have never done any work on waste utilization.) It is reasonable to me that this work is done within the mission of BETO.

- Approach/criteria: Why is $R^2 > 0.5$ set as a threshold? R^2 is not the only criterion to judge the robustness, sufficiency, and completeness of the data and models. A simple linear relationship was assumed for many cases of the study. It seems such a relationship does not exist in some of the cases. Other types of relationships, such as nonlinear, should be explored.

- Management: The project was presented as a short (2-year) and straightforward seed project. Team membership includes private industry, which should aid in identifying risk and mitigation strategies. Little information is available on MSW demand and pricing. There aren't any recorded prices for MSW if no one is buying it. Reliable supply and price data are hard to find, and once they are recorded, they are no longer a waste, but a resource.

  Approach: In this seed project, innovation will be required to use proxy resources and case studies to analyze at least two waste price elasticity of supply scenarios. A go/no-go point is defined.

  Impact: Recycling waste can result in environmental and societal benefits. When a resource has no value and a cost for disposal, it may be free for the taking. Once demand for that resource grows, it becomes a valuable commodity with a pricing structure. This project seeks to understand this potential market and the price elasticity of supply of waste. Industry engagement is included in the project's team.

  Progress and Outcomes: The project has already examined other waste products and the change in their supply and pricing over time. Future work involving two existing markets is planned.

  Overall Impressions: There are millions of tons of waste biomass. Other BETO projects are currently examining sorting and preprocessing costs. The results of this study, combined with the others, will aid in developing a TEA of waste as a resource.

- Management: This project has a difficult mandate—attempting to cost out waste products and their price elasticity with regard to supply/demand. The very term of waste denotes a negative cost, but we all know as soon as a beneficial use is identified the waste becomes a resource with a positive cost. Exploring this relationship is very valuable for long-term evaluation of this material as a resource for the bioeconomy. I think this is one of the most difficult projects but also one of the most innovative. Good data availability is a true risk identified. A good starting point is to identify what data are needed on a continuing basis. Case studies are only a very specific snapshot, so there should be some sensitivity analysis that helps to put them into broader perspective.

  Approach: The case study approach seems to be adequate for an initial evaluation of price elasticity of supply, especially given the availability of data constraints. There is a bit of cautious optimism that reliable data can be acquired, and that it will lead to a statistically significant trend. Waste is such a difficult resource! Many changes that are taking place in the packaging industry will significantly change the type and supply of waste materials, as will changes to MSW recycling programs. These models will be very helpful in predicting the implication to pricing for these and future changes.

  Impact: This work has a significant impact, and its outcomes will be widely used in evaluating an investment. Unclear as to how the project will communicate the findings to industry.

  Progress/Outcomes: Results collected thus far did not show meaningful trends. The metric used is easy to understand and is applicable ($/ton increase per 1% demand increase). The actual case studies proposed will be very interesting. Hopefully the PI has verified that pricing data and consumption can be obtained for the period of study.

- The project has a good management plan, solid data gathering plans, risk recognition, and mitigation plans. There was no communication plan, but this is a minor drawback as the team is small. The approach is good. I especially like the use of proxy data of real-life price histories for waste products to develop modeling scenarios. I do believe that one drawback is the lack of consideration for legislative actions currently taking place in the solid waste markets, especially where plastic is concerned. For example, three states have banned plastic bags and an additional five have banned single-use plastic bags. What effect does this have on the supply-demand curve and therefore pricing? The impact of the project is potentially important. More and more projects are economically viable with low- or negative-cost feedstock, but understanding the future of the supply demand curve and its effects is paramount. The project has followed its plan and shown clear data delineating price elasticity based upon supply-demand curves from existing sources such as yellow grease, distiller's grains, and refined glycerin. This is a good project that can have significant influence for projects using waste products as feedstock. The major drawback, but one that can be rectified, is adding data when available showing the effects of policy and/or legislation on plastic waste supply, demand, and pricing curves.
- This is an interesting tool to help understand future implications of moving biomass. I like how it was presented, and it appears to be managed well. This model concept would be helpful in determining supply/demand futures. Although I'm not an expert in modeling, I see the value and feel this process can produce important information. Thank you, well done.

PI RESPONSE TO REVIEWER COMMENTS

- The suggestion to add data showing effects of state policies is interesting and will be explored, as well as the suggestion to include other statistical attributes of the data. The R^2 threshold of 0.5 was arbitrarily selected and can be revisited. We will also assess the nonlinear relationships between supply and price, as we would expect price elasticity of supply values to vary within a data set because elasticity would decrease as waste supplies are exhausted. We agree that availability of waste supply and price data can be an analysis constraint. The suggestion to consider changes in the packaging industry is interesting and will be considered. The first case study finished after Peer Review has shown a price change in response to a supply shock; results from the second scenario remain to be quantified. The suggested sensitivity analysis for a broader perspective will be investigated. We agree that results may have implications for price assumptions, and we will explore options to communicate findings to stakeholders. We thank the reviewers for the constructive suggestions.

FEEDSTOCK HARVESTING & STORAGE: POST-HARVEST MANAGEMENT FOR QUALITY PRESERVATION

Idaho National Laboratory

PROJECT DESCRIPTION

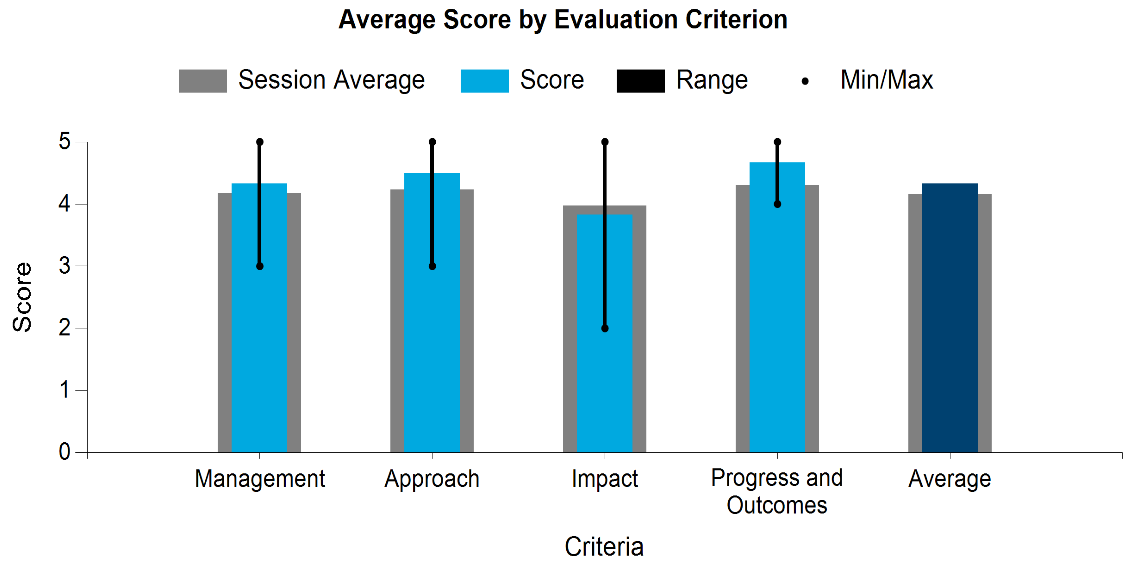
WBS:	1.2.1.1
Presenter(s):	William Smith
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2021
Total DOE Funding:	$2,840,000

Prior work by INL has shown that biomass consistency is difficult to control over the course of a year of outdoor storage. Storage costs and biomass quality must be balanced to assure delivery of a consistent feedstock. Prior designs focused on storage cost minimization; current designs evaluate the cost/quality trade-offs of alternative storage designs. This project focuses on the fundamental biological, chemical, and physical information needed to manage stored biomass, reduce the impact of environmental moisture, and promote moisture loss using functional and cost-effective means.

TEAs show that storage site improvements such as enhanced drainage impart modest cost increases of $0.80 to $1.58 over the on-farm design of the 2017 SOT ($6.55 per dry matter ton). However, the same analyses show that for each percent dry matter lost in storage, the as-delivered biomass price increases by $0.40 per dry matter ton. Results show how storage costs can be offset by improvements to dry matter preservation as little as 2% to 4%. Given the potential cost offsets for improved stability, we evaluated low-cost means to promote moisture loss in storage.

Experimental results and computational analyses were used to evaluate the potential for biological activity to enhance moisture loss via self-heating while maintaining acceptable levels of dry matter loss. Low-speed air movement through biomass was shown to reduce moisture content from 30% to <20% in 35 days with only 5% dry matter loss. Higher flow rates, available using on-farm equipment, have potential to dry a wrapped stack of 30% moisture bales at a cost of $5.71 per dry matter ton. This cost is comparable to 14% dry matter loss—an extent measured in past storage studies of high-moisture stover. While not economical for an entire annual feedstock supply, these costs could be borne by a portion of at-risk high-moisture materials, and the storage methods provide options in especially wet harvest conditions.

Feedstock quality monitoring requires rapid, accurate tools that can be deployed in the field. Storage time can be used to evaluate annual biomass supplies and identify quality variations and storage conditions that need attention. Improvements to our near-infrared (NIR) spectroscopic bale probe and predictive models continues with our partners Antares Group Inc. and Dr. Bonnie Hames. New ash models give us better results in materials up to 20% ash. These robust analytical tools enable quantification of critical components—glucan, xylan, moisture, and ash. Combined with computational models of biomass stability, these tools are the technical underpinnings of an information-driven biomass supply system that can reduce temporal variations in critical material attributes such as moisture, carbohydrate content, and ash in delivered biomass feedstocks.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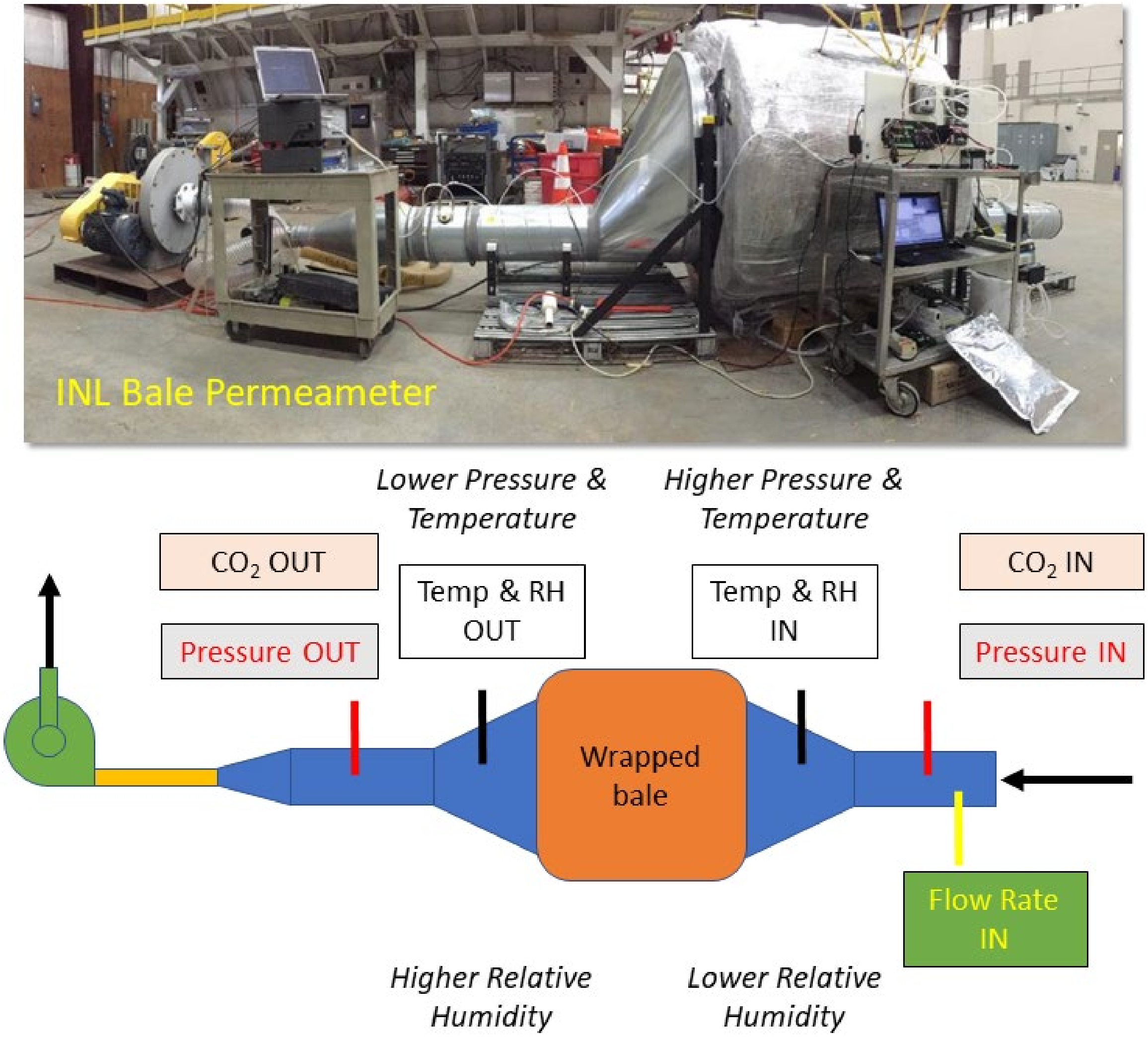


Photo courtesy of Idaho National Laboratory

COMMENTS

- I have no question concerning the need for this project. Large rectangular bales are, and will continue to be, an important harvest system in the emerging biorefinery industry. In the West and in certain parts of the Midwest, the large rectangular bale is the obvious choice. These bales are stored six high in ambient stacks, and these stacks are shipped during some buyer-defined week of the winter storage period. It is my view that the storage site needs to be graded and graveled to support vehicle traffic for load-out any week of the storage period. The cost for this gravel surface is a given; trying to operate on a sod surface is just not practical. Why is it ever a good idea to pick up soil stuck to the bottom of the bale given the now well-defined problems with ash content?

  1. Relative to the large rectangular bale stack, the top bale is exposed, has more rainfall penetration, and is more likely to be wet and maybe have other quality issues. Is there a way this bale can be identified in the load during shipment? Maybe it can always be the top bale. Then, during de-baling, it can be processed separately, if this provides a quality control advantage. The same is true of the bottom bale in the stack. How practical is this idea—cost versus benefit?

2. Most of the work has focused, understandability, on the large rectangular bale, but what about single-layer ambient storage of round bales? Some data have been collected, but I recommend more studies be done in the future. The round bale will be important in the Southeast and maybe some parts of the Midwest with high rainfall. I gave a "4" on Impact to hopefully encourage expansion to include round bale storage in the future.

3. My support of the work to develop the NIR probe is a bit self-serving; I have had a part (very small) in developing a method for inserting the probe into a bale. I will use this space to raise several points concerning the development and use of the NIR probe. I am thinking about probing the top layer bales when the load stops on the scales when delivering to the biorefinery. Bottom layer bales are not sampled. How does the quality determination based on sampling three top-tier bales compare with a weighted average based on sampling all bales? My personal goal is 3 minutes to complete the sampling. Why? A delay in unloading costs money—truck cycle time is increased and hauling cost is increased. Probing of round bales could measure a difference in properties of a round bale, weathered layer versus core. Is this useful?

- High-impact biomass was mentioned in the presentation. It is not clear that it refers to economic value, professing efficiency or environmental impacts. In addition to considering forest residue and energy crops in the future plan, the commercialization plan needs be discussed.

- Management: Good range of partnerships. Would be a benefit to include farmers or farm associations involved to give feedback on the direction of the project and its practicality to their ongoing practices.

  Approach: The main framework is to use storage to reduce extremes in quality and preconditioning to improve fractionation potential. Good combination of fieldwork and laboratory simulation will help to identify the operational challenges. Identifying the critical material attributes for downstream processing is a critical step, and it's good to see it part of the project. Focus on the most relatable properties such as dirt and moisture instability will go a long way to improving the consistency of the biomass.

  Impact: One of the goals is to enable informed decision and mitigation strategies; this will go a long way to gaining industrial engagement.

  Progress and Outcomes: Interesting findings from the field trials, reducing dry matter loss, by altering storage conditions. Meaningful presentation on the breakdown of costs. Can these costs be widely applied, or is it highly dependent on location and/or other factors? Is it reasonable to assume that the computational model based on the 100-L storage chamber be scaled up to industrial application? Good potential for NIR equipment for monitoring ash content. This would be very useful if the equipment is easy to use and can stay calibrated without ongoing correlation work. Are there plans to develop a practitioner's guide (i.e., best practices for farmers)?

- Management: This project places an emphasis on commercial relevance. Partnerships are formal and informal and include university and industry collaborators. Coordination with BETO program managers and other national lab groups is also included in project management.

  Approach: The approach includes field demonstrations, intermediate scaled tasks, and laboratory processes. It currently focuses on the showstoppers that are universal problems and uses the resources at INL to help leverage funds and knowledge gains. Industry partners will help relate findings to costs and performance.

  Impact: The project demonstrates a clear connection between annually harvested biomass and necessary storage to support year-round operations. Processes can occur during storage that may result in degraded feedstock quality and material-handling issues. This project looks at methods to limit feedstock variability. Connecting the cost of land to the value of improved storage was an innovative way of addressing some of the problems related to bale degradation.

Progress and Outcomes: Progress has been made on methods to control stover feedstock variability over time. Analyses have been performed to predict dry matter losses and compositional changes. The next steps were identified.

Overall Impressions: In this project, INL researchers continue to apply their expertise in understanding the impacts of storage on feedstock quality. The extent and scale of these initial tests have the potential to help support a year-round feedstock from an annually harvested crop.

- There are clear management plans. The desire to slow dry matter loss through drying is a great benefit and approach for industry. I'd like to see a clear bridge within the project and data from lab-scale bale dryer to the stacks of bales on industrial sites. This project has the distinct advantage of being able to evaluate commercial practices alongside the lab scale. Tarping, wind, relative humidity, bale stack geometry, and depth are all factors that will affect moisture and dry matter loss at commercial scale. I suggest in next steps broadening the approach and gearing the project data toward a recommendation for bale stacking/storage methods to prevent dry matter loss and moisture uptake. The project has generated interesting and useful data from the bale dryer, and I very much appreciate the reference to $/ton. That is very meaningful to industry. Thank you for a job well done.

- There is an excellent management plan with a good group of participants, including industry, labs, and university groups. The only thing lacking was a clear discussion of risks to the project and how to mitigate those risks. However, these risks and mitigation steps appeared later in the presentation. The project approach has solid recognition of the problems to be solved and methodology, and that depends very much on experimental results, which will then inform and verify modeling and TEA. There are clear quantitative go/no-go decision points. Herbaceous biomass long-term storage issues are significant, as many of the materials such as corn stover cannot employ "just in time" delivery systems. Any project that can advance and/or help solve these problems will be very impactful and clearly advance BETO MYPP goals by enabling bioeconomy conversion projects to perform up to their potential. The project's progress and outcomes show solid progress toward project goals and adherence to the project's timeline. Modeling was not just created, but verified for accuracy by field-collected data from tests and existing cellulosic projects. This project should prove to be very important by providing a basis for managing feedstock and producing quality feedstock management systems economically, not only without sacrificing quality, but also by improving it.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their thoughtful and constructive input. The reviewers clearly identify that the unique storage history of biomass relative to its format (i.e., round versus square bale) and storage environment (i.e., stack or pile location) affects its process performance. This is something that we have considered in our research—averages account for overall trends, but an annual feedstock supply system consists of a population that encompasses a range of material conditions. It is equally important to reduce the frequency of encountering off-specification materials as it is to improve the overall average quality of the material delivered to the biorefinery. For example, a challenge identified within INL's Biomass Feedstock National User Facility PDU (WBS 3.4.1.202) is that high-moisture regions within bales may contain >30% moisture, which significantly reduces mill throughput during size reduction. While the average moisture content of a top or bottom bale may be less than 30%, the impact of the higher-moisture zones within the bale increases its processing time/energy to that of a bale with a moisture content intermediate between its average moisture content and its highest moisture content. This supports the reviewer's suggestion that bales' stack positions should be noted, and that top and bottom bales could be milled in separate but parallel process conditions that address the problems associated with high-moisture materials. Such a design permits high throughput of the more numerous "average" bales while using separate lines to process the less numerous high-moisture bales. The economics of this possible solution can be explored using INL's Biomass Logistics Model, which has been used in our feedstocks-related research to track the impact of operational and cost improvements. Another option is to create storage conditions that reduce the top and bottom bales' exposure to water from the ground (surface and subsurface drainage) and enhance moisture loss from the stacks, which has been the primary focus of our research to date. Identification of these spatial biomass quality variations permits decisions that enable mitigation—either by storage improvements or by process operations—that improves throughput, uptime, and overall process economics. The modeled technical and economic impacts can be evaluated with help from INL's Feedstock Supply Chain Analysis (WBS 1.1.1.2). Tools such as the near-infrared bale probe, which was developed under a previous BETO High-Tonnage Logistics project (Antares Group, Inc. "B.A.L.E.S.S" project), permit rapid analyses during harvest, storage, and exchange (point-of-sale) operations for corn stover biomass. As a research tool, it enables temporal and spatial analysis of moisture migration and its impact on glucan, xylan, and ash content in baled stover and has been used in both round and "square" bales. We are sensitive to the reviewers' concerns that (1) it is currently only used for corn stover in low-temperature conversion pathways—not wood chips, and (2) it requires 7 to 10 seconds per individual sampling location to acquire results. Future work—in cooperation with our partners in the Feedstock-Conversion Interface Consortium—is proposed to develop NIR chemometric models for softwood and hardwood biomass, which are used in high-temperature conversion pathways. Additionally, our research team continues to work with Antares Group, Inc. and Iowa State University on a Small Business Innovation Research (SBIR) project to develop an automated probe insertion/extraction tool that can scan across a transect within a bale to get both spatial and average. The SBIR program offers support that enables small businesses to work with national laboratory partners to move technologies from the laboratory to commercial use.

