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

U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO) 2017 Project Peer Review 1.2.2.1 Advanced Feedstock Preprocessing

March 9, 2017

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Feedstock-Conversion Interface Consortium

Vicki Thompson
John Aston
Jeff Lacey
David Thompson
Idaho National Laboratory

Goal Statement

- **Goal** - The project goal is to enable the use of low quality raw biomass using mechanical and chemical preprocessing technologies such that it meets biorefinery quality specifications while still meeting feedstock cost targets, thus expanding the total quantity of biomass available to biorefineries

- **Outcome** – Reduced supply risks for biorefineries through preprocessing methods that mobilize as much of the available biomass resources as possible at the lowest cost and still meet biorefinery quality specifications

- **Relevance** – The Billion Ton Update (BT16) demonstrates how 1 billion tons of biomass could be available sustainably in the U.S. by 2040; however, much of that biomass has unacceptable quality, high costs and is not evenly distributed through the country. This project addresses all three issues.

Quad Chart Overview

Timeline

- Project Start:10/1/2013
- Project End: 9/30/2019
- On-going
- Percent Complete: 12%

Budget

	Total Costs FY 12–FY 14	FY 15 Costs	FY 16 Costs	Total Planned Funding (FY 17-Project End Date)
DOE Funded	$1.307M	$1.436M	$1.197M	$4.275M

Barriers

Ft-A Feedstock availability and cost
Ct-A Feedstock variability
Ct-C Efficient Preprocessing

Technical Targets

2017 – Deliver feedstock at spec. for $84/ton
2022 – Economically and sustainably supply 285 million tons to biorefinery industry

Collaborators

- Feedstock Conversion Interface Consortium
  - INL – Allie Ray, Tyler Westover
  - NREL – Nick Nagle, Melvin Tucker
  - SNL – Seema Singh
  - LBNL – Ning Sun
- INL Analysis/Sustainability
- Michigan Technological University
- Cascadia Consulting
- Key Technology

1 - Project Overview

- From MYPP, BETO goals for terrestrial feedstock supply and logistics
  - By 2017, deliver feedstock at $84/ton meeting conversion in-feed specifications
  - By 2022, economically and sustainably supply 285 million tons at $84/ton
- From INL 2017 Design Case, low-cost waste biomass must be used to meet cost target, but does not meet quality specifications
- From BT 2016, 411 million tons available in 2022
  - 208 million tons ag residues and forest products
  - 43 million tons forest residues
  - 82 million tons waste materials
  - 78 million tons energy crops
- Need to use low-quality biomass to meet quantity targets especially if energy crops do not come online as projected
- This project previously demonstrated that mechanical and chemical preprocessing can improve biomass quality for forest residues and stover

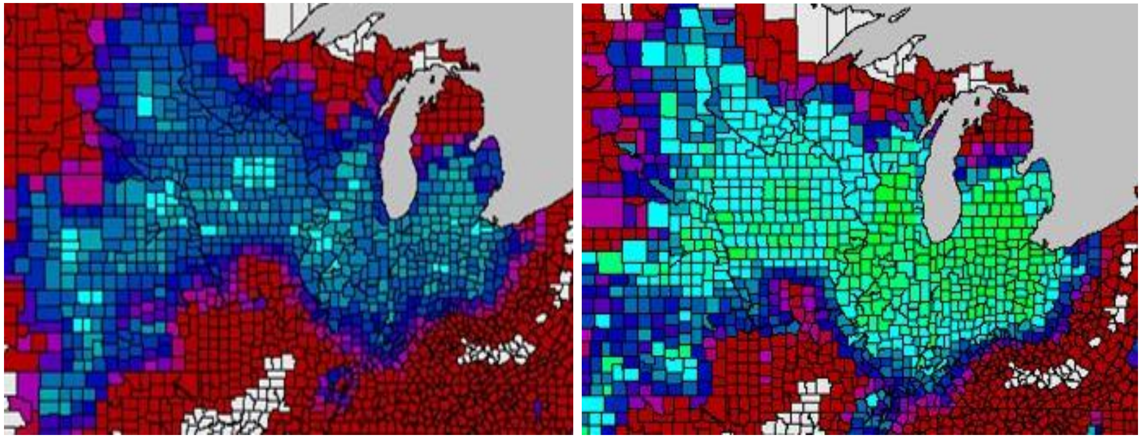
2 – Approach (Management)

- Project PI – David Thompson during FY15-16
  - Mechanical preprocessing, Jeff Lacey
  - Chemical preprocessing, John Aston
  - Formulation, Vicki Thompson
  - Analysis interface, David Thompson
- Milestones have inputs from all tasks for better integration
  - Tracking milestones
  - Annual milestone
- Go/No-Go decision points have guided selection of promising technologies
- Collaborations managed by subcontracts or by leveraging other projects
  - Subcontracts with Cascadia Consulting and Michigan Tech
  - Leveraging INL, NREL, SNL and LBNL FCIC projects

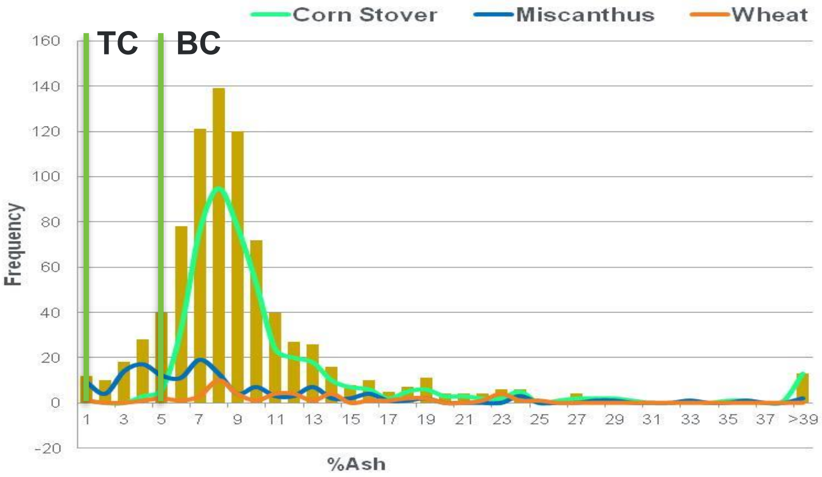
2 – Approach (Technical)

