

# **DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review**

## **WBS 1.2.3.3 Biomass Feedstock User Facility – Improving Bale Deconstruction and Material Flow**

March 4

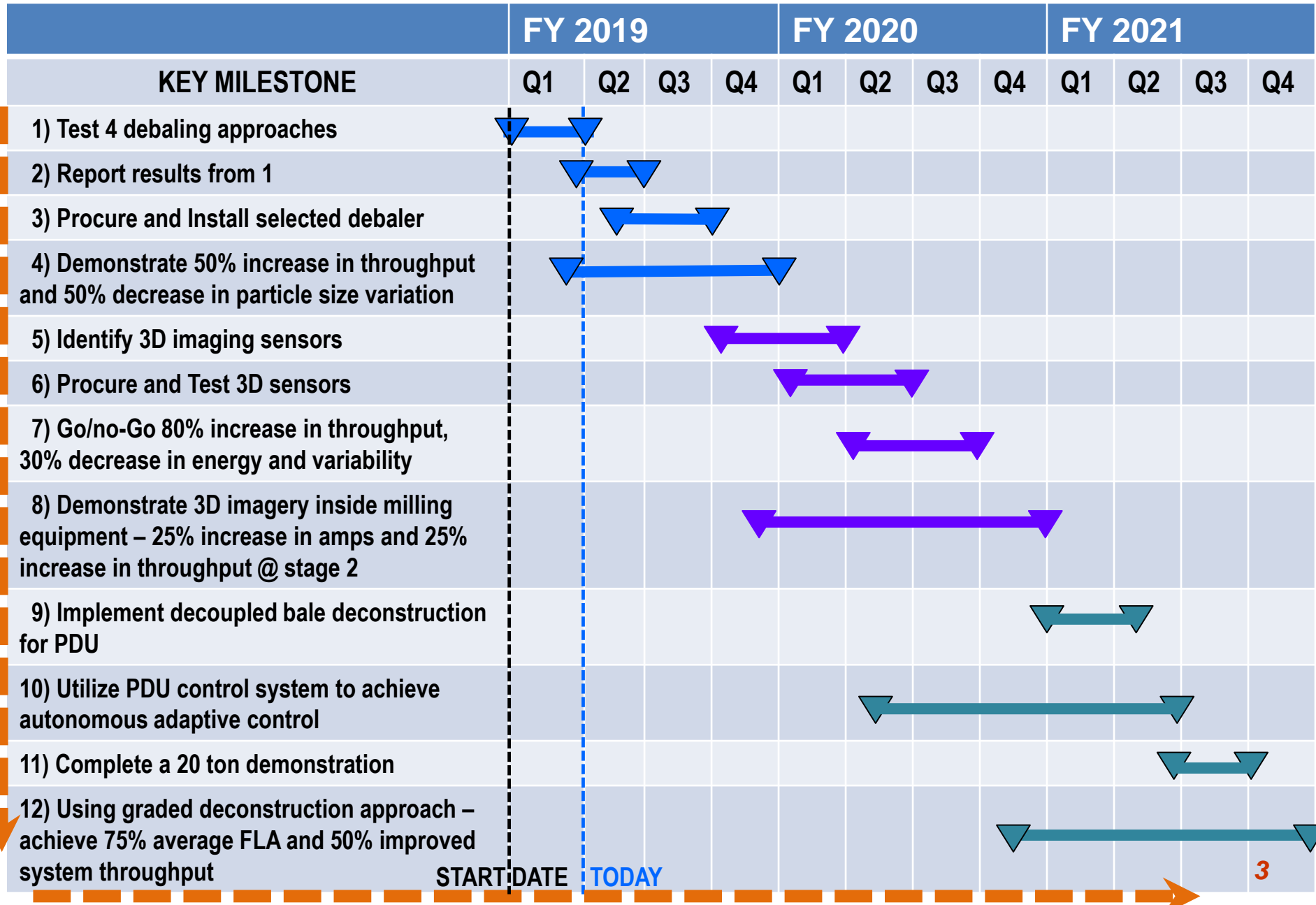
Bioenergy Technologies Office (BETO)  
Advanced Development and Optimization (ADO)  
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Idaho National Laboratory