The reviewers indicate that this project would benefit from greater input from the producers. To date, this research has focused on the needs of the biorefinery—principally, the processing and conversion performance of the delivered biomass. We admit that we can do a better job of getting grower input. In the past, we have relied on "early adopters" to provide biomass and storage sites for field trials—in exchange for access to the research results. Those informal relationships gave us valuable insight into the harvest and storage challenges faced by participating growers. Our focus on lower-level technology readiness levels and the current dearth of commercial biorefinery operations has cut back our field activities. A broader view of the operational challenges—the practical impacts of storage system improvements, for example—is needed. Potential opportunities include adding producers to existing BETO industry advisory boards, working with universities that are directly involved in relevant agriculture- and forestry-related research, and working with federal and state agencies such as the USDA Natural Resources Conservation Service, the USDA National Agroforestry Center, or the Iowa Corn Board to incorporate the practical outcomes of our research results into publications that are targeted to producers.

VALUE-ADDED PROCESS INTENSIFICATION IN THE SUPPLY CHAIN

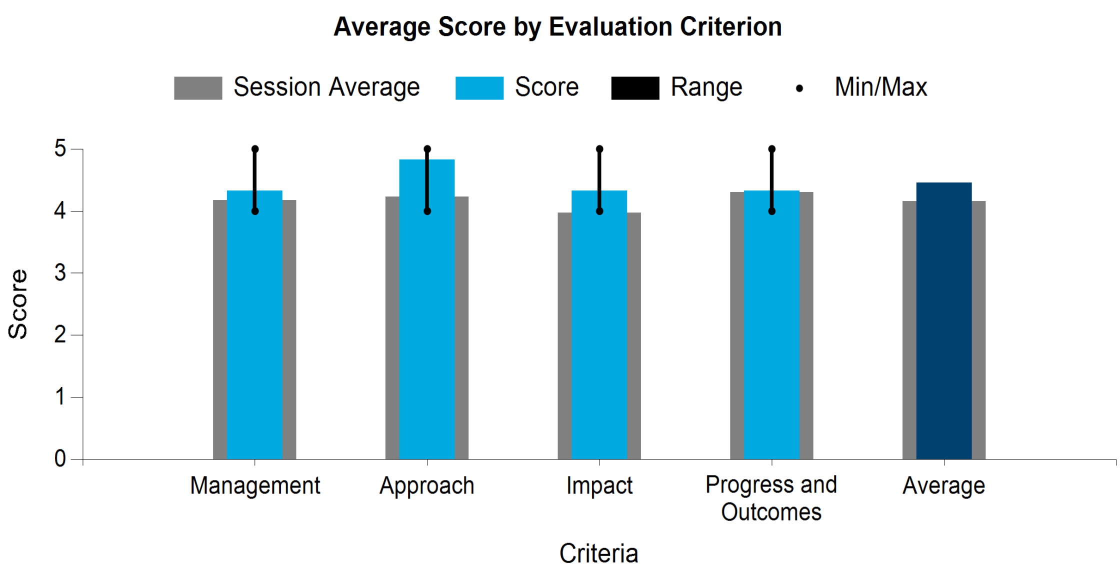
Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.1.1000
Presenter(s):	Lynn Wendt
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023
Total DOE Funding:	$1,540,347

Corn stover is one of the primary agricultural residues available for bioenergy production, but its cellular- and tissue-level complexity make it challenging to reduce to monomers that can then be converted to fuels and chemical precursors. The goal of this project is to improve the performance of corn stover for biochemical conversion to fuels and chemicals by reducing recalcitrance to deconstruction. The overarching aim of this research is to overcome the physiochemical barriers in corn stover that necessitate increased severity in conversion in terms of chemical loading, temperature, and time, during the residence time of long- and short-term storage operations. The hypothesis of this research is that low-severity chemical and microbial treatment during long-term storage will reduce the degree of polymerization through saponification of ester-linked side chains or glycosidic bonds in hemicellulose, or through oxidation of phenolic or non-phenolic components of lignin. These treatments will increase extractable components of corn stover and facilitate increased chemical impregnation and solubilization of structural components, leading to increased reactivity during downstream pretreatment.

This novel approach focuses on moving recalcitrance reduction upstream in the feedstock supply chain; thus, this passive operation that only preserves biomass will become an active environment that can positively impact conversion performance. Biological and chemical treatments applied during storage, one of the key unit operations in the feedstock logistics supply chain, were explored in this study with the goal of integrating these treatments into bioenergy logistics and conversion systems. Meanwhile, the mechanistic understanding of the biological and chemical reactions that can reduce biomass recalcitrance was to be obtained. The fundamental understanding on how these reactions change the biomass structure provided the scientific community with insight that can lead to new areas of exploration in bioenergy conversion. The overall product of this research will be performance data for a range of potential methods to provide “value add” in the supply chain. This research also addresses multiple MYPP barriers and contributes to the $2.50/GGE goals.



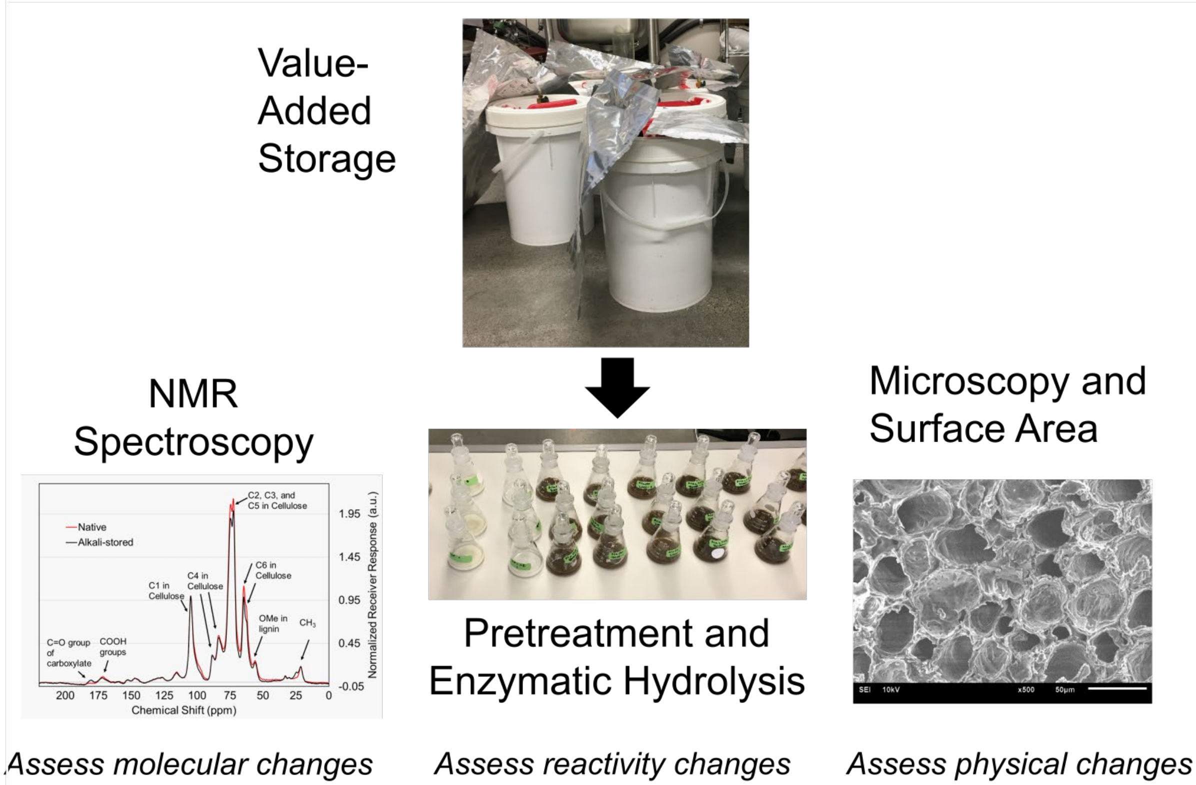


Photo courtesy of Idaho National Laboratory

COMMENTS

- The goal of gaining compositional change during storage that will provide benefit at conversion is important. If it is difficult to get the moisture content low enough for baling, as is the case in the northern region of the corn belt, then ensiling is an option that must be considered. The fact that it may be more expensive that baling and bale storage is not, in my judgement, a showstopper at this point. Let's define what these costs actually are in a production setting. I hope this project team will continue to do that and not be constrained by some current dollar-per-dry-ton goal. The project team has done some significant work over the last several years, and really done a good job of publishing their laboratory work. When reading the title, I expected to see slides for material being ensiled in 5-gal plastic buckets, and then a scale-up to a sileage bag, and then maybe a final scale-up to a silage tube. Maybe this has been done, but the presentation does not give detail. (I understand the time limit for the presentation.) My question is, is this project now at the maturity level (several years of history shown) where the project team can tell us what this technology looks like in a production setting? For example, I fill a sileage tube at a roadside storage, then pick this tube up with a module hauler (shown in the slide) after some storage period and deliver to the biorefinery. What happens next? How does the whole ensiling idea work in a production setting? This explains why I gave a "4" in the Impact and Progress and Outcomes categories. I realize it is difficult to compute a conversion cost benefit for the various ensiling treatments. (I may have missed important detail in the presentation.) BETO has a broad and very impressive talent base across the various national labs. A best-estimate conversion cost benefit can be computed, and I request that it be included in the next report on this project. One final comment—I asked the question after the presentation about how the chopped corn stover was collected. The answer was that it was collected after the grain harvest. Does this mean the forage harvester went through the field and lifted the downed stalks and chopped them? Not clear.

- It is a good project. However, it is not clear who the team members are and what their responsibilities could be to make/monitor the project progress. The project has refocused on value added instead of cost. I think both value added and cost can be considered simultaneously given that the project's ultimate goal is to increase the profit of biomass processing and storage for a facility. It is not clear what exactly the value-added components are and how much value these components can add to the process. Related test/experiment design and sample size need to be clearly defined to address progress and outcomes. In addition to focusing on woody biomass and herbaceous biomass for future goals, I think the scale-up of current study on corn stover can be further explored.

- Management: Project management resides at INL and includes membership across several national labs. This allows for integration of science and testing methodologies that are consistent across several projects in the BETO portfolio. Project risks are identified in the approach and impact sections. This ongoing project has resulted in several peer-reviewed publications.

  Approach: The project began in FY 2015 and changed the focus in FY 2018 from a cost-center to a value-added biomass storage project. The approach identified feedstock storage issues in long-term and short-term storage and proposes activities to potentially reduce losses and add value to biomass while in storage.

  Impact: The potential for alternatives to dry bale storage is innovative and has the potential for significant impacts on biomass storage systems.

  Progress and Outcomes: Progress has been made in the areas of long-term alkali storage and short-term fungi enhanced queuing that included not only feedstock response to the treatments, but also harvesting impacts. Dry matter losses are of concern and will continue to be examined as this project proceeds. Progress has also been made in isolating high-ash pine needles from wood residues.

  Overall Impressions: The progress and findings from this research project will be important for the future of bioenergy feedstock supplies. The potential impacts range from field operations through to the reactor throat. A TEA will further examine the impact of these opportunities for reducing losses in storage and improving extractive coproducts.

- Management: This project is a good illustration of the U.S.-centric approach seen in many of the projects in this review. Because this is the area of research in which I have been involved for the past 10 years, I feel confident to comment that there may be many lessons learned by those in other jurisdictions working in this field of research. It appears that all of the collaborators are only within the United States. These projects could benefit from cooperation with researchers in Europe and Canada facing similar biomass management issues. The management plan is provided in very general terms; hopefully as the project progresses, the items mentioned will become more explicit, with named collaborators and deliverables.

  Approach: Risks to the project results are identified, but I could not identify any risks to the management of the project in accomplishing the objectives. This project can lead to some very interesting and significant results that can have a significant impact on how the supply chain is managed. There are many technical risks that should be considered—for example, fungal mass itself may produce unwanted chemical components in downstream processing (i.e., proteins). These proteins may also account for added mass, consideration of the native microbial populations and their variability and how they will influence degradation (not controllable), etc. Perhaps many of these risks are already identified by the researcher, but because of the short presentation time she could not cover all technical and research aspects.

  Impact: Similar to some of the other research projects in this group, there is not clear evidence that a route to industrial engagement has been envisioned. This research is in an early stage, but I still feel that if the goal is to use the technologies, then there could be a road map to commercialization. This will help to identify the steps needed to get to industrial utilization. There are clear research outcomes that can be achieved, but taking the next step of industrialization is a large and difficult one, in my opinion.

Progress and Outcomes: Some interesting results are presented. Also, just wondering if the chart that has percent carbohydrates released is percent of dry weight or based on the potential carbohydrates available? Very nice work on using gas chromatography and gas chromatography/mass spectrometry for characterization work. Just wondering if this method is commonly used for quantitative results, or is it qualitative? I don’t understand enough about the supply chain, but the cost of $1.16 for receiving and preprocessing seems very low. Is this value from actual data, or hypothesized? I don't understand why storage time had no effect on percent glucose released. Doesn’t that mean that this strategy is not effective?

- The management plan is clear and concise. It has strong collaboration partners and a plan to disseminate results. There are regular milestones and a regular review process with BETO program management. There was not much in the way of project risk recognition and mitigation plans. However, risks were identified in the section on approach. This project's approach has used the novel and unique approach of "value-added storage" to store wet materials, and has met both its go/no-go decision and end-of-project goal of reducing feedstock cost during storage. These are just the types of projects that advance the SOT and BETO's MYPP goals. The project can enable any number of bioeconomy projects wishing to use wet feedstocks that have to be stored for virtually any period of time. To create storage that adds value and impacts the harvesting, collection, and delivery system for materials such as corn stover, as well as creating a system to minimize degradation, has huge implications and could easily become the state-of-the-art system. One thing that hasn't been mentioned is that if the harvesting of corn stover could be accomplished independent of moisture, the cost of that operation could be reduced significantly. The project has made great progress toward its interim and end-of-project goals and appears to be on its timeline. The project identified more than one benefit to the use of treatments such as alkalis for downstream conversion gains. It is difficult to ascertain if the timeline has been maintained, as the presentation didn't present a clear timeline. This project continues to impress with its value-added approach to long-term wet biomass storage. This advancement in techniques can be transformative in the management of feedstock variability.
- This project is well managed. Advancements uncovered in this project could add substantial value to the biofuels industry. Any preprocessing that could be done at harvest or storage could decrease the thermochemical effort of conversion. This project concept aligns well with the time function in the severity calculation. Annual corn stover harvest occurs in a 4-week window, and the crop spends the rest of the year in long-term storage of queuing. Corn stover markets extend into the cattle feed market as well, so it would be interesting to see if there is benefit of rumen digestion with these ideas. Increasing the demand of corn stover feedstock in the cattle industry will encourage more supply and likely lower the cost of corn stover feedstock in biofuels as baling and storage systems improve. This is an exciting study for biofuel potential. It would be interesting to see if treatment could be done at harvest/baling to help homogenize/stabilize the dynamics in the bale. One disconnect I have is the extremely high moisture content of the studies. Do the project plans include the addition of water at harvest/baling/storage?

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for these positive comments and their time reviewing the project. Future collaboration with the Feedstock-Conversion Interface Consortium is also planned to begin in FY 2022. In addition, this project has had industrial partners in the past, including Abengoa Bioenergy and Verd Company. We are interested in identifying additional appropriate partners. One approach we employed in the last review cycle was to serve as guest editors for the research topic in *Frontiers in Bioengineering and Biotechnology* entitled "Storage of Biomass Feedstocks: Risks and Opportunities." The collection featured research in U.S. national laboratories and academia, as well as from Europe. The review article published in that work highlighted the widespread use of anaerobic storage across the United States and Europe. It is our hope that this peer-reviewed literature will be part of the process of increasing the visibility of this project and attracting additional partnerships.

  Thank you for the question on the forage harvesting operation. Our models assume that the grain harvest occurs independent of the corn stover collection. The forage harvester would then be used to collect the stalk-rich fraction still standing, and yields are adjusted accordingly. Admittedly, this results in low yields, and the approach may be better suited for higher-yielding harvest approaches or energy crops. Harvesting can be accomplished independent of moisture content when anaerobic storage is utilized. Forage chopping of corn silage is often performed at 60% moisture, wet basis (w.b.) stable storage conditions have been demonstrated at 40% moisture previously. Anaerobic storage can also enable single-pass harvesting, as well as the combined grain and stover harvest enabled by the Single-Pass, Weather-Independent Fractionation (SWIFT) process.

  We will continue to incorporate TEA in the project as new value-added preprocessing opportunities are investigated. To date, we have finalized TEA on both the alkali storage and short-term fungi enhanced queuing. We agree that costs for all unit operations should be defined as they are in a production setting, not just in the n^{th}-plant scenario. The first-plant scenarios that are being proposed by the INL analysis team are one approach to address that. We agree that value-added storage and cost reductions go together to impact final profitability. We define the value-added component as anything that can reduce costs downstream in preprocessing or conversion, and an example of this is a credit for reduced temperature in a pretreatment reactor enabled by recalcitrance reduction in storage. The benefit to conversion systems of reduced pretreatment required have been quantified in terms of reduced alkali loading or reduced steam requirements for heating, and those are documented in manuscripts currently under peer review.

  We agree that the work should be expanded to woody biomass and even MSW. Scale-up of the alkali study to 10 kg has been accomplished, and further scale-up is warranted but not planned at this point. Scale-up of the anaerobic storage approach in a production setting of 500 tons was presented in the FY 2017 and FY 2019 BETO Peer Reviews. However, fieldwork was not pursued after this time due to the guidance of the previous administration to focus on low-technology-readiness-level research.

  A close collaborator on this project is the University of Wisconsin-led SWIFT project, where harvesting and anaerobic storage is occurring at multiple scales of 5-gallon buckets, 50-gallon barrels, and wrapped silage bales. One reviewer points out an interesting approach on rumen digestibility. Many studies show the promise for anaerobic storage and the production of associated lactic and acetic acids to improve digestibility of herbaceous biomass in the rumen gut. Limited studies exist on alkali-assisted storage providing a similar benefit to rumen digestion, but both calcium oxide and sodium hydroxide have been shown to have a positive benefit. The moisture contents explored in the study represent those in the working envelope of ensiling, as described above.

  Thank you for the positive comments on the pyrolysis characterization work. Pyrolysis gas chromatography and gas chromatography/mass spectrometry can be used for both qualitative screening approaches and quantitative characterization of pyrolysis products representing macromolecular building blocks of lignocellulosic biomass. In the conversion figure, which presents conversion results of percent glucose and xylose release, maximum yields of 100% are assumed based on total sugars originally present. The figure shows the impact of fungal treatment and time as a function of pretreatment severity, and while xylose yields are impacted, glucose is not. It is assumed that the fungal treatment did not impact cellulose microfibrils at a similar rate as hemicellulose components, and this is consistent with the pyrolysis gas chromatography and gas chromatography/mass spectrometry characterization.

We agree there are additional technical risks and understandings to explore. For example, microbial community analysis has been added to the project through collaboration with Idaho State University and the State University of New York College of Environmental Science and Forestry. Other technical risks such as formation of fungal proteins and fermentation inhibitors or solubilization of inorganic elements will be considered as funding allows.

