DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

WBS 1.1.1.2 – Feedstock Supply Chain Analysis

April 3, 2023

Feedstock Technologies Platform

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Project Overview

- Project started in FY06, looked at **conventional** feedstock supply system designs (**passive quality management**)
- In FY14 we began looking at **advanced** supply system designs that utilize **active quality management** and seek to **develop feedstock as a commodity** with defined quality constraints and flowable formats
- Through FY18, we **developed n^{th}-plant feedstock supply system designs**, the **delivered cost targets** for conversion-ready feedstocks, and **tracked R&D progress** toward those targets
- Industry feedback was that we were **not capturing everything contributing to cost** (**operational issues** due to moisture, ash and compositional variability add cost)
- Our FY17 Go/No-go developed a complementary TEA approach, utilizing **dynamic analysis of 1^{st}-plant designs using stochastic feedstock properties** to capture costs due to variability
- We redirected our goals to maximize biorefinery economics by **improving equipment and system operability**, **improving delivered quality**, and **comparing 1^{st}-plant estimates to the n^{th}-plant estimates**
- This led to a **fractionation approach** to quality management and maximizing the value of the feedstock
  - Separate plant tissues that have different physical and compositional properties/qualities
  - Use singly or recombine tissues in ratios that meet cost and all CMAs for multiple end uses

Project Overview (continued)

What we're trying to do

- Develop innovative, cost-effective solutions to provide conversion-ready feedstocks
- Meet MYP delivered cost, conversion CMAs and operating effectiveness targets
- Track R&D progress toward those targets
- Relevance to BETO: Inform BETO on its R&D investments (foundational to the FT Platform)

Comparison to the state of the art

- Conventional systems that are currently used seek to minimize feedstock costs by minimizing infrastructure and preprocessing operations

Active management of feedstock quality is necessary

- Inherent variability of biomass feedstocks affects the ability to optimize processing and conversion processes, ultimately decreasing plant economics
- The experiences of the BETO-funded pioneer biorefineries underscore this challenge

Risks in analysis approach

- The primary risk is lack of sufficient scale-relevant data to adequately model the systems and understand cost/quality trade-offs

1 – Approach

Technical Approach

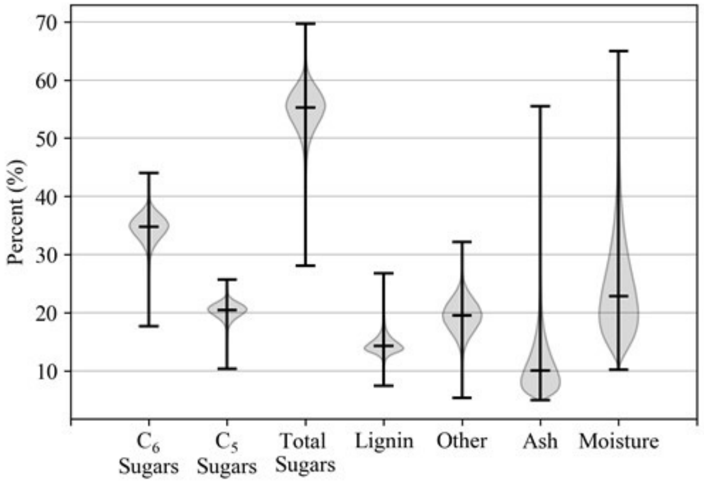
- Work with R&D staff, industry & stakeholders to understand barriers and potential technology solutions to meet cost and quality objectives
- Develop new computational capabilities to answer new questions
- Perform forward-looking “What-if” analyses to examine potential technology impacts on feedstock supply systems (e.g., fractionation approach)
- Develop Design Cases to identify specific R&D technical targets to achieve cost, quality and reliability targets
- Track annual R&D progress in State of Technology (SOT) reports toward BETO cost and technical targets established in the Design Cases

Top 3 Technical Challenges

- Existing paradigms related to feedstock supply (i.e., cheap vs. reliable and of consistent quality)
- Understanding and capturing all factors that contribute to cost
- Lack of complete datasets for harvest, composition, preprocessing and convertibility, across multiple biomass resources

Operability Challenges

Quality Challenges



1 – Approach (continued)

- Close collaboration with analysis teams across the BETO program including ORNL (supply production), NREL and PNNL (conversion TEAs), and ANL (LCA)
- Bi-weekly coordination calls with ORNL and BETO FT representatives
- Monthly conference calls with BETO FT and also with BETO DMA
- 5-7 milestones per year
  - Quarterly Progress Milestones drive schedule, forward-looking analysis of new approaches, and new tool development
  - SMART Annual Milestones for high-impact deliverables and outcomes such as Design Cases and SOTs
- DEI was not a formal part of this project for the current 3-year AOP, however, we are being Merit-Reviewed for the next AOP cycle during FY23 and DEI will be included in the planning

Spudnik air classifier for corn stover anatomical fraction separation

- Team Structure
  - <u>SOTs & Design Cases:</u> Damon Hartley, Yingqian (Tammy) Lin, Mohammad Roni (left INL during FY22)
  - <u>New Tools & Forward-Looking Analyses:</u> Pralhad Burli, Damon Hartley, Yingqian (Tammy) Lin, Mohammad Roni, Daniela Jones (NC State), Tasmin Hossein (NC State)

1 – Approach (continued)

Importance of Go/No-go Decision Points

- For this project, Go/No-go Decision Points guide the selection of new and advanced approaches for mobilizing the large fraction of the billion tons of biomass that are potentially available but unsuitable for use as bioenergy feedstocks
- Example from 2022: Assess whether it is possible to meet all CMAs for biochemical conversion and deliver feedstock at a cost of no more than $86/dry ton (2016$), while incorporating cost-advantaged waste feedstocks
  - Purpose: Determine whether it will be necessary to include blending with conventional feedstocks to meet the CMA quality requirements within allowable cost
  - Importance: Provide critical insights on viability of the maximum potential of the use of cost-advantaged waste feedstocks in a feedstock supply system and still meet cost and CMA requirements.

Risks and Mitigation

- The primary risk is lack of sufficient scale-relevant data to adequately model the systems and understand cost/quality trade-offs
- Mitigate by planning and executing milestone-driven data collection and alignment with BETO feedstock R&D projects and utilizing industry outreach and stakeholder engagement when possible

Performance Metrics

- Historic Metric: Delivered feedstock cost at the conversion reactor throat
- Additional Metric added in FY18: Overall Operating Effectiveness (OOE)

2 – Progress and Outcomes

Overall Operating Effectiveness

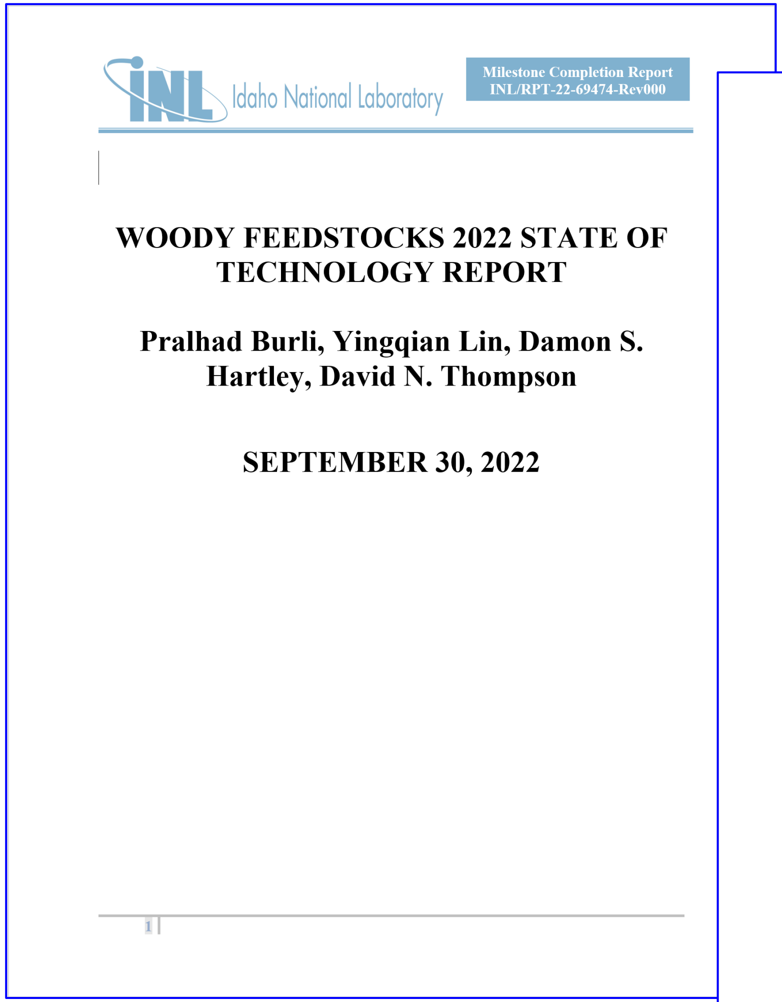
- Adapted from the concept of Overall Equipment Effectiveness (OEE), which is deterministic and focuses on individual pieces of equipment
  - OEE = (Availability) × (Performance Rate) × (Quality Rate)

- Overall Operating Effectiveness (OOE), examines the performance of a system by modeling the operating and quality performance of individual pieces of equipment and their interactions in the system
  - Mass-based discrete event simulation
  - Stochastically generates throughput over a specified period of time
  - Average fractional throughput for the time period and fractional quality achieved are estimated

$$\mathbf{OOE} = (A \times PR) \times QR \times 100 = \left(\frac{\textit{Total Units Produced}}{\textit{Design Units Planned}}\right) \times \left(\frac{\textit{Units Produced Meeting Quality}}{\textit{Total Units Produced}}\right) \times 100$$

State of Technology (SOT) Assessments

- Prepared annually to support the BETO Multi-Year Plan (MYP)
- Foundational to Feedstock Technologies Platform
- Two reports
  - Woody Feedstocks
  - Herbaceous Feedstock
- Each SOT includes two TEAs of the feedstock supply system
  - n^{th}-plant (deterministic)
  - 1^{st}-plant (stochastic)
- Published on OSTI unless there are proprietary data included

