Advanced Feedstock Supply System Development at the Idaho National Laboratory

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Biomass variability makes it a uniquely challenging feedstock compared to other energy feedstocks such as coal or crude.
Recognizing a core-competency in biomass scale-up and integration, DOE-EERE established a National User Facility around these capabilities.

**What we do:**
- Composition
- Grindability
- Stability
- Flowability
- Convertibility

**To inform:**
- Biomass valuation
- BMPs
- Preprocessing requirements
- Integrated pathway dev.

**Integrated biomass processing pilot facility:** grinding, drying, torrefaction, chemical preprocessing, pelleting, cubing, and multiple packaging options
- Preprocessing R&D
- Process development
- 3rd party testing & validation
- Toll processing & piloting

**Process Demonstration Unit (PDU)**

**Biomass Characterization Laboratory**
Projects/Outcomes

Bridging the gap between the biomass supply and conversion through development of drop-in, conversion-ready feedstocks

High-Moisture Densification
Reduces cost of moisture management and improves solids handling

Blended Feedstock Development
Reduces supply chain risk and feedstock cost by coupling location-specific resource use with biofuel production

Approach: Pellet biomass at > 3x normal moisture content, using preheating, frictional heat, and energy-efficient pellet drying
Results: Lignin glass transition temp is lowered at high moisture resulting in reduced energy inputs and up to 40% cost reduction

Approach: Developing blended feedstocks using empirical models to predict blend composition and performance
Results: Tests show that blend performance (sugar and bio-oil yields) can be predicted and therefore models can be used to develop least-cost blends

Both of these INL projects were selected for DOE Lab Corps
Bale Feedstock Supply System

- Same as the Livestock Forage System
- 10 material intermediates, 3 biomass format changes
- 14 process steps, 21 different types of equipment
- Supply system is bale format specific
The Rand Study

- Rand Corporation study from 1980’s showed that plants that process bulk solids typically operate at less than 50% of design capacity the first year of operation.
- DOE sponsored study followed significant difficulties in the start-up of new synthetic fuel plants.
- Performance of 37 new plants using data provided by 25 companies.
- Problems generally relate to an inadequate understanding of the behavior of particle systems (Bell 2005).

Image source: Merrow 1985
Why particle processes are so difficult

• A particle system is more likely to be inconsistent than consistent

• Particles can almost be described as a fourth state of matter
  – They can develop cohesive strength and transfer stresses like a solid
  – They can retain air and take on fluid-like properties
  – They are often compressible and elastic like a gas
  – Unlike liquids and gases, particles often remember where they have been and never forget
  – Gases and liquids do not grow, agglomerate, aggregate or suffer attrition, particles do

• Materials process differently after being aged or subjected to repetitive handling

• Particle behavior often does not scale
Particle morphology effect on flowability

Across a range of particle sizes and shapes the only consistent difference was morphology of particle tips


Feeding chopped & ground switch-grass

<table>
<thead>
<tr>
<th>Material</th>
<th>Feed rate (Dton/hr)</th>
<th>Duty cycle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chop</td>
<td>31.0</td>
<td>0 (flood)</td>
</tr>
<tr>
<td>Chop</td>
<td>29.8</td>
<td>35</td>
</tr>
<tr>
<td>Grind</td>
<td>4.9</td>
<td>99</td>
</tr>
</tbody>
</table>

Chop Grind

Pioneer biorefinery lessons learned

- The Rand study was a long time ago, hasn’t this improved?
- Look at the data…
  - In 2015, 2.0 million RINS generated from cellulosic ethanol; estimated ~3% of production capacity
- Inadequate understanding of the behavior of particle systems
- Feedstock variability and the limitations of current systems to handle it are significant factors

Making money

Losing money

Hybrid Biochem to Renewable Diesel

Making money

Losing money

Fast Pyrolysis to Renewable Gasoline
Industry Feed Handling Problems

- **Moisture**
  - Grinder throughput
  - Particle size variability
  - Variation causes inconsistent mass and heat transfer in conversion

- **Particle Size**
  - Large particles (aka pin chips)
    - Cause plugging problems in bins, augers
    - Do not fully cook – plugging in downstream equipment, microbial contamination
  - Fine particles
    - High in ash
    - Dust – fire, explosion, and health hazards
    - Plugging of weep holes in digesters
    - Buffering capacity, increase chemical usage
  - Variation causes inconsistent mass and heat transfer in conversion

- **Foreign material (dirt, metal)**
  - Plugging, equipment wear
Example: ABBK Plant in Hugoton, KS
Plugging Stage 1 Grinder Screens

