# FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

TECHNOLOGY AREA

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# INTRODUCTION

The Feedstock-Conversion Interface Consortium (FCIC) Technology Area is one of 14 related technology areas that were reviewed during the 2019 Bioenergy Technologies Office (BETO) Project Peer Review, which took place on March 4–7, 2019, at the Hilton Denver City Center in Denver, Colorado. A total of nine projects were reviewed in the FCIC session by five external experts from industry, academia, and other government agencies.

This review addressed a total U.S. Department of Energy (DOE) investment value of approximately $40,274,601 (Fiscal Year [FY] 2016–2019 obligations), which represents approximately 2% of the BETO portfolio reviewed during the 2019 Project Peer Review. During the Project Peer Review meeting, the principal investigator (PI) for each project was given 20 to 40 minutes (the presentation length was shortened for the consortium overview presentation) to deliver a presentation and respond to questions from the review panel.

Projects were evaluated and scored for their project approach, technical progress and accomplishments, and relevance to BETO goals. An additional presentation was dedicated to future work and plans of the FCIC. This section of the report contains the results of the Project Peer Review, including full scoring information for each project, summary comments from each reviewer, and any public response provided by the PI. Overview information on the FCIC, full scoring results and analysis, the Review Panel Summary Report, and the Technology Area Programmatic Response are also included in this section.

BETO designated Mr. Beau Hoffman as the FCIC Technology Area review lead, with contractor support from Mr. Andrew Kobusch (Allegheny Science & Technology). In this capacity, Mr. Hoffman was responsible for review planning and implementation with support from Dr. Mark Elless and Ms. Liz Moore, who represent the Feedstock Supply and Logistics (FSL) and Advanced Development and Optimization (ADO) programs, respectively.

# FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM OVERVIEW

Many process bottlenecks and difficulties experienced in the nascent bioenergy industry are centered on feedstock handling and preprocessing operations. These issues often arise from the complexity in feedstock physical, chemical, and mechanical attributes that are present in lignocellulosic biomass feedstocks. The FCIC seeks to quantify, understand, and manage variability in biomass feedstocks, from field through downstream conversion, and to understand how biomass composition, structure, and behavior impact system performance. The FCIC ultimately aims to develop first-principles-based knowledge and tools for technology development firms to use when designing, building, and operating biorefineries and to develop a framework through which technology developers can assess the quality and value of streams to achieve successful operations.

The FCIC began as a virtual consortium incorporating research-and-development (R&D) efforts from BETO's FSL, conversion, and ADO programs. Several projects from the FSL and conversion programs were integrated into this consortium. The consortium at its inception in FY 2018 focused on six key tasks: Feedstock Variability, Feedstock Physical Performance Modeling, Process Integration, System-Throughput Analysis, Process Controls and Optimization, and Industry Engagement/Project Management. Building on experimental and modeling developments, in FY 2019, the FCIC reorganized to focus on five tasks dedicated to various steps in the process chain: Feedstock Variability, Materials Handling, Preprocessing, Low-Temperature Conversion, and High-Temperature Conversion; as well as three enabling tasks that crosscut these unit operations: Materials of Construction, Data Integration/Management, and Crosscutting techno-economic analysis (TEA) and life cycle assessment analyses. These R&D efforts feed into a quality-by-design approach to ultimately manage variability and process risk in a systematic manner.

The FCIC Peer Review Panel reviewed the original six key tasks. The panel also reviewed future plans that cover the current quality-by-design approach and the eight tasks that are currently being pursued.

## FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM REVIEW PANEL

The following external experts served as reviewers for the FCIC Technology Area during the 2019 Project Peer Review.

| Name | Affiliation |
|---|---|
| Brandon Emme* | ICM, Inc. |
| Andrea Slayton | Slayton Technical Services, LLC |
| Glenn Farris | AGCO Corporation |
| Lorenz Bauer | LJB Chemical Consulting |
| Benjamin Levie | Seattle City Light |

* Lead reviewer

## TECHNOLOGY AREA SCORE RESULTS

# FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM REVIEW PANEL SUMMARY REPORT

*Prepared by the Feedstock-Conversion Interface Consortium Review Panel*

Realizing high uptime at pioneer commercial cellulosic facilities has continued to be a monumental challenge. Current technologies for delivering the feedstock to the reactor throat based on pulp and paper industry experience has proven to be insufficient for agricultural residues and similar materials. Feedstock characteristics such as tramp, ash, and variable moisture cause disruptions in feeding systems (plugging and abrasion) and induce conversion variations. The FCIC was created to identify and address these challenges though a crosscutting effort leveraging the skill sets of the DOE national laboratories supported by an industry advisory board (IAB).

## IMPACT

Knowledge attained by the FCIC projects informs equipment suppliers servicing the lignocellulosic industry, reduces risk and promotes improved process reliability, especially at the reactor throat, as a result of feedstock variability. The capabilities of both the Biomass Feedstock Process Development Unit (PDU) at Idaho National Laboratory (INL) and the Integrated Biorefinery Research Facility at the National Renewable Energy Laboratory (NREL) provide scalable information on equipment and process performance for both thermochemical and biochemical processes for relevant feedstock qualities (e.g., high- and low-moisture and ash). The comprehensive national laboratory crosscutting project management structure of the FCIC projects further augment the tools and knowledge base.

The panel received a good impression that the projects were well designed to meet the goals of the FCIC and further identified which questions to explore next (e.g., advanced controls, improved equipment design). The characterization database is a useful tool for industry. Increased communications of the FCIC project results could increase visibility in the industry, especially around priority specifications.

## INNOVATION

The FCIC projects provide several significant findings, including:

- X-ray diffraction methods for looking at feedstock and determining ash content
- System-wide throughput analysis, including process reliability impacts. Quantification of the impact of feedstock moisture and ash content on plant uptime as well as human intervention was relatively similar for both low- and high-temperature processes.
- Demonstration of improved feedstock milling through an adaptive control strategy was able to show high uptime but at the cost of less than design capacity.
- TEA models with the capability to include unit operation uptime reliabilities lead to the identification of system-wide throughput for pioneer plants.
- Material flow modeling in bins and hoppers (although many results are too complicated for a layperson to understand).

## SYNERGIES

The FCIC project portfolio represented a concerted effort to integrate development efforts, most notably by characterizing feedstock moisture and ash variation from the field through the PDUs at INL and NREL and by integrating process data into the TEA analysis modeling system-wide throughput. Further computational modeling of biomass flow in bins and hoppers was also performed but was not able to adequately predict flow reliability. In support of synergy, the national laboratories also produced a primer glossary to align nomenclature for industry.

## FOCUS

The future strategy to refocus the FCIC on the development of first-principles-based knowledge and tools for technology development firms to use when designing, building, and operating biorefineries has the potential to cross over and illuminate empirically based equipment choices. The output value could be increased by simultaneously developing a framework that technology developers could use to assess the quality and value of streams to design at a broader systems level.

## COMMERCIALIZATION

The FCIC portfolio was narrowed following the recommendations from the 2017 Project Peer Review. This resulted in more direct understanding of the impacts of feedstock moisture and ash content on the process uptime and human intervention, although full clarity was not attained as a result of other uncontrolled/uncontrollable processing factors at the PDU scale. The findings of the FCIC projects are useful, and as such the panel encourages the national laboratories to create more visibility of the results through a more deliberate marketing strategy, especially if this could also be used to create collaboration opportunities among the FCIC teams and industry.

## RECOMMENDATIONS

Following are recommendations from the review panel:

- Integrate as many developments included in the state of technology (SOT) into the FCIC demonstration/benchmarking runs as possible. In particular, the impact of blending depot and pellets on plant reliability and uptime should be quantified as well as mitigation strategies should be developed for controlling moisture and ash content in the reactor feedstock.
- Ensure that the goals of the quality-by-design/first-principles focus will result in commercially relevant process reliability and demonstration by stretching the success rate target and timing.
- Create more industry immersion experiences for the national laboratories/BETO to ensure relevance to pioneer plants/industry. Continue to leverage the value of the IAB to support project relevance when direct feedback from pioneer plants is not available. Consider innovative methods for getting industry knowledge into the national laboratories (fellowships, analytical loaners, FCIC meetings on-site at industrial entities, etc.).
- As part of the first-principles strategy, establish quality specifications on feedstocks as they pertain to reliable delivery to the reactor throat along with mitigation methods in design, storage, and operations for high-moisture content.
- Develop a clear marketing plan to aggressively promote FCIC projects and output on a widespread basis to achieve greater industry adoption. Increase visibility through road shows at relevant industry conferences and pioneer plants. Consider whether a skill/resource map of the national laboratories might support this.

# FEEDSTOCK-CONVERSION INTERFACE-CONSORTIUM PROGRAMMATIC RESPONSE

## INTRODUCTION/OVERVIEW

The FSL, Conversion R&D, and ADO programs thank the five reviewers for their time and careful review of the portfolio. We recognize that many technical disciplines are represented in the work of this consortium, thereby requiring a multidisciplinary panel. We also recognize that it is a difficult review processes because additional projects relevant to this work are present in many different sessions. Across the BETO portfolio, we have been working to adjust the format of the Project Peer Review to best communicate the efforts ongoing within our national laboratory consortia.

The following sections specifically address the recommendations from the review panel.

### Recommendation 1: Quantify blending, depot, ash, and moisture impacts.

The programs concur that quantifying the technical, economic, and sustainability impacts associated with any process change or feedstock attribute is a critical first step. In reorganizing the FCIC in FY 2019 and FY 2020, the programs have established a designated crosscutting analysis task to perform these cost-benefit and trade-off analyses. The programs have communicated the need to maintain adequate resources to be responsive to these process changes and feedstock attributes. Feedstock processing strategies that are employed to manage critical material attributes (e.g., inorganic species, intrinsic moisture) will be evaluated to investigate the costs associated with that unit's operation and to quantify the impacts for other unit operations both upstream and downstream. These technical performance experiments will be subjected to TEA to ensure that feedstock processing choices lead to systems-level techno-economic and sustainability improvements.

In response to the desire to explore blending options, the programs agree that there is economic opportunity associated with this strategy and will consider this in the future. Blends will not be explored in the first 3 years of this consortium. At present, the focus of the consortium is on understanding the physical, chemical, and mechanical effects imparted by single feedstocks (i.e., corn stover and forest residues). The rationale is that through a fundamental science-based understanding of the physical, chemical, and mechanical effects of individual feedstocks, the identification of critical material attributes and the impacts of processing on product quality can be identified and quantified. Once the critical material attributes are understood for individual unit operations, we might investigate other feedstocks or blends.

In response to the desire to explore depot processing, the programs believe that a depot concept could support commoditizing lignocellulosic biomass feedstocks; however, given the nascent nature of the lignocellulosic biomass supply chain, these activities are not currently prioritized. Through the success of the consortium, the programs strongly feel that lessons learned about critical material, process, and quality attributes will inform how a depot could operate.