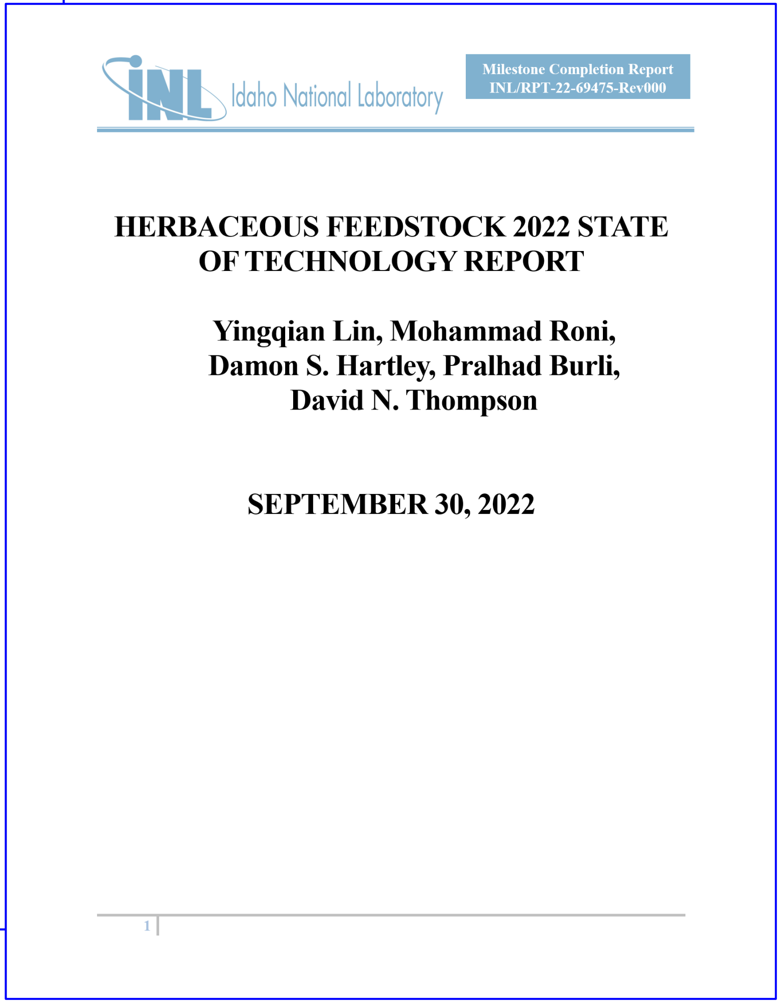

Idaho National Laboratory

Milestone Completion Report
INL/RPT-22-69474-Rev000

WOODY FEEDSTOCKS 2022 STATE OF TECHNOLOGY REPORT

Pralhad Burli, Yingqian Lin, Damon S. Hartley, David N. Thompson

SEPTEMBER 30, 2022


Idaho National Laboratory

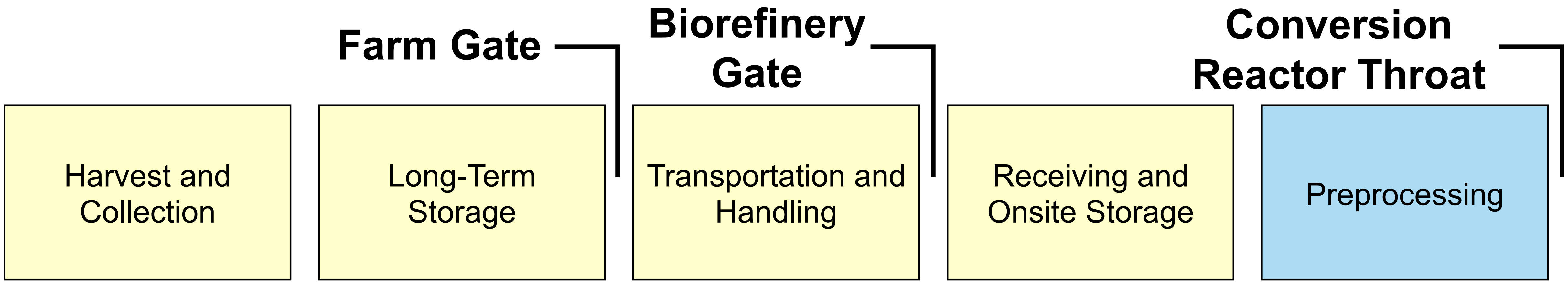
Milestone Completion Report
INL/RPT-22-69475-Rev000

HERBACEOUS FEEDSTOCK 2022 STATE OF TECHNOLOGY REPORT

Yingqian Lin, Mohammad Roni, Damon S. Hartley, Pralhad Burli, David N. Thompson

SEPTEMBER 30, 2022

Conventional Herbaceous Feedstock Supply Chain by Area



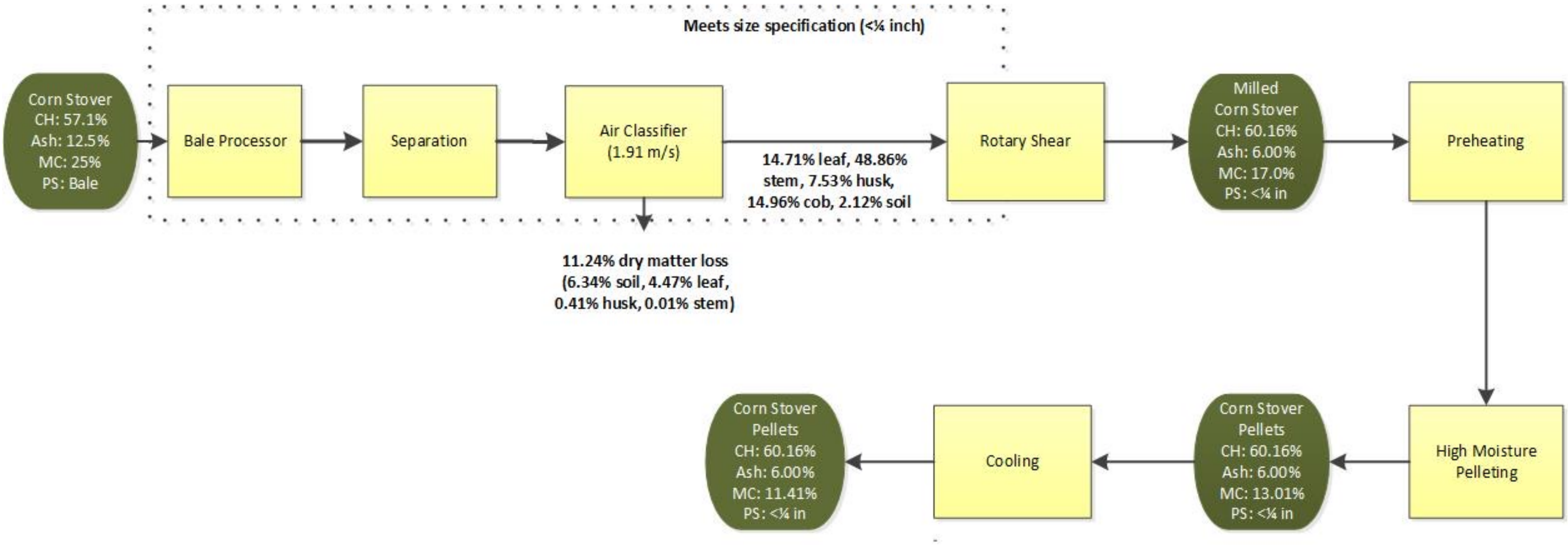
Design Approach for 2021

- Single stage air classification to remove some of the leaves as well as soil
- Removed material was discarded
- Nearly met compositional quality as regards ash, but the loss of material was a hit to throughput

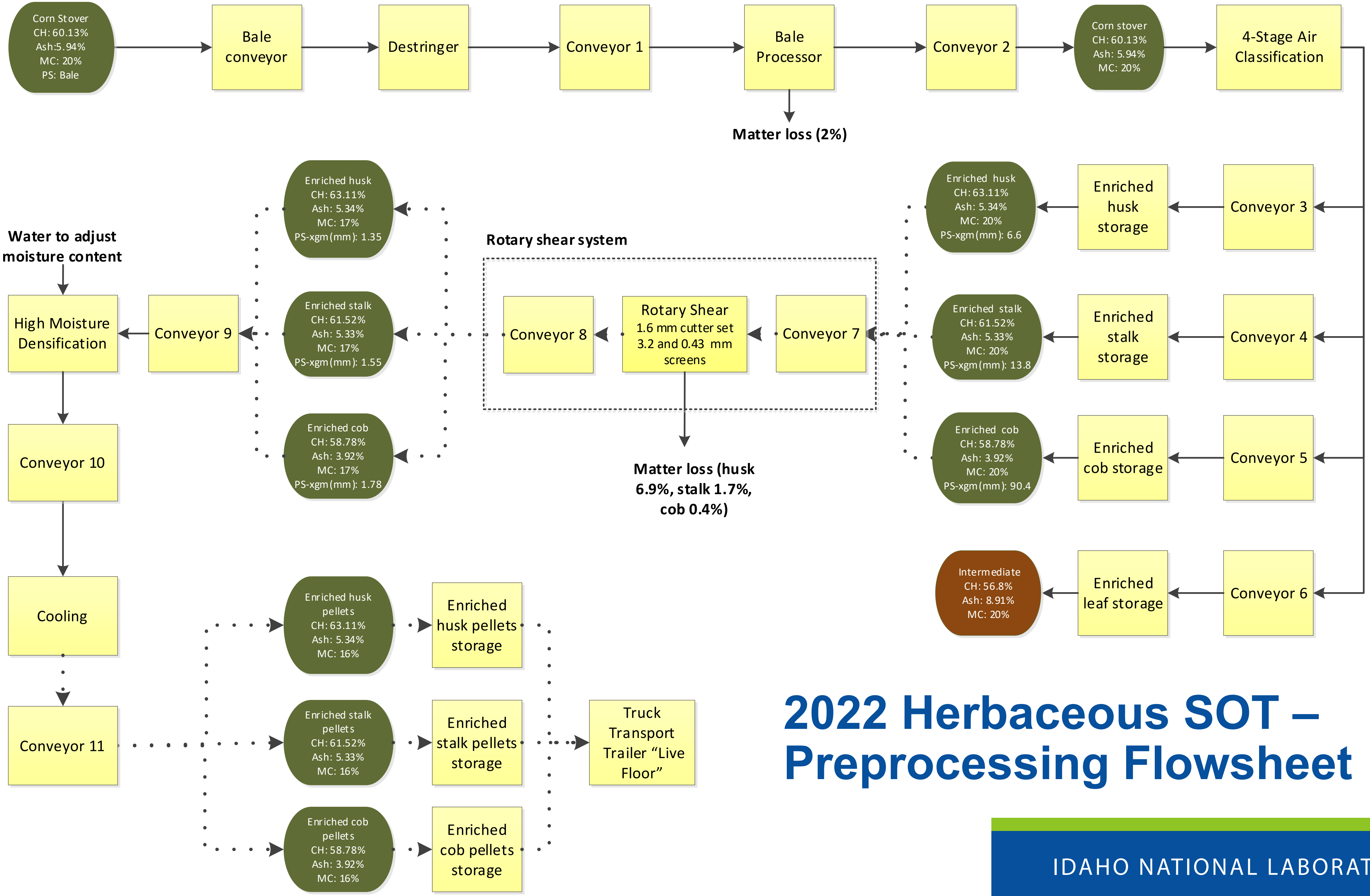
Design Approach for 2022

- Primary focus on meeting quality
- Employed full-blown fractionation approach
- Batch comminution/densification to minimize the high capital equipment cost
- Examined potential to monetize the waste stream

2021 Herbaceous SOT – Preprocessing Flowsheet



2022 Herbaceous SOT – Preprocessing Flowsheet



Example from the 2022 Herbaceous SOT: nth-Plant Analysis

Cost Element	Cost ($/dry ton)			
	Enriched Leaf Fraction	Enriched Husk Pellets	Enriched Stem Pellets	Enriched Cob Pellets
Proportion of preprocessed biomass	**23.42%**	**10.00%**	**50.24%**	**16.34%**
Grower payment	$21.71	$21.71	$21.71	$21.71
Harvest and collection	$13.84	$13.84	$13.84	$13.84
Storage and queuing	$6.40	$6.80	$6.80	$6.80
Transportation and handling	$7.51	$12.58	$12.58	$12.58
In-plant receiving and preprocessing	$6.69	$23.64	$24.17	$22.16
Dockage	$0.00	$0.15	$0.15	-$0.38
Total	**$56.15**	**$78.72**	**$79.25**	**$76.71**

