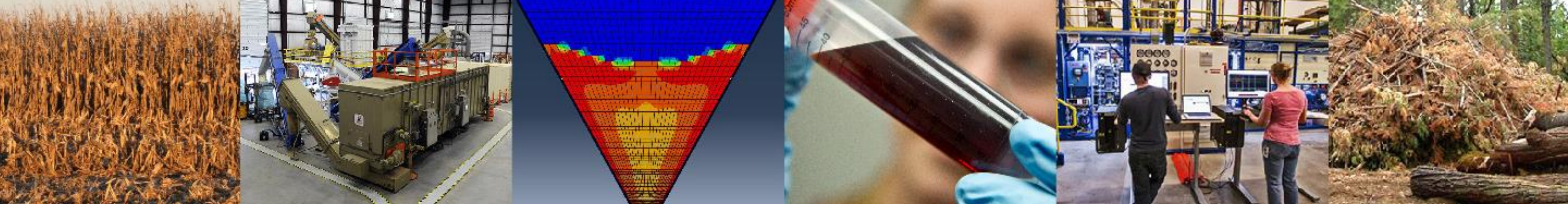


DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

Crosscutting Analyses

March 16, 2021
Feedstock Conversion Interface Consortium

Steven Phillips & Erin Webb
Pacific Northwest National Laboratory
Oak Ridge National Laboratory

This presentation does not contain any proprietary, confidential, or otherwise restricted information

fcic
FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

FCIC Task Organization

FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

Feedstock → **Preprocessing** → **Conversion**

Feedstock Variability:
Develop tools that quantify & **understand the sources of biomass resource and feedstock variability**

Preprocessing:
Develop tools to enable technologies that **provide well-defined and homogeneous feedstock** from variable biomass resources

Conversion (High & Low-Temperature Pathways):
Develop tools to enable technologies that **produce homogeneous intermediates** that can be converted into market-ready products

Materials Handling:
Develop tools that enable continuous, steady, trouble free feed into reactors

Materials of Construction:
Develop tools that **specify materials** that do not corrode, wear, or break at unacceptable rates.

Enabling Tasks

Data Integration: Ensure the data generated in the FCIC are **curated and stored** – FAIR guidelines

Crosscutting Analyses TEA/LCA:
Works with other Tasks to **enable valuation** of intermediate streams and quantify impacts of variability.

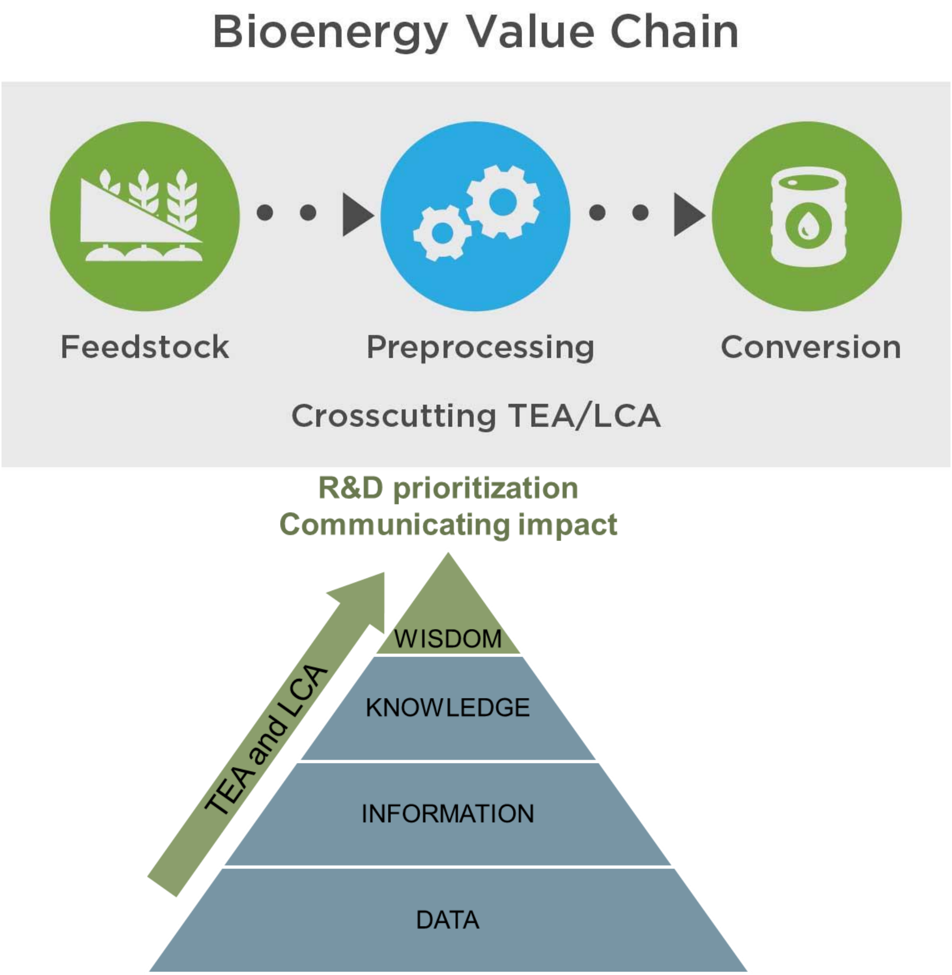
Project Overview

- **Objective:** Quantify and communicate industrially relevant, system-level costs and environmental impacts for the discoveries and innovations of the FCIC. ***How does feedstock variability affect economics and sustainability metrics throughout the biomass-to-fuel value chain****?*

- **Current limitations:** Commonly used TEA/LCA approaches focus on system optimization of steady-state processes and **do not account for impacts of dynamic variability** in feedstock streams.

- **Relevance: Provide cost and quality information to biorefinery owners and operators** needed for preliminary business analyses to accelerate progress along the technology learning curve from pioneer plants to a mature biorefinery industry.

- **Risks:** Delays in **data availability**; **scale-up assumptions** not representative; **equipment manufacturing cost data availability**



The Crosscutting Analyses task collaborates across the FCIC to integrate data and process information to improve understanding of the impacts of feedstock variability on the biorefinery value chain leading to better-informed decisions.

1 – Management

Subtask	Lead(s)	Major Responsibilities
8.1	Erin Webb (ORNL)	Feedstock Supply
8.2	David Thompson (INL) Damon Hartley (INL)	Preprocessing
8.3	Matt Wiatrowski (NREL) Steven Phillips (PNNL)	High Temperature Conversion
8.4	Ryan Davis (NREL)	Low Temperature Conversion
8.5	Hao Cai (ANL)	Life Cycle Assessments

- **Risks and mitigation strategies**
  - Delays in data availability: Assemble data from multiple sources; exhaustive sensitivity analyses to characterize impact of parameter uncertainty
  - Scale-up assumptions not representative: Seek insight and review from industry stakeholders
- **Communication strategy**
  - Within task – Biweekly team meetings
  - With other tasks – Each subtask liaises with another FCIC task for their respective part of the value chain
  - External – Active engagement with FCIC IAB, presentations at technical conferences (AIChE, ASABE), journal manuscripts (academic and trade publications)

Task 8 consists of staff from 5 national labs across four time zones. We also interact with all other (8) FCIC tasks, the IAB and BETO Tech. Mgrs. Frequent meetings are required to coordinate efforts and communicate results.

