U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

# U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO) 2017 Project Peer Review

Feedstock Supply and Logistics

Tuesday, March 7, 2017

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## WBS 1.2.1.1: Sensors and Measurement in Harvest & Collection for Rapid Quality Control of Corn Stover

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# Goal Statement & Outcomes

- *Monitor moisture and ash early in the corn stover supply chain to enable implementation of **active management** decisions that reduce grinding, drying, and conversion costs*
  - *Measure soil content of bales field-side and in storage using portable analytical equipment to provide valuable information about bale qualities of ash/soil content, moisture content, and storage stability*
  - *Predict feedstock drying rates and dry matter preservation over time in storage to support biomass queuing/scheduling decisions and reduce daily variations in feedstock moisture content and extents of dry matter loss*
- *Demonstrate two field-side analytical methods to evaluate baled stover soil content with results returned in **< 30 min. per bale***
- *Evaluate two potential on-equipment methods to **mitigate soil contamination** during harvest operations*
- *Develop a **data-driven storage management** tool that accurately predicts moisture content and dry matter loss in stored lots of baled stover*

# Quad Chart Overview

## Timeline

- Start Date: 10/1/15
- End Date: 9/30/18
- Percent complete: 50% (by date)
- On-going

## Barriers

- Ft-A. Feedstock Availability
  - Ash avoidance
- Ft-F. Storage Systems
  - Dry matter loss & water content
- Ft-E. Feedstock Quality & Monitoring
  - Ash & Moisture

## Budget

| | FY 16 Costs | Total Planned Funding (FY 17-Project End Date) |
|---|---|---|
| DOE Funded | $1.0M | $2.6M |

## Partners

- Antares Group – Corn stover harvesting & logistics
- B Hames Consulting– NIRS modeling
- Genera Energy – Switchgrass storage
- NREL – Process modeling
- LBNL – Conversion testing

# Project Overview

Corn Belt Demo '12 → Cost Quality '15 → Active Management '18

- <u>2012 Demonstration:</u> **Collection efficiency**, bale density & dry storage improvements in high-yield area at **target cost**
  - Challenges: Cost/quality interactions & high-moisture storage stability in high-impact biomass feedstock: corn stover
- <u>2012-2015:</u> Impact of equipment and harvest and collection practices on **yield, ash and cost**; impact of moisture content on **dry matter loss** in storage
  - **<u>Challenges:</u>** Need timely information for on-the-fly decisions in harvest before delivery
- <u>2015-2018:</u> Provide **actionable information** at decision points during harvesting and storage operations to manage soil and moisture content of delivered stover to **meet process needs**

# Overview & Relevance

360 Bales
840 lbs DM per bale
13% “ash” = ~10% soil
**15 tons of soil!**
**360 bales = 3 hr @ 30MGY**
**Soil belongs in the field**

30% moisture content corn stover
1,200 lbs per bale (840 lbs DM)
43 gallons of water per bale
- **¾ bale @ 20% mc = stable**
- **¼ bale @60% mc = at risk**

**Moisture moves; can it move out?**

# Management Approach

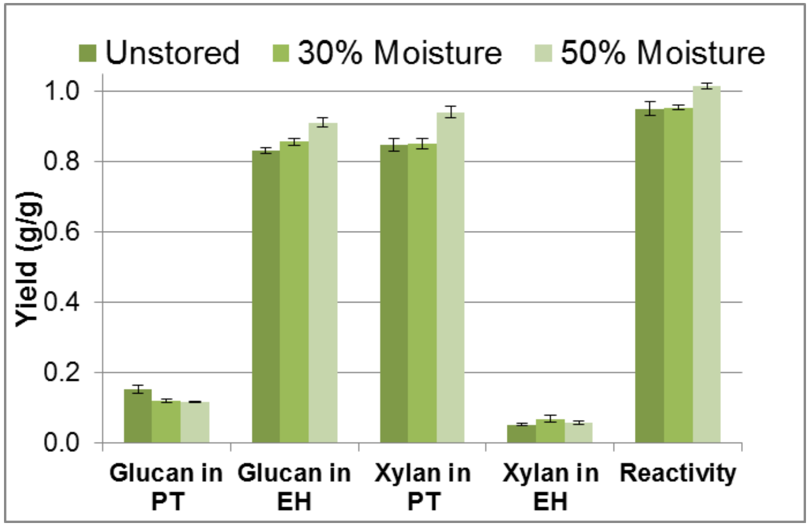
- From the field to the laboratory and back to the field
  - Work with Antares, Inc & B Hames Consulting in competitive awards, POET-DSM in user facility agreements, and in informal collaborations such as the DAM (Deere, ADM, Monsanto) project in Nevada, IA, and storage trials with Genera Energy and NexSteppe
- Utilize programmatic strengths of **biomass analysis** and **PDU**; engage others for analytical methods and conversion
  - Capitalize on working in a **multi-mission National Laboratory**
- Go/No-Go decisions and annual milestones based on **measurable** and **relevant** goals
  - Start with feasibility and defining technical goals (Can it be done?) and progress to performance goals (Is it cost effective? Does it integrate with existing systems?)
  - Metrics must be demonstrated as operationally and/or industrially relevant
  - Finally, test solutions in PDU and/or with commercial partners