- Root Cause: Variation in Moisture
- Solution: NONE in Extreme Cases, otherwise Slow!!
Bridging in Feedstock Bin
Corn Stover Bridging in Drop Chute
Unplugging a Conveyor
Example: Modeling Variability in Preprocessing Capacity

- Plant with a required production rate of 1440 bales a day (1 bale/min)
- Feedstock supply has range of moisture content
- Preprocessing rate is a function of moisture content
- The grinder capacity function is based on PDU experience
- Bale moisture content of 20% yields 1440 bales/day through preprocessing
- Using a daily time step, with different moistures being brought to the facility each day
- Modelled a 60 day snapshot of the facility’s bale processing rate
Scenario #1: 2010 NW Iowa Corn Stover

Dry Year
Bale Moisture (%)
Mean: 15.1
Stdev: 4.7

Minimum daily production relative to the required 1440

<table>
<thead>
<tr>
<th></th>
<th>Random</th>
<th>Blended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average bales/day</td>
<td>1960</td>
<td>1960</td>
</tr>
<tr>
<td>Stdev of bales/day</td>
<td>664</td>
<td>382</td>
</tr>
<tr>
<td>Low %</td>
<td>48%</td>
<td>86%</td>
</tr>
<tr>
<td>High %</td>
<td>190%</td>
<td>179%</td>
</tr>
</tbody>
</table>
Scenario #2: 2009 NW Iowa Corn Stover

Wet Year
Bale Moisture (%)
Mean: 32.6
Stdev: 7.7

<table>
<thead>
<tr>
<th></th>
<th>Random</th>
<th>Blended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average bales/day</td>
<td>612</td>
<td>612</td>
</tr>
<tr>
<td>Stdev of bales/day</td>
<td>212</td>
<td>76</td>
</tr>
<tr>
<td>Low % of req'd prod</td>
<td>25%</td>
<td>33%</td>
</tr>
<tr>
<td>High % of req'd prod</td>
<td>90%</td>
<td>61%</td>
</tr>
</tbody>
</table>
Scenario #3: 2010 NW Iowa, Post Storage

As-Harvested
Bale Moisture (%)
Mean: 15.1
Stdev: 4.7

Tarped Square Bale Stack

After 9 months of storage
Bale Moisture (%)
Mean: 22.8
Stdev: 16.0

Random

Blended

<table>
<thead>
<tr>
<th></th>
<th>Random</th>
<th>Blended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average bales/day</td>
<td>897</td>
<td>897</td>
</tr>
<tr>
<td>Stdev of bales/day</td>
<td>871</td>
<td>198</td>
</tr>
<tr>
<td>Low %</td>
<td>20%</td>
<td>32%</td>
</tr>
<tr>
<td>High %</td>
<td>190%</td>
<td>100%</td>
</tr>
</tbody>
</table>
What are low cost feedstocks?

- There is more to feedstock cost than purchase price.
- Biomass is difficult because it is compressible, elastic, and cohesive.
- These properties vary among types and physical and chemical properties.
- Consistency = Reliability = Lowest Cost.
- The role of preprocessing is not grinding or drying or densifying. It is to produce a consistent feedstock.
Decoupling Feed Processing from Conversion

- Wide-spread, interconnected supply network
- Stable, flowable, consistent, and conversion-ready feedstocks
- Reduced feedstock variability in quantity, quality, cost

Decoupling does not eliminate the feed handling problem, but it does reduce conversion plant downtime.
## Conversion-Ready Feedstock Properties

### Predicted Performance

<table>
<thead>
<tr>
<th></th>
<th>Stover Pellet Meal</th>
<th>¼ minus Stover</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10-ft Bin Diameter</strong></td>
<td><strong>2-ft Opening</strong></td>
<td></td>
</tr>
<tr>
<td>Flow Rate (lb/min)</td>
<td>2432</td>
<td>345</td>
</tr>
<tr>
<td>Feed Density (lb/ft³)</td>
<td>26.9</td>
<td>7.4</td>
</tr>
<tr>
<td>Bin Density (lb/ft³)</td>
<td>30.0</td>
<td>9.1</td>
</tr>
<tr>
<td>Compressibility (%)</td>
<td>12.8</td>
<td>28.1</td>
</tr>
<tr>
<td>Permeability (ft/sec)</td>
<td>0.24</td>
<td>0.18</td>
</tr>
<tr>
<td>Springback (%)</td>
<td>3.76</td>
<td>4.72</td>
</tr>
<tr>
<td>Hausner Index</td>
<td>1.13</td>
<td>1.28</td>
</tr>
<tr>
<td>Cohesion (kPa)</td>
<td>3.83</td>
<td>6.61</td>
</tr>
<tr>
<td>Angle of Repose</td>
<td>39.2°</td>
<td>35.3°</td>
</tr>
<tr>
<td>Flowability Factor</td>
<td>5.8 easy flowing</td>
<td>1.2 very cohesive</td>
</tr>
</tbody>
</table>