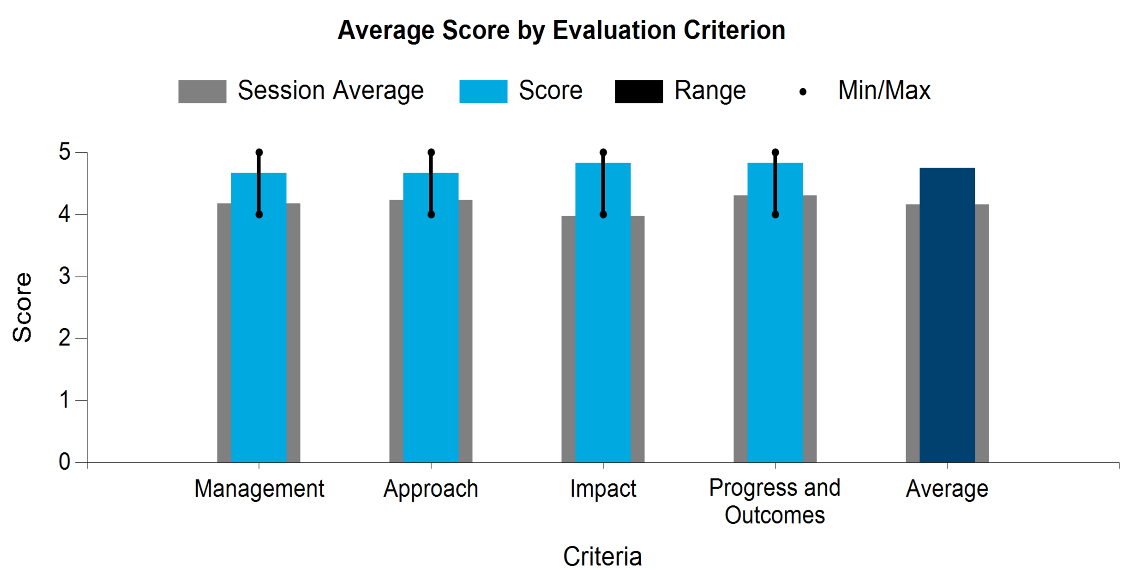
BIOMASS SIZE REDUCTION, DRYING, AND DENSIFICATION

Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.1.2
Presenter(s):	Jaya Tumuluru
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023
Total DOE Funding:	$2,465,000

The project objective is to reduce fines (<400 microns) in corn stover pellets to <7% (80% reduction compared to fines in 1/4-inch grind corn stover pellets). In FY 2019, corn stover pellets produced using a rotary shear and a 7/16-inch hammer mill screen grind had fines of about 5.2% and 12.5%. In FY 2020, work was focused on grinding and pelleting of cob, stalk, husk, and leaf corn stover fractions. Cobs required about 8–14 kWh/ton to grind, whereas stalks needed roughly 70–128 kWh/ton. Ground cobs had fines of about <1%, whereas leaves had about 8%. Corn stover fraction pellets produced at different conditions met the established particle attrition targets of <7%. Both the preheating temperature and compressive force influenced pellet quality. Also, corn stover fraction pellets can be blended to meet the desired quality in terms of fines and chemical composition. Scanning electron microscope images indicated that corn stover fractions retained their microstructure after grinding but lost it after pelleting. Computed tomography scan analysis indicated that the surface area for a given volume is highest for leaves but lowest for cobs. Focused ion beam tomography indicates stalk pellets do not have a definite structure, but leaf pellets have a denser structure. Cob pellets have a less-dense structure with connected layers giving a bi-continuous structure. Advanced imaging techniques can help to design pellets with the desired particle morphology and microstructure for the downstream conversion process.



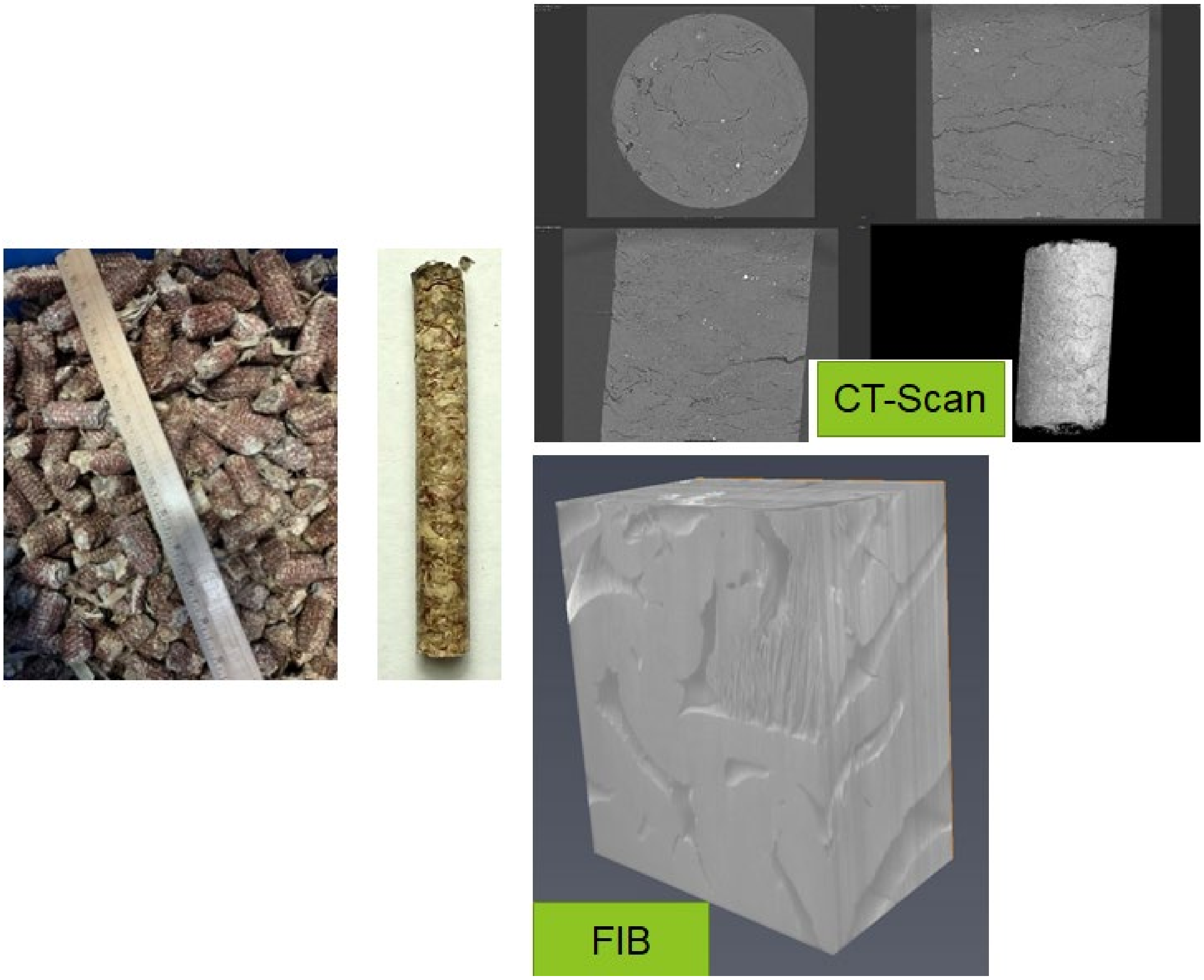


Photo courtesy of Idaho National Laboratory

COMMENTS

- I consider this project to be the best, or certainly one of the best, I reviewed. It is a mature project (several years of ongoing effort) that continues to make good progress toward commercialization. I do not have densification experience. I do know that there are cubing (really a big pellet) and wafering technologies in commercial application. There are also extrusion technologies that might partly expand corn stover fiber preparatory to densification.

- The project has had great efforts with industry partners, impressive pubs, and a book. For collaboration with Lignetics, in addition to testing advanced preprocessing, a potential commercialization plan should be explored. Pellets were made from leaves, cobs, stalks, and husks separately for testing. In reality, they can be mixed. It is not clear how the pellets from mixtures of leaves, cobs, stalks, and husks affect the pelletizing process and fine reduction. Wood palletization using logging and mill residues has been commercialized. It is not clear what specifically the future work on forest residue would be for later budget periods in this project. The results from this project thus far have been based on a single-pellet press. It would be good to consider pilot- or a commercial-scale testing for future focus.

- Management: The project team represents the knowledge and skills needed to address the continuation of this project. The management plan includes closely working with the BETO program manager. Risks are identified and mitigation is addressed. The management team has also worked with or gained support from pellet-using industries.

Approach: The approach for this project has been proven in two prior merit reviews. The continuation of this project is still relevant and holds significant potential for innovation in feedstock handling.

Impact: Value is derived from the reduction of fine material losses, which improves the economics of pellet production. The project has clear commercialization potential, as it can be used by biomass processors and designers for producing biofuels, chemicals, and bioproducts.

Progress and Outcomes: Significant progress has been made in feedstock characterization as a result of comminution processes. A detailed experiment has also been performed to pelletize stover fractions. It is interesting that pelletizing various stover fractions can result in increased or decreased fines. This project includes important information related to energy use.

Overall Impressions: This project extends beyond material handling and capture of fine material. Information gained by separately pelletizing various stover fractions could result in increased use of the poorer-quality portion fractions through blending. Energy use information can be incorporated into a TEA.

- Management: Very worthwhile and meaningful project. The problems in handling of low-density biomass affect all industries that need to control feed of biomass materials to the process. Good range of expertise on the team. Well-designed research project. Good partnering with industry manufacturers and biomass users.

  Approach: Project has a very well-identified problem statement, providing a very directed approach.

  Impact: The impact is significant, as it will help to reduce downstream implications in dealing with fine materials. Can these savings be quantified in economic terms? I look forward to the LCA.

  Progress and Outcomes: This project is showing some interesting preliminary results on the effect of equipment on fines production. This type of detailed testing is very useful information for LCAs and economic evaluations. What is the next step for the adoption of this work? Is there missing information that would inhibit its use in industry? Where could uptake be initiated? Is the capital cost for scale-up a factor? The work with scanning electron microscopy and tomography are also very interesting and innovative. What does the new microstructure represent? Is it perhaps easier for enzymes to access certain parts of the cell structure now that it has been partially modified? Has this process served as a pretreatment in breaking up the cell wall structure? Very interesting.

- The project has an excellent management plan and strong team with multidisciplined areas of expertise. They have clearly stated milestones, such as particle attrition targets and quantitative go/no-go decision points. PIs have recognized several risks and mitigation steps. This is one of the best plans of the presentations we reviewed. The approach is good and based upon recognized International Organization for Standardization (ISO) and American Society of Agricultural and Biological Engineers (ASABE) standards. Their approach has significant innovation and will definitely advance BETO goals and the SOT. This project could help propel the industry forward by virtue of its economic advantage in the production of standardized feedstocks for conversion. This is an important project that will impact and progress industry SOT and strongly advance BETO's MYPP in many ways, such as helping make the concept of multi-feedstock fuel depots possible, helping commoditize biomass feedstocks, and lowering biorefinery operating costs. The project PIs are to be commended for their strong effort in commercialization efforts for their work, which provides tangible evidence in the advancement of BETO's MYPP. This project demonstrates how a project can be influential over a wide array of feedstocks and conversion processes. There is also an indirect economic benefit to baling operations. If you can densify wet material, then harvesting operations can save significant time and money that is now spent waiting on material to dry in the field. The ability to use these advanced techniques and equipment such as focused ion beam technology and to design a pellet for its use in a particular downstream process is significant. Reducing variability will help in all downstream processes and operations. The advances made here with well-known technology such as pelletization that allow for feedstocks that can be customized for the downstream conversion processes will advance not only the SOT for pelletization processes, but also the SOT for the conversion industry using cellulosic feedstocks.

- Very high scores that can be attributed to multiple factors. The project is very well managed. The project will provide groundwork for the advancement of the corn stover biomass as a renewable fuel. I'm impressed with the design of experiment and execution. Very well done.

PI RESPONSE TO REVIEWER COMMENTS

We thank the reviewers for their useful comments and feedback on the impact of the project on MYPP goals and the SOT. We appreciate the reviewer's feedback on project management, execution, and process improvement achievements and how the project addresses variability and helps to create a product suitable for downstream conversion and operations.

We conducted grinding and pelleting of corn stover fractions independently to understand how the various process variables impacted the energy consumption and quality of each fraction's grind and pellets. We found that the grinding and pelleting energy consumption changes with cob, husk, leaf, and stalk, and each have different optimized conditions. Also, our SOT considers the various feedstock and fractions to be pelleted separately and blending them in downstream conversion.

In the pelleting work, the focus is on understanding how pelleting process variables impact the pellet quality in terms of unit density and particle attrition or fines (<400 microns) and meeting the particle attrition targets (<7%) established in the project. We conducted corn stover pelleting studies in a single-pellet press to understand the how process variables such as compressive force, residence time, moisture, and grind type impact the pellet quality in terms of unit density and particle attrition. The data obtained from a single-pellet press can be further used to scale up the process to lab-scale and pilot-scale studies. In our book on biomass densification, we developed a scale-up methodology based on the single-pellet press studies (https://doi.org/10.1007/978-3-030-62888-8_3). Also, instead of using briquetting, cubing, and extrusion technologies, we selected pelleting technology to address the feedstock quality issues. We thought addressing issues associated with pelleting process technology in terms of cost and quality could have a broader impact, as pellets are the most widely used commodity-type product for biofuels, biopower, and bioproducts. Improving process efficiencies of the pelleting process could have a bigger impact on the biofuels and bioproduct industry. We work closely with the INL analysis team, where data generated for grinding, pelleting, and pellet quality, e.g., fines and density, are fed to TEA, LCA, and reliability models.

The major challenge of forest residue fractions ("bark, needles, and whitewood") is high moisture (50–60%, w.b.) at the time of harvest and large variability in physical properties such as particle size, shape, aspect ratio, and density. Using conventional methods to preprocess the forest residue is very cost and capital intensive. For example, to reduce the moisture content of forest residues from an initial moisture of 40% (w.b.) to 10 % (w.b.) using a rotary dryer takes about 650 kWh/ton. Another challenge of using a hammer mill is it generates a lot of fines, which can create problems in downstream conversion, as observed in the present project. In future work, we plan to develop energy-efficient preprocessing technologies such as mechanical dewatering (which is more efficient than thermal drying methods), crumbling (generates less fines compared to hammer mill, as observed in the current project), high moisture densification, and low temperature drying to produce densified products from forest residue fractions. These densified products will meet the critical material attributes in terms of moisture, density, porosity, microstructure, aspect ratio, and particle size distribution. We also plan to do a LCA and TEA for the processes developed and compare with the current methods that are followed by the industry.

Unrelated to the current project, we are currently funded under DOE's Technology Commercialization Fund (TCF) to work with Lignetics. If we meet the TCF project goals and objectives, there is a good opportunity to commercialize INL's advanced preprocessing technologies. We are also working with Fulcrum Bioenergy on a direct FOA facilitated through the Feedstock Conversion Interface Consortium on testing the advanced preprocessing technologies developed in this project for MSW preprocessing. The Fulcrum research on MSW preprocessing has indicated that there is about a 40% reduction in the pelleting cost compared to conventional pelleting, and greenhouse gas emissions are about 50% lower compared to the conventional pelleting process followed by industry.

RESOURCE MOBILIZATION

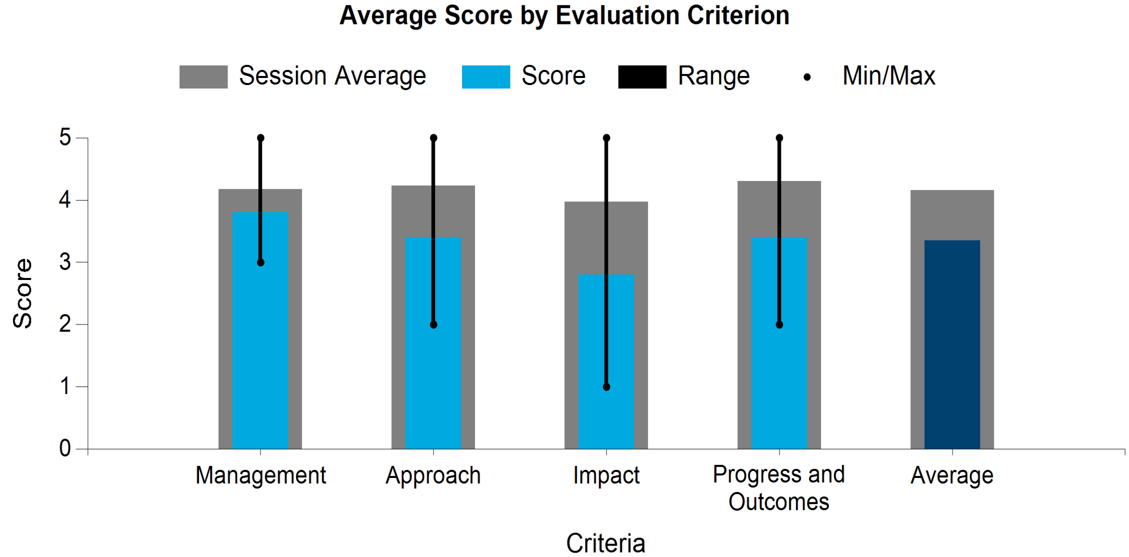
Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.1.5
Presenter(s):	Damon Hartley
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2021
Total DOE Funding:	$908,000

The mobilization of biomass feedstocks is contingent on multiple factors, the largest of which is establishing a network of growers that are willing to produce the feedstocks and supply them to the market. Ultimately, the future of the bioenergy sector hinges on farmers' participation and their willingness to supply feedstocks that will enable the economic viability of feedstock-to-fuel conversion operations. The work of this project has focused on identifying strategies that would lead to increased adoption of the production of energy feedstocks, primarily on the production of herbaceous feedstocks for biochemical conversion and defining strategies to establish biomass production in conventional cropping systems.

Agent-based models were used to simulate the evolution of farmer participation in crop residue harvesting and energy crop cultivation under multiple scenarios. Factors that were examined included contracting structures, cost-saving practices, market structure, and the influence of peers and media. The model was not intended to provide a unique solution, but rather identify patterns that provided insight into agent behavior. Our initial findings showed that the stability of a vertically integrated market structure, combined with the inclusion of influential farmers and a grower education campaign, was sufficient to steepen the adoption curve. Ultimately, the development of the biofuels industry is incumbent on increasing the value proposition and reducing the risk to the grower through innovative supply chain and contracting structures that maximize the value of the feedstock. Midstream markets can provide value to all portions of the biomass stream by using the portions in applications for which they are best suited. The midstream markets positioned along the supply chain provide diverse outlets and contribute to the reduction of supply chain risk. Therefore, incorporating midstream markets into the biomass mobilization strategy would increase recovery and use of all biomass fractions generated throughout the supply system and reduce supply costs to the biorefinery. Without the identification and development of mechanisms that drive the participation of growers and reduce risk in the development of feedstock supply chains, it will be nearly impossible to meet the BETO goal of fuel at $2.50/GGE by 2030. Specifically, this project addresses the barrier identified by BETO as Ft-A: Terrestrial Feedstock Availability and Cost. This project provides credible, objective analyses of feedstock supply systems and strategies to support BETO investments in the development of a sustainable, economically viable, national-scale bioenergy industry.



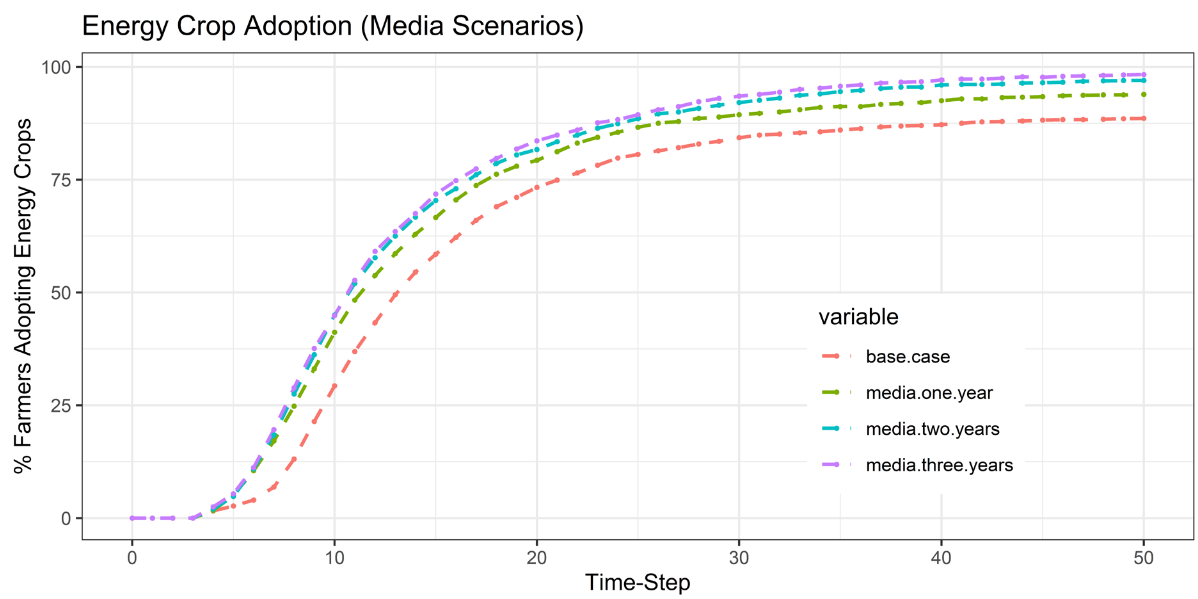


Photo courtesy of Idaho National Laboratory

COMMENTS

- I do not believe this project, as currently defined, will have a significant impact, and I will attempt to list some ideas for how it can have impact. To the project personnel, I am not criticizing the work you have done or the way you presented it. My criticism is in the way you approached your assignment. You have not dealt with some obvious factors that dictate the readiness of an individual to sign a feedstock contract.

  Key No. 1: The contract—When will landowners sign a feedstock contract? When they have an opportunity to make a profit. This is first and foremost. In the Southeast, if you want wood chips delivered to your biorefinery, and the current market is *x* dollars per ton and you offer 2*x* dollars per ton, you will get feedstock. The higher the price you offer, the more feedstock you get, until your competitors start to outbid you. There are other contract considerations: (1) multiyear contract; (2) capitalization required (am I going to have to invest $500,000 in equipment I don't currently have to get a contract?); (3) a contract feature that allows me to participate in the increased profits if energy prices increase; (4) penalties for non-performance (dry year and I cannot fill my contract; what about a bumper crop—can I sell the excess?); (5) I'm 65 and do not want to undertake a long-term contract—can this contract transfer if I sell out?; (6) if you are asking me to store biomass in satellite locations, are you going to compensate for storage losses?; (7) do I have to deliver to you, or are you doing the hauling, etc.; and (8) will a contract offered in the Midwest be attractive in the Southeast? Unlikely. A project like this can make a contribution by defining differences in contracts to obtain different feedstocks in various regions. I see a project like this as an "amendment" to the non-lab projects currently funded. The project personnel in the various regions know their local conditions and their feedstock crop. They can suggest how a contract might be developed.