2 – Approach

Technical Approach

- Incorporate data from FCIC experimental and fundamental modeling efforts to develop algorithms for predicting cost and environmental impacts of variable biomass quality
- Innovative use of biomass supply chain, preprocessing, and conversion system models developed in previous core BETO projects to predict operational impacts of variability
- An FCIC-wide integrated approach will be used to translate the impacts of feedstock variability and the cost-benefit tradeoffs of mitigation strategies into existing TEA/LCA models from process, economic and sustainability perspectives

Challenges: Our existing systems models were designed to identify an optimal system configuration. We are adapting them to 1) simulate impacts of dynamic changes in feedstock quality and 2) characterize the range of performance metrics for an expected range of critical feedstock characteristics.

Metrics: By end of project, complete at least 18 TEA/LCA case studies from along the value chain (feedstock supply, preprocessing, conversion) for stover and pine residues pathways, collectively.

Our approach is to use data-driven case studies to guide technoeconomic and sustainability analyses designed to valorize the strategies proposed to minimize the impacts of dynamic feedstock variability.

3 – Impact

Impact

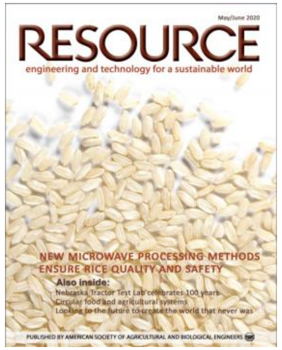
This project provides cost-benefit TEA and LCA focused on impacts of feedstock variability on yields, economics, and environmental sustainability to aid biorefinery engineers and equipment manufacturers conducting feasibility studies of proposed equipment and process design modifications.

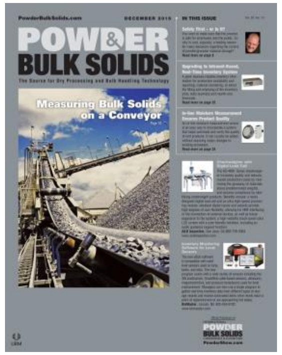
Conventional TEA/LCA – Assumes typical quality parameters for identifying optimal system designs

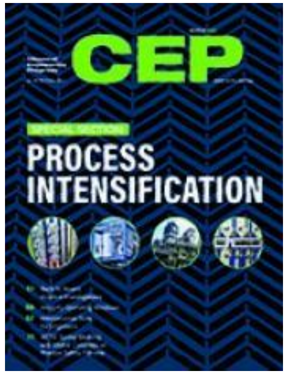
FCIC TEA/LCA –System simulations accounting for dynamic changes in feedstock quality characteristics

Dissemination

- Regularly present analysis results to FCIC IAB
- Presentations at technical conferences selected to represent stakeholders along the value chain

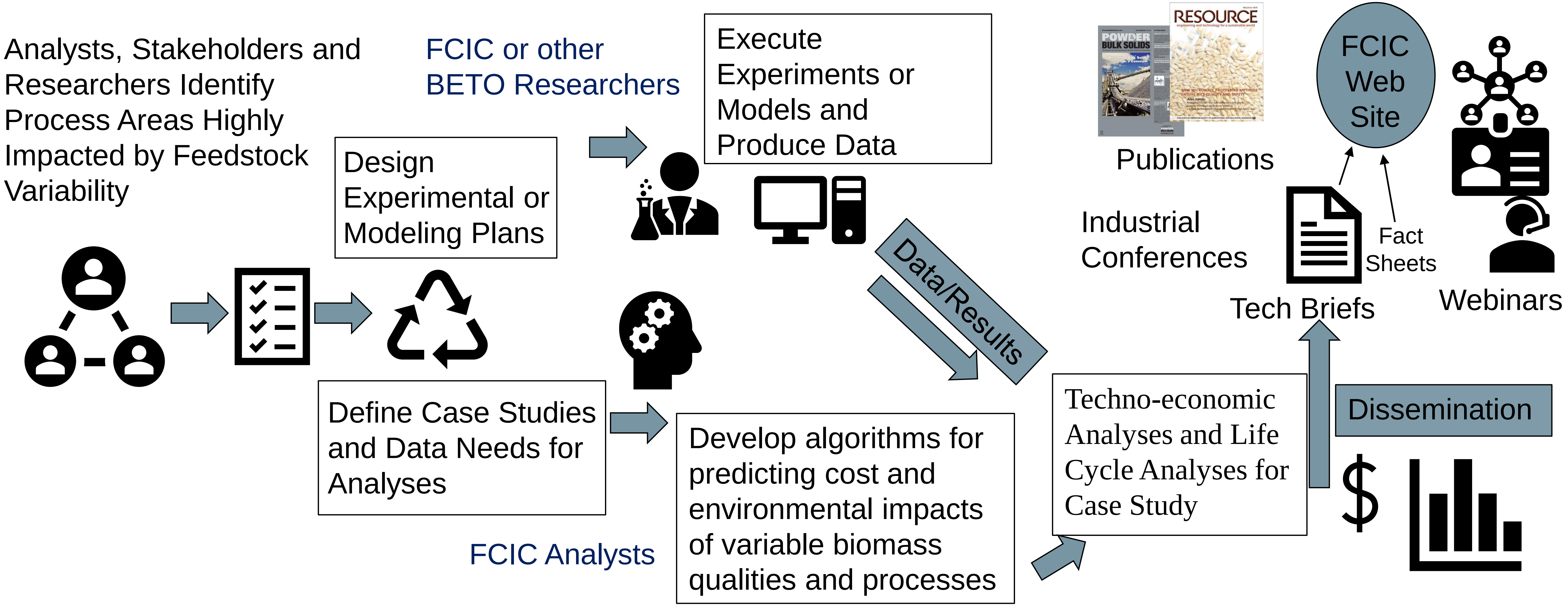




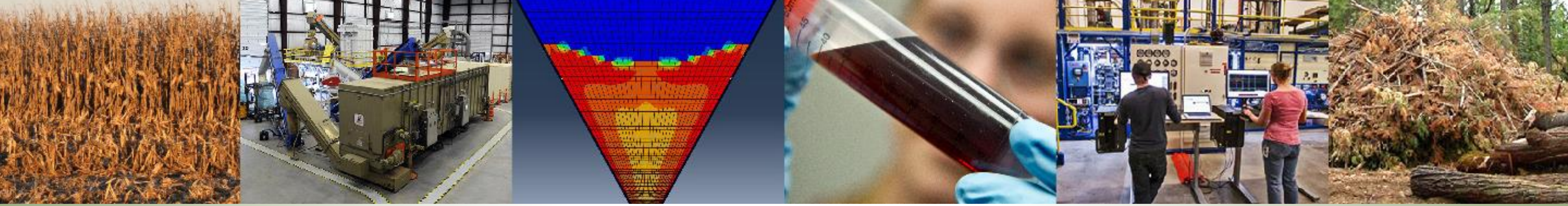


The impact of our analysis results and the knowledge gained about cost and sustainability impacts of feedstock variability mitigation depends wholly on successful dissemination through various mediums to a wide range of audiences from across the biorefinery community.