### Recommendation 2: Stretch the consortium end goals.

The programs concur that more ambitious goals (e.g., 1,000 hours of continuous operations vs. 500 hours) would have a positive effect on the broader bioeconomy in several ways. At present, and subject to budget levels, the programs plan to retain the 500-hour objective. The programs feel that being able to achieve required quality attributes despite variable-feed properties during this time will achieve the major consortium goal: to demonstrate a comprehensive understanding of the impacts of feedstock variability through the process supply chain such that it can be managed by adjusting processing steps or processing conditions.

### Recommendation 3: Develop innovative ways to immerse the national laboratories with industry.

The programs fully concur with this recommendation to develop innovative methods for getting industry knowledge into the national laboratory consortium. The programs hope to implement this recommendation in several ways:

- FY 2020 work in the consortium has heavily stressed the need for the national laboratory consortium to develop tools that are meaningful to industrial problems. Examples include feedstock attribute data sets, open-source code that can be used by external models, and publicly available TEA.
- The programs could employ additional funding opportunities and formal collaborations between the national laboratories and industry, including Energy I-Corps and consortium-led funding opportunities.
- Creating a more structured engagement and communication strategy with the IAB.

### Recommendation 4: Establish quality specifications on feedstocks.

Implicit to the quality-by-design approach is an understanding that feedstock quality will propagate through the entire process supply chain. The programs are prioritizing the identification of “critical material attributes” under the Feedstock Variability task, including variability as a function of storage, harvesting method, and environmental conditions. In FY 2020 planning, the consortium is developing deliverables and outcomes to make these data publicly available, including the metadata associated with downstream processing. It is envisioned that standardizing the terminology around these critical material attributes would enable technology developers to consistently communicate their feedstock quality requirements or specifications to feedstock providers.

### Recommendation 5: Aggressively promote the Feedstock-Conversion Interface Consortium results and visibility.

The programs fully concur and are implementing ways to improve the visibility of this consortium. The consortium is finalizing a communications plan that will include the use of best practices developed and employed by other consortia. This plan could include regular external webinars on special technical topics, colocating consortium listening days at key conferences and trade meetings, and dedicating a portion of the budget to maintaining a website with the consortium’s accomplishments and capabilities. In addition, and when possible, FY 2020 planning includes the dissemination of deliverables and outcomes that are publicly available, such as models and scripts as digital appendices associated with peer-reviewed journal articles.

# FEEDSTOCK VARIABILITY AND SPECIFICATION DEVELOPMENT – INL

## Idaho National Laboratory

## PROJECT DESCRIPTION

| WBS: | 1.2.2.401 |
|---|---|
| CID: | NL0033424 |
| Principal Investigator: | Dr. Allison Ray |
| Period of Performance: | 10/1/2017–9/30/2020 |
| Total DOE Funding: | $15,538,832 |
| DOE Funding FY16: | $6,535,000 |
| DOE Funding FY17: | $4,636,332 |
| DOE Funding FY18: | $4,367,500 |
| DOE Funding FY19: | $0 |
| Project Status: | Sunsetting |

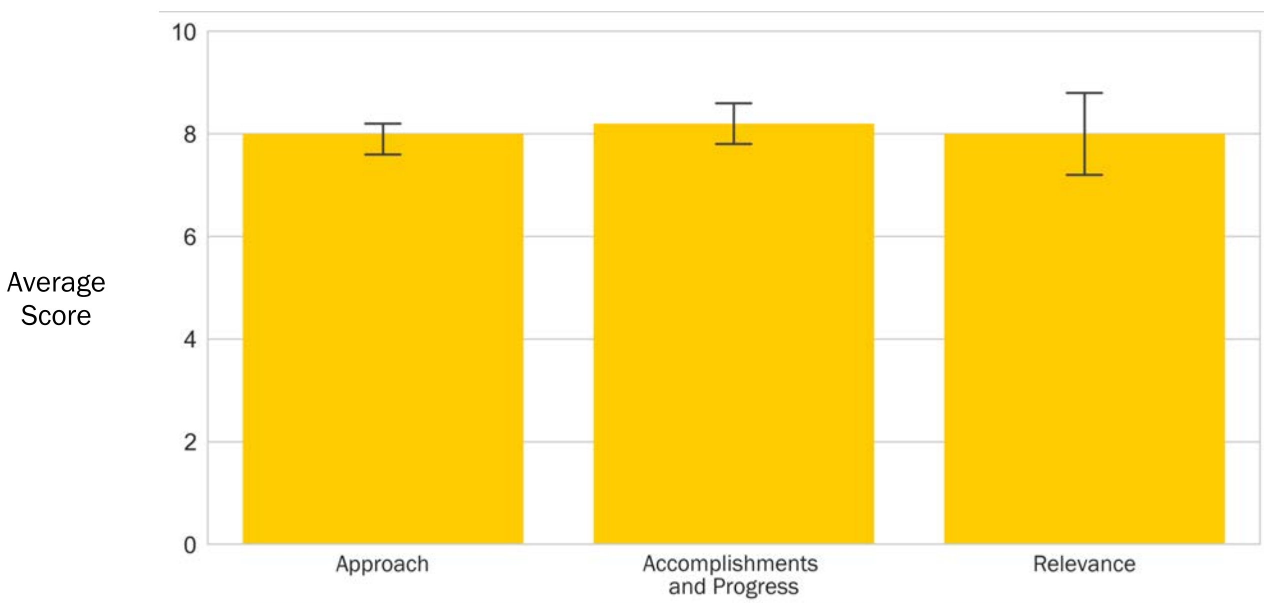
Co-PI contributors: A. Hoover, R. Emerson, J. Klinger, T. Westover, L. Williams, M. Ramirez-Corredores (Idaho National Laboratory [INL]); D. Tanjore (Lawrence Berkeley National Laboratory [LBNL]); T. Semelsberger (Los Alamos National Laboratory [LANL]); E. Webb (Oak Ridge National Laboratory [ORNL]); B. Donohoe, N. Nagle, E. Wolfrum (National Renewable Energy Laboratory [NREL]); K. Sale (Sandia National Laboratories [SNL]); J. Collett (Pacific Northwest National Laboratory [PNNL]); G. Fenske, O. Ajayi (Argonne National Laboratory [ANL])

Biomass variability has proven to be a formidable challenge to the emerging biorefining industry, impeding continuous operation, equipment uptime, and required throughput for economic production of lignocellulosic biofuels and chemicals at the commercial scale. Inconsistent feeding and handling operations at integrated biorefineries (IBRs) have been identified by the DOE BETO as a limiting factor in the conversion of lignocellulosic biomass to fuels and value-added coproducts. IBR development and operation have suffered from failing to account for the complexity and variability of lignocellulosic biomass.

The Feedstock Variability and Specification Development project aims to quantify the variability in chemical, physical, and mechanical properties of corn stover and loblolly pine residues and conduct fundamental

### Weighted Project Score: 8.1

Weighting for Sunsetting Projects: Approach-25%; Accomplishments and Progress-50%; Relevance-25%




One standard deviation of reviewers' scores

characterization required to understand property impacts on feeding, handling, preprocessing, operational reliability, and conversion performance in both low- and high-temperature conversion pathways. Understanding the magnitude and sources of variability will enable the development of technological solutions to integrate feedstock supply, storage, preprocessing, and conversion and improve operational reliability and, ultimately, maximize yields. This project generates foundational knowledge and develops methods required to contribute to the FCIC's goal of identifying and addressing the impacts of feedstock variability on preprocessing, conversion, and system performance to move toward 90% operational reliability. This presentation outlines project accomplishments toward: (1) biomass supply for the FCIC's experimental baseline runs for preprocessing, low-temperature conversion, and high-temperature conversion; (2) fundamental characterization to quantify variability and to identify critical factors that affect reliability from preprocessing through conversion; and (3) methods development tailored to lignocellulosic biomass.

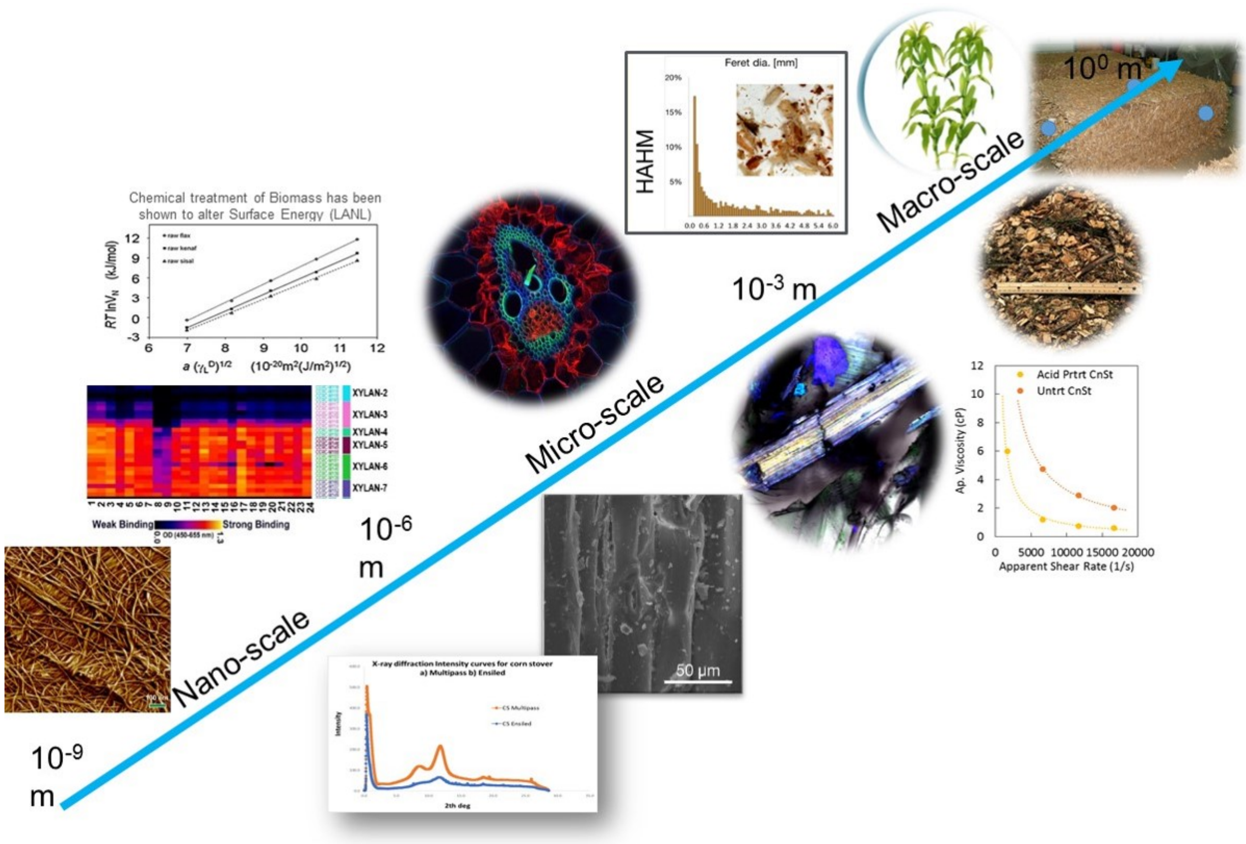



*Photo courtesy of Idaho National Laboratory*

## OVERALL IMPRESSIONS

- This work is critical to organizing, categorizing, and characterizing feedstocks. It looks to be a good framework and will benefit from new methods of property analysis.
- Great work establishing and characterizing relevant feedstock ranges that are largely industry-relevant baseline causes of variation in the incoming material. It includes new methods implemented and shown to describe "cleanliness" of the feedstock, which will help support industry. Data are collected and organized in an open-source format that will make it easier for public access and use.
- The objective of this project is good. By design, the project looks at two feedstocks; however, it would be beneficial to expand this research to multiple feedstocks. For agricultural waste in particular, an aging

feedstock affects use and changes in the characteristics would be very difficult to quantify. The scope of this project was limited because of the complexity of the subject matter; understanding this is not a criticism of this project, but instead a statement that more work should be done to expand knowledge of feedstock characteristics on the processes and processing equipment.