Average costs for individual tissues

Average costs and GHG emissions for the delivered husks/cobs/stalks

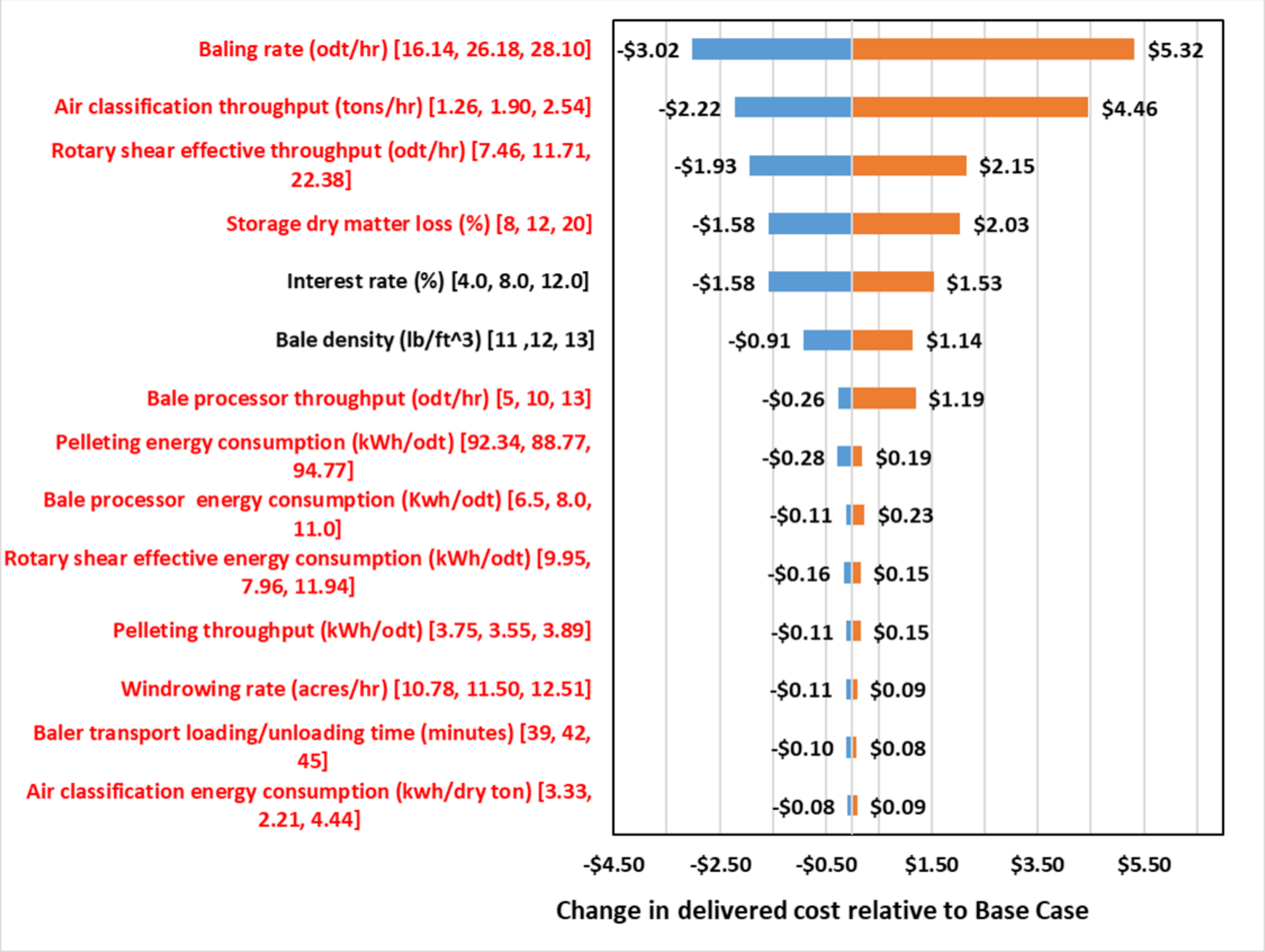
Progression of costs from 2021, 2022 and the 2018 Design Case Projection

Cost Element	Weighted Composite Cost of Delivered Pellets ($/dry ton)	GHG emissions (kg CO_2e/ton)
Grower payment	$21.71	
Harvest and collection	$13.84	10.35
Storage and queuing	$6.80	2.50
Transportation and handling	$12.58	13.37
In-plant receiving and preprocessing	$23.67	61.21
Dockage	$0.04	
Total	**$78.64**	**87.43**

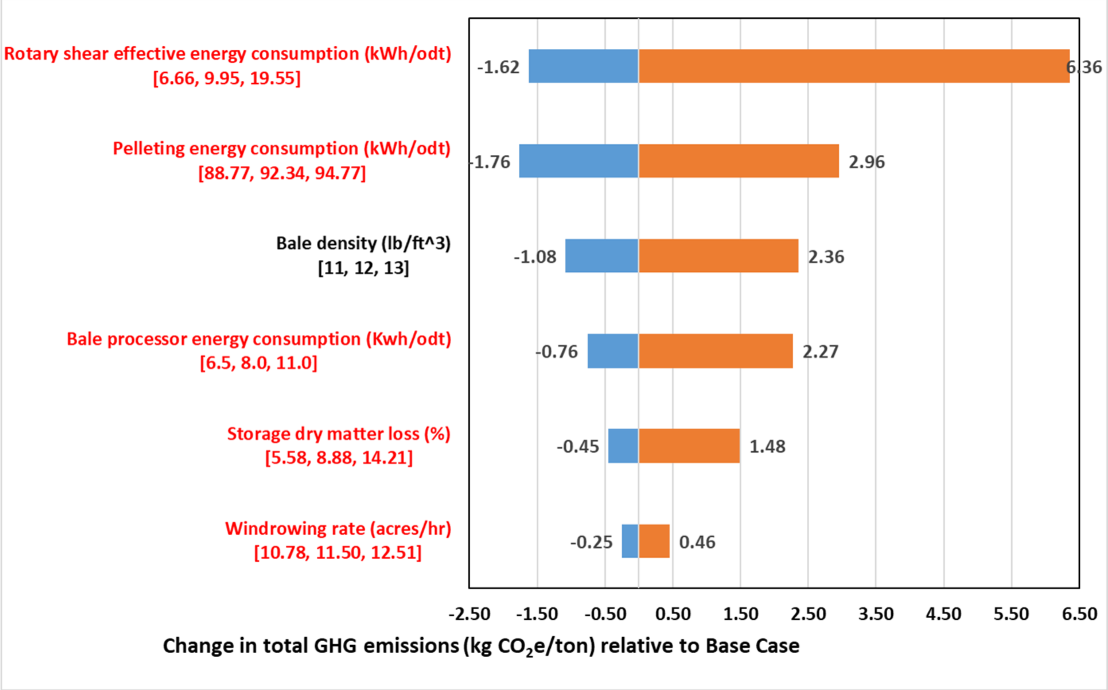
	2021 SOT	2022 SOT	2022 Projection
Feedstock	**Three-pass**	**Three-pass**	**Blend**
Net delivered cost ($/dry ton)	**$78.21**	**$78.64**	**$79.07**
Grower payment ($/dry ton)	$21.71	$21.71	$22.37
Feedstock logistics ($/dry ton)	**$56.50**	**$56.93**	**$56.70**
Harvest & collection ($/dry ton)	$13.84	$13.84	$12.79
Storage & queuing ($/dry ton)	$6.66	$6.80	$8.35
Preprocessing ($/dry ton)	$23.40	$23.67	$21.44
Transportation & handling ($/dry ton)	$12.20	$12.58	$12.44
Dockage ($/dry ton)	$0.40	$0.04	$1.68

2022 Herbaceous SOT: n^{th}-Plant Sensitivity Analysis

*Delivered Cost**

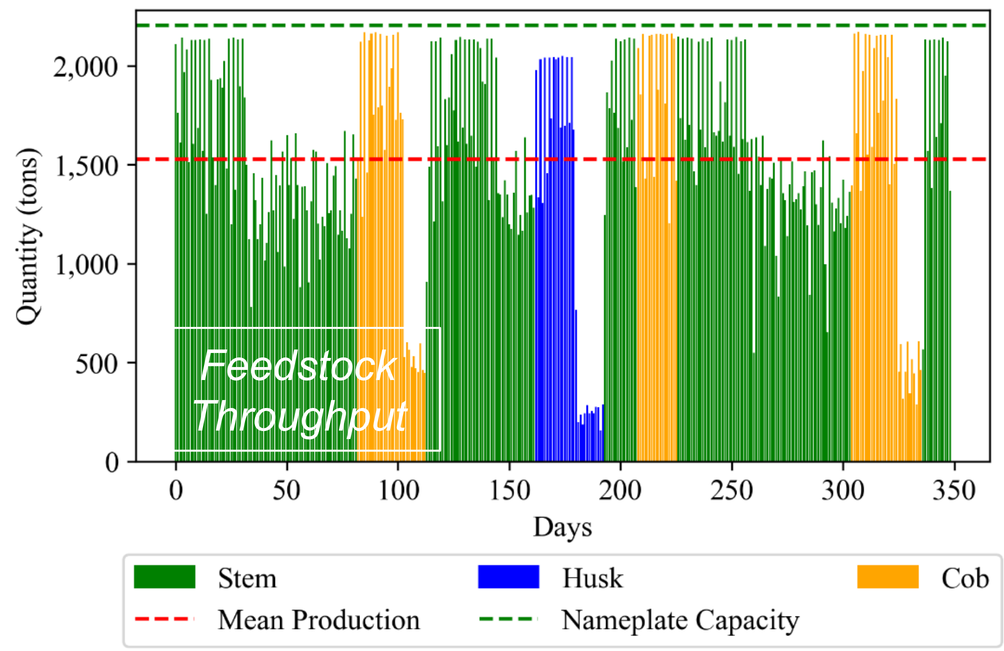


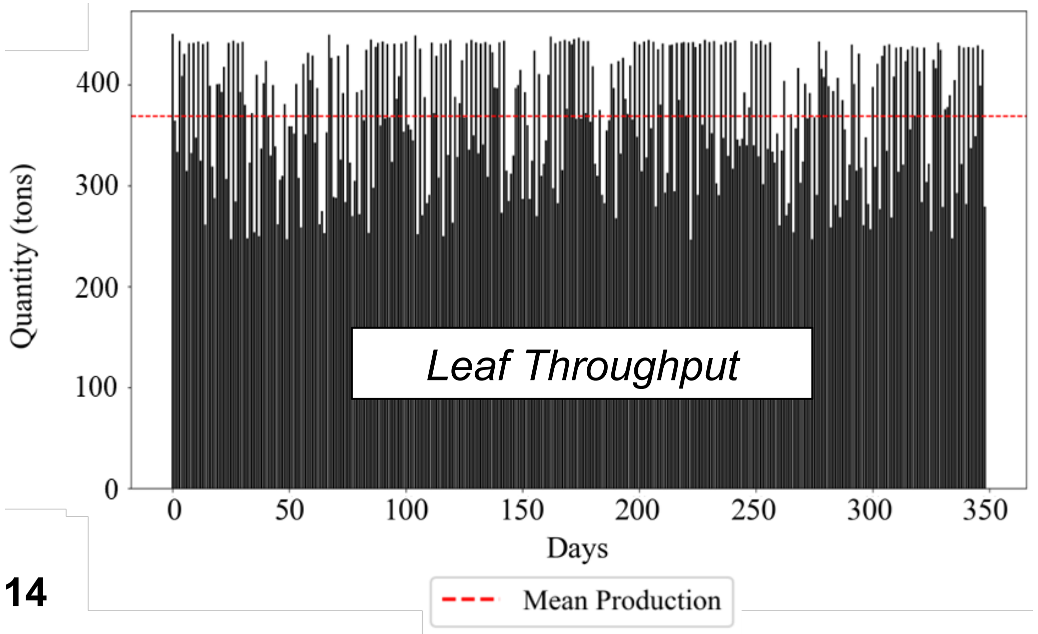
*GHG Emissions**



**Red text indicates BETO-funded*

2022 Herbaceous SOT: 1st-Plant





Failures & Downtime

	2022 SOT
Total Failures	**1012**
Moisture Failures (% of Total)	0%
Ash (Wear) Failures (% of Total)	90.91%
Regular Failures (% of Total)	9.09%
Total Operating Time (350 days) (min)	**504,000**
Total Downtime (min)	**346,055**
Moisture Downtime (% of Total)	0%
Ash (Wear) Downtime (% of Total)	94.17%
Regular Downtime (% of Total)	5.83%
Actual time-onstream (350 days) (%)	**82.83%**
Actual time-onstream (365 days) (%)	**79.43%**