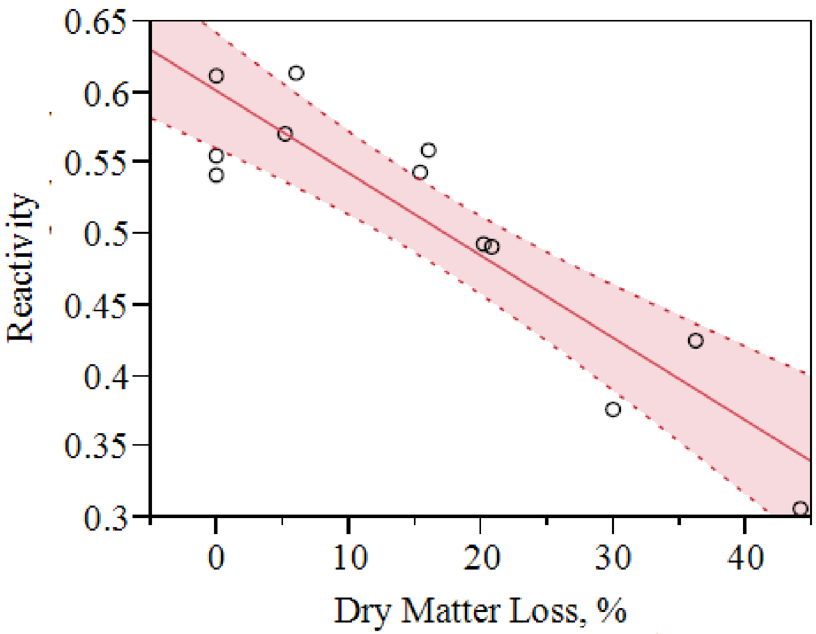
# Technical Approach & Challenges

- Observe what's **limiting** efficiency/reliability for stover (IBRs)
  - Challenge: best management practices result in highly-variable ash and moisture contents; active management intends to reduce this variation
  - Controlling moisture/ash in bales means measuring it, quickly/cheaply
- Adapt existing tools to **reduce lead time** to deployment
  - Challenge: move rapidly from lab to field
  - Classification rather than quantification (which, is a technical challenge…)
- Focus on the first **show-stoppers**: soil/ash and moisture
  - Challenge: IBRs have problems with biomass quality in preprocessing
  - Prioritize efforts based on program goals, industry challenges, and analysis results, i.e. most downstream impact/least cost and effort
- Define **success factors**
  - Incorporation of research results **across** BETO programs
  - Increasing commercial interest in research; partnerships in FOAs
  - Ultimate Goal: Industry adoption of ash/moisture avoidance practices, analytical tools, and biomass storage management practices/tools