- To be successful, Biorefineries will require a sustainable supply of low-cost biomass in sufficient quantities and with sufficient quality

Corn Stover　　Corn stover + MSW



- Challenges
  - Biomass is seasonal and not evenly distributed impacting quantity
  - Biomass varies in quality which affects quality of feedstock
  - Methods to improve biomass quality add cost



2 – Approach (Technical)

- Assess mechanical and chemical preprocessing
  - Air classification and sieving
  - Acid leaching, water washing, and alkaline extraction
- Economics
  - Spreadsheet
  - AspenPlus™
  - TEA from harvest to reactor throat
- Identify blends that meet cost, quality and quantity specifications
  - Obtain waste biomass (Cascadia Consulting)
  - Apply combinations of mechanical and chemical preprocessing to generate ingredients
  - Measure properties (ash, ash species, composition)
  - Determine blends of feedstocks and/or ingredients meeting specifications at lowest cost
  - Test blends for conversion performance

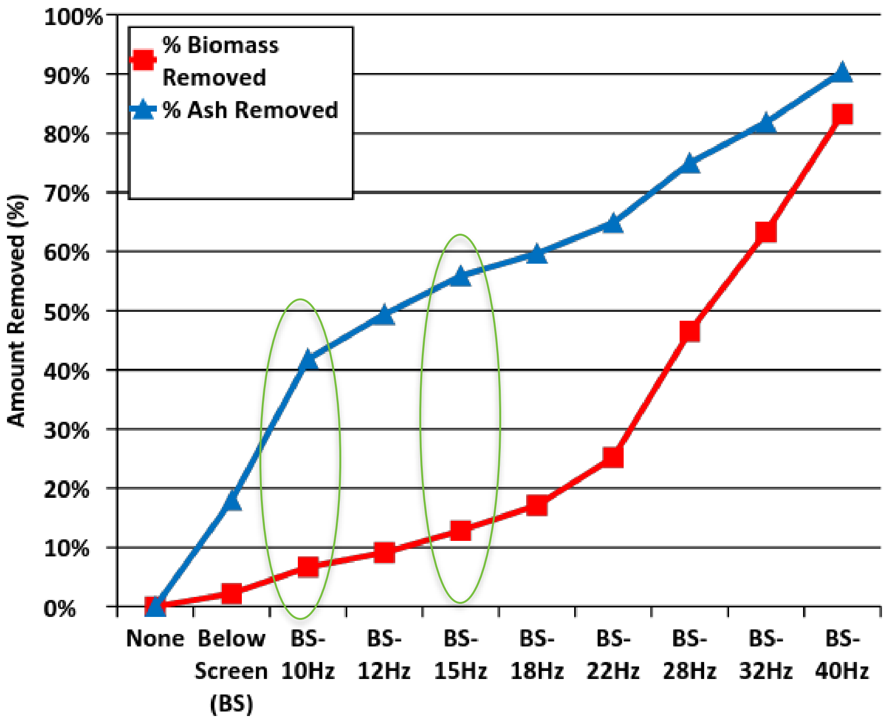
2 – Approach (Technical)

- Go/No-Go decision points
  - Can air classification separate biomass from ash without losing large amounts of biomass?
  - Is leaching feasible for ash removal from biomass given current cost targets?
- Economic and technical metrics
  - Biomass quantities and prices obtained from BT-2 and BT-16
  - Feedstock logistics costs obtained from INL 2015 SOT
  - Cost models for mechanical and chemical preprocessing
  - Conversion specifications from PNNL and NREL SOTs and literature
  - Biomass properties obtained from INL biomass library or measured
  - Subcontracts for waste feedstocks and thermochemical conversion
  - Collaboration with NREL, SNL and LBNL for biochemical conversion

3 – Technical Accomplishments/Progress/Results

Go/No-Go decision 3/31/2015 – Can air classification fractionate biomass into high ash and low ash fractions?

Target: <15% of biomass and >40% of total ash



Results:

- 42% ash concentrated into 7% biomass
- 58% ash concentrated into 13% biomass
- High-ash fractions can be chemically preprocessed at lower cost
- High-ash fractions can be used as co-product (combustion)
- Low-ash fractions are below 0.9% total ash
- Air classification can be used to fractionate biomass

