FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

TECHNOLOGY AREA

CONTENTS

INTRODUCTION

Six external experts from industry and academia reviewed 14 projects (9 presentations) during the Feedstock-Conversion Interface Consortium (FCIC) portion of the 2017 Bioenergy Technologies Office (BETO or the Office) Peer Review.

Since FCIC is still in the planning stages (it is expected to be fully integrated and functional in fiscal year [FY] 2018), this review addressed existing feedstock conversion efforts. FCIC accounts for a total U.S. Department of Energy (DOE) investment value of approximately $35,062,470, which represents approximately 5% of BETO's portfolio reviewed during the 2017 Peer Review. During the Project Peer Review meeting, the principal investigator (PI) for each project was given between 15 and 60 minutes to deliver a presentation and respond to questions from the Review Panel. Timeslots were assigned based on each project's funding level and relative importance to achieving BETO goals.

The Review Panel evaluated and scored projects based on Peer Review evaluation criteria (approach, technical progress and accomplishments from FY 2015–FY 2017, relevance to BETO goals, and future plans). This section of the report contains the results of the project review, including full scoring information for each project, summary comments from each reviewer, and public responses from PIs. This section also includes an overview of FCIC, full scoring results and analyses, the Review Panel's summary report, and BETO's programmatic response.

BETO designated Dr. Steven Thomas as the FCIC Technology Area Review Lead. In this capacity, Dr. Thomas was responsible for all aspects of review planning and implementation.

FSL OVERVIEW

Many of the serious bottlenecks in the nascent bioenergy industry are centered on feedstock handling and preprocessing operations and on introducing feedstocks into the conversion process. These issues all occur where the feedstock supply system couples with the conversion process, referred to as the feedstock-conversion interface. Due to the increasing importance of these issues, these existing feedstock-conversion related efforts are being organized into FCIC, which will be fully integrated and functional in FY 2018. The consortium is funded primarily by three BETO program areas: (1) Feedstock Supply and Logistics (FSL), (2) Conversion Research and Development (R&D), and (3) Demonstration and Market Transformation (recently renamed Advanced Development and Optimization).

FCIC Support of Office Strategic Goals

The central concept behind FCIC includes managing feedstock quality characteristics to (1) optimize the amount of harvested biomass suitable for introduction into biomass conversion processes and conversion process yield, while (2) minimizing equipment downtime due to wear and tear, plugging, or fires.

FCIC's overall goal is to develop and demonstrate integrated feedstock/conversion processes that achieve >90% operational reliability (i.e., time on-stream), within the constraints of the established cost targets.

The guiding principle for FCIC is that feedstock's physical, chemical, and mechanical characteristics are primary design considerations for process development, scale-up, and integration. Understanding and managing these characteristics will reduce the cost of production and reduce the risk to sustainable biorefinery operation.[12]

[12] The FCIC overview was provided by Kevin Kenney at the Peer Review; it is posted online at https://energy.gov/sites/prod/files/2017/08/f35/fcic_overview.pdf.

FCIC Support of Office Performance Goals

FCIC supports four of the Office success indicators/milestones as published in BETO's *Strategic Plan for a Thriving and Sustainable Bioeconomy*[13] and BETO's *2016 Multi-Year Program Plan*[14]:

- By 2018, start to develop a biomass feedstock grading or classification system for energy production and other end uses
- By 2019, develop and provide a framework for biomass quality grading systems for at least one woody and one herbaceous biomass supply shed associated with an existing or planned demonstration-scale (or larger) biorefinery
- By 2020, determine the impact of advanced blending and formulation concepts on available volumes that meet quality and environmental criteria, while also meeting the $84/dry ton delivered cost target ($2014), including grower payment/stumpage fee and all logistics costs
- By 2022, validate one blendstock for thermochemical conversion and one blendstock for biochemical conversion at a scale of 1 ton/day while also meeting the $84/dry ton cost target, including grower payment/stumpage fee and logistics costs.

FCIC Approach for Overcoming Challenges

FCIC efforts are focused on feedstock-conversion interface issues, such as the following:

- Determining the required particle size and distribution for feedstock handling and conversion
- Minimizing equipment wear
- Minimizing fire and dust explosion risk
- Introducing feedstocks into conversion processes against a pressure gradient
- Understanding process yield variation as a function of physical and chemical characteristics of feedstock materials.

Effective communication between FSL and Conversion R&D researchers on conversion performance as a function of feedstock physical and chemical quality parameters and preprocessing operations is critical to developing an economically viable and sustainable value chain. Feedstock-conversion interface efforts therefore emphasize correlating conversion performance characteristics—such as product yield, quality, and process kinetic parameters—with the physical and chemical characteristics of the feedstock and preprocessing operating conditions to define ranges of conversion process input specifications that permit reliable and routine achievement of techno-economic and environmental targets. This effort also develops and produces a suitable variety of preprocessed feedstocks for testing in bench-scale reactors for different conversion pathways. Larger quantities of specific feedstock(s) that meet(s) conversion in-feed specifications will also be prepared for scale-up testing and verification of conversion process performance.

The Biomass Feedstock Library, an element of the Biomass Feedstock National User Facility (BFNUF), is also included in FCIC. The library includes information on sample origin and agronomic treatments and enables users to access all data related to raw or preprocessed biomass samples and any conversion process intermediates. This allows subsequent analyses conducted on any sample to be linked to the sample's source and all

[13] U.S. Department of Energy, Bioenergy Technologies Office (BETO), Strategic Plan for a Thriving and Sustainable Bioeconomy (BETO, December 2016), https://www.energy.gov/sites/prod/files/2016/12/f34/beto_strategic_plan_december_2016_0.pdf.

[14] U.S. Department of Energy, Bioenergy Technologies Office (BETO), Multi-Year Program Plan (BETO, March 2016), https://www.energy.gov/sites/prod/files/2016/07/f33/mypp_march2016.pdf.

related publications relevant to that sample. Library data improve understanding of the impact of feedstock variability on conversion process performance characteristics and biofuel production costs. The Biomass Feedstock Library data and physical samples are available at bioenergylibrary.inl.gov, or via the Bioenergy Knowledge Discovery Framework at bioenergykdf.net.

FSL REVIEW PANEL

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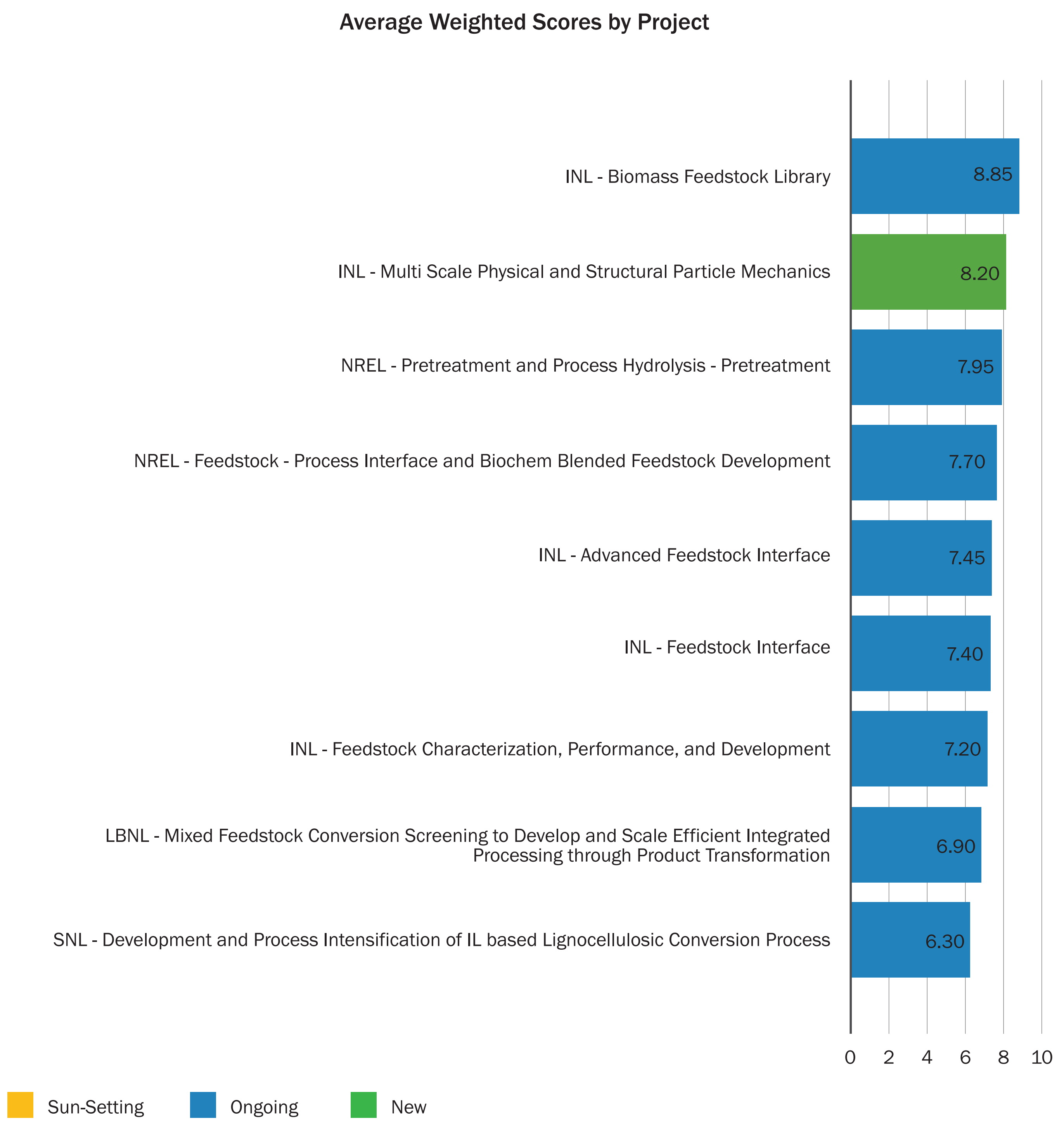
TECHNOLOGY AREA SCORE RESULTS



FCIC REVIEW PANEL SUMMARY REPORT

Prepared by the FCIC Review Panel

Collecting, delivering, cleaning, and preprocessing biomass substrates for biofuels and chemicals conversion is one of the most underestimated challenges in biomass-to-fuel conversion. Industry believed that engineered solutions were available for the design, construction, and operation of the first commercial facilities, but this belief has been proven wrong. Front-end processing has been problematic and very expensive for the first few pioneer plants. Full-scale biomass transport issues (e.g., biomass plugging and ash abrasion) are plaguing the startup, commissioning, and operation of these pioneer plants even after insights have been realized from building and operating pilot and demonstration facilities.

This summary report is intended to provide high-level, general comments to BETO program managers to help guide and focus FCIC projects to increase the return on the public investment. This summary does not necessarily reconcile the opinions of the individual reviewers to form a consensus; it is only intended to capture general themes and ideas for the manager's consideration. Detailed comments are provided in the individual project reviews. In addition, the Panel commends BETO for recognizing the importance of FCIC activities by adding this session to the Peer Review process.

Impact

These activities will help guide equipment suppliers, process designers, and plant operators to lower the risk associated with biomass handling, transport, and conversion of heterogeneous biomass feedstock. This is especially true of the Biomass Feedstock Process Demonstration Unit (PDU) at Idaho National Laboratory (INL), which provides a platform for the development of design principles for the handling, transport, and preprocessing of biomass feedstock. This PDU will help define the concepts and strategies for FCIC considering the requirements of the feedstock and conversion processes. The preprocessing requirements for thermochemical and biochemical conversion are different and lend themselves to leverage various biomass attributes (e.g., the biochemical process may tolerate higher levels of moisture and ash while a thermochemical process may not).

Innovation

Following are examples of FCIC activities with significant potential to improve the operation and profitability of biomass biorefineries:

- The depot and blending concepts should help lower the cost and improve the quality of the feedstock for a mature biorefinery industry.
- Intelligent feedback control systems for biomass handling and processing will increase the operability and availability of the production plants.
- Development of heterogeneous biomass transport models for the design community have great potential. The current models based on biomass combustion and pelletization, pulp and paper, and sugar industries are insufficient to adequately meet the design requirements of the biorefinery industry.

Synergies

The Panel reviewed a portfolio of projects that are examples of forthcoming FCIC projects. If the intent is to address this critical subject, FCIC should develop an integrated plan to connect and address the near-, mid-, and long-term needs of FCIC. There are significant knowledge and capabilities at the national laboratories, commercial industrial partners, and biomass industries to help define and support the development of an integrated FCIC plan.

Focus

The recommendations of the Biorefinery Optimization Workshop[15] should be the basis for the goals and objectives of the FCIC. The consortium should focus its activities on the development and implementation of an integrated, cohesive plan based on Workshop recommendations and balance the portfolio of projects to meet the objectives of the plan.

Commercialization

The present FCIC portfolio of projects is too broad and must be aligned with the recommendations of the Biorefinery Optimization Workshop to better the commercialization objectives of BETO.

