2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

1.3.1.3 Feedstock Logistics Fundamentals

Date: May 21, 2013
Technology Area Review: Feedstock Supply & Logistics

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Organization: Idaho National Laboratory

Goal Statement

Develop and demonstrate advanced preprocessing technologies that

- Provide innovative, disruptive solutions to feedstock logistics challenges
- Enable the use of low-cost & low-quality biomass resources to support the goal of providing consistent, low-cost, high-quality feedstocks

Quad Chart Overview

Timeline

- Project start date: FY-10
- Project end date: FY-17

Budget

- Funding for FY11: $1.5M DOE
- Funding for FY12: $1.2M DOE
- Funding for FY13: $1.85M DOE
- Years the project has been funded / average annual funding: 4 years, avg. funding $1.5M/yr.

Partners

- LBNL & NREL
- Michigan Biotechnology Institute
- Oklahoma State University.
- University of Wisconsin / Great Lakes Bioenergy Center

Barriers

- Ft-G Feedstock Quality and Monitoring
- Ft-K Biomass Physical State Alteration
- Ft-L Biomass Material Handling and Transportation
- Ft-M Overall Integration and Scale-Up

Project Overview

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- Densification Workshop in Aug 2011
  - Introduced advanced preprocessing concepts
  - Gathered stakeholders' feedback on potential value and barriers (technical, commercial, etc.)
  - Published workshop report (available on INL website)
- Workshop identified 4 primary advanced preprocessing concepts
  - Densification – Increasing the value of densification by reducing the cost through improved process efficiency/process variables
  - Formulation – blended feedstocks that reduce feedstock cost, improve feedstock quality, and/or improve feedstock availability and utilization
  - Mechanical Separations - removal of particulate impurities (e.g., soil) and fractionation of biomass tissues for co-product production
  - Chemical Preconversion – chemical modification for removal of physiological and structural ash and inhibitors, and potentially improve convertability

1. Approach

- Initial focus on Technoeconomic Assessment (TEA)
  - Evaluate cost:value relationships
    - Value includes
      - Improved quality – quantify relative to conversion performance
      - Improvements in the feedstock supply chain operations (e.g., improved stability, etc.)
  - Informed by lab-scale R&D that develops parametric relationships among physical properties and energy consumption
  - Establish potential impacts on unit operation costs and net feedstock costs across the feedstock supply chain
  - Develop R&D targets to conduct fundamental research to identify technologies
  - Validate through peer-reviewed journal articles
- TEA informs go/no-go decision
- Lab-scale technology development
  - Engage “Interface” tasks for conversion performance testing
- Transition the data to Engineering tasks for scale-up

2. Densification – Technical Accomplishments

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Why biomass densification

- Absolutely necessary for the DOE vision of distributed (depot) preprocessing and commoditization

Challenge of densification

- Improved cost: value relationship
- Cost
  - Reduce through proper selection of densification systems
  - Better understanding of interaction of process variables and product quality attributes
- Value
  - Increase bulk density
  - Improved storage stability
  - Maintains convertibility (Biochem Interface Task)
  - Economic solution for high moisture biomass

Densification Systems

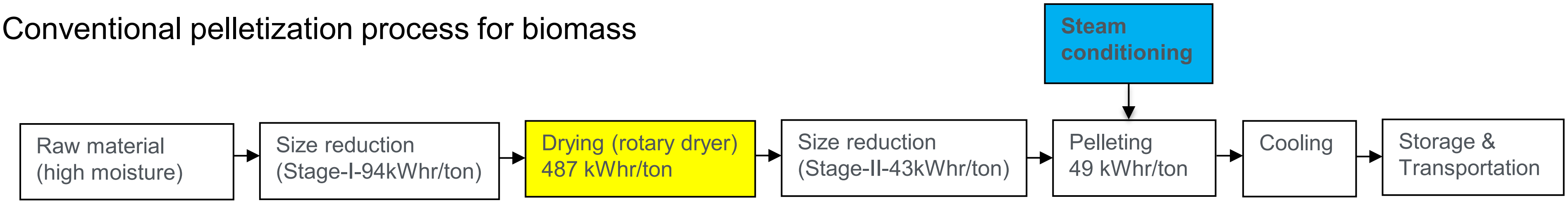
- Pellet mill
- Briquette press
- Screw extruder
- Tablet press
- Agglomorator

Densification Variables

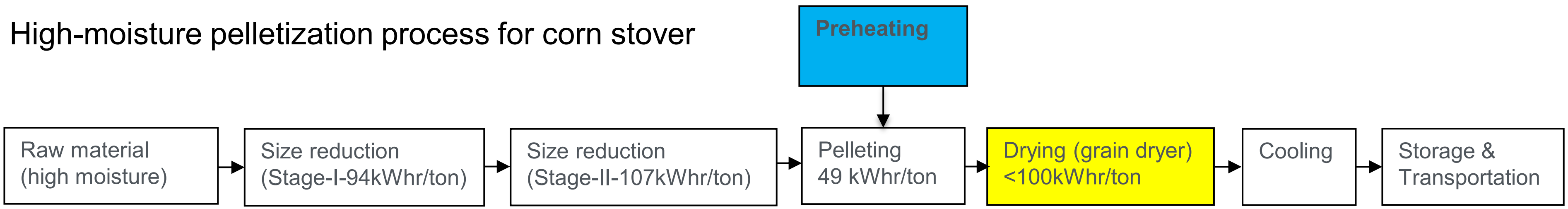
- Feedstock variables
- Process variables
- Biomass composition
- Preconditioning
- Binders