# Technical Accomplishments, Progress, and Results

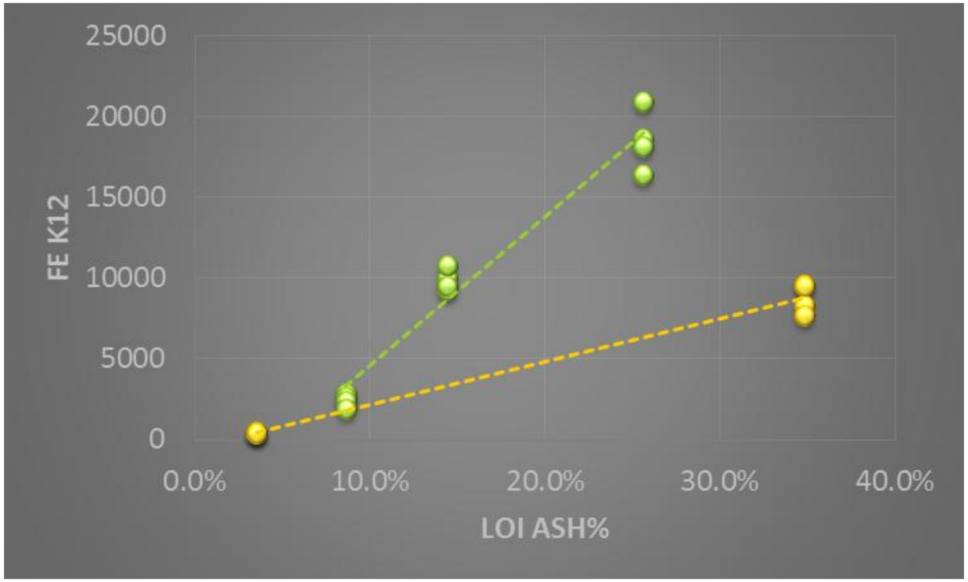
- **Success:** Dockage for not achieving quality targets—**Ash**
  - ~$0.37/dmt for each percent ash over 5% for feedstock replacement, ash disposal, and operating costs (varies by feedstock price)
  - NREL 2.1.0.100 Milestone 2015 – TEA of compositional variability
    - As ash increased from **3% to 12%, MFSP** increased proportionally
  - Independent analysis confirm INL's ash dockage in sugar-based conversions
- **Success:** Dockage for not achieving quality targets—**Sugars & DML**
  - 0.6% loss in available sugars for each 1% dry matter lost in storage for switchgrass
  - Applied in SOT, assuming 12% DML
  - Q1 FY17: **DROPPED for stover**



# Technical Accomplishments, Progress, and Results

- X-ray fluorescence has been used in minimally-prepared biomass
  - Morgan, T. J., et al. (2015)
- Ash-forming elements result in "fingerprint" of soil content based on soil chemistry and plant physiology (<u>Challenge:</u> variable by plant tissue)
- Qualitative use of hand-held XRF to measure ash content by single element; quantitative via multi-element to come…




- <u>Challenge:</u> Soil type matters! Provenance alters elemental composition.
- Results in as little as 30 sec/spot; estimating 20 min/bale

# Technical Accomplishments, Progress, and Results

- Near infrared spectroscopy has been used in the laboratory
  - Hames, B. R., et al. (2003)
  - Measure fewer operationally-important components in the field
- BALES High-tonnage logistics project is extending it to the field

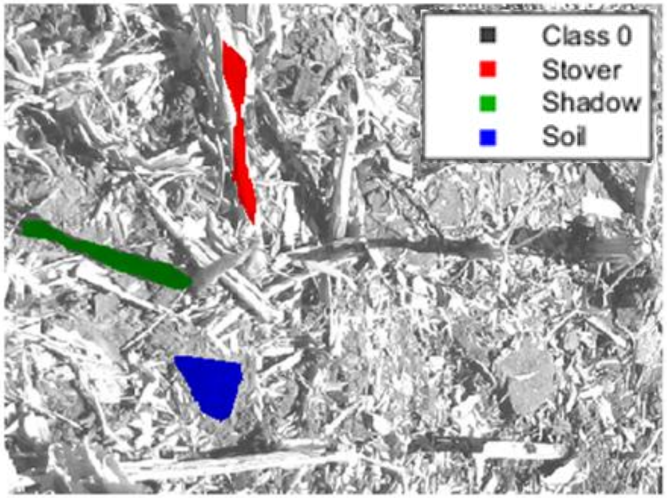
  - Antares, Inc., PANaly bale probe
  - Calibrated for four c Moisture, and Ash
  - This AOP added total ash vs. soil contamination