Recommendations

Following are the recommendations of the Review Panel:

- Identify and appoint a diverse industrial guiding committee to build on the recommendations of the Biorefinery Optimization Workshop to continue capturing real world technical and operational issues
- Develop an integrated FCIC plan based on the recommendations of the Biorefinery Optimization Workshop and the guiding committee considering the different requirements of the various thermochemical and biochemical conversion processes
- Balance the portfolio of projects to include near-, mid-, and long-term FCIC projects. Wind down or terminate projects that do not fit in the portfolio.
- Perform a trade-off evaluation of the depot and blending concepts to validate the solutions and guide FCIC activities. The evaluation should consider and help define the battery limits of the depot and blending facility, the preprocessing requirements, and the capital allocation, e.g., if the interface is defined at the throat of the reactor, where the preprocessing will be conducted and how the biomass will be delivered. In addition, the techno-economic analysis (TEA) will have to consider where the preprocessing capital allocation will be made, at the blending depot or the plant.

FCIC PROGRAMMATIC RESPONSE

Introduction/Overview

BETO sincerely thanks the Peer Review Panel for its hard work, constructive reviews, and insights in shaping the emergence of FCIC. The Panel commended BETO for recognizing the importance of FCIC, and we would like to reiterate our strong commitment to this effort going forward. Reviewers described INL's Biomass Feedstock Library and Biomass Feedstock PDU efforts as important projects and crucial to FCIC. They also pointed to the National Renewable Energy Laboratory's (NREL's) Pretreatment and Process Hydrolysis project as having far reaching significance.

We very much appreciate the Panel's comment that FCIC's activities will help guide equipment suppliers, process designers, and plant operators to lower the risk associated with biomass handling, transport, and conversion of biomass feedstock. Risk reduction is key to the evolving bioeconomy sector, a focus of FCIC, and an area where FCIC can have significant impact. Our goal is to use a multidisciplinary approach to innovation in technology development. We appreciate the Panel members' recognition of the innovations in use of depots, blending, feedback controls, and advanced transportation systems. The lack of commercial facilities for testing will be handled through INL's and NREL's feedstock and conversion PDUs and simulation modeling. We agree to the importance of having industry involvement as well, and have made this a priority. We also agree that an immediate

[15] The Biorefinery Optimization Workshop presentations and summary report are available on the workshop web page: https://energy.gov/eere/bioenergy/events/biorefinery-optimization-workshop.

need and goal is to develop an operating plan to address industrial involvement and the best ways to integrate the various activities for a synergetic approach. The individual recommendations are addressed below.

Recommendation 1: Establish an Industrial Advisory Board

It has been BETO's intention from the onset to establish an industrial advisory board for FCIC. The advisory board will include members from a wide range of sectors including agriculture and forestry harvesting equipment manufacturers, biomass producers and suppliers, preprocessing equipment manufacturers, co-product distributors, conversion technology developers, biorefineries, and end users. A workshop in FY 2018 will bring together diverse stakeholders to crystalize FCIC's priorities and approaches.

BETO will support the national laboratory partners and FCIC researchers to engage industry stakeholders, gather input, and solicit feedback via activities such as listening days, workshops, and webinars. A "virtual scale-up team" will be created to assist companies that are preparing to scale their technologies. The team could lead to cost-shared collaborative R&D with industry.

Recommendation 2: Develop an Integrated FCIC Plan

Three BETO program areas—FSL, Conversion R&D, and Advanced Development and Optimization (previously Demonstration and Market Transformation)—are working closely with the national laboratories during the Merit Review cycle to develop well-integrated, impactful work plans for FY 2018–FY 2020.

A package of new projects, involving tight coordination among seven national laboratories, is being developed to cover the range of FCIC research priorities to help enable >90% operational reliability in biorefineries. The following are the current FCIC project titles:

- Feedstock Variability
- Feedstock Informed Process Development
- Modeling of Biomass and Feedstock Physical Performance
- Integrated Analysis
- Industry Engagement.

Recommendation 3: Balance the Portfolio and Wind Down Out-of-Scope Projects

All of the current FCIC-relevant annual operating plans (AOPs) will be terminated at the end of FY 2017. FCIC work plans are now included in a package of new AOPs designed to operate on the same 3-year cycle (FY 2018–FY 2020), and are undergoing independent review as well as receiving strong guidance from BETO. All projects are focused on mutually agreed upon, well-integrated FCIC goals and objectives. The overall goal is to help enable integrated feedstock/conversion processes that function at >90% operational reliability (i.e., time on-stream). FCIC projects will appropriately balance near-, mid-, and long-term activities, with a near-term focus on operational issues caused by feedstock variability. Feedstock variability is a high impact challenge because several integrated biorefineries (IBRs) have failed due to unexpected operational issues. Due to feedback received from the Peer Review Panel, depot and blending projects will be longer-term activities instead of near-term.

Recommendation 4: Perform TEA of the Depot and Preprocessing Concepts

BETO agrees on the importance of understanding the downstream technical and financial impacts of feedstock quality parameters, potential preprocessing operations, and the depot concept for FCIC activities on overall process reliability.

FCIC's Integrated Analysis project will evaluate the integrated value chain, which spans the field-to-fuel, system-wide impacts of feedstock variability on cost, down time, achievable biofuel yield, and environmental sustainability trade-offs to understand the path forward for IBRs to realize reliable and profitable operations.

MULTI-SCALE PHYSICAL AND STRUCTURAL PARTICLE MECHANICS

(WBS #: 1.2.1.3)

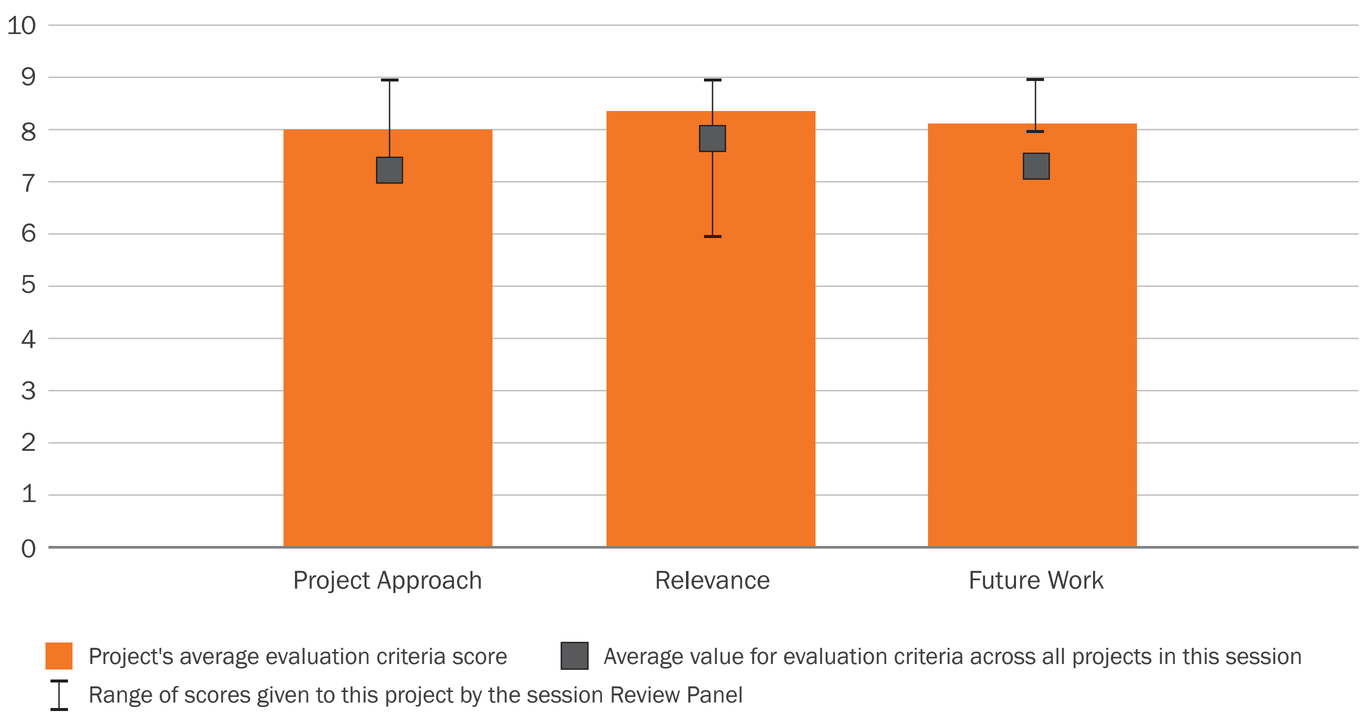
Recipient:	Idaho National Laboratory
Principal Investigator:	Tyler Westover
Project Dates:	10/1/2016–9/30/2017
Project Category:	New
Project Type:	AOP
DOE Funding FY 2014:	$200,000
DOE Funding FY 2015:	$0
DOE Funding FY 2016:	$0
DOE Funding FY 2017:	$650,000

Project Description

Feeding and handling represent a substantial challenge in biomass feedstock supply systems. Conventional systems for dry bulk solids are generally not suitable for lignocellulosic biomass, which typically has large particle size variations, low densities, and high compressibility. Methods do not exist to either physically characterize or computationally model the complex mechanical response of such materials. As such, the primary objective of this project is to develop robust mechanical characterization methods and computational models that can be applied to reliably predict the flow of biomass materials at all scales in a wide range of feeding and handling operations. This objective will be accomplished in several steps. First, materials will be physically and mechanically characterized at the individual particle and bulk solid scales. Next, discrete element (e.g., particle) models at bench scale will be combined with material characterization to determine the multi-dimensional and time-sensitive stress-strain relationships (e.g., constitutive relations) that govern the flow behavior at all relevant conditions. These constitutive relations will then be used in finite-element or control-volume models to predict the flow behavior at all scales. Finally, bench- and pilot-scale physical tests will be conducted to validate the flow models. The resultant

Weighted Project Score: 8.2

Weighting: Approach–25%; Relevance–25%; Future Work–50%.



characterization methods and flow models will be used to control the sensitivity of feeding and handling operations to variation in biomass properties.

Overall Impressions

- Overall, this project seems like an effective balance between empirical data collection and model development/validation and is a good template for how BETO might effectively frame other projects. If it really does relate well to commercial scale as proposed, this should be directly practical today, while making considerable advances to the state of the art in both engineering and material science.

  The degree of involvement from industry experts needs to be described. If we assume the pioneer plants involved experts in their design, one might wonder why this kind of analysis (e.g., work by Jenike and Johanson Inc.) has not already been done if they wanted to be dominant in the nascent biomass industry. Can we understand/quantify the degree of de-risking the output from this project? The project needs to have a high level of relevant industrial partner/pioneer interaction helping to design and analyze the experiments.

  The relative impact of the milling example is scary. With high levels of anticipated wear on the milling systems, there will be transient flow quality. How will the project deal with this dynamic engineering requirement?

  A key deliverable should be a series of protocols that can be applied to any feedstock. A relative scoring of different feedstock forms will also help grade biomass supplies.

  Should the project also study flow aids? Knowing mitigation methods can be as valuable as knowing the design. The speaker mentioned part of the project will be to set quality limits on the feedstocks to keep them in controllable range.

- This is an excellent project that is starting to address the biomass feedstock conversion interface. Before it embarks on the testing program, the project should seek the input of industry and equipment suppliers to help prioritize and focus the development and testing effort.

- This is a good project of clear relevance for BETO. The challenge is to prevent it from being a pure science project by introducing more direct ties to vendors, operational recommendations, and explicit TEA.

- Overall, I really like this project and believe that it fits well within FCIC. There is a distinct lack of data for the design of biomass handling systems, and this work could fill a major gap. Better designed systems would also reduce the startup time of biorefineries and increase their availability. My only recommendation would be that some of the work focus on wet materials as many industrial partners use soak tanks to reduce silica and increase biomass availability, and these materials handle differently than dry materials.

- This project, which focuses on understanding and developing tools for predicting the behavior of biomass feedstock solids handling, is unique and of great importance. Solids handling problems are one of the biggest issues hindering operation at existing biorefineries, so this project addresses a critical industry need at this time. The approach appears to be straightforward and involves a good mix of experimental measurement testing with modeling. It will be important to tap into the expertise of the solids handling companies that are part of the team to ensure that the right issues are being addressed without "reinventing the wheel." Also, developments should be tested at commercial scale to ensure assumptions are correct and because acceptance of results and any proposed feed handling modifications by industry will be critical to the project's ultimate success.

PI Response to Reviewer Comments

- This project will continue to balance empirical data collection and model development/validation during each year of the project with the intent to bring both approaches to sufficient maturity that they can be ready for testing at commercial scale in future DOE-funded efforts. Establishing strong connections with operators and consultants in the industry is a high priority for this project. Once significant progress is made toward understanding the flow performance of dry materials, the intent is to start a similar effort for wet materials, which should be able to borrow many of the characterization and modeling approaches already developed for the dry materials.

  We strongly agree that close collaboration with industry stake holders is necessary to identify the correct problems to focus on and also to deploy the solutions that are developed.

  The degree of de-risking that this project will provide to biorefineries can be estimated by using a preliminary TEA to determine the impact of the project outputs on pilot-scale feeding and handling operations at INL and possibly partner institutions. The pilot-scale information will have to be extrapolated to commercial scale until commercial data become available. Until then, it is clear that there are substantial cost incentives to reduce feeding and handling problems, and it is the hypothesis of this project that workable solutions need not be cost prohibitive.