↑ or ↓ Indicate desired direction of change

### Other Preprocessed Products:
- Fractionated (Stover Fiber)
- Thermal Treated
- Various Densification Formats
- Blended
Equipment Engineering Solutions

- Improve the design of biomass processing and handling equipment
  - Designed to biomass material properties
  - Robust to handle variability
- Limitations
  - Limited options for existing installations
  - Potential of fixing a symptom (handling), not the problem, so problem cascades
  - Empirically based designs based on subjective judgements of material properties and flow behavior
  - Must design to worst case scenario (can be costly)
- Benefits
  - Wide range of options from simple fixes to new technologies
  - Improved design and selection are “easy” fixes
Material Engineering Solutions

• Insert processes to alter biomass material properties and enable use of existing equipment

• Examples
  – Blending: variability
  – Densification: compressible, elastic behavior
  – Flow Additives: cohesiveness
  – Heat Treatment: mild deconstruction of cell structure to alter properties

• Limitations
  – Limited range of application
  – Often includes additional unit ops that add cost (need to fully understand cost:value)
  – Changing mat’l properties may fix one problem and create another (example, densification/fines)

• Benefits
  – Fixes the problem and keeps it from cascading
  – Scalable solution – only use it when and as much as needed
High Density Bulk Receiving and Handling

<table>
<thead>
<tr>
<th>Installed Capital Costs ($/dry ton)</th>
<th>Ownership Costs ($/dry ton)</th>
<th>Operating Costs ($/dry ton)</th>
<th>Total Costs ($/dry ton)</th>
<th>Energy Use (Mbtu/dry ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ 1.38</td>
<td>$ 0.19</td>
<td>$ 0.80</td>
<td>$0.99</td>
<td>6.2</td>
</tr>
</tbody>
</table>

Notable Assumptions:

- 72-hr. inventory - 469,000 ft³ (377,000 bushels)
- Conveyor density 23.8 lb/ft³, bin density 29.2 lb/ft³
- Stored in conventional bin, 90 ft diameter
- Handled with grain handling equipment
- Truck unloading 14 hrs/day, 6 days/wk
Control System Solutions

• Develop control systems that monitor and adjust processing conditions to maintain consistent production rate and feedstock quality

• Examples
  – Reactive Control: Maintain constant mass flow
  – Adaptive Control: Maintain feed specs as infeed properties vary

• Limitations
  – The most difficult
    • Requires best understanding of particle systems
    • Particle interactions with process equipment can be unpredictable
      – Adds complexity (software, sensors, actuators)
      – Development requires a fully integrated system

• Benefits
  – Get the most performance from any equipment
  – Data and understanding of particle systems will benefit equipment and material engineering solutions
DOE Biomass National User Facility (BFNUF)

Capabilities that Span the Biofuels Supply Chain

Production
- Feedstock characterization (chemical, solid fuel properties)
- Pairing feedstock to pathways
- Storage
- Pellet properties

Logistics
- Techno-economic assessments

Preprocessing
- Independent testing, development, & scale-up of preprocessing technologies

Conversion
- Feedstock Supply
- Scale-up & integration of preprocessing systems
- Feedstock Feasibility Studies

Feedstock Supply/Logistics Demonstration
Supply Chain Development

- Feasibility studies and techno-economic assessments
- Storage performance characterization (unique in-lab capability)
- Characterization of biomass resources
- Feedstock product characterization
- Supply chain design

Our understanding of cost, quality, and risk tradeoffs helps customers establish a successful supply chain
Scale-up and Integration

- Expertise and capabilities to meet a customer’s lab- and pilot-scale testing needs
  - Sourcing for common and unique feedstocks
  - Process development, testing, and design
  - Feedstocks processed to partner specifications
  - Feedstock characterization datasheets
  - Packaging and shipping for partner testing

Working with industrial feedstocks during process design, scale-up, and integration can accelerate commercialization and prevent costly delays during commissioning and start-up
**Process Demonstration Unit (PDU)**

- Full-scale, integrated biomass processing system
  - Hammer mill grinding
  - Rotary drying and torrefaction
  - Pelleting and cubing
  - Multiple packaging options

- In operation since October 2013
  - Toll processing & characterization
  - Process Development
  - Preprocessing RD&D

