Feedstock Logistics for a Biofuels Industry

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Idaho National Laboratory

Biomass Research and Development Technical Advisory Committee Meeting
2 March, 2011 – Washington, DC
Scope of Feedstock Supply System R&D

Equipment Performance Metrics:
- Equipment Efficiency / Capacity
- Dry Matter Losses
- Operational Window

Biomass Performance Metrics:
- Physical, Chemical, & Rheological Properties
- Product Bulk/Energy Density
- Material Stability

Documents Guiding Supply System Logistics
Core R&D

Biomass Production:
- Ag. Resources
- Forest Resources

Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply

Feedstock Production Interface

- Harvest & Collection
- Equipment Capacity
- Compositional Impacts
- Pretreatment Impacts
- Shrinkage
- Soluble Sugar Capture

- Storage
- Equipment Capacity
- Material Bulk Density
- Compositional Impacts
- Pretreatment Impacts

- Preprocessing
- Equipment Capacity
- Equipment Efficiency
- Material Bulk Density
- Compositional Impacts
- Pretreatment Impacts
- Truck Capacity
- Loading compaction
- Loading efficiencies

- Transportation
- Handling efficiencies
- Handling compaction
- Material Bulk Properties

- Handling & Queuing

Biomass Conversion:
- Biopower
- Biofuels
  - Biochem
  - Thermochem

Feedstock Conversion Interface
The Uniform Format Solution: A Commodity-Scale Design

Commodity Attributes:
- Standardized Material/Quality
- National Market
- Biomass Exchange Market

Supply Buffer

Multiple Biorefineries

Conversion (Biochemical or Thermochemical)

IN Variation

Supply Buffer

Out Variation

IN Variation

Supply Buffer

Out Variation
Conventional Feedstock Supply System

**Conventional-Bale/Log**
- Harvest and Collection
- Farm/Field Gate
- Storage
- Transportation and Handling
- Biorefinery Gate
- Preprocessing

**Existing Supply Systems** vs **Depot Supply Systems**

<table>
<thead>
<tr>
<th>Existing Supply Systems</th>
<th>Depot Supply Systems</th>
</tr>
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<tbody>
<tr>
<td>Access to a niche or limited feedstock resource</td>
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Addressing Feedstock Logistics Barriers and Costs via a Depot Supply System

**Advanced-Uniform**

<table>
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<tr>
<th>Harvest and Collection</th>
<th>Preprocessing</th>
<th>Farm/Field Gate</th>
<th>Storage</th>
<th>Transportation/Handling</th>
<th>Biorefinery Gate</th>
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**Existing Supply Systems**

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Unlocking the Resource – An illustrative example

Number of counties that could potentially produce high-density biomass feedstock resources under existing production and logistics systems

- Little to no improvement in feedstock yield
- Existing harvesting, collection, storage, and transportation techniques
- Sustainability considerations limited
- Conversion specifications for feedstock not addressed
- Supply risk due to price fluctuations, weather events, lack of year-round supply, etc.

Number of counties that could potentially produce high-density biomass feedstock resources under advanced production and logistics systems

- Feedstock yield improved via genetics, genomics, breeding, improved production practices, etc.
- Shift to a uniform-format feedstock preprocessing depot logistics supply system
- Sustainability considerations expanded
- Conversion specifications for feedstock addressed
- Supply risk due to price fluctuations, weather events, lack of year-round supply, etc. decreased
Conventional and Advanced Supply Systems: Cost Dynamics

- Conventional system demonstrates high spatial variability in costs, even in highly productive regions. Iowa example:
  - Large range in costs
  - Local average supply costs impacted by resource density

- Advanced Uniform has higher average supply system costs, but reduced spatial and temporal variability
  - Smaller range in costs
  - Average cost more stable between locations

Conventional supply system design costs by county in Iowa for a projected resource draw of corn stover.
Conventional and Advanced Supply Systems: Accessibility Risk Dynamics

- Conventional system are limited by conditions on the ground, resulting in:
  - Lower and unpredictable accessible resource quantities
  - Higher and unpredictable losses due to inability to stabilize
  - Wide ranges of material specs delivered to the biorefinery: lower conversion yields