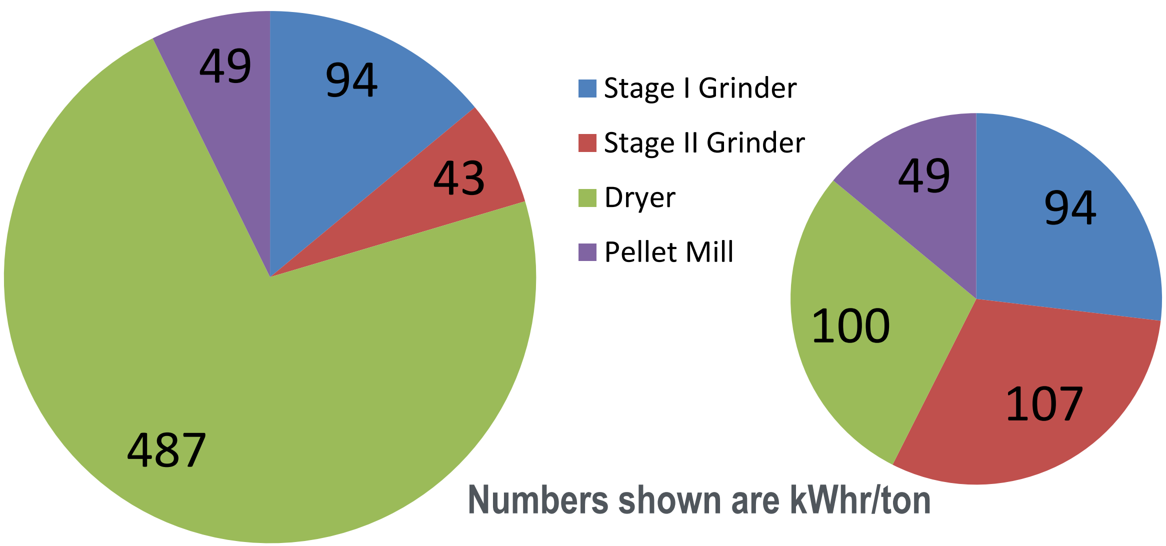
Densification – Technical Accomplishments

Conventional pelletization process for biomass



High-moisture pelletization process for corn stover





Pelletization process	Total energy (kWhr/ton)
Conventional	672
High moisture	350

Conventional pelletization process **High moisture pelletization process**

Densification – Technical Accomplishments

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Pelletization Studies on High Moisture Corn Stover Feedstock

- Moisture content: 28-38%
- Die rotational speed: 40-60 Hz
- Preheating temperature: 30-110° C
- Particle size: 3/16 inch
- Die diameter: 6 & 8 mm

Product properties

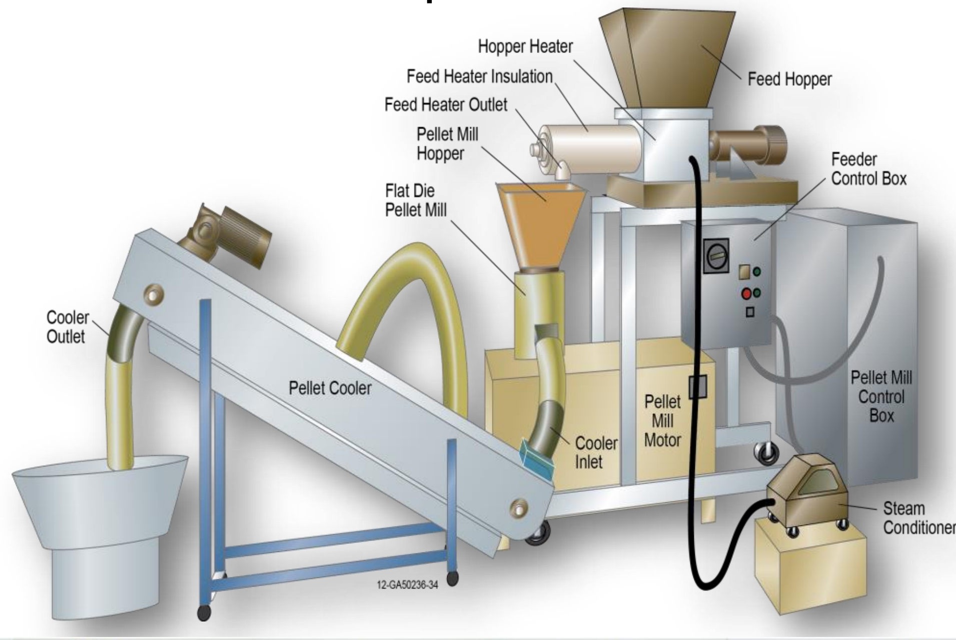
- Pellet moisture content (%, w.b)
- Unit, bulk and tapped density (kg/m3)
- Durability
- Percent fines
- Expansion ratio

Pelletization energy

- Specific energy (kWhr/ton)

Modeling of the experimental data

Flat die pellet mill at INL



Raw material and pelletized corn stover at different process conditions

- Note: Expt No.1: FMC: 28 %; DS: 40 Hz; PH: 30°C; Expt No.2: FMC: 38 %; DS: 40 Hz; PH: 30°C; Expt No.3: FMC: 28 %; DS: 60 Hz; PH: 30°C; Expt No.3: FMC: 38 %; DS: 60 Hz; PH: 30°C
- FMC: Feedstock moisture content; DS: die speed (Hz); PH: preheating

