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William A. Smith
Idaho National Laboratory
Biological & Chemical Processing

DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

Feedstock Supply and Logistics

WBS 1.2.1.1: Feedstock Harvesting & Storage: Post-Harvest Management for Quality Preservation

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Idaho National Laboratory

Project Overview

- *Pre-2012:* Showed conventional equipment in high-production conditions met quantity needs
- *2012-2015:* Showed equipment impact on quality—Quantified dockage for "off-spec" material
- *2015-2018:* Evaluated moisture migration & microbial activity in storage—impact on cost & quality
- *2018-2021:* Developed modeling & analyses of complex biological/physical changes in storage—utilize storage time for beneficial effects of drying & preservation; collect valuable information

- *Project Goals:*
  - *Utilize harvest & storage to identify/control critical feedstock properties impacting preprocessing & conversion (Ft-F. Biomass Storage Systems)*
    - *Currently contractually prescribed &/or "accept/reject" at plant gate*
  - *Develop tools—analytical & computational—to predict feedstock performance (Ft-E. Feedstock Quality: Monitoring & Impact on Preprocessing & Conversion Performance)*
    - *Model the grain industry's tools for pricing*
  - *Enable informed decisions & mitigation strategies to maintain quality & assure operability*
    - *Focus on critical material attributes*

Management

<u>Task Breakdown:</u>

- Interrogation of Fundamentals of Moisture Migration & Bio-deterioration After Harvest
  - Field trials, demonstrations, and INL storage environmental chambers

- Reactive Transport Modeling in Bulk & Baled Biomass
  - INL Biomass Feedstock National User Facility (BFNUF) & INL computational modeling

- Chemical & Biological Screening Methods for Baled & Bulk Biomass
  - Feedstock Conversion Interface Consortium (FCIC)

- Forest Residue Storage/Conditioning (NEW)
  - INL BFNUF & Annual Operating Plans (AOPs)

Management (cont.)

- Identify early supply chain problems at scale via industry collaborations with feedstock aggregators, biorefineries, & university partners near pioneer biorefinery supply-sheds
  - Currently working with Antares Group, Inc. & Iowa State University (Small Business Innovation & Research grant)
- Working directly with INL's Process Development Unit (PDU), Research Library, & FCIC to identify critical material attributes
  - Work with INL's Analysis Group to quantify milestones & Go/No Go decisions
- External partners provide access to (1) relevant biomass materials, (2) direct experience with harvesting and storage related challenges, (3) expert opinions regarding practicality &/or costs of implementing/adopting mitigation strategies
- Communications:
  - Peer reviewed presentations, manuscripts, & monographs
  - Participation in professional webinars & symposia
  - Monthly meetings with Bioenergy Technologies Office (BETO) management & Feedstock Supply members

Approach

Challenges:

- Identify preprocessing problems arising from harvesting & storage
  - From 2019 Peer Review: "Describe details of proposed mitigation strategies"
  - Research at a range of scales—stacks, bales, & storage simulation chambers
- Address commercial-scale problems with relevant materials
  - Partially overcome by ongoing PDU work via AOP &/or "toll processing"
- Focus on the show-stoppers: soil entrainment (ash) and instability related to storage moisture
  - Start with "universal" problems—those that affect the broadest scope of high-impact biomass
- Prioritize based on level of impact
  - Rely on industry input & BETO programmatic targets identified via technoeconomic analyses (TEAs)

Approach (cont.)

- Milestones:
  - Show technical improvements using experimental results & computational modeling
  - Show cost improvements using INL's Analysis Task's annual State of Technology (SOT) reports, which assume n^{th} plant (steady-state & everything works)
  - Research & report available industry "as-is" data as available
- Go/No Go Milestones:
  - Met 2020 goal of moisture reduction from 30% to <20% at a cost of $3.86/DMT (1.5 x 2017 SOT cost for storage)
    - Partition materials into "stable" and "at risk"
    - Propose more costly storage solutions for a fraction of "at-risk" materials; cost offsets may come from lower cost storage of "stable" materials
    - Relaxed cost targets permit evaluation of more innovative solutions