- Advanced Uniform design concept:
  - Responds to harvest conditions
  - Stabilizes material early in the supply chain reducing losses
  - Can guarantee material specifications

Harvest progress (corn grain) by week in Iowa: 2009, 2010 by Crop Reporting District
Factors Driving Commodity Scale Supply Systems

- **Yield**
  - Tons/acre
  - Tons/square mile (Landscape Scale Design, Increases Diversity)

- **Stability**
  - Shelf-Life
  - Chemical/Biological Reactivity

- **Specifications Properties (e.g., quality)**
  - Physical
  - Chemical
  - Rheological

- **Density**
  - Bulk Density
  - Energy Density

Factor Not on the List: Format
Depot Supply System Produces Uniform Commodity Spec Products – Densified Solid and Liquid Formats

Biomass Diversity

Herbaceous Residues
Herbaceous Energy Crops
Woody Residues
Algal Resources

Biomass Uniformity/Reliability

Two-Stage Preprocessing Depot

1. Preconditioning
2. Densification

Milling/Stabilization
Solid Densification
Pyrolysis

Solid
Liquid

Biopower
Biochem
Gasification
Oil Refining

Combined Heat and Power
Animal Feed
Soil Amendments
Sustainable Resource Access – The Yield Struggle

Development of Agricultural Residues for Bioenergy Feedstock

Economics
- Logistics
- Contract establishment and delivery
- Delivered feedstock cost targets
- Feedstock quality
- Harvesting strategies
  - Selective harvest
  - Single pass

Limiting Factors
- Soil organic carbon
- Soil erosion
- Management of plant nutrients
- Soil water and temperature dynamics
- Soil compaction
- Environmental degradation

Agronomic Strategies
- Integrated cropping systems
- Landscape discretization
- Ecosystem services valuation

Initial Resource Assessment
Economic Analysis
Environmental Impact Analysis
Implementation of Tools and Strategies

Uniform-Format Feedstock
Reliable, Sustainable, Consistent, and High Conversion Value
Limiting Factor Based Assessment: Guiding the Development of Sustainable Bioenergy Landscapes

Using plot-based experimental methodologies and data, sustainable watershed-scale bioenergy cropping systems can be designed, verified, and implemented using integrated **Limiting Factor** models, thus avoiding the unintended consequences of independent field-level conversion of land to supply bioenergy markets.
Through carefully designed plot networks, data management, and integrated limiting factor modeling we can:

- Implement bioenergy landscape design concepts at the plot scale
- Calibrate and test multi-factor environmental process modeling tools
- Quantitatively predict watershed scale performance
Solution: Landscape-scale Management Approach Using Integrated, Science-Based Assessment Techniques

Examine economic and social drivers associated with global need for renewable biofuels in tandem with other important issues:

• Carbon sequestration
• Water and air quality
• Wildlife food and habitat
• Erosion, sedimentation, & hypoxia
• Community development
• Transportation infrastructure
Unstable Biomass Harvest Intermediates

Crop Residues

Increase Yields

Variable Rate Harvest

Dedicated Energy Crops

Increase Efficiencies

Feedstock Specs

Biomass specifications enable advanced technologies
Corncob/Stover Project

After 10 months of storage

Open-air stack

Wrapped stack

Tarped stack

How do we determine best storage method?
- Dry matter loss
- Moisture content
- Quality
Corncob/Stover Project
2009 Baled-cob Storage Self-Heating Profile

- Signature self-heating profile
  - Consistent over full range (25-40%) of moisture content
  - Consistent across all stack configurations except the Wrapped stacks
- “Drop-out” varies depending on moisture content and stack configuration
Wood Chip Pile Self-Heating Profile

Temperature (°C)

Time (Days)

- Storage simulator
- Chip piles

INL

Biomass
Harvest, Collection & Storage – Process Intermediate

Field Demonstration

*Focused on developing biomass specific harvest, collection & storage options*

Dry matter loss converts structural carbohydrate to “water soluble carbohydrates”

- Direct bale system
- High moisture materials (≤45%)
- Multiple areas of perturbation
- Driver for development of lab based methods for studying mechanisms of dry matter loss, self-heating, & degradation
- Provides capability to fabricate & evaluate larger numbers of process intermediates

