Cellulosic Biomass: Harvesting, Transportation, and Storage

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Northern Plains Biomass Economy: What Makes Sense?
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Collaborators

Plant & Soil Sciences
   Charles Taliaferro (Retired) – grass breeding
   Yanqi Wu – feedstock development

Biosystems & Agricultural Engineering
   Ray Huhnke – biomass harvest and storage
   Dani Bellmer - gasification
   Tim Bowser - gasification
   Mark Wilkins - bioconversion

Chemical Engineering
   A.J. Johannes – process engineering
   Randy Lewis (BYU) – bioreactor, bioconversion

Microbiology
   Ralph Tanner (OU) – microbial catalyst development
Outline

• Perspective
  – Size of the Energy Business
  – Land Requirements
    • Acres
    • Yield

• Harvest System
  – One Alternative
  – Importance of Harvest Costs

• Challenges

Total 2007 U.S. Energy Consumption: 101.6 quadrillion BTU

- Ethanol from 2.4 billion bu of Corn (U.S. 2007): 0.49 quadrillio BTU, 1.7% of Net 2007 Imports
- Potential Ethanol from Total 2007 U.S. Corn Production (13.1 billion bu): 2.68 quadrillio BTU, 9.2% of Net 2007 Imports
Cellulosic Ethanol

• Energy Independence and Security Act of 2007

  – By 2022, 21 billion gallons of ethanol to be derived from non-cornstarch products (e.g. sugar or cellulose)
U.S. Energy Imports and Potential Energy from 21 Billion Gallons of Cellulosic Ethanol (EISA Mandate for 2022)

Energy Imports (quadrillion BTU)

- Ethanol from 2.4 billion bu of Corn (U.S. 2007): 0.49 (1.7% of Net 2007 Imports)
- Cellulosic Ethanol from 21 Billion Gallon Mandate: 1.60 (5.5% of Net 2007 Imports)
Feedstock Acres

- 21 billion gallons (2007 Energy Act)
- 90 gallons per ton (DOE NREL goal)
- **233 million tons**
- 3 - 7 dry tons per acre
- **33 - 78 million acres**
- In 2007 US farmers planted
  - 94 million acres of corn
  - 64 million acres of soybeans
  - 60 million acres of wheat
  - 11 million acres of cotton
Quantity of Feedstock Required for a 2,000 tons per day Biorefinery

- 700,000 tons / y / biorefinery
- 218,750 (3.2 t/a) acres
- 63 million gal / y / biorefinery (90 gal/t)
- 333 biorefineries to produce 21 billion gal / y (73 million acres)
Quantity of Feedstock Required for a 2,000 tons per day Biorefinery

- 700,000 tons of biomass per year
- 350 days of operation per year
- 17 dry tons per truck
- 118 trucks per day
- 24 hours per day
- 4.9 trucks per hour
“...The rationale for developing lignocellulosic crops for energy is that ...poorer quality land can be used for these crops, thereby avoiding competition with food production on better quality land....” (McLaughlin et al. 1999, p. 293).

### Idle Cropland and Cropland Used for Pasture

(million acres)

<table>
<thead>
<tr>
<th>State</th>
<th>Idle Cropland</th>
<th>Cropland Used for Pasture</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota</td>
<td>3.0</td>
<td>1.3</td>
<td>4.3</td>
</tr>
<tr>
<td>South Dakota</td>
<td>1.3</td>
<td>2.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Nebraska</td>
<td>1.1</td>
<td>1.9</td>
<td>3.0</td>
</tr>
<tr>
<td>Kansas</td>
<td>2.5</td>
<td>2.5</td>
<td>5.0</td>
</tr>
</tbody>
</table>
Biomass Yield Potential ?
Central Grassland Region Biomass Production During Years of Average Precipitation (tons/acre)

Source: Sala et al., 1988.
Switchgrass Yields - Northern Plains
marginal cropland – 10 farms

Switchgrass Yields Northern Plains

marginal cropland – 10 farms
Annual Yields Across Three Years

<table>
<thead>
<tr>
<th></th>
<th>10 farms</th>
<th>2 farms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 States</td>
<td>North Dakota</td>
</tr>
<tr>
<td>Mean</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>

tons/acre

Switchgrass

Oklahoma Data

- Yields more than
  - miscanthus; bermudagrass; flaccidgrass; lovegrass; eastern gamagrass
- Harvest window extends from July through February
- Single harvest per year is more economical than multiple harvest
- Nutrient requirements depend on time of harvest
  - single harvest October 5.5 t/a 60 lb/a N
  - two harvests (July, Oct) 6.3 t/a 170 lb/a N
Switchgrass Expected Harvestable Yield
Oklahoma Cropland (tons/acre)

expected yield 5.5 to 4 t/a depending on county and month of harvest (preliminary data)
Production Challenges

• Continuous year-round flow of material from fields to biorefinery

• Unlike corn grain, harvest, storage, transportation, marketing, and risk management infrastructure does not exist
  – Spot markets work fine for corn grain
  – Spot markets don’t exist for switchgrass

• Large investment required in harvest machines

• Massive quantities must be stored until processed
Harvest System

• Depends on whether the processing system prefers
  – dry versus wet
  – loose versus dense

• Depends on which cellulose processing technology “wins”
  – enzymatic hydrolysis
  – acid hydrolysis
  – gasification
  – gasification-fermentation
  – liquefaction
  – mixalco
Which Harvest Method?