2 – Case Study Approach Overview



The Case Study framework focuses TEA/LCA on small sections of the value chain that can be completed in relatively short time permitting more targeted, in-depth studies to be completed from across the value chain. Results dissemination critical!



4 – Progress and Outcomes

FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

FCIC Task 8 Case Studies for FY21

Pathway: Catalytic Fast Pyrolysis of Pine Residues

In Progress

LCA: *Life Cycle Analysis of pine tree age*

Feedstock Supply: *Impact of tree age on pine residue collection*

LCA: *Life Cycle Analysis of pine residue fractionation technologies*

LCA: *Energy requirement of particle size and moisture reduction for pine residues*

Preprocessing: *Value proposition of coatings or new alloys on knife wear*

Preprocessing: *Air-classification of pine residue for tissue and ash separation efficiency*

Conversion: *Forest residue tree age and impact on CFP conversion (precommercial thinning vs. pulpwood residues)*

Conversion: *Impact of air-classified feedstock on MFSP and fuel yield*

Feedstock → **Preprocessing** → **Conversion**

Complete

Feedstock Supply: *TEA of anatomical fractionation of pine residues at the landing*

Preprocessing: *Particle scale impacts on deconstruction energy*

LCA: *Dynamic LCA of interactions between feedstock variability and fast pyrolysis conversion*

Conversion: *Fast pyrolysis product yields from particle-level modeling*

Additional information available in supplemental slides – Completed Case Studies

FCIC Task 8 Case Studies for FY21

Pathway: Catalytic Fast Pyrolysis of Pine Residues

LCA: *Life Cycle Analysis of pine tree*
age

In Process

Supplying a higher-quality feedstock by delivering delimbed tops only vs. all portions of treetops increased per ton costs 21%. Additional study needed for cost offsets from quality benefits.

Hammer milling pine feed wet (e.g. – "as delivered") then drying had significantly lower production costs vs. a drying-then-milling approach due to decreased fines production and overall energy savings

esidue fractionation technologies

ize and

dues

Variability in mineral matter content (e.g., ash) in the feed to the pyrolysis reactor accounts for ~99% of the MFSP variability due to impacts on conversion.

Complete

Feedstock Supply: *TEA of*

le scale
ion energy

interactions
ability and fast

Conversion: *Fast pyrolysis product yields from particle-level modeling*

Four case studies were completed for CFP pathway in FY21 Q1. Another eight case studies are planned for Q2 and Q3. (4 of 12 completed for CFP pathway). Studies are leading to new insights about feedstock handling and processing.

FCIC Task 8 Case Studies for FY21
Pathway: DMR/EH of Corn Stover

In Progress

Feedstock Supply: *Anatomical fractionation of corn stover*

Preprocessing: *(1) Stover air-classification for anatomical fractionation and (2) Forest Concepts Crumbler vs. hammer mill with stover anatomical fractions at 3 moistures (10% to 30%)*

Preprocessing: *Value proposition of coatings or new alloys on knife wear*

Conversion: *Pretreatment CPP conditions to process biomass over various states of degradation*

Conversion: *Sugar/lignin fermentation dependence on CMAs imparted from upstream processing*

Feedstock → **Preprocessing** → **Conversion**

Complete

Feedstock Supply: *TEA of corn stover storage options considering variable degradation within bale stacks*

Preprocessing: *Value proposition of coatings or new alloys on hammer wear*

Preprocessing: *Impact of anatomical fractionation on hammer milling throughput and energy consumption at 3 moistures*

Conversion: *Biomass deconstruction (DMR/EH) + fermentation performance based on isolated anatomical fractions*

Additional information available in supplemental slides – Completed Case Studies

FCIC Task 8 Case Studies for FY21
Pathway: DMR/EH of Corn Stover

fcic
FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

In Progress

Preprocessing: *(1) Stover air-classifi... fr... ...nts*

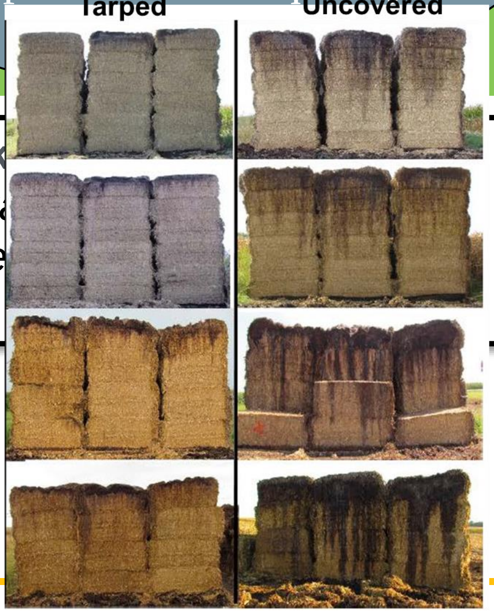
Better, although more expensive storage methods can be justified with only minor improvements in preprocessing costs or improved yields due to improved stover quality

From a production cost perspective, it is more cost effective to hammer mill fractionated corn stover tissues than whole stover. Reduced grinding energy was significant.

Conversion of individual anatomical fractions (cobs, husks, and stalks = 50% of whole) separately vs. whole corn stover showed modest MFSP improvements. Additional study of "other" 50% needed.

Complete

Feedstock *stover stor... variable de... stacks*



Darr et al. *ASABE Annual International Meeting* 2018

Preprocessing: *Value proposition of coatings or new alloys on hammer wear*

Preprocessing: *Impact of anatomical fractionation on hammer milling throughput and energy consumption at 3 moistures*

Conversion: *Biomass deconstruction (DMR/EH) + fermentation performance based on isolated anatomical fractions*

Four case studies were completed for DMR/EH (low temperature) pathway in FY21 Q1. Another five case studies are planned for Q2 and Q3. (4 of 9 completed for DMR/EH pathway). Studies are leading to new insights about feedstock handling and processing.

