Development of a Bulk-Format System to Harvest, Handle, Store, and Deliver High-Tonnage Low-Moisture Switchgrass Feedstock

May 19-23, 2013
Feedstock Supply & Logistics
Al Womac, University of Tennessee
Lead Organization: Genera Energy Inc.
Goal Statement

- Develop and test bulk-format logistics for low-moisture switchgrass incorporating bulk-handled loose, bulk compacted with overburden, and bulk compacted with mechanical systems - comparing costs with round-bale logistics.

  - Supports “Advanced Uniform-Format Feedstock Supply System”
    - Distributed depots
    - Densification & Handling
    - Feedstock R&D harvesting, storage, handling & transportation for Ethanol Infrastructure
    - Perennial grass, dry herbaceous (<20% m.c. (w.b. ))

  - Results apply to bulk-format feedstock supply chain

  - Important lessons learned that can be transferred to other feedstock supply systems include bulk handling after size reduction.
Quad Chart Overview

**Timeline**
- Project start date: July 30, 2010
- Project end date: June 30, 2013
- Percent complete: 95%

**Barriers**
- Barriers addressed
  - Sustainable Harvesting
  - Biomass Storage Systems
  - Biomass Material Handling & Transportation

**Budget**
- Funding for FY11 (DOE $2.44M/ Cost share $2.79M)
- Funding for FY12 (DOE $2.04M/ Cost share $1.94M)
- Funding for FY13 (DOE $316k/ Cost share $435k)
- Years the project has been funded (3)
  Avg. annual funding (DOE $1.6M/ Cost share $1.72M)

**Partners** (Next Slide)
Collaborations /Project management

• Project Partners/Roles
  o **Genera Energy** – Switchgrass, farmers, storage and handling
  o **University of Tennessee** – Logistics analysis, reporting
  o **Laidig Systems** – Storage and reclaiming
  o **Marathon Equipment** – Bulk compaction
  o **Kice Industries** – Material conveyance and dust collection
  o **Deere & Co.** – Harvest equipment
  o **Idaho National Lab** – Material properties analysis
  o **Oak Ridge National Lab** – Independent cost analysis
  o **Dupont Cellulosic Ethanol** – Feedstock analysis

• Project Management
  o **Genera Energy** – Coordinates with partner input; permits, construction, and contracts
# Project Overview - History

<table>
<thead>
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<th>Jan</th>
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<td>Bulk Handling/ Sampling Experiments</td>
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<td>Wrapup Data Analysis – DuPont, UT, INL, &amp; ORNL</td>
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Objectives

- Develop a bulk-based switchgrass harvest, handling, storage, compaction, transport, and off-load system to supply a demonstration biorefinery
- Determine switchgrass handling efficiencies of the bulk system and identify areas to improve efficiencies with respect to equipment investments and operators
- Determine switchgrass quality associated with the bulk system compared to the current bale system based on ethanol production and potential
1- Approach

- Logistics spans harvest of biomass material standing in the field to conveyance of a uniform, industrial milled product into the throat of a biomass conversion.
- Size reduction is integrated early into supply chain. Compaction process is examined to increase bulk density.
- Unique application of mechanical reclaim, pneumatic conveyance, compaction
- Involvement of wide range of key experts and companies representing span of logistics
2 - Technical Accomplishments

In-Field Harvest & Collection Operations

1 Mower-Conditioner
2 Rotary Rake
3 Pull-Type Chopper
4 Pull-Type Tip Wagon
5 Walking Floor Truck

LOOSE

6 Farm Gate
7 Walking Floor Truck
8 Depot Gate
9 Bulk Receiving Pit
10 Silo Storage

CONFINED BY OVERBURDEN

11 Bulk Compactor
12 Depot Gate
13 Ejector Trailer
14 Biorefinery Gate
15 Bulk Receiving Pit

COMPACTED INTO EJECTOR TRAILER
## Technical Accomplishments

Range of harvest conditions, including field shape, terrain, distance, day & night