Densification – Technical Accomplishments

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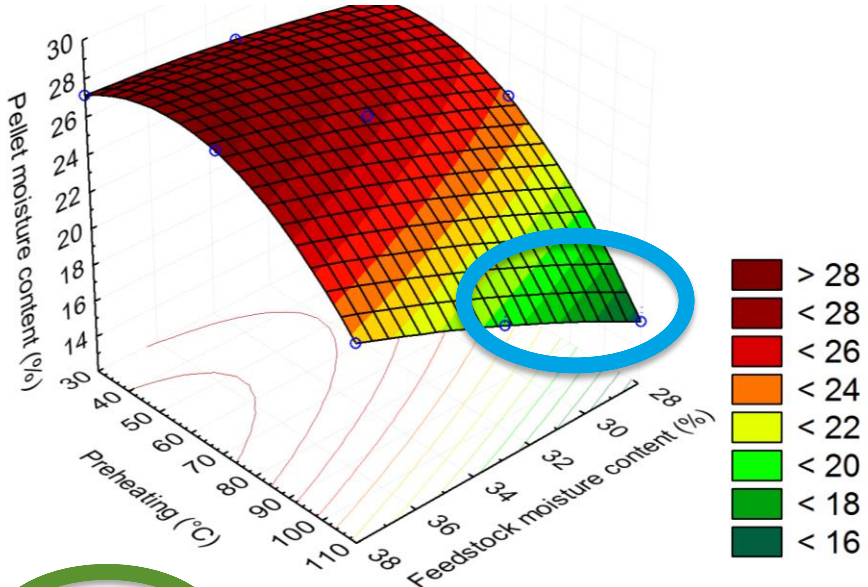
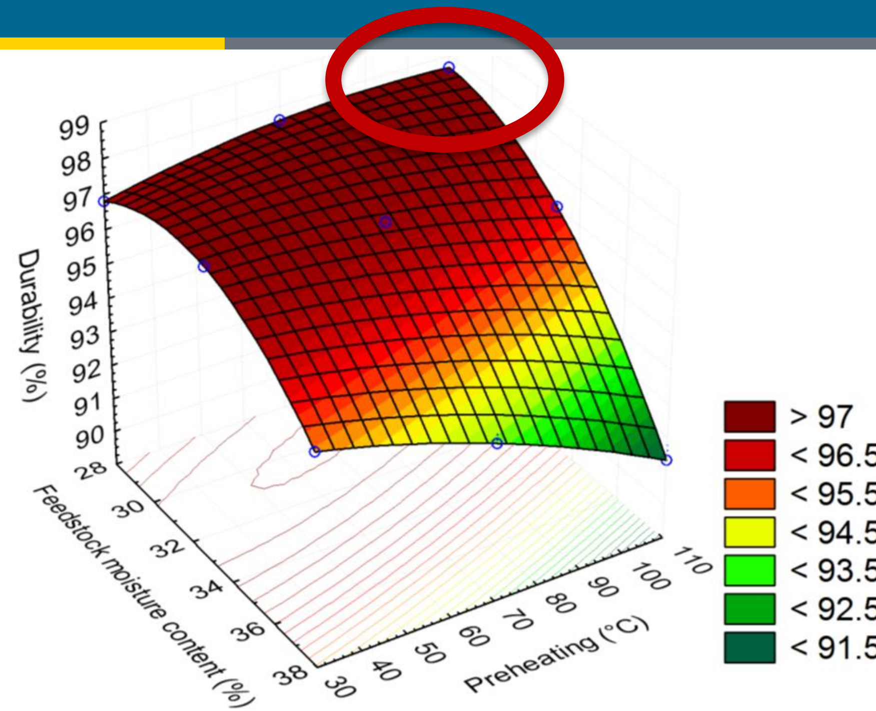
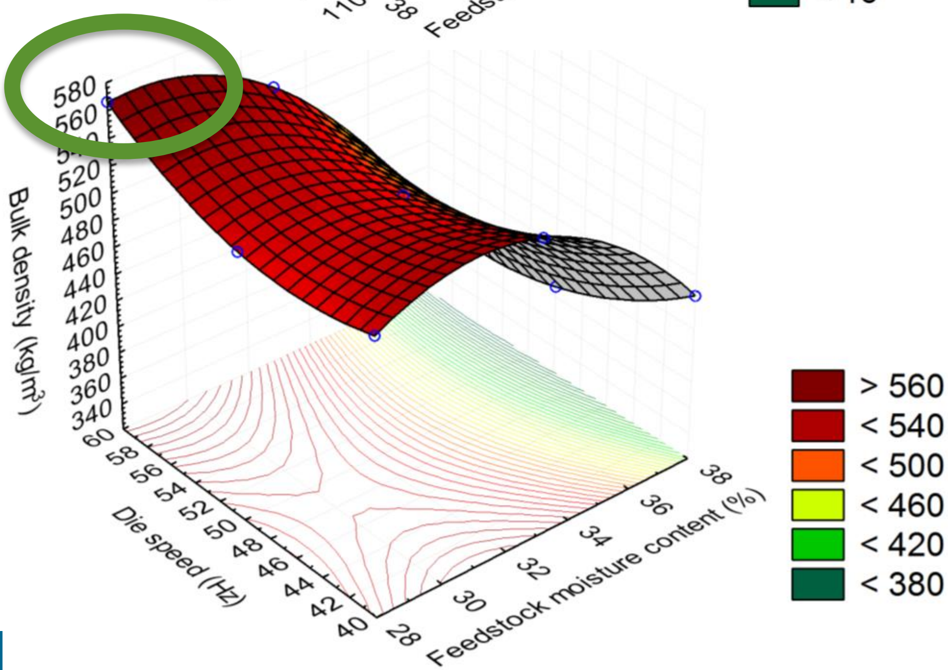


