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

DOE Bioenergy Technologies Office 2015 Project Peer Review

1.2.1.1 Biomass Engineering: Harvest, Collection, and Storage

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Feedstock Supply and Logistics

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Biomass and Bioenergy

Goal Statement

- Objective
  - Identify and develop solutions to feedstock supply and storage barriers facing existing and emerging bioenergy industries
    - Balance cost, quality, and quantity
- DOE-BETO Link
  - Targeted solutions reduce supply risks associated with quality changes in harvesting, collection, and storage and lead to consistently-performing feedstocks
  - Elimination of dockage for quality/ash and contribution to $80/DMT by 2017
- Outcome & Relevance
  - Confidence/security in biomass removal
  - Provide guidance/tools for storage management
  - Meet specifications including performance at target price

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Quad Chart Overview

Timeline

- Start Date: October 1, 2006
- End Date: September 30, 2017
- Percent complete: 80% (by date)

Budget

	Total Costs FY 10 –FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-17)
DOE Funded	$8.39M (1.3.4.1); HC&S ~$3M	$1.4M	$1.4M	$3.88M
Project Cost Share				

Barriers

- Ft-A. Feedstock Availability
  - Ash avoidance & yield
- Ft-F. Storage Systems
  - DML, composition, & conversion
- Ft-G. Quality & Monitoring
  - Ash, moisture & conversion yield

Partners

- Abengoa
- Agco
- FDCE
- Genera
- IA State U
- NREL
- OK State U
- ORNL
- POET

Project Overview

- Past (FY-06 to FY-12)
  - Broken out of 1.3.1.4 "Logistics Engineering" in 2013 (see Quad Chart)
  - Focused on high-impact herbaceous crop residue—corn stover
  - 2012 Demonstration: cost reductions via collection efficiency (38%), bale density (11.1 lb ft^3), and low dry matter loss in storage (8%)
    - Conventional case in high-yield region
- Current (FY-12 to present)
  - Changed focus to higher risk areas (moisture, ash & yield)
    - Harvesting operations' impact on quality, specifically soil contamination/ash, relative to conversion cost (dockage)
    - Moisture migration in bale storage and its role in dry matter loss and subsequent impacts on conversion costs
    - Laboratory-scale conversion testing to quantify storage impacts on performance
  - Expanding storage-related switchgrass work

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Approach (Technical)

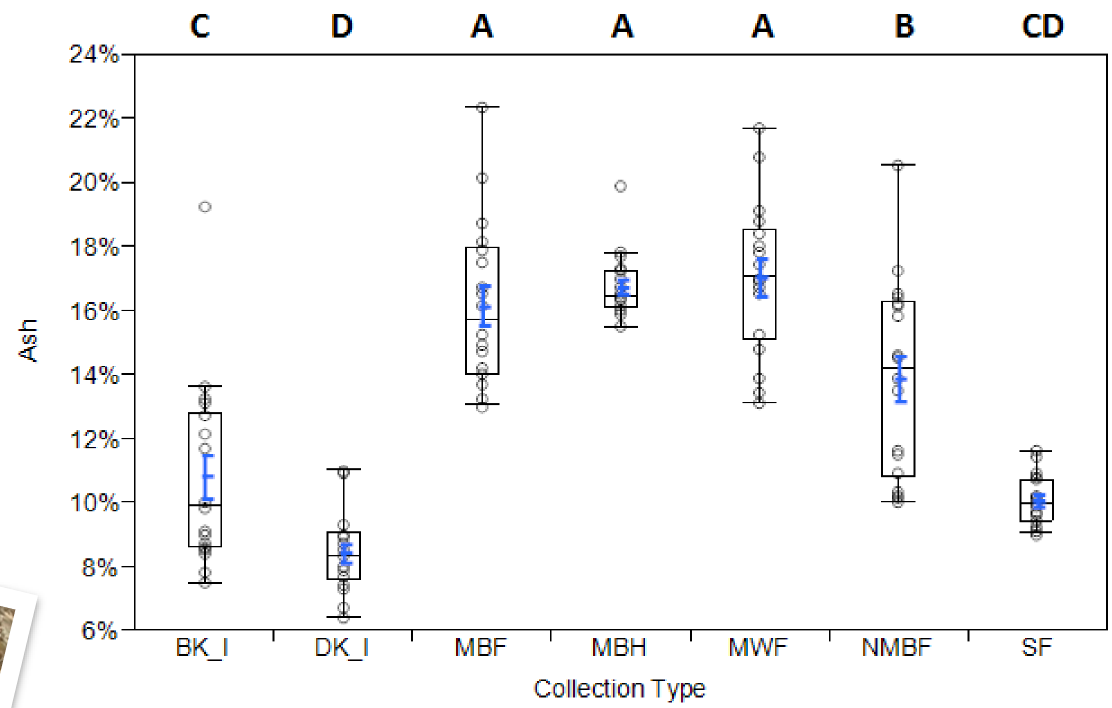
- Industry Partnership
  - Identify R&D barriers with industry partners via cooperative field trials, laboratory experiments, and economic modeling
  - Focus on main effects and find/adapt/create quantitative testing tools
    - Ash avoidance in harvest—balance quality and yield
    - Storage simulation reactors for moisture & DML—maintain performance
- Success Factors
  - Net improvements to the supply chain: reduced costs, improved performance, & reduced variability
  - Industrial adoption by biomass harvesters and biorefineries
- Current Challenges
  - Integrating sustainability, yield, cost, and quality in harvest & collection
  - Quantifying supply chain risks/costs related to storage degradation
  - Creating quality controls in storage for year-round delivery

