HIGH TONNAGE FOREST BIOMASS
FROM SOUTHERN PINE

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OLADIRAN FASINA, TIM MC DONALD, MATHEW SMIDT
To meet U.S. energy goals, high-productivity, low-cost biomass supply systems are needed

U.S. Department of Energy goals:

- Logistical systems to produce 100 million dry tons/yr biomass
- Harvest and transport biomass for $25 per dry ton by 2012
FEEDSTOCK CHALLENGES

Supply

- Biomass is the South’s greatest opportunity for a renewable energy source
  - 200 million acres of forests
  - 35 million acres of productive pine plantations
- Two sources of feedstock
  - Forest residues
  - Dedicated energy harvest
FOREST RESIDUES

Approximately 40 million tons/yr available
FEEDSTOCK CHALLENGES
Supply

- Dedicated southern pine energy plantations can provide significant feedstocks for U.S. biofuel and biopower demands
- Biomass yields of 7 dry tons/acre*yr may be possible with genetic advances
- 15 million acres of southern pine plantations could produce 105 million tons/yr
AUBURN HIGH TONNAGE CONSORTIUM

- Auburn University
- USDA Forest Service
- Corley Land Services
- Tigercat
- Precision Husky
- Biorefinery collaborators
  - Coskata
  - Genera Energy
  - Rentech
- Department of Energy
BIOMASS SUPPLY SYSTEM
Dedicated energy plantation

+ Southern pine
  - Loblolly pine is primary species
  - Proposed final harvest at age 10 – 12
  - Target production of 7 dry tons/acre*year

+ Benefits
  - Increased harvesting productivity (and lower costs) over traditional thinnings
  - More frequent cash flow for landowner with flexible management options
Biomass Logistics Systems

Traditional Longwood System
- Felling
- Skidding
- Delimbing
- Loading
- Transport
- Log Storage and Handling
- Debarking
- Size Reduction (Chipping)
- Drying
- Conversion

In-woods Chipping System
- Felling
- Skidding
- Delimbing
- Debarking
- In-woods Chipping
- Transport
- Chip Storage and Handling
- Size Reduction
- Drying
- Conversion

Chip-at-Stump Systems
- Chip-at-Stump
- In-woods Chip Transport
- Loading
- Transport
- Chip Storage
- Size Reduction
- Drying
- Conversion
Harvest and Transport

High Productivity Harvesting System

- Track-type feller buncher
  - High efficiency
  - Low site impacts

- Wheeled Skidder
  - Traditional transport option in southern pine systems
High Productivity Processing and Transport

- **In-woods chipping**
  - High productivity chipper
  - Debarking for clean chips

- **Truck transport**
  - High capacity trailers
**High Productivity Harvesting System**

- **“Cold” logging system**
  - Separation of felling, skidding, and chipping
  - Higher productivity

- **“Transpirational drying”**
  - After felling, bunches remain in forest for 6 weeks to reduce moisture content to near 30%
  - Increases transportation efficiency
  - Increases energy content and process efficiency
**Example** transport costs for wood chips at various moisture contents (for 60 mile haul distance).

<table>
<thead>
<tr>
<th>% Moisture</th>
<th>Green Tons per Load</th>
<th>Dry Tons per Load</th>
<th>Cost per Dry Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>28.0</td>
<td>14.0</td>
<td>$14.40</td>
</tr>
<tr>
<td>45%</td>
<td>28.0</td>
<td>15.4</td>
<td>$13.09</td>
</tr>
<tr>
<td>40%</td>
<td>28.0</td>
<td>16.8</td>
<td>$12.00</td>
</tr>
<tr>
<td>35%</td>
<td>28.0</td>
<td>18.2</td>
<td>$11.08</td>
</tr>
<tr>
<td>30%</td>
<td>28.0</td>
<td>19.6</td>
<td>$10.29</td>
</tr>
<tr>
<td>25%</td>
<td>28.0</td>
<td>21.0</td>
<td>$9.60</td>
</tr>
</tbody>
</table>
PROJECT SCOPE