  Being aware of the potential for equipment wear to impact material flow properties opens opportunities to solve this problem before it becomes an issue. Equipment wear does not usually occur suddenly, so that if biomass flow properties can be measured real-time inline during processing, then it should be straightforward to use active monitoring to correct equipment deficiencies before they cause expensive failures. This approach is common in the pharmaceutical industry, which requires extensive testing for quality assurance in regard to determining appropriate intervals for equipment maintenance and replacement.

  Looking more into flow aids is certainly advisable. The common approach of flow experts for handling springy materials is to design equipment to prevent over-pressures that may cause problematic elastic behavior.[16] By investigating the fundamental flow behavior of biomass materials, we believe that insights can be gained into effective equipment designs that incorporate measures, such as flow aids, to facilitate flow at critical points.

[16] For example, Jerry Johanson, "Bin and Feeder Design for Wood Chips and Other Springy Bulk Solids," *Powder and Bulk Conference Proceedings* (Chicago, IL, May 1989), http://www.diamondbacktechnology.com/Articles-and-Papers.html.

ADVANCED FEEDSTOCK PREPROCESSING

(WBS#: 1.2.2.1)

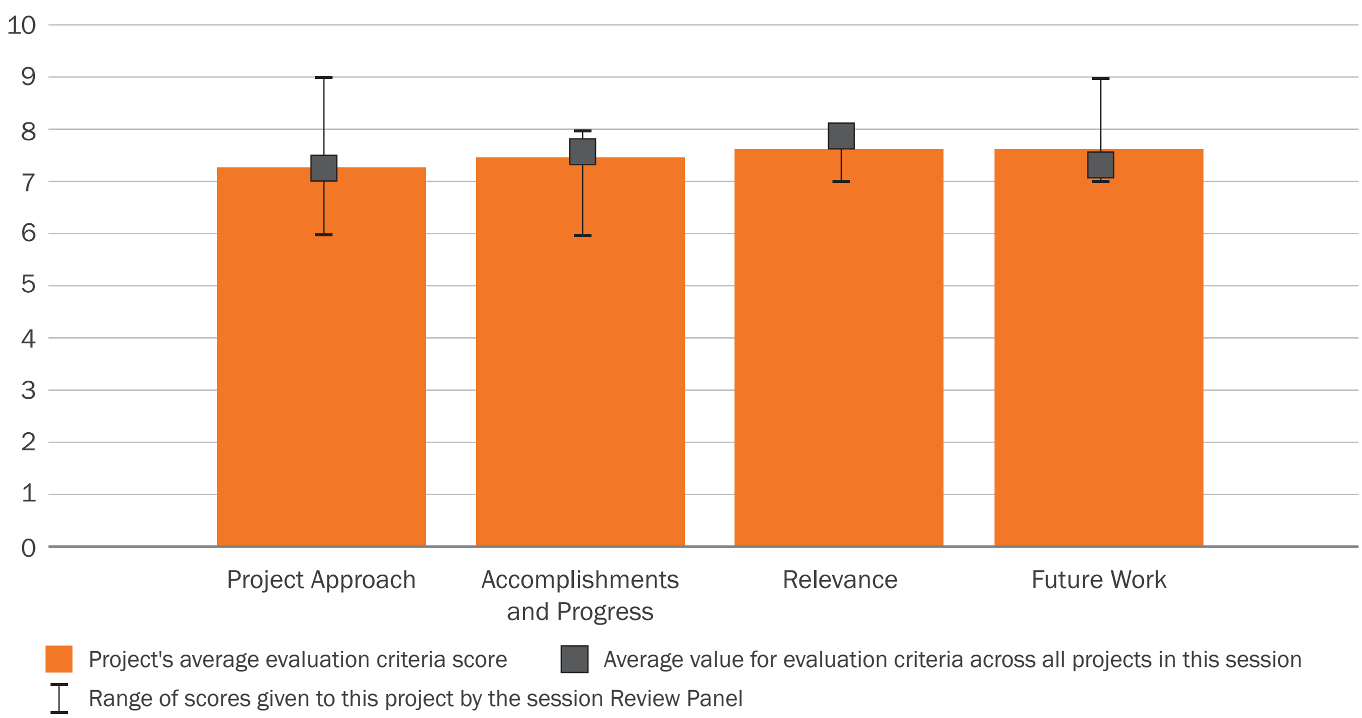
Recipient:	Idaho National Laboratory
Principal Investigator:	Vicki Thompson
Project Dates:	10/1/2009–9/30/2019
Project Category:	Ongoing
Project Type:	AOP
DOE Funding FY 2014:	$1,350,000
DOE Funding FY 2015:	$1,435,000
DOE Funding FY 2016:	$1,275,000
DOE Funding FY 2017:	$871,970

Project Description

To be successful, the Bioenergy industry requires a sustainable supply of low-cost biomass in sufficient quantities and with sufficient quality. This is challenging for several reasons: (1) biomass is not evenly distributed so few areas have a single biomass resource; (2) in areas with a single biomass types (e.g., corn stover), there are large ranges in compositions and characteristics; (3) methods to improve quality add cost; and (4) biomass is seasonal and degrades in storage reducing quality. Our approach is to mobilize low–cost and/quality biomass and take advantage of the low cost to use preprocessing methods to improve quality. These preprocessed materials can then be blended with other available biomass to reduce cost, improve quality, and increase quantities available. Our methods include mechanical preprocessing (i.e., air classification and sieving), chemical preprocessing (i.e., acid leaching, water washing, and alkaline extraction), and formulation. A parallel task developed cost models for preprocessing methods and TEA to target the best preprocessing technologies. We have developed a flexible method for optimizing all biomass resources in a region and meeting the required cost/quality/quantity targets. We demonstrated this by developing blends for fast pyrolysis using logging residues, clean pine, and construction and demolition waste that are air classified, acid leached, and formulated to be 16%–20% cheaper than clean pine.

Weighted Project Score: 7.5

Weighting: For ongoing projects, there is equal weighting across all four evaluation criteria: Approach, Relevance, Accomplishments and Progress, and Future Work.



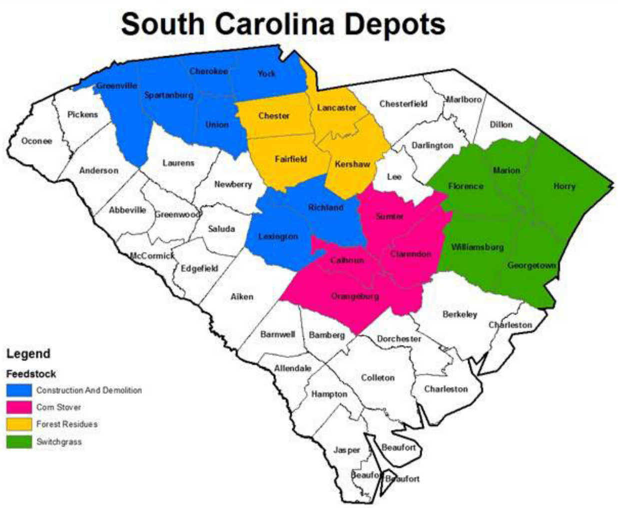


Photo Courtesy of Idaho National Laboratory

Overall Impressions

- Overall, this project uses a combined modeling and data collection approach that results in improved models as well as useful data. It is very useful for enabling improved decision making today for the industry, as well as providing data and improved tools for future work.
- This is interesting work and it is good to see national laboratory data backing up field observations.

  It is a promising concept to blend in small amounts of cheap, low-quality materials without much, if any, penalty. It might be interesting to consider then how this would tie into the grading project; if there is not much of the cheap feedstock around where it would only be added in low concentration where there really isn't a practical penalty, will the price still be lower?

  A key concern around lower grade feedstocks is how it will fit with the new Food Safety Modernization Act (FSMA) that all ethanol plants that make animal feed co-product will have to comply with starting in 2017. This will require a higher level of lot traceability and diligence about the feedstock safety. I have some doubts if municipal solid waste will be allowed at all.
- The project provides additional preprocessing alternatives for industrial consideration with the objective of lowering the cost, reducing the risk, and increasing the quality of the feedstock.
- I struggled with this project which starts as a TEA of feedstock blends to meet a specific requirement and ends focusing on a very relevant, but only marginally connected to the main topic proposed of technique analysis to reduce abrasiveness of biomass on size reduction equipment.
- The project was a good one in that it examined processes that would be helpful for a number of different conversion platforms and that it demonstrated the efficacy of the air classification and leaching systems. This project fits squarely within FCIC and would be a good model going forward.
- This project, which focuses on investigating how the use of preprocessing steps and blending impacts feedstock cost and availability, is important in assessing how these parameters can be used to optimize feedstock properties for biochemical and thermochemical conversion processes. The results demonstrate clearly that use of air classification and leaching can achieve a significant improvement in key feedstock qualities, and that these preprocessing steps with the right combination of biomass feed blends can be used to design optimal feed choice strategies for meeting cost targets. Since it is not clear if the results shown represent the best options or are just examples of what is possible, it is recommended that a more systematic study of all variables be performed to map out the best combinations that will meet the desired cost and quantity targets. It is also important to examine the effects on the ultimate bioenergy product to ensure that any additional costs incurred to improve feedstock cost and quantity do not get hidden downstream and added to the more important final product cost.

PI Response to Reviewer Comments

The perceived disconnect between TEA and biomass abrasiveness comes from seeing two different projects. The bulk of the work shown represented the conclusion of a 3-year project which ended in 2016. We prepared a proposal for a new scope of work and chose to apply the methods we had previously developed to solve problems that the biorefineries are facing now (abrasion). The previous work scope had a different goal, which was to provide feedstocks to the biorefinery that met BETO cost, quality, and volume targets.

We will monitor the implementation of the FSMA and will make adjustments to our feedstock blends as necessary.

BIOMASS FEEDSTOCK LIBRARY

(WBS#: 1.2.2.2)

Recipient:	Idaho National Laboratory
Principal Investigator:	Victor Walker
Project Dates:	10/1/2009–9/30/2017
Project Category:	Ongoing
Project Type:	AOP
DOE Funding FY 2014:	$750,000
DOE Funding FY 2015:	$885,000
DOE Funding FY 2016:	$752,250
DOE Funding FY 2017:	$993,250

Project Description

The Bioenergy Feedstock Library is creating a central repository for biomass/feedstock samples, information, and research data. Biomass and feedstocks are the foundation of all activity in BETO and understanding the qualities, characteristics, variability, and operations of feedstocks is critical to advancing a bioeconomy. This project advanced from collecting BETO research samples to develop a public web application for secure, reliable access to data and robust methods to examine it. The project continues to gather samples of physical biomass which it shares with researchers to advance analysis understanding. The Library provides tools and methods to help learn from the research data. To effectively meet the needs of the community, the Library is challenged to gather a more complete and rich data set, to identify reliable answers to critical questions, and increase visibility and use. To meet these challenges, the Library underwent a redesign and introduced several public and private tools that aggregates data into usable formats. These tools include graphing, blend prediction, variability examination, and tools to determine the least cost formulations with quality constraints. The Library continues to focus on increasing use by external groups, gathering targeted data sets, increasing categorization of the data, and providing more powerful tools to understand variability sources and impacts of operations.

Weighted Project Score: 8.9

Weighting: For ongoing projects, there is equal weighting across all four evaluation criteria: Approach, Relevance, Accomplishments and Progress, and Future Work.