<table>
<thead>
<tr>
<th>Theoretical EtOH Yield</th>
<th>Initial</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>gal/DMT</td>
<td>116.9</td>
<td>114.7</td>
<td>117.8</td>
<td>104.2</td>
<td>98.5</td>
</tr>
</tbody>
</table>
Specifications-Based Commodity Scale Supply System

Feedstock Specs

- Resource Draw and Mix (Tons)
- Supply System Design (Uniform Product Specs)
- Cost at Reactor Throat (Cost)

Challenge - Increasing Specifications Limits
Supply; e.g., ---
- Moisture
- Ash
- Density
## Development and Characterization of Process Intermediates

### Gasification Feedstock Specifications

<table>
<thead>
<tr>
<th>Advanced Material (Thermally Treated)</th>
<th>Mechanically Densified (Pelletized or Similar)</th>
<th>For Comparison</th>
<th>Plant Operations Impacts</th>
</tr>
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<tr>
<td>HHV (Btu/Lb) as received</td>
<td>8,600</td>
<td>7,650</td>
<td>3,200-5,700</td>
</tr>
<tr>
<td>Bulk energy density (Btu/ft³)</td>
<td>387,000</td>
<td>230,000</td>
<td>80,750 - 89,000</td>
</tr>
<tr>
<td>Bulk density (lb/ft³)</td>
<td>46 (Pelletized)</td>
<td>30</td>
<td>19 - 21</td>
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<td>5</td>
<td>10</td>
<td>40 - 60</td>
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### Production

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<tr>
<th>Input Specifications</th>
<th>Specifications for Multiple Formats</th>
<th>Stored Intermediate Specifications</th>
<th>For Comparison</th>
</tr>
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<tr>
<td>HHV (Btu/Lb) as received</td>
<td>8,600</td>
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<td>Green Wood</td>
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### Note:
- Values to be established based on research and interactive collaborations with other platforms.
Harvest and Collection Systems – Process Intermediates

Field Demonstration

Focused on evaluating biomass specific harvest & collection operations

Significant variability in ash & fines content

Variability observed within windrowing treatment

- Sequential collection operation
- Chopped corn stover windrowed via 4 systems
- Low moisture materials (<30%)
- Secondary driver was the development of unit operation to produce representative process intermediates
- Provided insight into non-pristine stover quality attributes

<table>
<thead>
<tr>
<th>Windrowing Treatment</th>
<th>%Moisture (w.b.)</th>
<th>%Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel Rake</td>
<td>12-18</td>
<td>17.0</td>
</tr>
<tr>
<td>SP Windrower</td>
<td>11-31</td>
<td>22.8</td>
</tr>
<tr>
<td>Bar Rake</td>
<td>11-20</td>
<td>7.3</td>
</tr>
<tr>
<td>Flail Shredder</td>
<td>9-13</td>
<td>18.6</td>
</tr>
</tbody>
</table>
Resolving Biochem Interface Paradox – Prevention & Mitigation Feedstock Issues

Interface Paradox

Feedstock Logistics

- Stable
- Low Moisture
- Dense

Uniform Format Targets

Biochemical Conversion

- Sugars content
- Recalcitrance

Fundamental Requirements

Impact
# Solving Thermochem Interface Barriers – Improving Feedstock Feed Issues

## Predicted Performance

<table>
<thead>
<tr>
<th>10 ft Bin Diameter 2 ft Opening</th>
<th>Advanced Material</th>
<th>Corn Stover</th>
</tr>
</thead>
<tbody>
<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>
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## Observed Performance

### Corn Stover

- Uniform Format Targets
- ¼ minus Feedstocks

The observed performance shows differences in various properties between the predicted and observed values. The images depict a feedstock system with materials being processed.
Feedstock Particle Size Impact on Syngas Tar Composition

Correlation to particle size is likely cross correlated to other matrix conditions

Wood tar formation is slightly lower than herbaceous materials
✓ May reduce tar cleanup costs

Yield (g/g dry, ash-free feed)

NREL data: Kim Magrini, Personal Communication, 2010
Biomass Differential or Factional Deconstruction

**Miscanthus Particle Size Distribution**

- Rind and vascular tissues hold together under impact forces and require shear / torsion forces to effectively size reduce.
- Pith and other tissues rapidly deconstruct upon impact.