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

3 – Technical Accomplishments/Progress/Results

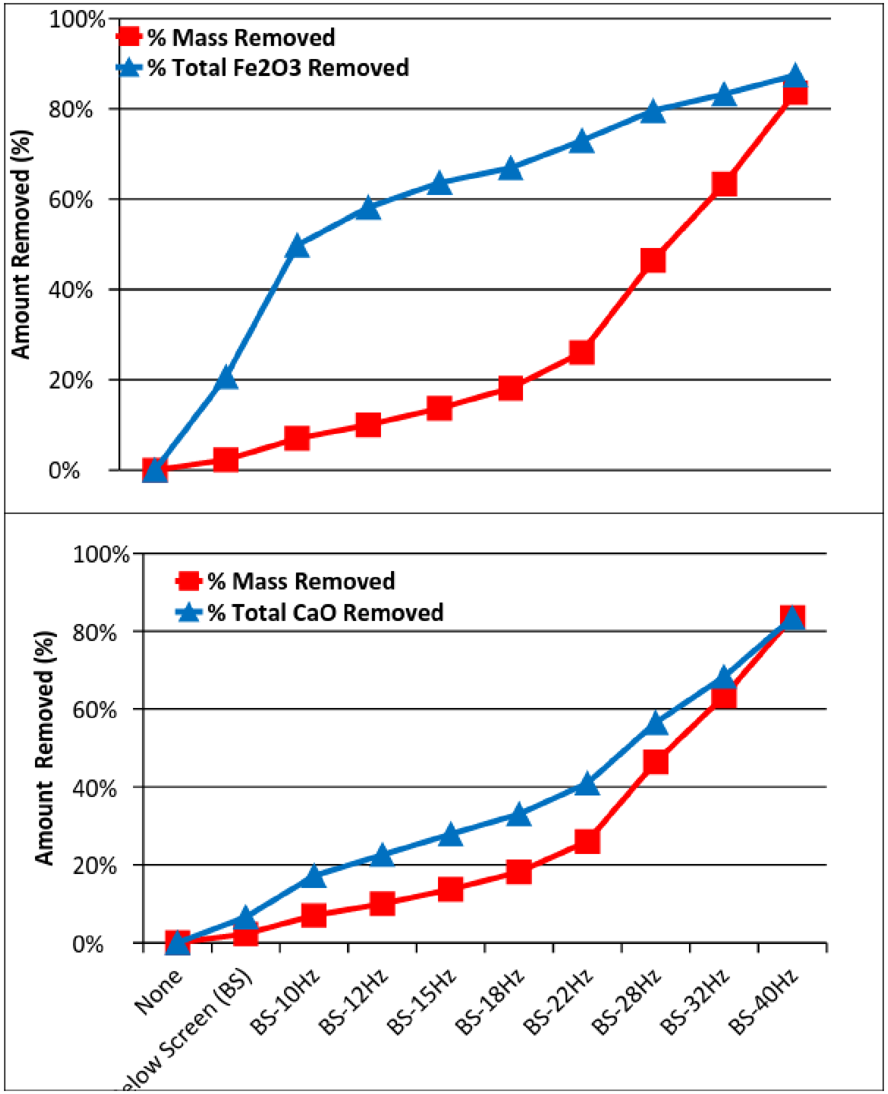
Go/No-Go 3/31/2016 – Is leaching economical to improve feedstock quality?

Target – 10% reduction in cost over baseline and 15% increase in available biomass

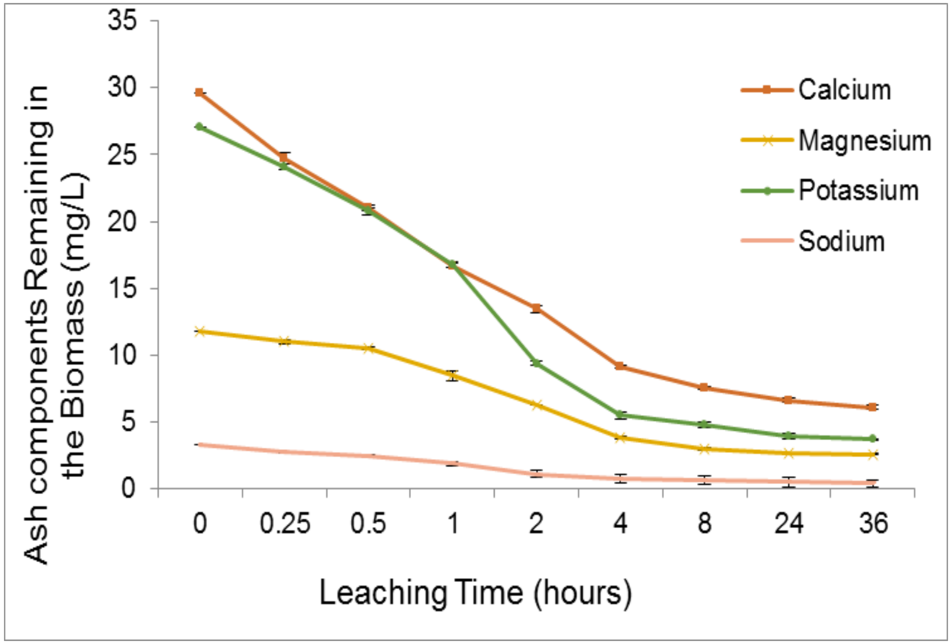
- Quality Specifications
  - 0.9% total ash (PNNL uncatalyzed fast pyrolysis SOT)
  - 1300 ppm AAEM (Ca, K, Na, and Mg) based on levels found in clean pine
- Costs
  - Clean pine, delivered (baseline) (INL 2015 Feedstock SOT)
    - $117.01/ton
  - Logging residues, delivered (INL 2015 Feedstock SOT)
    - $70.85-$84.05/ton
  - Air classification (Lacey et al, 2015)
    - $0.88/ton
  - Acid leach (Hu et al, 2016)
    - $9.56-$21.79/ton
- Quantities in South Carolina
  - 202,000 tons clean pine (USFS inventory)
  - 380,600 tons of logging residues (BT2)