Additional information available in supplemental slides – Completed Case Studies

TEA of corn stover storage options considering variable degradation within bale stacks

Knowledge

Knowledge Gap

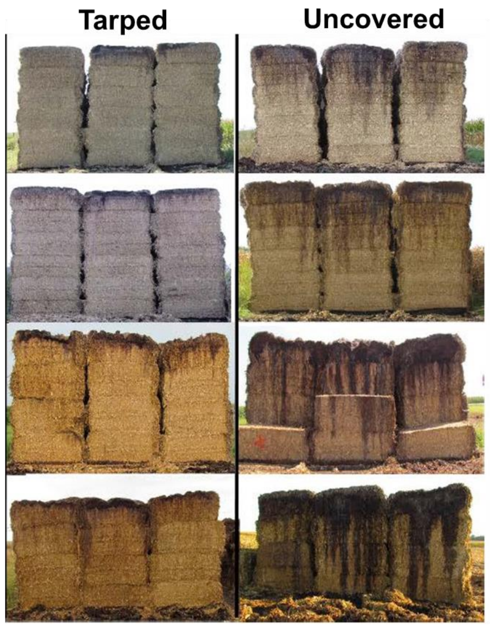
Moisture migration through biomass bale stacks create zones of varying levels of degradation that behave differently in preprocessing and conversion

Achievement

- **Applied knowledge gained in Task 2**, Feedstock Variability, to assign two categories of biomass degradation based on chemical composition, surface characteristics, and dry matter loss
- **Developed a mathematical model of degradation zones within a corn stover bale stack** based on moisture migration over the course of one year
- Corn stover TEA created to **predict fraction of delivered biomass with (1) mild-to-moderate degradation and (2) moderate-to-severe degradation for three storage treatments: uncovered, tarped, and protected**

Relevance

- TEA models using average estimates of losses and composition miss the operational impacts of biomass variability.
- This approach makes it possible to predict the impact of biomass changes during storage on dynamic performance of biorefinery operations.
- Lays the groundwork for modeling impacts of stover preprocessing and conversion with variable degradation levels in incoming feedstock streams (planned for FY21)



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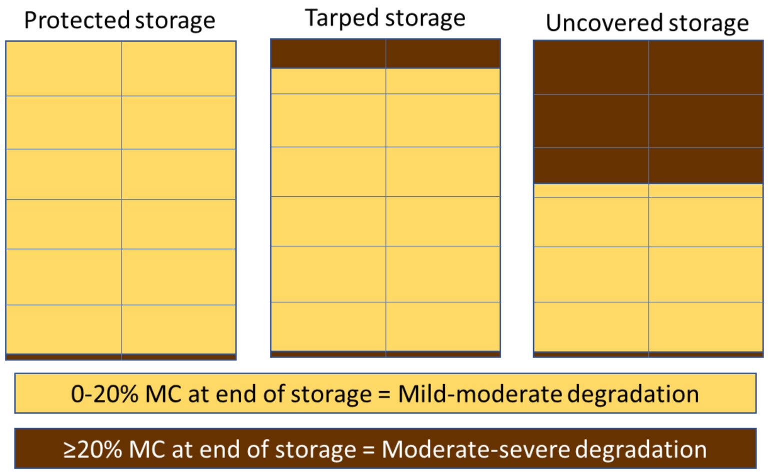
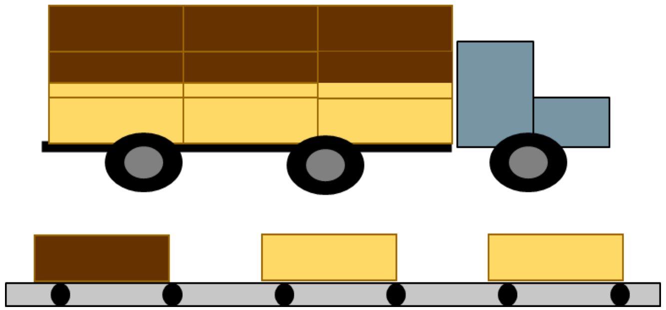


This approach

Categorize fractions of delivered biomass by degradation levels



Other value chain cost reductions will be needed to justify investment in improved storage: Tarped adds $1-2/dry ton and Covered adds ~$10/dry ton to feedstock cost. Example: $10/ton adds $0.3/gge to the MFSP; 2%-pt. increase in carb% offsets it.

MFSP impacts predicted from fast pyrolysis product yields based on particle-level modeling

Knowledge

Knowledge Gap

- TEA impacts of feedstock material attributes and process parameters associated with fast pyrolysis are not well-understood

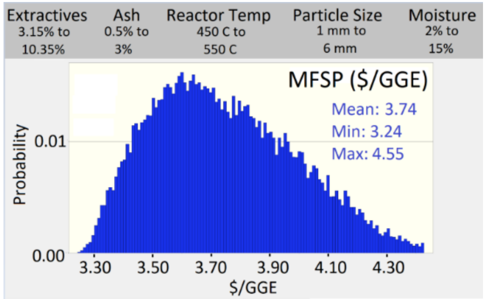
Achievement

- Particle-scale model, validated from literature, was used in combination with multiple linear regression models to develop high-level correlations of each varied parameter linked to fast pyrolysis (FP) oil yield and char yield.
- CFP fuel carbon efficiency and char yield were correlated with MFSP from multiple runs of Aspen model, bridging the gap between particle correlations and MFSP. Empirical correlations derived from experimental information from literature regarding the impact of mineral matter on FP oil yield were also considered.
- Distributions of varied parameters were used in Monte Carlo simulations to understand their impacts on MFSP

Relevance

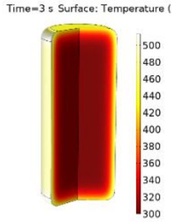
- Correlations can capture impacts of variation in feedstock attributes on the MFSP
- Increase in mineral matter was shown to have the biggest impact, predominantly due to reduced FP oil yield.
- Current correlations are for fast pyrolysis yields; assumes direct correlation between FP oil and CFP fuel yields; future work will establish more detailed linkage; current predictions are directionally correct and provide insights

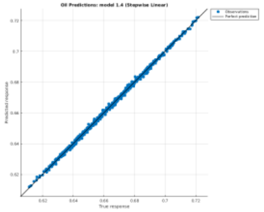
FY20 Q4 Deliverable

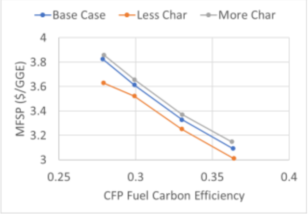


MFSP

Varied Parameters	
FP Material Attributes (**MAs**)	• mineral matter content • moisture content • particle diameter • extractives content
FP Process Parameters (**PPs**)	• reactor temperature







Validated Particle-Scale Model (Task 6.3) → **Multiple Linear Regression Models (Task 6.3)** → **Link with MFSP from CFP TEA models (Task 8.3)** → **MFSP**

Intrinsic mineral matter (ash) had the largest impact on MFSP (-13%/+22%) due to catalytic effects and lower relative amounts of liquid-range product. At low levels of ash, increased extractives in forest residues helped compensate for some yield losses associated with ash.

MFSP: Minimum Fuel Selling Price; **FP**: Fast Pyrolysis; **CFP**: Catalytic Fast Pyrolysis; **TEA**: Techno-Economic Analysis

Contributors: Pecha, Crowley, Ciesielski, Dutta, Wiatrowski, Carpenter
Key Collaborations: CCPC and Thermochemical Platform Analysis (2.1.0.302)

Addressing unit operation-level causal effects with dynamic LCA

Knowledge

Current Knowledge Gap

- What are the causal effects between feedstock CMAs, CQAs, and CPPs across key unit operations of the fast pyrolysis conversion platform?
- How do the CMAs, CPPs, and CQAs of key unit operations affect system sustainability?