<table>
<thead>
<tr>
<th>Operation</th>
<th>Demo-Scale*</th>
<th>Projected Commercial Scale**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rate (per unit, Dton/h)</td>
<td>Efficiency or Utilization (%)</td>
</tr>
<tr>
<td>MoCo, 3-m (1 unit)</td>
<td>17.7</td>
<td>75.9</td>
</tr>
<tr>
<td>Pull-type Forage Harvester (1 unit)</td>
<td>8.4</td>
<td>70.6</td>
</tr>
<tr>
<td>Tip Wagons (3 units)</td>
<td>3.1</td>
<td>64.8</td>
</tr>
<tr>
<td>Bulk-Trailer Trucks, 52 cu-yd, 3.8 Dton/load (2 units)</td>
<td>4.4</td>
<td>69.1</td>
</tr>
<tr>
<td>Depot Receiving (1 unit)</td>
<td>8.8</td>
<td>36.6</td>
</tr>
</tbody>
</table>

* 2.85-3.61 Dton/ac

** 8 Dton/ac

From GPS, GIS, On-site Truck Scales, etc.:
2 – Technical Accomplishments

<table>
<thead>
<tr>
<th>Particle size</th>
<th>Wet Bulk Density* (lb/ft³) (@ 13% m.c.-w.b.)</th>
<th>Demo-Scale Loads* (tons)</th>
<th>Commercial-Scale Loads* (tons)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Loose</td>
<td>Compacted</td>
<td>52 yd³ (Loose)</td>
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<tr>
<td>Field Chop</td>
<td>6.20</td>
<td>10.64</td>
<td>4.35</td>
</tr>
<tr>
<td>Coarse Tub Grind</td>
<td>4.90</td>
<td>8.61</td>
<td>3.44</td>
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<tr>
<td>Fine Tub Grind</td>
<td>6.00</td>
<td>10.61</td>
<td>4.21</td>
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</table>

*In practice, fill efficiency affects loads and are taken into account.
### Technical Accomplishments

#### Field to Storage Haul Distances
5.5 - 8.5 miles

#### Limiting Factor During Harvest Logistics

<table>
<thead>
<tr>
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<th>Daily Proportion of time (%)</th>
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<tr>
<td></td>
<td>(Calc. for 1-sec resolution)</td>
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<tr>
<td></td>
<td>Min.</td>
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<tr>
<td>Forage Harvester</td>
<td>74.3</td>
</tr>
<tr>
<td>(1 unit)</td>
<td></td>
</tr>
<tr>
<td>Tip Wagons</td>
<td>0.1</td>
</tr>
<tr>
<td>(3 units)</td>
<td></td>
</tr>
<tr>
<td>Trucks</td>
<td>1.3</td>
</tr>
<tr>
<td>(2 units)</td>
<td></td>
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</table>

*Caused by receiving startup delay on first day of harvest*

#### Operational Classification Analysis

- Tip Wagon Loading
- Tip Wagon Hauling
- Tip Wagon Backhauling

1-sec sample interval, 7 pieces equipment, 1 shown above
Commissioned receiving, storage, handling, & dust collection systems
2 – Technical Accomplishments

Risk Management

• System design in accordance with appropriate codes
  o International Building Code (IBC)
  o International Fire Code (IFC)
  o National Electric Code (NEC)
  o National Fire Prevention Association (NFPA)
    • NFPA 61 Standard for Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities
    • NFPA 68 Standard on Explosion Protection by Deflagration Venting

• Compliance - local authority w/ jurisdiction

• Insurance Risk - Property Specialists review

• Operations – Standard Operating Procedures (SOPs) compliance & education
## 2 – Technical Accomplishments

### Bin Load (field chop)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value</th>
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<tbody>
<tr>
<td>93% Bin fill</td>
<td>874 tons (13.3% m.c.)</td>
</tr>
<tr>
<td>Bin top</td>
<td>5.4 Dlb/ft³</td>
</tr>
<tr>
<td>Overall Avg.</td>
<td>8.4 Dlb/ft³</td>
</tr>
<tr>
<td>Bin bottom (est.)</td>
<td>11.3 Dlb/ft³</td>
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</table>

### Factor

<table>
<thead>
<tr>
<th>Reclaimer Length (ft)</th>
<th>Pit</th>
<th>Bin</th>
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<tr>
<td></td>
<td>15</td>
<td>30</td>
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</table>

<table>
<thead>
<tr>
<th>Max. Screw Reclaim Rate (cfm)</th>
<th>Pit</th>
<th>Bin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>166</td>
<td>166</td>
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</table>

<table>
<thead>
<tr>
<th>Max. Screw Reclaim Sweep Rate (ft²/h, initial setting)</th>
<th>Pit</th>
<th>Bin</th>
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<td>187</td>
<td>336</td>
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</table>

<table>
<thead>
<tr>
<th>Max. DESIGN Screw Reclaim Rate (density of 5.5 Dlb/ft³) (Dton/h)</th>
<th>Pit</th>
<th>Bin</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>27.4</td>
<td>27.4</td>
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</table>

Lessons learned from Storage & Reclaim provide fundamental knowledge to implement increased-scale bulk storage stacks & applicable Stacker-Reclaim technology.