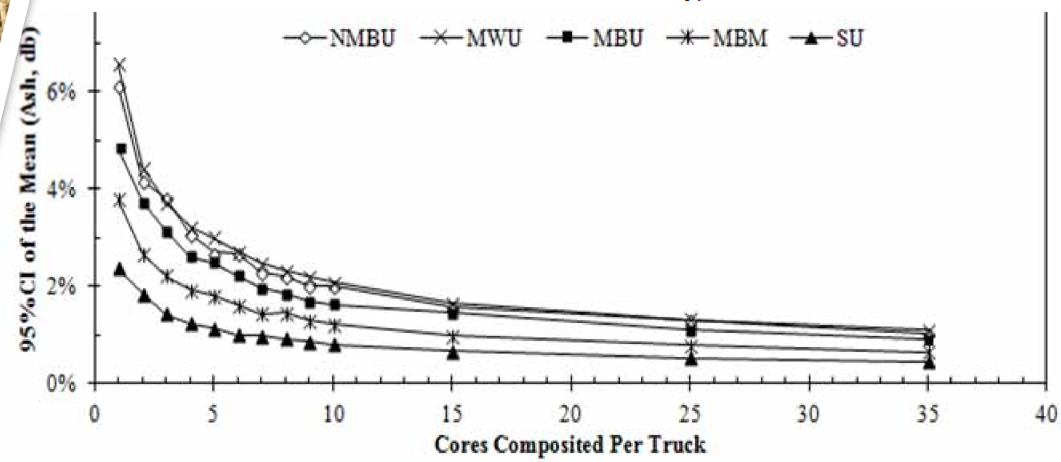
Approach (Management)

- Engage industry partners through user facility agreements, CRADAs, and competitive proposals
  - Challenges include research communications and tight schedules
- Start small(er) and grow
  - In-kind contributions and sub-contracts lead to CRADAs and shared scope
- Utilize INL partners for their skills
  - Analysis & Interface Groups, numerical modeling, chemistry, …
- Go/No-Go decisions based upon measurable goals
  - Metrics may or may not fit into the BLM, but must be program-relevant
  - Technically based early-stage; cost & performance based late-stage

Technical Accomplishments/ Progress/Results

- Results to 2013
  - Equipment Impact: Soil
  - Operational Impact: Yield
  - Variability
  - Sampling improvements

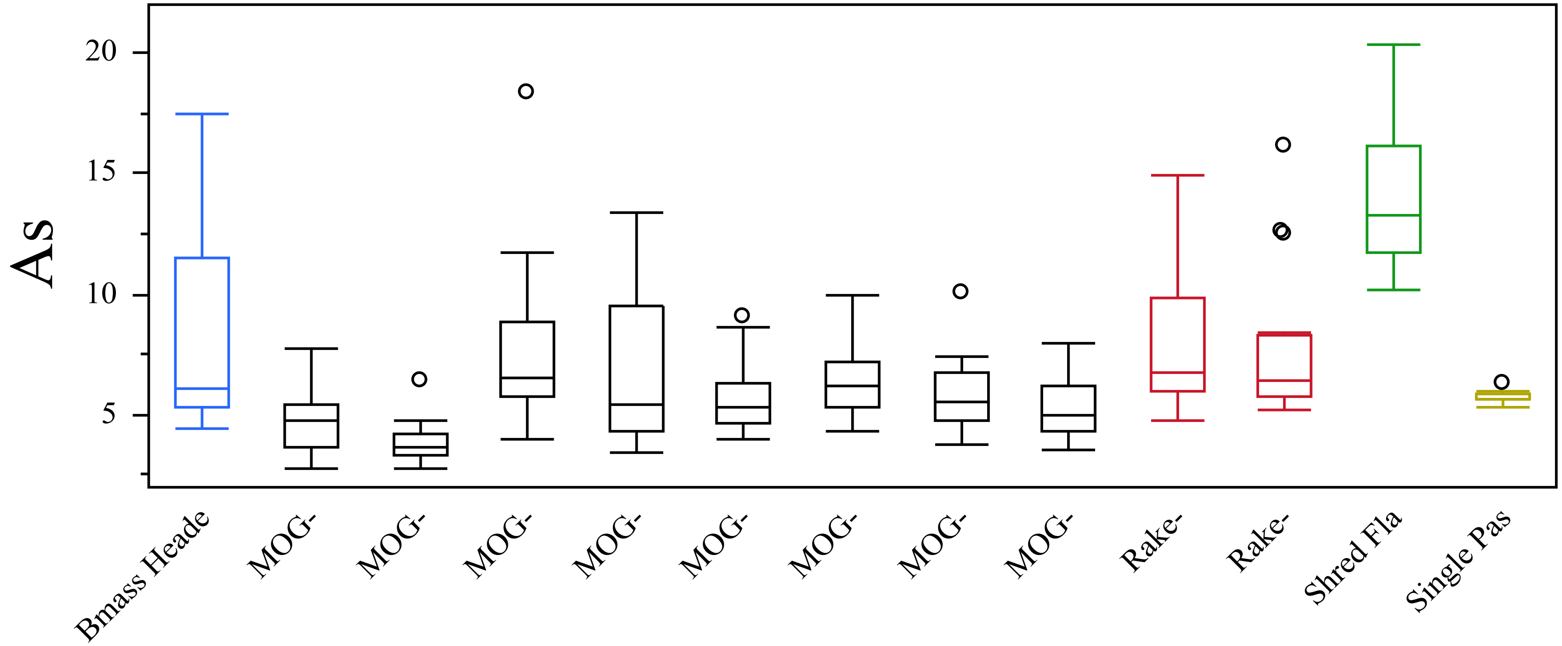




Technical Accomplishments/ Progress/Results

FDC Enterprises Grasslands Services

- Harvest & Collection: Ash Mitigation
  - Corn stover collected from POET and DuPont supply sheds
  - Meets 2015 target (<9%) using multi-pass "MOG" (POET "EZ-Bale")
  - Variability within method still high
  - Yield < 1 ton per acre, which is not consistent with BT2