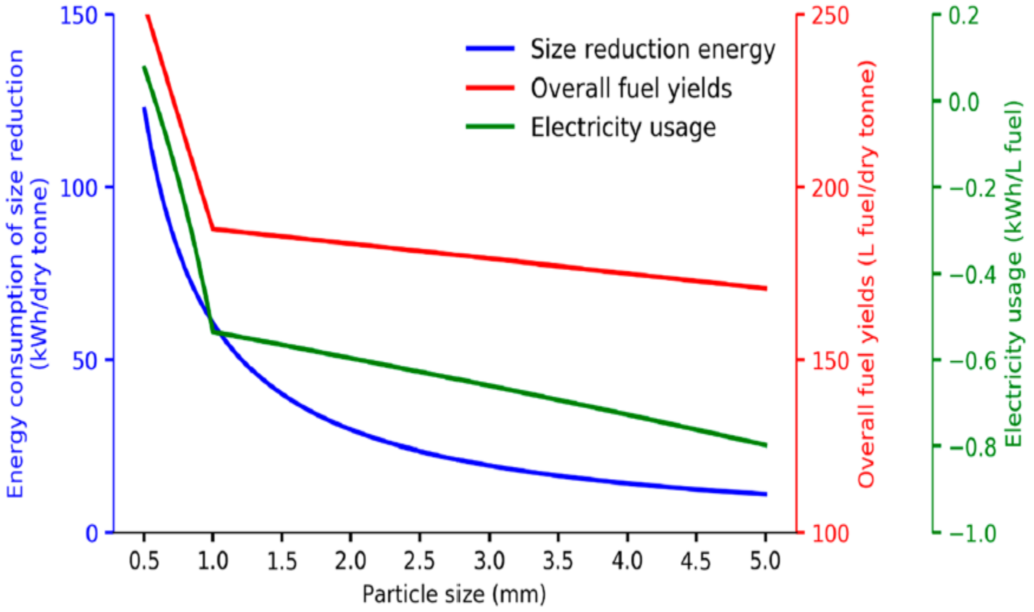
Achievement

- Demonstrated application of a dynamic LCA framework to address system-wide sustainability impacts of CMAs, CPPs, and CQAs across the supply chain and unit operations.
- Developed quantitative relationships between feedstock properties (particle size and moisture content) and key unit operations (preprocessing energy requirement, pyrolysis yields, and overall electricity usage/credits, etc.) that affect system-level sustainability.

Relevance

- Dynamic LCA can improve our understanding of life cycle implications of key CMAs and CPPs when relevant data is available.
- Dynamic LCA can address sustainability impacts of novel technologies such as feedstock fractionation, preprocessing, and conversion technologies.

Dynamic LCA addresses the impacts of feedstock variability on system sustainability focusing on unit operational causal effects.



Reducing the pine residues particle size leads to worse sustainability because energy consumption increases faster than the associated biofuel yield improves.

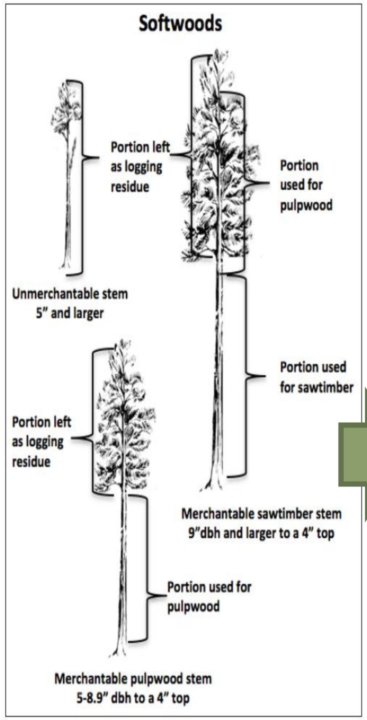
Longwen Ou and Hao Cai, 2020. Dynamic Life-Cycle Analysis of Fast Pyrolysis Biorefineries: Impacts of Feedstock Moisture Content and Particle Size. *ACS Sustainable Chemistry & Engineering* 8(16): 6211-21.

Example of FY21 Case Studies to Valorize Impacts of Feedstock Variability

Knowledge

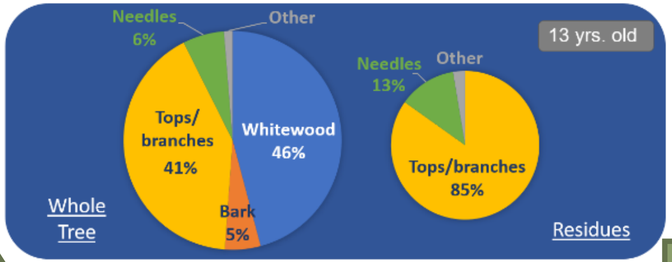
FY21 Case Studies and Associated Connections for Pine Residue Pathway

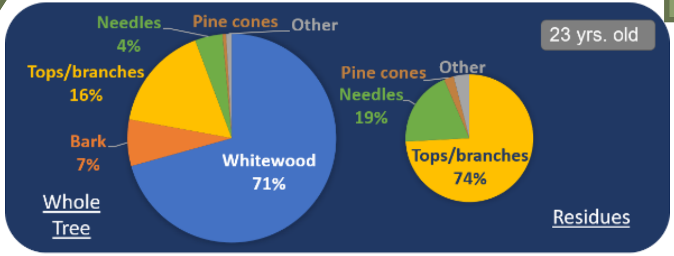
Feedstock → **Preprocessing** → **Conversion**



(Bardon and Hazel, 2014)

Task 2: Feedstock Variability
Feedstock data on 13-yr vs 23-yr tree





Task 5: Pre-Processing
Data on distribution of feedstock CMAs

Task 6: High Temp Conversion
Translation of CMAs to CQAs in unit op

Pre-Processing

- **Physical Characteristics**
- **Chemical Speciation**
- **Aerodynamic Properties**
- **Other Properties**

→ **Fast Pyrolysis** → **Downstream Upgrading**

ChemCatBio
Chemical Catalysis for Bioenergy

Task 8: Crosscutting Analysis
TEA and LCA (with data input along process)

Task 8 is collaborating with 3 FCIC tasks to complete 3 separate, but associated case studies to better understand the impacts of tree age on costs and sustainability at each step of the value chain.

Slide Courtesy of Task 6 – High Temperature Conversion

Summary

Management: We work closely with FCIC researchers and industry stakeholders to predict changes in costs and GHG emissions arising from operational impacts of feedstock variability. The Quality-by-Design framework is used to provide common terminology and approach between FCIC tasks.

Technical Approach:

- Incorporate data from FCIC experimental and fundamental modeling efforts to develop algorithms for predicting cost and environmental impacts of variable biomass quality
- Innovative use of biomass supply chain, preprocessing, and conversion system models developed in preview core BETO projects to predict operational impacts of variability

Impact: This project provides cost-benefit TEA and LCA focused on impacts of feedstock variability on yields, economics, and environmental sustainability to aid biorefinery engineers and equipment manufacturers conducting feasibility studies of proposed equipment and process design modifications.