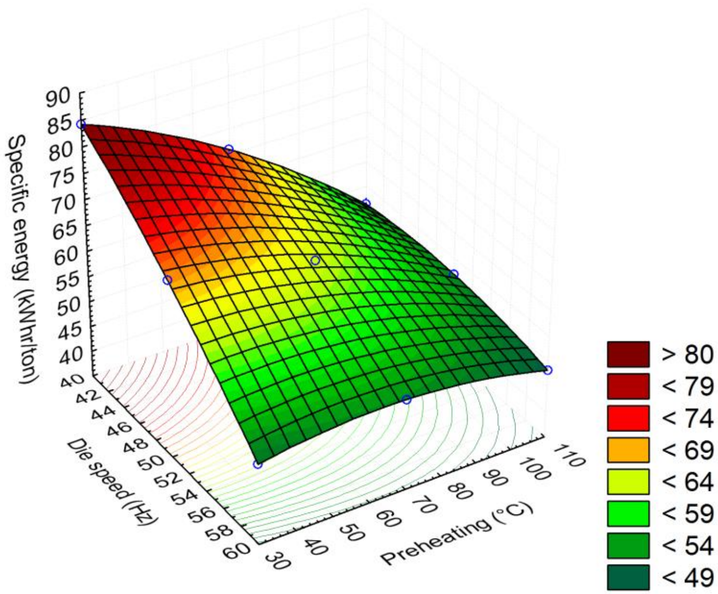




- Experiments show that it is possible to pellet high moisture biomass and still achieve high density and high durability
- Challenge is to simultaneously optimize these variables

Densification – Technical Accomplishments

Specific energy consumption (kWhr/ton)



Pellet Properties	Response surface models	R^2
Moisture content (%, w.b)	$-33.5312 + 1.7547x_1 + 1.0976x_2 - 0.0357x_3 - 0.0135x_1^2 - 0.0053x_2^2 - 0.0021x_3^2 - 0.0176x_1x_2 + 0.0067x_1x_3 + 0.0004x_2x_3$	0.93
Unit density (kg/m³)	$-4197.51 + 301.00x_1 + 14.87x_2 + 5.83x_3 - 4.23x_1^2 - 0.01x_2^2 - 0.02x_3^2 - 0.51x_1x_2 - 0.21x_1x_3 + 0.06x_2x_3$	0.74
Bulk density (kg/m³)	$-1775.84 + 162.87x_1 - 10.11x_2 + 2.78x_3 - 2.20x_1^2 + 0.26x_2^2 - 0.01x_3^2 - 0.52x_1x_2 - 0.07x_1x_3 + 0.01x_2x_3$	0.80
Tapped density (kg/m³)	$-3374.78 + 218.44x_1 + 18.42x_2 + 4.99x_3 - 3.04x_1^2 - 0.03x_2^2 - 0.02x_3^2 - 0.51x_1x_2 - 0.10x_1x_3 + 0.02x_2x_3$	0.78
Durability rating	$37.12467 + 4.21499x_1 - 0.39728x_2 + 0.20865x_3 - 0.06213x_1^2 + 0.00475x_2^2 - 0.00023x_3^2 - 0.00195x_1x_2 - 0.00590x_1x_3 - 0.00001x_2x_3$	0.85
Specific energy consumption	$195.3566 - 13.5161x_1 + 1.97x_2 + 1.5874x_3 + 0.3515x_1^2 - 0.02x_2^2 - 0.002x_3^2 - 0.0674x_1x_2 - 0.0752x_1x_3 + 0.0191x_2x_3$	0.84

x_1=Feedstock moisture content (%, w.b); x_2= Die rotational speed (Hz) and x_3= Preheating temperature (°C)

Conversion Performance of Blended Feedstocks (INL/LBNL)

- Developed a blend of agricultural and forest feedstocks
  - Switchgrass
  - Corn Stover
  - Lodgepole Pine
  - Eucalyptus
  - Not a realistic blend, but shows a wide range of feedstock characteristics
  - These feedstocks all have differing optimum pretreatment and processing conditions for optimum sugar recovery
- Results
  - Blended feedstocks versus individual feedstocks (LBNL)
    - Sugar released from blended feedstock was slightly higher than the average of individual feedstocks
    - No inhibition of growth observed for two *E. coli* strains grown on pretreated blended feedstock versus controls grown on pretreated eucalyptus or pure sugars
  - Blended feedstock (ground versus pelleted) comparison (INL/LBNL)
    - Pelleting did not introduce recalcitrance
    - Ground blended feedstock showed same sugar yield as pelleted blended feedstock
    - Published results in Biofuels, 2013, 4(1):63-72.

Formulation – Technical Accomplishments

Municipal Solid Waste (MSW) as a Low Cost/Low Quality Feedstock

- Convertible Fractions of MSW
  - Paper and paperboard
  - Organics
  - Plastic
- Spatial Assessment
  - Examined MSW compositions at state/local levels
  - Substantial variations observed
  - Data not available for many areas of U.S.
  - Providing these data to INL modeling tasks
- Collaborations
  - Waste haulers
  - Manufacturers of waste sorting equipments
  - Engineering firms who specialize in waste characterization

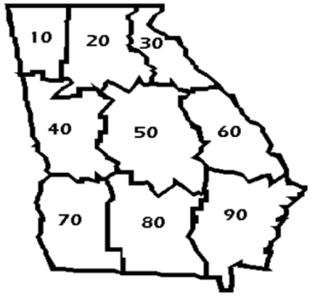
National Average MSW Composition (2010)

Material	% Total MSW	% After Recycling
Paper and paperboard	28.5%	10.7%
Glass	4.6%	3.4%
Steel	6.8%	4.5%
Aluminum	1.4%	1.1%
Other nonferrous metals	0.8%	0.2%
Plastics	12.4%	11.4%
Rubber and leather	3.1%	2.6%
Textiles	5.3%	4.5%
Wood	6.4%	5.4%
Other materials	1.9%	1.4%
Food	13.9%	13.5%
Yard trimmings	13.4%	5.7%
Misc. inorganic wastes	1.5%	1.5%