# Goal Statement

- This project has both technical and programmatic goals
  - Technical goal – decouple bale deconstruction from size reduction and develop sensor and visualization modeling capabilities to enable an “Energy to Molecules” concept
    - Create a uniform flow from heterogeneous non-uniform feedstocks
    - Create uniform quality feedstocks from highly variable source materials
    - Determine and model material flow and deconstruction phenomena inside milling/grinding equipment using real time sensors and 3D imaging
  - Programmatic goal – increase BFNUF utilization to greater than 60%
- The project advances the BETO goal of growing a bio-economy by developing robust biomass preprocessing strategies to overcome feedstock variability and feed handling challenges faced by the biofuel and bio product industries
- The successful achievement of these goals will result in successful bio refinery startup and operation – leading to improved National energy independence.



# Key Milestones - Example



# Project Budget Table - Example

	Original Project Cost (Estimated)			Project Spending and Balance		Final Project Costs
Budget Periods	DOE Funding	Project Team Cost Shared Funding	Contingency	Spending to Date	Remaining Balance	What funding is needed to complete the project.
BP1 (BFNUF User Facility)	\$4.35M	-	-	\$387K	\$3.96M	\$3.96M
- In-Situ Process Monitoring	\$596K	-	-	\$70K	\$526K	\$526K
- User Facility Maintenance	\$820K	-	-	\$80K	\$740K	\$740K
- Testing Bale Deconstruction/Fractional milling	\$600k	-	-	\$191K	\$415	\$415
- Automated Test Report and Database Management	\$200K	-	-	\$46K	\$154K	\$154K
- CRADA Light DFO Collaborations	\$1M	-	-	0	\$1M	\$1M
- Equipment Upgrades	\$1M	-	-	0	\$1M	\$1M

# Quad Chart Overview

## Timeline

- Project start date: 10/01/18
- Project end date: 09/30/21
- Percent complete: 12%

## Budget

	Total Costs Pre FY 17	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-FY21)
DOE Funded		\$1.95M	\$1.74M	\$4.35M

## Barriers

- ADO-H Materials Compatibility, and Equipment Design and Optimization -- Inability of equipment to eliminate surges in biomass
- At-B Analytical Tools and Capabilities for System-Level Analysis – Variability in biomass properties and ability to identify appropriate sensors to accomplish.

## Partners

- NREL, PNNL, LBL
- Virginia Commonwealth University
- Forest Concepts
- Bliss
- Vermeer
- Rotex
- Warren and Baerg
- Bulk Handling Systems
- B. Hames Consulting

# 1 - Project Overview

## Project Objectives for Improving Bale Deconstruction and Improving Material Flow:

*Solve industrial feed handling problems associated with variability in biomass properties by developing a segmented bale deconstruction process that prevents slugging or surging of biomass – improving throughput and product quality.*

Technology	Throughput (T)	Quality (Q)	Reliability (R)
Conventional Feedstocks Preprocessing	Low T, uneven flow, inability to adjust to changing biomass characteristics	Low Q, inability to maintain consistent particle size, ash content, and other compositional components	Low R, frequent plugging often resulting in equipment damage
Advanced Feedstock Preprocessing	High T, able to adjust to changing properties to achieve uniform flow	High Q, able to adjust autonomously to maintain quality compositional characteristics	High R, less down time observed