3 – Technical Accomplishments/Progress/Results

Air classification logging residues

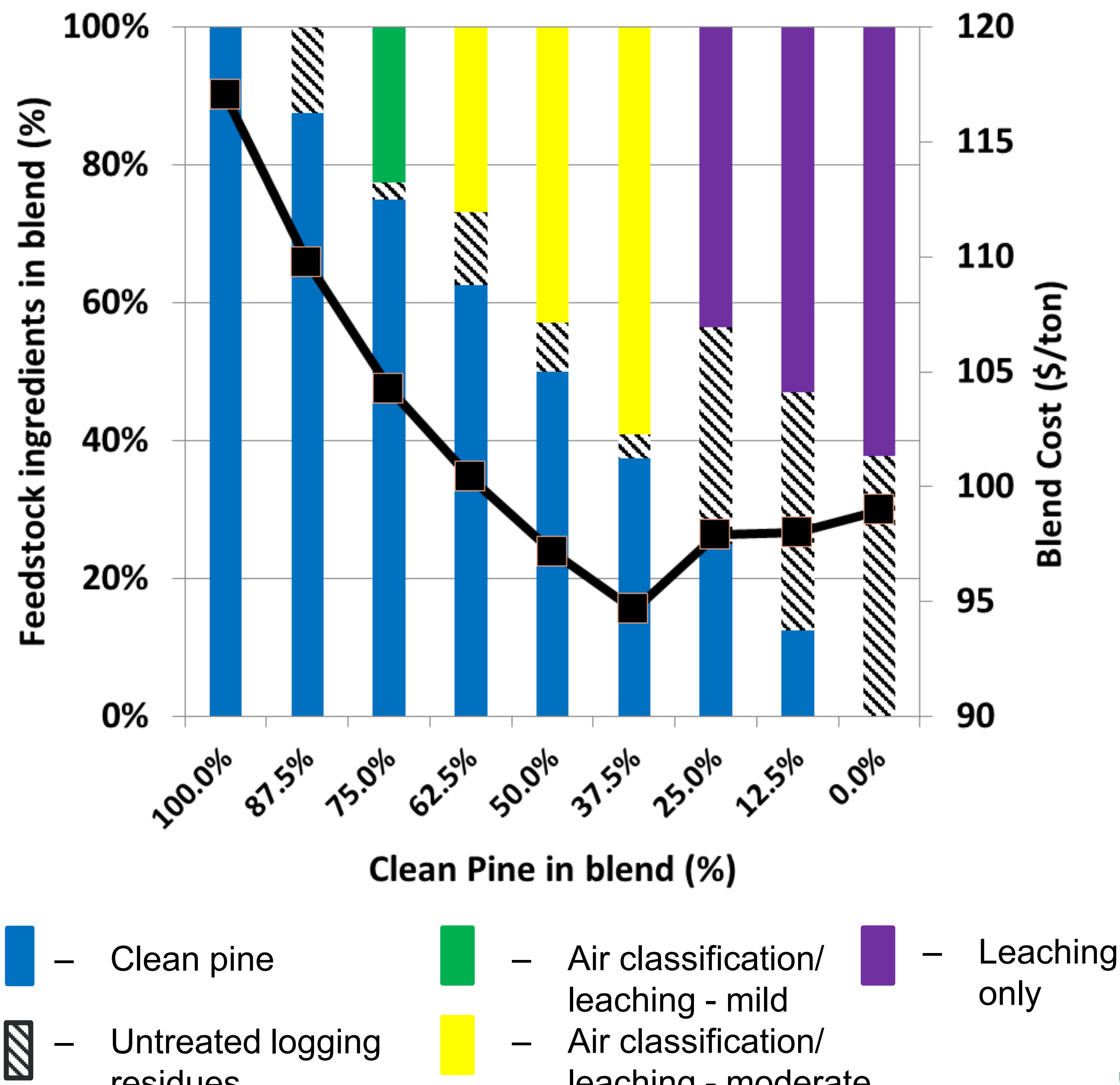


Acid leaching - 0.1% H_2SO_4, 25°C



- Air classification
  - Removes soil ash
  - Poor removal of AAEMs
- Acid leaching
  - 78-86% removal AAEMs