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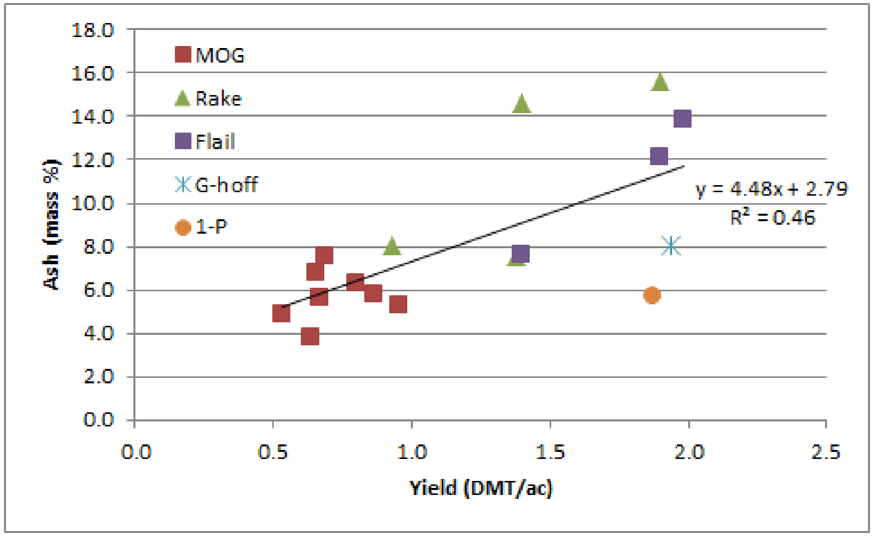
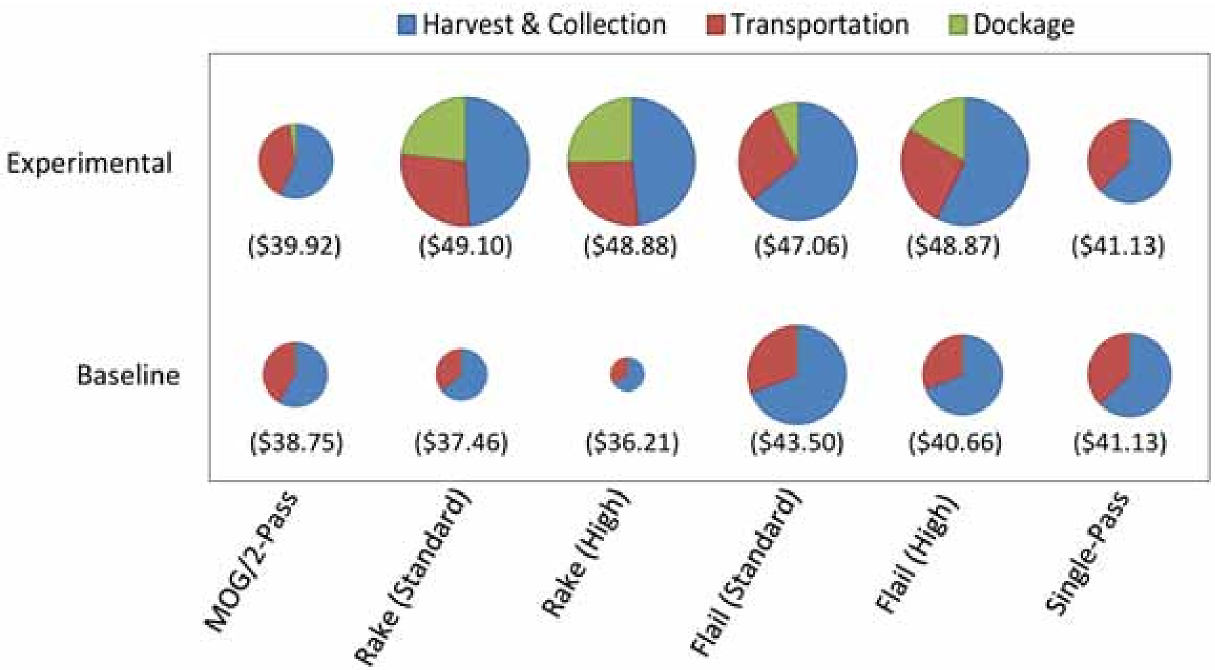
Technical Accomplishments/ Progress/Results

- Ash Mitigation
  - Yield & equipment affect quality
    - "Baseline" *assumes* <5% ash
    - "Experimental" includes *actual* ash content and dockage
      - Dockage: replacement, disposal, & conversion costs
  - Quality affects delivered costs





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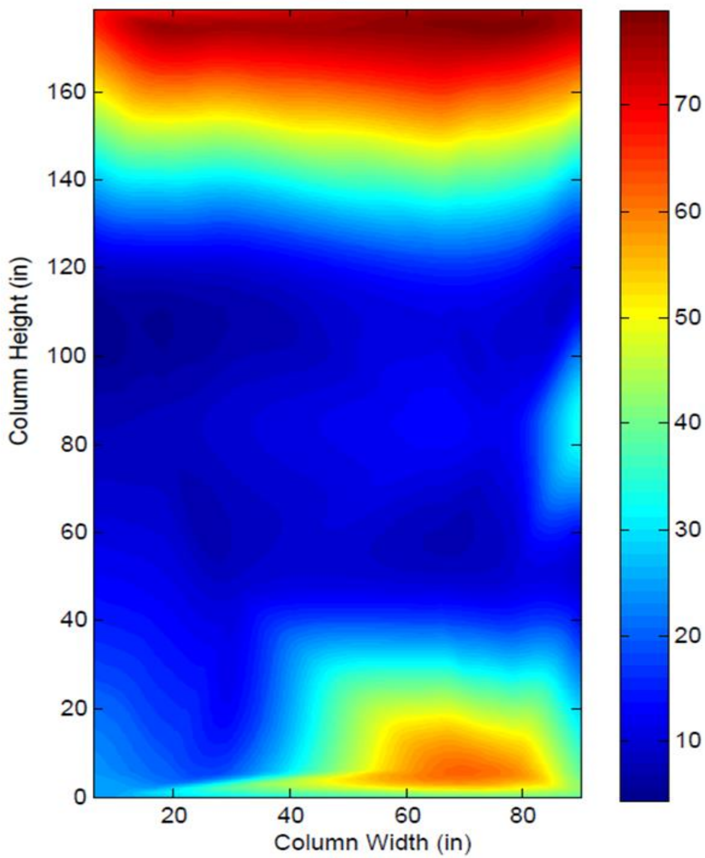
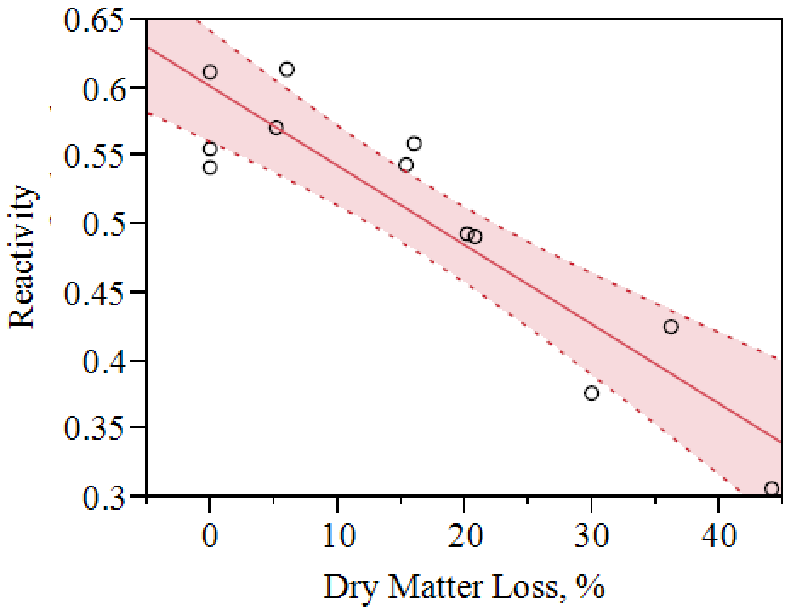
Technical Accomplishments/ Progress/Results