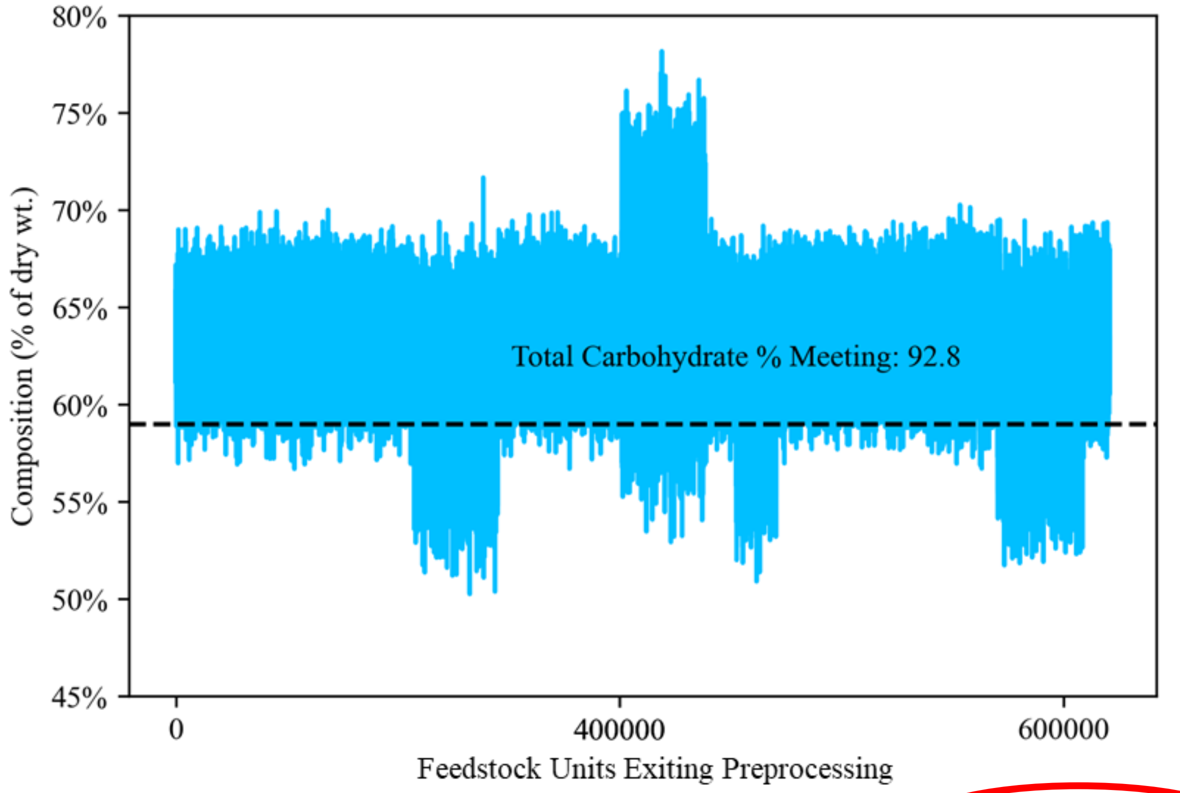
	$/dry ton (2016$)
Mean Production Cost	$74.68
Cost of Delays	$10.87
Total Production Cost	$85.55

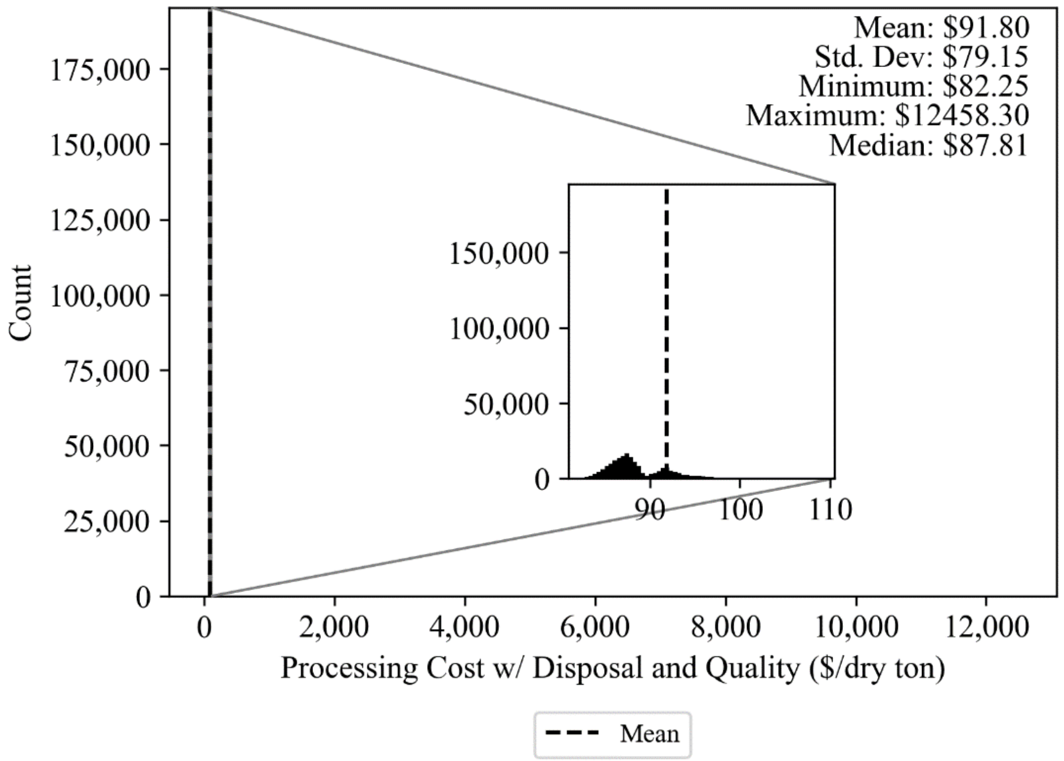
For Comparison: n^{th}-Plant

Time on-stream = 90%

Delivered Cost = $78.64/dt

2022 Herbaceous SOT : 1st-Plant





Cost of Preprocessed tons not meeting = $6.25/dry ton

Total Delivered Cost = $91.80/dry ton

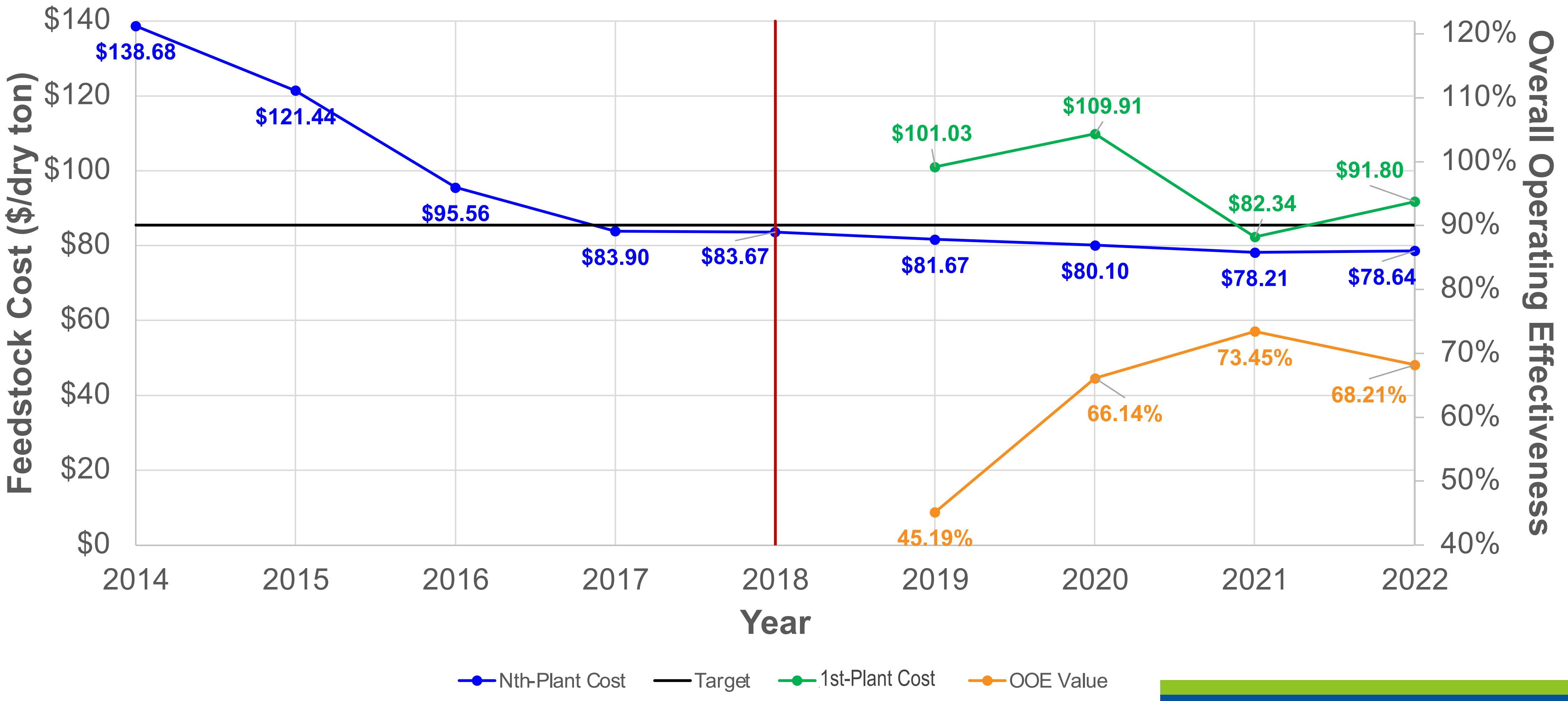
Impact of fractionation on delivered quality

$$Supply\ Logistics: \quad OOE_S = F_{f,S} \times F_{B,S} = 0.8989 \times 0.2517 = 0.2263\ (22.63\%)$$

$$Preprocessing: \quad OOE_P = F_{f,P} \times F_{B,P} = 0.7350 \times 0.9280 = 0.6821\ (68.21\%)$$

Impact of storage losses & operational impacts on throughput

Modeled progress toward cost and performance goals for herbaceous biochemical conversion feedstock



3 – Impact

State of Technology & Industry Impacts

- Moves the state of technology forward by developing innovative approaches and tracking R&D progress
- We are directly addressing industry issues as regards operability, feedstock quality and actual delivered cost