- More than 500 tons of feedstock processed
  - Ag residues (corn stover, sugarcane bagasse)
  - Energy Crops (switchgrass, miscanthus)
  - Woody biomass (clean and whole tree chips)
  - Municipal Solid Waste
  - Cellulosic co-product

Reconfigurable PDU is located in 27,000-ft³ high bay at INL’s Energy Systems Laboratory
Working with Industry

• Example (DuPont)
  – Scale-up and demonstration of co-product production
  – Engaged User Facility for drying capability and reconfigurable design to accommodate a unique process flow and additional third-party equipment
  – ~ 350 hours PDU operation: 3 months, up to 12 hours/day, 6 days/week

• Results
  • Collaboration supported process validation with industrial feedstocks
    – Supplied product for combustion trial
    – Produced processing data and information to inform commercial design
    – Accelerated commercialization
National Biomass R&D Library

Integrated knowledge management that:

• Facilitates physical storage and tracking of research feedstocks

• Assimilates biomass sample data into a single data system
  – Feedstock pedigree information
  – Harvest and storage information
  – Operational data from the PDU and field trials
  – Physiochemical characterization data
  – Lab-based biological data
  – Lab-scale conversion data
  – Full-scale conversion data from the conversion platforms

• Enables better understanding supply chain processes and feedstock performance.
Library Overview

**Parent Samples**
- Harvest
- Stored
- Intermediates

**Process Demonstration Unit**
- Drying
- Grinding
- Densification
- Splitting

**Analytical Laboratory**
- Composition
- Ash
- Prox. & Ult.
- Elemental

**Library**
- **Samples**:
  - Raw
  - Processed
  - Reference Matls.
  - Bulk resources
- **Data**:
  - Crop
  - Harvest
  - Operations
  - Locations
  - Characteristics
- **Tools**:
  - Sample Tracking
  - Data Processing
  - Least Cost

**Sample Tracking**
- Raw Samples
- Harvest Data
- Processed Samples
- Operations Data
- Prepared Samples
- Quality Data

**Regional Feedstock Partnership**
- National Labs
- Universities
- Industry
- International Researchers
- Other Gov. Researchers

**Data/Analysis**
- Switchgrass
  - County/State: Muskogee Oklahoma
  - Format: Raw Material
  - Date: 11/11/2014
  - Project: Regional Partnership
  - Contact: Gary Gresham
Data Collection

- Over 62,000 samples tracked
  - (23,000 originals + children)
- Over 1,200,000 sample information data points
- Over 65,000 analysis data points
- Over 80 projects (tracking unique datasets)
- Over 100 crop types

- Sample information
  - Crop type, location, harvest information, field information, etc.
- Analysis information
  - Chemical composition, fuel properties, ash, etc.
- Operations
  - grinding, pelleting, leaching, storage, etc.
Tools – Attribute Graphs

- Publicly and privately available aggregate Information
  - Quality reviewed for applicability
- Targeted search
- Overview and detailed statistics
- Exportable information and data

Visual Statistical Analyses

Data Easily Exported
8 Biomass materials in bulk
  - Fully characterized and available for request

Examples:
  - University of Kentucky – Lignin research
  - University of Cincinnati – Fundamental conversion research
  - Louisiana Tech – Organosolv research
  - University of Delaware – NSF research
Working with Us

Challenge: Biorefineries typically operate at just 50% of design capacity\(^1\)

- Capabilities - INL’s core strengths in feedstock supply, logistics, and preprocessing are helping address key industry challenges
- Innovation - Work with DOE program investments to create innovative solutions that avoid challenges and expand the bioenergy market
- New Business Tools - User Facility and other business tools are rapidly progressing to function *at the speed of business*
- For more information contact Kevin Kenney at [Kevin.Kenney@inl.gov](mailto:Kevin.Kenney@inl.gov)

The Uniform Commodity Feedstock Vision enables commodity-scale, custom-formulated feedstocks to play a critical role in producing biofuels, biopower, and other bioproducts.

Biomass Preprocessing

Biomass preprocessing, which transforms biomass into feedstock, is key to a commodity bioenergy vision. A preprocessing depot can provide a link between biomass producers and refiners. It also allows flexibility for local communities to produce bioproducts including feedstocks customized for biochemical, thermochemical, and combustion conversion facilities. It also enables production of renewable products, such as livestock feeds, and recycled byproducts, such as soil amendments.

The Preprocessing Depot enables development of commodity biomass feedstock markets by managing diverse biomass, promoting increased resource access, and ensuring quality, on-spec feedstock delivery to conversion facilities. But a preprocessing depot can do much more. It offers limitless opportunities for innovations to supply entirely new products and markets.