- Impact of Dry Matter Loss in Storage on Conversion
  - Dry baled/un-tarped switchgrass bales → 10-37% DML & yield loss
  - Conversion efficiency drops, requiring more feedstock to make the same amount of product

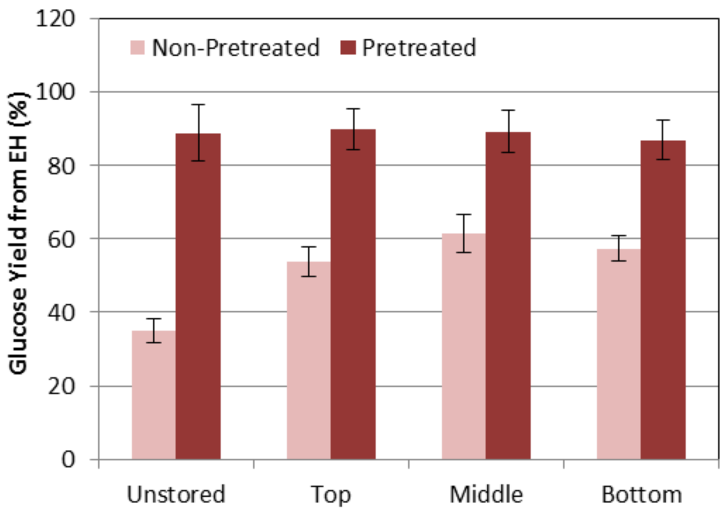


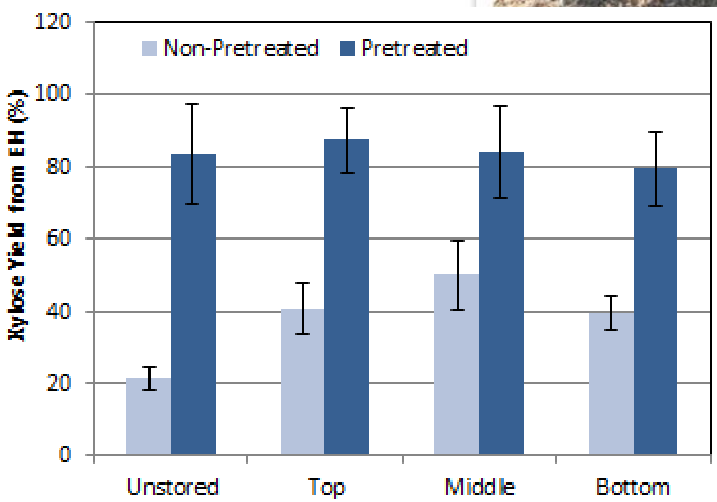


0.6% loss in reactivity per 1% DML

Technical Accomplishments/ Progress/Results

- Impact of Dry Matter Loss in Storage on Conversion
  - Single-pass/tarped corn stover bales → 5-34% DML & **no** yield loss
  - Reduced-severity dilute acid pre-treatment & enzymatic hydrolysis shows no impact on performance
    - Testing at higher PT severities is needed to look for "over pre-treatment"
    - Testing at lower PT severities is needed to look for possible PT cost reductions