3 – Technical Accomplishments/Progress/Results

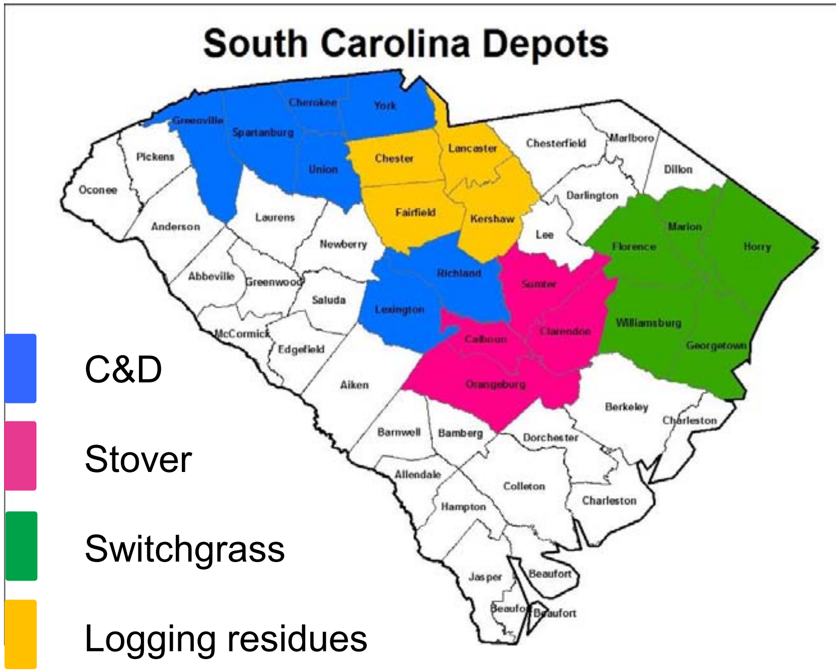


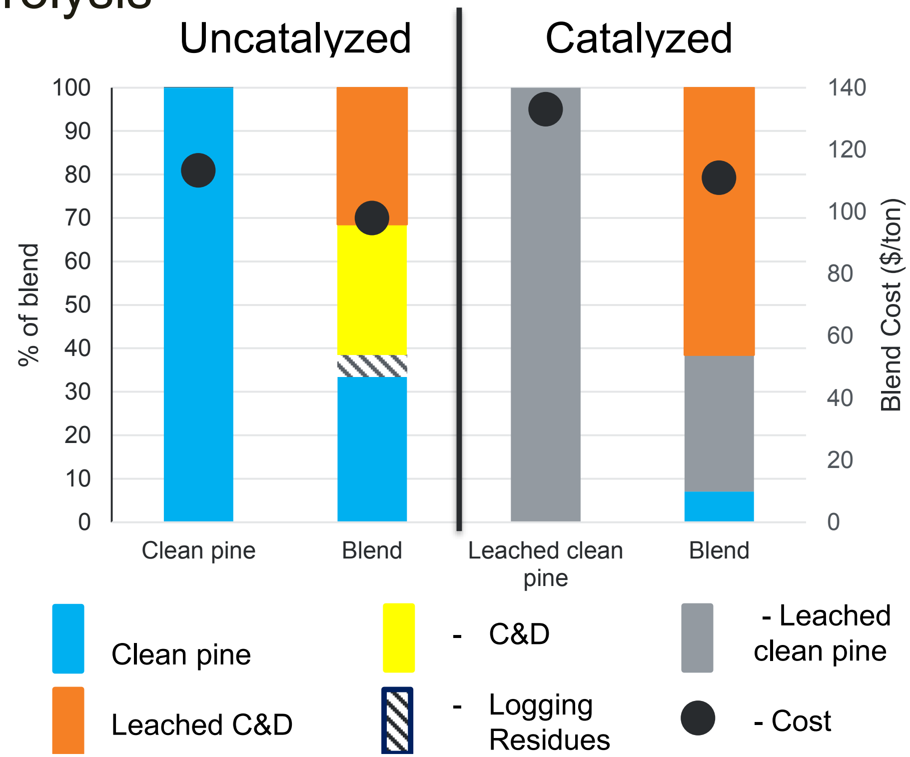
Results

- Cost
  - $117.01 to $94.66
  - 19% decrease
- Quantity
  - 202,000 tons to 582,000 tons
  - 2.9 fold increase
- Quality
  - 0.5% total ash
  - 1300 ppm AAEM
- All specifications met using only logging residues (far right bar)
  - 15% cost decrease
- Leaching is beneficial if the biomass is cheap enough

3 – Technical Accomplishments/ Progress/Results

Annual milestone 9/30/2016 – Identify at least one high impact feedstock blend for catalyzed and uncatalyzed fast pyrolysis



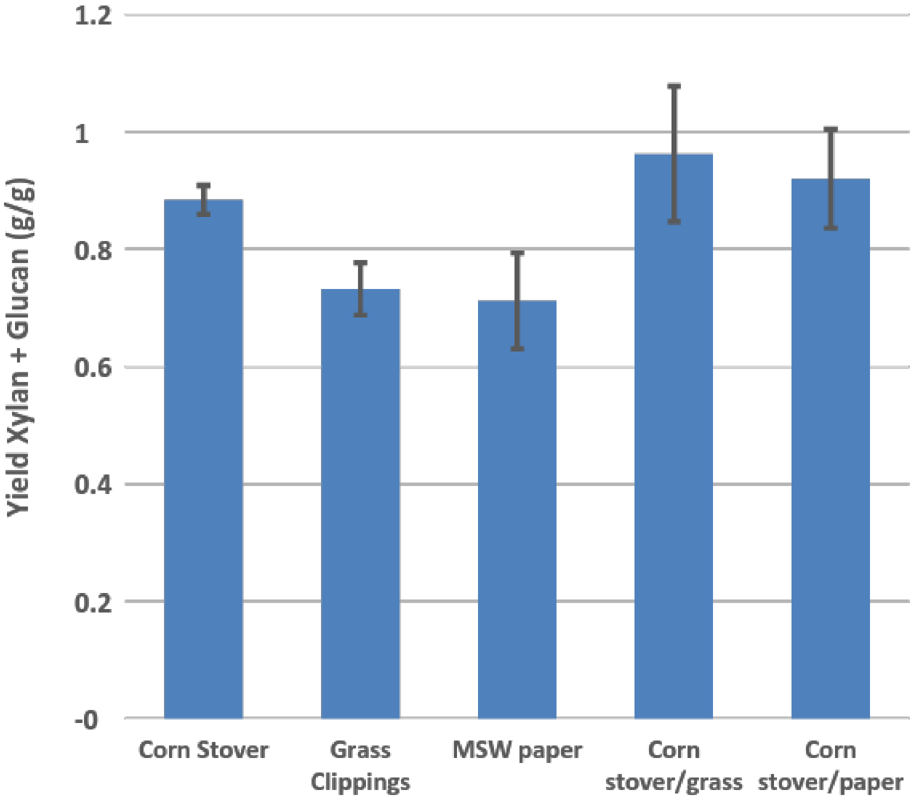


- Specifications
  - 200,000 tons annually
  - Uncatalyzed - 0.9% total ash &1300 ppm AAEM
  - Catalyzed – 240 ppm of Ca, Mg, K, and Na

- Blends lower cost despite leaching
  - Uncatalyzed - 16%
  - Catalyzed – 20%

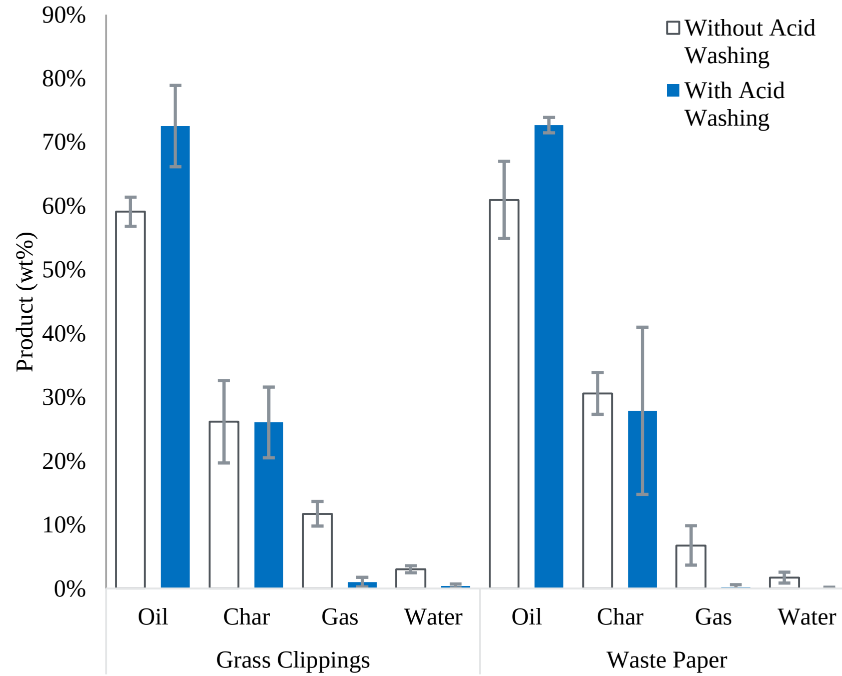
3 – Technical Accomplishments/ Progress/Results