- This project has many important aspects, such as the development of a database for industry to call upon for design information when contemplating the cost and operation of a commercial project. Development of a common language and principles of biomass from a technical basis will help accomplish this as well. Lacking, however, is a more detailed quantitative discussion of what a successful project here means. For example, how much can a developer be expected to save in testing costs by having this database available or knowing which variables must be planned for when designing a feed hopper?

- The feedstock variability and specification project is an important accomplishment and provides basic information that will useful to all those working in the biomass conversion field, both the actual data collected and as a model of the type of characterization work needed. Efforts should be taken to make these data more accessible to biogeotechnology developers and to continue to add more data, particularly on underreported properties such as ash characterization. The Chemical Catalysis for Bioenergy Consortium data hub would be a good model. It should be possible to reach out to land grant colleges and state agriculture organizations to aid in the collection of useful data that could expand the database. The FCIC primer is a useful document that provides a means for more uniform and effective communication about feedstock properties.. The X-ray diffraction analysis of biomass is a novel way to speciate metals and other ash materials.

## RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We appreciate the reviewer's comments. Likewise, we believe that some of the new approaches and methods developed and applied for property analysis offer significant potential for quantifying biomass quality and elucidating property-driven impacts on preprocessing and conversion.

- We appreciate the reviewer's comments. We certainly agree and will plan to expand the scope of our feedstock variability analyses as the consortium progresses and as funding allows. Moving forward in FY 2019, FCIC 2.0 will develop a fundamental understanding of how aging impacts biomass properties. Controlled studies under conditions that simulate aging of agricultural residues will be conducted to improve deconvolution of the complexities of resulting alterations in multiscale chemical, structural, and physical properties and how interactions among properties translate to behavior of these materials. Although this project focused on corn stover and pine residues, the consortium has industry collaborative projects under the direct funding opportunity that focus on diverse feedstocks, such as municipal solid wastes and almond wastes.

- We appreciate the reviewer's input. In FY 2018, the goal of the feedstock variability project was to quantify variability in physicochemical and mechanical properties of biomass for the FY 2018 experimental baseline runs. The culmination of knowledge derived from all the FCIC projects was aimed at solving challenges related to the design and identification of critical properties. Although FY 2018 FCIC represents a 1-year effort, these data sets provide a basis for informing FCIC 2.0 and the quality-by-design approach that is tailored to identifying critical attributes and process variables that are requisite for improving equipment operation and design.

- Thank you for this feedback. Data sets generated from the FY 2018 experimental baseline runs are available through the Bioenergy Feedstock Library (BFL), and the FCIC primer, which was developed as part of this project, is also available through the BFL (https://bioenergylibrary.inl.gov/Home/Home.aspx).

# FEEDSTOCK PHYSICAL PERFORMANCE MODELING – INL

## Idaho National Laboratory

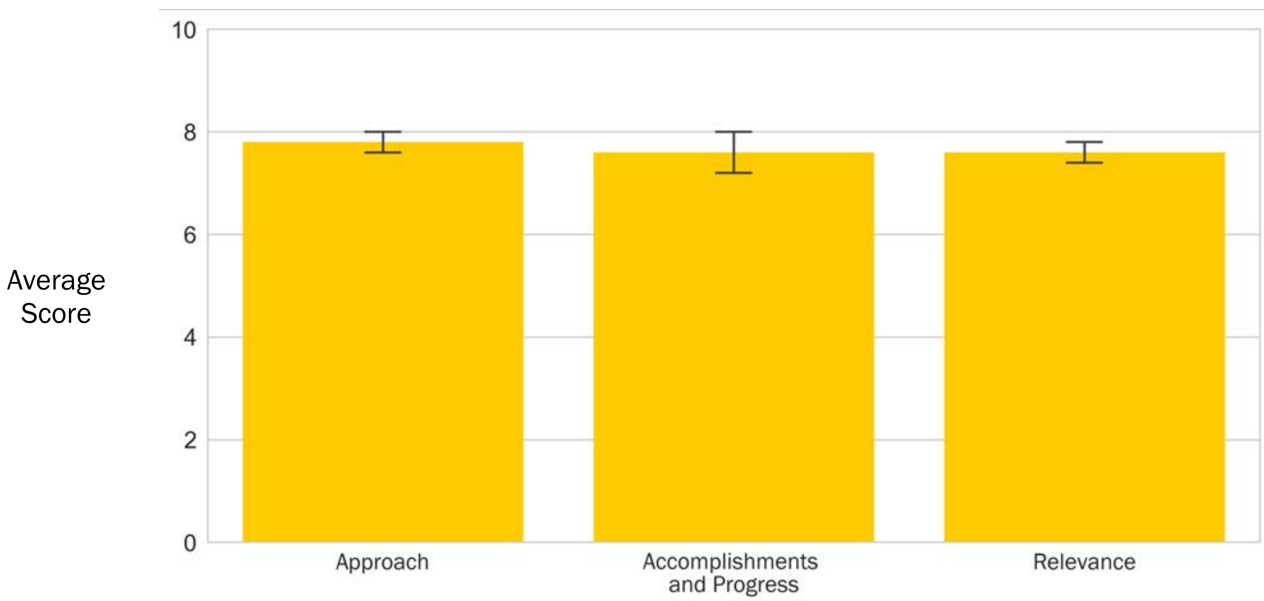
### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 1.2.2.501 |
| CID: | NL0033425 |
| Principal Investigator: | Dr. Tyler Westover |
| Period of Performance: | 10/1/2017–9/30/2020 |
| Total DOE Funding: | $2,115,000 |
| DOE Funding FY16: | $0 |
| DOE Funding FY17: | $650,000 |
| DOE Funding FY18: | $1,465,000 |
| DOE Funding FY19: | $0 |
| Project Status: | Sunsetting |

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 exhibits large particle size variations, low density, and high compressibility. Methods do not yet exist to either physically characterize or computationally model the complex mechanical response of such materials. The primary objective of this project is to develop physics-based computational models that reliably predict the mechanical behavior of a loblolly pine residue and a corn stover sample in a lab-scale direct axial shear test. These models are then used to identify critical material attributes that impact feeding and handling performance. Two types of physics-based models were pursued. First, the discrete element method (DEM) was applied to develop high-fidelity particle-based simulations that capture interactions between representative particles. Although DEM models can robustly capture all dominant particle flow mechanics, they are extremely expensive in terms of computation time and memory and are difficult to scale to industrial applications. Therefore, the necessary scaling is achieved by developing reduced-order continuum finite element method (FEM) models that essentially average over many particles to reduce computational cost. The robustness of the FEM models was verified using physical experiments and by comparing their predictions to those of the DEM models. Particle-based DEM models are essential for

### Weighted Project Score: 7.7

Weighting for Sunsetting Projects: Approach-25%; Accomplishments and Progress-50%; Relevance-25%




One standard deviation of reviewers' scores

developing and verifying FEM models to ensure that the FEM models capture appropriate functional relationships between key parameters. In many cases, these functional relationships cannot be measured experimentally (for example, the relationships between internal material stresses, strains, dilation, and shear strength) because the needed sensors do not exist or lack enough accuracy.

The objective of the project was accomplished by achieving greater than 80% agreement between the lab-scale direct axial shear test and computational simulations. Results of the flow tests and simulations using different geometries indicate that flow modes of biomass materials are coupled, resulting in highly complex flow that cannot be fully understood using classical continuum methods. Future effort will focus on developing more advanced continuum FEM flow models based on results of DEM particle models.

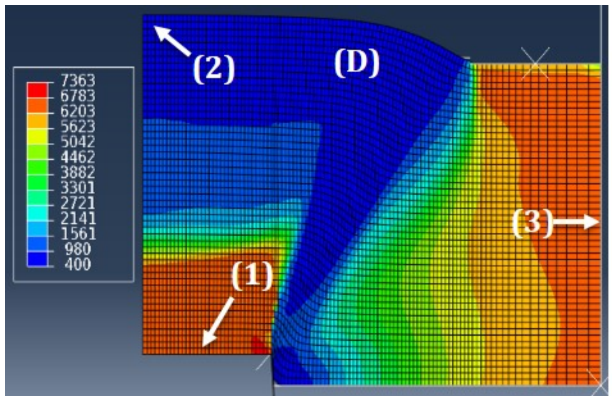



*Photo courtesy of Idaho National Laboratory*

## OVERALL IMPRESSIONS

- This is ambitious work that has high use to industry if it can be understood and general enough.
- The early cellulosic biorefineries experienced significant problems in the interface of feedstock handling and conversion. The modeling created in this project suggests that if a project developer understands the physical properties of the feedstock in their plan, the proper feeding and handling system could be designed and hopefully not have the same sorts of problems that the industry presently faces. This could be an important step forward in the SOT as it exists today.
- This project undertook a very challenging application, and, not surprisingly, it found that several models need to be applied simultaneously to get reasonable system models. Congratulations on the frontier-type work; the reviewer anticipates that it will lead to new concepts for improving biomass flow through hoppers and screws.
- Relevant industry partners were involved in the project, but it was not clear where they had vetted the modeling analysis or this had been done only on the flow characterization methods. The reviewer suggests this is done as part of fully completing the work and helping to ensure its value to equipment designers.
- The presentation did a good job of providing a general understanding of the complexity of the problem; however, the details needed to be explained in plain language.
- A variety of flow modeling methods were applied, although the details were difficult to follow. This is an interesting project, but a model with a goal of an R-square of 0.8 might not be able to drive significant improvements. The results of the project are of limited impact on the overall biorefining industry. This is because a new set of tests would likely be required depending on the equipment and feedstock used. Unfortunately, the calculation approach failed to provide usable results.