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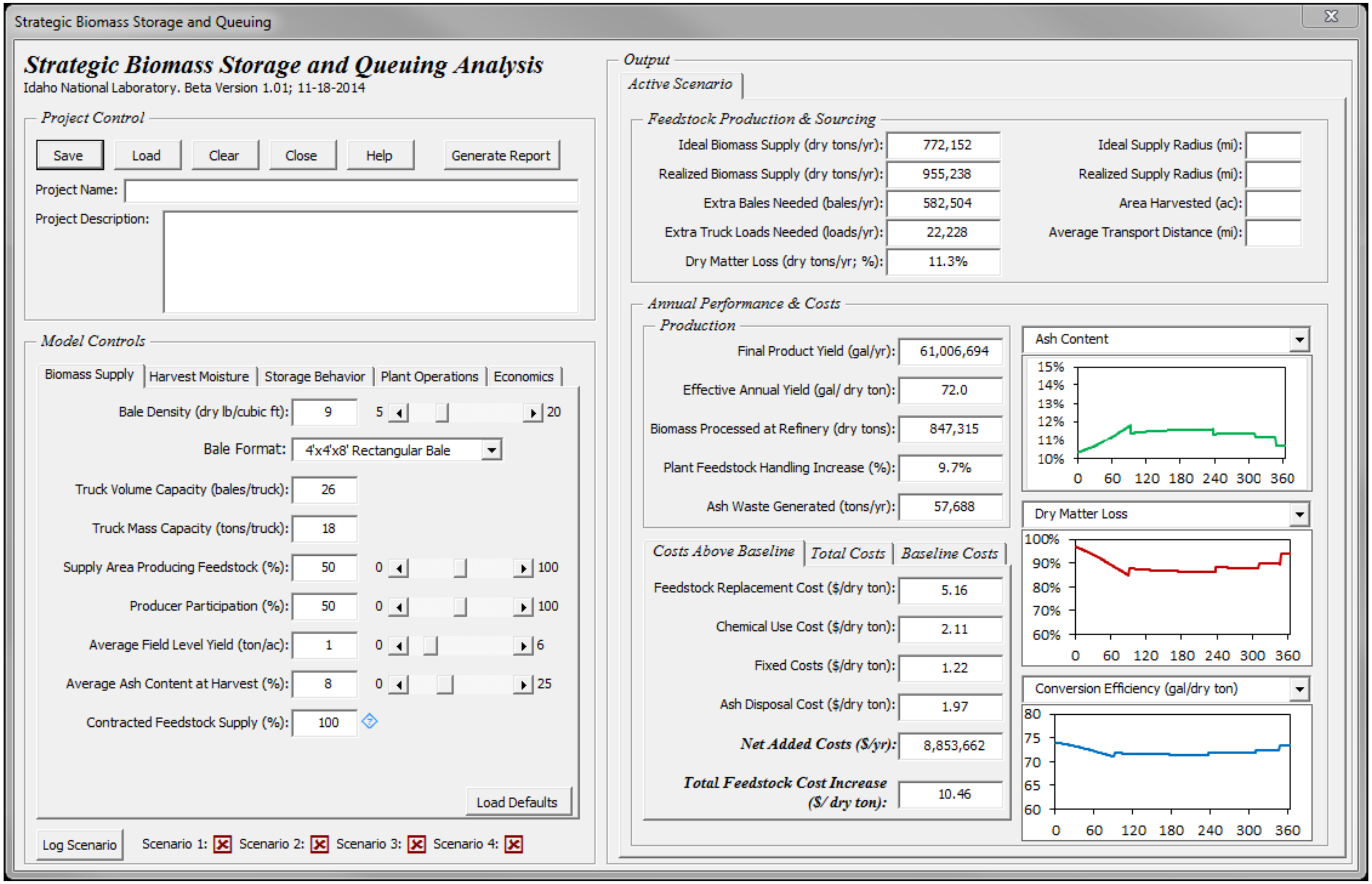
Technical Accomplishments/ Progress/Results

- Product: Strategic Biomass Storage and Queuing tool



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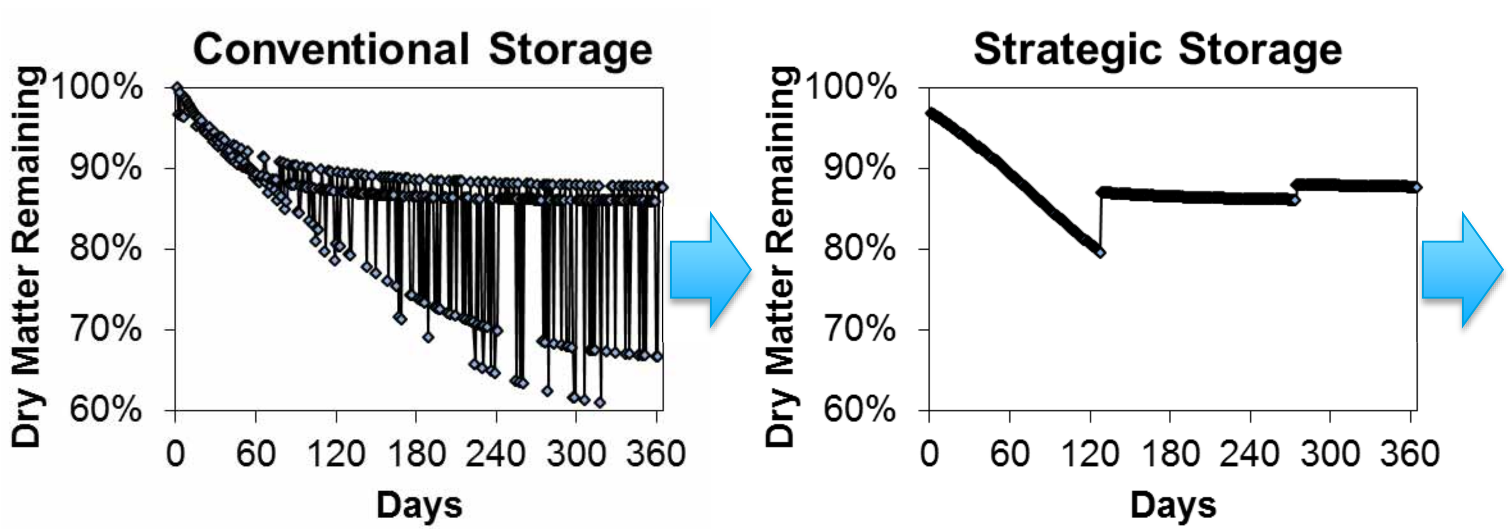
Technical Accomplishments/ Progress/Results

- Product: Strategic Biomass Storage and Queuing tool
  - Spreadsheet-based model developed by INL HC&S staff to:
    - Estimates DML by moisture content based on laboratory simulator results
    - Calculates the **impact of ash content** on feedstock value based on carbohydrate replacement, conversion (NREL 2012), and soil disposal costs
    - Accepts variable feedstock **moisture contents** for variable **DML** rates
    - Shows $/DMT impact of random vs. scheduled delivery of “at risk” feedstock throughout the year



2 $/DMT Savings

Relevance

- BETO MYPP Contributions
  - 2015: Reduce dockage by ash reduction in harvest and reduced DML in storage
  - 2017: Support validation of a logistics system delivering feedstock at in-feed specifications at $80/dmt by 2017
    - Blend TBD, but includes stover, switchgrass, and some waste component
- Impact
  - Ash < 5% to avoid dockage in 2017
    - yield sufficient to reach 250M DMT/yr (2017), 350 M DMT/yr in 2022
  - Moisture management to reduce storage losses <8% and maintain in-feed specification
  - Queuing tool will be made available in a manner that lets users customize the inputs to facilitate scale-up and integration
- Stakeholders
  - Industry—inform end users and producers to collect and maintain stable supply of high-quality feedstock; reduce loss & maintain value
  - Producers—address farm-scale operations that maximize value at point of sale