Phase I - R&D

- Design new machines and systems
- Develop benchmarks for existing system productivity, cost, feedstock quality

Phase 2 - Commercial-Scale Test and Demonstration

- Test new machines
- Test transpirational drying
- Test extended shifts
- Quantify industry and landowner acceptance
- Develop and demonstrate information systems
PHASE 1 – R&D

Benchmarking of existing operations

+ Testing typical southern pine tree-length harvesting systems
  × Wheeled feller buncher
  × Wheeled skidder
  × Whole tree chipper
  × Trucking to mill

+ Benchmark tests
  × 9 month period to document cost, productivity, and feedstock quality
BENCHMARKING COST EXAMPLES

Utilization

65% Feller buncher

59% Skidder

50% Loader

59% Chipper
Design activities

+ System design
  - Based on models of predicted machine and system productivity/cost

+ Mechanical design
  - Standard engineering design and analysis to meet functional requirements and productivity goals
HARVESTING SYSTEM DESIGN

- Model developed to predict productivity of the tracked feller buncher - wheeled skidder system
  - Productivity models for felling and skidding functions
  - Machine rate methods used for cost calculations
  - Overall system productivity / cost prediction

<table>
<thead>
<tr>
<th>Felling Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time per cut</td>
</tr>
<tr>
<td>Time per dump</td>
</tr>
<tr>
<td>Time per move</td>
</tr>
<tr>
<td>Bundle Building?</td>
</tr>
<tr>
<td># of Dumps for Full Bundle</td>
</tr>
</tbody>
</table>

Felling Performance: 511 trees/hr
Trees-per-Bundle: 25

<table>
<thead>
<tr>
<th>Skidder Projected Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost per PMH</td>
</tr>
<tr>
<td>Total Cost per SMH</td>
</tr>
<tr>
<td>Cost per ton</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feller Buncher Projected Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost per PMH</td>
</tr>
<tr>
<td>Total Cost per SMH</td>
</tr>
<tr>
<td>Cost per ton</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Overall Productivity and Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feller Productivity</td>
</tr>
<tr>
<td>Skidder Productivity</td>
</tr>
<tr>
<td>Feller Cost</td>
</tr>
<tr>
<td>Skidder Cost</td>
</tr>
<tr>
<td>Total Cost</td>
</tr>
</tbody>
</table>
HARVESTING SYSTEM DESIGN

- Model results target average system productivity >70 green tons/PMH
- Predicted (theoretical minimum) costs for felling and skidding <$4.00 per green ton
  + $2.00/ton felling
  + $1.60/ton skidding
FELLER BUNCHER DESIGN

- **Tigercat 845 D tracked feller buncher**
  + EPA Tier 4i compliant engine
  + High speed, low cost shear felling head
  + Designed for trees up to 18 in. dbh; average dbh = 6 in.
  + Energy recovery system for swing mechanism
  + ER boom system provides energy recovery and planar motion
• DT1802 Biomass Harvesting High Speed Shear
• 1.5 seconds to open or close shear
Wheeled Skidder Design

- **Tigercat 635 D wheeled skidder**
  - 25 sq. ft. grapple
  - 98 tree capacity at 6 in. tree diameter
**SKIDDING COST AND PRODUCTIVITY**

**648 JOHN DEERE**
- 926’ skid distance
- 5.5 minutes per cycle
- 3.1 tons per cycle
- 30 tons/PMH
- $90/PMH
- $3.00 per ton

**630D TIGER CAT**
- 1005’ skid distance
- 5.3 minutes per cycle
- 8.8 tons per cycle
- 100 tons/PMH
- $130/PMH
- $1.30 per ton
Precision WTC2675 disk chipper

- Multiple configurations possible
  - 4 or 8 knives
  - Pulp chips
  - Microchips
- Clean chips possible with addition of flail delimber
CHIPPING COST AND PRODUCTIVITY