Key No. 2: Local leadership—If the local leadership desires a biorefinery as a good thing for their county (community), it will happen. There are several examples—I will give one. In 1990, there was no cotton acreage in Virginia. In 1993, there were 100,000 acres. How did that happen? You do not plant cotton unless there is a gin. You do not build a gin unless there is cotton. Local leadership figured it out. This project can make a contribution by defining how DOE can give local leadership the support needed to attract the biorefinery investors. Participation of the USDA Cooperative Extension Service will be critical. This is the conduit to get information to the local leadership.

- Management: Alternative markets for biomass materials are very important, especially those markets with high value-add capacity. A concern with increasing supply of the feedstock is the resulting decrease in price. While this may be positive for the biorefineries, it is a negative for the farmers. How does this PI rationalize this inevitability? The project is in early stage, and although there is a suitable mitigation strategy, it is lacking in detail. Details on the type of industry/working groups would be nice to see, in order to make sure all important stakeholders are accounted for.

  Approach: Very novel approach to evaluating factors that will influence participant uptake of feedstock generation. The directed approach of looking to utilize land that is currently not farmed adds a practical dimension to the project. The market development work is very important, as there are potentially small higher-value markets that could be expanded in the future. Also, stabilizing the primary market through coproduct value is very important and can impact the success of the entire bioeconomy landscape. The data collection and categorizing might be a challenge for this project.

  Impact: Would be nice to see presentations to practitioners and stakeholders; this would help to de-risk the project.

  Progress/Outcomes: The assumption of no cap on demand is unrealistic; I am wondering why the PI is using that assumption, especially because this will have a large impact on price paid to farmers, and then would of course influence their participation.

- Management: This project has a small team of three people. Experience includes an examination of the economic drivers for switchgrass adoption. The communication plan includes team members, BETO program managers, and a partnership with two other BETO project groups, WBS 1.1.1.2 and WBS 4.2.1.20. The communication plan does not specifically state whether or not it includes growers. Risks and potential mitigation strategies were identified.

  Approach: The technical approach will identify factors surrounding a grower's willingness to participate in bioenergy feedstocks. Performance metrics were presented, and technical challenges were identified. A go/no-go decision point was met in 2019.

Impact: The impact of the project is clearly tied to the approach. Understanding grower adoption is important to growing the bioeconomy. Positive results of this project could include increased knowledge in de-risking production and increasing supply.

Progress and Outcomes: Progress has been made in developing a model for the analysis. Progress toward the project goal has included examining the farmer population and their demographics. The analysis also includes the distribution of land quality and soil productivity. The selected parameters are reasonable, and the analysis should meet the project's goals.

Overall Impressions: This project helps identify many factors that would impede adoption rates by growers. Future work in this area may examine broader topics that could impact adoption, such as business structure or the need for additional equipment investments. Media campaigns may also help increase adoptions.

- There is a clear management communication plan with several annual milestones. There is a good team in place with risk identification and mitigation strategy, which includes industry outreach. I did not see a clear plan to achieve the goals set in the project overview. There is a good project approach, and the plans are there to achieve project goals. I do find that modeling behavior must be difficult when it has been demonstrated that different farming segments react differently, and even with segments, large farmers may react differently than their smaller counterparts. I am not sure that the project promotes the BETO MYPP any more than it could promote use by any other farmer product. It would seem to me that you could use this model to promote growing wheat instead of corn. The problem I see with the project's impact is that in my mind, you could take any feedstock or herbaceous material and achieve the desired results by promoting the desired behavior. In other words, I don't know that the work really promotes the bioeconomy any more than it could promote conservation or food. I do believe that the PIs have shown progress toward their goals and outcomes. The concept that we can attract farmers by encouraging behaviors that increase participation to lower cost is novel, and I would believe to be potentially at odds with the concept that increasing farmer profits (and possibly increasing feedstock costs) will get farmers involved in participation.

- This project was tougher for me to get my head around the process and goal. Likely it is because I feel that it is looking out far into the markets and making assumptions. It is possible that some of the results that were claimed in the accomplishments section were not shared, but I did not see, for example, the business strategies employed to increase producer participation. I think markets are primarily driven by success of downstream biorefineries. The producers will likely participate only if it makes financial sense for them to invest time and effort for financial gain. I see some validity in working with the producer to educate them on the "cause" for using renewables to induce excitement and positive use of the land. It's possible that I did not connect the dots on how the results were calculated. Lower scores for not mentioning risk management and not connecting, for me, to the goals of BETO/DOE. I think to improve, the project management team could base market movement from downstream biorefinery success moving the markets as a percent utilization of available biomass. Thank you.

PI RESPONSE TO REVIEWER COMMENTS

- The work that is being completed in this project has a very strong connection to the MYPP goals of the Feedstock Technology program. Specifically, this project is directly tied to the BETO barrier Ft-A: Terrestrial Feedstock Availability and Cost and the goal of $2.50/GGE by 2030. Currently, feedstocks (especially dedicated energy crops) are not currently being produced in substantial quantities. Without sufficient quantities of material of required quality to meet the conversion yields, it will be very difficult to meet the defined cost target. By incorporating strategies that shorten the supply chain development time and reduce the cost of establishment leading to decreased transportation and access costs, we are directly involved with the attainment of the 2030 cost target.

The first step of this work is to understand what is potentially possible before tightening the constraints. For this analysis, the assumption of no cap on demand was a purposeful choice, as our intention was to examine what the maximum potential adoption would be under the scenarios being modeled. Additionally, while the modeling approach, and this model in particular, is not necessarily directed to any crop or practice by its structure, the key is in the application. While it would be possible to examine a diverse set of behaviors, the data that were used and decision processes and options presented to the agent make this model an energy feedstock adoption model.

While there are potentially any number of contract formats that could be examined and make sense regionally, producers are only likely to participate if there is a financial incentive. That is why the contracting structure is modeled after the Conservation Reserve Program, where land that is low-production, resulting in a reduction of farm profit, is contracted, and a rental rate is paid for access to produce energy crops. The agreement is for access to the land; the biomass user will be responsible for cultivation, harvest, and transport of the biomass, with no need for capitalization by the landowner. In addition, because the biomass company would have rights to the land, they would be able to store material at the site. Also, because the agreement is for access, there would be no penalty for non-performance, and similarly, there would not be a benefit in times of high yields or prices. As for the attractiveness of this contract in different regions, I would assume that any area that utilizes the Conservation Reserve Program to any great extent would be amenable to this structure, but this was outside of the scope of the project and can be examined as we progress. This makes the incentive to the landowner that land that currently costs money to farm would become profitable, which would ultimately increase the total on-farm profit.

- Finally, the expectation is that the supply of biomass would increase, and the price of biomass would decrease, exhibiting behavior similar to more traditional commodity crops when the maximum level of acceptance is attained.

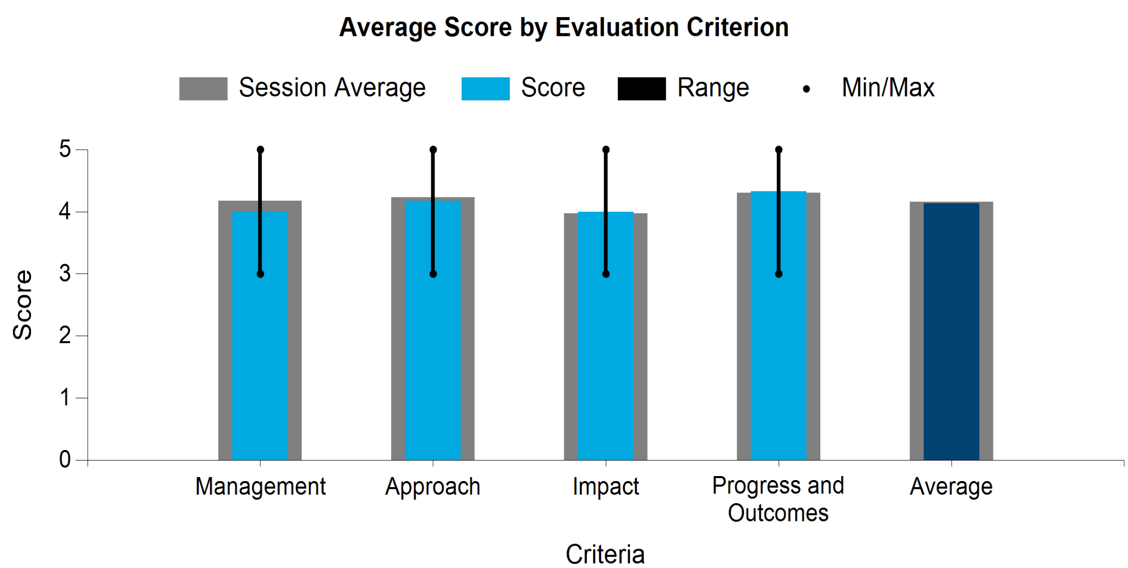
SEED PROJECT: MUNICIPAL SOLID WASTE DECONTAMINATION

Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.1.7
Presenter(s):	Vicki Thompson
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2021
Total DOE Funding:	$500,000

When China instituted its National Sword policy in 2018, much of the municipal solid waste generated in the United Sates was too contaminated, and it is currently being landfilled. This MSW (approximately 65 million tons in 2018) represents a new cost-advantaged feedstock for the biorefinery industry. However, MSW is cheap for a reason and will need preprocessing to sufficiently decontaminate the waste for conversion. This project is identifying relevant waste streams for BETO priority pathways (deacetylation/mechanical refining and fast pyrolysis), determining the impact of contamination on conversion yields, developing decontamination strategies coupled with TEA, and then demonstrating an optimized, cost-effective process for the two conversion pathways.



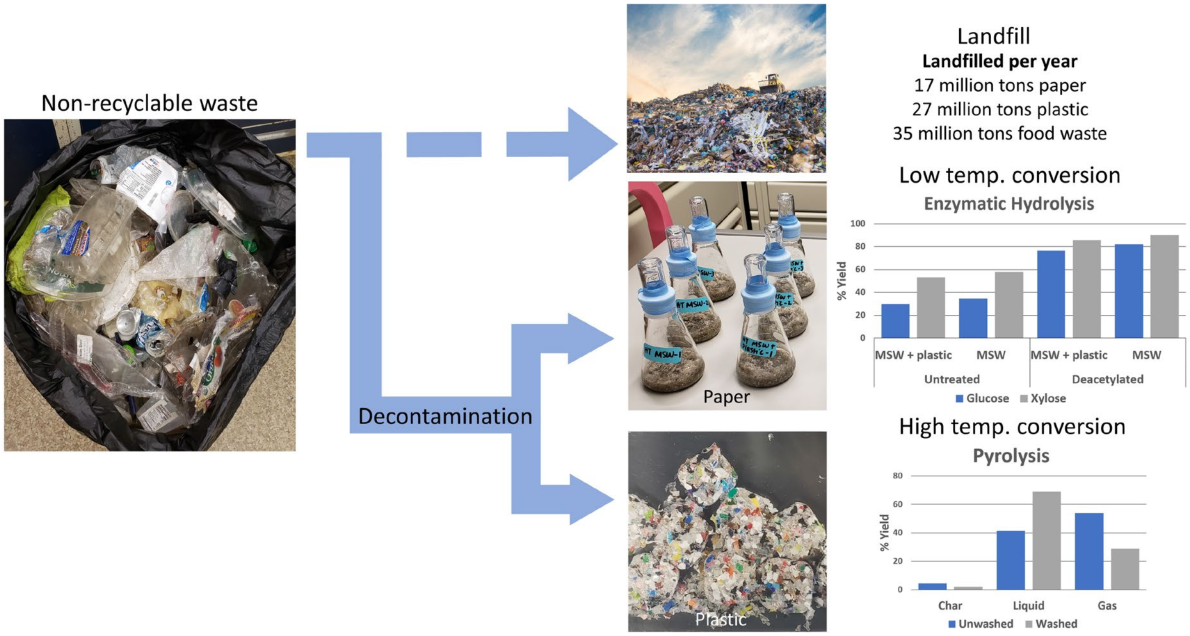


Photo courtesy of Idaho National Laboratory

COMMENTS

- I do congratulate the team on the quality of their presentation. I could read the slides. More importantly, they did not have too much information on each slide, a common problem with many of the other presentations. I also give an accolade to the team for reaching out to other groups (industry) with much more experience in MSW. Society needs success from this project. I hope my remarks are an encouragement. This is a new project, so conclusions are not expected. I wonder if, ultimately, pyrolysis will not emerge as the only practical option. The heterogeneity of the material, plus the contamination, is a steep mountain to climb.

- It is a sound project, and it is worth having some more investment in this area. Some details on approaches should be provided to move the project forward. An outreach component of the project should help promote the program with industry and communities for recycling and utilizing MSW. It is not clear what a future plan would be for the project.

- Management: The risks in the project are well thought out and quite realistic. The magnitude and effect of the risks may make this work less relevant in a very short time.

  Approach: The project fits well within the BETO goals as represented on the project slides. However, this is very time-consuming and painstaking work. My fear is that waste streams are subject to change, as mentioned in the presentation for China's National Sword policy. Other changes in consumer packaging are also evolving quickly. This raises the question as to how relevant this work may be long-term. What is the applicability of this work? There are many different systems for collection of municipal waste, and each will provide a varied feedstock. How will this be dealt with?

  Impact: Relevance to the industry may be too early to determine. The impact of this specific approach was not clear.

  Progress and Outcomes: Unfortunately, time did not permit for questions examining the outcomes. I don't understand the percent glucose and percent xylose yields. Is this based on yields/total material? I don’t think so, but I can’t understand what the basis for the percent is. It doesn’t make sense that yields of glucose and xylose add up to more than 160 in some cases.

- Management: This is a short-term seed project that began in October 2019. The management plan divided the project into tasks with leads identified for each. The project provides routes for communicating with other national labs and the local Biomass Feedstock National User Facility upgrade team. A waste recycling service will also be consulted. Risks and mitigation are addressed.

  Approach: This is a seed project, so little existing data are available. The approach clearly addresses the challenge of decontamination and ties it to the go/no-go decision point.

  Impact: There is a clear connection between the project approach and the potential for using MSW in conversion processes to create fuels and chemicals. The potential impact of a positive outcome could be significant by reintroducing recycling programs in areas where it has been discontinued/scaled back, and once again contribute to a circular economy. Technology transfer will occur in traditional publication outlets. A link to tie the results to potential stakeholders is provided by the RRS waste consulting company.

  Progress and Outcomes: This project has only been funded for a year, and much of that year was encumbered by the COVID-19 pandemic. MSW for the study has been obtained through a dual-stream recycling facility in Emmet County, Michigan, and contamination types have been identified. Conversion screening has been performed for both paper and plastic. Some initial findings were presented, such as how washing MSW can increase the liquid and gas yield from MSW plastics.

  Overall Impressions: This is an interesting project with the potential for making headway into understanding how MSW can be transformed into a conversion-ready feedstock and contribute to a circular economy.

- The project has a good division of labor responsibilities and communication plan. There is risk recognition coupled with mitigation strategies. With projects focused on MSW, I believe there should be some plan for monitoring of legislative actions that could affect the project to the point of rendering the approach unfit or obsolete, as well as increasing the project's importance. For example, just as the action by China increased the importance of this project, such actions currently taking place at the state and city levels are doing this as well. The project approach will advance the state of the art for technology goals at BETO. There are several conversion technologies that might become economically feasible, and therefore commercially available, if uncontaminated MSW is an available feedstock. It is of some concern that the approach did not mention how biohazards might affect the approach. There are quantifiable go/no-go decision points. I would have liked to have seen the corn stover price comparison points. I am not sure what the true potential for commercialization and the impacts from the production of a clean, economically advantageous MSW feedstock can or will be. The project has made solid progress toward its goals. There were timing challenges due to COVID-19, but the project is back on track, which is commendable. Overall, a good presentation in approach plan and management. Clear goals and progress. I would also like to know if there is a plan to test TEA/LCA conclusions and how legislative/regulatory actions can be accounted for and/or updated.

- This is a tough project. I think the management team has done a great job funneling this tough workspace into meaningful data. I like how the groundwork was laid on "what" the MSW is and the percent of the constituents. I think this work will become more and more important as society evolves. Well managed, well executed, and impressive progress understanding the issue in relation to fairly new regulation. Thank you.

PI RESPONSE TO REVIEWER COMMENTS

- We appreciate the positive comments from the reviewers, including the kind words on the quality of our presentation and the feedback that we are moving in the right direction. In addition, we are grateful for their comments for further consideration and future investigation. We agree that this work could lead to reintroduction of recycling programs that have been discontinued. That area is of particular interest to our team. We agree with the reviewer that it is a significant problem that waste streams are subject to change as changes at the policy level and in consumer packaging occur. In addition, every locale is likely to be different. Our approach was to begin with a defined case study that could be leveraged to provide a framework for other locations to study their individual waste issues. To maintain relevance, we have engaged with RRS, one of the premier waste consulting firms. Our collaboration with RRS provides us with an industry perspective on monitoring of legislative actions and allows us to pivot if needed. If things shift markedly in the industry, we can quickly shift waste streams to target as needed. Our current approach of manual sorting and characterization is indeed time-consuming, but we are also working on other BETO-funded projects to develop analytical techniques such as NIR, X-ray fluorescence, ultraviolet spectroscopy, 3D optical, etc. to characterize waste streams more rapidly.

  Regarding the project's current research, the approach we took to screening conversion of decontaminated MSW included enzymatic hydrolysis of paper and pyrolysis of plastic. The contaminants we tested were chosen based on their prevalence in our waste stream. To clarify the sugar yields, the glucose and xylose yields were based on yield of sugar/initial sugar present in the material (e.g., glucose solubilized/glucose in the original paper). We are finishing up TEA/LCA, and the initial results are quite promising and more than competitive with corn stover. We are aware of the biohazardous nature of MSW and are handling all these materials at a biosafety level 2. This will result in challenges to the industry moving forward, and it is likely that some type of decontamination will be needed for technologies that are commercialized. The project team attended the BETO waste workshop, and these ideas were captured and shared with BETO.

  Finally, to address the reviewer's comment about "It is not clear what a future plan would be for the project," we hope to turn this project into a full 3-year project and will be writing a proposal to continue this pathway, as well as expand into other types of MSW and conversion pathways. The current project worked with industry experts to obtain representative samples; however, the upcoming proposal will be a good place to address adding an outreach component to the project to further engage with industry and communities.

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

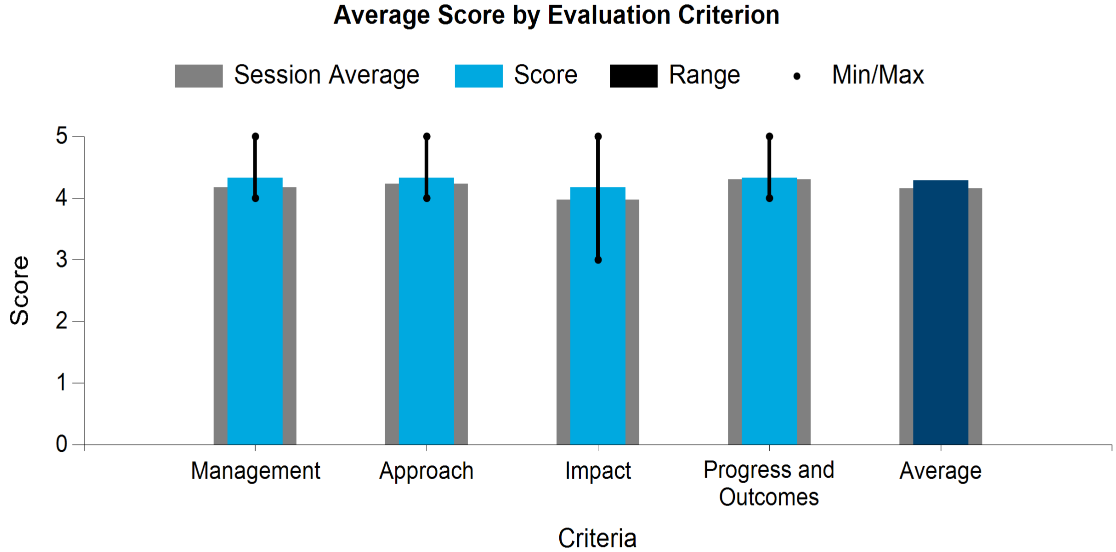
Montana State University

PROJECT DESCRIPTION

WBS:	1.2.2.100
Presenter(s):	David Hodge
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2022
Total DOE Funding:	$1,300,000

This project will address the challenge of processing the heterogeneous feedstock of corn stover by fractionating the biomass feedstock and both streamlining processing and generating new potential coproduct. Additionally, we will develop new field-deployable analytical tools that will be coupled with empirical models that will 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 two-stage physical fractionations; (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), next subjected to enhanced separations (scalping separation, sieving, and air classification) 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 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 to assess the relative abundance of tissue type in order to assess fractionation efficacy and to predict fraction performance during pretreatment and enzymatic hydrolysis.