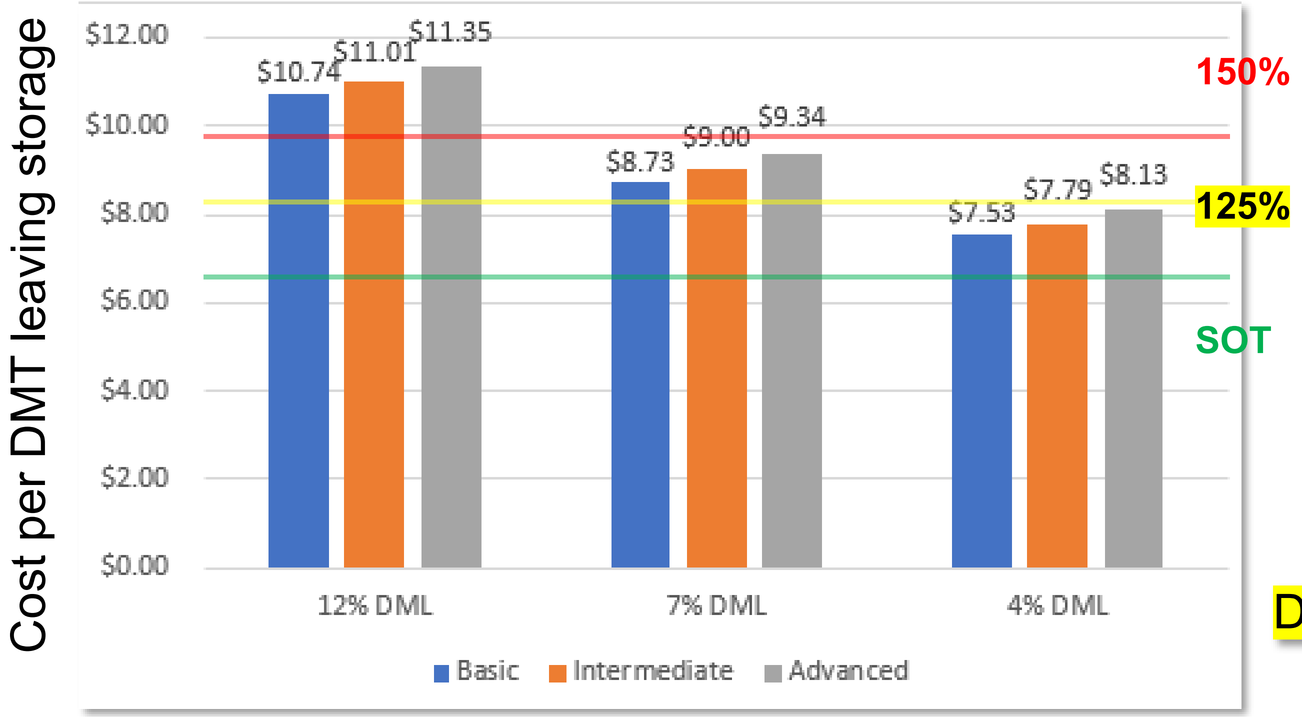
Impact

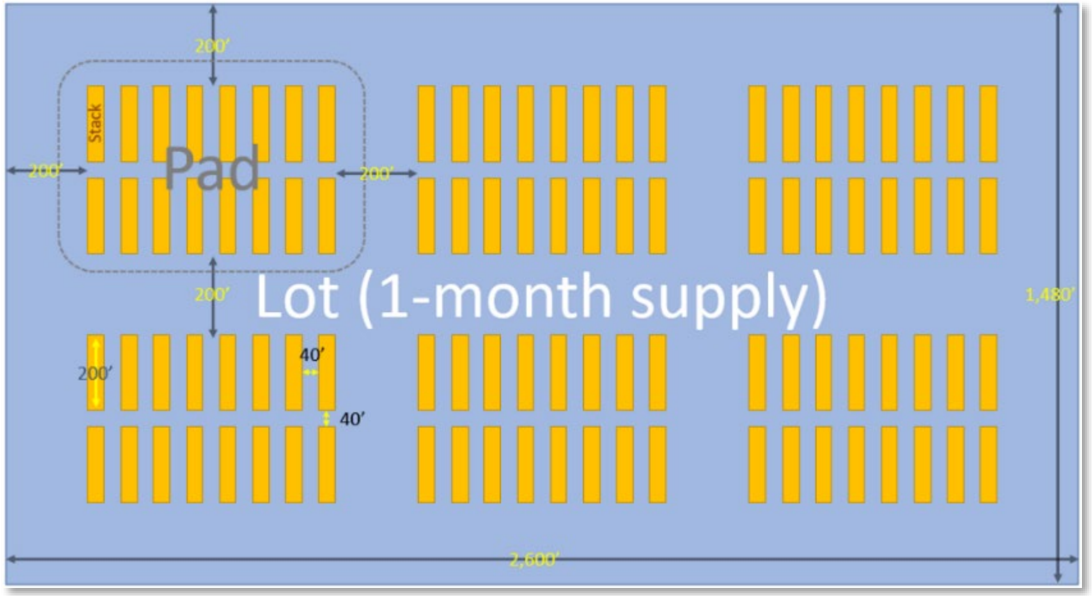
- Annually-harvested biomass requires storage to enable year-round operations
  - Outdoor storage exposes valuable feedstock to dynamic conditions
  - Unchecked, these changes result in physical & chemical degradation
- Pioneer biorefineries experienced storage related/induced problems that delayed startup
  - Rejected bales = 100% loss of all costs & efforts plus disposal costs
  - Moistures > ~25% reduce mill throughput & increase fines
- Biodegradation occurs when LOCAL (not average) moisture contents exceed ~20%
  - Moisture moves over time, but it can be anticipated
- Field-deployable tools & sensors are needed to evaluate feedstock supply/inventory
  - Rapid analyses let producers & users evaluate quality & storage stability

Progress and Outcomes

Baseline TEA of a commercial satellite bale storage system shows cost impacts of three different "as-built" designs relative to State of Technology (SOT)