### **Conventional feedstock processing results in:**



Down time to unplug equipment



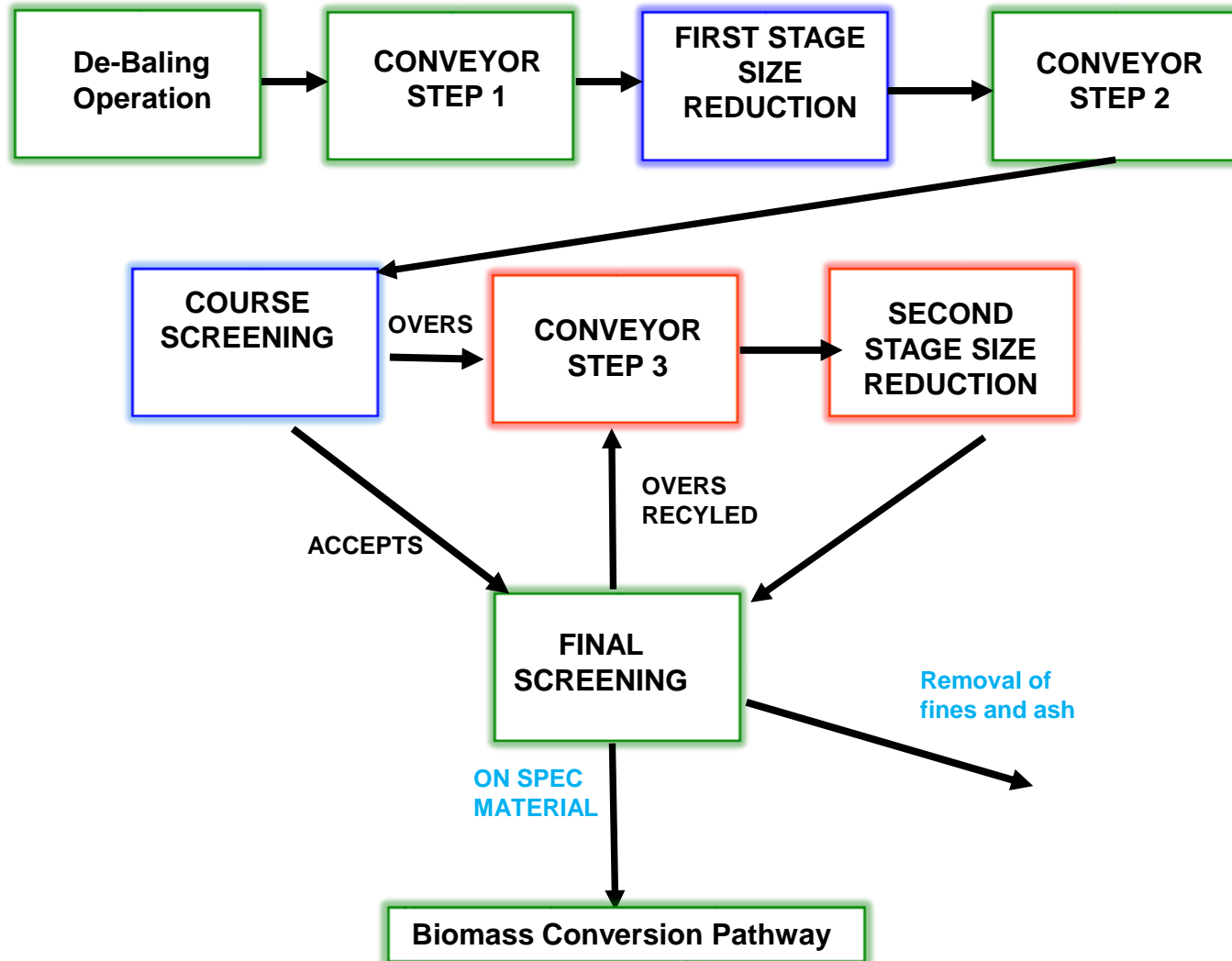
Down time replacing damaged equipment



# 2 – Approach (Technical)

- **Technical Approach (Quality by Design)**
  - *Decouple bale deconstruction from 1<sup>st</sup> stage size reduction*
  - *Test to determine improved material flow following bale deconstruction*
  - *Develop segmented bale deconstruction methodology for the PDU*
  - *Remove rock/tramp metal from infeed early in the process*
  - *Develop screening methodology to achieve consistent particle size regardless of infeed conditions*
  - *Develop inline and visual 3-D sensors to monitor real time quality metrics and equipment performance criteria*
  - *Increase User Facility Participation*
- **Success Factors**
  - *Achieve uniform flow, name plate throughput, decrease particle size variability*
  - *Engage industry to identify major equipment issues*
  - *Identify real time, inline sensors that measure critical material characteristics or mechanical operating conditions that have otherwise not been observed.*
  - *Identify industrial partners who will team with the BFNUF to demonstrate commercial viability of this project*
- **Potential Challenges**
  - *Lack of reliable in-line sensors*
  - *Unable to meet feedstock specifications for various conversion pathways*
  - *Unable to bring in enough business to be self-sustaining.*