A key impact of this project will be to develop 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, which 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.



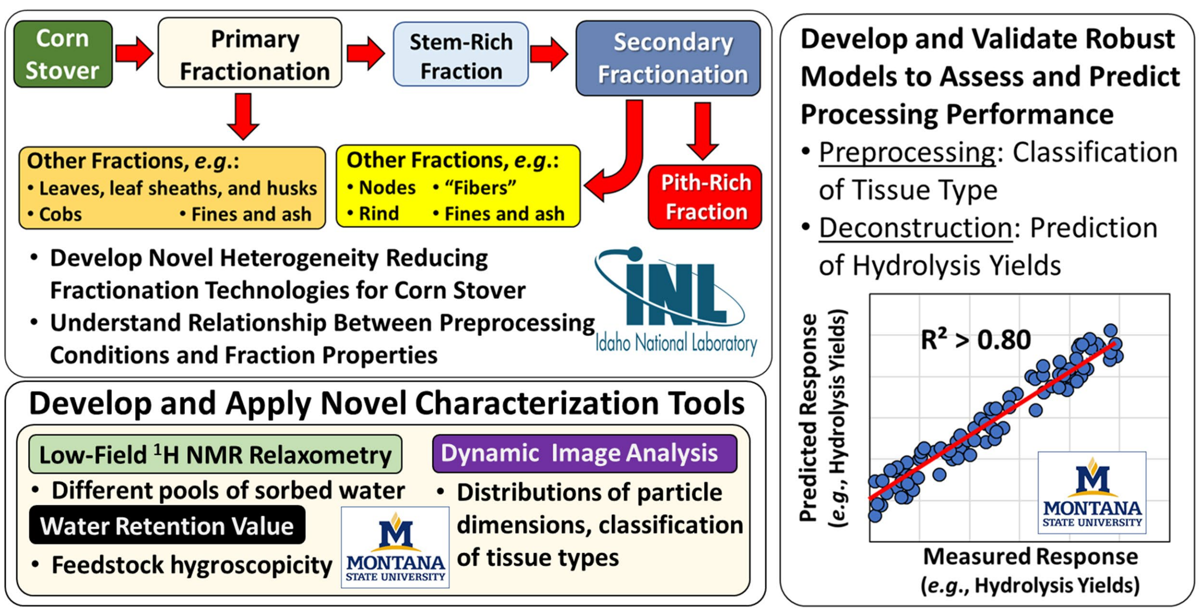


Photo courtesy of Montana State University

COMMENTS

- There is no question that the results obtained with this project are needed. Corn stover has more dirt contamination than many of the feedstocks being considered. We now know that it must be cleaned if it is going to be used for continuous biorefinery operation. This is not a unique requirement—sugar cane is washed before it is processed. A cotton gin has some of the most sophisticated solid-solid separation technologies in all bioprocessing. Not only is the dirt removed from the seed cotton, but also all the little pieces of leaf, stem, and bole. Cotton in the bale is almost pure fiber. The option for simply washing the stover using filtration and recycling of the wash water, as is done with sugar cane, is not farfetched for me. This may be a cost-effective option for removing the surface dirt (ash). I have no idea how wet particles might affect any downstream classification technology. Obviously, any comment I make here is not a suggestion the scope of work should be changed. I wish to raise two points for BETO to consider relative to a final report (outcome): (1) authors are asked to rank potential for newly defined cleaning/characterization technology to be scaled up for commercial use, and (2) authors are asked to rank the cost of the various commercial options. For example, Technology A costs $20/ton, and the ash content is *X*%. Technology B costs $25/ton, and the ash content is *X*-2%. This level of cost analysis may be beyond the scope of work for this study. However, it is a valuable result for biorefinery design.

- Experimental models will be tested, including artificial neural networks, partial least squares, and mixed linear regression. It is not clear how the data sets for training or regression and testing or validation will be set up; considerations include data set size, major data variables, and modeling evaluation criteria. $R^2 > 0.8$ is required for predictive models. Why is 0.8 a threshold? R^2 is not the only criterion to judge the robustness and sufficiency of a model. Regarding correlation verifications, it is a paired diagonal matrix of 11–12 variables examined. Why was hydrolysis not listed in the column, and pith content not listed in the row? This matrix just provides the correlation coefficients for paired variables. Using a paired test could provide the p-values of correlation significance of these paired variables. It is not clear how this process can be applied at a commercial scale with an industry partner.

- Management: Well-defined project with clear objectives. Didn't see any management or technical risks to the project.

  Approach: I can't help but think that a lot of this type of characterization work has been done and is available in the literature. Emphasis on valorizing these fractions would help to understand how much could practically be spent on preprocessing—for example, if the value justifies the extra cost of preprocessing or optimization of the downstream process (can this be quantified?).

  Impact: The goals of the project are very ambitious. Under the Impact slide, I hope that the project can progress toward reaching these goals. The project is quite experimental in nature, but the goals are very applied. I'm not sure exactly how the research will translate to the application as succinctly as indicated in the goals.

  Progress and Outcomes: Appears to be some good characterization data on the comminution and fractionation testing.

- Management: The team consists of two researchers from Montana State University and four researchers from INL. The communication plan includes meetings. This project will integrate with other work with FCIC members. Risks and mitigation will be discussed at team meetings. Challenges were identified, such as chemical and physical heterogeneity due to differences in anatomy and tissue types.

  Approach: The approach describes the technology to be used for property characterization, including an air classifier. Individual fractions are then pretreated to determine percent total glucan. Characterization tools, such as nuclear magnetic resonance, are used on the untreated and pretreated corn stover, and properties are further quantified.

  Impact: The impact of the project is clearly connected to potential significant outcomes, such as preprocessing in depots, to decouple feedstock handling from the biorefining process. The project will develop and use prediction models to assess preprocessing performance and predict corn stover fraction responses to biorefining.

  Progress and Outcomes: The fractionation process was verified.

  Overall Impressions: The project addresses the advantages of physical fractionation of corn stover. It examines several tools to characterize the heterogeneity within corn stover in conjunction with models to assess the benefits of preprocessing through hydrolysis. The team members suggest that this classification and characterization could occur in depots to decouple feedstock handling from the biorefining process. This is a unique project that explores a whole new system for harvesting and fractionation.

- This project has a good management and investigative team and excellent communications plan, as well as collaboration with the FCIC program. The work can have a positive effect on many of the issues that FCIC is trying to address with the handling and preprocessing of corn stover. I do believe that there should be more attention or thought to what risks may be on the project horizon and what plans can be developed to mitigate these risks. There was no real explanation on what the go/no-go decision points were or are. The approach is sound and thus far appearing to be following the timeline and reaching go/no-go decision points. In my mind, with a limited presentation time, there should have been more emphasis on existing work and less on the future of the project. This project can be very impactful and go a long way toward advancement of the SOT and BETO goals, especially the depot concept. There is a good plan for dissemination of results to industry. There has been good progress made and the schedule has been maintained. I believe in projects like this. It would be good for the PIs to include information not just on results, but also on what a successful project will enable industry to do. This is not to say that this was not mentioned, but I believe this is an important consideration. This project could be an important one to industry, and I would like to know what the PIs think this means.

- This project is important and near to me. I feel this project could support the next step in corn stover biomass commodity development. Understanding the plant's characteristics, as opposed to a view of the entire composite of the plant, will likely help industry move to a more robust biorefinery design. This project is supported by lots of detail and appears to be managed very well. Thank you.

PI RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for providing insightful comments. We are pleased and encouraged that the reviewers did not identify significant weaknesses in the technical aspects, relevance, management, or current progress of the project, and that most of the feedback was focused suggestions that would improve the industrial relevance.

  Regarding the suggestion, “Authors are asked to rank potential for newly defined cleaning/characterization technology to be scaled up for commercial use.” As the project progresses, we will commit to comparing and ranking potential new technologies relative to the benchmark case.

  As other examples, “Authors are asked to rank the cost of the various commercial options… This level of cost analysis may be beyond the scope of work for this study. However, it is a valuable result for biorefinery design” and “Emphasis on valorizing these fractions would help to understand how much could practically be spent on preprocessing—for example, if the value justifies the extra cost of preprocessing or optimization of the downstream process (can this be quantified?).” Although TEA was not originally proposed for the project, we will commit to performing TEA characterization of select biomass characterization and fractionation scenarios as one output of this project.

  Another concern was the analysis we presented: “It is not clear how the data set for training or regression and the data set for testing or validation will be set up, such as the data set size, major data variables, and modeling evaluation criteria. $R^2 > 0.8$ is required for predictive models. Why is 0.8 a threshold? R^2 is not the only criterion to judge the robustness and sufficiency of a model… a paired test could provide the p-values of correlation significance of these paired variables.” We are developing other models and means of relating characterization results to processing outcomes. We presented results with respect to the R^2 threshold of 0.8 because this was a target metric defined in the original FOA that we are addressing.

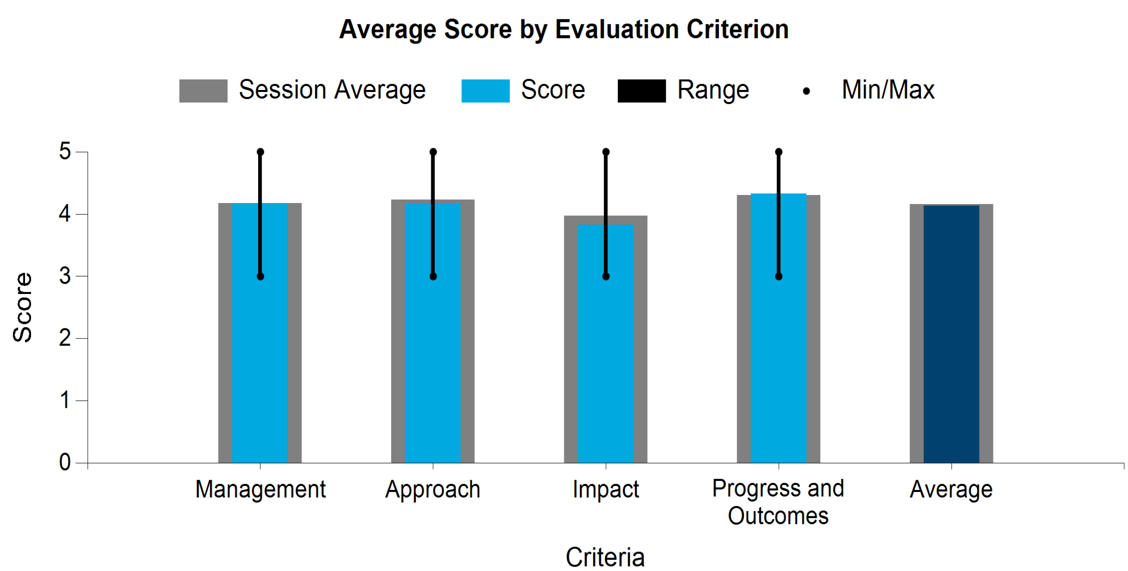
SWIFT: SINGLE-PASS, WEATHER-INDEPENDENT FRACTIONATION TECHNOLOGY FOR IMPROVED PROPERTY CONTROL OF CORN STOVER FEEDSTOCK

University of Wisconsin

PROJECT DESCRIPTION

WBS:	1.2.2.101
Presenter(s):	Matthew Digman
Project Start Date:	10/01/2019
Planned Project End Date:	12/31/2022
Total DOE Funding:	$1,248,748

Corn stover is an abundant source of biomass that can be utilized for bioenergy production, representing 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. SWIFT advances the use of corn stover as a feedstock for biofuels and high-value bioproducts through a novel and streamlined harvest, storage, and fractionation process. The novel approach employs four basic operations: whole-plant harvest with a modified forage harvester, anaerobic storage, cotransport of grain and stover, and separation of grain and stover anatomical fractions at the biorefinery.



Photos courtesy of the University of Wisconsin

COMMENTS

- If corn stover is going to be a viable feedstock in Wisconsin, option like the one described will be required. The project is well organized and the team well qualified. If anyone can make this option work, this team can. I do not think the $70/dry-ton goal is attainable. So what? I firmly support this effort to find out what the cost will be for this option. The team should be encouraged to report the most accurate cost estimates possible. Two key issues occurred to me as I reviewed the project: (1) Gross income to the farmer—$5/bushel corn grain × 180 bushels/acre = $900/acre gross income. Can this income be matched with the described option? If not, why do I want to do it? (2) Can I harvest my crop at the same rate with a forage harvester as with a combine (acres/hour)? In the Q&A we talked about the number of in-field haul vehicles needed to keep a forage harvester moving. I expect the expertise in forage harvesting is greater in Wisconsin than anywhere else in the country.

- It is not clear what major modifications to this single-pass harvester were, are, and will be made by the project team, in addition to the header. Visually, it seems the SWIFT harvest left relatively higher stumps compared to conventional harvesting, which would affect consequential site preparation and potential biomass collection. It lacks some details on what specific approaches will be used to achieve the project goals, such as data collection and validating for TEA and LCA.

- Management: Management identifies the tasks and identifies interactions between some tasks. The team includes members that appear to include the disciplines needed for project implementation. Both risks and mitigation measures are identified. The communication plan includes monthly meetings with an industry partner, John Deere Harvester Works. The team is sending graduate students to INL for the summer, which will aid in project communications between team members.

  Approach: The approach is clear and relates harvesting and biomass storage to the chemical and physical properties of stover. The approach will modify equipment to explore a new way of harvesting corn stover with a one-pass system, which, when combined with the various project tasks, may open more land for corn stover production.

  Impact: From the presentation photos (kernel damage, in-field kernel loss, storage alternatives, and separation techniques), it is apparent that the methodologies of field data collection are part of a larger, well-planned experimental design. If successful, there is clear potential impact from this project for not only widening the harvest window of time, but also in reducing the cost of pretreatments by fractional utilization. A manufacturer is a partner in the study, and this engagement is essential for commercialization of the modified equipment.

  Progress and Outcomes: A number of field experiments have been implemented in the first year of this study, including the modification of the whole-plant header, even with COVID limitations. An assessment relating kernel damage to cutterhead rotational speed has been completed. A storage study has been implemented, and separation work for anatomical fractionation has begun. All tasks planned for budget period 1, tasks 1 and 2 (verification and harvest), appear to be on schedule.

  Overall Impressions: This project proposes developing a single-pass harvesting system that can operate in a wider variety of field conditions than traditional multi-pass harvest systems. This system has the potential to make more acreage accessible for corn stover production. Other potential results may include a reduced cost associated with dry grain storage and increase in the number of full transportation payloads. Reductions in pretreatment and hydrolysis costs may be obtained through fractional utilization. On the other hand, farmers may be unwilling to mix their high-value grain with low-value stover.

- Management: The project is in an early stage and could benefit from additional stakeholder involvement. It is encouraging to see that John Deere Harvester Works is involved, but are they open-minded or trying to market *their* solution? Farm associations could be helpful in preparing for scale-up issues and early buy-in. Could provide an outline of tasks and persons responsible.

  Approach: I'm honestly not sure I understood this project. I'm not clear on what the material in the project is (i.e., SWIFT particles). This project had a very novel approach. It did not look at fractionating or increasing the homogeneity of the product, but rather at maximizing the yield of the crop, I think. While the biomass product is more heterogeneous at this stage, it may lend itself to fractionation in a downstream process. I think this is a very novel approach to producing a lower-cost feedstock that could be homogenized later, or new markets for the unique feedstock could be found. There were parts of the approach that I was just not clear on (e.g., rapidly iterating fractionation system with virtual verification). There does not appear to be any work related to evaluating ecosystem services or sustainability studies. As another reviewer pointed out, this would be very important at getting buy-in from the community. It could be analogous to some public view of clear-cutting in the forest, and don't want to create a negative perception, which will deter the implementation.

  Impact: Also wondering if there is any economic analysis that will be done and how will it evaluate the price of the final product if there is currently no market for it? This could be a risk that should be thought through.

  Progress and Outcomes: Early stage, but appears to be on schedule.

- The project has a strong management team, has established a clear management plan, has identified risks and mitigation steps, and has a good communication plan. I find two serious problems with the project premises. One, there is no such thing as weather-independent technology when entering and performing passes through a farm field. Even though one may work in wet conditions, serious damage can be done to a field, causing problems with future farming tasks such as planting. The second problem is there is no clear plan to address, earlier rather than later, the ability to separate the grain from the stover with little damage. If a farmer cannot realize maximum value for his or her grain, then this approach is a non-starter. It will not be economically feasible. The project has a good representation of their timeline and go/no-go decisions and a plan to match fractions with conversion techniques and production of a TEA/LCA model. This project has the possibility of advancing the SOT and providing a basis for other innovation. I still believe the approach needs to pay more and early attention to the grain fraction recovery and the movement of it to market. I am not sure how farm economics and return on investment is affected by not having to dry grain. Grain for delivery to an elevator will have to be either dry or dried for storage. Traditional multi-pass corn stover baling operations have already reached DOT truck weight maximums. There has already been a single-pass system developed with BETO support at least 9 years ago that reduces ash to the intrinsic ash of the stover. I am not sure what is included in the $70/ton delivered price. The project team has made significant progress on their goals and adhered to their timeline. Risk mitigation was employed when needed. I don't find problems with the quality of the work or the outcomes as much as what impact the outcomes will have.

- This project is very interesting from the biorefinery perspective. The potential for electrification of light-duty vehicles brings more interest to this project as the market for corn demand lowers. This process is intriguing from a harvest efficiency and ash reduction standpoint. It does appear difficult to manage ag bags, but I think there are other options/solutions that could be implemented. It will be interesting to learn more about separating corn kernel from corn plant parts and the efficiency. I would like to see a little more definition on the downstream in this project, as I think it's a logical next step. A lot of good work has been done here; it is cutting edge, and it certainly brings potential for biorefinery downstream. Thank you.

PI RESPONSE TO REVIEWER COMMENTS

- We appreciate the reviewer's perspective and critique of the SWIFT research project. We are encouraged by the comments and enthusiasm for this transformative process. Our team is pleased to hear that the reviewers agreed with our management plan and research approach. We are encouraged by the comments regarding our progress and outcomes. The motivation for the SWIFT process is that conventional stover harvest approaches result in an estimated 60% of the available corn stover collected at moisture contents that exceed 20%, resulting in a lack of ability to produce a reliable feedstock with conventional harvest and storage systems. Our stated goals for the SWIFT project are to (1) develop a corn stover harvest, storage, and transportation process that is less weather-dependent; (2) produce a corn stover feedstock with defined and measurable characteristics for superior conversion performance; and (3) reduce corn stover feedstock delivery cost to $70/dry ton ($2016).

  The task responsibilities are as follows: field harvest, storage, anatomical fractionation, and pith-rind separation (tasks 2, 5, 7, and 8) are the responsibility of co-PIs Digman and Shinners (University of Wisconsin); virtual verification (task 4), co-PI Tekeste (Iowa State University); anatomical fraction grouping, pretreatment, and hydrolysis yields (tasks 3 and 9), co-PI Wendt (INL) and TEA/LCA, co-PI Hartley (INL).

  To clarify the definition of SWIFT material: The SWIFT process starts with low-moisture (<40% w.b.) whole-plant corn. Consequently, SWIFT particles include grain, leaves, husks, cobs, and stalk fractions. The material is chopped (mean particle size <1 in), can be handled in a bulk format, and is stored anaerobically. There would be multiple options besides silo bags for anaerobically storing the whole-plant material, including drive-over piles and bunker silos. These options could be managed by cutting blocks of densified material and moving them just in time to the biorefinery. A similar technique is used in robotic feeding of dairy cows.

Regarding the innovations around the harvest process, the SWIFT process does not rely on proprietary technology developed by our project partner. The University of Wisconsin team has made all technical developments and machine modifications. One specific modification is the addition of a stalk cutoff knife on the ear snapper head. Depending on the placement of these knives, the corn stalk is cut off at a different location as the corn is pulled downward by the stalk rolls. This not only changes the cutoff height, but also preferentially selects the leaf fraction. This approach is less discriminating than the whole-plant header, which selects plant material by cutting height, and consequently, some fraction of both the stalk and leaf material is left behind in the field. Through this innovation, we have the capability of selectively harvesting material. We can leave as much or little stover in the field to meet the environmental requirements of the farmer or landowner. This isn't unlike whole-plant corn silage harvest that is widely practiced in dairy farming systems. Additionally, conventional stover harvest occurs days or weeks after grain harvest, challenging the ability to grow cover crops before winter onset. Cover crop seeding can begin the same day as SWIFT harvest, making it an attractive conservation option.

To address the risk associated with storing the grain fraction anaerobically, the team has focused on mitigating grain damage at harvest through process variable optimization on the self-propelled forage harvester, as well as developing an alternative strategy that utilizes a combine harvester that threshes but does not separate the grain. The team has also dedicated significant time and resources to recover a high-quality grain fraction from anaerobic storage. In the end, however, the SWIFT process will be most consequential when corn grain can be co-utilized at the biorefinery without drying. It is important to note that in the current state-of-technology system, grain is lost at harvest, contaminated with foreign material, and damaged during drying and handling. The SWIFT process provides the opportunity for downstream fractionation of the stover. This is one of the advantages of mitigating the risk associated with the co-storage of the grain and stover. Selective fractionation of the stover anatomical fractions has yet to occur and will be informed by our collaboration with Dr. Wendt at INL.