Acid pretreatment/enzymatic hydrolysis



- Waste materials had lower yields compared to stover
- Blends had comparable yields to stover
  - Predicted yield is lower
  - Synergy?

Uncatalyzed fast pyrolysis

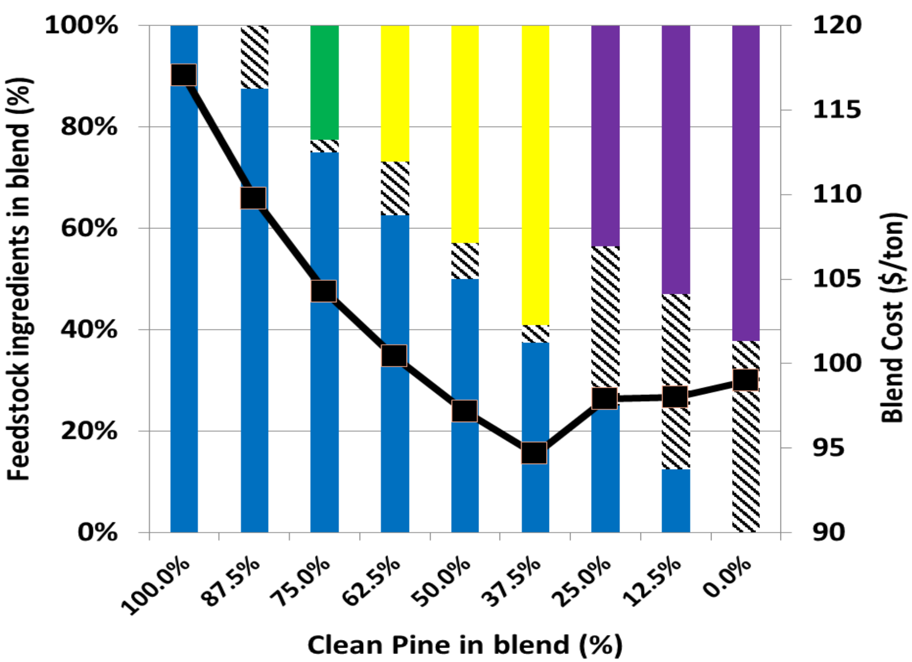


- Micropyrolysis system
- Compared leached to unleached
- Bio-oil yields increased with leaching
- Char unaffected and gas yields decreased

4 – Relevance

- Enabling the use of low quality biomass through preprocessing to meet cost, quality and quantity specifications
- Directly supports BETO's mission:
  - *"Developing and demonstrating transformative and revolutionary bioenergy technologies for a sustainable nation"*
- Addresses BETO's 2017 & 2022 goals for Feedstock Supply and Logistics
  - Deliver feedstock at in-feed specifications for $84/ton
  - Economically and sustainably supply 285 million tons/year at $84/ton
- Reduces feedstock supply risk to the bioenergy industry by mobilizing additional biomass that meets cost, quality and quantity specifications

- Project driven by a combination of TEA and laboratory research to meet metrics and technical targets
- Reductions in costs by using:
  - Low cost/low quality biomass
  - Mechanical preprocessing
  - Chemical preprocessing
  - Formulation



5 – Future Work

- Project ended three year cycle in FY16 and was merit reviewed for FY17-19 work
  - New scope seeks to utilize preprocessing techniques developed to solve problems relevant to the bioenergy industry
  - IBRs suffer from feedstock handling issues including severe abrasion to grinders, knife mills and handling equipment.
    - Anecdotal information that knives must be changed every few days (~10% of lifetime)
    - Holes worn in conveying equipment
  - Belief is abrasion is caused by introduced soil ash
    - Air classification removes introduced soil ash very well
    - Chemical preprocessing can remove silica – another ash component known to be abrasive
  - Work scope developed to apply preprocessing to abrasion
    - Partner with key biomass handling and processing equipment manufacturers
    - Develop an abrasion testing method
    - Study mechanisms of abrasion
    - Use preprocessing to remove ash components and reduce feedstock abrasiveness
  - Go/No-Go decision 3/31/2018 – achieve 25% reduction in abrasiveness using preprocessing methods

Summary

- Overview
  - To be successful, Biorefineries will require a sustainable supply of low cost biomass in sufficient quantities and with sufficient quality
- Approach
  - Mechanical and chemical preprocessing with formulation used to improve biomass quality and quantity yet keep costs as low as possible
- Technical Accomplishments/Progress/Results
  - A flexible method for optimizing all biomass resources in a region and meeting cost/quality/quantity targets
  - A blend for uncatalyzed fast pyrolysis that is 16% lower cost than baseline
  - A blend for catalyzed fast pyrolysis that is 20% lower cost than baseline
- Relevance
  - This project reduces biomass supply risk to the biorefineries by increasing feedstock quantities, reducing costs and still meeting quality targets
- Future work
  - Applying these methodologies to solve other critical issues hindering the bioenergy industry