Dissemination of Results

- Two nth-plant SOTs and two 1st-plant SOTs published annually (external reports available on OSTI)
- "The nth-plant scenario for blended feedstock conversion and preprocessing nationwide: Biorefineries and depots," published in *Applied Energy* (I.F. = 9.746) in 2021
- "Nth-plant scenario for forest resources and short rotation woody crops: A nationwide analysis for biorefineries and depots," published in *Applied Energy* (I.F. = 9.746) in 2022
- "Importance of Incorporating Spatial and Temporal Variability of Biomass Yield and Quality in Bioenergy Supply Chain," published in Nature *Scientific Reports* (Impact Factor = 4.996) in 2023
- Presentations to ExxonMobil, Charm, POET and Shell
- Multiple presentations at international meetings (AIChE, ASABE)

Summary: Future Direction and Path Forward

- **Challenge:** Inherent variability of biomass feedstock impacts preprocessing operability and reduces quantity of available feedstock meeting conversion specs, decreasing biorefinery economics and increasing carbon intensity
- **Goal:** Maximize available feedstock in a region-specific manner, with constraints on carbon intensity (CI) and allowable ranges of conversion Critical Material Attributes
- **Requirements:**
  - Minimize raw material variability
    - Organics composition → Yield
    - Particle size distribution → Convertibility & Losses
    - Flow properties → Throughput
    - Impacts of Moisture & Ash → Failures (throughput)
  - Approaches to improve quality and increase usable biomass within CI limits
- **Approaches:**
  - Fractionate → Formulate to spec → send remaining material to alternate uses/markets
  - Shift Feedstock Supply Design Cases and SOTs to region-specific analyses that identify available supplies of individual conversion-ready feedstocks based on regional characteristics that impact feedstock quality and carbon intensity

Shout out to the Projects and PIs that provide data for Design Cases and SOTs…

- ANL – *Hao Cai, Longwen Ou*
- Forest Concepts – *Jim Dooley, David Lanning*
- INL – *John Aston, Tiasha Bhattacharjee, Pralhad Burli, Ling Ding, Kristan Egan, Rachel Emerson, Damon Hartley, Amber Hoover, Jordan Klinger, Jeff Lacey, Allison Ray (left INL in FY21), Bill Smith, Vicki Thompson, Jaya Tumuluru (left INL in FY21), Lynn Wendt, Neal Yancey*
- NREL – *Ryan Davis, Abhijit Dutta, Matthew Wiatrowski*
- ORNL – *Maggie Davis, Chad Hellwinckel, Matt Langholtz*
- Purdue University – *Michael Ladisch, Diana Ramirez, Eduardo Ximenes*

Quad Chart Overview

Timeline

- *Project start date: 10/1/2020*
- *Project end date: 9/30/2023*

	FY22 Costed	Total Award
DOE Funding	*$1,011,592*	*$3,000,000*
Project Cost Share	NA	NA

TRL at Project Start: NA
TRL at Project End: NA

Project Goal

Through leading-edge feedstock analyses that identify R&D technology performance, quality and cost targets to achieve BETO goals, maximize biorefinery economics by better process and quality control of feedstock leading to greater plant availability and predictable yields of high value biofuels and co-products.

End of Project Milestone

FY23 State of Technology TEAs for Regional Feedstocks: Deliver completed reports for 2 regions, one focused on herbaceous and one focused on woody. Each will document the quantity of materials that are able to meet defined quality specifications and determine the continuum of delivered costs and carbon intensities based on required quality management techniques. The goal will be to show attainment at least 50% of material meeting quality specifications defined for each a woody and herbaceous supply region.

Funding Mechanism

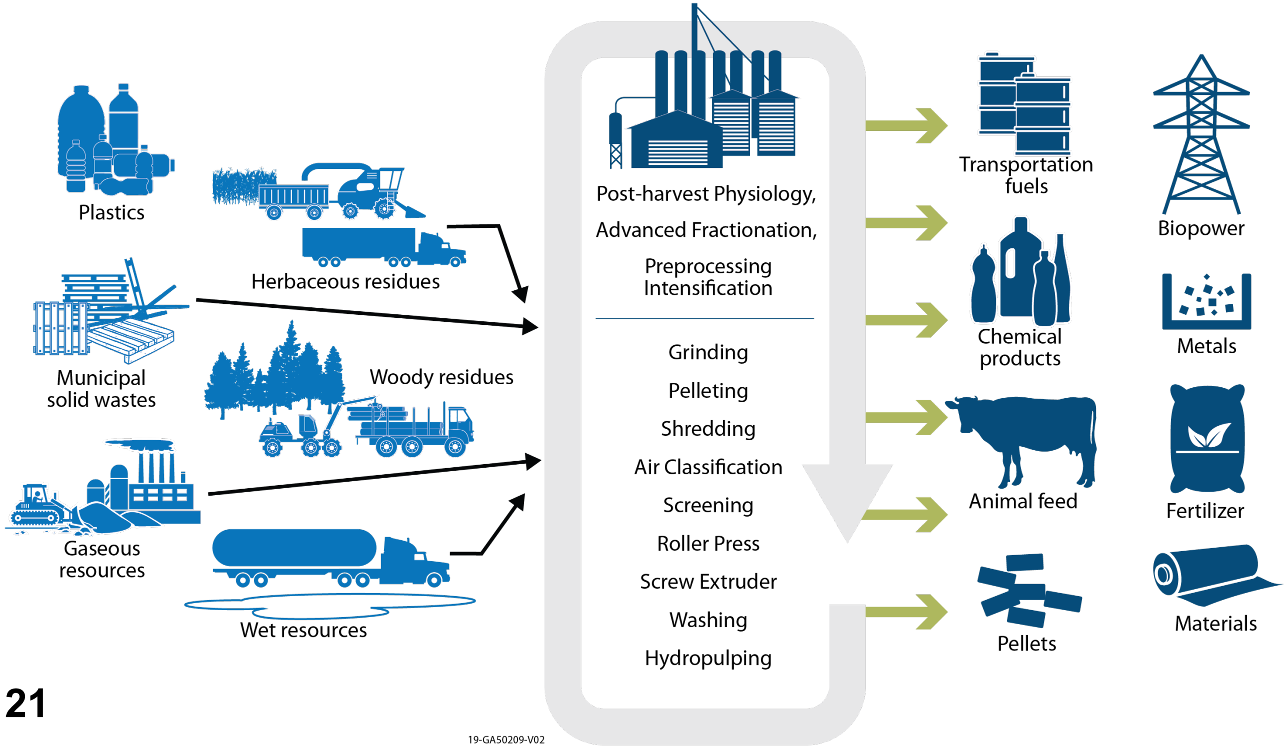
This project is a programmatic AOP project under the Feedstock Technologies Platform in BETO.

Project Partners

Collaborators include all FSL R&D AOP Projects, industry projects (data source), and other BETO National Laboratories performing TEA and LCA.

Project Overview

- Project started in FY06
- Prior to FY18
  - Developed n^{th}-plant feedstock supply system designs,
  - Delivered cost targets for conversion feedstocks, and
  - Tracked R&D progress toward those targets
- Industry feedback: Not capturing everything contributing to cost (<u>operational issues due to variability add cost</u>)



- FY17 Go/No-go developed a complementary TEA approach
  - Dynamic analysis of 1^{st}-plant designs using stochastic feedstock properties to capture costs due to variability
- Redirected goals to maximize biorefinery economics by
  - Improving equipment and system operability, and
  - Improving delivered quality
  - Comparing 1^{st}-plant estimates to n^{th}-plant estimates
- Led to a fractionation approach
  - Separate the plant tissues that have different physical and compositional properties/qualities
  - Use singly or recombine tissues in ratios that meet cost and all CMAs for multiple end uses

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

Additional Slides

Responses to 2021 Peer Review Comments

2021 Peer Review Comment

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

FY21-22 Actions Taken in Response to Comment

- Biomass feedstock quality is an issue that makes it necessary to either add preprocessing steps (at additional cost), or blend with higher quality energy crops to meet conversion specifications. As an example, corn stover is residue that is produced as a byproduct of farming to produce a grain commodity, and there is little incentive to the farmer to make harvest and collection modifications for corn stover that would improve its quality to meet conversion specifications, hence, a greater focus was needed on preprocessing approaches to mitigate variability.
- Recognizing this, we identified approaches to meet cost, quality and operational goals using corn stover alone, which led our program to the tissue fractionation and reformulation approach. Additionally, we began directly comparing 1st-plant stochastic SOT results to the nth-plant deterministic SOTs, which clearly differentiates the costs arising from preprocessing the stover from those arising from variability in compositional quality.

Highlights from FY22 Go/No-go Decision Point

FY22 Go/No-go Decision Point (March 31, 2022)

- Preliminary analysis to examine the viability of utilizing only waste feedstocks. Meet delivered cost of no higher than $86/dry ton (2016$) while meeting all conversion CMAs for at least one conversion process.
- Go: Identify analysis path forward integrating waste feedstocks, with conventional feedstocks to meet both cost and conversion CMA targets.

Decision: Go

- A preliminary analysis was carried for grass clippings, non-recyclable paper and 2-pass corn stover to assess whether it would be possible to meet all CMAs for biochemical conversion and deliver the material at a cost of no more than $86/dry ton (2016$), while incorporating the waste materials. The purpose of the analysis was to determine whether it will be necessary to include blending with conventional feedstocks to meet the CMA quality requirements within allowable cost.
- Demonstrated that it is possible to incorporate two cost-advantaged feedstocks (grass clippings and mixed paper) along with two-pass corn stover to deliver a blended feedstock that can meet all conversion CMAs (≥59 wt% carbohydrate, ≤ 4.93 wt% ash, and moisture =20 wt%) at a cost of $82.57/dry ton (2016$)
- From a biomass feedstock blend perspective, the ratios were 88.99% two-pass corn stover, 7.74% grass clippings, and 3.27% mixed paper. The pellet blend ratio ensures that the ash content in the blend is 4.93% and the carbohydrate content is 59%, meeting the conversion CMAs.

Publications and Presentations

Peer-Reviewed Journal Articles

- Roni, M.S., Y. Lin, L.M. Griffel, D.S. Hartley and D.N. Thompson. (2023). “Importance of incorporating spatial and temporal variability in feedstock supply chain design consideration.” *Scientific Reports*, Accepted and in press.
- Hossain, T., D.S. Jones, D. Hartley, D.N. Thompson, M. Langholtz and M. Davis. (2022). “Nth-plant scenario for forest resources and short rotation woody crops: A nationwide analysis for biorefineries and depots.” *Applied Energy* 325, 119881. DOI: 10.1016/j.apenergy.2022.119881
- Hossain, T., D. Jones, D. Hartley, M. Griffel, Y. Lin, P. Burli, D.N. Thompson, M. Langholtz, M. Davis and C. Brandt. (2021). “The nth-plant scenario for blended feedstock conversion and preprocessing nationwide: Biorefineries and depots.” *Applied Energy* 294, 116,946. DOI: 10.1016/j.apenergy.2021.116946