# Process Operations Block Diagram – BFNUF PDU





# 3D and Inline Sensor Block Diagram – BFNUF PDU

Raw Biomass Feedstocks

Moisture  
Ash  
Color  
Sugars  
Age

De-Baling Operation

Moisture  
Ash  
Color  
Particle Size  
Plant Fraction



High Speed Image of Hammer Impacting Stover

FIRST STAGE SIZE REDUCTION

Moisture  
Ash  
Particle Size  
Sugars  
Plant Fraction

COURSE SCREENING

Moisture  
Ash  
Plant Fraction  
Particle Size  
Sugars

SECOND STAGE SIZE REDUCTION

Moisture  
Ash  
Particle Size

FINAL SCREENING

Moisture, Ash, Particle Size

3D Imagery  
• Thermal  
• Visual  
• Mass Flow



Typical corn stover ↑

Color could be used to detect level of degradation!

Heat degraded stover ↓



# 2 – Approach (Management)

- *Project Scope for User Facility*
  - *Decouple bale processing from size reduction and initial segmented bale deconstruction*
  - *Single unit operation and integrated testing (Using a Quality by Design approach)*
  - *Inline sensor development, particle image velocimetry and optical flow visualization*
  - *Proprietary projects pay 100%*
  - *Non-proprietary project's required cost share*
- *Management Tools*
  - *BETO-sponsored and competitively awarded projects have priority*
  - *DOE review and approval of external projects*
  - *Industry Advisory Board*
  - *Marketing/trade shows for networking*
- *Success Factors*
  - *Become Self Sustaining – Increase number of projects, users, publications/patents*
  - *Knowledge gained and improve technologies for customers*
  - *Significant improvements to reliability of preprocessing systems*
  - *Achieve nameplate throughput and uniform quality*
  - *Successful identification and implementation of inline sensors*
- *Challenges:*
  - *Meeting feedstock specifications for different conversion pathways*
  - *Getting enough business to be self sustaining*

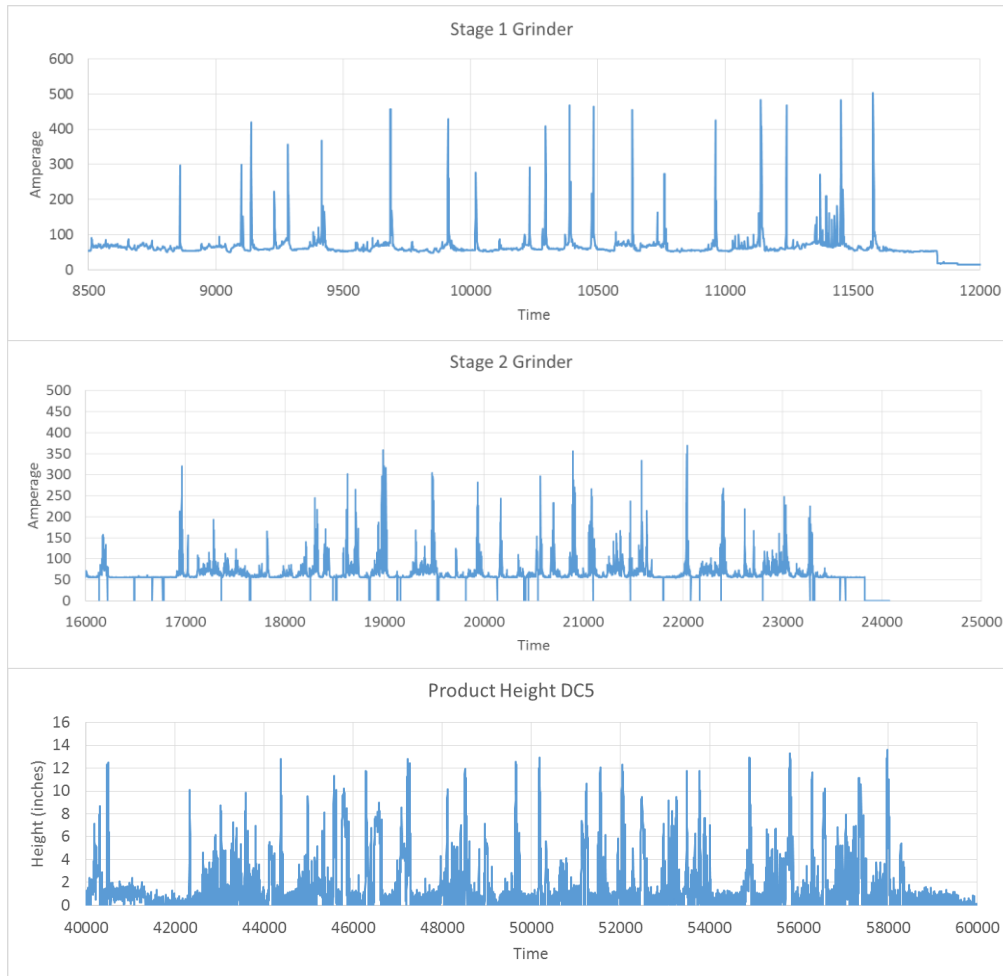
# 3 – Technical Accomplishments/ Progress/Results (cont'd)