Future Work

- FY13 Q2: Assessment of ash in commercial-harvested corn stover supply shed 2013 & 2014 (Ft-A)
  - Identify quality and logistics impact on projections of 61 B L/y cellulosic biofuel
- FY15 Q4: Report detailing the baseline storage performance of bulk switchgrass storage (Ft-H)
  - Measure dry matter losses and compositional changes in low-cost storage
- FY16 Q2: Go/No-Go: Drying potential in storage using modeled moisture migration (Ft-H, ties to transport & milling)
  - Target: 50% MC to <30% using simulated storage conditions
  - No go: Model oxygen limitation in high moisture bales
- FY17 Q4: HC&S field demo—single & multi-pass stover and switchgrass blend (integrated with FS platform 2017 demo)
  - < 5% ash, >59% carbohydrate, <$20/DMT HC&S or <$80/DMT total

Summary

- Focusing R&D on high-impact herbaceous crops
  - Corn stover & switchgrass using extant equipment and practice
- Technical & management approach emphasizes industry partnership and communication
- Moved from high yield (2012) to yield balanced with quality, transportation, and conversion costs in an integrated system
- Moving forward with analytical tools to predict storage performance and its impact on delivered cost/value
  - Modeling moisture migration in storage to support passive controls on moisture content and dry matter loss
  - Queuing tool to schedule delivery based on stability and quality
- Target audience includes producers and biorefineries—not just contracting (availability) but conversion costs (quality)

Publications, Patents, Presentations, Awards, and Commercialization

- Peer-Reviewed Publications

Kenney, K. L., et al. (2013). "Understanding biomass feedstock variability." Biofuels **4**: 111-127.

Smith, W. A., et al. (2013). "Practical considerations of moisture in baled biomass feedstocks." Biofuels **4**: 95-110.

Wendt, L. M., et al. (2014). " Influence of airflow on laboratory storage of high moisture corn stover." Bioenergy Research: 1-11.

Bonner, I., et al. (2014). " Impact of harvest equipment on ash variability of baled corn stover biomass for bioenergy." Bioenergy Research: 1-11.

Kenney, K. L., 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.

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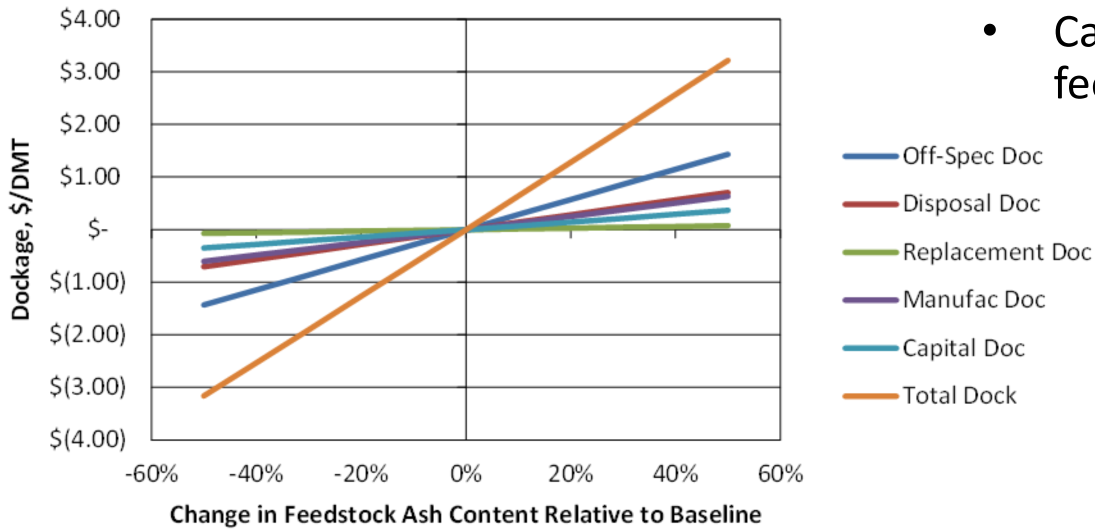
Additional Slides

Dockage

- Example using costs from Humbird et al. (2011) design

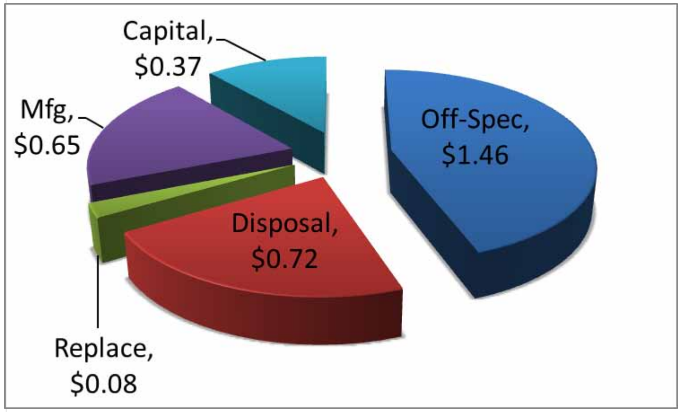
Feedstock cost: $58.50/DMT

- In-feed spec: 4.9% total ash
- FS demand: 800,000 DMT/yr
- Ash disposal: $28.86/DMT (waste)
- Product yield: 79 gal/DMT FS (EtOH)
- Manufacturing/Conversion costs (non-enzyme): $23.94/DMT
- Capital costs: $13.83/DMT