**Grinder Screen Sizes**

<table>
<thead>
<tr>
<th>Screen Size</th>
<th>Mass Retained on Screens (%)</th>
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<tbody>
<tr>
<td>Tray 2, 0.75-in</td>
<td>30%</td>
</tr>
<tr>
<td>Tray 3, 0.50-in</td>
<td>25%</td>
</tr>
<tr>
<td>Tray 4, 0.25-in</td>
<td>20%</td>
</tr>
<tr>
<td>Tray 5, 0.16-in</td>
<td>15%</td>
</tr>
<tr>
<td>Tray 6, 0.08-in</td>
<td>10%</td>
</tr>
<tr>
<td>Pan, &lt;0.08-in</td>
<td>5%</td>
</tr>
</tbody>
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**Grinder Capacity for Corn Stover with 1.25 Inch Screen**

- Belt Conveyance
- Pneumatic Conveyance

**Capacity (DM Tons/hour)**

- Hammer 2, Speed
Thermal Treatment & Stabilization Processes

Torrefaction and Pelletization Characterization

- Intermediate material energy density increased with degree of torrefaction
- Hydrophobicity is improved with degree of torrefaction
  - Decreases transportation cost
  - Improves storability of product
  - Increased energy density delivery to TC unit

ORNL data: Shahab Sokhansanj, Personal Communication, 2011
Torrefied vs Untorrified Woody Biomass Pyrolysis Screening

- Raw white oak sawdust versus torrefied material (220 °C and 270 °C)
- Particles ground to < 2 mm minus
- Pyrolysis conditions, ~1 kg/hr, 500 °C, residence time ~0.8 sec.

Preliminary test outcomes:

✓ Torrefaction enables a consistent pulverized feed to be produced with less energy
✓ Percent of feed going to non-condensable gas from each of the three tests were similar
✓ Percent of feed going to char increased with increasing torrefaction temperature
✓ As expected, water in the product oil decreased with increasing torrefaction temperature
✓ When calculated on a "dry" feed basis, the percent of feed ending up as organic product liquid is only slightly different between the baseline and 220 °C.
✓ Acid number appeared to increase slightly at 220 °C but decreased at 270 °C
Biomass Resource Library – To Sort Out the Spec Matrix

Sample Hierarchy

Corn Stover
dba9ea26-0f42-4d71-97cc-74e3073414e

County/State: Story, IA
Date: 9/10/2007 12:00:00 AM
Institution: Iowa State U
Operation: Harvest

Cultivar: Pioneer 34A20
Plot: 106
Sample: 1
Collector: Doug Karien
Library Physical Materials Archive & Storage

Bulk Materials  Process Intermediates  Unmodified

Representative Feedstock  Attribute Data
The Uniform Format Research Path

**Conventional Designs Priorities**
- Efficiency/Capacity
- Dry Matter Losses
- Operational Windows

**Uniform Format Designs Priorities**
- Altering Material Properties
- Stabilization
- Densification

**Phase 1: Lab/Bench Scale**
- Products
  - Uniform Format Candidates Identified

**Phase 2: Pilot/Commercial Scale**
- Economic Analysis
- Selected Candidates Uniform Format Specifications
  - Deploy PDU
    - Midwest
    - Southeast

**Feedstock Performance Testing by IBR and other collaborators**
- Biochem
- thermochem – gasification
  - Pyrolysis
- Biopower

**Characterize Feedstocks**
- Composition
- Physical
- Molecular/Structural

**Performance results/feedback**
- Handling
- Pretreatment
- Yield

**Define Uniform Format Specifications**

**Produce Uniform Format Feedstocks (PDU)**
- Size Reduction
- Pretreatment (preconversion)
- Fractionation
- Densification
- Blending