Finally, we are committed to scientific integrity and transparency in our cost models and assumptions. The harvest rate for SWIFT is favorable when compared to grain harvest. Our work to date demonstrates the utility of SWIFT to achieve a 30-ton/hour harvest rate compared to our verified baseline of 14 tons/hour for baling, in addition to eliminating non-value-added processes such as shredding and raking. Our preliminary analysis and that published by others indicates that the cycle times and cost associated with hauling the stover are favorable to collecting, loading, transporting, unloading, and stacking bales.

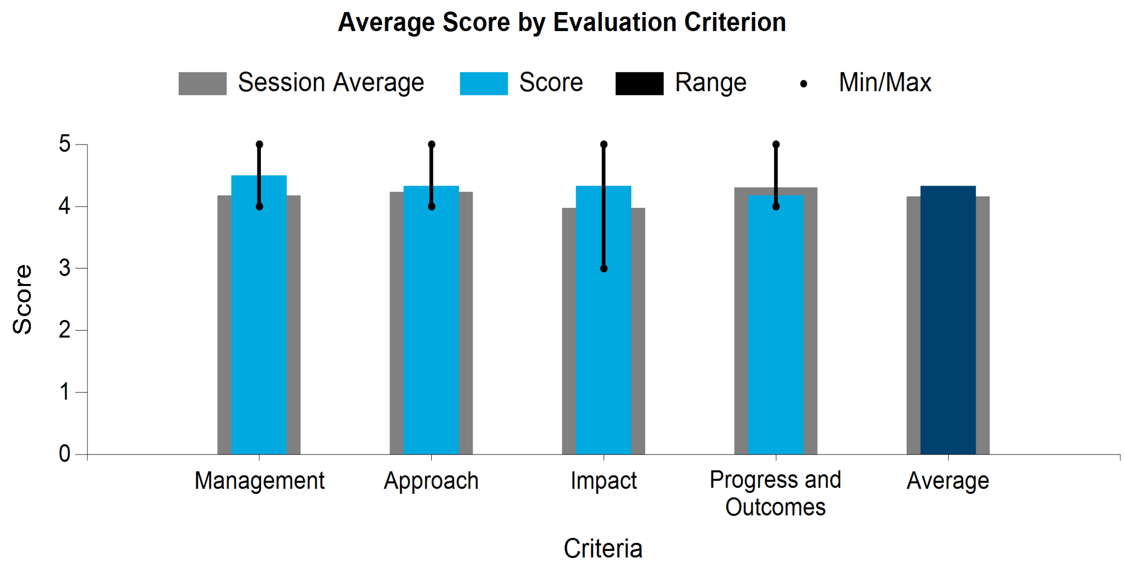
STANDARDIZED RISK ASSESSMENT AND CRITICAL PROPERTY ANALYTICS

Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	1.2.2.2
Presenter(s):	Rachel Emerson
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2021
Total DOE Funding:	$2,224,596

One of the primary hindrances to producing a viable, sustainable biomass industry for renewable biofuels and bioproducts is the lack of understanding and quantification of the risks associated with the biomass supply chain and preprocessing and conversion technologies. The objective of this project is to facilitate "de-risking" bio-project development by (1) developing systematic methodologies and frameworks to assess risk and (2) applying statistical approaches to identify and quantify biomass critical properties associated with risk. To address supply chain risk, Task 1.1, a collaboration with industry partner Ecostrat, is developing a Biomass Supply Chain Risk Standards (BSCRS) framework intended to provide a comprehensive list of risk indicators and scoring methodology to quantify project risk. To address technological risk, Task 1.2, in collaboration with the Feedstock-Conversion Interface Consortium, is developing a systematic criticality assessment methodology using well-accepted quantitative risk analysis methods to evaluate critical properties impacting preprocessing and conversion unit operations. To better understand risk assessment identified critical properties, the goals of Tasks 2 and 3 are to use available data sets for advanced computational applications to (1) quantify ranges and sources of critical property variability and (2) identify and quantify critical property impacts on preprocessing technologies.



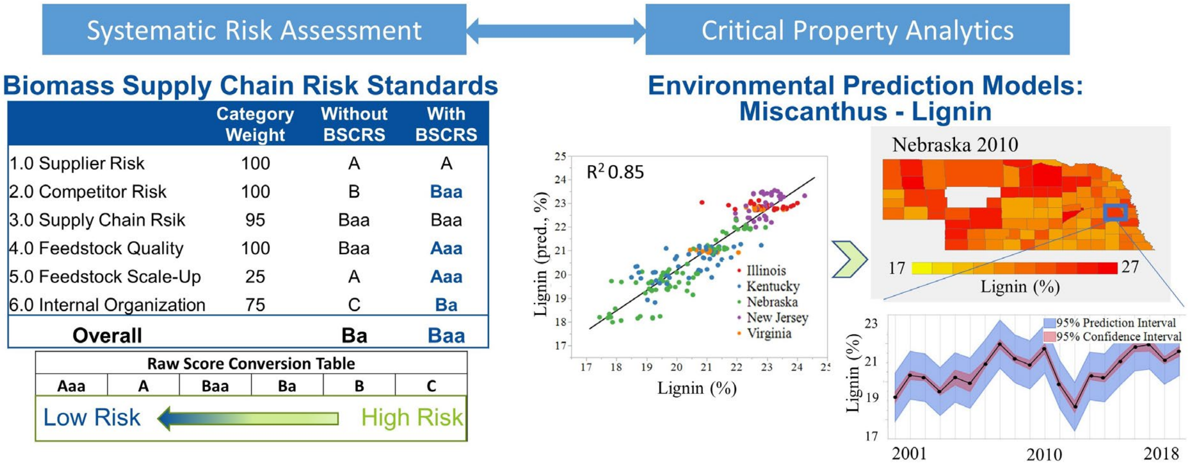


Photo courtesy of Idaho National Laboratory

COMMENTS

- It is a good, reasonable project. I am wondering how these 100 industry stakeholders were selected for inputs for risk factors and scoring system. These risk factors could be changed and varied according to policies by current and future administrations. It is not clear how to deal with the biases from the participants and uncertainties of major factors affecting risks. Regarding large historical field studies, in addition to Sun Grant programs, USDA's National Institute of Food and Agriculture has awarded more than 20 Coordinated Agricultural Projects nationwide over the last 8–10 years. Both INL and Oak Ridge National Laboratory were/are involved in some of these projects. A partnership could be developed for this project with them. Everything in here is economics driven. If a biomass supply chain project cannot attract investors, then it simply implies that risks exist in the project. They could be supply/demand related, technological and market of the final products, and beyond. I am thinking a weighting/normalizing scoring system might need to be further explored to improve the de-risking process.

- I will say that it appears to me this this project sets an example for communication between the various national lab projects. It looks like there is a well-developed flow of information from the other projects into this project. Well done. Anyone dealing with agriculture has a different risk scale. Particularly with herbaceous crops, a dry summer reduces yields, a wet harvest season will increase harvest losses and maybe also increase storage losses, etc. Weather models based on historical weather records might have a use in this work. I am a strong supporter of the Bioenergy Feedstock Library; it is a valuable resource. I am going to use the rest of my space here to advocate for a companion library for equipment cost. I am thinking specifically about the mobile machines used to harvest and deliver biomass. There is a wide variety of this equipment from a mower-conditioner cutting switchgrass to a chip van delivering wood chips. My idea is for a central repository for operating cost data ($/hour) for all these machines, and a common procedure for calculating these costs. There may be, and probably will be, a different cost for different regions, but these costs should be comparable. Simple example—What is the cost for a truck driver (with a commercial driver's license) in the Southeast versus the Midwest? These data are probably available in a database somewhere. Also, there are custom rate tables for harvest machines (balers, forage choppers, etc.) in various regions. I advocate that all BETO projects reference the central database (library) for their total economic analysis of harvest and delivery cost. Labor cost is typically the largest component of the dollar-per-hour cost. Can there be an agreement on how this cost is computed for comparison purposes? For example, I use a salary of $25/hour for an operator. Is it appropriate to use 25+25 (employer payments, benefits, etc.) to obtain a $50/hour labor cost in the analysis?

- Management plan has very little weakness. There are excellent objectives such as identification and quantification of biomass critical properties associated with risk. Good communications strategy with multiparty input from industry (over 100 advisors), national labs, and BETO. Clear recognition of risks associated with each task and subtask, as well as mitigation plans for those risks. This type of ratings service similar to Moody's or S&P's could make access to capital much easier, as well as cheaper. The project has clear go/no-go decision points and methodologies for this decision. Challenges are identified; however, not much in the way of risk mitigation. The overall approach is robust, and there is a good mix and volume of quantitative and qualitative data input and analysis to develop strong predictive models. The project will help advance BETO MYPP goals, as well as advance the SOT with an innovative approach. Developing a standardized methodology to assess risk in biomass supply and biomass variability risk for the financial community will expand access to capital. Many institutions currently feel uncomfortable with their abilities to analyze and quantify project risks. However, acceptance by the financial community could create a significant breakthrough for capital formation. Progress and outcome provide critical tools for the financial industry to have confidence in the methodology for the quantification of risk, which will enable capital formation for the industry. I do find that there needs to be more attention to how to generate industry acceptance. This will be critical for this project to meet its overall objective of making investment-grade capital available to bioeconomy/biomass project developers.

- Management: This project began in October 2018 and ends in September 2021. A go/no-go was held in FY 2020—$3.2 million. Management includes communication strategies that include advisory boards, subject matter experts, and stakeholder groups. Weekly team meetings are also included in the management plan. Risk identification and mitigation strategies are addressed.

  Approach: The project has developed a risk scoring method (BSCRS) and passed a go/no-go decision point in FY 2020. The Task 1 approach has been modified by adding a new subtask (task 1.2) to address technological risk. The approach for tasks 2 and 3 includes consideration of properties of materials from the Bioenergy Feedstock Library and other BETO projects. There is value in using a known data set to test the proposed assessment, as long as the data set includes the targeted material properties. However, innovation related to quantifying the impact of critical properties for preprocessing technologies is not clearly represented.

  Impact: There is value in having a systematic risk assessment, especially when it includes geographic influences on feedstock quality variability. However, there isn't enough detail provided to understand the full extent of how the project will provide a protocol for quantifying biomass supply chain risk. The full supply chain would include harvesting and transport, weather, and a host of other variables.

  Progress and Outcomes: Initial results indicate that the risk assessment provides a decision tool that may help in reducing perceived risk associated with bioenergy projects. The formed groups of subject area experts could contain bias, which could limit the severity/occurrence/detection guidance tables.

  Overall Impressions: This is a big project that is difficult for a lay audience to understand because of the abstract nature of it. It has the potential to remove barriers that could impede adoption of bioenergy technologies.

- Management: Good management structure outlined in the project, including inclusion of many stakeholders of various backgrounds. Task 1.1, which was near completion, seemed to be well managed. It is positive to see a large stakeholder group involvement, which is especially important for identifying diversity of risks. How will the results be disseminated, and can they reach the business community that needs this information? Details on the management of task 1.2 was not clear. The evaluation of failure mode and effects analysis (FMEA) as a tool for evaluating risk analysis to biomass quality is novel and important to investigate. Not confident from the presentation that a plan has been devised for acquiring the data required. No mitigation strategies were evident.

Approach: FMEA is advancing the state of the art for determining risk associated with biomass quality. Interesting approach for sure. I am not sure how the critical material attributes and critical process parameters are to be derived, but you will need significant industrial involvement, even more so than for task 1.1. A sophisticated and logical approach.

Impact: Task 1 will have a large impact on investors looking at bioenergy/biorefinery options. I am not sure the extent of the supply chain to be examined, but should be a good start. This is a significant piece of the quality-by-design piece of the puzzle that is missing. This will enable quantification of the impacts on downstream processing of the costs associated with out-of-spec biomass. Dissemination should include some industry-geared conferences.

Progress and Outcomes: Not sure how the risk assessment was affected by the analysis given my own lack of understanding of the system, but it showed positive results. Buy-in from investors is important, and consideration should be given to how this may be accomplished. Who do you need to partner with? One outstanding question is once you know a material is going to cause problems, can an action be taken? For example, if the whole crop of *Miscanthus* had a different chemical composition for a harvest cycle, what options does the biorefinery have (i.e., as shown on the slide). This demonstrates that understanding the limitations of the biorefinery needs to be considered.

- This project is well managed. I believe the data sets generated with this model will help provide insight into the validity of future capital investments for biorefinery. This work illustrates a good point that the grade of the biomass needs to improve. This result adds more horsepower behind improving the quality and commercialization of biomass commodity. Thank you for a job well done.

PI RESPONSE TO REVIEWER COMMENTS

- We appreciate the reviewers' positive comments for the project objectives to identify and quantify biomass properties associated with risk and contributions to BETO's MYPP goals. Biomass quality (critical properties specific to product quality, process efficiency, economics, and sustainability for a technology conversion pathway) will continue to be an important consideration for bio-project risk that this project captures well in both the BSCRS framework, which includes a risk category specific to variability in feedstock quality, and the FMEA approach, which includes generating relationships between critical properties and failure modes for specific feedstock technology unit operations.

  We thank the reviewers for their comments on the communication strategies of this project. We plan to further strengthen these various project-to-project communication aspects and improve our dissemination and outreach strategies.

  Regarding the use of weather models and other resources associated with the various risk indicators, the BSCRS framework includes a resource component intended to provide information regarding available resources associated with the risk indicators (e.g., environmental models being developed under Task 2 of this project, bioenergy resources databases such as the Bioenergy Feedstock Library).

  The reviewers point out the importance of dissemination and industry acceptance for the products developed through this project. This is specifically important for the BSCRS framework, as this tool has the most potential for market technology transfer. We completely agree with this concern and will need to continue to communicate with the project's stakeholder group, validate the BSCRS framework with relevant case studies, and disseminate the research. This will necessarily include a combination of industrial-relevant conferences and communication and expansion of our stakeholder group, which includes multiple representatives from financial institutions. Outreach and communication are core strengths of our project industry partner, Ecostrat, who has been key for communication of the BSCRS framework in the industry community.

The reviewer identifies the challenge of risk evaluation for bio-projects. The tools and knowledge developed through this project could help bio-projects perform self-evaluations for risk, along with providing a standardized framework understood by financial institutions. Though the BSCRS primary product is geared toward standardized risk evaluation by a bio-project lender and/or rating agency, the framework includes a comprehensive list of risk indicators, associated required project documentation, guidance, and identified available resources, all intended to be made publicly available. This would allow an institution to use the BSCRS framework for self-evaluation. Additionally, the FMEA approach proposed by this project has been thoroughly adopted by other industries, including automotive and pharmaceutical. In this project we are demonstrating how this approach could be adapted and adopted in the bioenergy sector. This could also be a self-administered method for bio-project technological risk assessment.

We value the reviewer's comments on the development of the BSCRS framework. The industry stakeholder group members for the BSCRS development were selected to maximize the representation of entities that would be involved in the bioenergy sector, including feedstock suppliers, financial institutions representing lenders and ranking agencies, landowners, equipment manufacturers, and relevant bio-project owners, along with academic and government research institutions. By collecting feedback/inputs from a wide range of stakeholders, diversity of opinions and experiences helps to ensure that individual biases do not impede objectivity of the analysis. The reviewer brings up a good point of an "economics-driven" focus. We believe that the current analysis and list of indicators/categories included in the BSCRS transcend economics alone and account for quality and environmental considerations.

Regarding an implementation of weighting criteria in the BSCRS scoring analysis—we thank the reviewer for this comment. We currently have employed a weighting system that does allow for the framework to be adjusted and applied to multiple feedstock supply chains (e.g., agricultural residues, woody). This weighting system continues to be refined as different feedstocks are evaluated through case studies using the standards. These case studies have also highlighted challenges related to data availability, which can also provide insights into potential improvements to our scoring and weighting methodologies.

We appreciate the reviewer bringing up the importance of risk indicators associated with harvest, transportation, and weather events, further supporting the inclusion of these indicators in the BSCRS framework. During the presentation there was not enough time to highlight all the various risk indicators that have been included in our framework. Altogether there are 128 risk indicators grouped into risk factors within the six risk categories used to evaluate project supply chain risk. Under the supply chain risk category (category 3), there are indicators included that do cover risks associated with harvest, transport, and weather aspects (e.g., risk indicator 3.7.1 "Seasonal weather impacts on feedstock supply" requires proponents to provide evidence of understanding of the impact of seasonal weather over time on harvest timing, quality, and yields). The BSCRS framework will be made publicly available and can be accessed at https://bioenergylibrary.inl.gov/BSCR/Home.aspx by the end of the project so that these indicators are more widely available to the broader bioenergy community.

The reviewer brings up an important aspect of an equipment logistics cost-type database. Though this is likely out of scope for this specific project, it is an important programmatic objective that INL is well poised to contribute potentially through INL's Feedstock Technologies platform projects. We appreciate the reviewer's thoughts on this higher-level goal.

We would like to clarify some of the aspects of our FMEA approach to address the reviewers' comments. Our FMEA efforts this year included completing a proof-of-concept FMEA with the goal of determining if the approach would be an appropriate tool for risk evaluation using the research approaches being investigated by the FCIC and INL's Feedstock Technology platform projects. The

FMEA approach requires interviews with subject matter experts to gather the necessary data. From these interviews, the primary failure modes for each unit operation in the context of a technology configuration pathway and operational mode are identified. For each of these failures, a risk priority number is calculated considering the severity, occurrence, and detection ranks. Along with these standard FMEA outputs, the associated critical quality attributes, critical material attributes, and critical process parameters are also documented in relation to the various failures and calculated risk priority number, allowing for more quantifiable impacts of critical properties in the context of a failure mode. The FMEA approach provides a valuable framework for evaluating preprocessing and conversion systems in a standardized manner. The success of full implementation of FMEA in the future will require standardization and refinement of language to ensure consistent interpretation amongst subject matter experts, as well as replication to incorporate diversity of experience for each unit operation evaluated.

Regarding the reviewer's comment on the potential bias of the subject matter experts used for our proposed FMEA risk analysis approach, our team agrees that this will always be a risk with this type of approach. The assembled subject matter expert teams would ideally include researchers with various experience levels, different backgrounds, and multiple researchers representing single unit operations. In this proof-of-concept stage of evaluating the use of FMEA, the subject matter expert teams are somewhat small, but it is intended that these teams expand with the adoption and potential expansion of FMEA as an approach to reduce potential bias. This adoption will be determined in the coming quarters of this fiscal year.

The reviewer's comment regarding quantifying the impacts of critical properties for preprocessing technologies is acknowledged. We agree that not having all of the suspected critical properties for this type of analysis would be problematic and result in underwhelming and ineffective results. Fortunately, the concurrent activities of this project and the experimental projects collecting the data sets have allowed for strong inter-project communication, better ensuring that the full suite of critical properties under investigation are collected. The properties presented for the presentation only represented the few properties that were found to be significantly related to the evaluated separation efficiency response; however, for this analysis, there were additional properties evaluated, including chemical properties (e.g., carbohydrates, lignin, total carbon) and physical properties (e.g., bulk density). Additionally, the statistical approaches selected for this analysis were intended to help identify potential missing critical properties. Along with our Task 1.2 FMEA development approach, this critical property impact quantification effort is relatively new and will need to be further refined to ensure that the results are relevant and useful.

Finally, the reviewer's comment regarding the options a biorefinery has once a problem has been identified is not something this project can solely address; however, this project can contribute some solutions to this overarching biorefinery challenge. (1) Through the BSCRS framework, a biorefinery project would necessarily have had to consider variability in the incoming supply and have supply-based mitigation strategies in place. (2) The BSCRS risk indicators, coupled with the environmental prediction models being developed by this project, could provide a forecasting ability for bio-projects to develop mitigation strategies for extreme case variability from a single harvest cycle due to climatic events prior to those events occurring. (3) Part of the FMEA approach includes documenting and assessing actions and/or mitigation strategies for the failure modes. These mitigation strategies can capture the innovative research and technology developments that the FCIC and INL's Feedstock Technologies platform projects are developing in the context of unit operation specific ranked failures that could be beneficial to bio-project development.

NEXT-GENERATION LOGISTICS SYSTEMS FOR DELIVERING OPTIMAL BIOMASS FEEDSTOCKS TO BIOREFINING INDUSTRIES IN THE SOUTHEASTERN UNITED STATES

University of Tennessee, Knoxville

PROJECT DESCRIPTION

WBS:	1.2.3.107
Presenter(s):	Tim Rials
Project Start Date:	02/01/2016
Planned Project End Date:	01/31/2021
Total DOE Funding:	$4,000,000

The diverse portfolio of biomass sources that is available in the Southeast, including a significant supply of pine "residue," represents a valuable strategic position for the region. Through blends formulated based on critical properties, this project will take full advantage of the range in biomass properties afforded by the portfolio to produce a consistent, high-performance feedstock for the industry, while lowering cost. Key developments being targeted to enable this potential include whole-tree transport to a state-of-the-art merchandising depot that will further access biomass from ongoing forest industry operations. The approach will more effectively utilize the tree and distribute cost, while minimizing in-woods contamination of the woody biomass component. To implement this vision, information on the chemical composition and changes that are induced during multiple preprocessing steps (size reduction, moisture removal, densification, etc.) is needed. Novel NIR sensor technology will be utilized for online monitoring of important biomass properties that impact process efficiency. The data will be incorporated into a statistical process control platform to improve process efficiency and meet required specifications. Advanced process models are being developed to inform the TEA and LCA of the program's impact. The new system will ultimately reduce operational risks from supply chain disruptions and allow larger-scale biorefineries.