PRECISION 2300

- Ave. 34 minutes/load
- 30 tons/PMH
- $280/PMH
- $9.33/ton

PRECISION 2675

- Ave. 19 minutes/load
- 70 tons/PMH
- $333/PMH
- $4.76/ton
SYSTEM COST COMPARISON

<table>
<thead>
<tr>
<th></th>
<th>Conventional System</th>
<th>New System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhd</td>
<td>$15.75</td>
<td>$12.72</td>
</tr>
<tr>
<td>Chipping</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skidding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Felling</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$ per ton
Harvesting system designed for transpirational drying of wood

- Trees allowed to dry in field for up to 6 weeks to reduce moisture content near 30%

High capacity trailers designed to transport greater volume of wood (at lower moisture content)

- Designs up to 114 cu. yds.
- Volume increases up to 30%
"TRANSPIRATIONAL" DRYING

Field Drying Test

Sample Date

Moisture Content (wb)

4-Apr
26-Apr
16-May

Disk Analysis
Weighed Trees
INFORMATION SYSTEMS

- **Chipping**
  - **Fuel consumption monitoring**
  - **Sensor for mass flow of chips**
  - **Sensors for biomass properties**
    - **Moisture content**
    - **Energy content**
    - **Ash content**
In-stream determination of fuel characteristics
Improved system management is key to meeting cost goals

Feller buncher systems to monitor productivity

- Productivity information gathered and displayed using CAN bus (e.g. trees/hr)
- Machine location and tree size collected by GPS and CAN bus to develop biomass yield information
- Machine performance (fuel consumption, etc.) supplied by CAN bus

Skidder productivity monitoring systems use GPS and CAN bus
379 trees cut, 1 hour, 49 minutes, 9 seconds = 208 trees hour$^{-1}$
80 accumulations, 4.7 trees accumulation$^{-1}$
Biofuel industry emphasized the importance of understanding harvesting system effects on feedstock quality

Feedstock data collected from:

- Standing trees
- Trees harvested with feller buncher and skidder
### Feedstock Quality Baseline

<table>
<thead>
<tr>
<th></th>
<th>Energy (BTU/lb)</th>
<th>Carbon (%)</th>
<th>Ash (%)</th>
<th>Alkali (% of ash)</th>
<th>Silica (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foliage</strong></td>
<td>8195&lt;sup&gt;a&lt;/sup&gt;</td>
<td>49.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.59&lt;sup&gt;a&lt;/sup&gt;</td>
<td>92.71&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.005&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Limbs</strong></td>
<td>7773&lt;sup&gt;a&lt;/sup&gt;</td>
<td>48.65&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.38&lt;sup&gt;b&lt;/sup&gt;</td>
<td>94.10&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>0.000&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Stem without Bark</strong></td>
<td>8111&lt;sup&gt;a&lt;/sup&gt;</td>
<td>48.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.40&lt;sup&gt;c&lt;/sup&gt;</td>
<td>97.93&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.000&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Bark</strong></td>
<td>8029&lt;sup&gt;a&lt;/sup&gt;</td>
<td>51.64&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.37&lt;sup&gt;b&lt;/sup&gt;</td>
<td>80.61&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.001&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Stem without Bark</strong></td>
<td>8714&lt;sup&gt;x&lt;/sup&gt;</td>
<td>49.71&lt;sup&gt;x&lt;/sup&gt;</td>
<td>0.38&lt;sup&gt;x&lt;/sup&gt;</td>
<td>94.04&lt;sup&gt;x&lt;/sup&gt;</td>
<td>0.000&lt;sup&gt;x&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Bark</strong></td>
<td>9131&lt;sup&gt;y&lt;/sup&gt;</td>
<td>52.76&lt;sup&gt;y&lt;/sup&gt;</td>
<td>1.30&lt;sup&gt;y&lt;/sup&gt;</td>
<td>89.14&lt;sup&gt;y&lt;/sup&gt;</td>
<td>0.180&lt;sup&gt;y&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

- Data from standing trees (loblolly pine)