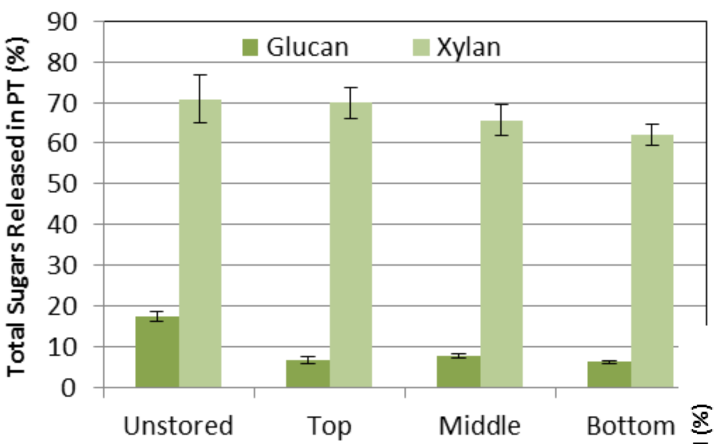
Calculated Dockages on 7.4% ash: $3.28/DMT

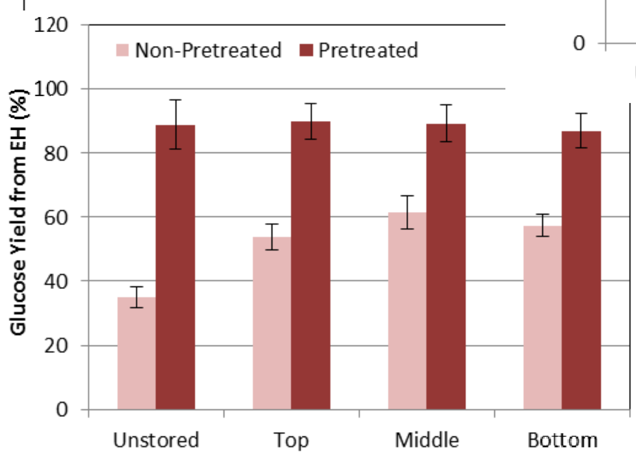
- "Off-spec" for ash >5% ($1.46)
- Additional disposal costs for ash >5% ($0.72)
- Replacement cost for more feedstock ($0.08)
- Manufacturing costs for additional feedstock ($0.65)
- Capital costs to process more feedstock ($0.37)

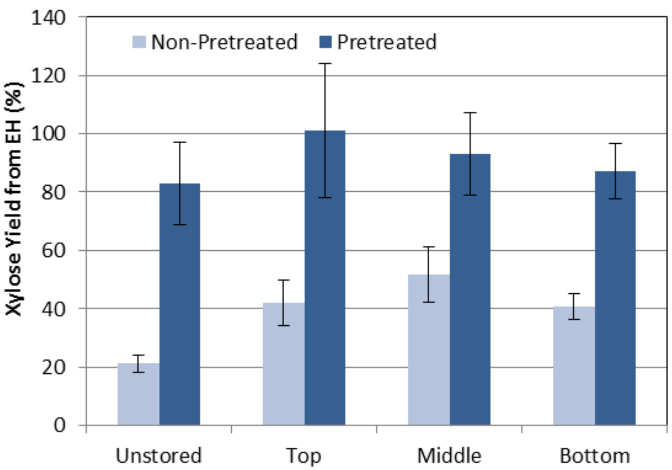


Sugar Yield in Corn Stover

- Corn stover harvested at high moisture (Show DML and bale pictures)
  - Less sugar released in stored material as a result of low-severity DAPT
  - No effect of storage after combined PT and EH
  - EH of non-pretreated stored material gives higher sugar yield
  - Reduced PT needs due to wet harvest, PT occurs in aerobic storage despite degradation





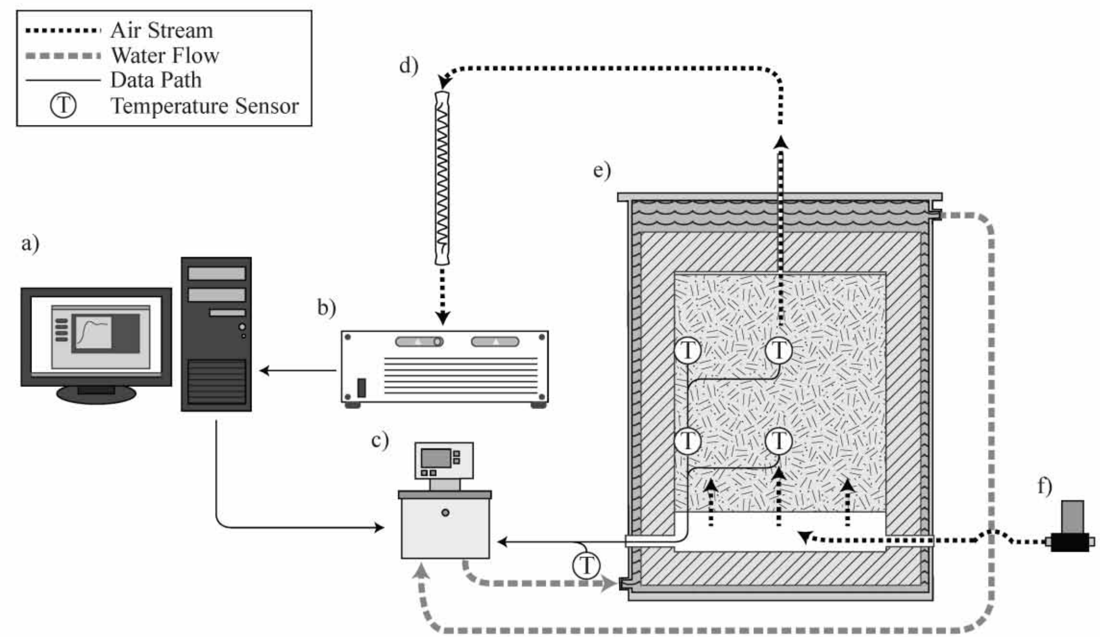


Storage Simulators

- Simulate the behavior of a range of storage conditions.
  - Control: heat loss, oxygen availability, moisture content
  - Monitor: heat generation, microbial respiration, moisture change, DML, composition.

- Generate ample quantities of post-storage material with a well documented history for chemical analysis.

