Feedstock Manufacturing

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Energy Manufacturing Workshop
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Lessons Learned from Biomass Feedstock National User Facility

• In operation since October 2013
• 11 User Facility projects involving
  – Process Specification Development
  – Feedstock Supply
  – Feedstock Characterization

• 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
Manufacturing Requires Product Specifications

What is in a feedstock specification?

Chemical, physical, and mechanical properties that affect cost and performance

- % Ash
- Elemental content (e.g., Cl, P, Ca, Si, and S)
- % Carbohydrate
- Recalcitrance (convertibility)
- Inhibitor content
- % Lignin
- % Moisture
- Particle size distribution
- Flowability / Material Handling
- Unknown foreign material content
- Contaminants (environmental and conversion)

Merriam Webster:
- A detailed description of work to be done or materials to be used in a project

Business Dictionary.com
- Exact statement of the essential characteristics of what a customer requires (in a good, material, method, process, service, system, or work) and which a vendor must deliver
Spec “Assumptions”

The Model Feedstock Approach

Model Feedstock: Corn Stover

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition (dry wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucan</td>
<td>35.05</td>
</tr>
<tr>
<td>Xylan</td>
<td>19.53</td>
</tr>
<tr>
<td>Lignin</td>
<td>15.76</td>
</tr>
<tr>
<td>Ash</td>
<td>4.93</td>
</tr>
<tr>
<td>Acetate</td>
<td>1.81</td>
</tr>
<tr>
<td>Protein</td>
<td>3.10</td>
</tr>
<tr>
<td>Extractives</td>
<td>14.65</td>
</tr>
<tr>
<td>Arabinan</td>
<td>2.38</td>
</tr>
<tr>
<td>Galactan</td>
<td>1.43</td>
</tr>
<tr>
<td>Mannan</td>
<td>0.60</td>
</tr>
<tr>
<td>Sucrose</td>
<td>0.77</td>
</tr>
<tr>
<td><strong>Total structural carbohydrate</strong></td>
<td><strong>58.99</strong></td>
</tr>
<tr>
<td><strong>Total structural carbohydrate + sucrose</strong></td>
<td><strong>59.76</strong></td>
</tr>
<tr>
<td><strong>Moisture (bulk wt%)</strong></td>
<td><strong>20.0</strong></td>
</tr>
</tbody>
</table>

Model Feedstock: Pulpwood

<table>
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<th>Composition (dry wt%)</th>
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<tbody>
<tr>
<td>Carbon</td>
<td>50.94</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>6.04</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.17</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.03</td>
</tr>
<tr>
<td>Oxygen</td>
<td>41.90</td>
</tr>
<tr>
<td>Ash</td>
<td><strong>0.9-1.0</strong></td>
</tr>
<tr>
<td>HHV BTU/lb)</td>
<td>8,601</td>
</tr>
<tr>
<td>LHV BTU/lb)</td>
<td>7,996</td>
</tr>
<tr>
<td><strong>Moisture (%, w.b.)</strong></td>
<td><strong>10.0</strong></td>
</tr>
</tbody>
</table>
The need and the challenge of feedstock specs

Variability

Sugars

- Corn Stover
- Miscanthus

BC: 59%

N=742

Moisture

- TC: 10%
- BC: 20%

2009 Harvest
2010 Harvest

N=339

Ash

- TC: 1%
- BC: 5%

Corn Stover

N=840

TC = Thermochem pathways
BC = Biochem pathways
Field Specs

The “Low-Hanging” Specs

Ash

Eliminate soil contamination

Sugars

Preserve carbohydrates in storage

0.6% loss in reactivity per 1% DML
Plants that process bulk solids operate at less than 50% of design capacity the first year of operation, often due to handling problems (RAND study).

Handling problems arise from feedstock variability beyond design spec.

- ~ 350 hours operation
- Scaling up a new process design, new equipment
- More integrated unit operations increase complexity
- Process designed without full understanding (data) of material variability
Preprocessing Specs
Challenged by Variability

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“Overs” cause feeding and handling problems (e.g., bridging)

“Fines” result in conversion losses (premature combustion, char in pyrolysis)

Particle size distribution (shape of curve above) affected by feedstock type, moisture, and screen size

Processing parameters are selected to provide a balance between overs and fines
Processing parameters are selected to provide a case-by-case balance between overs and fines.