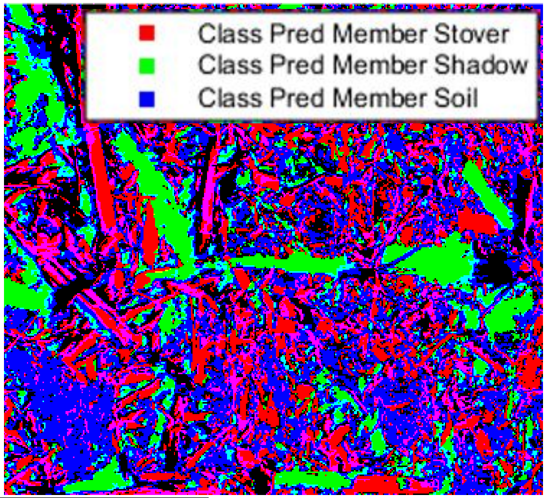
**Still (mostly) low** relative to lab. Challenge: bring to within ±5% (rel%) of lab value.

| Ash DW at harvest Oct 2014 | | | | | |
|---|---|---|---|---|---|
| **Bale Type** | **Description** | **Lab Range** | **Lab Avg.** | **NIR Range** | **NIR Avg.** |
| 21 | 4 Ft No Kemper | 3-6 | 3.3 | 5-7 | 6.3 |
| 20 | 5 Ft Kemper | 3-4 | 3.5 | 4-6 | 5.3 |
| 19 | 5 Ft No Kemper | 3-6 | 3.1 | 4-5 | 4.6 |
| 11 | Easy_Net Wrap_Outside | 5-14 | 7.8 | 7-8 | 7.7 |
| 12 | Easy_Net Wrap_under roof | 5-13 | 7.8 | 7-8 | 7.5 |
| 18 | Lge Square Twine | 6-9 | 7.0 | 6-7 | 6.7 |
| 17 | Lge Square_twine_roof_Easy | 5-8 | 5.7 | 4-6 | 5.3 |
| 15 | **Couser Lignin** | 6-17 | **9.0** | 5-7 | **6.0** |

# Technical Accomplishments, Progress, and Results

- Indirect methods under consideration
  - Observation: Stover removal rate is proportional to bale soil content
  - Goal: Measure soil vs. stover remaining in the field using image analysis
  - Technique: Digital photo and 1-D analysis of RGB (Challenge: lighting)



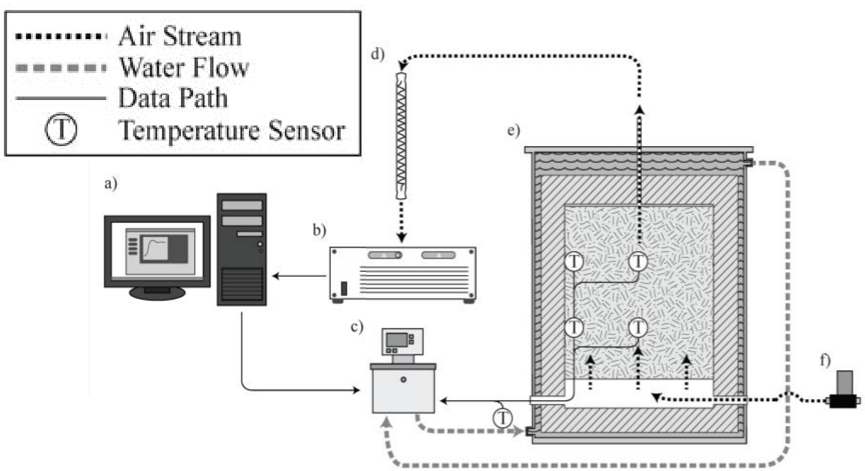



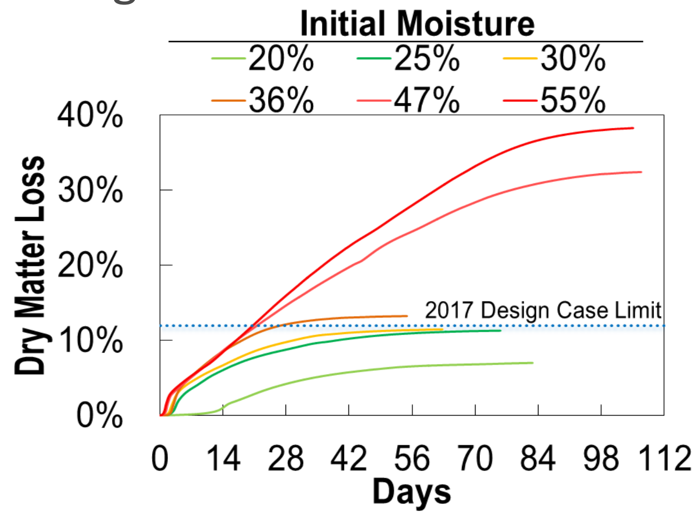

| Class | Pixel # | % of Image | w/o Shade |
|---|---|---|---|
| **Stover** | 56078 | 34% | 41% |
| **Shadow** | 27964 | 17% | -- |
| **Soil** | 79340 | 48% | 59% |