- *Testing bale feeding technologies*
  - *Low speed / high torque -- similar to that used in the livestock industry*
  - *Medium speed high torque bale processor – Industry Scale (Warren and Baerg and Conners)*
  - *Round and square bale capabilities*
- *We are currently comparing the data from those tests*
- *Work with the User Facility is usually slowest during the 1<sup>st</sup> Quarter. However, there were 15 tests conducted on the user facility during FY19 Q1:*
  - *8 tests with round and square bales with debaling equipment*
  - *1 grinding test with miscanthus*
  - *1 grinding test with MSW*
  - *2 drying tests with pine*
  - *2 drying tests with brewery waste*
  - *1 grinding test with pine*

# 3 – Technical Accomplishments/ Progress/Results (cont'd)

Comparison of Stage 1 and stage 2 amperage and product level in the conveyors during FY18 FCIC low temperature baseline testing

This demonstrates how inconstant the flow of biomass is – resulting in very poor performance



- Average current in stage 1 Grinder is 69 amps
- Normal full load operating current is 150 amps.
- Peaks exceed 3X full load amps while the average is less than ½ of the FLA

- Average current in stage 2 Grinder is 72 amps
- Normal full load operating current is 170 amps
- Peaks are 2X FLA and the average is less than half FLA

- Average product flow is 2 inches which is ~ same as the through put (2 ton/hr)
- Peaks are greater than 12 inches
- The name plate through put is 5 tons per hour so again, less than half of design capacity

# 3 – Technical Accomplishments/ Progress/Results (Cont.)

- *Test bale processors in FY19 Q1*
- *All of the bale processors showed improvements in material flow*
- *The design pictured at right has a patented dual feed rate for blending bales of different moisture or other attributes at different feed rates*



Industrial Mid-Speed Bale Processor



Low Speed High Torque Processor

### 3 – Technical Accomplishments/ Progress/Results (cont'd)



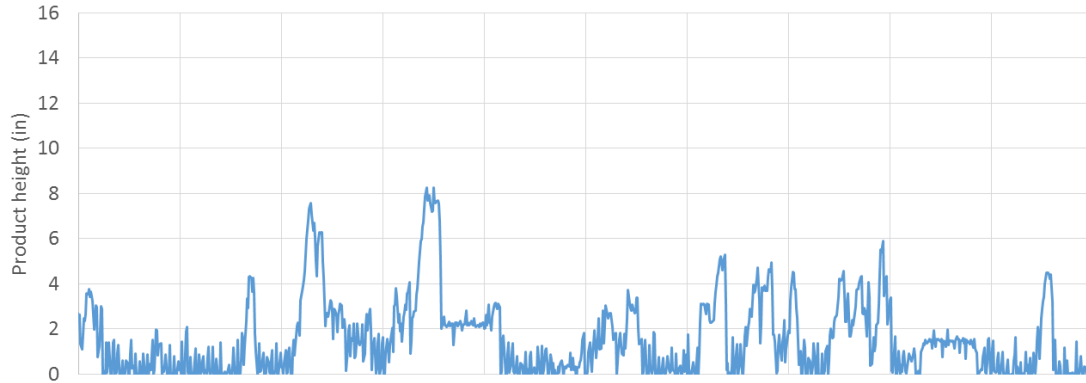
Low rpm debaling results in less fines generated and a uniform flow into downstream processing



Mechanical product level sensors measured the flow of material from the debaler.