Formulation with Low Cost Niche Resources

- Case Study: Agricultural Districts 70 and 80 in Georgia (100 x 150 miles)
- Major crops are winter wheat, cotton, peanuts and corn
- None are in sufficient quantity to support an average sized biorefinery

District	Wheat straw (tons)	Cotton gin trash (tons)	Peanut shells (tons)	Corn stover (tons)	Potential Ethanol(gal)
70	96,200	201,000	121,000	350,000	41,700,000
80	59,200	269,000	58,800	108,000	23,300,000



- U. of Georgia estimates for delivered cost per ton (50 mile radius)
  - Wheat straw $164.56
  - Cotton gin trash $19.94
  - Peanut Shells $19.63
  - Corn Stover $59.25
- A formulation of all four feedstocks would be sufficient to produce 65 million gallons ethanol per year at a cost of $51.94/ton
- If wheat straw were eliminated, there is still sufficient feedstock for 58 million gallons ethanol per year at a cost of $36.15/ton

Mechanical Separation – Technical Accomplishments

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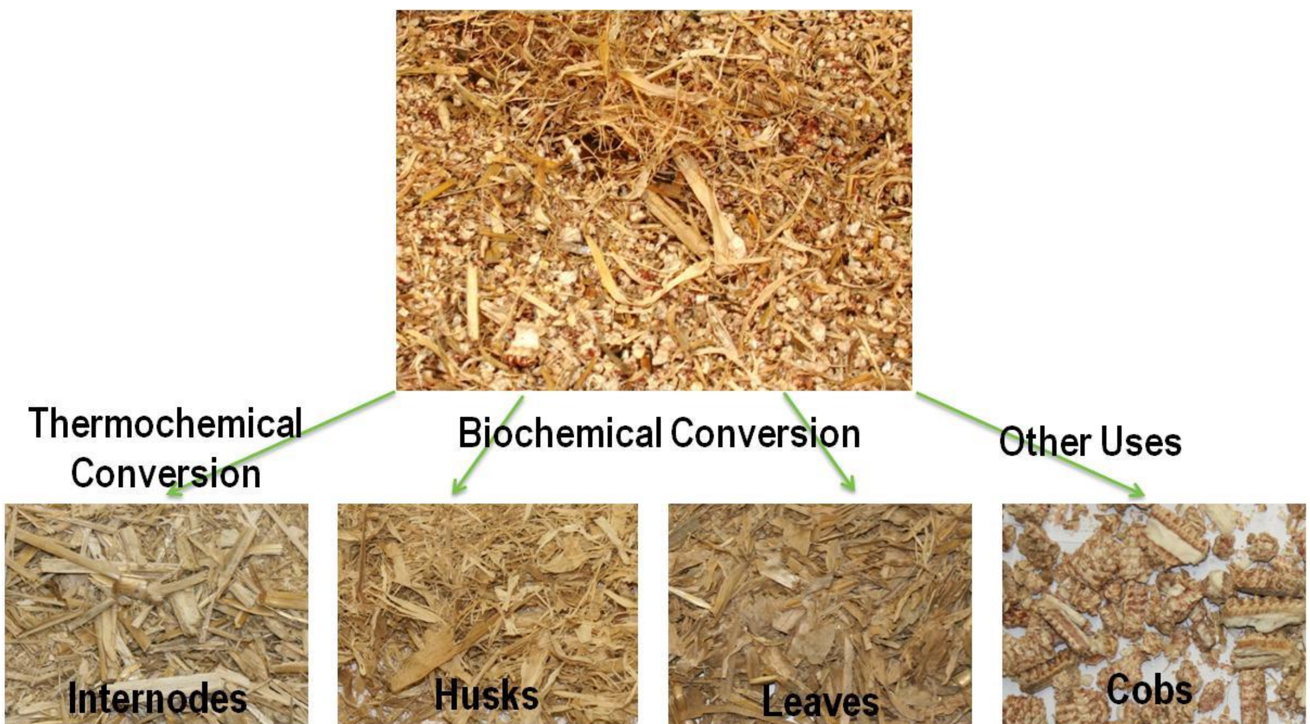
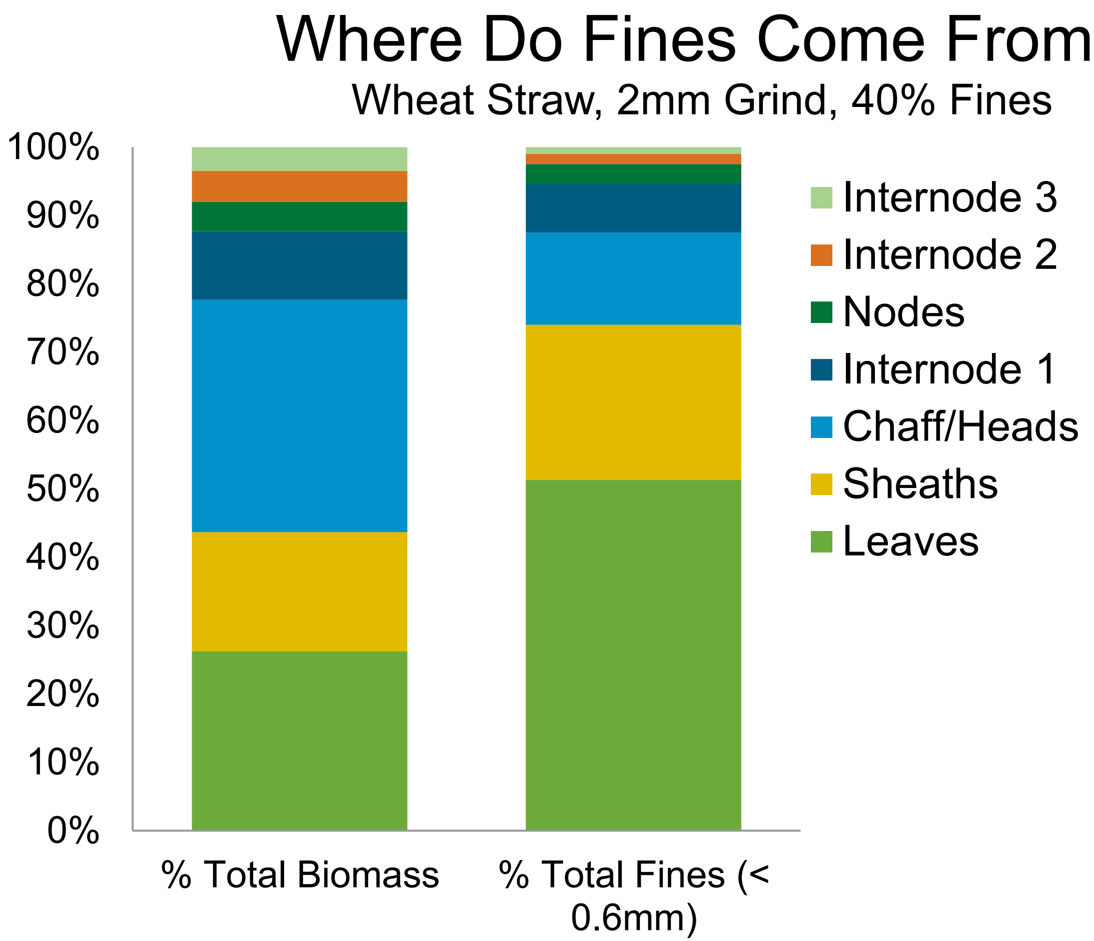
- Plant Anatomy Affects Composition
- Due to tissue and compositional differences, anatomical fractions have varying uses.
  - Plant structure (stems, nodes, husks, cobs, etc.)
  - Tissue type (pith, epidermis, etc.)