  - Principal components/discriminant analysis on 1-D RGB data (simple!)
  - Hand-held, on-equipment, or UAV platforms possible

# Technical Accomplishments, Progress, and Results

- Moisture, Dry Matter Loss, and Cost/Value
  - Quantify losses in real time under controlled conditions (temp/air/moisture)
  - Collect data for predictive modeling: airflow, heating, moisture loss
  - Compare lab to field data—past and present storage trials




  - Use simulation to examine sensitivity of drying to…
    - Air temperature and relative humidity (climate/regional effects)
    - Gas transport rate through material (density/storage conditions)
    - Respirative heating and dry matter loss dependence on temperature
  - Project Go/No-Go: Model <u>then</u> demo in FY18 with Antares, Inc in Iowa



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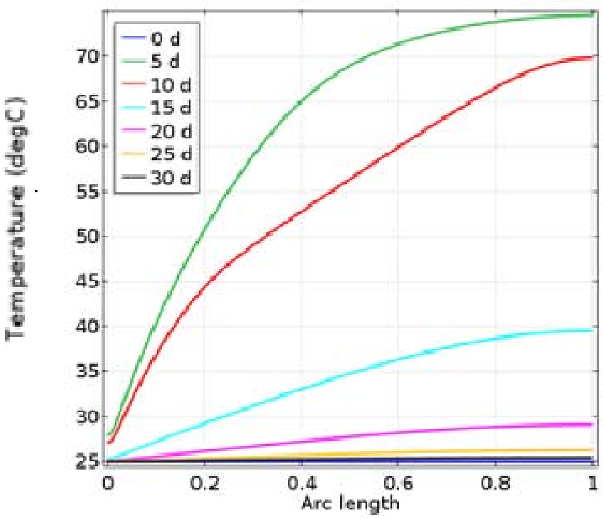
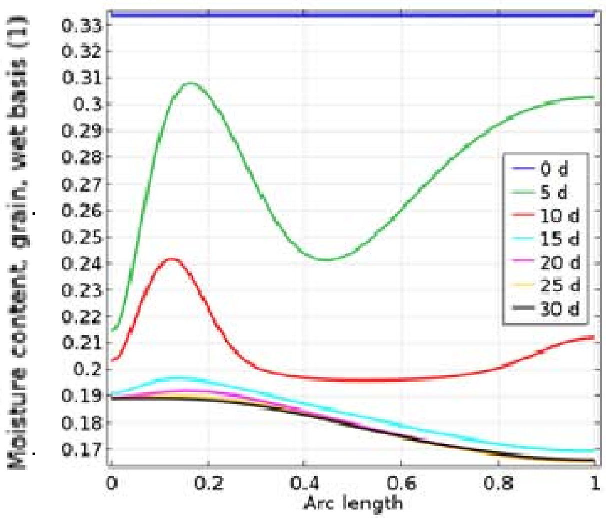
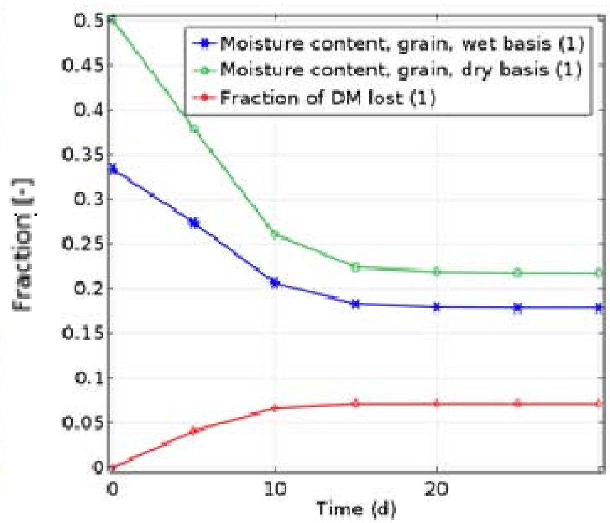
# Technical Accomplishments, Progress, and Results