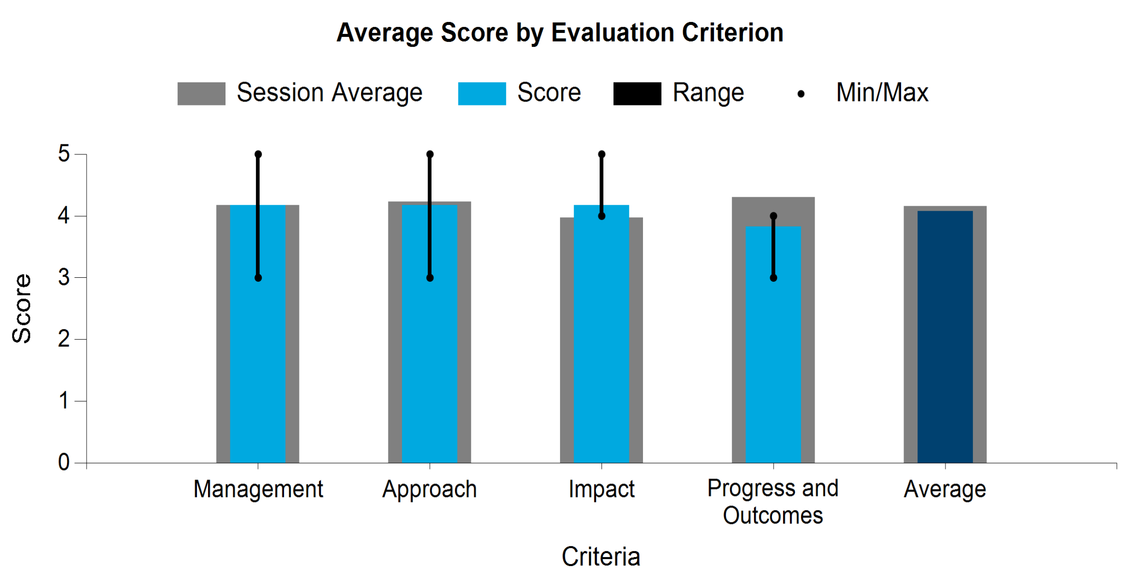


Photo courtesy of the University of Tennessee, Knoxville

COMMENTS

- The opportunity to campaign feedstocks (one feedstock supplied part of the year and then another feedstock [or feedstocks] fills in for the remainder of the year) provides a major advantage for the Southeast. The project identifies forest residue and switchgrass as the two feedstocks with the highest potential. I agree and endorse this project 100%. This project has a different approach to achieve the multi-feedstock advantage. I had not considered the option of blending switchgrass and pine forest residue continuously for year-round delivery. There was not sufficient time in the presentation to contrast the two approaches and explain why the continuous blend option is best. It was easy for me to visualize the delivery of chipped pine forest residue to the blending depot. This is commercial technology. The issue of receiving and processing bales of switchgrass is still unsolved, though some progress has been made. I hope this team will have an opportunity to continue their work. It is my view, a little self-serving, that the Southeast will ultimately have the largest biorefinery industry in the nation. This project provides significant progress toward that goal.

- Merchandizing and new equipment such as a new trailer design are the major components in this project for the next generation of biomass logistics systems. Certainly, merchandizing sawlog is always encouraged due to its higher value. However, the analysis should address the optimization of integrated sawlog, pulpwood, and biomass production with some case scenarios such as merchandizing in the woods versus on landing, and products combinations. For the trailer design, axle weight was mentioned. It is not clear to me how the dimension, gross vehicle weight, and field performance such as safety features and radial turning of the tractor trailer were evaluated. Depot concept was discussed in the project. It is not clear how the number of depots used and their distributions in a certain procurement area could affect the performance of the proposed logistics systems. The project focuses on pine residue, switchgrass, and hybrid poplar, which is fine. According to Oswalt's *Forest Resources of the United States, 2017* (2019), the net volume of hardwoods timber on timberland in the southeastern United States accounted for 57% versus 43% of softwoods timber, although the annual removal of hardwoods timber was 22% compared to 78% for softwoods timber. Considering potential hardwoods residue production, how could this proposed logistics system be applied under the hardwoods stand conditions?

- Management: The team members identified are respected in their fields. The project includes relevant industry partners. Communication plans are not presented but were mentioned in the responses to the 2019 reviewer comments. The risk and mitigation strategies are not presented under Management, but some were mentioned, such as trucking the pine residues to INL as soon as possible to avoid mold growth. This project ended on 1/31/21.

  Approach: Four main tasks are identified. The project overview describes connections from harvesting and transport logistics to characterization and blending that would reduce the dependence and potential risks related to single sources of biomass at conversion facilities. Of special note are the use of high-moisture pelletizing and online NIR sensor development. The project was limited in that it only modeled depot costs and did not address operational considerations for a depot.

  Impact: The project explored integrated merchandising, quality monitoring, and formulated feedstocks (blending pine and herbaceous crops in the Southeast, which can enable larger-scale biomass facilities).

  Progress and Outcomes: The finding that the merchandizing approach encouraged production of saw logs rather than pulpwood is not surprising. Single-stem handing always adds to the cost of producing woody biomass from standing trees. The summary indicates that blending increases the feedstock cost by $6/ton (not including pelleting), but it is unclear whether the project produced the blended material within the cost range of $84/dry ton or what needs to happen to meet that delivered cost.

  Overall impressions: This project reviewed a variety of important steps related to harvesting, feedstock characterization, blending, and pelletizing. It was well integrated and examined a full range of feedstock supply logistics.

- Management: Excellent group of collaborators. The variety of industrial participants is significant and will make great strides in getting the technology and ideas to the next level of implementation. Also, the involvement of industry from an early stage is very important for buy-in from industry, as well as bringing their perspective to the project.

  Approach: Sound approach to the project based on the idea of using various sources of biomass will expand the area of opportunity, which should reduce costs (i.e., transportation) and centralize capital and operational costs. This would make the preprocessing more efficient and bring the human resource expertise needed to focus on development and optimization. The idea of merchandising the biomass makes sense. It may open new markets and competition for specific components of the biomass. The blending of the biomass will assist in advancing the state of the art to delivery of a more consistent quality feedstock. Appreciated the number of industrial collaborators to keep the project relevant and allow these collaborators to enhance their own equipment/process research.

  Impact: This type of operation might allow for building expertise in preprocessing biomass and take this effort away from biorefinery, which is not focused on the raw material, but rather the process. This extra step in the supply chain needs to be carefully evaluated. Risks may be the added cost/greenhouse gas emissions and material loses. Benefit is the more consistent supply, but what I felt is missing is the value proposition for the sorted biomass. What is the higher price that users will be willing to pay? Unfortunately, there is not enough discussion on the LCA results to understand the results presented.

  Progress/Outcomes: It is difficult to evaluate the meaning of some of the more technical results because of the limited question period and the short presentation time allotted for the large number of significant findings. I am especially interested in understanding the LCA results, where the depot case showed higher global warming potential than the baseline. The pyrolytic product yield does not show a high degree of variability in the products when spanning mixes of 100% switchgrass to 100% pine residue. Therefore, I wonder how much effort should be put into the detailed characterization if the biomass is to be used for thermal conversion to heat. Good advancement of the NIR sensor development. Control strategy from the information might be the next step. How will the information be used to help the biorefinery operation? What about blending ahead of time or as information to the biorefinery operation so the process can be adjusted to incoming feedstock? I would have liked to hear more about high-moisture pellet processing. Advantages/disadvantages TEA?

- This is a completed project for the BETO program. It is generally a strong project with few significant weaknesses. As a completed project, some of the applicable scoring criteria are not as relevant. For example, I understand that the management communication plan is no longer relevant, but it would have been good to see the plan anyway, as it might serve as an example to other projects. The impact of the project is significant, as it has the potential to significantly expand existing supply shed areas of southeastern forest (woody) biomass supplies and add significant conversion potential. It should also be noted as a project strength the ability to mix feedstocks and produce a fuel that meets specifications for a biorefinery, which should ensure efficient and sustainable conversion. There is commercial potential and an excellent cross section of industry partners. I did not see a plan on how the information was to be communicated to industry, and this is a project weakness that should be rectified. A detail in the project I would have liked to see addressed is the significant trucking costs in a greatly expanded supply area. I am not saying they were not considered, but I did not see the information. Another potential weakness in the project is there was no work done to see how the projected $6/ton increase in feedstock cost might be offset by decreased pretreatment and preprocessing coupled with increased conversion efficiency at the biorefinery. I strongly encourage BETO to consider doing this work because an increase by $6/ton is significant.

- This is a great concept overall. The project statement lacked some risk mitigation thought; this is a commercial-scale operation, so it helps to alleviate some technical risks. I think the project demonstrates a clear connection to goals and commercialization. The depot concept is very intriguing to potentially push the commodity into other markets. There is also substantial benefit for transferring ownership of feedstock quality and management away from the biorefineries. Great work.

PI RESPONSE TO REVIEWER COMMENTS

- On behalf of the LEAF team, we appreciate the opportunity to participate in the 2021 Peer Review meeting and highlight the contributions the project made to deliver high-quality feedstock to the biorefinery. It is always challenging to provide a level of detail that captures the full impact of the work, and this year was no exception, as evidenced by the thoughtful questions and comments from the review panel. Our response to selected questions is presented below and hopefully offers an additional degree of clarity.

  A basic question impacting implementation of the depot concept is the capability to transport whole trees to the centralized depot for merchandising. The project team at Auburn University addressed the challenge by introducing a new trailer for hauling timber with the tops intact. The trailer was designed and fabricated to meet state and federal regulations that are in place today after surveying regulatory requirements in the region. The wheelbase of the trailer system was the same as current tandem axle trailers, so the turning radius of the tri-axle trailer will be the same as the conventional tandem axle trailers commonly used in the southeastern United States. Even with the gates swung back around the load, the trailer remains just under 53 feet, which is a legal length. As for gross vehicle weight, our conclusions state that with biomass attached, load weights can exceed 80,000 pounds (the current legal limit). There are efforts at the federal level to raise this weight limit to 96,000 pounds if there are six axles, which is why we put a tri-axle configuration under the trailer. If this legal limit could be raised to 96,000 pounds for the tri-axle configuration, this trailer design could be used to transport the additional biomass; otherwise, the benefit of hauling biomass in this trailer design will be reduced, as there will be more value in transporting higher-value products (pulpwood and sawtimber).

Our objective in doing these simulations was to study costs for a regional supplier hauling whole trees to an intermediate processing facility versus in-woods merchandising. "Regional" in this context was central Alabama, and a supplier was taken to be a collection of logging contractors in that particular region. This approach allowed us to compile considerable data on harvest cost in collaboration with our industry partner (ForesTree), lending an added degree of confidence to the simulations. Marginal costs associated with altering the location of the facility within the region were of secondary importance, because it was always assumed there would be a secondary transportation step necessary to convey residues to a conversion facility drawing from a number of such depots. Final hauling costs would, therefore, be confounded with configuration of the satellite processing facilities more so than any single facility location and would be best studied at a super-regional level. The location chosen in analyzing intermediate processing facility costs was near the center of the region from which wood was drawn. Costs were also evaluated for an alternate site, one near the perimeter of the roughly circular wood supply region. Costs for the in-woods processing option were slightly lower for certain sites (average \$2.04), the difference being higher primary transportation costs (average \$1.92). The difference was more dramatic for the intermediate processing facility option, with costs being generally higher by \$8.59 (25-ton truck capacity) and \$8.52 (33-ton capacity). Increases were again overwhelmingly due to higher primary transportation costs. Although residue costs were nearly 30% higher for the less centrally located intermediate processing facility, the difference might have been recouped in lower secondary transport costs. This scenario would need to be evaluated at a larger scale. The basic premise of this project was focused on southern pine and switchgrass. Our scope of work did not address hardwoods. Therefore, the work to design the trailer and model the merchandizing systems were focused only on southern pine.

The question regarding the value proposition of the approach very accurately summarizes the potential risks and potential benefits of the depot concept. The depot will add significant capital costs, and some operating costs, and in our analysis these costs are not likely to be recovered by lower transportation costs of the densified feedstock. While all manufacturing processes work hard to lower the costs of the feedstock, the feedstock cost is not the only factor that affects the minimum fuel selling price (MFSP). In the case of a biorefinery, the capital cost per annual gallon is also a major contributor to the MFSP. Thus, the added cost of the depot could be recovered by increasing the production scale of the biorefinery, which lowers the capital per annual gallon. With the centralized model, the size might be limited to 1,500 to 2,000 dry tons /day of feedstock, or 25–35 million gallons of hydrocarbon fuel. With the inclusion of three to five large depots, the production at the biorefinery could increase to 4,000–6,000 dry tons, or 70–105 million gallons of hydrocarbon fuel. This scale allows for much lower capital per annual gallon and a lower MFSP. It is also comparable to the average corn ethanol biorefinery. A second and potentially even more compelling benefit of the depot is the creation of the high-density feedstock, which will be much more easily handled within the biorefinery. Feeding problems have bedeviled the commercial biorefineries, but this densified depot product will be much easier to feed and handle. The U.S. wood pellet industry is producing more than 15 million dry tons of easily handled, flowable pellets that can help overcome the problems with raw, unconsolidated biomass. This work shows that increasing the time on stream 10% can lower the MFSP by \$0.20–\$0.30/gal. The benefits depend on the feedstock ratio and the biomass ash content. Although time constraints limited discussion on the LCA, the results for the depot concepts are detailed in our publications.

The review panel is correct that the composition and bio-oil yield were not heavily dependent on the biomass source, but the yield and overall economics were heavily dependent on the moisture content and ash content, which is related to the source of the biomass. In particular, the LCA implications of the depot are heavily dependent on the ratio of relatively wet forest residues and relatively dry switchgrass, which then determines the amount of natural gas needed to run the biomass drier at the depot. The centralized biorefinery has a large excess of process heat, and biomass dryer could be “heated” with off-gases from the pyrolysis unit or from the central power plant. Thus, the fuel produced in a centralized biorefinery will have lower greenhouse gas emissions than the fuel produced at a depot running at 25% or more forest residues. We hope to have the opportunity to continue the development and demonstration of the benefits afforded by the online NIR sensor. As noted, even though product composition was not found to be particularly sensitive to the formulation of the switchgrass/pine residue feedstock, moisture and ash do impact yield and overall process efficiency. The capability to monitor biomass properties in real time over an extended period is necessary to adequately cover the range of characteristics that will be encountered during standard operation of a biorefinery. The new information and the ability to link fundamental chemical properties to process behavior will undoubtedly generate new insight into opportunities to reduce downtime resulting from off-spec feedstock. We are very interested in establishing new partnerships with technology providers to identify those as-yet-unidentified directions to improve overall system efficiency. Expectations are that this insight, along with improved handling behavior provided by the pellet format, will lead to downstream benefits that may offset the added cost introduced by the depot and its capacity to handle multiple biomass types.

IMPROVED ADVANCED BIOMASS LOGISTICS UTILIZING WOODY AND OTHER FEEDSTOCKS IN THE NORTHEAST AND PACIFIC NORTHWEST

State University of New York

PROJECT DESCRIPTION

WBS:	1.2.3.108
Presenter(s):	Tim Volk
Project Start Date:	04/01/2016
Planned Project End Date:	09/30/2020
Total DOE Funding:	$3,000,000

Willow and poplar short-rotation woody crops have shown promise with regard to environmental benefits and rural development, but wide adoption lags due to underdeveloped markets and supply systems. High costs associated with harvesting, handling, and transportation (40%–60% of delivered cost) have impeded expansion. A better understanding of these systems will create opportunities to improve efficiency, reduce costs, and realize environmental benefits and impacts. The project's goal was to lower the delivered cost of hybrid poplar in the Northwest and willow in the Northeast by optimizing harvesting and logistics supply systems while maintaining or improving biomass quality along the supply chain. Over 3,400 Mg of biomass and 300 ha of willow and poplar were monitored over a range of crop and field conditions. Feedstock quality as affected by storage and preprocessing was shown to improve or maintain feedstock quality. Modeled harvesting costs ranged from $38–$61/Mg dry; when including delivery and preprocessing, feedstock costs ranged between $79–$83/Mg dry for willow and $106–$116/Mg dry for poplar. Costs for willow minimized when hot water extraction and high-moisture densification preprocessing were used. Models also suggest that social and regional factors could further reduce costs. Results will give guidance to feedstock growers, harvesting and logistic operations, biorefinery project developers, and policymakers developing short-rotation woody crops to support a growing bioeconomy.

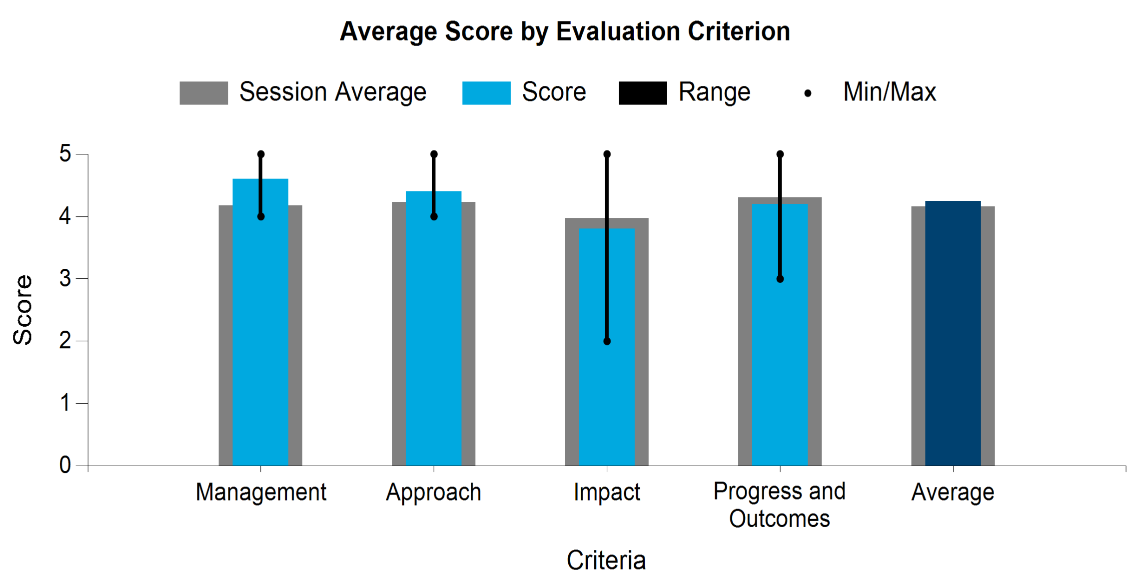


Photo courtesy of the State University of New York

COMMENTS

- This project supplies needed information for the national bioenergy knowledge base. It is going to cost more to deliver chopped willow in the Northeast than other feedstocks in other regions? Yes. Does this mean that BETO should not be studying short-rotation woody crops? My answer is a firm “no.” In my judgement, there will be a day in the buildout of the nation's bioenergy industry that willow in the Northeast will make an important contribution. BETO, via the progress made by this project, is helping us get ready for that day. I request that the final report have an explanation for the results in slide 22. The harvest cost decreases as yield increases and then levels off at 50 Mg/ha. Why? The forage harvester, as most harvest machines, is a "capacity-limited" machine. It is designed to ingest *x* tons/hour. If I choose a forward speed that introduces *x* tons/hour, I jam the machine. An experienced operator chooses a higher forward speed when yield is low and slows down when yield is higher, to keep a constant *x* tons/hour. Why is this not the case with the willow harvest? I came up with the following. At low yield, the stem diameters were larger, and the forage chopper had more trouble handling them; therefore, the forward speed had to be reduced, and the harvester capacity (ton/hour) was reduced. This means the harvest cost ($/ton) is increased. It is my understanding that BETO requires calculation of average delivered cost. It is meaningful to me if the cost is broken down as follows. (I do not know what guidelines are given.) Farmgate: growing the crop; harvest: collecting off the field and placing in storage; storage: does not apply in this case, since the biomass is delivered directly to a wood-fired power plant and added to their storage pile; delivery: it looks like you used chip vans filled with a high-dump sugar cane wagon at the edge of the field. Cost of in-field hauling, in this case maybe five wagons to keep the harvester moving, is a significant cost item. I hope you are encouraged to deal with this cost directly.

- Management: Management included scheduled meetings for various teams. Coordination with partners was improved by using unmanned aerial vehicles for improved communications (a strength). Risks and mitigation strategies are clearly described, and researchers recognized that losing samples during shipping is an unfortunate risk. The management team included Holland Agriculture and GreenWood Resources, but seems to lack the engineering resources required to anticipate equipment modifications. The final report was submitted in December 2020.

  Approach: This single-pass harvester fills a need for developing a system capable of reliably delivering large volumes of biomass from purpose-grown woody crops. The project addresses many logical steps from harvesting to the reactor throat. Equipment modifications were made throughout the project to improve harvesting. These modifications did not appear to be made early enough in the project to clearly compare the operability under a variety of conditions. The BETO cost milestone ($84/dry ton) was clearly stated, and, under the right conditions, delivered feedstock to the conversion reactor at a $/dry ton that was well below the target (strength).