Additional Slides

Responses to Previous Reviewers' Comments

- Need for project is not clear
  - Bioenergy industry needs a sustainable supply of biomass that meets cost, quality and quantity targets. With the current paradigm of single feedstock biorefineries, feedstock must be overcontracted to hedge against adverse weather. INL library data has also shown that most corn stover does not meet ash targets. Our project mobilizes low cost/low quality feedstocks and takes advantage of the low cost to improve quality. The additional feedstock reduces supply risk to the biorefineries by providing alternative sources.
- Sustainability of wastewater from ash removal
  - We apply mechanical methods such as air classification first to concentrate as much ash as possible into a small fraction of biomass (i.e. 42% of ash in 7% of biomass), then only 7% of the biomass must be treated instead of 100%. This will reduce the amount of wastewater needing treatment.
  - Our revised cost model for acid leaching includes recycle to reduce the total waster usage, as well as a concentration step to reduce the amount of wastewater needing treatment.
  - A concern was raised for biochemical conversion processes that needed fermentation nutrients would be leached out of biomass. Our results show that leaching is probably not necessary for biochemical feedstocks and that air classification alone would be sufficient to remove ash.
- Project needs to clarify its plan
  - Our efforts were divided into tasks that would each focus on one aspect of ash removal (mechanical, chemical and formulation), but milestones were integrated to have input from all of the tasks to keep them in sync.
  - An analysis interface task was added to determine costs and conduct TEAs for the project to help focus our efforts
  - Go/No-go decision points were put in place to eliminate unproductive research paths

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

Publications, Patents, Presentations, Awards & Commercialization

- Publications - FY15-present
  - Sun, N., F. Xu, N. Sathitsuksanoh, V.S. Thompson, K. Cafferty, C. Li, D. Tanjore, A. Narani, B.A. Simmons, and S. Singh. **2015**. Conversion of municipal solid waste using ionic liquids. *Bioresource Tech.*, **186**:200-206.
  - Li, Chenlin, D. Tanjore, W. He, J. Wong, J.L. Gardner, V.S. Thompson, N.A. Yancey, K. Sale, B.A. Simmons and S. Singh. **2015**. Scale-up of ionic liquid based fractionation of single and mixed feedstocks. *BioEnergy Research*, **8**:982-991.
  - Lacey, J.A., Aston, J.E., Westover, T.L., Cherry, R.S., Thompson, D.N., **2015**. Removal of introduced inorganic content from chipped forest residues via air classification. *Fuel* 160 (2015) 265-273.
  - Li, C., J.E. Aston, J.A. Lacey, V.S. Thompson, and D.N. Thompson. **2016**. Impact of feedstock quality and variation on biochemical and thermochemical conversion. *Renewable & Sustainable Energy Reviews*, 65:525-536, http://dx.doi.org/10.1016/j.rser.2016.06.063
  - Hongqiang, Hu, Westover, T.L., Lacey, J.A., Cherry, R., Aston, J.E., Thompson, D.N. **2016**. Process Simulation and Cost Analysis for Removing Inorganics from Wood Chips using Combined Mechanical and Chemical Preprocessing. *Bioenergy Research*, doi:10.1007/s12155-016-9794-3.
  - Thompson, V.S., J.A. Lacey, M.A. Jindra, J. Aston, and D.N. Thompson. **2016**. Application of air classification and formulation to manage feedstock cost, quality and availability for bioenergy. *Fuel*, 180:497-505. doi:10.1016/j.fuel.2016.04.040.
  - Lacey, J.A., Emerson, R.M., Westover, T.L., Thompson, D.N. **2016**. Ash reduction strategies in corn stover facilitated by anatomical and size fractionation. *Biomass and Bioenergy,* 90: 173-180.
  - Klemetsrud, B., S. Ukaew, V.S. Thompson, D.N. Thompson, J. Klinger, L. Li, D. Eatherton, P. Puengprasert, and D. Shonnard. **2016**. Characterization of products from fast micro-pyrolysis of municipal solid waste (MSW) biomass. *ACS Sustainable Chemistry & Engineering*. In press. doi:10.1021/acssuschemeng.6b00610.
  - Perez-Pimienta A.J., N. Sathitsuksanoh, V.S. Thompson, K. Tran, T. Ponce-Noyola, V. Stavila, S. Singh, and B.A. Simmons. **2016**. Ternary ionic liquid-water pretreatment systems of an agave bagasse and municipal solid waste blends. Submitted to *Biotechnology for Biofuels*, July 19, 2016.