## RECIPIENT RESPONSE TO REVIEWER COMMENTS

- Agreed. The advanced simulation and characterization methods will enable consulting firms in bulk solids handling to properly advise industrial biorefineries, and the rapid and reduced-order models will be directly useful for industrial biorefineries to better understand the effects of feedstock variability.
- Exactly. It is also understood that the project developer will likely need to consult with firms that specialize in handling bulk solid (particulate) materials to appropriately apply advanced methods developed by this project.
- Industry partners primarily assisted by helping with the flow characterization methods and early discussion of simulation options. As the models develop and additional results are obtained, input will be sought from a wide range of industry and academic experts. This input will be sought through subcontracts and through the Particle Technology Forum within the American Institute of Chemical Engineers.
- For general understanding, complex models and characterization methods must be simplified to low-level reduced-order models. Please see responses 1 and 2.
- We agree that being able to predict flow behavior with 80% accuracy might not be adequate for the industry. Current advanced models that we have tested exhibit errors that are greater than 100% for key multidimensional predictions. We believe that the models can be improved substantially, which will lead to improved understanding and more reliable designs. Efforts at adapting advanced continuum and particle models are still in their relative infancy and will be pursued further in a future project to provide useful results.

# SYSTEM-WIDE THROUGHPUT ANALYSIS – INL

## Idaho National Laboratory

### PROJECT DESCRIPTION

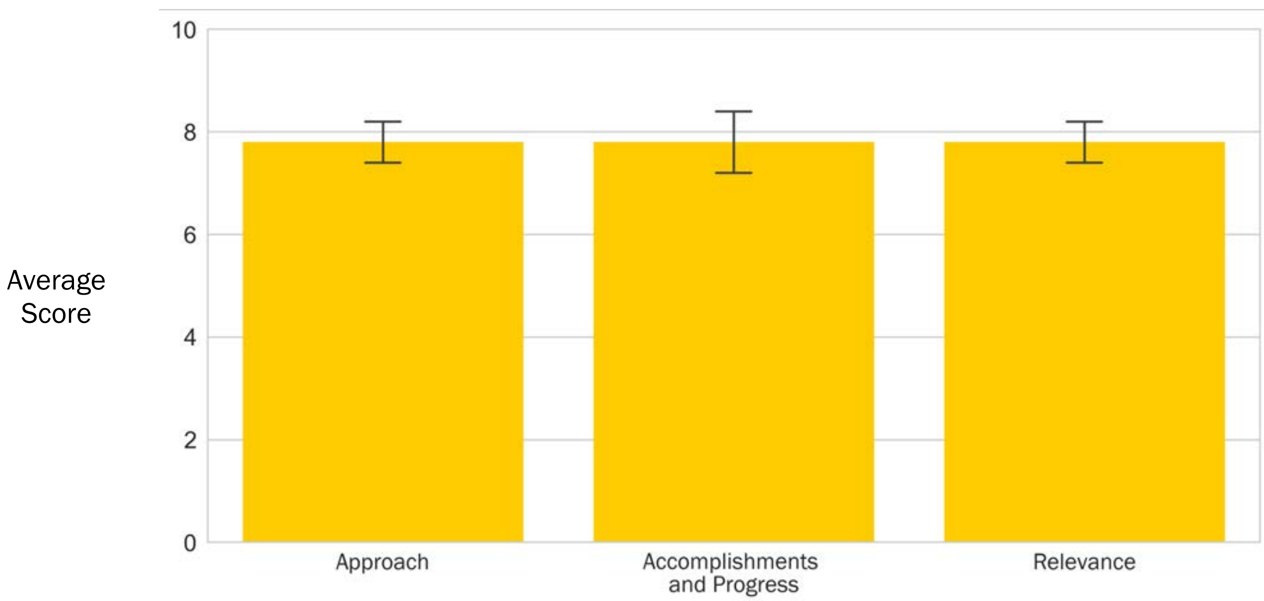
| | |
|---|---|
| WBS: | 1.2.2.601 |
| CID: | NL0033426 |
| Principal Investigator: | Dr. David Thompson |
| Period of Performance: | 10/1/2017–9/30/2020 |
| Total DOE Funding: | $3,477,499 |
| DOE Funding FY16: | $1,050,000 |
| DOE Funding FY17: | $950,000 |
| DOE Funding FY18: | $1,477,499 |
| DOE Funding FY19: | $0 |
| Project Status: | Sunsetting |

Recent evidence indicates that the operational performance of the DOE's cofunded pioneer project on integrated biorefineries (IBRs) is significantly impacted by variability in feedstock properties and composition. This is a high-impact problem because several IBRs have already failed largely because of underestimated operational issues related to this variability. Thus, a timely solution to these operational issues is essential if second-generation biofuels are to be commercialized in any significant volume, allowing the economic benefits of new jobs and improved security of our fuel supply to be realized. The remaining IBRs are trying to solve these operational upsets; however, solving one issue invariably creates or reveals others because of interactions across the system and or the masking of downstream issues by upstream problems. It is well known that compositional variability can have significant impacts on titer, rate, and yield from conversion processes; however, the system-wide impacts and trade-offs of variation in feedstock physical properties on first-plant scales are not well understood.

The objective of this project is to provide analyses that identify and quantify specific impacts that feedstock properties have on feedstock handling, processing, and conversion unit operation performance and how these impacts cascade throughout the system and impact the attainment of 90% uptime and design biofuel yields and costs. This project uses a combination of discrete event modeling and modified steady-state process simulation

Weighted Project Score: 7.8

Weighting for Sunsetting Projects: Approach-25%; Accomplishments and Progress-50%; Relevance-25%

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to model the dynamic throughput and conversion process performance impacts of feedstock properties across the field-to-biofuel system. We define the operational reliability of a system to include the feedstock attribute-derived impacts of below-design throughput (including downtime, or zero throughput) and yield (i.e., conversion performance). This operational reliability is then used to estimate annual capacity, productivity, process economics, and sustainability metrics. To accomplish this, we use throughput analysis combined with existing and developing knowledge of the sources and impacts of variable feedstock properties on operational reliability.

To maximize the potential impact of our analyses to current pioneer biorefinery processes, the analyses focused on conventional feedstock supply systems used by the pioneer biorefineries. Additionally, past conversion platform design cases that were reasonably representative of pioneer biorefinery technologies were used. These included biochemical (fermentative, low-temperature) conversion of nonpristine corn stover biomass to ethanol (2011 biochemical corn stover-to-ethanol design case) and fast pyrolysis of nonpristine southern pine residues to hydrocarbon fuel products (2013 pyrolysis and upgrading to hydrocarbons design case).

This project fulfills a critical role for DOE and industry stakeholders by developing and using an approach for the early identification of bottlenecks and pinch points across the entire field-to-biofuel system as well as quantifying their relative impacts on achievable throughput, yield, process economics, and sustainability metrics. Using input data generated during the experimental baselining of the preprocessing and conversion deconstruction process development units, this project developed modeled operational reliability baselines for the two feedstock conversion systems operated during a year's time. The modeled baselines agreed well with the experimental observations, allowing for the generation of the distributions of expected throughput and conversion yield that would have resulted from the given feedstock property input distributions.

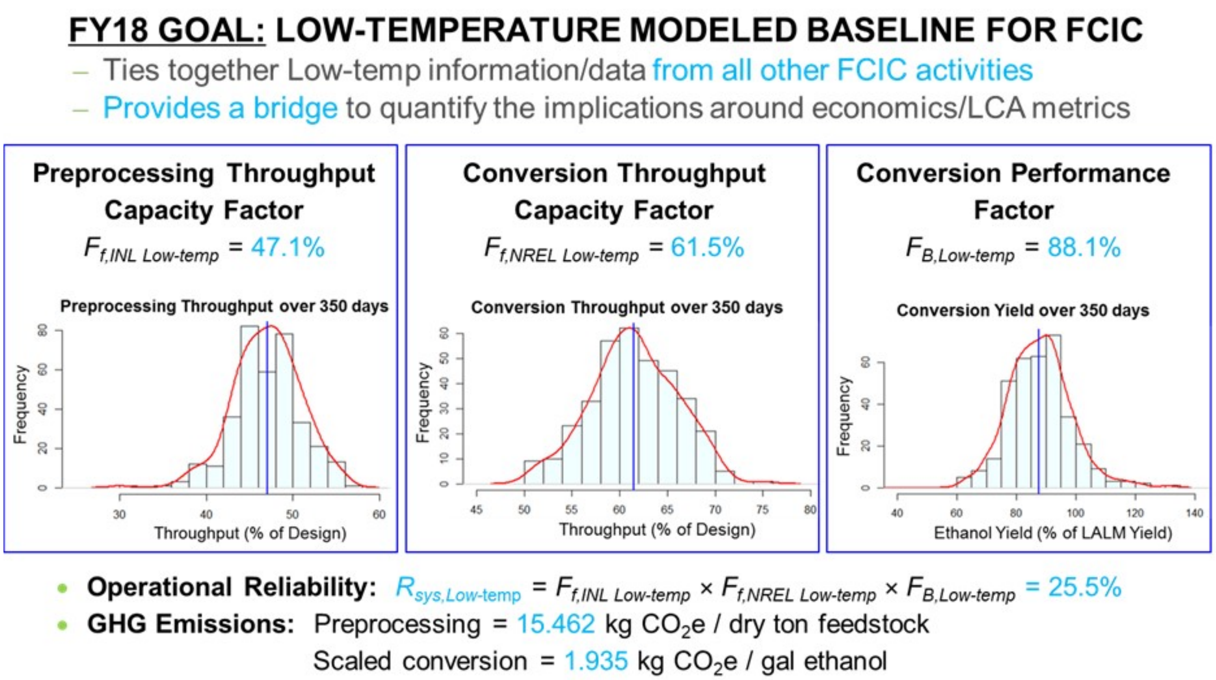



*Photo courtesy of Idaho National Laboratory*

## OVERALL IMPRESSIONS

- The system-wide view is important in integrating all the other parts of the FCIC work. The work is important in determining the overall capacity of a plant in terms of where the bottleneck is and which parameters in the biomass cause capacity to be diminished.

- Models such as those created by this project—which capture both operating reliability and production throughputs based on the effects of feedstock variability—will have significant advantage to inform both commercial and R&D activities. Currently, the main weakness is the lack of data for parts of the modeling, such as the scale-up cost for low-throughput systems and operating reliability data for high-throughput systems. This is not a fault of the PIs but a weakness, nonetheless, limiting the models' use and value. Over time, however, as more data become available, dynamic models like these will become a valuable tool.

- This project is a great new way to apply the Aspen/TEA models because it incorporates relevant highly variable unit operation capacities/uptime such that the model was able to predict which steps of variation are the true rate-limiting steps to the plant. Modeled uptime for pioneer plants was reasonable but still needs to be validated against industry when data are available.

- Use of the models to help direct future work will need to include broader mitigation options. It is suggested to use the FCIC/FSL IABs and industry interviews to help define some of the more relevant approaches to bring into the model. Moisture control should be a focus topic.

- This was not an easy topic to present because of the need to really think about what was being presented. It is an interesting approach to looking at plant reliability and thus profitability by getting the most out of what a plant has and directing money toward improvement; however, it would have taken much long than a half hour of time to show the strength of the models.