  Impact: A significant number of technical transfer activities were performed and appear to have reached an assortment of stakeholders. The project resulted in a coppice header that is commercially available through New Holland dealers. The addition of a sugar cane wagon was an unplanned improvement brought about by information sharing.

  Progress and Outcomes: This project ended on September 30, 2020, and the final report was submitted in December 2020.

  Overall Impressions: This project included a wide range of topics that were an impressive mix. From equipment modifications to storage, feedstock characterization/classification, preprocessing and blending, and modeling, this project was a full package. It would have been nice to see some more definitive results in the summary and lessons learned section, but presentation time was limited.

- Management: Excellent group of collaborators, including industry partnerships. The collaboration should help with the uptake of findings. Also, nice to see the project management so well laid out, detailing which group/person will be responsible for each piece of the project (the slide with the five integrated tasks made a complex project easy to follow). Good management of a complex project because of the operational scale of the activities. Lessons could be learned from this project, as thoughtful risk and mitigation strategies were identified.

  Approach: This work is a good progression in industrial development of short-rotation woody crops beyond the smaller trials that have been reported on previously. Definitely a need for evaluating these types of operations to aid in the next step of commercialization.

  Impact: Field day is an excellent means of promoting the work done within the community. Great initiative to keeping the community engaged.

  Progress and Outcomes: Covered a large part of supply chain and collected important data. I personally was not clear on the benefit of the water extraction or how this might be practically incorporated into a supply chain.

- The team has a clear management plan to monitor many hybrid poplar and switchgrass harvests to evaluate and lower cost in relation to the goal. Advanced state-of-the-art efforts seemed to mainly monitor an existing harvesting operation without advancing harvest; however, exploring washing, hot water extraction, and drying for preprocessing is novel and beneficial for downstream processing. Wasn't clear if there were efforts to advance harvesting to reduce cost. I struggled to make a connection on the conclusion of the work. It wasn't all that clear to me how the data/outcomes resulted in cost reduction. It wasn't clear how washing, hot water extraction, and drying affected the cost of preprocessing. There was a lot of great data collected on cost and biomass quality, but they don't appear to make the connection to the goal of cost reduction. The results were a range in cost that encompass the goal $/ton but lacked granularity in how the outcomes affected the cost.

- This is another project that has come to completion. It is overall a strong project whose strengths include the following: (1) an excellent team, project management plan, and communications plan that was able to identify risks and put in place solid mitigation strategies. (2) The approach was built upon previous DOE work and advanced the BETO MYPP; there is strong commercialization potential, and industrial partners were shown the value of short-rotation woody crops as feedstock. The statement that cost targets can be met under certain circumstances needs clarification. (3) The project has disseminated information through several means—publications, communications with industry partners, and field demonstrations, to name a few. Some equipment that was tested in the program is already available through the New Holland dealer network. Hot water extraction has commercialization potential, and plans for commercialization are underway. (4) I believe all project goals were met, and potentially high-value models have been developed with data from the field trials. There have been significant information contributions to the library of information on biomass materials. All in all, an overall strong project successfully pursued with little weakness.

PI RESPONSE TO REVIEWER COMMENTS

- We are grateful for the time and effort that the review panel invested in understanding this project and providing useful feedback. Below we provide some information in response to the main questions raised by the reviewers. People interested in further details of this work are encouraged to look at our final report and associated published papers.

  There were questions from the review panel about the costs for producing wood chips from short-rotation woody crops and how this varied under different conditions. A strength of this project was that we were able to collect data on harvesting operations under a range of crop, ground, and climate conditions and respond to modeler data requests in order to address model assumptions and sensitivities. Overall, this provided valuable and targeted information on how variables such as harvester throughput and fuel consumption varied under different crop, ground, and weather conditions. These data were essential and provided new input for models to reflect costs and harvesting system performance for large-scale biorefineries.

  The harvesting cost modeling work was led by the team at Oak Ridge National Laboratory, and there are summaries of the key results from this work in the final report, and a paper will soon be submitted for review with more details and an explanation on why harvesting costs vary with changes in the standing crop biomass. Data on biomass quality and characteristics under different field conditions and times of the year have been built into this modeling work. Additionally, the IBSAL model allowed scenarios that were not practical to test operationally to be evaluated (e.g., multiple harvesters, large numbers of collection vehicles, varying climate). While there are a wide range of different variables that impact the harvesting cost for short-rotation woody crops, an important one is harvester throughput. Results from this project show that harvester throughput increases as the standing biomass in the crop increases, and then begins to level off when standing biomass reaches 40–50 Mg wet/ha in the field, and then levels off. Results on this detail of the harvester throughput are in the final report and in two published papers for willow and another one for poplar. Results from this project clearly show that there is considerable variation in throughput and fuel consumption, and in particular with changes in ground conditions (wet and dry) and time of season when material is harvested (leaf off or leaf on). The information collected during this project has allowed more accurate modeling of woody feedstock supply for large-scale biorefineries and the trade-offs in cost associated with harvesting at different times of the year. Data on variations in ground conditions have been important in these models to project how many harvesting days are available under certain climate patterns, which impacts the number of harvesters and associated collection vehicles needed to meet biorefinery demands. All these factors are combined in the IBSAL model to provide costs for harvesting short-rotation woody crops (see Task 5 summaries in our final report).

One reviewer asked for clarification on how circumstances affect cost targets. One novel feature of this project was our reliance on the strengths of multiple models in order to address different project objectives. IBSAL (Oak Ridge National Laboratory) was used for harvesting logistics, the Biomass Logistics Model (INL) was used to evaluate processing costs, and the West Virginia University model was used to evaluate geographic and social questions associated with biorefineries. All these models evaluated cost targets in different ways, sharing inputs and outputs. For instance, tractor trailer loads of willow and poplar from both leaf-on and leaf-off harvests were shipped to INL, where a combination of drying and size reduction preprocessing work was conducted in the Biomass Feedstock National User Facility. Several tons of hot-water-extracted willow were also sent there for preprocessing. Hot water extraction is a technique that has been of increasing interest for improving the quality of woody biomass. Hot water extraction removes approximately 60% of the ash in biomass, resulting in water-resistant material that can be used in wood pellets and reduces energy consumption in pellet manufacture. It also generates a range of coproducts, including fermentable sugars (e.g., for biofuels), lignin (e.g., as a chemical feedstock), acetic acid, formic acid, methanol (as commodity chemicals), and furfural (as a specialty chemical). Data on energy consumption and flow rates for leaf-off and leaf-on willow and poplar and how water extraction material processed at the Biomass Feedstock National User Facility were tracked as part of Task 3 and used as key inputs in the Biomass Logistics Model developed at INL. This model is used to model feedstock supply system cost and energy consumption for a variety of biomass resources. Results showed that high moisture densification had the lowest processing costs compared to the baseline scenario. Using a combination of high moisture densification and hot water extraction, the potential blend proportions of shrub willow increased from 20.5% to 61.8% and decreased the cost from $82.72/dry ton to $78.56/dry ton for a biochemical conversion pathway scenario.

One reviewer raised valid concerns about how harvester modifications were executed and tested; it was a philosophical dilemma. In order to maintain operational relevance and realism, we gave the operators and harvest managers free reign to troubleshoot and adapt the system, taking advantage of their expertise. Many of the modifications to harvesting equipment were made in response to conditions that were encountered during harvesting operations in both willow and poplar and were designed and made with project team members and partners. This group included operators and equipment experts from the State University of New York College of Environmental Science and Forestry, Greenwood Resources, and New Holland Agriculture, who collectively have the greatest amount of experience with the New Holland single-pass cut and chip harvester system in woody crops in North America. As a result, equipment, repairs, modifications, and improvements did occur in an operational context. However, we did not try to control them in this project because the overarching objective of this project was to collect operational data to inform the modeling efforts. In circumstances where these objectives conflicted, capturing operational data to feed the models was paramount. Assessments of some factors, including modifications and repairs to equipment and changes in harvester operators, were conducted and are included in the final report. Because these were not designed studies and ground and crop conditions varied over time, the results were often quite variable. Other results from this project have proven to be more valuable and useful and were selected for the presentation at the peer review. Details of the assessment of some of the changes and modifications are available in our final report.

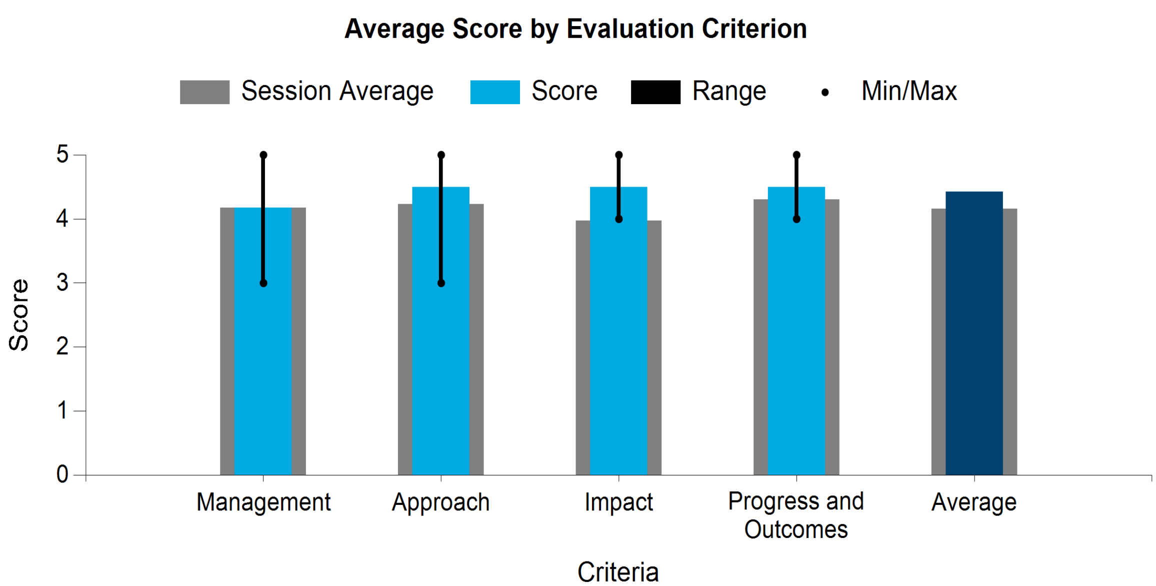
TORREFACTION OF SORTED MUNICIPAL SOLID WASTE PELLETS FOR UNIFORM BIOPOWER FEEDSTOCK

Idaho National Laboratory

PROJECT DESCRIPTION

WBS:	5.1.2.101
Presenter(s):	Jordan Klinger
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2021
Total DOE Funding:	$495,615

In a collaborative project between Idaho National Laboratory, Michigan Technological University, and Convergen Energy, mixed plastic and fiber wastes are being used as a feedstock to produce a uniform and upgraded fuel product through torrefaction. In this project, a combined and intensified torrefaction and densification process is used to upgrade the fuel value of the wastes, remove chlorine from the plastic waste, and mobilize the plastic through a softening phase transition to act as a binder and weather barrier. During this work, the team has documented reactive interaction of the material components during the processing that lowers processing intensity, increases throughput, and lowers the cost overall. Through pilot-scale testing, the team has demonstrated effective operation and used the data to estimate TEA costs associated with the process. Applying the lessons learned and preprocessing systems in a forward-looking sense can provide a pathway to production of a customized and tailored fuel or feedstock pellet where biogenic carbon from wastes is sequestered in a durable good.



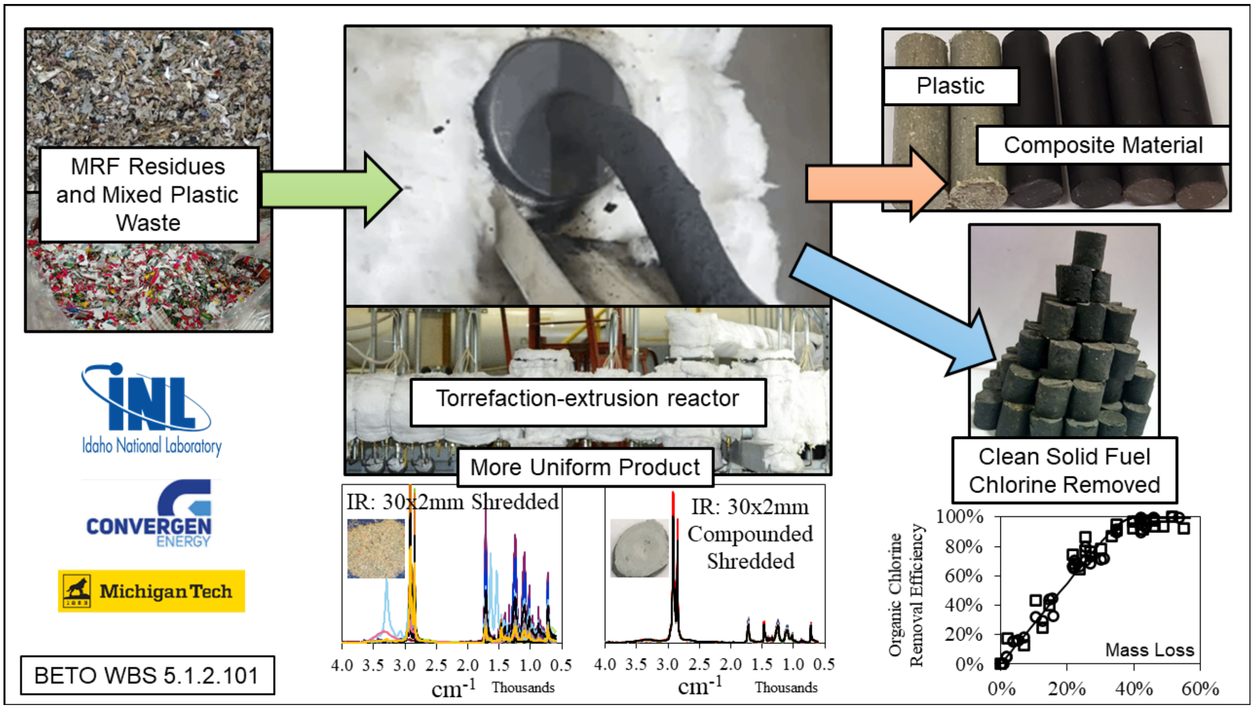


Photo courtesy of Idaho National Laboratory

COMMENTS

- This project is well organized and was well presented. I can see a targeted market as follows. A mid-size city puts in a torrefaction plant to reduce the MSW to their landfill; they then supply fuel to local industries that are producing and using process steam. The emphasis is on a "local" market, perhaps even an over-the-fence partner. The question then becomes, what size torrefaction plant is economical—10 ton/d? 100 ton/d? 250 ton/d? Perhaps this question can be answered in future work, with dollar-per-ton cost as a function of plant capacity.

- It is worth having some more investment to conduct more tests and provide robust data for TEA. Some details should be provided for approaches, such as numerical thresholds for go/no-go evaluations. Future plans should be addressed for the project.

- Management: The management team consists of researchers and includes a commercial partner. The communication plan is enriched through the inclusion of collaborations across various INL research teams working in other WBS areas.

  Approach: The approach is clearly defined and responds directly to a competitive laboratory call for early-stage research and development. The industrial partner ensures that the waste stream to be tested is realistic. This project is closely tied to TEA and LCA work of other teams. Challenges are identified and a go/no-go decision point was identified.

  Impact: The approach demonstrates a clear connection to the potential for significant impact and outcomes related to the project goal. The industry partner engagement lends a reality check component to the study.

  Progress and Outcomes: The two-year project has made appropriate progress toward the project goals. The preprocessing cost breakdown was informative, and each step of the research was integrated into the next. Accomplishments have been made to date, and outcomes include peer-reviewed journal publications.

Overall Impressions: It appears that this project will inform BETO on successful generation of a uniform feedstock and fuel from wastes. Costs have been explored and will be incorporated into a TEA partner project.

- Management: Good collaboration and partnerships.

  Approach: "Non-recyclable wastes" is a very broad term, and perhaps it could be defined to explain which material the project is focused on. The variability of MSW makes it difficult to develop predictive models. Just wondering how useful the models will be. The material pictured seems quite consistent and not like materials that I have observed at facilities processing MSW to power (i.e., Covanta). In the justification for the project, it is suggested that the only alternative is incineration. I believe there are many waste-to-energy plants that are meeting power demands with little to no sorting or preprocessing. I didn't see any provision for rejected material. Is there a probability that some of the material cannot be processed through the equipment (i.e., metal contaminants, dirt, combustibles)? Would appreciate seeing the quality-by-design standards that are targeted and achievable. May need input from boiler manufacturers for this information.

  Impact: There could be cost savings and process efficiency savings downstream in the process, which could make the findings very significant. The idea of a more homogeneous fuel pellet is very interesting and significant. All depends on costs and consistency of the product, as well as harmful emissions that may result. This type of characterization should be examined before the project proceeds too far. It may be beneficial to involve some boiler manufacturers to understand other characteristics of importance. This will also assist with next-stage buy-in from the boiler manufacturers.

  Progress and Outcomes: Good results thus far with respect to making the pellet and demonstrating that its characteristics are more homogeneous than the initial material. Positive results for achieving the goal, removing chlorine, and increasing energy density.

- The management communication strategy is good; there are collaborative partners and a plan for dissemination. I did not find there was much in the way of an implementation strategy, risk identification, or risk mitigation strategy. I do know these are in the approach, but the management plan should have what you are intending to do with an implementation strategy. There is a strong approach, with challenges and mitigation plans mentioned. I believe a project strength is using existing techniques to advance the production of a largely contaminant-free, energy-dense, and uniform feedstock. There is a clear, measurable go/no-go decision point. Performing TEA and LCA simultaneously with project work is a strength, as this work can inform the project team with near-real-time changes and/or decisions. I have always found waiting until the end to perform this work an inefficient approach. The project can have an important impact by producing a feedstock that would have wider acceptance and use from non-recyclable materials, which would have the positive effect of reducing the need for landfill space. The project has made significant progress. It is unclear whether a timeline has been met. I assume so, but there wasn't much in the way of a timeline presented. Challenges have been met and interesting possibilities for capital cost reductions identified. This is a good project that has made progress toward producing an energy-dense, cost-effective feedstock from a non-recyclable resource that can have positive effect on biopower production in furtherance of BETO's FT goals and MYPP. This feedstock would also have the added effect of reducing the environmental negative footprint and cost of building MSW mass-burn facilities.

- This is a bright spot in the tough arena of MSW. This project is well managed and designed to produce meaningful data. The project has been executed well with impressive results. Keep up the great work. Thank you.

PI RESPONSE TO REVIEWER COMMENTS

- The team and PI would like to thank the reviewers for their time and thoughtful consideration. The feedback is essential and very valuable to ensure meaningful outcomes and relevant goals. The project team apologizes for the transposition of information between sections in the short presentation. Indeed, this project represents a near-term solution that can be deployed immediately at the municipality scale and could displace waste generation and provide local power through discarded natural resources. Certainly mass-burn facilities are the highest generator of energy from waste in the United States. To clarify, the goal of this project is to transform the material such that it is compatible with the much larger dispatchable power sector as a whole—largely coal plants in the United States (and natural gas, of course, but that is beyond the scope of this project).

  We agree that boiler testing and standards are essential to evaluate with any finished product. We are currently relying on our industrial partner, who operates a power boiler, to assist with interpretation and clarification of quality standards. The reviewer correctly points out that the materials studied here are not what might be seen in a mass-burn facility. For this study, rather, the team was focused on rejected material from a material recovery facility, as well as industrial residues collected from our project partner. Although the approach was fundamental, the work benefited from the characterization and model development using real feedstocks. Although we cannot realistically claim we cover the range in variability for all wastes, we made a concerted effort to vary the distribution of waste components over a wide range of plastic, fiber, and other waste ratios (all of which were well represented by the model approach). The key to the broad-ranging approach is the use of a lumped parameter and pseudo-intermediates. These are widely used in petroleum refining and other industries to predict generalized chemistries and outcomes without detailed knowledge of a chemical mechanism. This flexibility is needed for realistic wastes. As the preliminary TEA presented, the total estimated cost based on pilot-scale data collected in the project is around $50/ton output from the factory gate. The project team agrees that TEA "along the way" is absolutely essential, even if it is preliminary as a "smell test" to make sure the results are applicable and feasible.

  For project timing, the work is scheduled to complete at the end of this fiscal year (end of September 2021). Along the way, the team has passed quarterly milestone objectives as well as a go/no-go decision point at the halfway mark (end of year 1). In addition, the final project goal is to perform continuous production of the torrefied product in the integrated system at Michigan Technological University, and this provides another opportunity for the team to refine the TEA data inputs as the reviewer suggests. The scalability issues raised are interesting and would be needed to evaluate location-specific site planning, along with perhaps a study of local waste characterization. This could be interesting future work. In addition, the team is exploring opportunities to continue the work into the future by addressing newly identified hurdles of: (1) real-time sensing and controls for combined MSW feed/high-temperature systems, (2) carbon sequestration in durable goods from MSW, and (3) identification and fractionation strategies for high-value products in MSW streams.