Technical Reports

- Lin, Y., M. Roni, D.S. Hartley, P. Burli and D.N. Thompson. (2022.). “Herbaceous Feedstock 2022 State of Technology Report.” Report prepared for the U.S. Department of Energy, Bioenergy Technologies Office, INL, Idaho Falls, ID. INL/RPT-22-69475.
- Burli, P., Y. Lin, D. Hartley and D.N. Thompson. (2022). “Woody Feedstocks 2022 State of Technology Report.” Report prepared for the U.S. Department of Energy, Bioenergy Technologies Office, INL, Idaho Falls, ID. INL/RPT-22-69474.
- Cai, H., L. Ou, M. Wang, R. Davis, A. Dutta, K. Harris, M. Wiatrowski, E. Tan, A. Bartling, B. Klein, D. Hartley, Y. Lin, M. Roni, D.N. Thompson, L. Snowden-Swan, Y. Zhu and S. Li. (2022). “Supply Chain Sustainability Analysis of Renewable Hydrocarbon Fuels via Indirect Liquefaction, Hydrothermal Liquefaction, Combined Algal Processing, and Biochemical Conversion: Update of the 2021 State-of-Technology Cases.” Report prepared for the U.S. Department of Energy, Bioenergy Technologies Office, Argonne National Laboratory (ANL), Lemont, IL. ANL/ESD-22/5. DOI: 10.2172/1862925
- Lin, Y., M. Roni, P. Burli, D. Hartley and D.N. Thompson. (2021). “Herbaceous Feedstock 2021 State of Technology Report.” Report prepared for the U.S. Department of Energy, Bioenergy Technologies Office, INL, Idaho Falls, ID. INL/EXT-21-64635. DOI: 10.2172/1908668
- Burli, P., D. Hartley, D.N. Thompson. (2021). “Woody Feedstocks 2021 State of Technology Report.” Report prepared for the U.S. Department of Energy, Bioenergy Technologies Office, INL, Idaho Falls, ID. INL/EXT-21-64638. DOI: 10.2172/1908667

Publications and Presentations (continued)

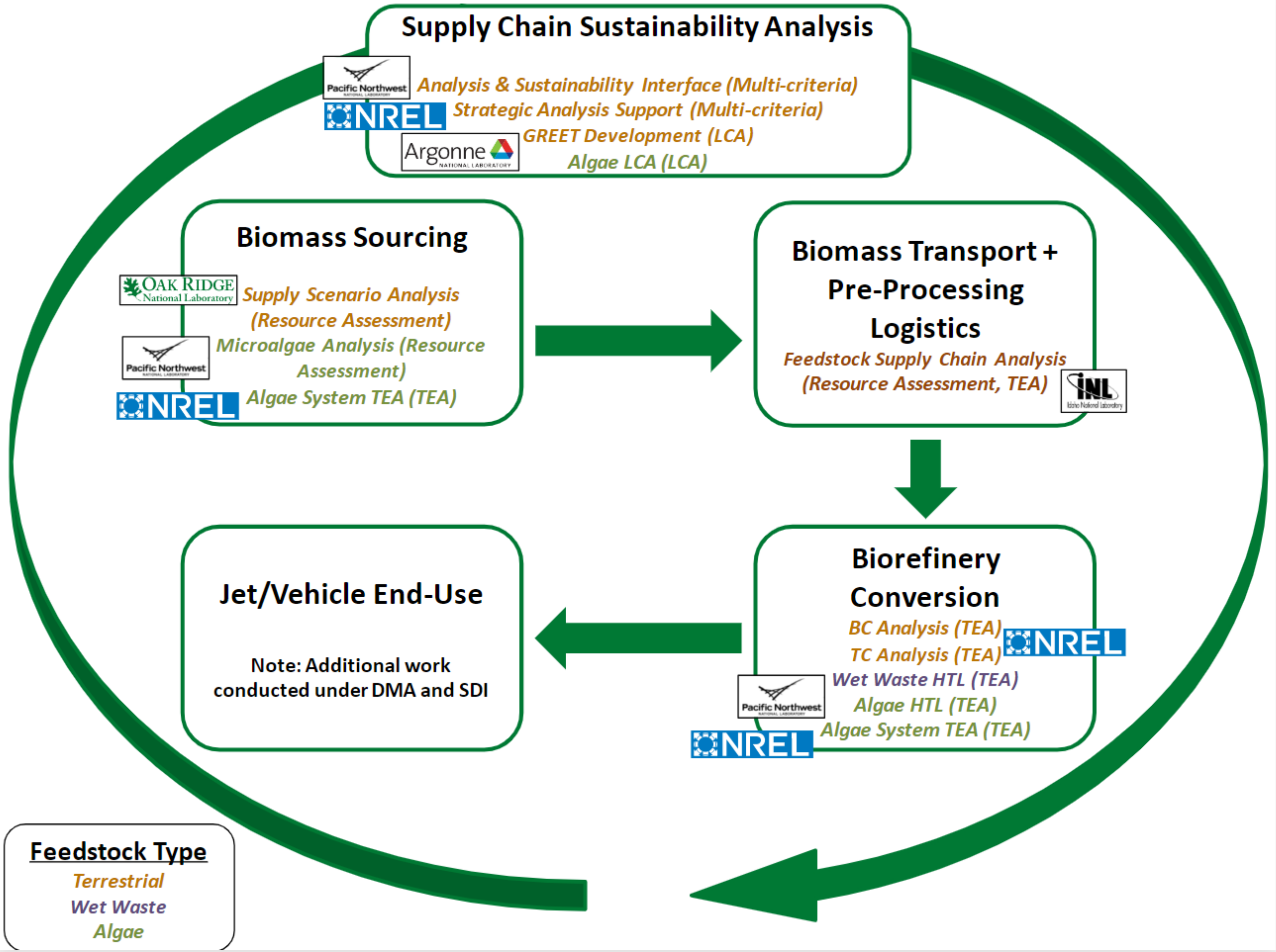
Technical Reports (continued)

- Burli, P.H., Y. Lin, D.S. Hartley and D.N. Thompson. (2021). "Technoeconomic analysis of torrefied pellets produced from municipal solid wastes." Report prepared for the U.S. Department of Energy, Bioenergy Technologies Office, INL, Idaho Falls, ID. INL/EXT-21-61350.
- Cai, H., L. Ou, M. Wang, R. Davis, A. Dutta, K. Harris, M. Wiatrowski, E. Tan, A. Bartling, B. Klein, D. Hartley, Y. Lin, M. Roni, D.N. Thompson, L. Snowden-Swan and Y. Zhu. (2021). "Supply Chain Sustainability Analysis of Renewable Hydrocarbon Fuels via Indirect Liquefaction, Ex Situ Catalytic Fast Pyrolysis, Hydrothermal Liquefaction, Combined Algal Processing, and Biochemical Conversion: Update of the 2020 State-of-Technology Cases and Design Cases." Report prepared for the U.S. Department of Energy, Bioenergy Technologies Office, Argonne National Laboratory (ANL), Lemont, IL. ANL/ESD-21/1. DOI: 10.2172/1823113

Presentations

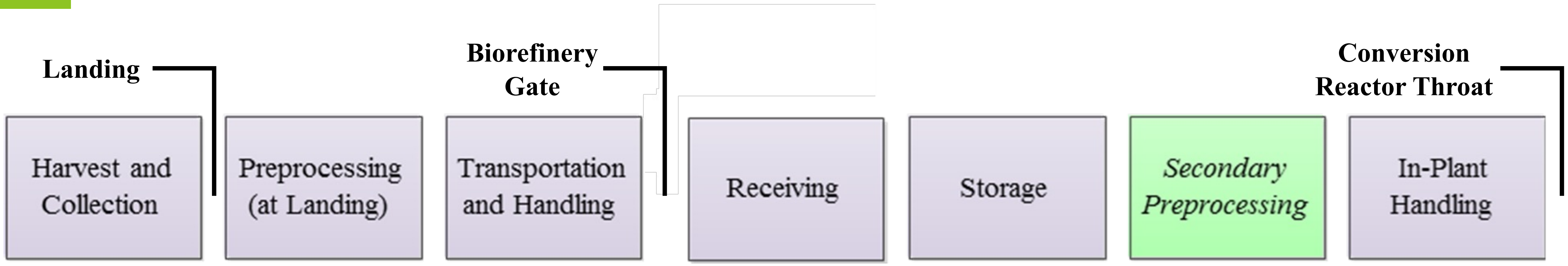
- Hossain, T., D. Jones, D. Hartley, D.N. Thompson, M. Langholtz and M. Davis. (2022). "Nth-plant scenario for forest resources and short rotation woody crops: A nationwide analysis for biorefineries and depots." *ASABE 2022 Annual International Meeting*, Houston, TX, July 17-20, 2022.
- Lin, Y., M.S. Roni, D.S. Hartley, D.N. Thompson, A. Hoover and R. Emerson. (2021). "Optimal depot size and location selection in biofuel supply chain under temporal and spatial variabilities over a 10-year period." *2021 Virtual AIChE Annual Meeting*, November 15-18, 2021.

Supporting Slides



Supply Chain Sustainability Analysis
Pacific Northwest
Analysis & Sustainability Interface (Multi-criteria)
NREL
Strategic Analysis Support (Multi-criteria)
GREET Development (LCA)
Argonne NATIONAL LABORATORY
Algae LCA (LCA)
Biomass Sourcing
OAK RIDGE National Laboratory
Supply Scenario Analysis (Resource Assessment)
Pacific Northwest
Microalgae Analysis (Resource Assessment)
NREL
Algae System TEA (TEA)
Biomass Transport + Pre-Processing Logistics
Feedstock Supply Chain Analysis (Resource Assessment, TEA)
INL
Biorefinery Conversion
BC Analysis (TEA)
TC Analysis (TEA)
NREL
Pacific Northwest
Wet Waste HTL (TEA)
Algae HTL (TEA)
NREL
Algae System TEA (TEA)
Jet/Vehicle End-Use
Note: Additional work conducted under DMA and SDI
Feedstock Type
Terrestrial
Wet Waste
Algae

Conventional Woody Feedstock Supply Chain by Area



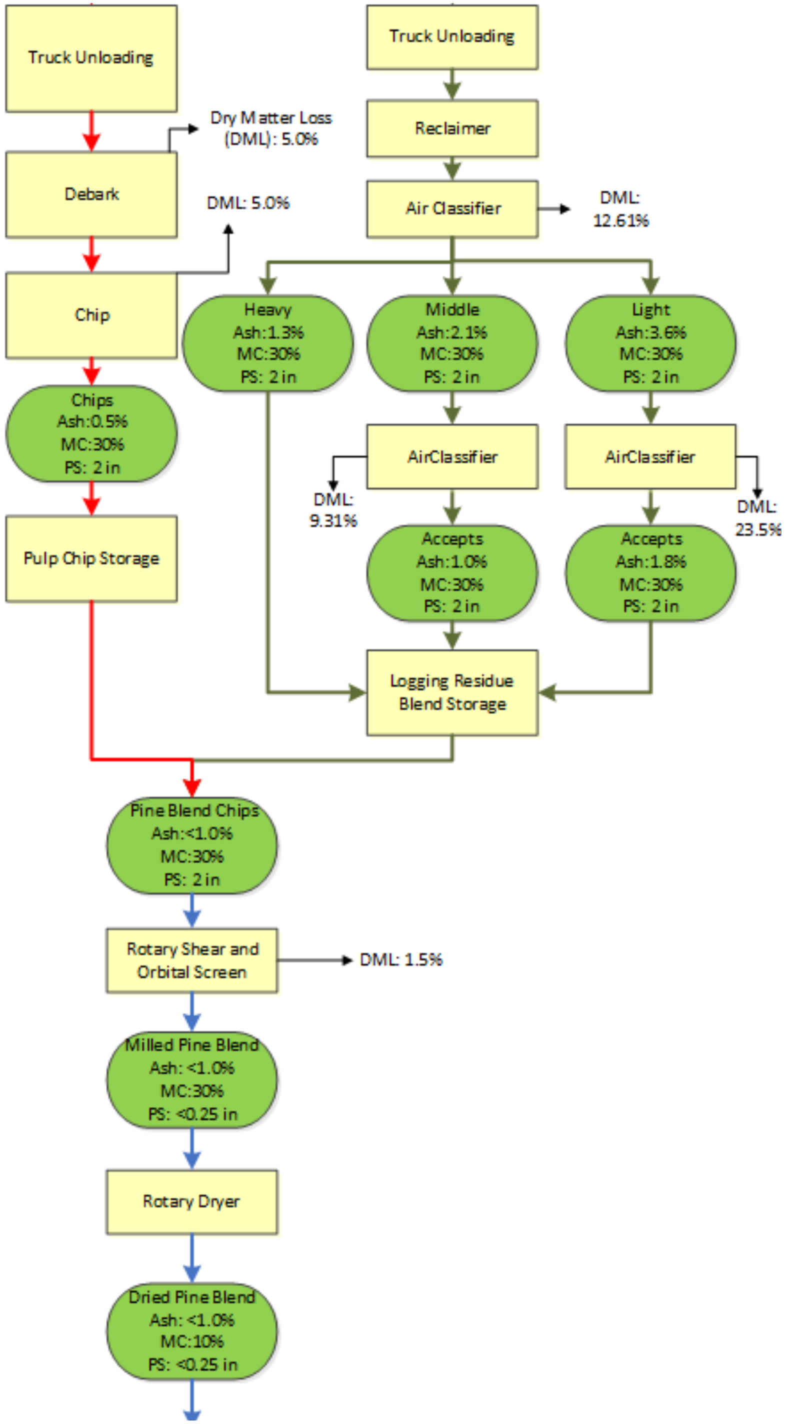
Design Approach for 2021

- Multi-stage air classification of logging residues to remove ash
- Removed material was discarded
- Blend at 50% with clean pine
- Met cost but only 76% met the CQA for compositional quality and there was a very large hit to throughput

