IPRO 349

Solid Fuel from Biomass for Cogeneration
Corn for food
Not for fuel
Our Problem

• Non-renewable resources
Our Solution

• **Biomass:**
  – Solid organic waste
    • Specifically, corn stover

• **Corn stover:**
  – Everything except the corn kernels
    • Does not effect the food supply
Explanatory Project
Providing the Basis for Further Study

- **Our resources:**
  Publicly available government, industrial, and university reports.
  - Phone and e-mail inquiries of individual firms.

- **Our project plan and approach:**
  - Consolidating, and analysing information
  - Logistics specific to corn stover as solid fuel.

- **Result:**
  Report with detail references and recommendations for follow-up.
Which direction?

• **Small Scale**
  - One farm being self-sufficient

• **Large Scale**
  - Many farms
  - Centralized processing
  - Large power plant
Why not ethanol?

- Ethanol is produced through the fermentation and decomposition of simple sugars

\[ C_6H_{12}O_6 \rightarrow 2C_2H_6O + 2CO_2 \]

= large amount of sugar
= high efficiency in producing ethanol

Sugar cane - Brazilian cash crop used in their ethanol production processes
Why not ethanol?

≠ comprised of large amounts of free sugars, but rather contains mostly cellulose

• Needs extra processing to make sugars available

• High loss of efficiency

However, combustion process release energy directly from cellulosic material!

Perhaps cogeneration is the best route for extracting energy from corn...
Cogeneration produces a given amount of electric power and process heat with 10% to 30% less fuel than it takes to produce the electricity and process heat separately.

- Higher efficiency than normal electricity generator
  - Normal generator: 33%
  - Co-generator: 60-90%
Cogeneration System

Diagram 1

- High Pressure Steam
- Boiler
- Condensate Return
- Turbine
- Generator
- Generator Control Panel
- Plant Bus
- Process or Space Heat
## Comparison

<table>
<thead>
<tr>
<th></th>
<th>Gas Turbine</th>
<th>Gas Turbine w/Duct Firing</th>
<th>Boiler/Steam Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity, MW</strong></td>
<td>1 - 15</td>
<td>1 - 15</td>
<td>0.5 - 5</td>
</tr>
<tr>
<td><strong>Electrical Efficiency, % (HHV)</strong></td>
<td>22 - 32</td>
<td>12 - 17</td>
<td>6 - 10</td>
</tr>
<tr>
<td><strong>Steam Output, Btu/kWh</strong></td>
<td>4,500 - 6,700</td>
<td>12,000 - 20,000</td>
<td>35,000 - 40,000</td>
</tr>
<tr>
<td><strong>Overall Efficiency, % (HHV)</strong></td>
<td>65 - 70</td>
<td>80 - 85</td>
<td>75 - 85</td>
</tr>
<tr>
<td><strong>Power to Steam Ratio</strong></td>
<td>0.4 - 0.6</td>
<td>0.17 - 0.27</td>
<td>0.08 - 0.12</td>
</tr>
<tr>
<td><strong>Installed Costs, $/kW</strong></td>
<td>1,800 - 900</td>
<td>2,000 - 1,000</td>
<td>350 - 900*</td>
</tr>
<tr>
<td><strong>Non-fuel O&amp;M Costs, $/kWh</strong></td>
<td>0.006 - 0.01</td>
<td>0.006 - 0.01</td>
<td>&lt;0.004</td>
</tr>
</tbody>
</table>
Pure Potential – Small Scale

Average Farm Size in Illinois: 374 acres

Average Corn Yield in Illinois: 175 bushels/acre

1 bushel of corn = 56 lbs of corn
For every pound of corn harvested, 1 pound of stover is produced.

EPA recommends that 30% of stover is left on land in order to prevent erosion.

When burned, dry corn stover produces 7540 Btu/lb.
Turbines’ electrical efficiencies range from 6% to 32%.

3.4 Btu’s = 1 watt-hour

This means...
The average farm in Illinois could produce between $3.4 \times 10^8$ watt-hours and $1.8 \times 10^9$ watt-hours in a year.
The average house uses 9.24 MW-hrs/year, so...

Theoretically, between 35 and 195 farm houses could be powered by 1 farm's stover!

Unfortunately, stover can only be collected from farms that use no-tillage farming.

17% of Illinois corn farms use no-tillage farming.
Pure Potential – Large Scale

- 50MW-hrs/Day * 365Days/Year = 18250MW-hrs/Year

- 3.4Btu/W * 18250MW-hrs/Year = 62050MBtu/Year

- 175B/Acre * 56lb/B * 70% * 7540Btu/lb = 51.7MBtu/Acre

- 62050MBtu/Year / 51.7MBtu/Acre = 1199.63Acre/Year
• Factoring in the efficiency of the turbine. 6% or 32% respectively 19,993.8 Acre/Year or 3,748 Acre/Year

• 27,310,833 Acre / 102 County = 267,753 Acre/County on Avg.