- System-wide throughput analysis is a critical part of improving the efficiency of biofuel production. This type of stepwise analysis is the foundation of Six Sigma and other process design analysis approaches. The results of the analysis reflected the poor throughput of both the low- and high-temperature processes related to equipment reliability. This information confirms the importance of the FCIC to the overall success of biofuel production. There is a clear need to include equipment performance data in the TEA analyses, as discussed in the project. The problem is the lack of availability of these data, particularly at the commercial scale. Unfortunately, these data are considered highly proprietary; however, I believe that NREL has a larger unit that might also be able to provide data. Operational data should be included in the TEA evaluation of projects to provide a better estimate of early plant performance.

## RECIPIENT RESPONSE TO REVIEWER COMMENTS

- Throughput analysis is usually applied in supply system optimization and in manufacturing industries, and to date it has not been applied to any great extent in the chemical industry. Generally, classical reliability and use approaches are followed to maximize time on stream, whereas mismatches of capacity are solved through the insertion of material flow buffers between mismatched equipment. Although this approach has been shown to be successful for liquids and gases, bulk solids such as biomass that have a range of structural and mechanical properties that depend on hard-to-control variables (such as moisture and ash) present challenges that cannot simply be solved by inserting material flow buffers. Including throughput capacity use and conversion performance in an operational reliability metric provides an approach to solving these challenges.

- We previously used this method along with observational and experiential data to develop estimates of equipment-level at-scale downtimes and performance impacts. In that case, we were able to produce results that were consistent with the observations of the DOE tiger team that worked with the pioneer biorefineries to identify reasons for much longer than expected startup times and feeding system-derived conversion system upsets. Through that analysis, we were able to identify which unit operations and high-level feedstock properties (moisture and particle size) were most impactful to the operation of the preprocessing system. As we learn more fundamental causes of impacts, we will be able to integrate those into the models. Additionally, first-principles modeling in other FCIC projects will directly inform both equipment and system designs.

- The objective of the analysis during FY 2018 was to define modeled operational reliability baselines for the systems that the FCIC have access to (i.e., data sources that were available). The prior estimates for at-scale impacts from the previous analysis were not used for these baselines because they were not directly measured. We believe that as we gain a better understanding of the fundamental (i.e., feedstock property-based) mechanisms of impacts to individual PDU-scale equipment through the efforts of the FCIC, there will be a better basis for predicting impacts to larger scale equipment through fundamental modeling, which can then be applied to throughput modeling of the system. In this way, the redirected FCIC efforts will improve the modeling approach for system-wide throughput/cost/sustainability analysis, fill in identified data gaps, and develop tools/models that are focused on helping industry.

# INDUSTRY ENGAGEMENT AND PROJECT MANAGEMENT – NREL

## National Renewable Energy Laboratory

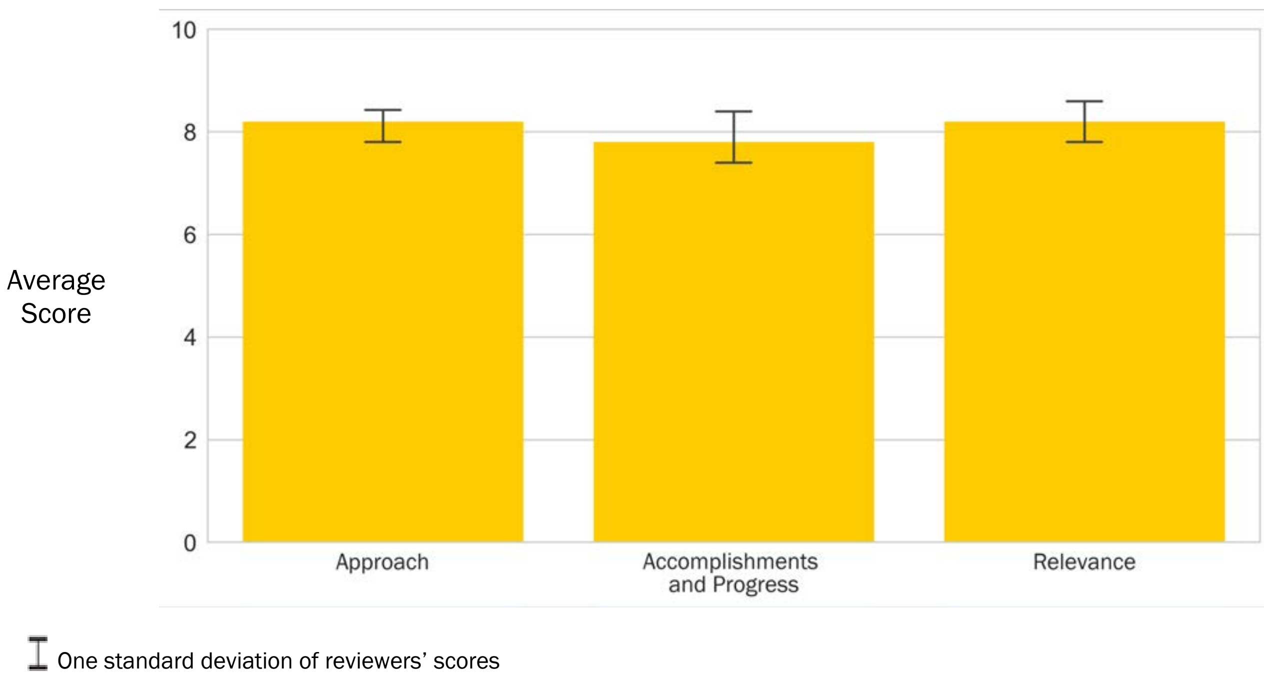
### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 1.2.2.702 |
| CID: | NL0033723 |
| Principal Investigator: | Dr. Michael Resch |
| Period of Performance: | 10/1/2017–9/30/2020 |
| Total DOE Funding: | $824,000 |
| DOE Funding FY16: | $0 |
| DOE Funding FY17: | $0 |
| DOE Funding FY18: | $824,000 |
| DOE Funding FY19: | $0 |
| Project Status: | Sunsetting |

Industry Engagement and Project Management aims to coordinate and manage FCIC R&D activities and to promote interactions with IAB members and stakeholders to deliver technological solutions developed within the FCIC for industry adoption. This project consists of three tasks: industry engagement, industry collaborative R&D, and project management. INL and NREL will serve as two lead institutions for the FCIC efforts and will work proactively with PNNL, ORNL, LANL, LBNL, ANL, and SNL to develop and execute work plans, to prioritize and coordinate R&D activities, to establish communications pipelines and leadership teams for the different FCIC R&D projects, and, finally, to engage industry to solicit significant input and translate FCIC innovations for industry adoption. In the industry engagement task, the project management team has engaged with industry stakeholders and established an IAB. The goal of these actions is to ensure more efficient communications and, ultimately, to promote and enable industry national laboratory collaborations that will be effective in helping industry overcome technical barriers, thereby improving operational throughput and, thus, profitability. Communication of FCIC accomplishments and capabilities has been largely through the development of the FCIC website (www.fcic.inl.gov). The industry collaborative R&D task has promoted industry national laboratory collaborations by funding $8 MM in R&D projects through FCIC directed funding opportunity awards. A web-based process tool was also established to

Weighted Project Score: 8.0

Weighting for Sunsetting Projects: Approach-25%; Accomplishments and Progress-50%; Relevance-25%



manage the funding opportunity program's proposal submission, review, approval, award process, and project execution. In the project management task, a sensible project management structure, workflow system, and reporting process was put in place to ensure that the FCIC will continue to be efficient and effective. This task focused on global FCIC integration and coordination of activities to ensure rapid and efficient progress toward goals. The FCIC project management team ensured that deliverables were provided to DOE in accordance with the approved work plan and budget. The FCIC project management team also coordinated establishing a leadership team comprising representatives from DOE and national laboratories to establish the vision and define the strategy of the R&D focus as well as to approve the direction of and changes to the R&D focus as the FCIC evolves.

The objectives of this project were to: (1) ensure the effective management of the consortium to achieve FCIC objectives and outcomes using scientific expertise and core capabilities of the national laboratories, (2) establish a functional FCIC IAB representing the broad range of stakeholder interests and an active FCIC industry engagement team, (3) complete at least two industry collaborative projects, and (4) engage and promote partnerships that translate FCIC innovations to industry. This project will ensure the accomplishment of overall FCIC goals through active project management, industry engagement, and outreach activities with R&D projects that address the development and optimization needs of bioenergy industry stakeholders. Industry engagement will include activities that provide industry input to FCIC annual operating plans, communication of FCIC capabilities and accomplishments to industry, and the transfer of technical knowledge developed by FCIC research to industry via technical reports and presentations. R&D projects will include strong potential for industry adoption and industry collaborative R&D projects that are competitively awarded through a FCIC directed funding opportunity. The intended outcomes of this work include industry input on FCIC direction, active and diverse partnerships with industry, and industry use of FCIC innovations.

*Photo courtesy of National Renewable Energy Laboratory*

## OVERALL IMPRESSIONS

- The FCIC was an important industry-driven effort by BETO to address real needs of pioneer biomass plants. The focus areas were based on what was indirectly known to be the challenges at the pioneer plants during their commissioning phases, although direct participation by pioneer companies was not possible, and in lieu of that the decision to use an IAB for this purpose was helpful if not directly executable.

- Obtaining results from the consortium in only 2 years was exceptional, and all consortium members should be commended. Inclusion of the full breadth of national laboratories was useful to deliver a more diverse knowledge and skill set to the projects, even when only a few of the laboratories needed to do the majority of the project execution. This approach should be replicated in the future whenever possible.

- The main aim of the FCIC was to establish high reliability of feedstock delivery to the reactor throat; however, a set of quality specifications was not a highly visible output of much of the work. Moisture and ash were identified as significant impact variables, but no clear guidance has yet been given to drive upstream control methods. If pellets of blended feedstocks are a viable option, there should be some analysis/scoring of how well they meet the reliability specifications, not only the cost targets.

- Managing a consortium such as the FCIC is not only an important undertaking but also a complex task. The work of the FCIC will prove to be a necessity to the success of a robust cellulosic bioenergy business. It is difficult to assess this project through this presentation, however, because we now know that FCIC work has been completely refocused in approach although how and why this happened is not entirely clear. Therefore, the FCIC's overarching goal was not attained. The original progress of the FCIC technology area would suggest that the program very likely would have been successful. The goals as set out in this presentation were achieved, and individual program goals were achieved for the most part. Therefore, it is difficult to reconcile the two positions, whether they were successful or not.

- The consortium is a good way to organize industry and national laboratories, and this one seems to be doing that well, with lots of cooperation and contribution from members.

- Engaging industry that is attempting to implement biotechnologies provides key feedback concerning their problems and concerns. The concept of addressing the cross-biomass conversion operability problems because of feedstock variability addresses a major issue that had previously received little attention. Many biorefineries have failed because of problems related to feed handling. It is difficult for people developing new technologies to address these issues. This project is the first concentrated effort to apply a manufacturing science approach to biofuel production. Some high-quality projects with commercial groups were launched by the project team. These industry-driven projects will help keep the FCIC relevant.

## RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We appreciate the support for this work from the reviewer's comments. We agree that a great outcome from this work would be to develop feedstock specifications and ranges of material and chemical properties that would be acceptable and beyond those ranges would be detrimental to throughput and conversion. We will work toward approaching feedstock quality metrics to help guide current and future use of lignocellulosic feedstocks in a biorefinery. Blended and pelleted feedstocks were not evaluated within the current FCIC projects; the related pellet studies are funded under the FSL Program and the FCIC's industrial collaborative research. We will leverage those research results in the future for analysis of reliability specifications.

- We thank this reviewer's acknowledgement of how difficult and complex managing a multi-laboratory consortium is. Much of the first-year accomplishments resulted in newfound collaborations among national laboratories and team formation. The first-year objectives were met as we demonstrated a high- and low-temperature experimental and modeled baseline. We also set up research teams and reviewed and funded the directed funding opportunities to foster industry-national laboratory collaborative projects. These successes will be built upon in the next iteration of the FCIC.

# PROCESS INTEGRATION – NREL

## National Renewable Energy Laboratory

### PROJECT DESCRIPTION

| | |
|---|---|
| WBS: | 2.2.1.502 |
| CID: | NL0033394 |
| Principal Investigator: | Dr. Ed Wolfrum |
| Period of Performance: | 10/1/2017–9/30/2020 |
| Total DOE Funding: | $7,422,970 |
| DOE Funding FY16: | $1,275,000 |
| DOE Funding FY17: | $871,970 |
| DOE Funding FY18: | $5,276,000 |
| DOE Funding FY19: | $0 |
| Project Status: | Sunsetting |

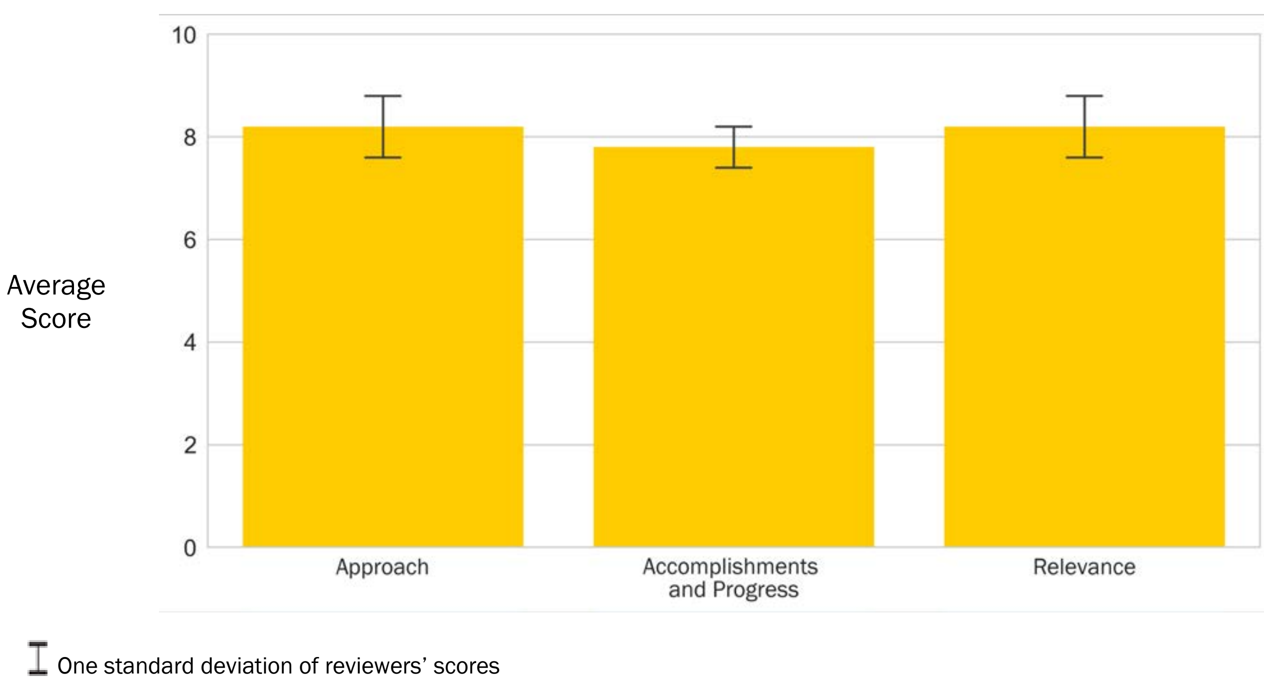
The Process Integration project is part of the FCIC, an integrated and collaborative network of eight national laboratories (ANL, INL, LANL, LBNL, NREL, ORNL, PNNL, and SNL) dedicated to identifying and addressing the impacts of feedstock variability—chemical, physical, and mechanical—on biomass preprocessing and conversion equipment and system performance to move toward a target of 90% operational reliability. In FY 2018, the Process Integration project supported this overall FCIC goal of improving operational reliability and conversion performance of low-temperature and high-temperature integrated processes through laboratory and process-relevant experiments to document and mitigate the negative effects of feedstock variability.

The key objective of the Process Integration project in FY 2018 was to execute robust, industrially relevant baseline experiments that document process reliability and conversion performance across biomass preprocessing and both low- and high-temperature conversion performance

Because this project encompasses a substantial portion of the feedstock logistics and conversion value chain, it addresses a number of Multi-Year Plan (MYP) barriers: Ft-E: Terrestrial Feedstock Quality, Monitoring, and Impact on Conversion Performance; Ft-G: Biomass Physical State Alteration; Ft-I: Overall Integration and

### Weighted Project Score: 8.0

Weighting for Sunsetting Projects: Approach-25%; Accomplishments and Progress-50%; Relevance-25%



Scale-Up; Ct-A: Feedstock Variability; Ct-C: Efficient Preprocessing; Ct-D: Efficient Pretreatment; Ct-I: Product Finishing Acceptability and Performance; and Ct-J: Process Integration.

## OVERALL IMPRESSIONS

- The work done makes good use of the strengths of the two national laboratories and was performed with a high degree of consistency.
- Benchmarking is a key activity of scale-up, thus the baselining of 2016 SOT variance performance was absolutely a key activity, especially because such work in the national laboratories had not been executed to date. The project demonstrated several operational challenges also seen at pioneer plants and underscored the importance of the identification and quantification of process variation (as seen through uptime/capacity).
- Use of wear-sensitive equipment in portions of the process introduced some additional levels of variation that make it difficult to parse out the impact of the feedstock quality against equipment performance. In any future benchmarking runs such as was conducted here, it would be advisable to implement a well-defined feedstock control (i.e., cellulose powder) that can be run before and after each case to establish the "plant health" to decouple from the feedstock itself. It would also be advantageous to run more than one run of each feedstock if time and budget allow.
- This project was well managed and thorough. It would be wonderful if every project could have such extensive work done to improve operations. It would be useful to target other feedstock characteristics as well as downstream processing.
- This project is a solid contributor to the FCIC team and developed significant data, but more detail on the conclusions or summary is needed. For example, the presentation makes the conclusion that some sources of variability in biomass cannot be controlled. In a presentation of findings, a list of those would seem to be a necessity. But overall, this is good work that I am sure informed the decision-making process in the new FCIC move toward the quality by design as seen in future work for FCIC.
- The process integration project provided the operational data for use in the other FCIC programs, including pretreatment and conversion. It was the first attempt to obtain controlled data on the integrated operation of all the unit operations of the process and as such provides unique data for use by the remainder of the groups. The data collected on operability, including the number of times human intervention was required, is particularly useful information about equipment reliability. The development of a rapid way to predict wear will be a great assistance to engineers selecting the material of construction.

## RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We thank the reviewers for their comments. This project was challenging because it was split across two laboratories (INL, NREL) for the actual experimental baseline runs, with work at two other laboratories for the equipment wear portion (ORNL, ANL). It was as rewarding as it was challenging, however.
- We agree that the lack of a "feedstock control" will make the information collected harder to interpret. We will consider options to add such a control in future benchmarking experiments. We also agree that multiple runs of each feedstock would have provided additional information, but we were limited by time and budget. In the end, we chose to perform single runs on multiple feedstocks rather than repeated runs on a single feedstock.
- We appreciate the reviewer's comments on the project management. We had very strong teams, which simplifies project management.

- We agree that more detail should have been included; the milestone reports we submitted in FY 2018 were quite detailed, but this level of information was not presented in the presentation because of time constraints. We stated that "biomass is variable, and many sources of variability cannot be controlled" on Slide 31. That was imprecise, however. We should have said that upstream processes (harvesting/storage/transport) can result in significant variability that the preprocessing and conversion processes cannot predict and must be able to address. In future years, the FCIC will be looking upstream from first-stage deconstruction to understand the source(s) and effect(s) of this variability and developing science-based solutions to the problems caused by this variability.
- We are pleased that the reviewers found our results to be valuable, both the operability and the conversion data. We believe they are already helping to inform work in the FCIC in FY 2019.

# PROCESS CONTROLS AND OPTIMIZATION – INL

## Idaho National Laboratory

### PROJECT DESCRIPTION

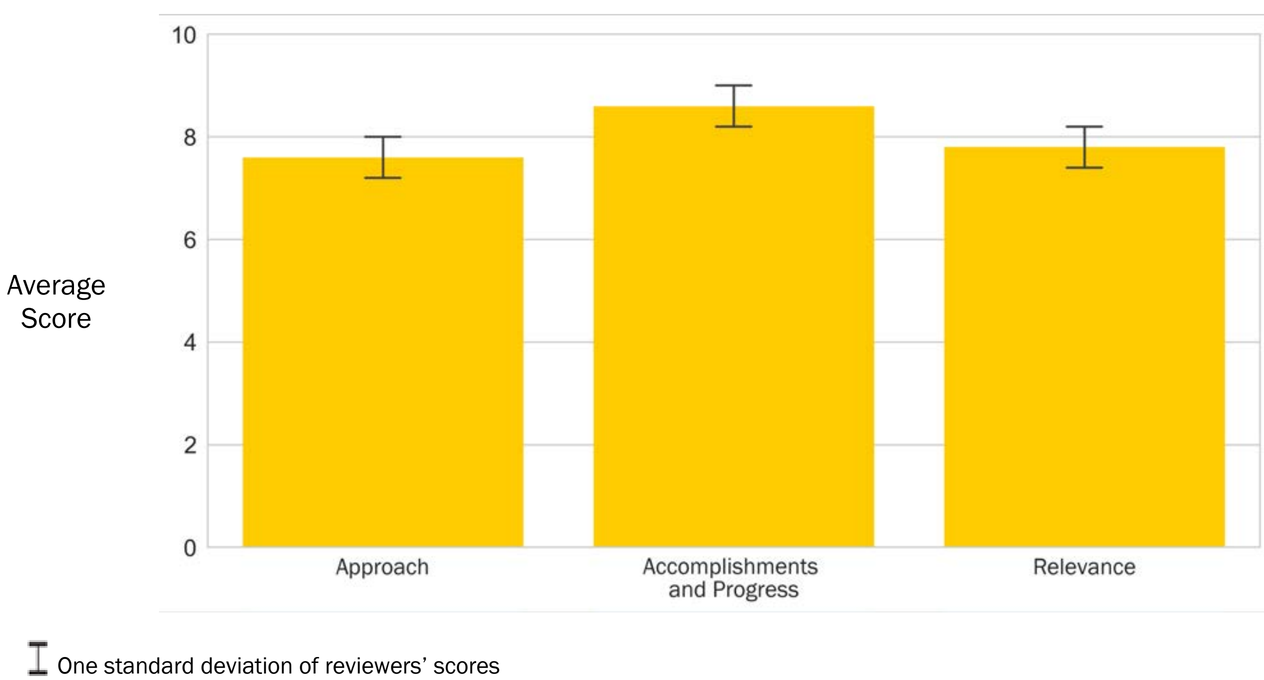
| | |
|---|---|
| WBS: | 3.3.1.101 |
| CID: | NL0033726 |
| Principal Investigator: | Dr. Quang Nguyen |
| Period of Performance: | 10/1/2017–9/30/2020 |
| Total DOE Funding: | $1,896,300 |
| DOE Funding FY16: | $0 |
| DOE Funding FY17: | $0 |
| DOE Funding FY18: | $1,896,300 |
| DOE Funding FY19: | $0 |
| Project Status: | Sunsetting |

The Process Controls and Optimization project studied the impact of biomass properties on the performance of preprocessing and primary deconstruction process and equipment and developed strategies and methods to achieve greater than 90% operational reliability while meeting the specifications of feedstock quality. The Process Controls and Optimization project is part of the FCIC, an integrated and collaborative network of eight national laboratories: ANL, INL, LANL, LBNL, NREL, ORNL, PNNL, and SNL.