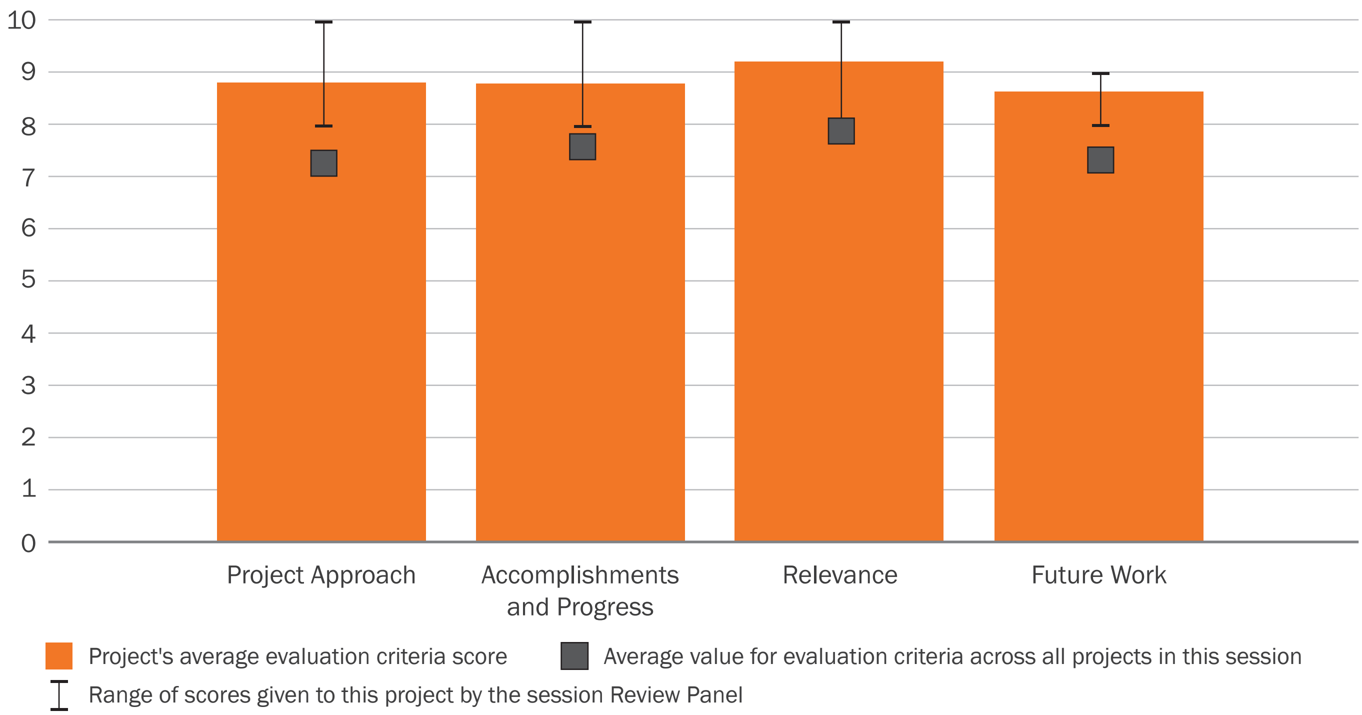


Photo Courtesy of Idaho National Laboratory

Overall Impressions

- This library is critical to BETO's mission. It is one of the most potentially impactful projects in the BETO portfolio because it underpins not only feedstock, but also sustainability and conversion work. Providing data resources is one of the single most effective ways to inform industry and academia, enabling synthetic understanding and avoiding duplicative or myopic activities. It is important that the library team be empowered to make the library connect to the Bioenergy Knowledge Discovery Framework (critical!) and the broader data community. It is also essential that other BETO projects are using the library data (and its variability!) to inform their work. Predictive modeling about biomass, feedstock, and feedstock blends is useless without informing those models with prior information. See papers by Dave LeBauer and/or Michael Dietze.

  A lot of great, meaningful information is accumulated and into a myriad of usable forms in the Library. It seems like a rather daunting task for a novice to come into the system and harvest value from it. The speaker described a relatively recent effort to produce tutorials and support resources so that industry and academia can get adept at the information quickly as the database is made public.

  A danger to any database of information like this is the context/history of the data. As we learn and get smarter, the information we collect gets more relevant; but what happens to our history/memory of the past? Is there are filter of some sort to help qualify some data as more relevant than others? Do some data have an expiration date? What if the Laboratory Analytical Procedures (LAPs) methods change over time? Do data get flagged when things like this occur as part of learning? The speaker described the project's quality control methods to help this challenge. Should it also include (perhaps prioritized by data relevance and volume) a round of reaching out to past data contributors to interview them and gain this added level of data identity that experience has shown is also important with the data?

- This is an excellent effort to create a common baseline for the academic and industrial communities to facilitate the development and growth of the industry.

- The Library is a highly relevant project. As mentioned, this is an area where BETO R&D can fill a need that is unlikely to be occupied by the private enterprise. The key challenge for the developers will be to drive an aggressive adoption. On the other hand, the more successful they will be in driving adoption, the more the tools will be recognized as authoritative by the researchers generating data in a virtuous cycle of expanding adoption and content of the database. These considerations could and should drive future work.

- This is a very important project that transfers data from the national laboratories to the industrial users involved in the deployment of technologies. The collection of the data, tools developed, and outreach have been impressive to date. The composition, moisture, fuel properties, and particle data look particularly robust. A focus on rheology and other material handling data in the near term would be particularly useful for future work.
- Though this project does not involve generation of any new experimental data or models, it is arguably one of the most important projects that BETO has implemented. The value of a large database that can be publicly accessed, sorted, and explored cannot be underestimated and can make the jobs of all stakeholders much easier and efficient. The storage of physical samples as well as analytical data is another advantage which makes this project even more unique and valuable. The biggest challenge this project needs to address is increasing public awareness of this incredible resource, as this reviewer, for example, was previously unaware of the extent and availability of this database.

PI Response to Reviewer Comments

- Thank you to the reviewers for their excellent input and feedback. I appreciate that the significant impact that this work can have on the industry is evident and I agree with many of the challenges you have identified.

Some of these challenges, such as ensuring that we can gain greater visibility and usability of the library tools and database, are ones that require us to work with partners and increase the ties to the Library. We are working toward this and hope to make some progress as part of our current year work. For instance, we will be completing a focused effort on creating tools and policies for external research groups to contribute and cite their data in the Library application. We anticipate an academic paper to increase visibility of these results and any input into the structure of these policies and tools is welcome.

I agree with the desire to have the Library connected with more related data sources and we are proposing some focused effort in this area into the next BETO cycle. We also will work on increasing robustness of the data sets by requesting more data (such as additional physical characteristics) from related projects and ensuring that most relevant BETO projects are represented.

Through all our efforts, the quality of the data is critical and we are currently working on ways to make it clearer what the data represent so that users understand the results and comparisons. So, rather than removing older data we hope to make it clear what may have changed from one set of data to another set of data. We hope that the history and context of the data can be a significant learning environment.

Overall, we anticipate that further focus on visibility, usability, connectivity, and quality can make this an even more effective tool.

FEEDSTOCK–PROCESS INTERFACE AND BIOCHEM BLENDED FEEDSTOCK DEVELOPMENT

(WBS#: 2.2.1.101 and 2.2.1.102)

Recipient:	Idaho National Laboratory/ National Renewable Energy Laboratory
Principal Investigator:	Alison Ray/Nick Nagle
Project Dates:	10/1/2006–9/30/2018
Project Category:	Ongoing
Project Type:	AOP
DOE Funding FY 2014:	$550,000
DOE Funding FY 2015:	$1,625,000
DOE Funding FY 2016:	$1,625,000
DOE Funding FY 2017:	$1,625,000

Project Description

Densification and blending are strategies to reduce the cost of feedstock logistics, maintain quality, and provide consistent feedstock properties. Densification reduces transportation costs, while producing feedstock with consistent physical properties. Blending diversifies biomass supply to include low-cost biomass resources that reduce cost and risk associated with reliance on a single resource. Current data on the impact of these combined strategies on sugar and lignin yields are limited. During FY 201517, this project evaluated more than 25 feedstocks and blends and developed predictive models based on laboratory-scale conversion testing. A study, examining blends of corn stover, switchgrass and waste, grass clippings, combined total glucose and xylose yields from laboratory-scale, dilute acid pretreatment, and enzymatic hydrolysis with grower payment data from the U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry to develop a model for blend formulation based on cost and performance. In FY 2016, corn stover, switchgrass, and a 50:50 blend of corn stover and switchgrass, both pelleted and non-pelleted formats were dilute acid pretreated under continuous operation and process-relevant conditions.

Weighted Project Score: 7.7

Weighting: For ongoing projects, there is equal weighting across all four evaluation criteria: Approach, Relevance, Accomplishments and Progress, and Future Work.

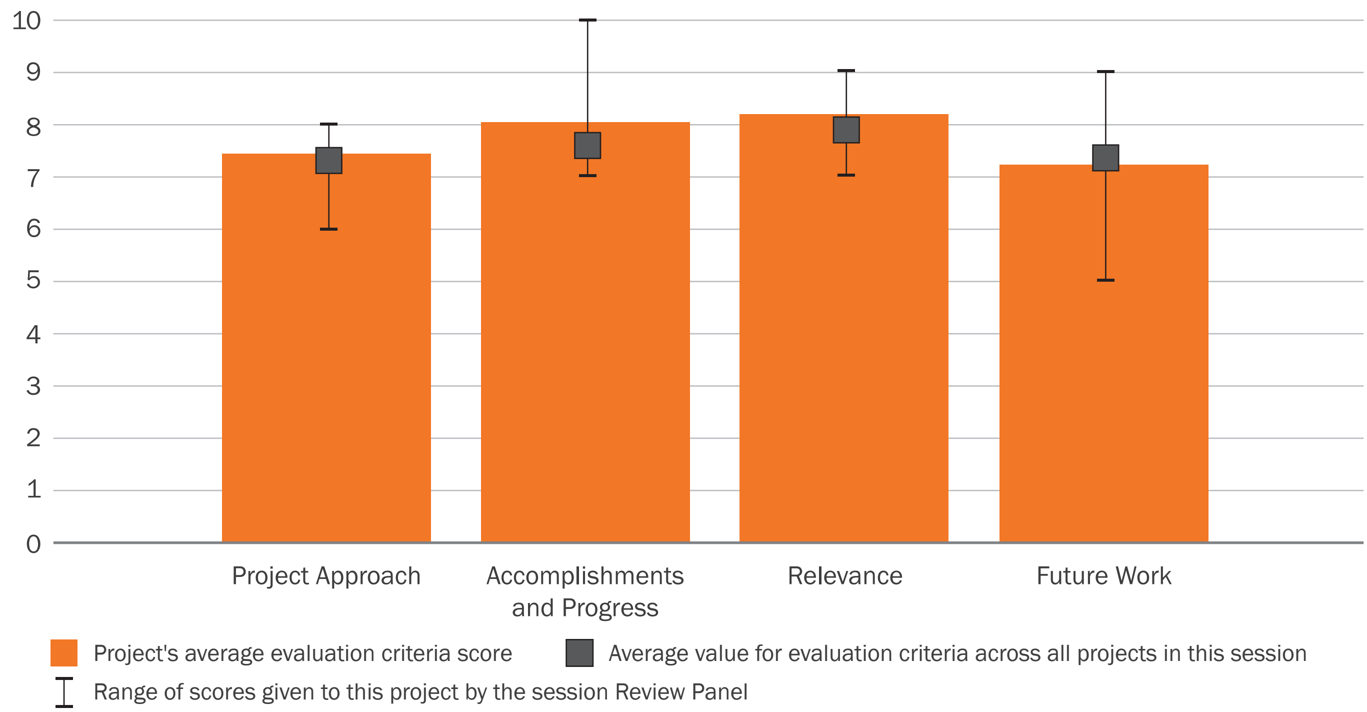


Photo Courtesy of Idaho National Laboratory/ National Renewable Energy Laboratory

The 50:50 blends of corn stover and switchgrass showed improved performance with reduced torque loading in the screw feeders and similar sugar yields when compared to corn stover. These results demonstrate that blending and densification provide great promise for more cost-effective downstream processing.

Overall Impressions

- My assessment based on my understanding of the work presented is that this project is not well informed by existing work elsewhere in BETO. It might be using experimentally sound biochemical science, but it is not clear that the project is examining anything that actually matters for BETO.
- The speaker mentioned that the blend will still be somewhat local; does this fit with any goal to normalize/commoditize the biomass with Analysis of Sustainability, Scale, Economics, Risk and Trade? I expect densification and blending will allow feedstocks to come from larger distances. If the feedstock is local, does the cost of pelleting densification still make it reasonable to pursue from a variability/processability standpoint? I would like to see some information come out about the TEA benefits and trade-offs to give some clarity and get some vetting from industry.
- Overall the project results are interesting and probably very relevant for the nth of a kind facility if one assumes that future biomass feedstock supply systems are based on blending and densification.
- Overall impressions are similar to other projects around this general area:
    - The effort has merits and the approach is relevant especially for future IBRs.
    - The execution is somewhat disjointed although individual impressive results can be found.
    - The TEA should be strengthened.
    - It appears that there is a duplication of effort with other similar project and there would be benefits in some coordination.
    - While relevant for future IBRs, this whole effort seems of limited applicability to the few existing IBRs which are struggling with a variety of interface problems. Can we find some more connection to today's IBR's problems without losing the long view approach to these projects?
- Overall, this is important work in that it will help the industry with availability concerns and blending for cost/availability in the medium term. The size impact on yield is an important learning as well as the improvement on yield/narrowing of the yield distribution with a blend. The project does seem too focused on deacetylation, and may benefit from a refocus on the more common dilute acid hydrolysis processes so that the work has the maximum impact.

PI Response to Reviewer Comments

- Given the time limitations, we did not explicitly discuss linkages and identify specific research efforts between FCIC and the FSL and Conversion Program Areas that were previously presented and regret this wasn't clear to the reviewer. This project is informed by the Feedstock Supply Chain Analysis (TEA), Bioenergy Feedstock Library, Advanced

Preprocessing, Feedstock Characterization and Densification projects at INL. In addition, we work in conjunction with conversion platform projects at NREL-Biochemical Platform Analysis (TEA), Pretreatment and Process Hydrolysis, Lignin Utilization, and Lawrence Berkeley National Laboratory Mixed Feedstock to look at the impact of advanced feedstock preprocessing strategies on sugar and lignin-derived fuels and co-products for meeting $3/gasoline gallon equivalent cost target. This project directly supports larger BETO goals and objectives outlined in the 2016 *Multi-Year Program Plan*:

- By 2017, validate sustainable feedstock supply and logistics cost of $84/dry ton at conversion reactor throat (including grower payment and logistics cost) for at least one biochemical and one thermochemical conversion process)
- By 2018, select an integrated bench-scale lignin deconstruction and upgrading strategy for valorization of lignin in a hydrocarbon fuel production process
- By 2020, determine the impact of advanced blending and formulation concepts on available volumes that meet quality and environmental criteria, while also meeting the $84/dry ton cost target ($2014) (including grower payment/stumpage fee and logistics costs)
- By 2022, validate one blendstock for thermochemical conversion and one blendstock for biochemical conversion at a scale of 1 ton per day while also meeting the $84/dry ton cost target (including grower payment/stumpage fee and logistics costs).