Mechanical Separation – Technical Accomplishments



Leaves and sheaths represent 44% of the total biomass, but account for 74% of the biomass smaller than 0.6mm

Mechanical Separation – Technical Accomplishments

- Clean fractionation
  - Improve quality
  - Provide valuable co-products
- Automated sorting technology shows promise
  - Tobacco sorting and grading
  - Food processing
  - Recycling and MSW
- Advanced sorting capabilities include size, shape, density, color (visible light, UV, IR, fluorescence), X-ray characteristics
- Equipment manufacturers are working with INL to test/optimize their technology for feedstock quality enhancement

Chemical Preconversion– Technical Accomplishments

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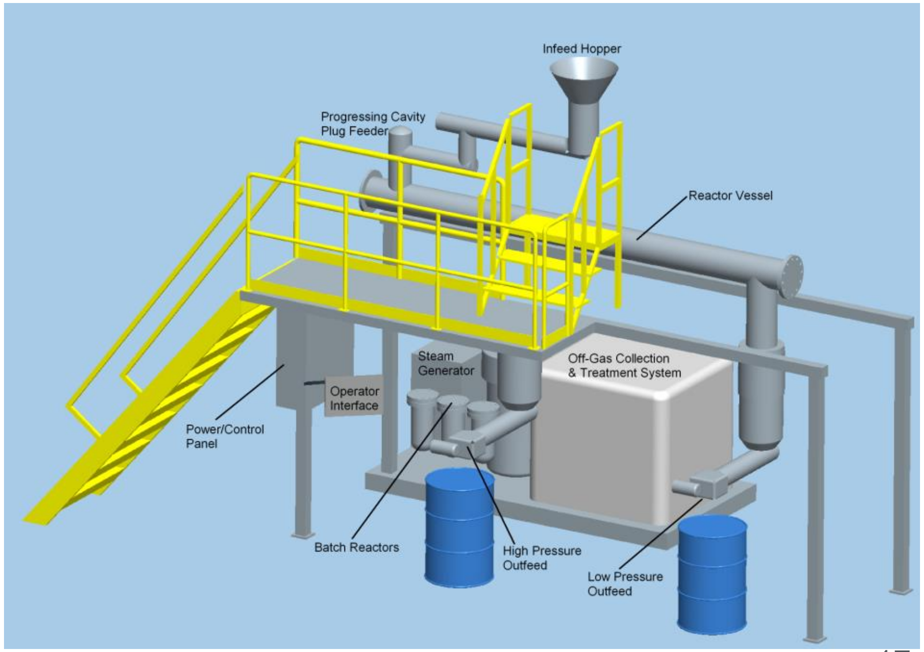
- Literature survey regarding effects of different chemistries on lignocellulose structure and chemical modification
- Identified likely strategies to disrupt cell walls with minimal yield losses
  - Low-severity pretreatments
    - Acids
    - Alkalis
    - Liquid ammonia
- Perspective article on biomass commoditization & chemical preconversion (*Biofuels* 4(3), 2013)

- Contract placed for construction of Chemical Preconversion System (expected delivery in Aug. 2013)
- Near term targets [relevant to]
  - Depot-located ash reduction [Thermochem Interface]
  - Depot-located deacetylation (initiated NREL for location at the biorefinery) [Biochem Interface]
  - Structural changes to enable cost-effective densification [Feedstock Logistics]