# 3 – Technical Accomplishments/ Progress/Results (cont'd)

Product Height DC5 (inches) FCIC Run 3



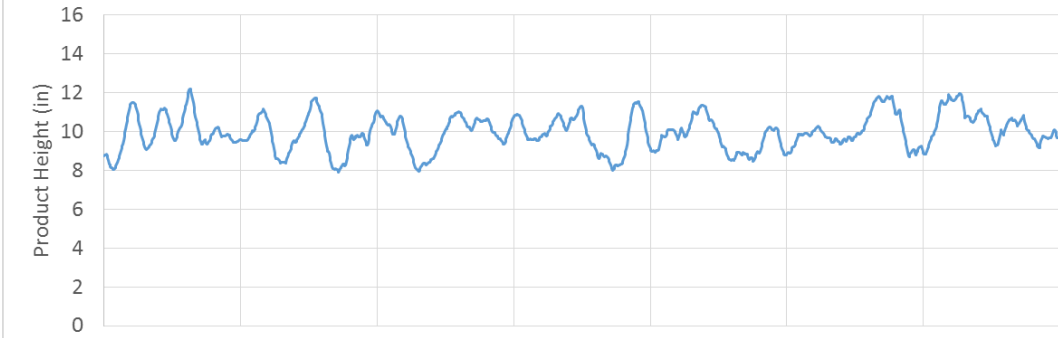
Uneven Flow caused by high speed combined bale processing and size reduction



Much less variation in flow when bale processing is decoupled from size reduction



Product Height (in)



# 4 – Relevance

*Biomass feed handling remains one of the major barriers for success in the cellulosic biomass industry*

- *Biomass handling problems were blamed for slow start-up of biorefiners. This was confirmed in the 2018 FCIC baseline tests where material handling problems, were the primary reason for failure and inability to achieve nameplate throughput*
- *Overcoming material surging will:*
  - *Increase system throughput*
  - *Improve particle size uniformity*
  - *Reduce energy costs*
  - *Increase system reliability*





# 4 – Relevance

- Rand Corporation study (Merrow, 1984) showed that plants that process bulk solids typically operate at less than 50% of design capacity the first year of operation – Performance of 37 new plants using data provided by 25 companies
- Problems generally relate to an [inadequate understanding of the behavior of elastic & compressible particle systems](#) (Bell, 2005). This observation is still true today.

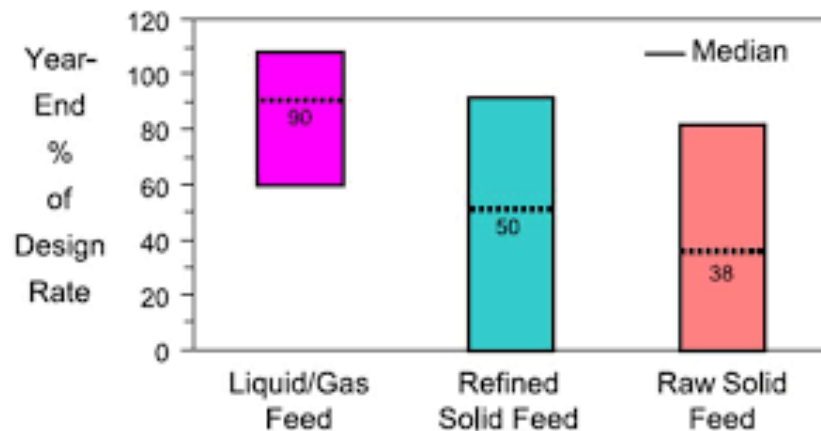


Image source: Merrow, 1984 (Rand Corp. P-7034)

# 4 – Relevance

- User Facility projects depend upon collaboration with industry to address real world feedstock handling problems
- User Facility projects are helping INL and BETO
  - Understand range of feedstock specifications for different conversion pathways
  - Understand the gap between specifications and what is achievable at an industrial scale
  - Identify innovative solutions to industrial preprocessing needs (closing the gap)
  - Supply data to support BETO techno-economic assessments and state of technology reports
- Collaborations are helping our partners (users)
  - Develop robust feedstock preprocessing technologies that enhance the reliability of integrated biorefineries
  - Scale up from pilot scale to industrial scale