We agree with the reviewer: addressing the challenges faced by the existing IBRs is a critical near-term issue. In FY 2018 we will be re-scoping our AOPs to provide more resources for IBR issues, specifically focusing on feeding and handling biomass at the biorefinery. Integrated efforts between the laboratories will allow for both the near-term focus on IBR challenges and on achieving longer-term BETO goals.

We will continue to use dilute acid hydrolysis (pretreatment) and enzymatic hydrolysis as the baseline conversion process to evaluate new/existing feedstocks and feedstock formats. As this work is integrated with the Pretreatment and Process Hydrolysis project, we will employ deacetylation, where it has demonstrated that it can reduce variability in feedstock performance.

We agree with the reviewer that there are factors, beyond yield, associated with densification that affects the overall process. Some of the initial work will happen in later FY 2017--guided by TEA, we'll be producing data to compare several types of densification processes to determine cost/benefits associated with each format.

Thanks for the opportunity to clarify this. A more accurate statement would be that blends will be defined regionally. In the Advanced Feedstock Supply System model, biomass pellets need not be only from local sources, as they are densified in distributed depots and transported to regional blending terminals. Individual biomass pellet sources (blendstocks) need not meet any given set of specifications; however, the blended feedstock meets all specifications for a given conversion process. This includes composition, feeding, handling and aerobic stability requirements. In the sense of a commodity, only the feedstock blend meets all of the requirements. While densification will allow for larger economic supply radii, there will still be an economic benefit to being able to utilize materials that are available locally. In addition to the transportation benefits, densification improves feeding and handling, material stability, and compatibility with existing grain system infrastructure.

Thanks to all of our reviewers—your feedback will be used to focus FY 2018 AOPs and advance FCIC goals.

DEVELOPMENT AND PROCESS INTENSIFICATION OF IONIC LIQUID–BASED LIGNOCELLULOSIC CONVERSION PROCESS

(WBS#: 2.2.1.103 and 2.2.1.104)

Recipient:	Sandia National Laboratories/Lawrence Berkeley National Laboratory
Principal Investigator:	Seema Singh/Ning Sun
Project Dates:	10/1/2013–9/30/2016
Project Category:	Ongoing
Project Type:	AOP
DOE Funding FY 2014:	$150,000
DOE Funding FY 2015:	$160,000
DOE Funding FY 2016:	$175,000
DOE Funding FY 2017:	$250,000

Project Description

Renewable energy technologies are being looked at as significant new sources to meet our current and future energy needs. Cellulosic biomass is an important source for the production of biofuels and bioproducts. Biomass feedstock costs remain a large contributor to biofuel production costs. Feedstock blending using municipal solid waste (MSW) with year-round availability and low cost could decrease the feedstock cost to achieve BETO feedstock cost target of $84/ton. However, MSW utilization to reduce feedstock must be investigated since current biomass conversion technologies are not feedstock flexible and have a low tolerance for feedstock heterogeneity. Ionic liquid–based pretreatment technologies for biomass conversion are novel approaches with the potential to overcome feedstock flexibility problem, and need to reduce enzyme and process consolidation to enable lignocellulosic biorefineries. The objectives of this AOP are to evaluate the (1) potential of MSW as a blending agent, (2) efficiency of ionic liquid–based technologies for conversion efficiency on blended feedstock, and (3) impact of ionic liquid and any MSW-derived inhibitors on downstream fermentation processes.

Weighted Project Score: 6.3

Weighting: For ongoing projects, there is equal weighting across all four evaluation criteria: Approach, Relevance, Accomplishments and Progress, and Future Work.

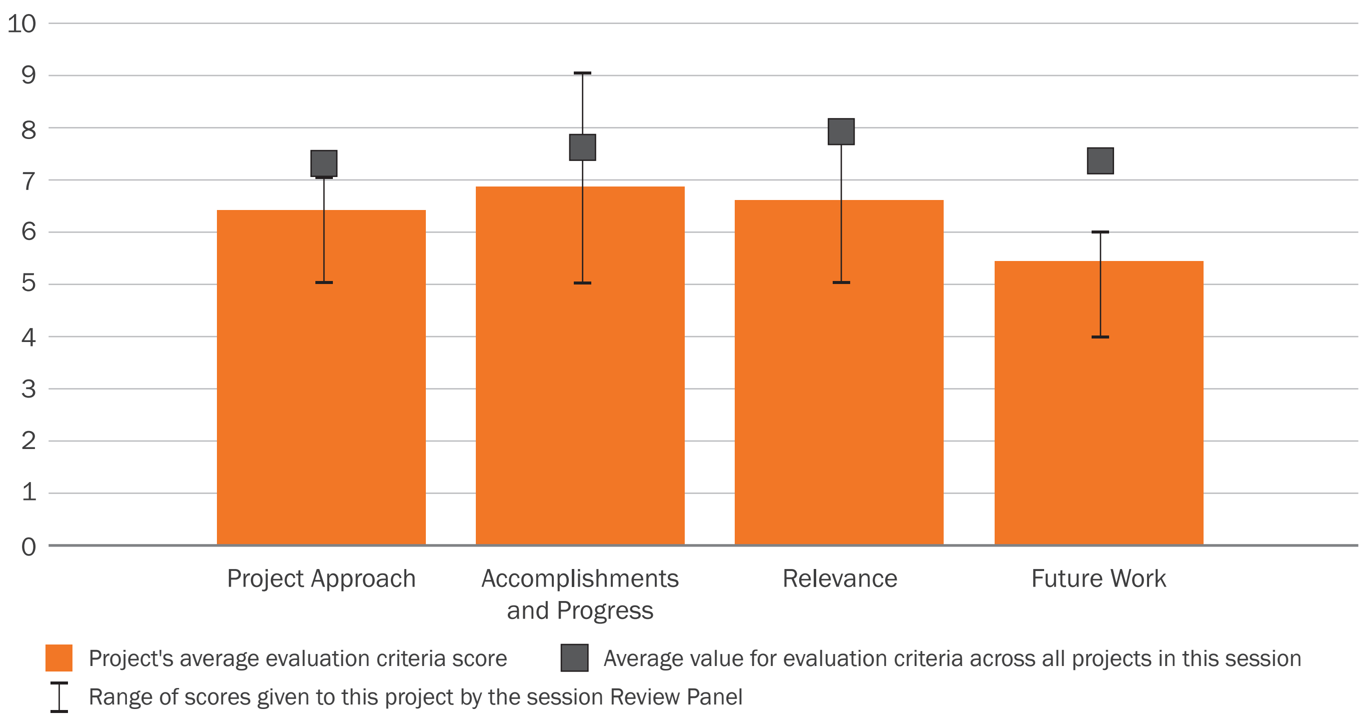


Photo Courtesy of Sandia National Laboratories/ Lawrence Berkeley National Laboratory

Overall Impressions

- Presentation of conversion data that only goes to 5–50 g/L is not relevant—data should be shown at TEA concentrations. It is not completely clear if the conditions are going to be relevant for larger scale and industrial conditions with reference to solids loading and practical needs for processing. Relevance needs to be more clearly defined and tested. What are the total solids limitations to these ionic liquids? Speaker stated 15%–20% Total Solids at different stages; have gone as high as 50% in past ionic liquid cases.

  Catalyst use cost is historically the main issue from a TEA perspective. Is this a sufficient concern/key performance indicator in the project? Will recycling/recovery be the main technical barrier? TEA assumption was 90%, but state of technology is at ~80%.

  Wastewater treatment considerations need to be defined, validated, and tracked.

- The objectives of this project are not commensurate with the available resources; the project should refocus to demonstrate the viability of ionic liquids on a model feedstock to define the technical and economic barriers to future commercialization. Based on my experience, the organic fraction of MSW is not cheap and very difficult to segregate. It is not suitable as a raw material for blending or large-scale production of biofuels.

- Is this a relevant project or an interesting science exercise which at this time has no commercial applicability? If the latter is the case is there a set of circumstances under which the project would be again commercially feasible? These are unanswered questions.

- Overall, the work is impressive and the reduced conversion times could potentially lower the capital cost for future facilities. I am not sure that the project belongs in FCIC, but rather in the Biological Conversion Technology Area. The project does need significant work in the separation and recovery of the ionic liquid—this work should be prioritized over the conversion of sugar to fuels (which is covered by other projects).

- This project, which is focused on improving feedstock preprocessing for downstream biochemical conversion, is unique in its focus on use of ionic liquids to improve sugar yields. The results clearly show an improvement in yield from use of ionic liquids (much more than blending) and scale-up results are also encouraging. However, there needs to be an honest cost/benefit analysis done to determine whether the improved yield justifies the added cost of ionic liquid use, which may be significant. Based on minimal cost data presented so far, it is not clear whether the BETO cost target can be achieved with this approach, and thus this goal should be closely monitored periodically to ensure that all future work has a reasonable chance at meeting the cost target.

[17] Jian Sun, N. V. S. N. Murthy Konda, Jian Shi, Ramakrishnan Parthasarathi, Tanmoy Dutta, Feng Xu, Corinne D. Scown, et al., "CO_2 Enabled Process Integration for the Production of Cellulosic Ethanol Using Bionic Liquids," *Energy and Environmental Science* 9 (2016): 2822–2834, doi:10.1039/C6EE00913A; Feng Xu, Jian Sun, N. V. S. N. Murthy Konda, Jian Shi, Tanmoy Dutta, Corinne D. Scown, Blake A. Simmons, and Seema Singh, "Transforming Biomass Conversion with Ionic Liquids: Process Intensification and the Development of a High-Gravity, One-Pot Process for the Production of Cellulosic Ethanol," *Energy and Environmental Science* 3 (2016): 1042–1049, doi:10.1039/C5EE02940F.

PI Response to Reviewer Comments

- We thank all the reviewers for their comments.
- The wastewater treatment is being looked at and we have an initial life-cycle analysis draft currently under peer review. We have included TEA as part of the study in our recent peer-reviewed publications,[17] which also looks into total solids loading, key industrial factors, and development of a high-gravity fed batch process. As we put our effort on ionic liquid screening for ionic liquids that can overcome the need of dilution and ionic liquid dehydration, the life-cycle analysis and TEA will be an integral part for that particular ionic liquid and processes. We thank the reviewer again for pointing out these important considerations—they are consistent with our drive and future directions.

  We have refocused our efforts away from MSW and onto ionic liquid screening, recovery, process intensification, and comprehensive TEA. Early efforts on the project and success were critical to start to understand the commercial viability and identification of areas of improvements for this promising novel conversion technology.

  The rapid advancement made in the development of low-cost ionic liquids and effectiveness of aqueous ionic liquids (very small ionic liquid amount needed) is overcoming the early, unfounded conclusions drawn by many. The ionic liquid technology is fairly new but very promising and should be pursued as currently there is no silver bullet technology that is deployable and viable for recalcitrant second-generation feedstocks utilization and enabling hefty goals of replacing petroleum fuels with biofuels.

We thank the reviewer for the thoughtful comments about the fit of the project in FCIC, and completely agree with the opinion. The project was part of biological conversion in previous years. In addition, I can also see several reasons this effort could also be part of FCIC (where feedstock heterogeneity and necessary preprocessing is a big challenge). Ionic liquid technology also has advantage on sugar to chemicals (in addition to fuel) and from lignin to chemicals. The ionic liquid technology provides a very clean stream of lignin and early results show depolymerization/conversion in the absence of expansive catalyst and these are all potential avenues to be explored in out years.

We are pleased with the reviewer's comments on sugar yields, "one pot" process development, process scale-up, and ionic liquids. These are some of the rapid advancement made on ionic liquid technology in such a short span (in comparison, dilute acid and ammonia-based processes are being looked at since early 1930s–1940s). We also agree with reviewer's comment on a detailed cost/benefit analysis. The current one-pot costs are indeed well above the BETO target for the methyl ketone production due to relatively low titers of the microbial production. For the ethanol case, our preliminary TEA and sensitivity analysis indicates the Minimum Ethanol Selling Price range of ~$2.80-$4.50. Therefore, our research effort in FY 2018 and beyond would be on neutral ionic liquid screening and lignin utilization. The success on this effort could be game changing for enabling the lignocellulosic biorefineries).