![Receiving Pit](image1.png)  
![Bin](image2.png)

**Receiving Pit**  
**Bin**
### 2 – Technical Accomplishments

3 unique particle sizes tested

<table>
<thead>
<tr>
<th>Device</th>
<th>Material</th>
<th>Overburden (ft)</th>
<th>Avg. Reclaim Rate (Dton/h)</th>
<th>Reclaim Duty Cycle (%)</th>
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<tbody>
<tr>
<td>Bin 1</td>
<td>FC*</td>
<td>85</td>
<td>31.0**</td>
<td>0**</td>
</tr>
<tr>
<td>Bin 2</td>
<td>FC</td>
<td>16</td>
<td>29.8**</td>
<td>35**</td>
</tr>
<tr>
<td>Bin 2</td>
<td>CTG</td>
<td>19</td>
<td>4.9</td>
<td>99</td>
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<tr>
<td>Bin 2</td>
<td>FTG</td>
<td>16</td>
<td>11.0</td>
<td>75</td>
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<tr>
<td>Receiving Pit</td>
<td>FC</td>
<td>6</td>
<td>22.4</td>
<td>48</td>
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<tr>
<td>Receiving Pit</td>
<td>CTG</td>
<td>6</td>
<td>12.9</td>
<td>57</td>
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<tr>
<td>Receiving Pit</td>
<td>FTG</td>
<td>6</td>
<td>16.7</td>
<td>52</td>
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*FC – Field Chop  CTG – Coarse Tub Grind  FTG – Fine Tub Grind

**Influence of rushing, free-flowing FC bulk during bin discharge, as high as 40 Dton/h – exceeded reclaim design rate of 27 Dton/h
2 – Technical Accomplishments

Bulk Compaction - mobile

<table>
<thead>
<tr>
<th>Material</th>
<th>Avg. Compaction Rate (Dton/h)</th>
<th>Avg. Ejector trailer Discharge Rate (Dton/h)</th>
<th>Dry Bulk Density (Dlb/ft³)</th>
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<td>Field Chop</td>
<td>34.6</td>
<td>142</td>
<td>9.23</td>
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<tr>
<td>Coarse Tub Grind</td>
<td>8.0*</td>
<td>113</td>
<td>7.49</td>
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<tr>
<td>Fine Tub Grind</td>
<td>10.63*</td>
<td>137</td>
<td>9.22</td>
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*Primarily limited by supply rate

Field Chop - Ejector Trailer Load

![Field Chop - Ejector Trailer Load](image)

Novel means to re-distribute compactor weight during transport

![Novel means to re-distribute compactor weight during transport](image)
2 - Technical Accomplishments

- No detected self-heating during storage & reclaim
- Management of moisture content
  - Forage Harvester (at harvest) ~13.3% (w.b.)
  - After Storage and Handling ~11.3% (w.b.)
2 – Technical Accomplishments

Bulk Flow/ Reclaim/ Handling Experiments

- Randomized Complete Block
- Switchgrass re-circulation
- 3 particle sizes, 4 replications each
- 4-hour experimental unit
- 1-Hz data collection rate (14,400 repeated measures)
- 58-variables for handling system
- Controls system source of many variables
- Focus on power-relations

Example for field chop & coarse tub grind combined data:

<table>
<thead>
<tr>
<th>Conveyance Variable</th>
<th>Pearson Correlation Coeff. (P-level)</th>
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<tr>
<td>kW-positive Conveyance</td>
<td>kW-vacuum Conveyance</td>
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<tr>
<td>kW-positive Conveyance</td>
<td>1.00</td>
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<tr>
<td>kW-vacuum Conveyance</td>
<td>-0.913 (&lt;0.0001)</td>
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<tr>
<td>kW-dust Collection</td>
<td>0.537 (&lt;0.0001)</td>
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</table>
2 - Technical Accomplishments

- Kice bulk flow handling – pneumatic handling system
  - Vacuum (negative pressure) conveyance (safety in confined areas)
  - Pressure (blowing) conveyance (efficient tube size)
  - Dust collection integrally designed (safety and emissions)
  - Cyclone, Vortex chamber, Airlock concept
  - Initial tests with switchgrass stems up to 8-in length in scale system
  - Design details tweaked during commissioning
  - Current system throughput (ton/h) mostly limited by positive pressure conveyance leg