**Transition to Phase 2**
Depot Preprocessing to Uniform Format Products

- Thermochemical Biofuels and Heat/Power Market:
  - Preprocessing and blending for ash, moisture and rheological properties
  - Commodity has grades same as corn or coal (e.g., #1, 2, 3, ...)
- Biochemical Biofuels and Products Market:
  - Preprocessing and segregation for specific conversion process
  - Commodity similar to wheat (e.g., blend within species/variety)
- Petroleum Refinery Market:
  - Energy density and feedstock stability are key characteristics (e.g., Liquid Format)
Modules are designed to operate individually or in any combination and alternate equipment can replace one or more modules.
PDU – Instrumentation, Controls, and Data Systems

- Modular in hardware and software design and implementation.
- Designed to accommodate any type of measurements required for research data without major modification/redesign.
- Local and remote control of modules.
- Local safety system implementation.
- National Instruments Labview software for quick development and modification.
- Control Trailer provides networked process control, archival storage and data analysis capability.
- Control Trailer also serves as a documentation library and tool crib for maintenance on the PDU.
PDU – An R&D tool for Developing a Depot Preprocessing Supply System

PDU Functionality – Data Collection and Data Integration

Example above: current (amps) from multiple motors while operating PDU.

Example below: conveyor current (amps) used to prevent operation upsets.

Key Input Data Streams
- In-feed Mass Flow
- In-feed Moisture
- Steam Flow Rate
- Steam Quality
- Power Usage

Engineering Performance
- Feedstock Quality
- $/ton

Densification Module
PDU - Dryer System Module

- Provides feedstock moisture reduction as needed to assist in product stabilization
- Dryer system is fully self contained for independent operation and skid mounted for easy transportation and assembly.
- Designed for research missions with:
  - Variable capacity and operating modes to accommodate multiple feedstock types, moisture, and research needs including: temperature, flow rate, fan rates, particle size, residence times, etc.
  - Provisions for insertion of component fractionation at various points in dryer process and use as a preprocessor for torrefaction and other processes.
- May be used as part of a separate research activity or in combination with other modules.
PDU – An R&D tool for Developing a Depot Preprocessing Supply System

PDU Functionality – Portable, Modular, Reconfigurable

Rotating drum dryer (50 to 150 C) deployed to California as a single module for biomass drying studies.
PDU – Grinder, Milling and Densification Modules

All PDU modules can be reconfigured to develop, verify and produce numerous biomass preprocessed intermediates for conversion testing

- Accepts a variety of bale formats,
- input of bulk feed material into the system,
- component fractionation equipment.

Hammer mill may be replaced with other types of mills

Pellet Mill mounted in movable containers.
Steam generator and coolers may be separated and use for other processes

Grinding and Fractionation Module
Milling Module
Densification Module
Multiple conveyors move the material at all stages of processing from one operation to the next. All are conveyors are enclosed to prevent excessive dust generation and allow complete material balance accounting.

Conveyors are designed to support a variety of material types, densities, and capacities.

Modifications were made to standard conveyances to provide portability and flexibility.

- Design allows for ease of reconfiguration of the system for testing baseline operations and alternative or new concept equipment.
- Design provides the ability to deploy at a crop or plant location with fewer site requirements and lower setup costs.
Need for a Uniform Format Approach

• Lower productive systems can contribute (i.e. reduce stranded resources, higher resource volumes)

• Risk of obtaining a stable feedstock supply is virtually eliminated

• Feedstock supply buffer added to the system
  • Stable supply and price
  • Lower capital financing costs
  • Strategic reserves

• Consistent feedstock specifications delivered to plant gate

• Biorefinery citing and sizing can shift from resource draw constraints to infrastructure variables such as water, gas, electricity, labor, transportation systems, tax incentives, product distribution, and product demand.
The Uniform Format Research Path

Resource Coupled Supply System Design

Harvest and Collection
- County level production data
- Local climate impacts
- Material specifications identified into storage

Local
- Storage design based on county production statistics
- Local climate impacts
- Spatially and temporally explicit material specifications

Depot Preprocessing
- Requirements established by local production
- Performance adjustments with material quality
- Produces gradable, on-spec material

Regional/National
- Transport and Terminal Blending
  - Spatially and temporally explicit material flows
  - To grade material blending

Biorefinery Transport and Handling
- Demonstrate siting flexibility
- Spatially and temporally explicit material specifications

Biomass