- Numerical simulation
  - Analytical methods for bulk drying do not capture biological effects of:
    - **Internal heating** associated with biological activity
    - **Dry matter loss** associated with air addition
  - Commercial general, 3D, PDE solver, COMSOL Multiphysics
  - Combined equations describe drying and…
    - Heat transfers in air and solid phases
    - Water transport in liquid and gas phases drying
    - $O_2$ transport
    - Dry matter loss with heat and water production



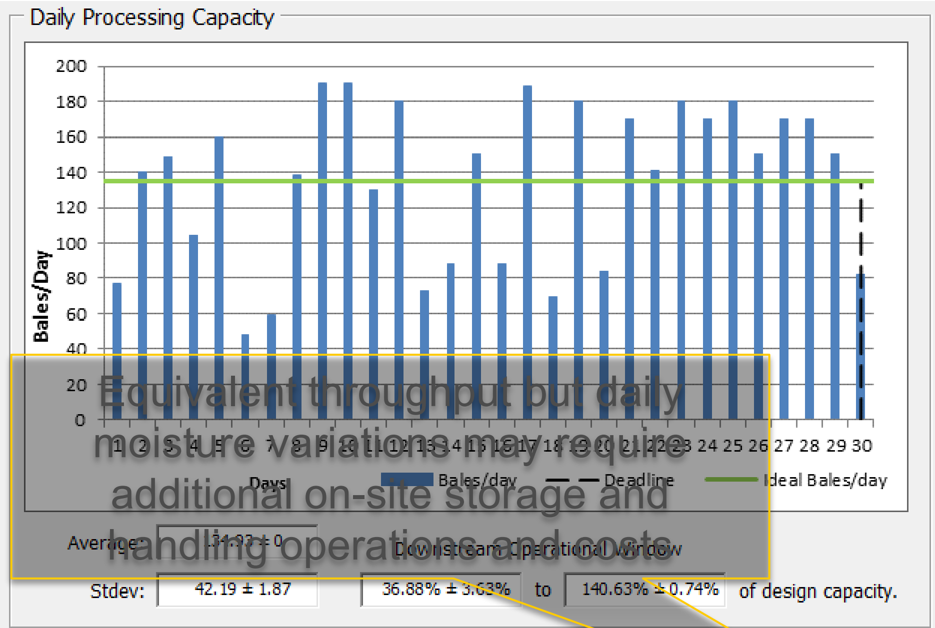



# Technical Accomplishments, Progress, and Results

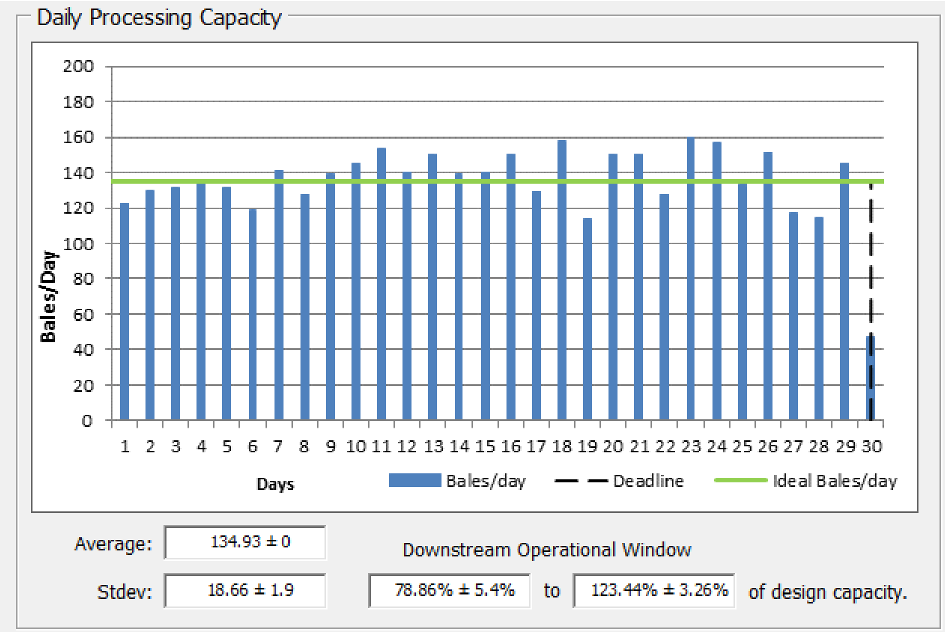
- Moisture Variation Impact on <u>Modeled</u> Bale Throughput in Preprocessing

Random




Equivalent throughput but daily moisture variations may require additional on-site storage and handling operations and costs

Sorted




| | Random | Mixing |
|---|---|---|
| Standard Deviation | 42.19 ± 1.87 | 18.66 ± 1.9 |
| Downstream Operational Window- Low Val | 36.88% ± 3.63% | 78.86% ± 5.4% |
| Downstream Operational Window- High Val | 140.63% ± 0.74% | 123.44% ± 3.26% |

- Mixing lowers daily **variation**. Mixing requires **information**.