- *Included land lease, ground preparations, tarping, and monthly maintenance*
- *Three levels of improvements: Basic (graded), Intermediate (graded and gravel), and Advanced (graded, graveled, and tiled).*
- *Three fixed dry matter losses (DML) were evaluated: 4% (BETO goal), 7% (2017 SOT), and 12% (INL measured for 30% moisture content stover)*





DML losses drive costs $0.40 per percent lost per DMT

Progress and Outcomes (cont.)

IF siting a storage lot on higher-value (i.e. improved drainage) land can preserve 1% in dry matter loss, THEN the cost has paid for itself

- *A cash flow analysis was run using land rent values for both pasture ($54/ac) and ($321/ac) tillable land resulting in a modest cost of $0.30 per dry matter ton. Site selection should balance revenue lost from crop yield with biomass loss from moisture-related degradation.*

Progress and Outcomes (cont.)

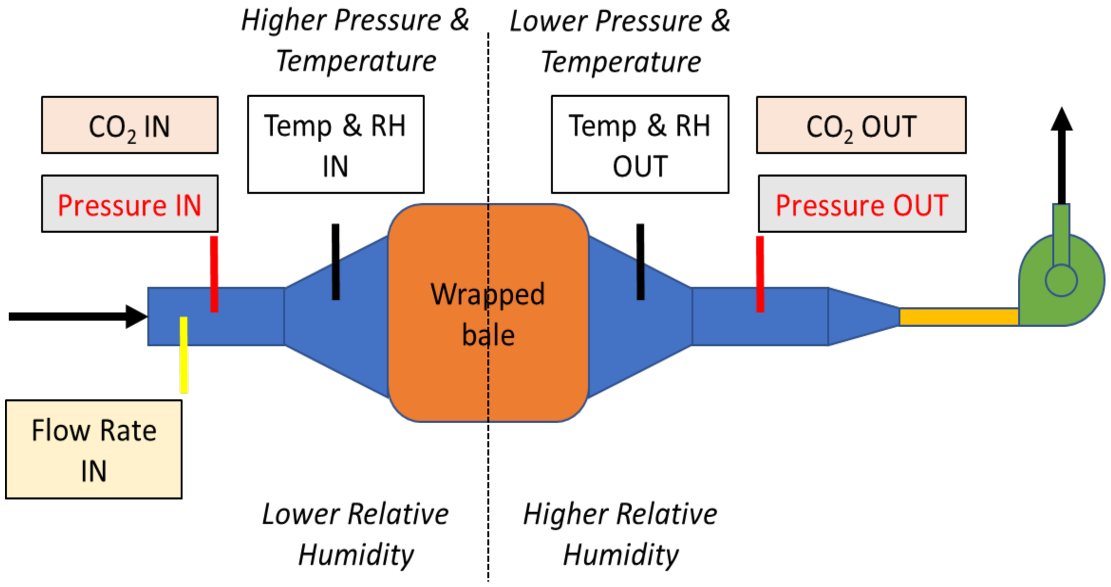
<u>Go/No-Go Milestone:</u> ***Active systems reduce moisture to <20% in 90d within 1.5x 2017 SOT cost (w/ DML)***