Progress: Completed 8 case study analyses along the value chain for stover and pine residues. An additional 13 are currently in progress.

We are using innovative TEA/LCA methods to valorize dynamic feedstock variability with a focus on disseminating knowledge to the biorefinery community.

Quad Chart Overview- FCIC, Task 8

Timeline

- 10/1/2018 - 9/30/2021

	FY20	Active Project
DOE Funding	$1,099K	FY19- $1,400K FY20- $1,099K FY21- $1,099K Total- $3,598K

Project Partners (N/A)

Barriers addressed

- 19Ft-J, FSL, Operational Reliability
- 19ADO-A, ADO, Process Integration

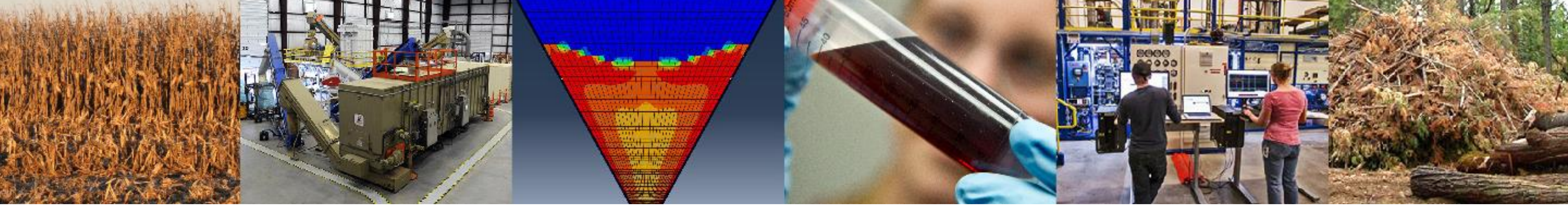
Project Goal

Quantify and communicate industrially relevant, system-level cost and environmental impacts for the discoveries and innovations of the FCIC. Analyses will use experimental and modeling data to quantify how feedstock variability affects underlying economics and sustainability metrics through the entire value chain, from feedstock production through preprocessing and conversion.

End of Project Milestone

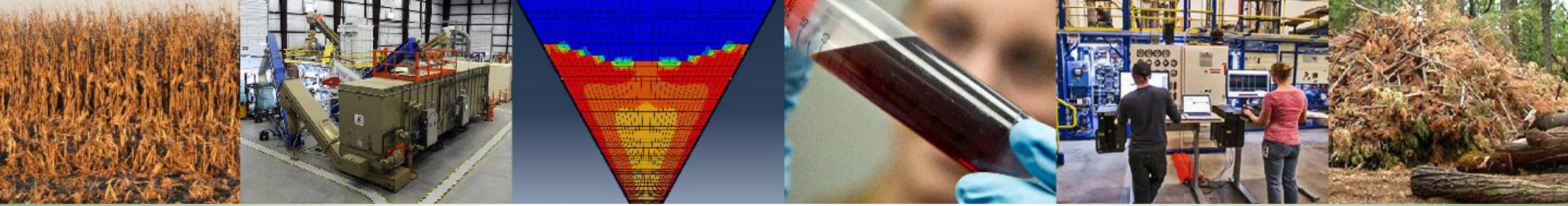
- A report documenting our systems-level understanding of how feedstock variability and related CMAs affect underlying economics and sustainability metrics across the value chain for both high-temperature and low-temperature conversion processes.
- These analyses will outline trade-offs among unit operations to identify where mitigation strategies and feedstock variability have the largest impacts.
- Industry outreach: Public webinar to share TEA/LCA results with industry stakeholders; presentations to at least two major conferences

Funding Mechanism (N/A)



Thank you

energy.gov/fcic



Additional Slides

Responses to Previous Reviewers' Comments

- Task 8 was new in FY19 but had some connections with the System-wide Throughput Analysis Task from FCIC 1.0

Reviewer Comment from last Peer Review	Task 8 Response to Comment
…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.	In FCIC 2.0 we have attempted to improve the technoeconomic and sustainability analyses by collaborating with external and internal stakeholders to identify areas of the value chain that are highly impacted by feedstock variability. Case studies are used to evaluate the cost and sustainability impacts of mitigation strategies being pursued by experimental and modeling tasks and are typically limited to a small part of the value chain such as a unit operation or a conversion step for which we can obtain the data needed to make a reasonable estimate of impacts and tradeoffs for different mitigation approaches to feedstock variability. Although still impacted by a lack in data, the ability to estimate costs for a smaller operational scope allows tradeoffs to be estimated using best available estimates that are not confounded by the problem being too large and unwieldy.
Modeled uptime for pioneer plants was reasonable but still needs to be validated against industry when data are available	This will continue to be a problem until more biorefineries exist. Ability to access their data will persist due to proprietary nature of business sensitive information. Anecdotal testimonials of how our analyses helps the industry might be the best we can get without funding collaboration with equipment providers.

Responses to Previous Reviewers' Comments

- Peer Review Comments - continued

Reviewer Comment from last Peer Review	Task 8 Response to Comment
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.	Mitigation approaches are chosen by the various R&D tasks in the FCIC using the resources mentioned in the reviewer's comment. Task 8 has been tasked with determining the cost and sustainability impacts of the selected mitigation strategies. The affects of dynamic variability is incorporated into our models to provide sensitivity to variability in feedstock properties that have significant impact on results. The use of the Quality-by-Design framework helps to define problems and focus on the critical parameters.
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…	We attempt to include the equipment performance in our analyses if data are available. The use of NREL and INL pilot facilities provides some data useful for estimation purposes, but industrial-scale equipment performance and reliability is mostly anecdotal currently. However, sensitivity studies around pilot-scale results can provide useful information to those with access to proprietary operational data. Future development of the biorefinery industry and collaborative efforts between BETO and Industry will help fill this knowledge gap.

Go/No Go Results

- A Go/No-Go review was completed in March 2020. There were no reviewer comments. The analysis approach of using Case Studies with vetting to down select the most relevant studies that will also have the necessary data from experimental tasks or literature was a “Go”. There were 8 case studies approved to move forward and complete in FY20. 1 case study was a “No Go” due to insufficient data availability at that time. The “No Go” case study was returned to the perpetual list of potential case studies for re-evaluation once more data are available. There are always more case study ideas than funds to do them.

Publications, Patents, Presentations, Awards, and Commercialization

Longwen Ou and Hao Cai, 2020. Dynamic Life-Cycle Analysis of Fast Pyrolysis Biorefineries: Impacts of Feedstock Moisture Content and Particle Size. *ACS Sustainable Chemistry & Engineering* 8(16): 6211-21.