# Relevance

- Measure moisture and ash early in the supply chain to implement active management decisions that reduce grinding and transportation costs, and preserve sugar yield and conversion performance
  - Soil and water in stover bales increases transportation and handling costs
  - Soil increases wear-and-tear in preprocessing equipment, consumes acid in dilute acid pretreatment, and must be disposed of at the plant (IBRs)
  - High-moisture content bales (>20%) consume more grinding energy/time and produce a wider particle size distribution than dry (<20% mc) bales (INL data)
  - High-moisture bales (>20%) degrade to a greater extent in storage as a result of biological consumption of sugars, reducing amount delivered vs harvested
- Information about feedstock stability in storage enables active management of daily deliveries and reduces operational variations that lead to shutdowns
  - Ash and moisture reduction early in the supply chain reduce downstream transportation, handling, and preprocessing costs; preferably before baling
  - Information about bales—by lot—allows producers to schedule deliveries to blend highs and lows to reduce daily variations
  - Early identification of “problem materials” permits operational choices (ie. sell wet/high ash stover somewhere else or preprocess separately)

# Future Work

- Go/No-Go this quarter
  - Under what conditions is moisture loss possible in baled corn stover?
  - Can moisture be reduced to <30% before 12% DML occurs? (2017 SOT)
  - Drying/DML modeling to continue through FY18 to broaden locations
- Field harvest and storage testing with Antares Fall FY18
  - Demonstrate conditions for 50% mc to 30% mc loss in outdoor storage in Iowa
  - Equipment testing for soil content—Image analysis after baling
  - Samples and bales for NIRS and XRF
- Continued work with XRF and NIRS; Add X-Ray Image Analyses
  - Mini-bale to full-size bale scale up in FY17
  - Use tomography to identify foreign matter (rocks, tramp metal) and soil
- Technical performance thresholds built into existing milestones
  - If it doesn't work in the lab, we don't go to the field
  - By end of project: if it demos in the field, we take it to a partner
- Challenges related to analytical instrumentation and agreements with external industrial/university partners for engineering and prototyping
  - Technical success in the lab demonstrate progress to BETO
  - Demonstration of technical success in the field is **essential** to commercial partners
  - Identify potential IP and act early in the development process

# Summary

- Moisture and ash (soil content) increased preprocessing costs and reduce product yield in corn stover.
- Best management practices based on past performance; active management responds to changing conditions in harvest & storage.
- Decisions made early in the supply chain can reduce soil content and DML and control daily variations in feedstock moisture and ash.
- Decisions require information "in hand"; we need timely results for ash and moisture in harvesting/storage/preprocessing
- Information needs to be of sufficient quality to make the immediate decision and is not intended to be a "final" analysis
- Move from lab to field with industry partners to remain focused on PRACTICAL solutions that fit within existing supply chains.
- Work within BETO (analysis, SOT, interface) to identify opportunities for future extension and development of improvements that enable an advanced supply system.

# Acknowledgements


INL Idaho National Laboratory

Lynn Wendt
Austin Murphy
Matt Dee
Allison Ray
Rachel Emerson
Amber Hoover
Troy Uhru
Sergio Hernandez
Rachel Colby
Karen Delezene-Briggs

B Hames Consulting

Dr Bonnie Hames

GENERA

Dr Sam Jackson
Lance Stewart

ANTARES Group Incorporated

Kevin Comer
Bill Belden

ABPDU ADVANCED BIOFUELS PROCESS DEMONSTRATION UNIT

Dr Ning Sun
Dr Deepti Tanjore

POET | DSM Advanced Biofuels

Alex Johnson

nexsteppe

Dr Rebecca Arundale

**…And Others…**

Bill Couser, Couser Cattle
Tom Robb, Consultant
Reed Herzig, Monsanto

# Responses to 2015 Peer Review Comments

- I suggest continued work on developing similar data/projects for other feedstocks over additional modeling.
  - We've worked with Genera in 2015 & 2016 to perform a parallel field/lab switchgrass storage study, which was presented at SIMB-SBFC in April, 2016
  - We're currently working with NexSteppe (MTA) to characterize biomass sorghum storage stability across a range of moisture contents