- ***Multi-dimensional models based on physical and biological parameters (heat flow, moisture migration, respiration, and DML) measured in INL's storage simulation/environmental chambers.***

Progress and Outcomes (cont.)

Go/No-Go Milestone: ***Results of computational models were tested at 100-L storage chamber & whole-bale scale—addressing reviewer comments from 2019 Peer Review***

- Laboratory tests using INL Storage Simulators:
  - **30% MC to 17% MC in 35 days w/ 5% DML**
  - 0.25 cm/min flow through bed
- Results using INL's Bale Permeameter:
  - **30% MC to 17% MC in 3 days w/ <1% DML**
  - 2,900 cm/min flow through bale



Progress and Outcomes (cont.)

Go/No-Go Milestone: ***Results of computational models were tested at 100-L storage chamber & whole-bale scale***

- Laboratory tests using INL Storage Simulators:
  - **Linear velocities comparable to wind-loading on stack**
- Results using INL's Bale Permeameter:
  - **Forced air pressure drop across bale on the order of < ½" water per bale**

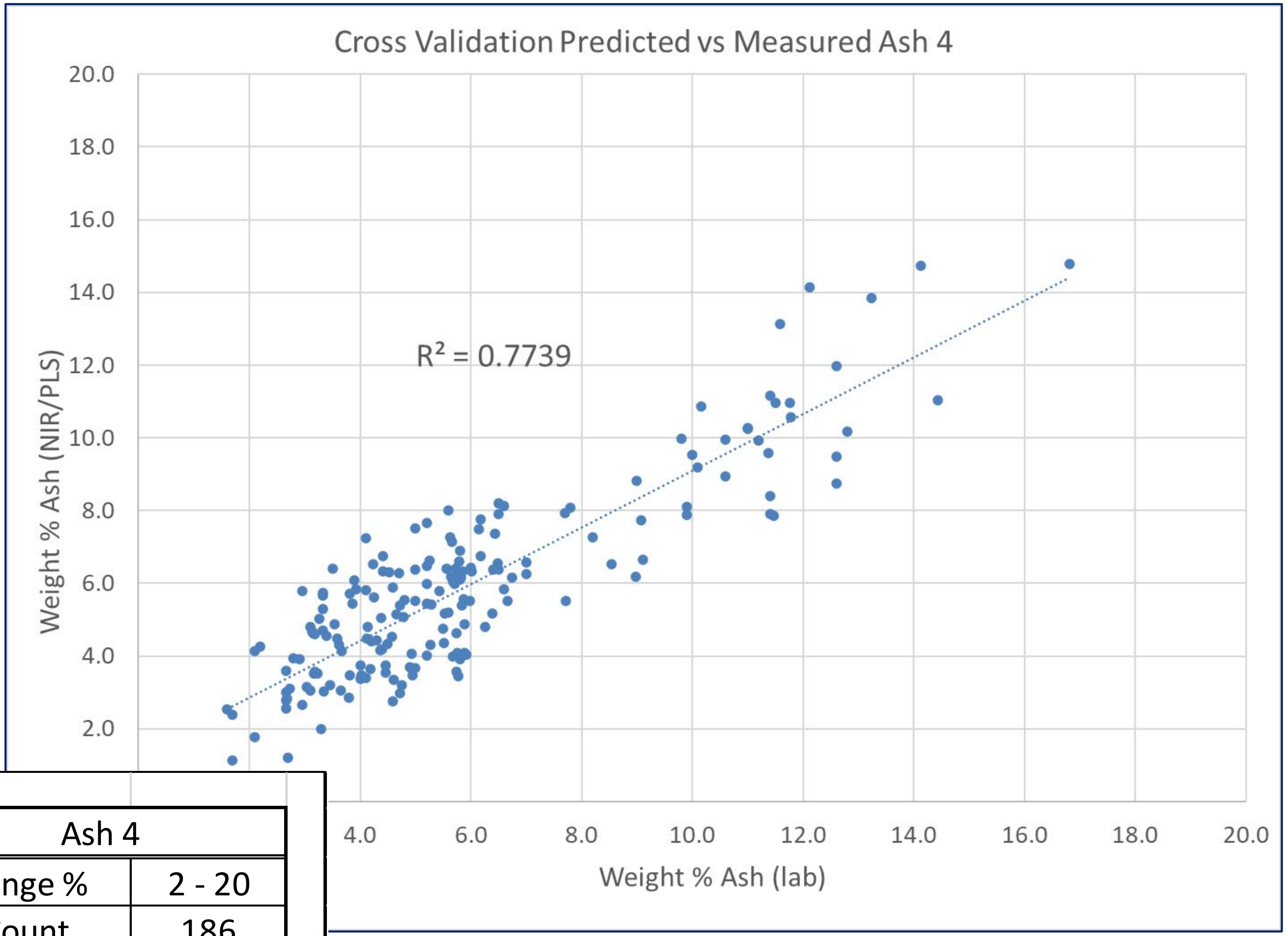
- **Calculated drying costs = $5.71/DMT includes wrap, storage, and power *(5-hp blower per 12-bale long 3-high wrapped stack, 12h on during day/12 hr off at night)***