Additional Information for Completed Case Studies

Value Chain Area	Feed	Title	Executive Summary
Feedstock Supply	Corn Stover	TEA of corn stover storage options considering variable degradation within bale stacks	The objective of this TEA was to estimate costs of delivered corn stover and level of degradation caused by changes in long-term storage design and to align storage cost estimates with characterization studies previously conducted by Task 2. A dynamic simulation model was developed in ExtendSim based on experiments conducted by Task 2 on corn stover bales and field observations in a storage study by Iowa State. Key Takeaway: The results of this model give ranges of improvements needed in biorefinery operations needed to justify increased investment in storage. It can also provide data to characterize the degradation level of biorefinery incoming feedstock streams for preprocessing and conversion TEAs to identify potential operational disruptions caused by the biomass condition. Preliminary results indicated that the if a biorefinery has costs reductions in preprocessing or conversion of approximately $1-2/dry ton for tarped stover or $10 for covered storage, the higher investment in storage protection is justified and could lead to improved MFSP.
Feedstock Supply	Pine Residue	TEA of anatomical Fractionation of pine residues at the landing	The objective of this TEA was to estimate the delivered costs of pine residue feedstocks supplied with industrial harvest operations that align with the anatomical fractions studied in Task 2. In a spreadsheet model, we quantified the delivered costs of two pine residue supply chains – a least-cost option to supply all portions of treetops and a higher-quality option to deliver delimbed tops only (no branches or needles). The total cost of the higher-quality supply chain scenario was $45.43/dry ton, an increase of 21% over the conventional design. In future work, model currently under development in FY21, we will expand this analysis to develop a discrete-event model to account for variability in tree size due to growing conditions and harvest rotation.

Additional Information for Completed Case Studies

Value Chain Area	Feed	Title	Executive Summary
Preprocessing	Pine	Particle scale impacts on deconstruction energy	The goal of this Case Study was to quantify the impacts of variable moisture and ash on hammer mill throughput and energy consumption and on generation of fines that are not able to be fed to conversion, as compared to a status quo Base Case system. Also considered was convertible carbon content (minimum carbon specification) and maximum ash content and the delivered feedstock cost impacts of not being able to feed residue not meeting both specifications to the conversion reactor. **Key takeaway** from this Case Study is that it is significantly more cost effective to hammer mill the residue prior to drying even though the grinder throughput is lower and energy consumption is higher versus drying before grinding.
Preprocessing	Corn Stover	Impact of anatomical fractionation on hammer milling throughput and energy consumption at 3 moistures	The goal of this Case Study was to quantify the impacts of variable moisture and ash on hammer mill throughput and energy consumption and on loss of very wet stover that causes failures in the first stage grinder and that are not able to be fed to conversion, as compared to a status quo Base Case system. Also considered was convertible carbohydrate content (minimum total carbohydrate specification) and maximum ash content and the delivered feedstock cost impacts of not being able to feed stover not meeting the total carbohydrate specification to the conversion reactor. **Key takeaways** from this Case Study are that from a production cost perspective it is more cost effective to hammer mill fractionated corn stover tissues than whole stover. Reduction of grinding energy was significant and may possibly be connected to particle-particle interactions in the grinder that lead to increased residence time of leaves and husks, resulting in decreased throughput and higher generation of fines when milling whole stover.

Additional Information for Completed Case Studies

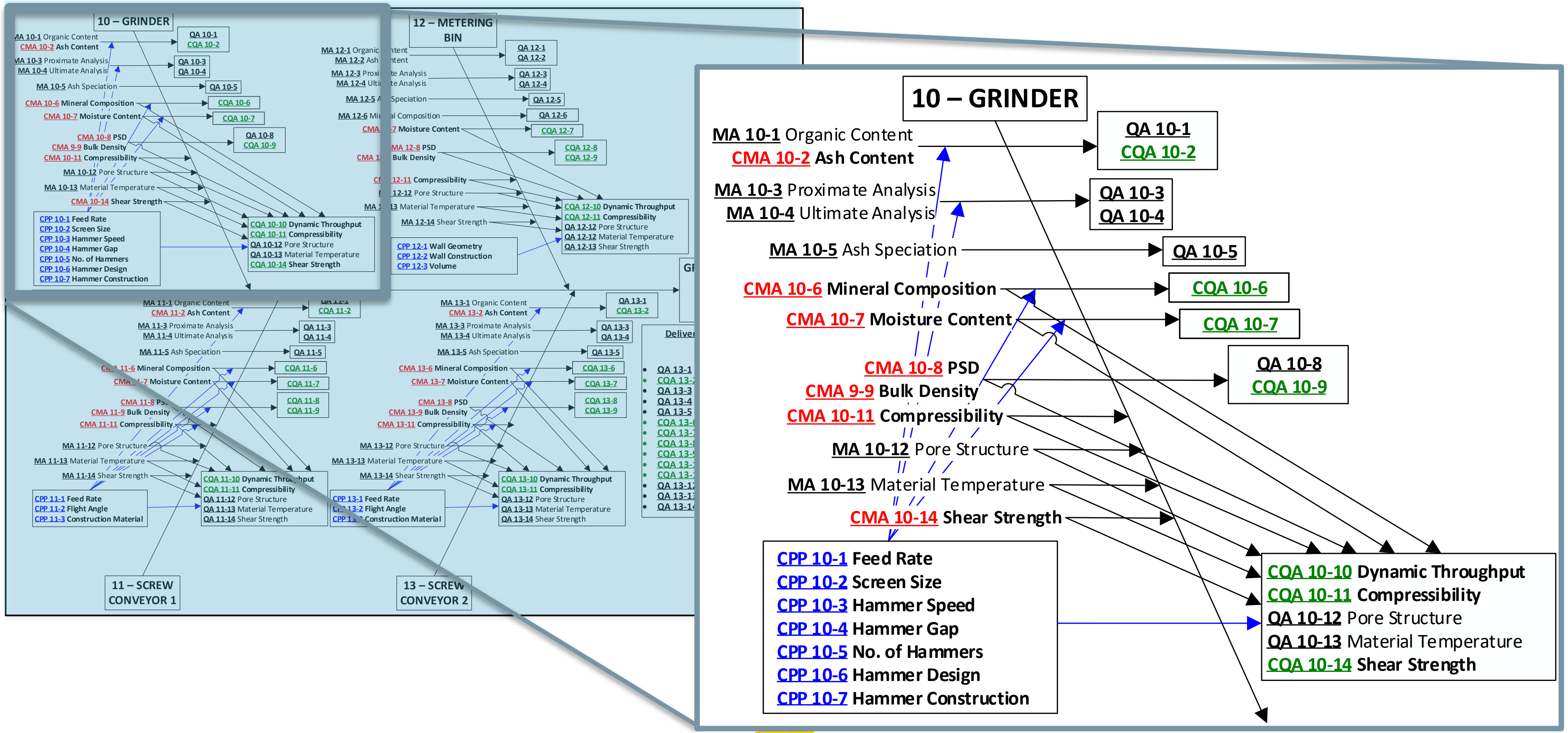
Value Chain Area	Feed	Title	Executive Summary
Preprocessing	Corn Stover	Value proposition of coatings or new alloys on hammer wear	The goal of this Case Study was to elucidate the value of improving of the life of parts that wear within a system in terms of the additional material cost that it takes to reach the level of improvement. **Key takeaway**: The feasible area of relative hammer cost increase ranges from 110% to 122% of the relative life increase, i.e. a 3x life increase can cost 3.66x the cost of the original hammers
High-Temperature Conversion – Catalytic Fast Pyrolysis	Pine Residue	Prediction of Cost Impacts of Feedstock Material Attributes and Conversion Process Parameters in a Catalytic Fast Pyrolysis (CFP) Process Using Fitted Correlations from (a) Particle-Level Fast Pyrolysis Yield Model and (b) Detailed TEA Cost Model	The economic impacts of feedstock material attributes during the conversion of biomass in fast pyrolysis (FP) and catalytic fast pyrolysis (CFP) processes are not well-understood. To address this, biomass deconstruction phenomena predicted at the particle scale were linked to techno-economic impacts via reduced-order models. A particle-scale model was used in combination with multiple linear regression models to develop high-level correlations between feedstock attributes and yields of oil, gas, and char in FP. Yields were then correlated with the minimum fuel selling price (MFSP) from multiple runs of a techno-economic model, bridging the gap between particle-scale predictions and MFSP. Empirical correlations derived from literature regarding the impact of mineral matter on FP oil yield were also considered. **Key Takeaway**: Variations in mineral matter (ash) was shown to have the biggest impact, varying MFSP by -13%/+22% due to catalytic effects and lower relative amounts of convertible lignocellulosic material. If ash can be controlled at low levels, increased extractives in forest residues can help compensate some yield losses associated with increased ash. Other inputs considered (particle size, moisture content, and reactor temperature) had a negligible effect on process economics within the ranges analyzed.