MIXED FEEDSTOCK CONVERSION SCREENING TO DEVELOP AND SCALE EFFICIENT INTEGRATED PROCESSING THROUGH PRODUCT TRANSFORMATION

(WBS#: 2.2.1.106 and 2.2.1.107)

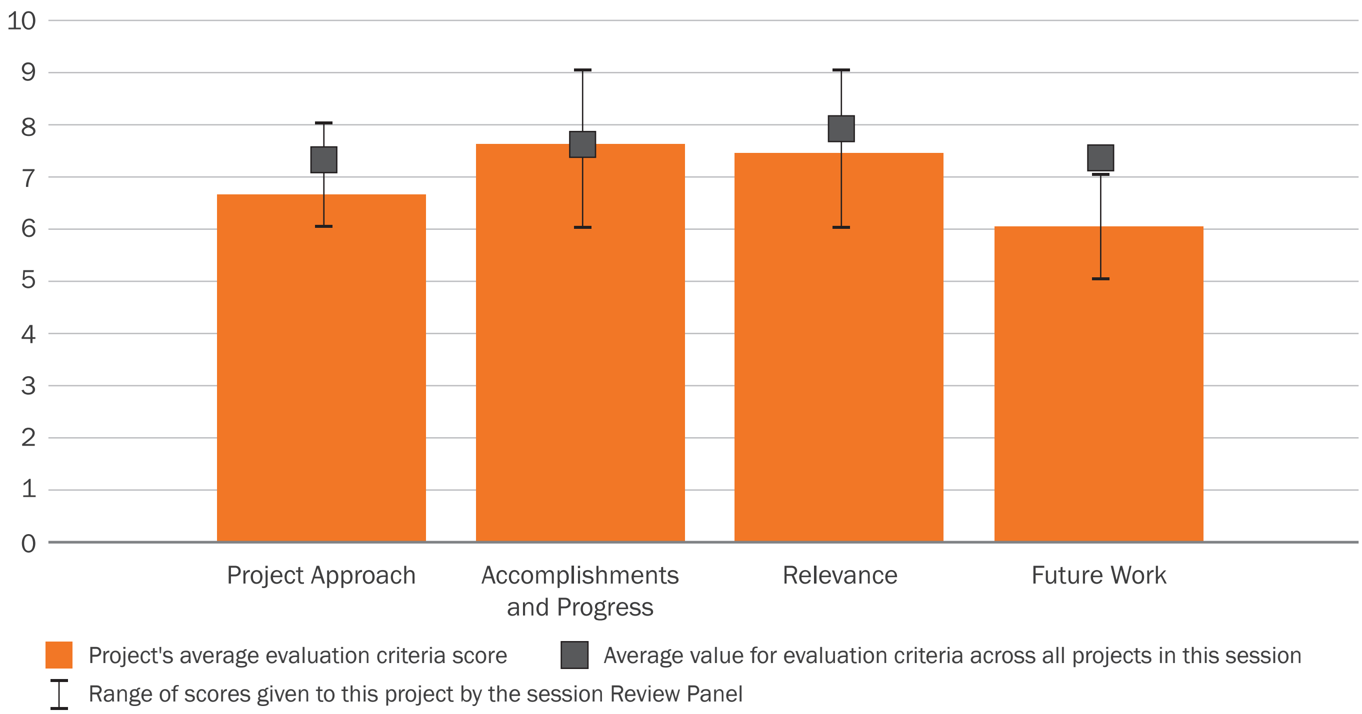
Recipient:	Lawrence Berkeley National Laboratory/Sandia National Laboratories
Principal Investigator:	Deepti Tanjore/Seema Singh
Project Dates:	10/1/2015–9/30/2016
Project Category:	Ongoing
Project Type:	AOP
DOE Funding FY 2014:	$0
DOE Funding FY 2015:	$255,000
DOE Funding FY 2016:	$255,000
DOE Funding FY 2017:	$255,000

Project Description

Commercial-scale biorefineries are designed to process 2,000 tons/day of single lignocellulosic biomass. Several geographical areas in the United States generate diverse feedstocks that, when combined, can be substantial for biobased manufacturing. Blending multiple feedstocks is a strategy being investigated to expand biobased manufacturing outside the Corn Belt. In this study, we developed a model to predict continuous envelopes of biomass blends that are optimal for a given pretreatment condition to achieve a predetermined sugar yield or vice versa. For example, our model predicted more than 60% glucose yield can be achieved by treating an equal part blend of energy cane, corn stover, and switchgrass at 10% solid loading with alkali at 120°C for 14.8 hours. By using ionic liquids to pretreat an equal part blend of the biomass feedstocks at 160°C for 2.2 hours, we achieved 87.6% glucose yield. Such a predictive model can potentially overcome dependence on a single feedstock, substantially lower feedstock costs, and reduce supply chain risks for a biorefinery. To assess the commercial applications of the model, we tested predictions from the model at higher

Weighted Project Score: 6.9

Weighting: For ongoing projects, there is equal weighting across all four evaluation criteria: Approach, Relevance, Accomplishments and Progress, and Future Work.



biomass loading of 30% weight by weight (w/w). Higher biomass loading led to half the sugar yields as those observed from lower loadings, but bore similar trends as predicted by the model. A blend of energy cane and switchgrass yielded at a lower shear stress (10 Pa) than energy cane itself (50 Pa). We observed 100% (of theoretical) ethanol yield from fermentation of biomass blend with only 20% corn stover. TEA provided a comprehensive understanding of the impact of biomass blends on biobased manufacturing.

Overall Impressions

- This is interesting work but is not well-informed by upstream variability in biomass and feedstocks. Results are not currently actionable because they need to incorporate biomass variability. I do commend the way the approach tries to incorporate upstream information from INL, but it is not yet doing it properly.
- It is not altogether clear if models produced at this tube/bomb scale are especially relevant as noted by the speaker. Laboratory scale should generally be used just for high-level screening, and then taken to pilot scale for creating valid models because significant differences in heat transfer, flowability, residence time distribution, solids loading, et al, can be simulated. Speaker made the comment that the pretreatment ranges were perhaps too narrow as time and temperature were insignificant in the model. Similarly, the ionic liquid yields did not vary enough to make for a strong model. I suggest adding an R2 goal on the model with all insignificant variables removed while at the same time having method controls added.

  An R_2 of 80% for a model is good but is largely coming from feedstocks, which hides the other variables. I suggest making mini models for each feedstock to understand the other variables.

  If the project team finds the 20% corn stover blend relevant, they should consider adding mechanistic understanding as to why to their future work.

  Acid pretreatment of mixtures led to furfural generation due to uneven severities for feedstocks with different recalcitrance. Excessive furfural indicates the pretreatment laboratory protocol is potentially not in control. I would suggest doing some method/protocol validation with finer steps to quantify.
- This project creates the foundation and proves the concept for a future predictive model based on industrial data.
- This is a general comment for a variety of these activities focusing on the interaction between biomass types and blends and pretreatment. At this stage, the effort appears still a bit disjointed. The project has very interesting technical results, though it is based on highly idealized process conditions. In turn, the TEA is preliminary at best, and in most cases, there is not a precise analysis of risk factors. In general, scalability appears to be an afterthought if at all present. Lastly, it is not clear if these tools will allow only better planning for location of future IBRs or also better operations.

  Overall, I still consider this interesting research. However, it would benefit from a concerted effort to focus it better.
- The rheology work is incredibly important, and could translate to useful learnings for industrial facilities in the near term. More focus there would place this work squarely within FCIC. The researchers did use a good experimental method that varies parameters resulting in good useful data on the rheology. I am not sure that the fermentation work is not duplicative from projects in the Biochemical Conversion Technology Area.
- This project is one of several in this session exploring various pretreatment effects on sugar production (via experiment and modeling) for biochemical conversion processes. The presentation of model results via triangular diagram with all key variable values highlighted is impressive. The rheological studies are also unique and important. It is not clear how blending tests, while important, differ from those in at least two other studies presented in this session,

which presents a concern of possible duplication of efforts. Seeing that this FCIC session is relatively new, BETO should verify all project scopes and revise as necessary so that all projects build constructively on each other's work.

PI Response to Reviewer Comments

TWe appreciate reviewer's concerns about the comprehensiveness of this project. With a limited budget, we attempted to study a broad research topic, and as such designed studies to primarily identify the most impactful variables. Scale-up work was an integral part of the proposal submitted in FY 2014. As a research unit placed in the PDU, scale-up is always in the forefront of several of our research projects, and never an afterthought. Scale-up of our predictions continues to be our intention. Due to the time limit of the Peer Review, we could not go into the details of the TEA efforts. The analysis was limited by a $60K budget but was studied in detail. Our quarterly reports to BETO captured this detail with several risk factors considered.

We appreciate the reviewer's concern about possible overlap. While some of the efforts seem similar, the experiments were very different. In the future, we want to focus on the interface of feedstock conversion, e.g., fermentation of hydrolysates to a variety of biofuels including bisabolene and mixed ketones. This work coupled with rheological characterization will separate our efforts from those of other research teams in the BETO portfolio.

We echo the reviewer's comment on creating a foundation, a proof of concept, required to build a robust predictive model. We emphasize that the plan for FY 2017 and proposed future work are oriented toward developing a comprehensive predictive model applicable in an industrial setting.

To ensure relevance, in FY 2017, we will scale up predicted blends and deconstruction conditions to 100 L at 30% (w/w) biomass loading. In the future, we propose to develop a predictive model by performing all laboratory-scale alkali pretreatment studies at 30% (w/w) alone. This will allow us to create valid models for batch processing at the pilot scale. We propose to expand our rheological understanding of the blends to predict flowability issues, but the reviewer is accurate in pointing that we may not be able to estimate residence time in a continuous reactor. For this, we propose to work with an industry partner in FY 2019–FY 2020 to ensure that our model is applicable in real world scenarios.

We are now modeling data from each pretreatment catalyst individually. As such, ionic liquid data are not interfering with acid or alkali models. As our data set is limited, we were unable to further break it down based on feedstock. We will incorporate this suggestion into our future work, beyond FY 2018. Mechanistic modeling is also a part of the proposed future work. Our design of experiments, focused on extracting low- and high-sugar yields, led to some high severity acid pretreatments that may have caused furfural production. As mentioned in the accomplishments and progress section of our presentation, we will be performing only alkali pretreatments in the future and thereby furfural production will not be an issue.

Studying upstream variability seemed to be the most common suggestion from the Peer Review. We agree with the reviewers that this topic is most interest, when developing a model applicable in real world scenario. Accordingly, upstream variability in feedstocks is the factor of highest priority in developing our predictive model in the coming years.

FEEDSTOCK INTERFACE

(WBS#: 2.2.1.301, 2.2.1.304, and 2.2.1.305)

Recipient:	Idaho National Laboratory/ National Renewable Energy Laboratory/ Pacific Northwest National Laboratory
Principal Investigator:	Tyler Westover/Dan Carpenter/Dan Howe
Project Dates:	10/1/2015–9/30/2018
Project Category:	Ongoing
Project Type:	AOP
DOE Funding FY 2014:	$1,200,000
DOE Funding FY 2015:	$3,335,000
DOE Funding FY 2016:	$2,465,000
DOE Funding FY 2017:	$2,465,000

Project Description

Cost-competitive production of domestic biofuels on a national scale will require the conversion of low-cost and diverse biomass types, the impact of which on product yield and process efficiency is poorly understood. The joint Feedstock Interface project between National Renewable Energy Laboratory/Idaho National Laboratory/Pacific Northwest National Laboratory seeks to understand the process and economic impacts of variable biomass resources in thermochemical processes (i.e., fast pyrolysis, hydrothermal liquefaction, catalytic fast pyrolysis, gasification, and hydrotreating). We are testing commercially-relevant feedstocks at the bench scale with a near-term goal of establishing in-feed specifications that ensure BETO's conversion cost targets (e.g., $2.53/gasoline gallon equivalent for pyrolysis/hydrotreating) are met using an $84/dry ton blended feedstock. Among this project's key recent achievements was confirming that a low-cost blend can meet conversion targets, reducing the modeled fuel production cost by 7% ($0.24/gasoline gallon equivalent), and the development of a model to predict pyrolysis oil yield based on feedstock composition. Our work shows that feedstock impacts multiple parts of the process, including pyrolysis oil yield/composition, hydrotreating yield,

Weighted Project Score: 7.4

Weighting: For ongoing projects, there is equal weighting across all four evaluation criteria: Approach, Relevance, Accomplishments and Progress, and Future Work.