For IBRs to achieve reliable process operability through feed handling, preprocessing, and conversion operations, it is essential to control processing equipment to accommodate a wide range of feedstock properties that affect the operation of the equipment. These properties include moisture content, ash content, fiber integrity, and particle size distribution. The project focused on the development and application of in-line sensors and adaptive control systems that enable reliable operation of feedstock preprocessing equipment as well as low-temperature and high-temperature primary deconstruction operations while maintaining downstream conversion performance with wide-ranging feedstock properties.

Weighted Project Score: 8.2

Weighting for Sunsetting Projects: Approach-25%; Accomplishments and Progress-50%; Relevance-25%



The project successfully demonstrated that an autonomous adaptive control system achieved 90% operational reliability for the two-stage grinding of baled corn stover. The study of comprehensive FCIC project data from the baseline runs yielded correlations among parameters collected across laboratories, including:

- Physical properties for input biomass materials
- Process control data collected from preprocessing along with low- and high-temperature conversion
- Properties and conversion yields of output materials from those same processes.

*Photo courtesy of Idaho National Laboratory*

## OVERALL IMPRESSIONS

- The demonstration of a method for increasing the uptime of the front end of the biomass process was a valuable approach to supporting pioneer plants struggling with grinder uptime. The implementation of advanced control methods and instrumentation allowed for the project team to not only address downtime issues but also develop a practical method of online compositional analysis to further guide plant operations. The reviewer recognizes the successful approach of adaptive control to solve the particular issue with the INL scale and setup, but benchmarking the solution against other alternative approaches (i.e., bale full/partial rejection, oversizing of grinding) might have further increased the industrial value/relevance of the work.

- The key findings that further input homogenization of bales and practical capacity limits to the grinding operation are both relevant for industry and should be considered by equipment suppliers. The scalability of the INL system will be a secondary activity to realize the full impact of the project work.
- This project appeared to be hugely successful in meeting its objectives. It is easy to see how the results could be applied to commercial applications. Good project execution appeared to yield excellent results.
- The PIs developed a robust autonomous feed-forward operating system, and such systems are relevant for successful bioeconomy projects. They were successful in obtaining solid data about the impacts of feedstock variability on equipment performance. This is a sunsetting project but will provide good baseline information to inform the new FCIC activities in this area of work and continue the progress this work represented.
- I believe that controls are a critical part of the FCIC, and the work here has done much to show its value overall to reducing material variability impacts.
- Process control and optimization provides key tools improving the throughput of biofuel production. The project was conducted using a sound approach the impact on biofuel product seems to be limited to providing proof of the performance of in-line sensors with an adaptive control loop for a single piece of equipment. It is a good example, however, of how adaptive control can predict operational problems before they happen and adjust the parameters to prevent shutdowns. The model developed illustrates the impact of feed variability and control methods on yields and operability and how focusing on a single unit can produce significant improvements. It is not clear, however, whether the specific results will be widely transferable.

## RECIPIENT RESPONSE TO REVIEWER COMMENTS

- We agree with the reviewer's comment regarding benchmarking the use of the adaptive control system to maintain the equipment online against alternative approaches of rejecting off-specification bales (e.g., high moisture) or oversizing the equipment because these latter methods result in high biomass loss and increased capital and operating costs.
- We appreciate the reviewer's comment. We expect that additional work in developing an adaptive control system will be required for new unit operations and equipment as the FCIC 2.0 R&D activities progress.
- We appreciate the reviewer's comment. We believe that having the adaptive control system will allow the avoidance of downtime and, possibly, the need for additional processing steps.
- The adaptive control logics should be applicable to most, if not all, biomass preprocessing systems as well as downstream unit operations. The specific results are applicable to the equipment studied (hammermill, screw conveyors). Different equipment will have different performance characteristics. For example, moisture content of biomass has less impact on the capacity of rotary shear devices than hammermill.

# FCIC OVERVIEW PRESENTATION

## Feedstock-Conversion Interface Consortium

### PROJECT DESCRIPTION

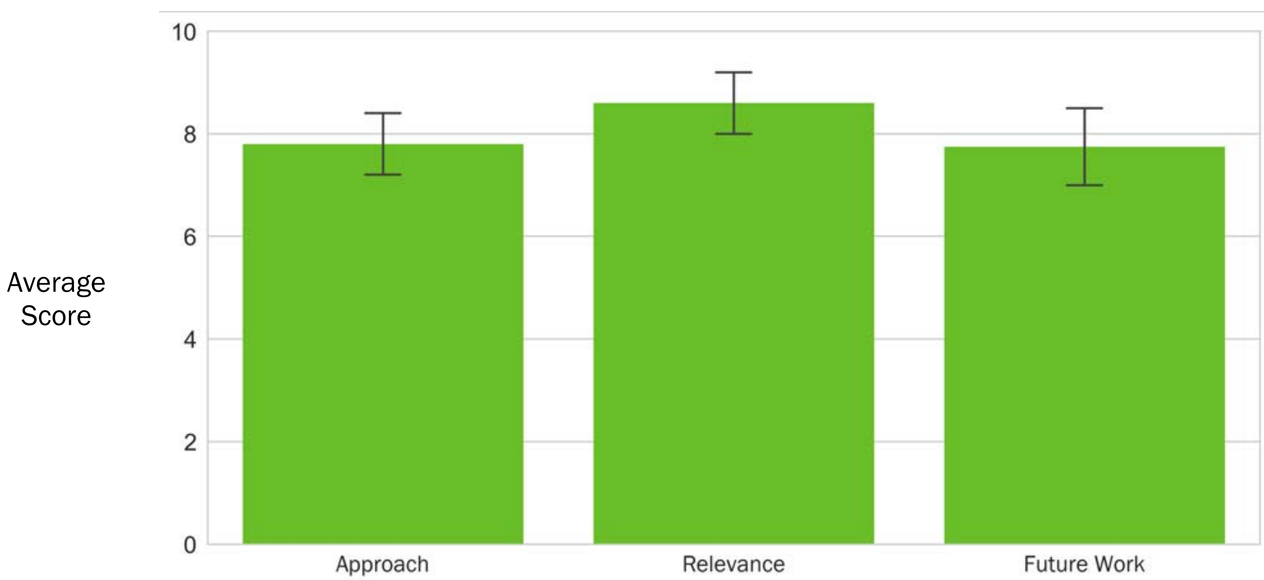
| | |
|---|---|
| WBS: | FCIC.1 |
| CID: | NL00FCIC1 |
| Principal Investigator: | Dr. Michael Resch |
| Period of Performance: | 10/1/2017–9/30/2019 |
| Total DOE Funding: | N/A |
| DOE Funding FY16: | N/A |
| DOE Funding FY17: | N/A |
| DOE Funding FY18: | N/A |
| DOE Funding FY19: | N/A |
| Project Status: | New |

Many of the serious bottlenecks being experienced in the nascent bioenergy industry are centered on feedstock handling and preprocessing operations. Further, these bottlenecks directly affect the process of feeding feedstocks into the conversion process, conversion equipment operation, and process integration. The complexity and variability in feedstock physical, chemical, and mechanical attributes directly relate to the operational difficulties encountered with handling the elastic solid materials, the recalcitrance of feedstocks to efficiently convert into products, and the inhomogeneity of intermediates resulting in nonuniform conversion. All these issues tend to occur where the feedstock supply system couples with the conversion process, referred to as the feedstock-conversion interface. These issues are then largely responsible for the problematic operation of the integrated biorefineries. This is a big, complex problem that requires robust solutions involving extensive testing and R&D.

because of the increasing importance of these issues, the existing feedstock-conversion related efforts are being organized into a FCIC, which became fully integrated and functional in FY 2018. This consortium is funded by the three BETO programs: FSL), Conversion, and ADO. The FCIC goals are to identify and address the impacts feedstock chemical, mechanical, and physical variability have on supply logistics, storage handling, preprocessing, conversion equipment operation, and process integration to develop and demonstrate improved

Weighted Project Score: 8.0

Weighting for New Projects: Approach-25%; Relevance-25%; Future Work-50%




One standard deviation of reviewers' scores

integrated feedstock conversion. The DOE national laboratories possess unique and differentiated capabilities in biomass characterization, preprocessing of various biomass into on-specification feedstocks, high- and low-temperature conversion technologies, physical and mechanical modeling, and integrated analysis of economic and sustainable impacts. All these capabilities will be leveraged to establish a consortium that surpasses what an individual laboratory can deliver. The FCIC consists of six projects with an integrated and collaborative network of eight national laboratories (ANL, INL, LANL, LBNL, NREL, ORNL, PNNL, and SNL). The FCIC R&D efforts are focused on five primary areas: (1) Feedstock Variability and Specification Development, (2) Feedstock Physical Performance Modeling, (3) Process Integration, (4) System-wide Throughput Analysis, and (5) Process Controls and Optimization, with a sixth area related to industry engagement and project management.

The reliability issues addressed by the FCIC projects are significant barriers to the growth and success of the biofuel industry. The FCIC was set up to develop scientific knowledge and solutions needed to overcome these barriers and will work with industry to translate FCIC outputs to industry operations. Meeting the FCIC goals will lead to consistently functioning biorefineries, improved profitability, and increased investment and use of the billion tons of available biomass resources. This presentation provides an overview and scope of the consortium and highlights the interactions among the five R&D projects.

## OVERALL IMPRESSIONS

- The FCIC has been valuable to validate main feedstock factors facing pioneer plant operations through a comprehensive approach of characterization, modeling, and demonstration. Use of the full breadth of the national laboratories through higher levels of inter-laboratory coordination has been useful to leverage unique knowledge and skill sets available within the greater national laboratory network that longer term will create increased value to taxpayers. BETO should continue to look for industry roadblocks where the consortium (and inclusion of IABs) can have this kind of positive impact within such a short development cycle.