- …It needs to be expanded so that we can link economic and environmental models from the sub-field scale all the way through to national impacts.
  - Results such as ash content and yield by various emerging collection equipment are incorporated into our SOTs, which link operations with economics via INL's BLM. We also collaborate with our sustainability group at INL and with Antares to examine equipment performance and biomass ash content in parallel with the Integrated Landscape Design project.

# Responses to 2015 Peer Review Comments

- The work should continue to improve efficiency in moving feedstocks from field to “storage/processing/conversion”.
  - The focus on field-based measurements and prediction of biomass drying in storage are a direct result of our efforts to demonstrate an active, informed, and integrated supply system to handle conventional herbaceous biomass

- This is important work and the results need to be communicated outside of academic journals.
  - Current path to field-deployed sensors for moisture and ash presented at ABFC 2015 and AETC 2016
  - Stover biomass storage stability shared at Biomass 2015
  - On-going storage/NIRS work with DAM project at Couser Cattle, Nevada, IA

# Presentations, Publications, & Patents

- Kenney, Kevin, et al. (2014). Biomass Logistics. Bioprocessing of Renewable Resources to Commodity Bioproducts. V. S. Bisaria and A. Kondo. Hoboken, New Jersey, John Wiley & Sons, Inc.: 29-41.
- Wendt, Lynn., et al. (2014). "Influence of Airflow on Laboratory Storage of High Moisture Corn Stover." Bioenergy Research: 1-11.
- Smith, William, et al. “Characterizing Biomass Within the Supply Chain.” Advanced Bioeconomy Feedstocks Conference, June 10, 2015, New Orleans, LA.
- Murphy, Austin, et al. “Evaluation of Bulk, High Moisture Corn Stover in Anaerobic Storage.” American Institute of Chemical Engineers Annual Meeting, November 8, 2015. Salt Lake City, UT.
- Bonner, Ian, et al. (2015). A Laboratory Scale Reactor for Simulating Biomass Storage for Bioenergy. 2015 ASABE Annual International Meeting. New Orleans, Louisiana, American Society of Agricultural and Biological Engineer: 11.
- Smith, William, et al. “Getting the Right Information at the Right Time.” Agricultural Equipment Technology Conference, February 8, 2016, Louisville, KY.
- Smith, William, et al. “Outdoor Storage Performance of Chopped Switchgrass for Bioenergy Use.” Symposium on Biotechnology for Fuels and Chemicals, April 28, 2016, Baltimore, MD.
- INL Invention Disclosure Record No. BA-935. Smith, William A, Bonnie R Hames, Kevin S Comer, Jason Peoples. “Direct-Push Near Infra-Red Spectroscopic Bale Probe and Chemometric Models for Biomass Feedstock Composition.” Date Accepted: 10/10/2016.

# Additional Materials

- Citations:
  - Morgan, T. J., et al. (2015). "Quantitative X-ray Fluorescence Analysis of Biomass (Switchgrass, Corn Stover, Eucalyptus, Beech, and Pine Wood) with a Typical Commercial Multi-Element Method on a WD-XRF Spectrometer." Energy & Fuels **29(3): 1669-1685.**
  - Hames, B. R., et al. (2003). "Rapid biomass analysis - New tools for compositional analysis of corn stover feedstocks and process intermediates from ethanol production." Applied Biochemistry and Biotechnology **105: 5-16.**

# Additional Materials

- Example: Ash-forming elements
  - Inorganics in stover: depend on growth stage/maturity
    - Rich in Si, K, Ca, P, S, and Na at part per thousand levels
  - Inorganics in soil: depend on provenance/region
    - Rich in Si, Al, K, Na, Fe, and Ca in percent levels
- Elemental "fingerprinting" of soil contamination
  - Elemental abundances in bales can be used to quantify soil content vs. total ash
    - Based on plant physiology and soil chemistry
  - Elemental quantification can be done with a range of instrumentation
    - Some instruments are more portable than others!