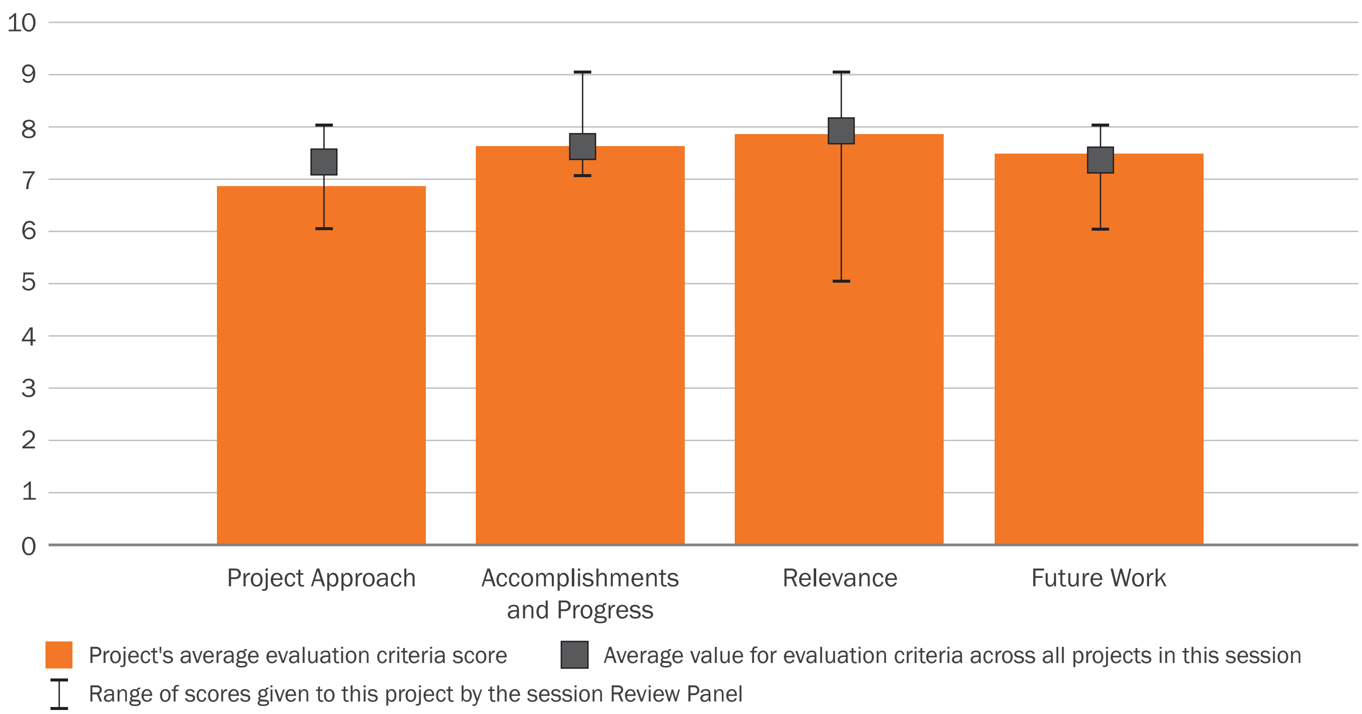


Photo Courtesy of Idaho National Laboratories/ National Renewable Energy Laboratory
Pacific Northwest National Laboratory

hydrogen consumption, selectivity to fuel products, and can result in a 40% variation in final biofuel cost. By quantifying these impacts, this project provides insight into the financial risks of various conversion approaches with respect to feedstock, enabling more flexible and market-responsive technologies.

Overall Impressions

- Generally, this is a useful project and a first step to enable assessment of field to fuel. It is nice to finally see this happen. However, it is still not particularly realistic in assessment of non-pristine feedstocks, and the statistical model developed is likely not capable of capturing the variability of all factors assessed, and therefor probably doesn't accurately predict "winners." The project team needs to use different methods to assess and incorporate variability (e.g., Bayesian approaches) and identify places where future effort should focus.
- Why pilot after the modeling step? This isn't a typical way to do it with the relatively significant impact of scale. Consider some piloting earlier in the project.

  I would like to see some thoughts about where variation comes from between the field and the reactor throat? Impact of pelleting and others in the future plans may need considered. Aging impacts on the blending quality could be significant.

  Relevance: The plan is to do other thermochemical treatments—is this particularly value adding versus other downstream tests? Can the variation on the optimal blend be good enough for all? Broad success ranges would be easier to rollout broadly.
- Overall the quality of the work is adequate and it is moving toward the achievement of its stated goals. The project does not adequately address the feedstock interface questions and it assumes that a blended feedstock will help the achievement of the cost objective. The optimization tool should help the nth-of-a-kind facility, but it is unlikely to answer the needs of the first of a kind facilities.
- I have very mixed feeling about this project. The blending of feedstocks and the understanding of blend properties is going to be of significant importance. However, as the proposed reference technologies haven't been credibly proven at any scale, I struggled on whether this is a relevant project at this stage. The work on ash removal and control is an important redeeming quality.
- It appears that the project is doing a good job of addressing the BETO goals from a few years ago, but it may be prudent for a minor adjustment to focus more on the feedstock interface for the new FCIC area. Product yield and cost reductions due to blending are more medium- or long-term issues, where blending for optimization or ease of processing may fit the current needs better. The project is an impressive blend of different laboratories and complementary capabilities.

- The concept behind this project, which focuses on addressing feedstock variability effects on thermochemical conversion processes, is an important contribution to process optimization. By concentrating on the effects of blending of pure feedstocks, this project represents a good start. However, other feedstock aspects that impact variability and thus product yield (e.g., ash content, feedstock local and seasonal quality, and impurities) need to also be considered in order for the full value of this project to be realized.

PI Response to Reviewer Comments

- We appreciate the reviewers' concerns over capturing variability across the supply chain. This project started with testing a wide variety of potential feedstocks with the intent of capturing a large range of performances and developing robust models with respect to feed composition. Future work will hone in on key thermochemical conversion feedstocks including forest residues, pulpwood, and sorted construction and demolition wastes to determine the impacts of preprocessing on conversion performance at different scales. Ultimately, the objective is to correlate conversion performance to feedstock attributes rather than type or cultivar. The type of feedstock for each test in this work is provided only as a means to identify the particular test and is not intended to represent the wide range of properties and attributes that can be found in every feedstock type.

  Regarding the modeling efforts, the statistical regression fits used to date have identified strong correlations between feedstock attributes and conversion parameters, but we acknowledge the more complex effects will require more advanced modeling. We will pursue these types of approaches in coming years. Bayesian and other similar statistical approaches to understand the impact of feedstock variability will require knowledge of the distributions of the key feedstock attributes, both in the raw biomass and in the preprocessing operations. Those data are being generated within BETO and will be incorporated into this project as they become available.

  We agree that there are challenges presented by evaluating feedstocks in conversion processes that are rapidly developing, and there will likely be additional challenges during scale up. However, as a de-risking strategy, we feel that there is value in identifying potential feedstock-related issues early on that can help avoid these scale-up problems (e.g., dealing with contaminants or catalyst poisons by hot filtration). We understand the importance of assessing feedstock performance at multiple scales. Bench- and pilot-scale efforts are being pursued simultaneously, although the pilot facilities were only recently brought online for long-term testing.

  Future efforts will focus on determining the impact of feedstock attributes on the ease of processing at pilot scale and the ability to control variability sufficiently in both raw materials and preprocessing operations such that feedstocks are reactor-ready (i.e., they meet conversion specifications, which this project assists in establishing). Based on comments from the project reviewers and new directions within FCIC, the focus on blends is being somewhat deemphasized to allow more focus on the impacts of feedstock attributes within a smaller range of high-impact feedstocks.

FEEDSTOCK CHARACTERIZATION, PERFORMANCE, AND DEVELOPMENT

(WBS#: 2.2.1.501)

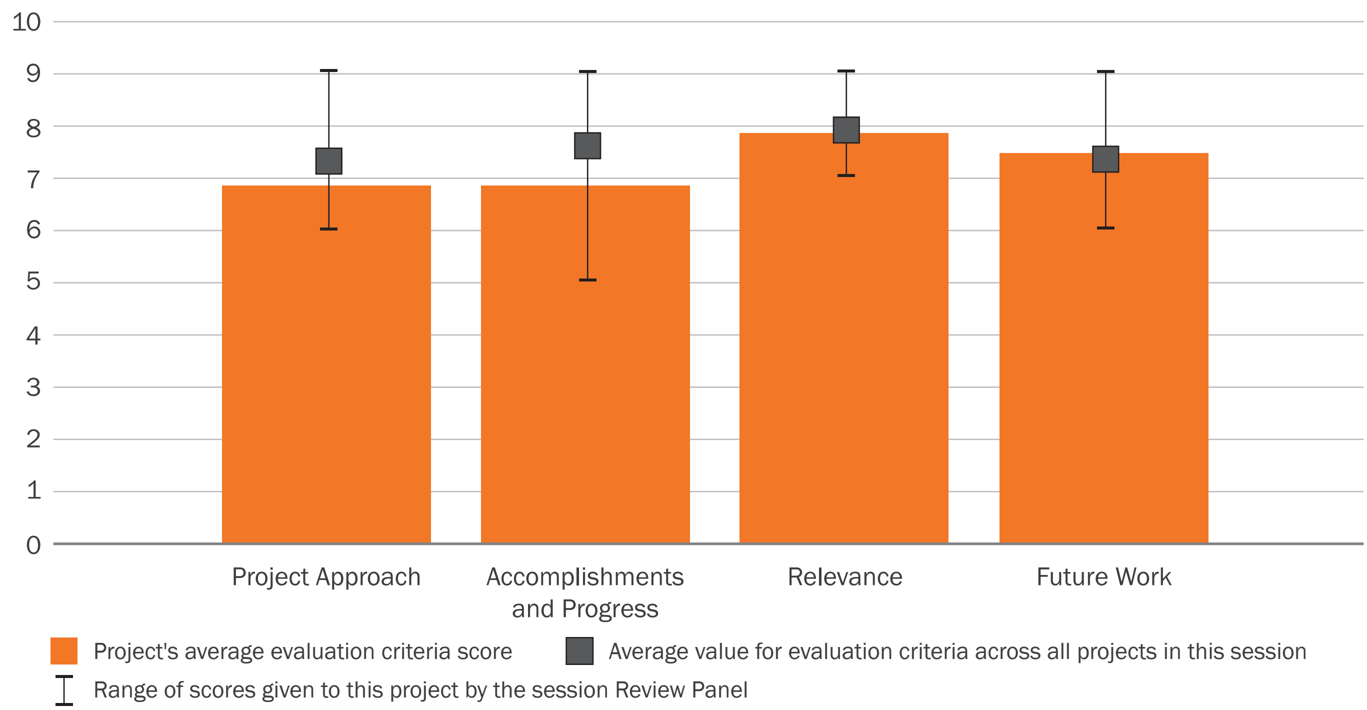
Recipient:	Idaho National Laboratory
Principal Investigator:	Magdalena Ramirez
Project Dates:	10/1/2005–9/30/2018
Project Category:	Ongoing
Project Type:	AOP
DOE Funding FY 2014:	$630,000
DOE Funding FY 2015:	$0
DOE Funding FY 2016:	$1,940,000
DOE Funding FY 2017:	$1,940,000

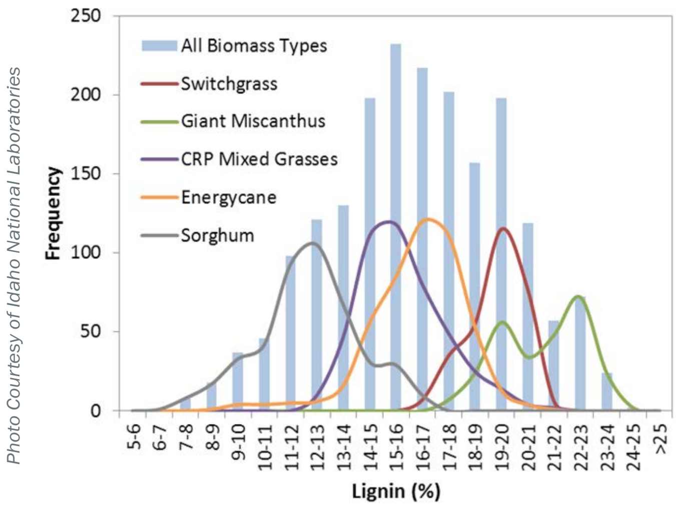
Project Description

The first-of-a-kind cellulosic ethanol demonstration plants have been struggling with feedstock variability. Performance, processing, and operations are significantly affected by the quality variation and the presence of contaminants in the biomass materials that are fed into these units. This clearly indicates that not every biomass material is a feedstock. This project tries to map the biomass resources to potential conversion pathways, maximizing their incorporation into the bioeconomy. Our approach is to define and implement a conversion-based biomass grading system founded on key biomass characteristics selected from the comprehensive characterization of more than 150 commercially relevant samples. The selected characteristics are those that most affect conversion to fuels. The ranges of variation of these key properties have to be determined to define the corresponding grades. This simple three-step approach includes a binning methodology and an extensive network of collaborators and partners to facilitate the solution of such a complex problem. A framework has been already defined that provides economic and technical rationale for the quality grades and establishes the basic principles for grading. It is expected that grading not only will set the price scale for the supply side and the

Weighted Project Score: 7.2

Weighting: For ongoing projects, there is equal weighting across all four evaluation criteria: Approach, Relevance, Accomplishments and Progress, and Future Work.





preprocessing needs for the demand side, but also will allow the incorporation of low cost and/or low-quality resources into the bioeconomy.

Overall Impressions

- This is a useful project and foundational to the industry. It needs to tie into the existing biomass grading systems so it is possible to translate between industries. For example, how does a thermochemical grade here relate to a grade in the heat and power industry? The team is aware and is looking forward to involvement of advisory board to guide future work and deployment.
- Same comments for other projects. The effort has merit but is a bit confused.
- A standard grading system could increase the deployment rate of biomass energy projects by establishing biomass as a tradable commodity. It would be particularly useful for future purpose grown crops and would help farmers select the most valuable strains to plant. A commodity system for agricultural waste that focuses on items that the farmer/harvester can control such as moisture or ash content could be very useful.
- The concept behind this project, which is focused on establishing a grading system for feedstocks based on measurements of key properties, is good and would be a helpful tool. If successful, a grading system has the potential to more fairly assess cost and balance and the need for any necessary preprocessing. However, any grading system developed has to be sufficiently comprehensive to accurately classify wide varieties of feedstock types, but at the same time be simple to implement and use, which is no easy task. Until all the metrics are fully identified and bin ranges established, it is not clear if the proposed approach will be successful. Furthermore, a bigger potential challenge is getting buy-in from the feedstock supplier community where there is potential for lost revenue from lower quality stock under the new grading system that previously would have been sold at the same price. Finding a way to involve these stakeholders in this project is critical to its future implementation.
- The project is a good idea that could benefit from the biomass suppliers and the industry users to focus on the present needs of the industry.
- What sort of timeline for the grading implementation is targeted to be able to help support the Co-optima? The speaker stated that the existing INL information is likely already available to start rollout.