Progress and Outcomes (cont.)

BHames Consulting

"Ash 4" Near Infrared/Partial Least Squares (NIR/PLS) model challenges

- 186 Calibration Samples
  - INL Archives
  - Emmetsburg, IA
    - Harvest, 12 months
  - Nevada, IA
    - 3-year storage study
    - 4 storage times per harvest year
    - Multiple harvest methods
    - Multiple storage options
  - Hugoton, KS
    - Harvest, 12 months



Ash 4	
Range %	2 - 20
Count	186
Factors	6
RMSECV	1.23
R^2	0.774

ANTARES

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Progress and Outcomes (cont.)

ANTARES

NIR/PLS model for potassium/calcium (K/Ca) ratio enables improved ash quantitation methods

- NIR/PLS method developed to determine K/Ca ratio
- This method used to identify high K samples for high ash calibration set
- Improved ash method developed using fewer factors
- New ash ("Ash 6") method should more accurately identify and measure ash in dirty, aged and sieved samples

Ash 6 Cal Stats	
Range %	3 - 20
Count	40
Factors	4
RMSECV	1.78
R_2	0.839

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Summary

- *Biological respiration, at the expense of minimal dry matter loss enables self heating, which can enhance drying & storage stability*
  - *Air flow rates are consistent with “wind loading” but can be increased using mechanical ventilation (grain dryer) and can reduce moisture from 30% to < 20% with ~5% DML*
- *DML & compositional changes can be predicted to permit blending thus reduce daily variations in critical feedstock qualities such as moisture, carbohydrate, & ash*
  - *NIRS can be used to measure starting conditions; models can predict stability, & by adding climate data and/or intermediate moisture/carb/ash measurements, respond to changing environmental conditions*
- *Quality biomass & data about it can be delivered to a biorefinery to enable proactive responses that preempt uncontrolled feedstock variations; this is the core of an information driven biomass supply chain design*
  - *Work needs to be done to understand physical impacts of storage & biodeterioration & its impacts on CQAs*
- *Next up: forest residues, cost-advantaged feedstocks & bioenergy crops*
- *The science of degradation is the basis for the future conditioning & advanced fractionation*

Quad Chart Overview: INL WBS 1.2.1.1 Feedstock Harvesting & Storage: Post-Harvest Management for Quality Preservation