Underlying mechanism for free-flow FC* compared to CTG* or FTG* is not understood - active effort to find measurement that contrasts flow properties

- INL property measurements to understand rushing, free-flowing FC during bin unload
  - Compressibility
  - Springback
  - Wall friction
  - Flow indices
  - Water activity

*FC – Field Chop  CTG – Coarse Tub Grind  FTG – Fine Tub Grind
2 - Technical Accomplishments

- DuPont assists by evaluating switchgrass samples for compositional analysis and ethanol potential
  - Comparing bulk-format with baseline bale system
  - Evaluating temporal effect of storage time up to 1 year.
  - No surprises seen thus far in results
  - Switchgrass composition from windrow during harvest are not affected by whether forage harvester or baler is picking up windrow
  - Several publications document switchgrass potential
3 - Relevance

1. Project tackles bulk-format logistics and bulk handling aspects that are applicable to most feedstock supply systems
2. Downstream processing was incorporated early in the logistics system – to reduce often ignored issues with creating feedstock specifications for biorefinery needs
3. Depot format was incorporated into logistics system design
4. Novel densification was examined that still allows economy of bulk handling
5. Bulk-format reclaimer and handling experiments provide detailed data previously not available for industrial scale up
6. A “model energy crop” of perennial grass at low moisture was examined through equipment systems that had limited or no prior experiences and/or data collection
7. Biomass selection, harvest time, and processing method were identified for fundamental advantages in handling opportunities
4 – Critical Success Factors

**Project**
- Past challenges dealt with by this project were:
  - timely startup, since startup coincided with prioritized Recovery Act projects (6 to 8 month delay in project start up)
  - timely manufacturing of equipment – much was standard equipment, but not stock items
  - timely design and approvals for various permits, codes, jurisdictions, and risk management
  - timely construction of facilities that involved various partners, suppliers, contractors, and natural conditions (karst, weather, etc.)

**Adoption/ Commercial Deployment**
- Business climate and energy policies impact the bio-energy industry, fiscal stability, and return-on-investment.
- Project increases technical knowledge level of bulk-format and other systems employing bulk handling into the throat of the biorefinery.
  - logistics and handling systems for bulk-format were thoroughly advanced, per previous slides
5 – Future Work

**Project**

- Project wraps up June 30, 2013, about 1 month away
- Remaining tasks in process for completion:
  - Efficiency and utilization calculations from GPS/GIS
  - Logistics conclusions for improved efficiencies and unit energy (kW-h/Dton)
  - Statistical analysis of replicated handling experiments with emphasis on power and unit energy (kW-h/Dton)
  - Summary of switchgrass quality comparisons between bale and bulk-format

**Adoption/ Commercial Deployment**

- Stacker-reclaimer using track-less technology to facilitate mobile deployment for tall-stack storage, handling, and out-loading of transport units
- Tall stack and membrane technology for moisture management
Advantages of bulk-format go beyond cost – since supply of scalable large quantities of uniform, pre-processed feedstock at biorefinery specifications aides risk-management.