- Microbial respiration: Gas exiting the reactor is analyzed for CO_2 production in real-time
  - DML estimated by $CH_2O + O_2 \rightarrow CO_2 + H_2O$



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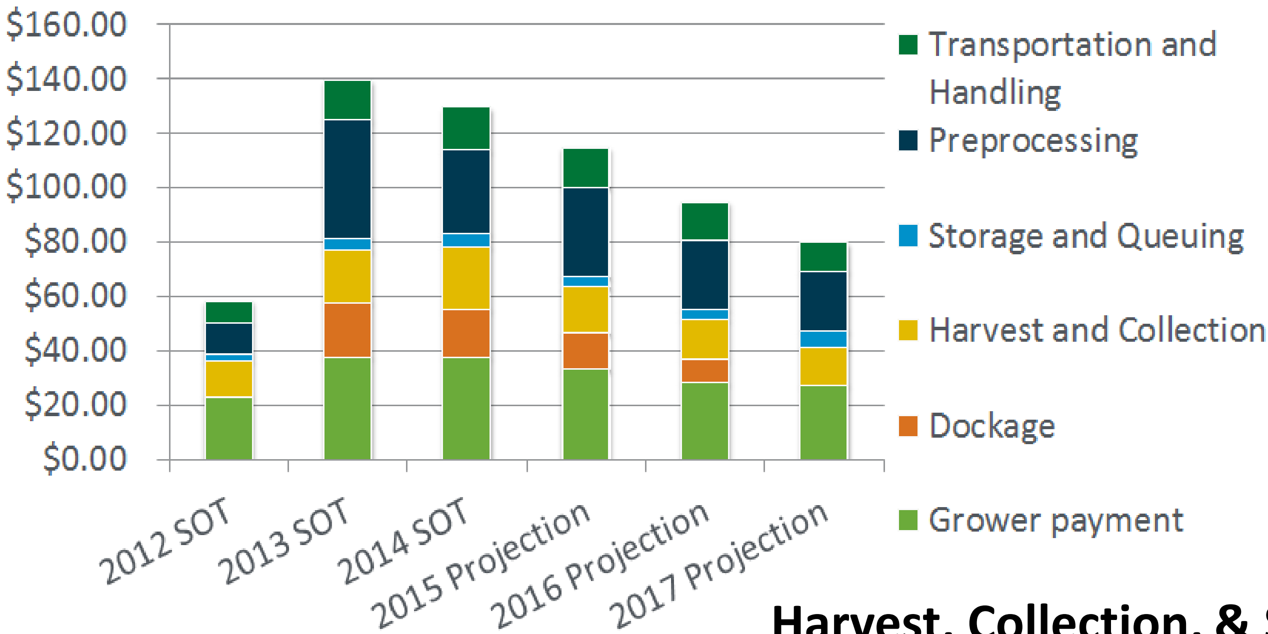
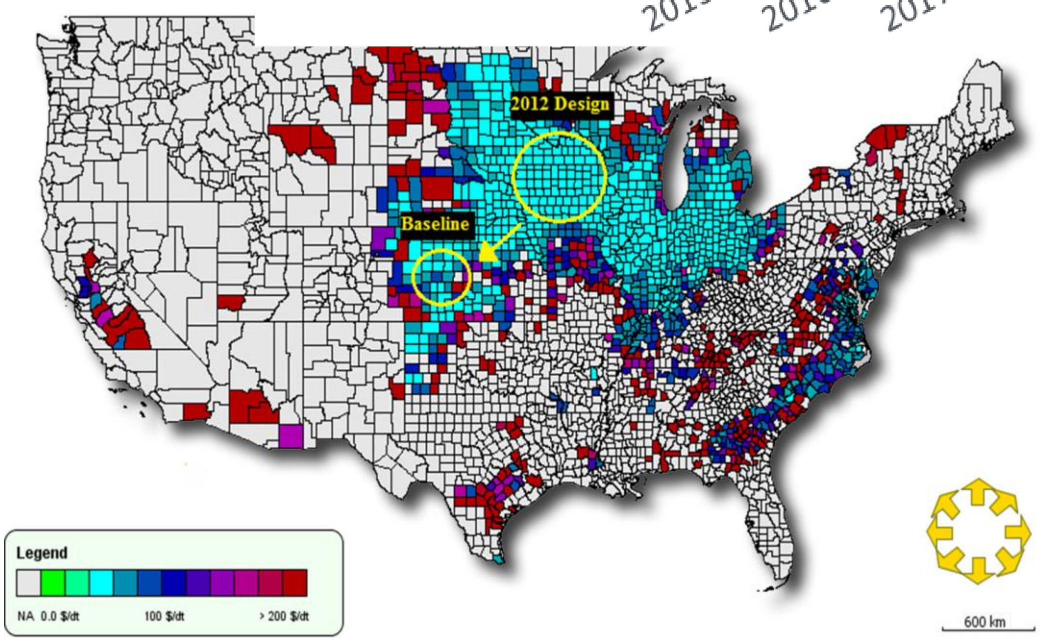
Feedstock Cost Reductions to 2017





Harvest, Collection, & Storage:

- Reduce dockages
  - Reduce contamination
  - Manage moisture
- Reduce collection costs
  - Balance yield & quality
- Improve storage stability
  - Manage DML

Responses to Previous Reviewers' Comments

- Reviewer Comment: Methodical approach, but not clear how widely the technology improvements have been communicated or deployed in industry.
  – Response: We communicate our research through high-quality, peer-reviewed journals, but we recognize that prospective operators do not likely read these journals. Therefore we also communicate in the form of best management practices (BMPs) that are disseminated through our industrial collaborators.

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Responses to Previous Reviewers' Comments

- Reviewer Comment: To ascertain relevant costs for delivery of material to converter throat, need to utilize actual numbers based on findings published in peer reviewed journals rather than models based on assumptions and attempts to meet set target numbers. With respect to utilization of corn stover as a biomass source, various items of interest must be considered…
  - Many factors must be considered in developing a sustainable and economical feedstock supply chain. The reality is that there is not a one-size fits all solution. Factors that may be limiting for one crop, grower, or refinery may not be limiting for others; operations and processes that may work in one scenario may not work in others. We have tried to address this by first initiating our research with intensive modeling and simulations that cover a broad range of inputs and outputs to identify broadly applicable barriers and uncertainties. Our research, and ultimately our solutions then have the best chance to be broadly applicable to the emerging industry rather than point source solutions that are applicable only to niche resources or specific scenarios