Auburn site

Corley benchmark sites
Data from chipped trees

<table>
<thead>
<tr>
<th></th>
<th>Energy (BTU/lb)</th>
<th>Ash (%)</th>
<th>Carbon (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole tree</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not skidded</td>
<td>8715&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.84&lt;sup&gt;a&lt;/sup&gt;</td>
<td>49.92&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Delimbed tree</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not skidded</td>
<td>8702&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td>50.16&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Whole tree skidded</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8566&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.85&lt;sup&gt;b&lt;/sup&gt;</td>
<td>50.09&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
ENERGY VERSUS ASH CONTENT (PINE)

$y = -92.479x + 8743.6$

$R^2 = 0.9221$
ENERGY CONTENT VS. PARTICLE DENSITY

\[ y = -11921x + 25839 \]

\[ R^2 = 0.724 \]
LANDOWNER AND LOGGER ACCEPTANCE

Will landowners accept short rotation pine energy plantation?
Will loggers accept new equipment and operating practices?

Focus groups:
- 5 landowner groups
- 5 logger groups
- 100+ landowners
- 30 loggers
## Landowner Bioenergy Concerns

### My decision to produce and sell trees for conversion to energy...

<table>
<thead>
<tr>
<th>Concern</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>The “right” price</td>
<td>1.3</td>
</tr>
<tr>
<td>A steady market</td>
<td>1.6</td>
</tr>
<tr>
<td>The environmental impacts of intensive forest management</td>
<td>2.6</td>
</tr>
<tr>
<td>The benefit to the local economy</td>
<td>2.7</td>
</tr>
<tr>
<td>A sense that I am addressing a larger problem</td>
<td>2.9</td>
</tr>
<tr>
<td>Long term contracts with buyers</td>
<td>3.1</td>
</tr>
<tr>
<td>Enrollment in BCAP</td>
<td>3.6</td>
</tr>
</tbody>
</table>

### Short rotation forest management practiced on some of my property will likely fit with my objectives to:

<table>
<thead>
<tr>
<th>Objective</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide income</td>
<td>1.9</td>
</tr>
<tr>
<td>Protect soil and water resources</td>
<td>3.0</td>
</tr>
<tr>
<td>Protect the visual appearance of my property</td>
<td>3.1</td>
</tr>
<tr>
<td>Provide wildlife habitat</td>
<td>3.2</td>
</tr>
<tr>
<td>Enhance my personal enjoyment</td>
<td>3.5</td>
</tr>
</tbody>
</table>

**Average Score**

1 = Very Important

7 = Not Important
My decision to invest in equipment for harvesting biomass could be determined by

<table>
<thead>
<tr>
<th>Factor</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profitability</td>
<td>1.9</td>
</tr>
<tr>
<td>Long term contracts with buyers</td>
<td>2.0</td>
</tr>
<tr>
<td>A steady market</td>
<td>2.0</td>
</tr>
<tr>
<td>The “right” price</td>
<td>2.1</td>
</tr>
<tr>
<td>The benefit to the local economy</td>
<td>2.8</td>
</tr>
<tr>
<td>A sense that I am addressing a larger problem</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Current barriers to investing in equipment for harvesting biomass are

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Markets for biomass</td>
<td>2.0</td>
</tr>
<tr>
<td>Availability of long term contracts</td>
<td>2.3</td>
</tr>
<tr>
<td>Source of timber for biomass</td>
<td>2.4</td>
</tr>
<tr>
<td>Adoption of new technology</td>
<td>2.6</td>
</tr>
<tr>
<td>Access to financing</td>
<td>2.7</td>
</tr>
<tr>
<td>Availability of trucking (contractors or drivers)</td>
<td>2.8</td>
</tr>
<tr>
<td>Labor availability</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Averages
1 = Strongly Agree
7 = Strongly Disagree
SUMMARY

- High yield pine plantations can supply significant portion of U.S. biofuel and biopower feedstocks.
- New techniques and high-productivity machines can reduce delivered costs.
- Producers will adopt new systems if the market develops.