3. Relevance

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- Relevance to BETO
  - Enable use of low-cost, low-quality feedstocks in advanced biofuels conversion pathways
  - Improves feedstock logistics
  - Potential for additional local co-products
  - Provides potentially cost-effective solutions to tailor feedstocks for advanced biofuels conversion pathways
    - Decreases variability of feedstocks entering biorefinery
    - Improves conversion characteristics
    - Enables increased feedstock supply radius
- Relevance to Industry
  - Addresses emerging interest in waste-to-energy
  - Reduces variability in convertible fraction of biomass
  - Reduces contaminants that are liabilities to conversion processes
  - Increases the available feedstock for a biorefinery

4. Critical Success Factors

Critical success factors

- Net reduction in feedstock cost
- Improved feedstock composition and quality
- Increased quantities of accessible feedstocks

Barriers

- Unknown impact on convertability
- Multiple uses for the same feedstock (multiple specifications)
- Lack of data and models to evaluate cost to value for entire supply chain.
- Current quality measurements are too costly for routine use in R&D (interface task)
- End-user acceptance of altered feedstocks for bioenergy applications

5. Future Work

- Simultaneously optimize the process conditions for reducing biomass moisture, maximizing pellet density and durability, and minimizing pelletization specific energy consumption

- Develop and characterize additional low-cost, low-quality feedstock formulation blends for regions of the U.S. and test the formulation blends for different technology pathways

- Identify biomass characteristics that can be used to enable separation, and test other feedstocks to identify valuable clean fractions and co-products

- Determine cost-effective preconversion chemistries and severities for a range of feedstocks

Summary

- Pelletization of high moisture corn stover feedstock
  - Experiments show that it is possible to pellet high moisture biomass and still achieve high density and high durability
  - Challenge is to simultaneously optimize these variables
- Showed that formulation can be effective even with complex feedstock mixtures, and demonstrated that costs can be reduced using waste feedstocks
- Laid the groundwork for utilizing TEA and chemical preconversion fundamental research to guide the development of cost-effective feedstock chemical modification to meet the FY-17 design case

Responses to Previous Reviewers' Comments

Project approach: Integrate research to manage the steps…

The Feedstock Logistics and Engineering projects (WBS 1.3.1.3 and 1.3.1.4) were restructured since the 2011 review to do just this. Thermal treatment was moved from the Fundamentals project to the Thermochem Interface task; all of the core logistics and supply chain processes (harvest and collection, storage, size reduction, and transportation/handling) were moved to the Engineering project; and all advanced preprocessing technology development were moved to the Fundamentals task.

There were several reviewer comments on the thermal treatment / deep drying work that was presented. This work has been moved to the Thermochem interface task, and many of the comments are being addressed.

Technical progress and accomplishments: It is not clear how target particle sizes, moisture content after drying, and densification objectives are set in the context of logistics or conversion. For biochemical conversion, the conventional wisdom is that drying bound water contributes to recalcitrance, and drying for thermochemical conversion below 10% MC(wb) is not warranted. What is the basis for setting targets used in the research?

The advanced preprocessing tasks are all working to develop techno-economic assessment to identify both technical and economic (targets). Work is also integrated with the Interface tasks (densification with biochem interface task for example), to also let conversion performance weigh in on targets.

Responses to Previous Reviewers' Comments

Technology Transfer : What reports have been generated based on the work? FY10 state of tech report on corn stover has been completed. What publications? They do have a review paper on torrefaction.

Several publications have been generated on densification and torrefaction since 2011. Please refer to the publication list in the slide presentation.

Overall Impressions: …economic analysis and assumptions appear lacking

The cost:value relationship of advanced preprocessing operations are a recognized barrier in the research, Lab R&D and TEAs are being conducted to better inform this issue, to develop cost and performance targets for these technologies and to evaluate the overall feasibility of these technologies.

Publications, Presentations, and Commercialization

Shi, J., Thompson, V.S., Yancey, N. A., Stavila, V., Simmons, B.A. and Singh, S. 2013. Impact of mixed feedstocks and feedstock densification on ionic liquide pretreatment effciency. *Biofuels*, 4(1), 63-72.

Thompson, D. N., Campbell, T., Bals, B., Runge, T., Teymouri, F. and Ovard, L. P. 2013. Chemical preconversion: application of low-severity pretreatment chemistries for commoditization of lignocellulosic feedstock. *Biofuels* (In press).

Yancey, N. A., Tumuluru, J. S.and Wright, C. T. 2013. Drying, grinding and pelletization studies on raw and formulated biomass feedstock's for bioenergy applications. Journal of Biobased Materials and Bioenergy (accepted for publication).

Tumuluru, J.S., Tabil, L., Song, Y., Iroba, K. L., Meda, V. 2012. Grinding energy and physical properties of chopped and hammer milled barley, what, oat and canola straws. *Biomass and Bioenergy* (Under review).

Tumuluru, J.S., Tabil, L., Song, Y., Iroba, K. L., Meda, V. 2012. Process variables effect on quality attributes of wheat, oat, canola and barley briquettes. Biomass and Bioenergy (Under review).

Tumuluru, J.S., J.R. Hess, R.D. Boardman, C.T. Wright, and T.L. Westover (2012). Formulation, pretreatment, and densification options to improve biomass specifications for co-firing high percentages with coal, Industrial Biotechnology, 8(3), 113–132.

Tumuluru, J.S., C.T. Wright, J.R. Hess, and K.L. Kenney (2011). A review of biomass densification systems to develop uniform feedstock commodities for bioenergy applications. *Biofuels, Bioproducts & Biorefining*, 5(6), 683–707.

Tumuluru, J.S., S. Sokhansanj, J.R. Hess, C.T. Wright, and R.D. Boardman (2011). A review on biomass torrefaction process and product properties for energy applications, Industrial Biotechnology, 7(5), 384–401.