• Meaning it would be possible to supply a 50MW-hrs/Day plant on a Btu / county basis.
Flowchart

Field → Harvest → Bunching → Storage

Small Transportation → Processing → Cogeneration

Large Transportation → Processing → Cogeneration
• No stover can be collected from tilled fields (83% of Illinois corn fields)

• Accounting for tilled fields and 30% coverage for erosion preventions, $2.7 \times 10^8$ bushels of stover available in Illinois

• Right now, stover is either used for animal feed or just left on the land
Harvest

Single-Pass Harvest

- Stover is collected simultaneously with corn
- Needs attachment to combines used by farmers
- In development, not available to public

Multi-Pass Harvest

- Stover is collected after harvest
- Stover can decompose over time
- Requires baling to gather and store
- Currently used to collect stover
Bunching

Square Bales
- Requires multiple people
- Easier to move on trucks
- More can be stacked in a storage barn
- $17.70 per acre

Round Bales
- Can be done by one person
- Harder to move
- Inefficient stacking
- $22.70 per acre
Storage

Small

Large
KDS Micronex Dryer/Grinder
• Can handle up to 6” diameter materials
• Functions for wood, straw, and everything in between
• Size of output particles can be adjusted; ranging from 100-2000 microns
• Takes up to 80% moisture material and reduces it to 5% moisture
  • Input is 1-4 tons per hour
  • Fully automatic operation
• Power consumption ranges from 130-175 kW
• Maintenance costs $1-$2/hour
CF Nielsen BP6000 Briquetter

- 100 mm diameter briquettes produced
- 55 kW power consumption
- Capacity: 2200 kg/h
- Weight: 5000 kg
- Automatic operation
Small Scale – Cogeneration

- Cogeneration System: 50kW
- Measured performance:
  - Combustion temperature 900-1150°C
  - Turbine entry temperature 700-850°C
  - Net electrical output testing range 18-35kW
  - Heat exchanger efficiency 71%
  - Exhaust gas temperature 300-330°C (for CHP)
  - Compressor isentropic efficiency 62%
  - Turbine isentropic efficiency 80%
- Measured emissions:
  - CO 0.001 to 0.01 vol %
  - CO2 7.4 to 7.5 vol %
  - NOx 2-10 ppm
  - Particulate emission 50 mg/m3
**Large Scale - Transportation**

- 7540 Btu/lb of dried corn stover
- 1300 lbs per rectangular bale
- 26 bales per truck
- \(26 \times 1300 \times 7540 = 2.54 \times 10^8\) btu (74689 kw*hr)
- When burnt, diesel releases 154000 kJ/G or 42.8 (kw*hr)/G
- One truck full of corn stover is equivalent to 74689 (kw*hr)/G
- Semi trucks achieve 5-10 miles per gallon
- Using worst case scenario, a fully loaded truck with corn stover can travel 1745 G * 5 mpg = 8725 miles before the energy balance between diesel fuel and stover is zero
Large Scale – Cogeneration

• Cogeneration System: 50MW
• Cost: $1,700,000
• Brown Boveri Synchronous Generator:
  – Type WX16L-037LLT
  – S/N# STG-00605
  – 51,200 kVA
  – 13,200 Volts
  – 2,240 Amps
  – 3,600 Rpm
  – 3 Phase 60 Hz
  – Power Factor .85
  – Inlet Temp 40 Degrees C
  – Temp Rise 70 Degrees C
  – Stator 85 Degrees C Rotor
  – Efficiency: 35%
• Emission:
  • NO <120 mg/Nm (15% O₂, dry)
  • CO <10 mg/Nm (15% O₂, dry)
CARBON ZERO NET GAIN

$\text{CO}_2$ released during burning of biomass is later absorbed by the growing crop.
Large Scale Energy Loss

1832.6 tons 2.76e10 btu
-30%
-3.22e5 btu/ton
-0%

Field Harvest Bunching Storage

Transportation Processing Cogeneration

-1.01e5 btu/ton
-3.24e5 btu/ton

10.8 GW-hrs/year from 1 county of farms
Compared to 50 MW-hrs/year from avg. power plant

Cost benefit of biomass supply and pre-processing; BIOCAP Synthesis Paper
Conclusions/Recommendations

- Our team explored the several benefits of converting some waste that would otherwise be left on the field for no further use to a commodity that could provide power and heat to numerous facilities.

- Collaboration of the work of both the business and research team has lead to an outstanding end product which describes all the logistics taken into consideration.

- Additional equipment costs/requirements would further support that corn stover is indeed a novel fuel for generating electricity.
Ethics

- Follow all laws concerning EPA guidelines and emissions standards
- Fair agreements will be made with farmers, contractors and employees for the purchase of their stover and/or labor
- Only warranted and truthful data will be presented to prove the process
- Quality control standards for equipment and processes will be maintained and followed
- A good working relationship will be maintained with the farming community
- An atmosphere of cooperation and interdependence will be created through this process as means of contributing to the community and society
- Participants on the operation of the process will be treated with respect and dignity
Teams

- **Research Team - Research raw data on Biofuel**
  - Anna D., Jonathan, Josh, Joseph, Xin Yi, Bing, Anna V.
- **Business Team – Organize tasks for efficiency**
  - Serena, Ryan, Terrance
- **Visual Team (poster, etc.)**
  - Anna D., Anna V., Xin Yi, Bing, Joe, Terrance
- **Report Team**
  - Xin Yi, Jonathan
- **Flowchart Team**
  - Ryan
- **Deliverable Team**
  - Serena, Ryan
- **Presentation Team**
  - Josh, Terrance, Ryan