Timeline

- 10/01/2019
- 09/30/2021

	FY20	Active Project
DOE Funding	$911,620	$2,734,860

Project Partners*

- Antares Group, Inc. (feedstock supply)
- B. Hames Consulting, Inc. (chemometrics)

Barriers addressed

- Ft. F: Biomass Storage Systems
  - Moisture dynamics in storage
  - Fundamentals of biodegradation
  - Chemical & physical impacts of instability
- Ft-E. Terrestrial Feedstock Quality, Monitoring, & Impact on Performance
  - Robust field-ready analytical tools

Project Goal

Develop a predictive understanding of moisture migration, biological degradation, & its impact on biomass quality & downstream performance. Adapt laboratory analytical tools to provide rapid compositional analyses at field-side & in storage. Combine results of storage stability, computational models, & rapid analytical tools that enable an information driven storage system design.

End of Project Milestone

Report at laboratory scale and with techno-economic analysis of each proposed operation, the individual components of an engineered storage and delivery system capable of supplying an 800,000 DMT/yr biorefinery with baled corn stover that meet BETO biochemical conversion in-feed quality targets for structural stability, moisture, ash, and carbohydrates at the lowest achievable cost.

Funding Mechanism

DOE-BETO Annual Operating Plan

Additional Slides

Responses to Previous Reviewers' Comments

- *"…the reviewer is concerned that the mitigation techniques are not clearly defined in the projects scope."*
  - Potential mitigations strategies such as passive and forced air drying in storage were not described in enough detail in FY19 but were evaluated in FY20. We believe that mitigations strategies such as using active drying for the most wet and "at-risk" portions of the annual supply have potential to help balance costs between these expensive storage methods and the costs associated with dry matter loss and degradation.
- *"It was not clear how the NIR probe testing would be scaled up…"*
  - A team led by Antares Group, Inc. and including INL and Iowa State University has Phase 1 Small Business Innovation Research (SBIR) funding to develop a mechanical probe insertion, data collection, and information management system that automates the process of in-field analysis of corn stover bale composition. This team will be the core of a follow-on Phase 2 SBIR proposal in FY21.
- *"There are two areas I wish the presentation and project performers would have taken time to explore, however: (1) the current economic estimates of the economic effects of the work and (2) the early potential design characteristics that are developing or what problems the designs need to solve."*
  - Results show that dry matter loss increases delivered feedstock costs approximately $0.40 per dry matter ton for each percent dry matter lost. Practical improvements (site selection and maintenance) have potential to pay for themselves in dry matter saved. Moisture reduction (30% to < 20%) is possible in storage using low-cost means and can reduce dry matter losses to 5% or less.

Publications, Patents, Presentations, Awards, and Commercialization

- Publications:
  - Nguyen, Q. A., et al. (2020). "Total and Sustainable Utilization of Biomass Resources: A Perspective." Frontiers in Bioengineering and Biotechnology **8(546): 546.**
  - Quiroz-Arita, C., et al. (2020). "Microbial Heat and Organic Matter Loss in an Aerobic Corn Stover Storage Reactor: A Model Validation and Prediction Approach Using Lumped-Parameter Dynamical Formulation." Frontiers in Bioengineering and Biotechnology **8(777): 777.**
  - Smith, W. A., et al. (2020). "Effects of Storage Moisture Content on Corn Stover Biomass Stability, Composition, and Conversion Efficacy." Frontiers in Bioengineering and Biotechnology **8(716): 716.**
  - Wendt, L. M., et al. (2018). "Compatibility of High-Moisture Storage for Biochemical Conversion of Corn Stover: Storage Performance at Laboratory and Field Scales." Frontiers in Bioengineering and Biotechnology **6(30): 30.**
  - Wendt, L. M., et al. (2018). "Techno-Economic Assessment of a Chopped Feedstock Logistics Supply Chain for Corn Stover." Frontiers in Energy Research **6: 14.**

- Other (Commercialization pathway):
  - DE-FOA-0002146: SBIR/STTR FY2020 PHASE I RELEASE 2 *Near Infrared Biomass Probe and Deployment Methods for Real-time, Field-Based Biomass*; Prime Recipient: Antares Group Incorporated; Team Member Organizations: Idaho National Laboratory • Iowa State University BioCentury Research Farm