Additional Information for Completed Case Studies

Value Chain Area	Feed	Title	Executive Summary
Low-Temperature Conversion – DMR/EH and Fermentation	Corn Stover	Biomass Deconstruction and Fermentation Performance based on Isolated Anatomical Fractions	This report summarizes the work conducted to support an FCIC case study focused on TEA modeling to quantify the yield and cost ramifications for processing isolated anatomical fractions of corn stover through a low-temperature conversion (biochemical pathway) biorefinery. It is hypothesized that different individual anatomical fractions of corn stover vary in composition and recalcitrance, such that processing each fraction on its own e.g., through dedicated campaigns may enable better biorefinery economics overall relative to processing the whole stover material
Dynamic LCA	Pine residue	Dynamic LCA of interactions between feedstock variability and fast pyrolysis conversion	Critical Process Parameters: Temperature: Impact on the CQAs (e.g., oil yield, oil quality, char yield, and energy balance, etc.): Total oil yield, organics yield, and oil carbon yield decrease with temperature for all feedstocks; No clear trend for char yield and char carbon yield; Gas yield and gas carbon yield increase with temperature; No clear trend for the carbon content in oil; 500 °C is the optimal pyrolysis temperature out of the three temperatures investigated for maximized bio-oil yield, assuming the final fuel yield in hydrotreating is constant; 500 °C also will likely require less heat for preheating of the feedstock than higher reaction temperatures, thus reducing the life-cycle energy consumption and environmental impacts.

CMA, CPP, and CQA Relationships

In FY19 Task 8 developed a series of detailed Ishikawa diagrams to define hypothesized cause-and-effect relationships between CMAs, CPPs, and CQAs for each operation of the field-to-fuel value chain.



Anatomical Fractions are Different

1

Pine Plantation

2

Feller-buncher

3

Grapple skidder

6

Drum knife chipper

5

Residue pile

4

Whole tree disc knife chipper with chain flail

Residue Chips

Clean Pine Chips

Corn Stover Properties Change over Time

Feedstock Supply TEA in FY21 Evaluated the Cost Impacts on Using Improved Storage Methods

Anatomical Fractions are Different

TEA/LCA studies in FY21 investigating the cost impacts of fractionating residues to improve preprocessing and conversion

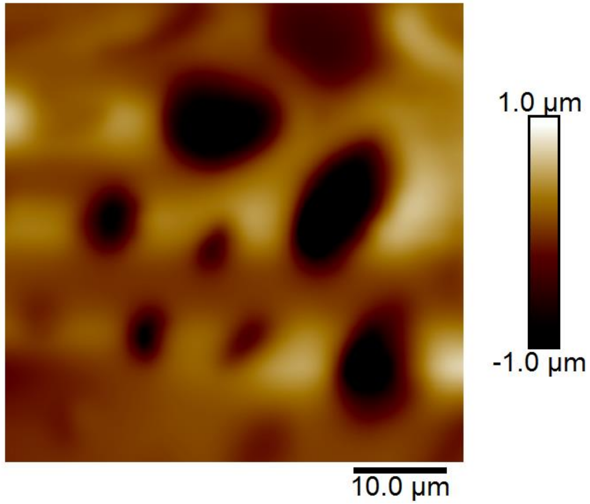
CLEAN CHIPS

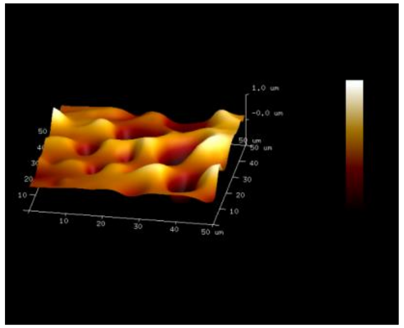
RESIDUE

FY21 Task 8 – Multiple Case Studies Support 13 years- vs. 23 years-old pine tree residues

Knowledge

Test hypothesis that pine tissue fractions differ substantially in nanomechanical properties thought to impact materials handling and preprocessing



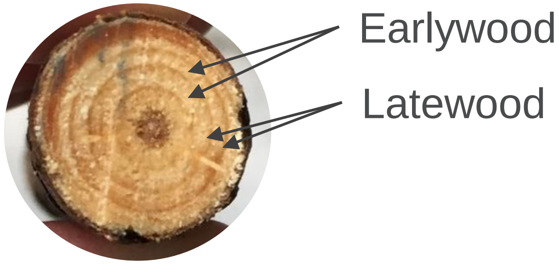


AFM topography images of severely degraded stem of corn stover

Slide Credit: Task 2 – Feedstock Variability

Current Knowledge Gap

- In progress quantitative nanomechanical mapping of loblolly pine tissue fractions from a 13 yr. old tree and a 23 yr. old tree
- Elastic modulus mapping of (1) needles, (2) early and latewood from branches and (3) bark from branches



Achievement

- Fundamental nanomechanical attributes support examination of how multiscale attributes in pine and stover anatomical fractions impact behavior in preprocessing and conversion

Relevance

- Knowledge of the effects of intrinsic/supply chain factors on biomass physical/mechanical material attributes and their impacts downstream can **inform harvest and collection best management practices** and **biorefinery risk management** on the origins of biomass variability and how the variability may be modified