- The FCIC consortium and funding are correctly targeted at a key factor that has prevented biofuel refineries from achieving the target performance predicted by the laboratory experiments. The lack of consistent feedstocks and equipment reliability have been the reasons for failure on many projects and have suppressed interest by investors in the bioeconomy. It is difficult for groups attempting to commercialize biorefineries to perform this type of basic research. Any work providing high-quality data in this area is critical to future success. The work this year was to establish baseline information that will be useful for future work. The projects from this year are not being renewed, except for the annual operating plan projects with industry partners. The FCIC area is being refocused on a more fundamental approach. I believe that the 2017 projects were all worthwhile, however, and would have provided results that would have helped many biotechnology developers. One limitation was the focus on a limited range of processes and conditions. The planned refocusing on fundamentals might provide information with a wider impact.

## RECIPIENT RESPONSE TO REVIEWER COMMENTS

The recipient choose not to respond to the reviewers’ overall impressions of their project.

# FCIC FY 2019 AND BEYOND PLANS

## Feedstock-Conversion Interface Consortium

### PROJECT DESCRIPTION

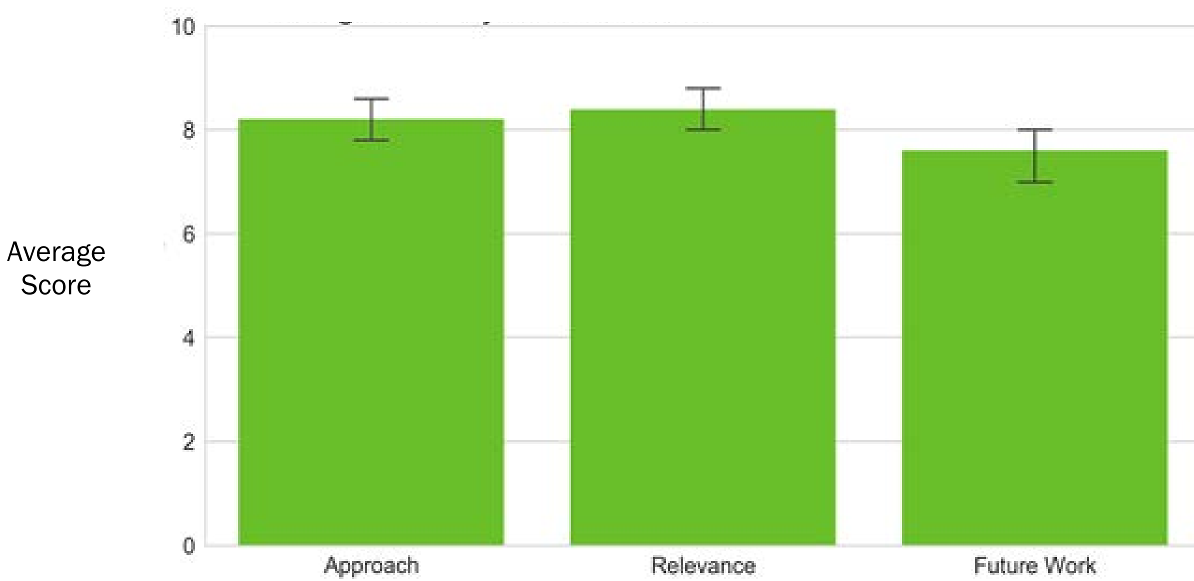
| | |
|---|---|
| WBS: | FCIC.2 |
| CID: | NL00FCIC2 |
| Principal Investigator: | Dr. Zia Abdullah |
| Period of Performance: | 10/1/2018–9/30/2020 |
| Total DOE Funding: | $9,000,000 |
| DOE Funding FY16: | $0 |
| DOE Funding FY17: | $0 |
| DOE Funding FY18: | $0 |
| DOE Funding FY19: | $9,000,000 |
| Project Status: | New |

Many of the process bottlenecks and difficulties experienced in the nascent bioenergy industry are centered on feedstock handling and preprocessing operations, the process of feeding feedstocks into the conversion process, conversion equipment operation, and process integration. These specific issues—including the complexity and variability in feedstock dimensional, physical, chemical, and mechanical attributes; the operational difficulties encountered with handling solids; recalcitrance of feedstocks to be efficiently converted into fuels and products; and inhomogeneity of intermediates resulting in nonuniform conversion—all mostly occur where the feedstock supply system couples with the conversion process. This is referred to as the feedstock-conversion interface, and this is where problematic operation of the integrated biorefineries is experienced. To address this, the FCIC was formed, leveraging core capabilities at ANL, SNL, LANL, LBNL, INL, NREL, ORNL, and PNNL.

Presently, biorefineries are designed and built by firms that have engineered equipment mostly for the mature agricultural and pulp and paper industries, where the processes are well understood. The approach used for mature industries is usually incremental, and it is not suitable for new industries, where the physics of conversion processes, the impact of feedstock variability, and scale-up rules are not well understood.

Weighted Project Score: 8.0

Weighting for New Projects: Approach-25%; Relevance-25%; Future Work-50%




One standard deviation of reviewers' scores

A key hypothesis underlying FCIC's framework is that poor quantification, understanding, and management of variability in biorefinery streams contributes significantly to the inability of biorefineries to operate continuously and profitability. To address this problem, the FCIC will employ the quality-by-design approach originated by the pharmaceutical industry to manage variability in process streams in a very disciplined manner.

The objectives of the FCIC are to:

1. Develop knowledge and tools that will help technology developers so that with improved design, as well as process specifications, a greater number (~70%) of biorefineries will succeed through startup and continuous operation.
2. Develop a framework through which technology developers will be able to assess the quality and value of various streams in their processes for the purpose of using that valuation to make decisions to achieve Objective 1.

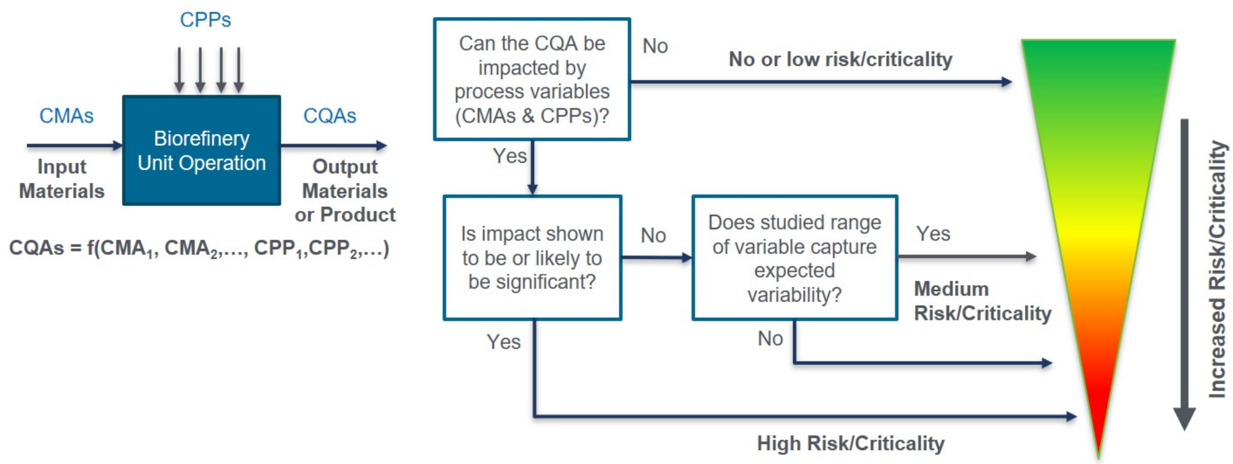



*Photo courtesy of Feedstock-Conversion Interface Consortium*

## OVERALL IMPRESSIONS

- Future FCIC efforts to scale down integrated processes by developing transfer functions between unit operations is a good approach to not only better understanding each block but also allowing for easier assimilation of local process developments into holistic process operation. It would be good to create some visualization/training on how these would be used by equipment manufacturers so that those who are not familiar with the method would be able to use the results and hence also provide relevant feedback to the projects.
- The 500-hour integrated run goal is a good way to establish validity of both the development methodology as well as the actual process improvements; however, only a 70% success rate is not, so what that means to industry/investors needs to be clarified.
- This FCIC FY 2019 proposal is a major improvement over the 2018 plan. It includes more specific milestones and objects. It describes a new overall approach based on focusing on fundamentals and the quality-by-design approach. The critical success factors are clearly identified. The FCIC has the potential to greatly impact the biomass-to-fuel and renewable chemicals process by addressing an area that has been neglected in the past. It would be useful if the impact on improvements related to the FCIC program could be estimated. What is the sensitivity of throughput on the price of the product? Most continuous chemical technologies assume a 90% operational uptime. How much was conversion improved by monitoring feedstock quality? One concern is that the use of a pharmaceutical approach for

a low-margin, high-capital process might not be a good fit. What is the effect on feedstock costs? The TEA analysis is critical and needs to be considered in all the project work.

- There is much to like in this presentation of the reboot and rethinking of the approach of the FCIC; however, the central piece to this plan being the adoption of the quality-by-design product development approach used in the pharmaceutical industry might prove to be both the strength and weakness of the project. Only time will tell. We will learn a great deal by using this design philosophy to produce commodity fuels and chemicals instead of medicine. I do believe that there needs to be rigorous controls in place to not slip into making designer biomass feedstocks. Trying to reduce variability could easily lead one down that path.

- The new approach outlined will be a good new perspective, but much of the actual work will remain similar to before. I like the focus on making sure first principles are mostly used and that the product quality defines the design.

## RECIPIENT RESPONSE TO REVIEWER COMMENTS

- Thank you for the suggestion to create a visualization-based training tool. This is a good idea, and we will explore opportunities for implementation.

- The success rate of 70% was chosen as an aspirational goal to acknowledge the significant challenges that face biorefineries. We agree that this will be very difficult to measure but hope that this will inspire our research teams to make great strides to improve the success rate. By significantly improving the success rate, we will identify the largest impacts on failure and focus on further increment improvements in the future.

- Thank you for the feedback. We plan to conduct extensive TEA and use the results to guide research priorities, the impact of performance improvements, as well as uptime.

- Task 8 will include TEA activities for the key areas of preprocessing, low-temperature conversion, and high-temperature conversion. We recognize that constraining downstream critical material attributes (CMAs) too tightly will simply result in shifting apparent costs upstream, so Task 8 includes the development of process-wide TEAs to minimize costs at the system level.

- We also appreciate the relative insensitivity of the pharmaceutical approach to cost and will strive to adjust our approach to high-capital, low-margin processes.

- Thank you for the feedback. We plan to conduct extensive TEA and believe that this will enable us to focus on improving the conversion processes.

- Because we will be constrained by the final product cost targets, the TEA will prevent us from defaulting to the solution of “designer feedstock,” which will tend to be too expensive to allow us to meet those product cost targets.