# 5 – Future Work

- *Complete testing, reporting and implementation of bale processing prior to stage 1 grinding*
- *Develop Segmented Bale Deconstruction using a Quality by Design approach– integrate bale processor, stage 1 and 2 milling, screening to achieve 50% improvement in throughput and reduce particle size variation*
- *Identify and implement 3D imagery within the milling process*
- *Go/No-Go Milestone (Q2 FY20) will demonstrate the ability to eliminate material slugging and incorporate fractional milling/screening to increase throughput by 80% over baseline methods and achieve 30% reduction on particle size variability.*
- *This project has just completed the 1<sup>st</sup> quarter of work and is still on budget to complete all of the tasks as outlined.*
- *Expand user facility capabilities*
  - *Add screening system to facilitate fractional milling and improve particle size distribution of feedstock*
  - *Add inline/real-time sensors*

# Summary

## 1. Overview

The INL BFNUF User Facility provides a critical capability for projects that require an integrated system with data logging/analysis capability that are too complex for industry test laboratories/facilities. Enabling the ability to scale up pilot scale solutions to achieve industrial scale validity.

## 2. Approach:

Eliminate material slugging by decoupling bale deconstruction with 1<sup>st</sup> stage size reduction. Engage industry with project development to ensure relevance to industry and DOE/BETO

## 3. Technical Accomplishments/Progress/Results

Eliminate material slugging/improve material flow

Enable real-time sensor utilization

## 4. Relevance

Developing robust feedstock preprocessing technologies will help accelerate the expansion of a bioeconomy

Increase product quality for down stream conversion processes

## 5. Future work

Develop 3D imaging within the grinder chamber to increase understanding and cause/effect of material properties and product quality.

# Additional Slides

# Publications, Patents, Presentations, Awards, and Commercialization

## Publications:

- Kenney, K. L. and K. G. Cafferty, J. J. Jacobson, I. J. Bonner, G. L. Gresham, J. R. Hess, L. P. Ovard, W. A. Smith, D. N. Thompson, V. S. Thompson, J. S. Tumuluru, and N. Yancey. 2013. "Feedstock Supply System Design and Economics for Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels. Conversion Pathway: Biological Conversion of Sugars to Hydrocarbons: The 2017 Design Case." Idaho National Laboratory Report. INL/EXT-13-30342.
- Quang, N, J.S. Tumuluru, L. Wendt, and N.A. Yancey. Design and Testing of Tobacco Residue Supply Chain Processes. 2018.
- Tumuluru et al., Impact of Feedstock Supply System Unit Operation on Feedstock Cost and Quality for Bioenergy Applications. Chapter 1. 2016
- Tumuluru, J. S. and N. Yancey, R. McCulloch, C. Fox, C.C. Conner, D. Hartley, M. Dee, and M. Plummer, 2017. Biomass Engineering: Size reduction, drying and densification of high moisture biomass. Feedstock supply and logistics platform, DOE, Project Peer Review, US. Department of energy, Bioenergy Technologies Office, March, Denver, Colorado, 7th, 2017
- Tumuluru and Yancey. Conventional and Advanced Mechanical Preprocessing Methods for Biomass: Performance Quality Attributes and Cost Analysis.
- Yancey, N. A. and J. S. Tumuluru and C. Wright. 2013. Grinding and densification studies on raw and formulated woody and herbaceous biomass feedstocks. J. Biobased Mater. Bio. 7(5): 549-558.
- Yancey, N. A. and J. S. Tumuluru. 2015. DOE Quarterly Milestone Completion Report. Idaho National Laboratory.
- Yancey, N. A. Impact of Moisture, Ash, and Bale Degredation of Preprocessing Performance and Feedstock Quality. 2019. 41<sup>st</sup> Symposium on Biotechnology for Fuels and Chemicals.

# Publications, Patents, Presentations, Awards, and Commercialization

## Patents/Invention Disclosures

- Intelligent, adaptive control system for integrated preprocessing of biomass feedstocks
- Bale Grinder Flow Controller
- Method for producing cellulosic ethanol in dry grind ethanol plants
- Biomass Axial Flow Preprocessing And Separation System
- Simultaneous Lignocellulosic Biomass Preprocessing And Drying
- Biomass Sizing And Thermal Densifying Unit
- Drying Of Biomass Bales Using Radiofrequency And Conventional Method
- Reducing Off-gas Emissions From Stored Woodchips, Sawdust And Wood Pellets