Publications, Patents, Presentations, Awards & Commercialization

- Publications, continued
  - Thompson, V.S., J.E. Aston, J.A. Lacey and D.N. Thompson. **2016**. Optimizing biomass feedstocks blends with respect to cost, supply and quality for catalyzed and uncatalyzed fast pyrolysis applications. Submitted to *BioEnergy Research* September 30, 2016.
  - Aston, J.A., Thompson, D.N. and Westover, T.L. **2016**. Performance assessment of dilute-acid leaching to improve corn stover quality for thermochemical conversion. *Fuel*, 186:311-319.
  - Li, C., L Liang, N. Sun, V.S. Thompson, F. Xu, A. Narani, Q. He, D. Tanjore, T. Pray, B.A. Simmons, and S. Singh. **2017.** Scale-up and process integration of sugar production by acidolysis of municipal solid waste/corn stover blends in ionic liquids. *Biotechnology for Biofuels* 10:13, doi:10.1186/s13068-016-0694-8.
  - Ling Liang; Feng Xu; Qian He; Jipeng Yan; Tina Luong; Chenlin Li; Vicki S Thompson; Blake A Simmons; Todd R Pray; Seema Singh; Ning Sun. **2017**. Conversion of Municipal Solid Waste Blends Using Ionic Liquids: Feedstock Convertibility and Process Scale-up. Submitted to *BioEnergy Research* January 25, 2017.
  - Ray, A.E., Li, C., Thompson, V.S**.**, Daubaras, D.L., Hartley, D.S. and Nagle, N. **2017**. Biomass blending and densification: Impacts on feedstock supply and biochemical conversion performance. In: Biomass Volume Estimation and Valorization to Energy. ISBN 978-953-51-4909-5.
- Presentations - FY15-present
  - Emerson, R.M., Westover, T.W., Lacey, J.A., Thompson, D.N., **2014**. Ash composition analysis of anatomical and particle size fractions for corn stover using laser-induced breakdown spectroscopy (LIBS). Selected for oral presentation by Rachel Emerson at SciX 2014, September 28-October 3, 2014. Reno, NV.
  - Aston, J.E., Cherry, R.S., Lacey, J.A., Westover, T.L., Thompson, D.N., **2014**. Ash reduction methods to provide feedstocks for conversion processes. Poster presentation at the 2014 AIChE Annual Meeting in Atlanta, GA, November 16-21, 2014.
  - Thompson, V.S. **,** A. Ray, D. Stevens, D. Daubaras, A. Hoover, R. Emerson, S. Ukaew, B. Klemetsrud, J. Klinger, D. Eatherton, and D. Shonnard. **2015**. "Assessment of municipal solid waste for biochemical and thermochemical conversion pathways". Oral presentation at 37th Annual meeting on Biotechnology for Fuels and Chemicals Symposium. San Diego, CA. April 29.

Publications, Patents, Presentations, Awards & Commercialization

- Presentations, continued
  - Lacey, J.A., Aston, J.E., Westover, T.L., Cherry, R.S., Thompson, D.N., **2015**. Selective removal of ash and specific elements of ash in air classified fractions of loblolly pine forest residues. Oral presentation at the 37th Symposium on Biotechnology for Fuels and Chemicals in San Diego, CA, April 27-30, 2015.
  - Lacey, J.A., Aston, J.E., Delezene-Briggs, K., Westover, T.L., Thompson, D.N., **2015**. Biomass fractionation methods for ash removal: sieving, anatomical, and air classification. Poster presentation at the 37th Symposium on Biotechnology for Fuels and Chemicals in San Diego, CA, April 27-30, 2015.
  - Aston, J.A., Tumuluru, J.S., Lacey, J.A., Thompson, D.N., Thompson, V.S. and Fox, S.L. **2015**. Alkaline deacetylation of corn stover: Effects on feedstock quality, Oral presentation at AIChE annual meeting, Salt Lake City, UT, November 8-13, 2015.
  - Thompson, V.S. **,** A. Ray, D. Stevens, D. Daubaras, A. Hoover, R. Emerson, S. Ukaew, B. Klemetsrud, J. Klinger, D. Eatherton and D. Shonnard. **2015**. "Assessment of municipal solid waste for biochemical and thermochemical conversion pathways", Oral Presentation at AIChE Annual meeting, Salt Lake City, UT, November 11.
  - Thompson, D.N., Thompson, V.S., Lacey, J.A., Hartley, D.S., Jindra, M.A., Aston, J.E., **2016**. Strategies for post-harvest reduction of ash content in biomass feedstocks. Oral presentation at the 2016 Agricultural Equipment Technology Conference in Louisville, KY, February 8-10, 2016.
  - Thompson, V.S. **,** J.A. Lacey, J. Aston, D. Hartley, E. Searcy, and D. Thompson. **2016**. Application of air classification, acid leaching and formulation to manage feedstock cost, quality and quantity for bioenergy. Oral presentation at 38th Symposium on Biotechnology for Fuels and Chemicals, Baltimore, MD, April 25-28, 2016.
  - Lacey, J.A., Thompson, V.S., Aston, J.E., Jindra, M.A., Thompson, D.N., **2016**. Air classification of herbaceous feedstocks for ash removal and quality improvement. Poster presentation at the 38th Symposium on Biotechnology for Fuels and Chemicals in Baltimore, MD, April 25-28, 2016.
  - Thompson, D.N., Li, C., Aston, J.E., Lacey, J.A., Thompson, V.S., Williams, C.L., Emerson, R.M., Hoover, A.N., Gresham, G.L., **2016.** Feedstock quality: A poorly understood but critical aspect for the development of a biorefining industry. Oral presentation at the 38th Symposium on Biotechnology for Fuels and Chemicals in Baltimore, MD, April 25-28, 2016.

Publications, Patents, Presentations, Awards & Commercialization

- Presentations, continued
  - Lacey, J.A., Aston, J.E., Westover, T.L., Cherry, R.S., Thompson, D.N., **2015**. Selective removal of ash and specific elements of ash in air classified fractions of loblolly pine forest residues. Oral presentation at the 37th Symposium on Biotechnology for Fuels and Chemicals in San Diego, CA, April 27-30, 2015.
  - Gaffney, A.M., Thompson, V.S., Lacey, J.A., Aston, J.E., Hartley, D.S., Searcy, E.M. and Thompson, D.N. **2016**. Biomass pretreatment process using low waste woody materials to produce biofuels. Oral presentation at American Chemical Society, Philadelphia, PA, August 21-25, 2016.
  - Aston, J.A. and Thompson, D.N. **2016**. Deacetylation and pelleting of corn stover at the depot. Oral presentation at AIChE general meeting, San Francisco, CA, November 13-18, 2016
  - Lacey, J.A., Thompson, V.S., Aston, J.A., and Thompson, D.N. **2017**. The cost of improved quality feedstocks: How good is good enough?. Accepted for oral presentation at 39th Symposium on Biotechnology for Fuels and Chemicals, San Francisco, CA, May 1-4, 2017.
- Patents
  - Filed an invention disclosure record on blending strategy with INL in August 2016.
  - Discussions with INL Technology Transfer department on best route for commercialization