Screens: Grinder 2”, Hammermill 3/4”
Sample: Lodgepole Pine

2” x 3/4”
Mean: 2.12 mm
Standard Deviation: 1.85 mm

2” x 3/8”
Mean: 1.29 mm
Standard Deviation: 0.92 mm

2” x 1/2”
Mean: 1.67 mm
Standard Deviation: 1.40 mm

2” x 3/4”
Mean: 2.12 mm
Standard Deviation: 1.85 mm

*Fines and overs not indicative of customer spec
**Hammer Mill** (swinging hammers, 1-in. screen)
- Modest increase in “fines” compared to infeed material
- Effective at grinding particles greater than 1.5 mm in size

**Rotary Shear** (interlocking 3/16-in. disks)
- Did not create “fines”
- Effective at grinding particles greater than 3 mm in size

**Collision Mill** (particle-particle collisions in air stream vortices)
- Created the finest and “roundest” particles

**Infeed:**
- Corn stover
- Bales processed through hammer mill with 6” screen
Manufacturing Needs
For Transforming Biomass Into Feedstocks

• Improved Insights—to inform innovative solutions
  – Sources of feedstock variability
  – Sensitivities of conversion processes
  – Capabilities of industrial feedstock equipment/processes
  – Cost vs. value-added across entire supply chain
• Improved Technologies & Processes—to reduce cost
• Intelligent and Adaptive Control—to improve performance
  – Rapid, low-cost measurement (sensors & chemometrics)
  – Unit-op and system process models
• New Science—to inform design
  – Reliable rheology/flowability measurements for elastic solids
• Modular Designs—to enable a feedstock enterprise
Spec Development

**Understanding Sources of Variability**

- Genetic
  - Feedstock type, variety
- Environmental
  - Soil type
  - Weather
  - Agronomic practices
- Seasonal
- Supply Chain Operations

Variability is a feature.

Uncertainty of variability is the problem.
Spec Development
Quantifying Impacts of Variability

• Moisture
  – Grinding costs increase with moisture content (~$0.8 per % MC)
  – $10-20/ton to dry

• Ash
  – Replacement costs
  – Disposal costs
  – ~$2.25/ton per %ash above the 5% spec
  – Other effects not yet accounted for (wear, pretreatment…)

• Storage Losses
  – Reduced convertibility associated with storage degradation/losses
  – Estimate 0.6% loss in convertibility per 1% DML
Monitor & analyze feedstocks during preprocessing & adjust operating parameters in real-time to maintain preprocessing specifications.
Modular Feedstock Manufacturing
Pathway Approach

**FEEDSTOCK SPECIFICATIONS**
- Energy content
- Moisture
- Ash
- Carbohydrates
- Recalcitrance (convertibility)
- Inhibitor content
- Lignin content
- Elemental ash (e.g., Cl, P, Ca, Si, and S)
- Particle size distribution
- Density
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- Foreign material content
- Contaminants

**FEEDSTOCK SUPPLY**
- Terrestrial
  - Ag Residues
  - Pulpwood
  - Forest Residues
  - Dedicated Energy Crops

- Algal
  - Monocultures
  - Polycultures

- Municipal Solid Waste
  - Construction & Demolition Waste
  - Yard Waste
  - Food Waste
  - Paper/Cardboard

**FEEDSTOCK PREPROCESSING**
- Size Reduction
- Separations
- Leaching
- Drying
- Torrefaction
- Blending
- Densification

**DECONSTRUCTION & FRACTIONATION**
- Pretreatment
- Hydrolysis
- Pyrolysis
- Gasification
- Hydrothermal Liquefaction
- Combustion

**SYNTHESIS & UPGRADING**
- Sugar/Organic
- Bio-Oil
- Gaseous

**PRODUCTS**
- Hydrocarbon Biofuels (gas, diesel, jet)
- Co-products
- Heat & Power
Modular Feedstock Manufacturing
Pyrolysis Pathway

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Combustion Pathway

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Managing Specs
Active Quality Management

A Graded Approach

• Flexible front end tightened with Best Management Practices
• Backed up with preprocessing
• Enforcing through penalty (dockage) or incentive

Example: Ash Spec

- Screening/Separation ($$)
- Leaching of high ash fraction ($$$)
- Blending ($$

Best Management Practices ($)
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 refineries. 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.