Tumuluru, J.S., R.D. Boardman, and C.T. Wright (2012). Response surface analysis of elemental composition and energy properties of corn stover during torrefaction. Journal of Biobased Material and Bioenergy, 6, 1–12.

Tumuluru, J.S., Sokhansanj, S., Lim, C.J., Bi, X. T., Kuang, X. and Melin, S. 2012. Effect of low and high storage temperatures on headspace gas concentations and physical properties of wood pellets. International Wood Products Journal, 4 (2), (Appeared or available online: June 29, 2012).

Tumuluru, J.S.; Boardman, R.D.; Wright, C.T.; Hess, J.R. Some Chemical Compositional Changes in Miscanthus and White Oak Sawdust Samples during Torrefaction. Energies 2012, 5, 3928-3947.

Tumuluru, J.S., S. Sokhansanj, C.J. Lim, X.T. Bi, A. Lau, S. Melin, T. Sowlati, and E. Oveisi (2010). Quality of wood pellets produced in British Columbia for export. Applied Engineering in Agriculture, 26(6), 1013–1020.

Tumuluru, J.S., Tabil, L.G., Opoku, A., Mosqueda, M.R.and O. Fadeyi (2010). Effect of process variables on the quality characteristics of pelleted wheat distiller's dried grains with soluble, Biosystems Engineering, 105(4), 466–475.

Publications, Presentations, and Commercialization

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Reports

Tumuluru, J. S., Ray, A. E. and Male, J. (2012). Densification. In: *Densification Workshop: Transforming Raw Biomass to Feedstock - Summary Report*. Kenney KL, Ovard LP (Eds.), Idaho National Laboratory, Idaho Falls, ID, USA, INL/EXT-10-18930.

Lacey, J. A., Scheller, H., Agneta, D. and Li, J. (2012). Biotechnology/ Genetics. In: *Densification Workshop: Transforming Raw Biomass to Feedstock - Summary Report*. Kenney KL, Ovard LP (Eds.), Idaho National Laboratory, Idaho Falls, ID, USA, INL/EXT-10-18930.

Thompson, D. (2012). Chemical Preconversion. In: *Densification Workshop: Transforming Raw Biomass to Feedstock - Summary Report*. Kenney KL, Ovard LP (Eds.), Idaho National Laboratory, Idaho Falls, ID, USA, INL/EXT-10-18930.

Thompson, V. (2012). Formulation. In: *Densification Workshop: Transforming Raw Biomass to Feedstock - Summary Report*. Kenney KL, Ovard LP (Eds.), Idaho National Laboratory, Idaho Falls, ID, USA, INL/EXT-10-18930.

Phanphanich, M., Westover, T., Tumuluru, J. S. and Ray, A. E. (2012). Thermal Pretreatment. In: *Densification Workshop: Transforming Raw Biomass to Feedstock - Summary Report*. Kenney KL, Ovard LP (Eds.), Idaho National Laboratory, Idaho Falls, ID, USA, INL/EXT-10-18930.

Michael, D., Bradley, D., Hekto, B., Hess, J. R., Nikolaisen, L., Tumuluru, J. S. and Wild, M. (2012). Possible effect of torrefaction on biomass trade. IEA Bioenergy Task 40.

Book chapter

Tumuluru, J. S., Sokhansanj, S., Wright, C.T. and Kremer, T. (2012). GC Analysis of Volatiles and Other Products from Biomass Torrefaction Process. In: *Advanced Gas Chromatography - Progress in Agricultural, Biomedical and Industrial Applications*, Mohammed, M.A. (Ed.), ISBN: 978-953-51-0298-4, InTech, DOI: 10.5772/33488.

Invention Disclosure Record

Tumuluru, J. S. 2012. Submitted an Invention Disclosure Record titled “Densification of high moisture raw and pretreated biomass feedstocks for Bioenergy applications”-IDR # BA-777.

Publications, Presentations, and Commercialization

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Tumuluru, J. S. Sokhansanj, S., Wright, C. T., Hess, J. R. Boardman, R., Kremer, T. (2011). A review on biomass torrefaction process, product properties and desing of a moving bed torrefaction system. *ASABE Annual International Meeting*, Paper Number: 1110459, Louisville, Kentucky, August 7-10, 2011 (oral presentation).

Tumuluru, J. S. Sokhansanj, S., Wright, C. T., Boardman, R. D. and Yancey, N. A. (2011). A review on biomass classification and composition, corifing issues and pretreatment methods. *ASABE Annual International Meeting*, Paper Number: 1110458, Louisville, Kentucky, August 7-10, 2011 (oral presentation).

Tumuluru, J. S., Conner, C. C. and Wright, C. T. (2012). Studies on quality attributes of pellet made from high moisture corn stover. *ASABE Annual International Meeting*, Dallas, Texas, July 29 - August 1, 2012 (oral presentation).

Tumuluru, J. S., Kremer, T., Wright, C. T. and Boardman, R. D. (2012). Proximate and ultimate compositional changes in corn stover during torrefaction using thermogravimetric analyzer and microwaves. *ASABE Annual International Meeting*, Paper number 121337398, Dallas, Texas, July 29 - August 1, 2012 (oral presentation).

Schedule Prior to Peer Review

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Activity	Date
Send PIs formal invitation letters and presentation templates	March 26th
PI Overview Call	April 4th
PIs Upload Completed Presentations	April 22nd
DOE Leads review PI Presentations	April 22nd-26th
PIs make requested changes	April 29th-May 3rd
All Final Agenda Changes Complete	May 1st
Reviewers / SC Receive Completed PI Presentations	May 6th
Project Peer Review Meeting	May 20-23rd

Peer Review Portal

Questions?

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