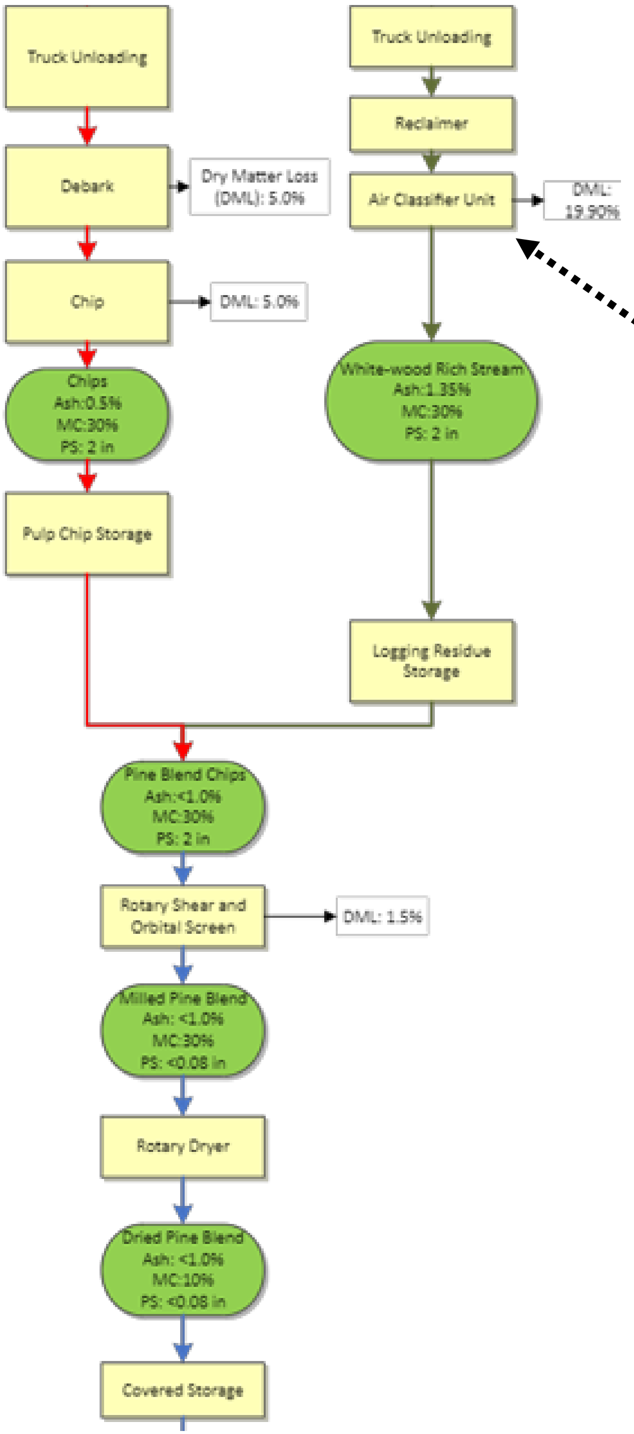
Design Approach for 2022

- Primary focus on improving throughput
- Used improved multi-stage air classification strategy to retain more whitewood
- Blend at 50% with clean pine
- Examined potential to monetize the waste stream

2021 Woody SOT – Preprocessing Flowsheet



2022 Woody SOT – Preprocessing Flowsheet



Multi-stage air classification system (design not in the public domain)

Example from the 2022 Woody SOT: n^{th}-Plant Analysis

Average costs and GHG emissions for the delivered clean pine, logging residue and the blend

	Cost ($/dry ton) (2016$)			
	Clean Pine	Logging Residue	Total[a]	GHG Emissions (kg CO_2e/dry ton)
Grower Payment	$15.73	$3.75	$9.74	
Harvest & Collection	$9.88	$0.00	$4.94	6.74
Field-side Preprocessing	$4.73	$12.09	$8.41	10.04
Transportation	$7.67	$14.02	$10.84	10.22
Preprocessing	$27.32	$30.69	$29.00	149.68
Storage	$0.68	$0.68	$0.68	0.90
Handling	$2.65	$2.65	$2.65	0.81
Preprocessing Construction	$2.96	$2.96	$2.96	
Grand Total	**$71.62**	**$66.84**	**$69.23**	**178.39**

a The total is a weighted average of the blend components, with 50% clean pine and 50% logging residue.

Progression of costs from 2019-2022

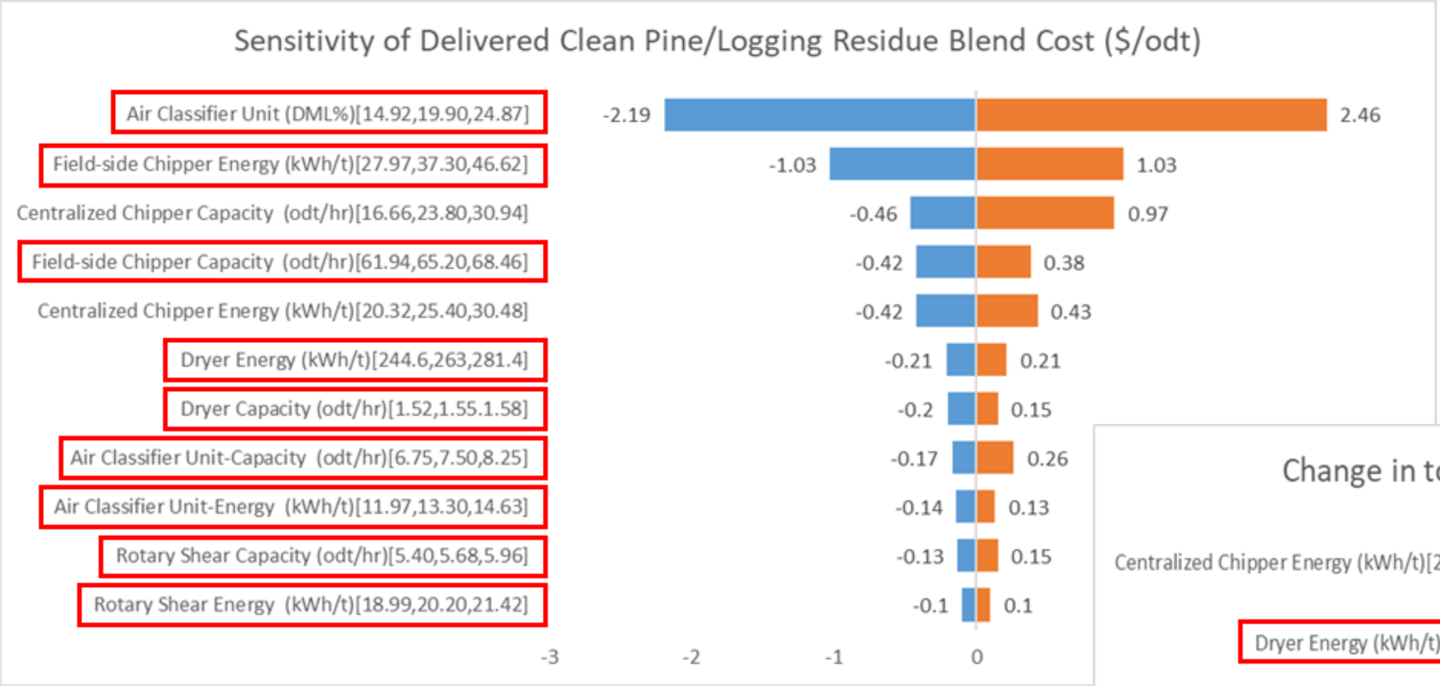
	Cost Summary ($/Dry Ton) (2016$)			
	CFP 2019 SOT	CFP 2020 SOT	2021 SOT[b]	2022 SOT[c]
Grower Payment	$9.74	$9.74	$9.74	$9.74
Harvest & Collection	$4.94	$4.94	$4.94	$4.94
Field-side Preprocessing	$8.41	$8.41	$8.41	$8.41
Transportation	$12.22	$12.22	$12.22	$10.84
Preprocessing	$28.55	$25.43	$34.27	$29.00
Storage	$0.68	$0.68	$0.68	$0.68
Handling	$2.65	$2.65	$2.65	$2.65
Preprocessing Construction	$2.96	$2.96	$2.96	$2.96
Quality Dockage	$0.00[a]	$0.00	$0.00	$0.00
Grand Total	**$70.15**	**$67.03**	**$75.87**	**$69.23**

a The conversion process model has been updated with conversion data for this blend which accounts for yield changes, hence, dockage is not added for ash content exceeding the specification.

b The 2021 cost represents meeting the ash specification of <1% instead of <1.75% as in previous years, disposing of below quality material

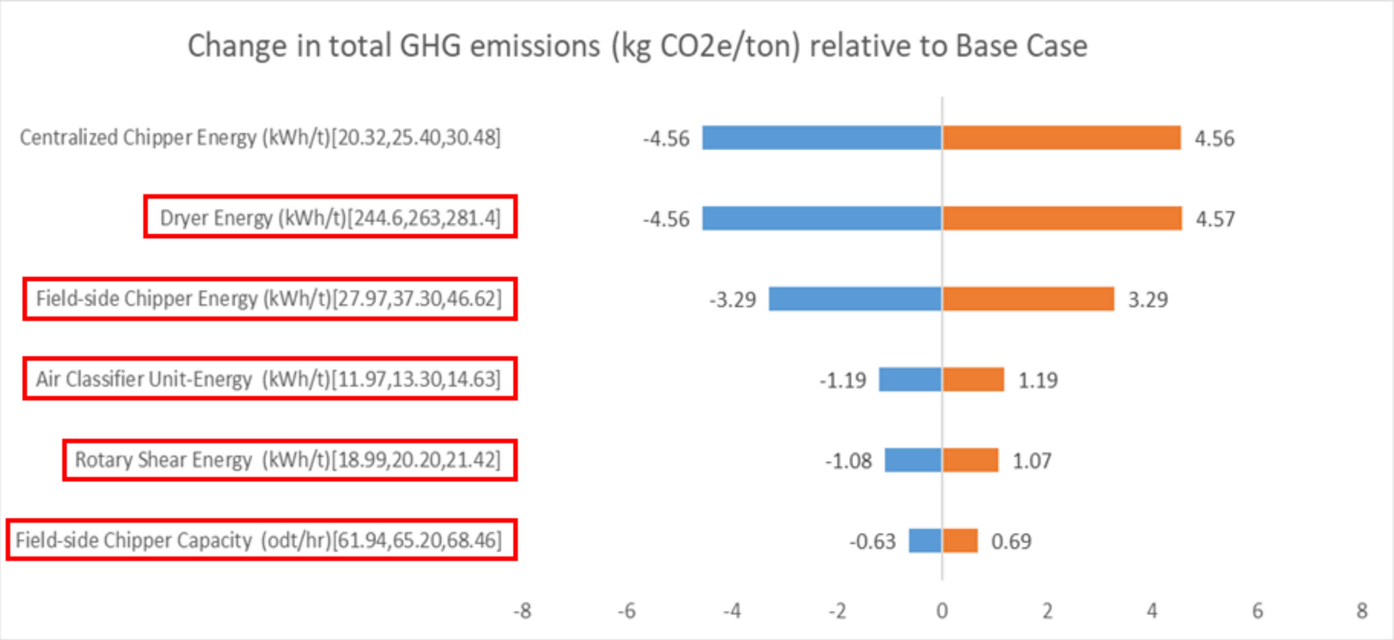
2022 Woody SOT: n^{th}-Plant Sensitivity Analysis