- Current forage harvest systems
  - Small bales
  - Large cylindrical solid bales
  - Large rectangular solid bales
  - Loose chop
  - Cotton module systems
  - Silage systems

- Collect for field storage and transport substantial distances

- For large volume, and current forage harvest technologies, large rectangular solid bales is the most economical system for harvesting biomass from perennial grasses in the Western Plains  (Source: Thorsell et al.)
Bale
Collect Bales and Stack for Field Storage

http://www.stingerltd.com/Products/stacker/2400_pics.htm
Experience from Custom Grain Harvest Companies (Great Plains)

- A substantial quantity of the grain in the Great Plains is harvested by Custom Harvest Companies

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acres Harvested per Year</td>
<td>28,049</td>
</tr>
<tr>
<td>Number of Combines</td>
<td>4.1</td>
</tr>
<tr>
<td>Number of Trucks</td>
<td>6.3</td>
</tr>
<tr>
<td>Number of Employees</td>
<td>10.3</td>
</tr>
</tbody>
</table>

(Source: Kastens and Dhuyvetter, 2006)
Coordinated Harvest System for Switchgrass

- 1 Field Stacker
- 3 Balers (large rectangular solid bales)
- 3 Mowers
- 3 Rakes
- 9 Tractors
- 10 Workers

(Source: Thorsell et al.)
Modeling

• Multi-region, multi-period, mixed integer mathematical programming model
Oklahoma Model

• Field workday distributions built from historical weather data (Mesonet system)
  – Mowing days
  – Raking, baling, stacking days

• Single harvest per year
  – 8 month harvest window (Jul – Feb)

• 2,000 dry tons per day

• Use the model to determine optimal number of harvest machines and harvest, storage, and transportation by month
Switchgrass harvested per month for both a two- and eight-month harvest season to provide a flow of feedstock to a 2,000 dry tons per day biorefinery.
Field storage by month for both a two- and eight-month harvest season to provide a flow of feedstock to a 2,000 dry tons per day biorefinery.
Estimated number of harvest machines for two- and eight-month harvest season to provide a flow of 2,000 t/day.
Estimated number of acres harvested per year per raking, baling, stacking harvest unit for two- and eight-month harvest season to provide a flow of 2,000 t/day

<table>
<thead>
<tr>
<th></th>
<th>Two-month Harvest Season</th>
<th>Eight-month Harvest Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Acres</td>
<td>2,137</td>
<td>6,772</td>
</tr>
<tr>
<td>Harvested per</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RBS Unit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Estimated average investment in harvest machines required to provide a flow of 2,000 t/day for two- and eight-month harvest season.

- **Eight-month Harvest Season**: $10,777,162
- **Two-month Harvest Season**: $26,725,919

The investment for the eight-month harvest season is significantly lower than for the two-month harvest season.
Harvest Costs
45-65 % of “Farm Gate” Production Costs
(2007 prices)
Estimated cost to deliver a flow of 2,000 t/day of switchgrass for both a two- and eight-month harvest season (2007 prices)

- Two-month Harvest Season: 65
- Eight-month Harvest Season: 49

- Transportation
- Field Storage
- Harvest
- Field Cost
- Land Rent
What do the Models Tell Us?

• Harvest would extend over as many months as permitted by weather, feedstock sources, and policy

• Given the quantity of biomass required, and the lack of an existing infrastructure to harvest and transport a continuous flow of massive quantities of biomass, it is likely that an integrated and centrally controlled harvest and transportation system would develop

  – Very risky for a biorefinery to depend on spot markets for feedstock
What do the Models Tell Us?

• The structure of a mature biomass to bioproducts industry that produces bulk commodities such as liquid fuel, from dedicated feedstocks such as switchgrass, may evolve to resemble a vertically integrated timber production and processing business.

• Public policy that restricts business ties between feedstock production and feedstock processing is likely to hinder the development of a cellulosic biomass biorefinery industry.
Industry Structure?

• Perennial grass

• After establishment year, very little annual maintenance required
  – One trip to broadcast fertilizer
  – Harvest

• Structure likely to be determined by the most efficient harvest, storage and transportation system
Possible Arrangements to Insure a Reliable Flow of Feedstock

• Acquire Land

• Long-term land leases similar to Conservation Reserve Program

• Contract with individual growers

• Contract with a group of growers via cooperative arrangement
Additional Challenges

• Risk management
  – Feedstock yield variability
  – Fire of standing and stored switchgrass

• 16 million acres of idle cropland and cropland pasture in the Northern Plains are widely dispersed

• The grain-ethanol program has increased the cost of inputs (land, fertilizer, machinery) required to produce switchgrass

• Discover, develop, design, and demonstrate an economically competitive biorefinery technology

• Build a profitable business model