<table>
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<tr>
<th>Logistics Step</th>
<th>Units (n)</th>
<th>Cost ($/dton)</th>
<th>Logistics Step</th>
<th>Units (n)</th>
<th>Cost ($/dton)</th>
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<tr>
<td>Mower-Conditioner cut</td>
<td>17</td>
<td>1.32</td>
<td>Mower-Conditioner cut</td>
<td>17</td>
<td>1.32</td>
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<tr>
<td>Rake crop</td>
<td>17</td>
<td>0.75</td>
<td>Self-Propelled Forage Harvester</td>
<td>27</td>
<td>6.92</td>
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<tr>
<td>Round Bale crop, net wrap</td>
<td>31</td>
<td>6.38</td>
<td>Collect and haul loose bulk in van trailer</td>
<td>151</td>
<td>8.97</td>
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<tr>
<td>Self-load Bale wagon, bales to field edge</td>
<td>31</td>
<td>2.21</td>
<td>Depot Bulk Receiving Station</td>
<td>5</td>
<td>2.91</td>
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<tr>
<td>Tractor loader Stack Bales 3-2-1</td>
<td>31</td>
<td>1.37</td>
<td>Depot Conveyance Receiving</td>
<td>5</td>
<td>1.80</td>
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<td>Field Edge Storage - 1-acre Rockbase/ tarp</td>
<td>244</td>
<td>12.11</td>
<td>Depot Conveyance Discharge</td>
<td>5</td>
<td>5.08</td>
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<td>Truck field telehandlers to storage sites</td>
<td>1</td>
<td>0.41</td>
<td>Depot Dust Collection</td>
<td>5</td>
<td>2.95</td>
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<tr>
<td>Field telehandler load bales on Truck</td>
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<td>0.98</td>
<td>Depot Storage - 6-acre Rockbase/ tarp</td>
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<td>1.49</td>
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<tr>
<td>Truck bales to biorefinery</td>
<td>39</td>
<td>13.06</td>
<td>Depot Stacker/Reclaimer - Stacking</td>
<td>5</td>
<td>1.35</td>
</tr>
<tr>
<td>Biorefinery telehandler offload bales</td>
<td>6</td>
<td>1.18</td>
<td>Depot Stacker/Reclaimer - Reclaimer</td>
<td>5</td>
<td>8.19</td>
</tr>
<tr>
<td>Biorefinery telehandler - bales to grinder</td>
<td>6</td>
<td>1.18</td>
<td>Bulk Compactor</td>
<td>7</td>
<td>1.57</td>
</tr>
<tr>
<td>Tubgrind bales</td>
<td>12</td>
<td>13.51</td>
<td>Ejector Trailers for compacted bulk format</td>
<td>32</td>
<td>11.10</td>
</tr>
<tr>
<td>Dust collection</td>
<td>3</td>
<td>1.77</td>
<td>Biorefinery bulk receiving</td>
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<td>0.73</td>
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<td></td>
<td></td>
<td></td>
<td>Dust collection</td>
<td>2</td>
<td>1.18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>56.23</strong></td>
<td></td>
<td><strong>Total</strong></td>
<td><strong>55.56</strong></td>
<td></td>
</tr>
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</table>
Summary

1. Approach
   • This project dealt with a most comprehensive supply chain to handle feedstock delivered at biorefinery specifications

2. Technical accomplishments
   • monitor/ classify logistics operations
   • lessons for development of advanced turn-key, feedstock supply systems
   • contrast loose- versus compacted-bulk conditions
   • biomass reclaiming and handling - discovery of free-flow field chop

3. Relevance
   • results apply to most feedstock supply systems, through bulk handling aspects

4. Critical Success factors & challenges
   • construction challenges and harvest logistics – obstacles were overcome

5. Future Work
   • project is near end, data wrap-up is being conducted

6. Technology transfer
   • a platform for enhancing uniform-format feedstock supply was identified for high-quantity handling with bulk stacker – reclaimer technology
Systems Matter!
Questions?

www.biomassprocessing.org

www.biomasslogistics.org

www.generaenergy.com
Response to 2011 Review comments

- Under 2. Technical Progress and Accomplishments
  - Comment: “It will be hard to finish by 2012.” “Aggressive target timeline is noted.”
  - Response: Project start was delayed 6 to 8 months due to DOE priority of Recovery Act projects, even though this project required substantial construction and dependence of harvest campaign and handling experiments on system being constructed. Excellent progress was made on this complex project due to responsive project management and the fact that excellent partners had been selected. A 6-month no-cost project extension was requested and granted to allow 1 full year for material storage and subsequent evaluation.
Under 4. Critical Success Factors
Comment: “It is unclear how the delivered material, which appears to re-fluff on delivery will be integrated with storage activities at conversion facilities.”

Response: Field chopped switchgrass at low moisture has a natural, loose high bulk density compared to other biomass. Confining pressure is provided by various means purposely engineered into the system. A simple mechanism is through the overburden-effect that increases bulk density. The bulk compactor technology was also proven effective. A strength of the project is using handling equipment that is typically used at receiving stations of biomass conversion facilities. This project more thoroughly evaluated the supply chain to the biorefinery.
Response to 2011 Review comments

Under 5. Technology Transfer and Collaborations
Comment: “No mention of technology transfer.” “Tech transfer should be fairly natural...”

Response: As part of the Biomass Innovation Park, project technologies receive much visibility through public events (2 biomass field days since last review) and nearly daily visits by various firms, entities, and organizations. As with any business venture and activity, intellectual property and agreements are regularly executed by Genera and are not advertised. Much interest has been demonstrated regarding the bulk-format and handling technologies.
Publications, Presentations, and Commercialization

- And others…