How does the project anticipate the grading will influence the feedstock cost and therefore the general rollout of the industry? The presenter anticipates the project will allow for low-cost and/or low-quality resources.

How will storage losses/quality changes be managed in the grading system? Due to the combustion application where high lignin fetches higher value/price, a given feedstock "batch" will likely have a somewhat dynamic valuation. The presenter discussed a need to create models to simulate the storage changes on the value versus reanalyzing batches.

This is a good project providing a necessary tool to the industry.

PI Response to Reviewer Comments

- Direct translation among different industrial interests may be difficult if not impossible. For instance, translating fuel oil grades into coal grades would be difficult, and both are used by the same end user (energy generation via combustion). Nevertheless, the forecast from companion markets and the advice of the FCIC Industry Advisory Board will be used to keep on the right track.

  Not all grading properties have been selected. The grading properties would ideally be intrinsic characteristics of the biomass and the penalties would be under farmer/harvester control. In this way, best practices will be promoted. Hopefully, the number of grades can be minimized. Our goal is to define a small number of technically (and economically) meaningful bins. It is understood that ash and moisture are important parameters in a grading system for biofuels. The main problem with ash incorporation in the grading system at this time is lack of availability of analytical tools that can easily discriminate between soil contamination (caused mainly by harvesting technique) and inorganic nutrients in the biomass itself (e.g., affected by climate, soil, or fertilizers). The project interacts with another project that is developing methodologies to discriminate between these two measurements. Once these techniques become available the mode of incorporation into the grading system can be defined. The effects of moisture certainly go beyond degradation, which was cited in the presentation as an example. Moisture affects different preprocessing techniques as well as conversion processes. We are working with INL projects that have already collected some information regarding the impacts of moisture and ash and their potential cost in addition to the Bioenergy Library where much of this characterization information is stored.

  We agree with the reviewer that it will be a challenge getting buy-in from the feedstock supplier community where there is potential for lost revenue from lower quality. It is difficult to keep the vendor and the buyer happy on only economic grounds. Finding the win/win balance between the supply and demand sides is the determinant. Involvement of industrial stakeholders on each side will mitigate implementation risks.

  Focusing on the present needs of industry will start in FY 2018 by working with the FCIC Industry Advisory Board.

  We envision a closer industrial involvement in the immediate future, particularly to ensure the consistency checking exercise and to minimize industrial concerns during the future rollout. The timing for the rollout is yet to be determined and will be influenced by these efforts.

  The development of the grading system requires large efforts in characterization work. The resulting characterization data and identification of a small number of properties that have the most impact on conversion can be used to focus on the most meaningful preprocessing, allowing for a more cost-effective approach. Hopefully, low-cost and/or low-quality resources could be incorporated with less technical risk.

  The definition of penalties (dockage) or rewards is part of the scope for the remainder of FY 2017 and FY 2018, and will be included as part of a preliminary grading system. This scope will include working with analysis and feedstock projects at INL.

PRETREATMENT AND PROCESS HYDROLYSIS—PRETREATMENT

(WBS#: 2.2.3.100)

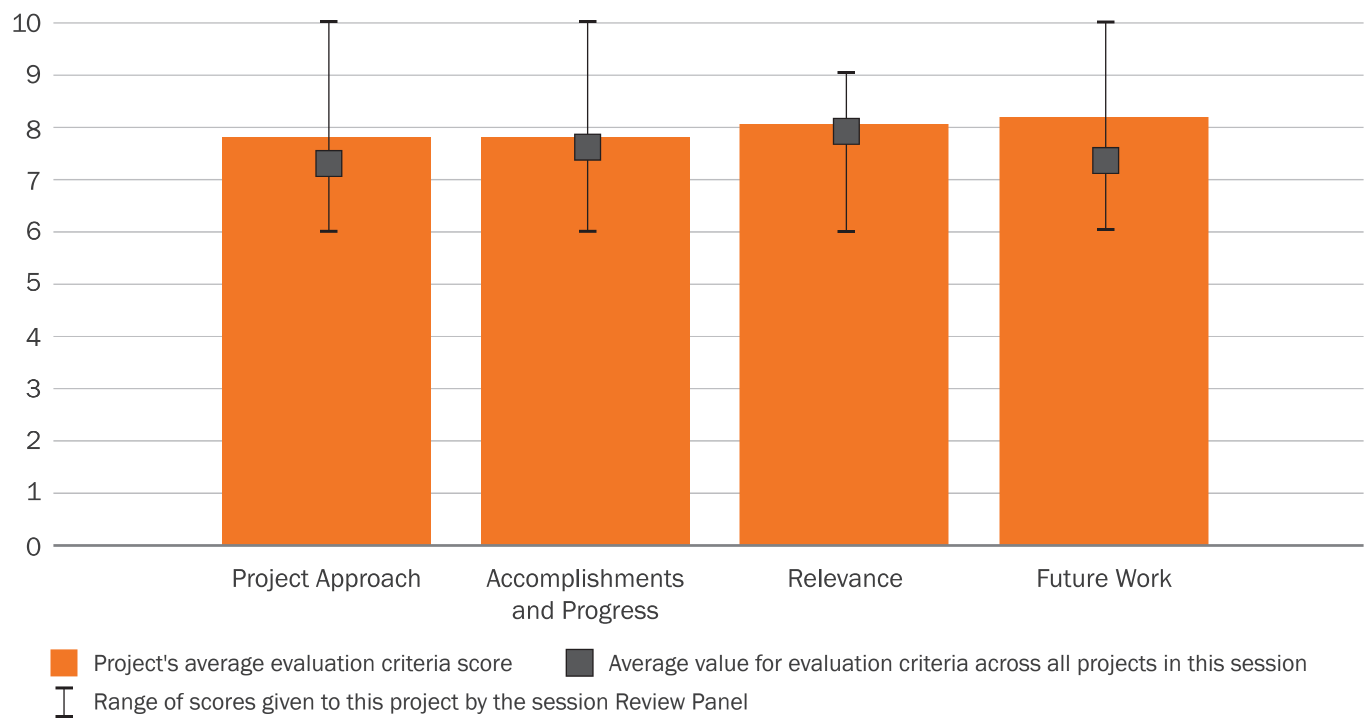
Recipient:	National Renewable Energy Laboratory
Principal Investigator:	Melvin Tucker
Project Dates:	1/30/2003–9/30/2018
Project Category:	Ongoing
Project Type:	AOP
DOE Funding FY 2014:	$800,000
DOE Funding FY 2015:	$1,400,000
DOE Funding FY 2016:	$1,400,000
DOE Funding FY 2017:	$1,400,000

Project Description

The Pretreatment and Process Hydrolysis project develops scalable lower severity deconstruction/fractionation processes that produce low cost, low toxicity, high concentration sugar syrups and tractable, reactive lignin streams at low enzyme loadings using relevant advanced blended and formatted feedstocks in collaboration with FCIC and INL for the biological and catalytic upgrading to hydrocarbon fuel precursors. Enzymatic hydrolysis reactions with deacetylation/mechanical refining (DMR) corn stover substrates at 32 weight percent (wt%) insoluble solids achieved 270 g/L fermentable monomeric sugars at >80% yields (with up to 10% oligomers) that are fermentable to 86 g/L at >90% process yields with a co-fermenting Zymomonas strain, demonstrating the low toxicity of the syrups. Rheology studies showed the hydrolysate was pumpable at 60 h. Batch-wise counter-current recycle of deacetylation black liquor showed minimal effects on deacetylation, enzymatic hydrolysis, and fermentation performances, with TEA showing a decrease in water and energy usage and decreased fuel selling price. Blended feedstocks were found to be more recalcitrant, with enzymatic hydrolysis yields of 80% monomeric sugars achieved with deacetylation/dilute acid (DDA) and DMR. In the future we are investigating continuous deacetylation, testing advanced blended and formatted tri- and quad-blended feedstock performance

Weighted Project Score: 8.0

Weighting: For ongoing projects, there is equal weighting across all four evaluation criteria: Approach, Relevance, Accomplishments and Progress, and Future Work.



in DDA and DMR, and a microbial electrochemical technology to recycle the sodium hydroxide without the use of an expensive recovery boiler/lime kiln.

Overall Impressions

- This is an excellent project with far reaching significance.
- This project has an innovative approach to lower the severity of the pretreatment process.
- I ended up being a bit confused by the project as the author tried to cram too much into it and failed to provide a clear pathway to scalability focusing on a few critical issues. Overall the technical results are interesting, but the TEA is not well spelled out. Because of it, it is difficult to assess the real prospect of this project for commercial viability and under which conditions.
- The researchers have an interesting process focused on underutilized/abandoned pulp and paper assets. This project may be better suited for the Biochemical Conversion Technology Area, as it is a full process and not an agnostic pretreatment process that could be utilized with a number of existing processes.
- This project, which focuses on developing chemical and mechanical pretreatment steps for separating lignin and increasing sugar yield form biomass, is unique and important work. If successful, these pretreatment steps may help improve the feedstock quality for downstream bioconversion processes and thereby lower the fuel or bioproduct cost closer to or below the target value. The results from several investigations in this project are encouraging. However, it is not entirely clear how all of the individual tests and results described fit together to achieve the overall goal. A more systematic study of the effects of key variables on sugar yield and/or lignin separation (if not already done or planned) would be good to consider, as well as a comparison of the overall cost of the full production process with pretreatment steps relative to baseline to know the true value of any proposed improvements.

PI Response to Reviewer Comments

- We thank all of the reviewers for their insightful comments.

  This project collaborates very closely with other Biochemical Conversion projects and INL, concentrating on DDA pretreatments and DMR deconstruction/fractionation processes performed in parallel on aliquots of the same deacetylated individual and blended feedstocks, with results incorporated into TEA analysis for direct comparisons. The TEA analyses were performed by key personnel from the Biochemical Platform Analysis project to maintain consistency with the methods and assumptions within the NREL TEA models. Thus, DDA pretreatments were used as baselines for comparison to DMR.

  Dilute alkali (0.1 to 0.3 molar sodium hydroxide) deacetylation is retained for both processes because up to 30 wt% (or more) of the incoming biomass is solubilized in the unit operation, substantially decreasing downstream equipment sizes, thus saving capital and operating expenses. The DMR process was shown here to be as robust as DDA pretreatments on corn stover harvested in multiple years from various parts of the country, switchgrass, sorghum and other herbaceous crops. In contrast to DDA, the low toxicity, high concentration sugar syrups, and reactive lignin streams significantly enhance downstream biological and catalytic upgrading of these streams, where the DMR sugar streams allowed fermentations to intermediates (i.e., lipids or 2,3-butanediol) with high titers, rates, and productivities similar to pure sugar controls as presented in other project reviews within Biochemical Conversion sessions.

The lignin streams from DMR have been shown to be biologically and catalytically upgradable to bioproducts and bio-jet blendstocks by a number of peer-reviewed publications and work presented in other project reviews within the Biochemical Conversion sessions. We showed the progression of DMR research from 2014 through 2018 and beyond, starting with bench-scale work and low solids enzymatic hydrolysis then addressing critical issues such as efficacy on feedstock blends and increasing insoluble solids concentrations in enzymatic hydrolysis (up to 33 wt% and 270 g/L monomeric sugar concentrations) while maintaining high yields at low-enzyme loadings using DMR substrates. We are investigating higher solids loadings. In contrast, we found DDA pretreated substrates reached a maximum of ~150 g/L monomeric sugar concentrations in enzymatic hydrolysis, and the hydrolysates were more toxic.

All of the DMR results presented here were obtained using a pilot-scale 36-inch disc refiner (at measured 20 to 36 dry ton/day throughputs) that can be directly scaled to larger 54- and 60-inch refiners of 700 dry tons/day throughputs. Because DMR provides an opportunity for a simpler, atmospheric pressure deconstruction process and uses equipment well known in commercial industries that could help resolve feedstock management and feeding issues being encountered commercially in the pioneer biorefineries, thus it could be considered to be highly relevant to the feedstock interface problem.

Due to the time constraints, an in-depth discussion of all the assumptions in the three TEA analyses presented was not possible. These assumptions were described by Ryan Davis in his talk for the Biochemical Platform Analysis Project in the Biochemical Conversion session.

We have tested several key variables in DMR such as sodium hydroxide concentrations/loadings, temperature, residence times, refiner plate gaps, refiner feed rates, solids concentrations entering the refining step, refining energy, and solids and enzyme loadings in high solids enzymatic digestions, etc. on sugar yields, lignin separation, lignin quality (e.g., degree of polymerization, β-O-4 linkages, molecular weight, and catalytic/biological upgradability), all of which were compared in parallel directly with DDA pretreatment results using aliquots of the same deacetylated feedstocks. The DDA pretreatment results (including fermentations) were used as the baselines for the TEA comparisons presented.