*Delivered Cost**

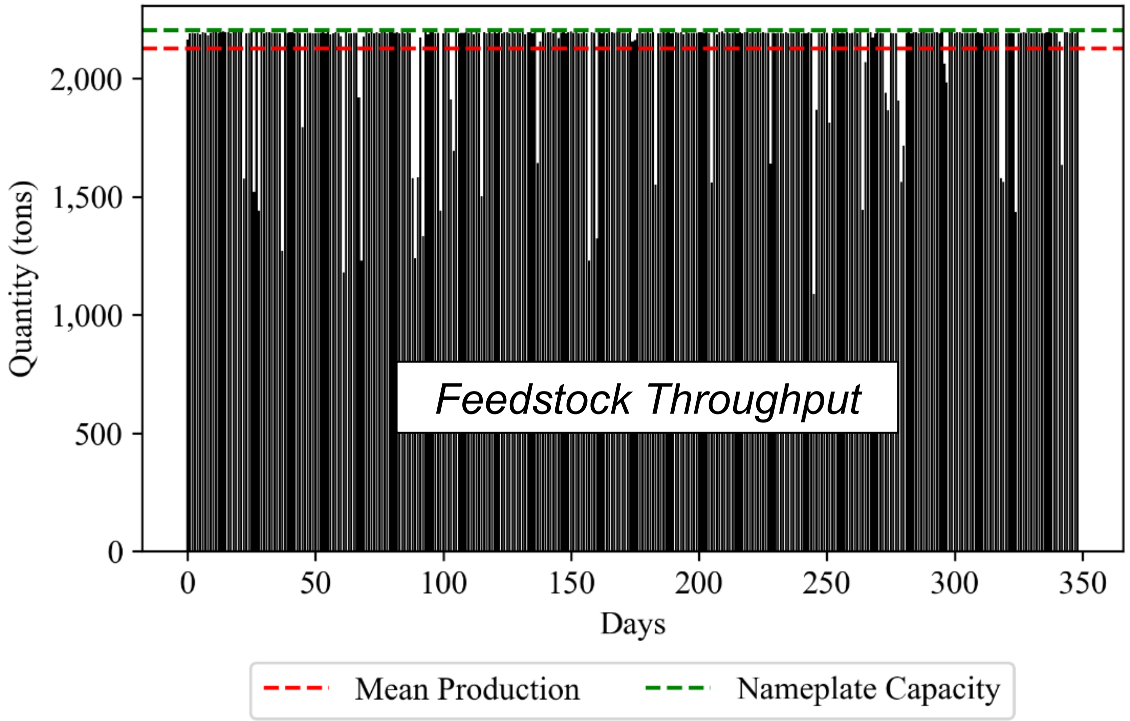


**Red boxes indicate BETO-funded*

*GHG Emissions**



2022 Woody SOT: 1st-Plant



Failures & Downtime	2022 SOT
Total Failures	**160**
Moisture Failures (% of Total)	0%
Ash (Wear) Failures (% of Total)	37.5 %
Regular Failures (% of Total)	62.5%
Total Operating Time (350 days) (min)	**504,000**
Total Downtime (min)	**61,307**
Moisture Downtime (% of Total)	0%
Ash (Wear) Downtime (% of Total)	37.4%
Regular Downtime (% of Total)	62.6%
Actual time-onstream (350 days) (%)	**87.84%**
Actual time-onstream (365 days) (%)	**84.23%**

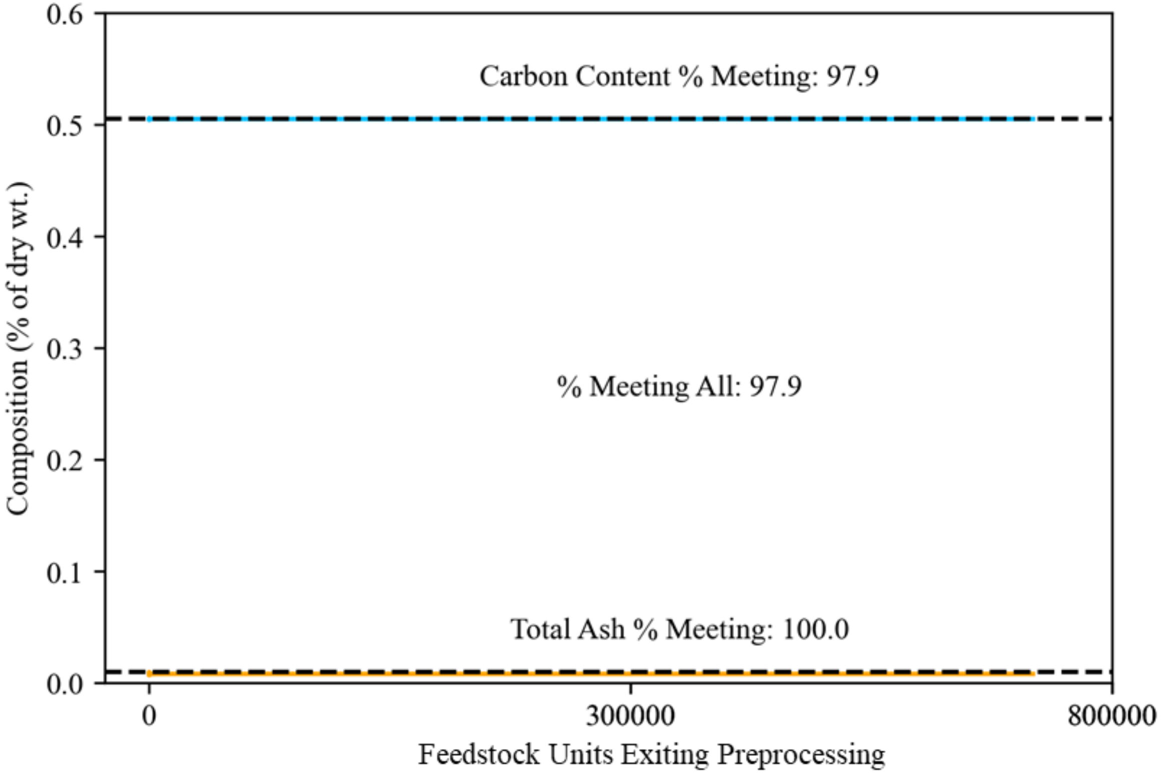
	$/dry ton (2016$)
Mean Production Cost	$71.66
Cost of Delays	$3.45
Total Production Cost	$75.11

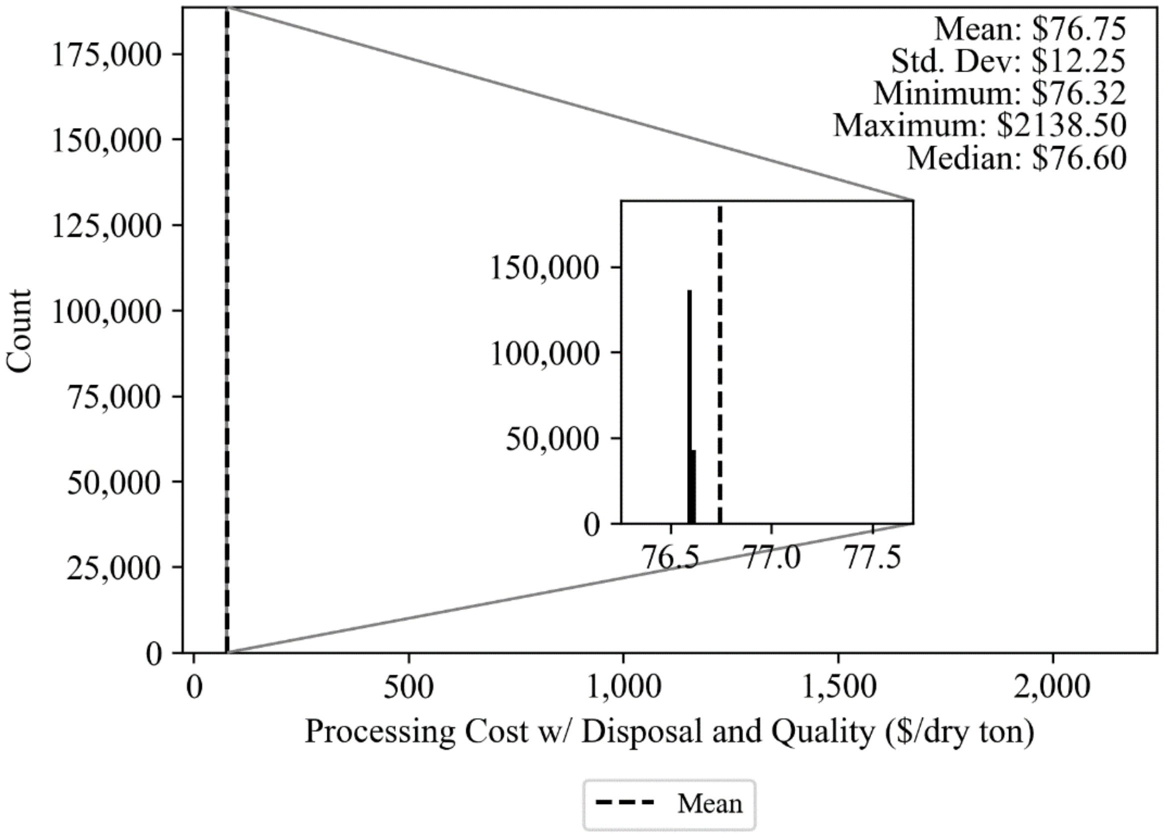
For Comparison: nth-Plant

Time on-stream = 90%

Delivered Cost = $69.23/dt

2022 Woody SOT : 1st-Plant





Cost of Preprocessed tons not meeting = $1.64/dry ton

Total Delivered Cost = $76.75/dry ton

Impact of fractionation on delivered quality

$$Supply\ Logistics: \quad OOE_S = F_{f,S} \times F_{B,S} = 1.000 \times 0.3250 = 0.3250\ (32.50\%)$$

$$Preprocessing: \quad OOE_P = F_{f,P} \times F_{B,P} = 0.9964 \times 0.9790 = 0.9755\ (97.55\%)$$

Impact of operational impacts on throughput

Modeled progress toward cost and performance goals for woody thermochemical conversion feedstock (CFP)