Importance

- The U.S. is moving towards sustainability.
- Biomass popular, but unexplored.
- Increase in demand and a decline in production of natural gas. [1]
- Potential energy from stover is greater than natural gas, propane, and heating oil. [2]
- Places value on stover which was once considered waste.

Matlock, Mark, 2008 NWU Presentation
Problem Statement

There is a need for a practical method to efficiently convert corn stover to usable energy via cogeneration.
Objectives

- Investigate pathways for small scale conversion of stover to usable energy
- Research different tools, equipment, and processes to develop a cost, time, and energy efficient process
- Determine the cost and energy efficiency of each step of the system
- Develop a detailed system for a small scale CHP process
Methodology

Team Leader: Branden Schombert

Research Sub-Teams

Collection and Harvesting: Sung Kim
Transportation: Funso Ajigbo, Ken Ogata
Storage: Sangkyoung Lee
Process: Grace Chee, MinSoo Kang
Cogeneration: Tyler Rhodes, YeSeul Lee, Kelsey Camp
Legality and Emissions: Sangkyoung Lee, Branden Schombert
Economics: Ademola Adekola, YeSeul Lee

Administration Sub-Teams

Minutes: Funso Ajigbo, MinSoo Kang
Code of Ethics: Sangkyoung Lee, Ken Ogata
iGroup Maintenance: Funso Ajigbo
Methods

Contact Different Companies

Internet

Research Articles

ADM
Monsanto
John Deere
Vermeer

Department of Energy

Mechanical Properties of Corn Stover

Cost of Harvesting, Transporting and Storing Corn Stover in Wet Form

IPRO Meeting Guest

Packer Engineering
Red Arrow Products
Viskase Companies, Inc.

5000 acre farm in Dixon, IL
ADM presentation at Northwestern University

Visits

5000 acre farm in Dixon, IL
ADM presentation at Northwestern University
Ethics

• *Seven layers of Ethics*
  
• Law
  • Must abide by all EPA regulations

• Professional Code of Ethics
  • Must not represent our team falsely. Rather, be smart when contacting companies.

• Community
  • Corn for food – waste for fuel
Large Scale versus Small Scale

- Mini debate on whether this project should focus on small or large scale
  - Hope that both small and large scale systems will eventually be implemented
- Divided into 2 groups and presented pros and cons of each option
- Results of mini debate:
  - Large scale left as recommendation for next IPRO
  - Small scale was chosen for following reasons...
Results

- **Small Scale Benefits**
  - Conventional
  - Transportation
  - Simpler equipment
  - Smaller investment
  - Profitability

- **Disadvantages**
  - Not as efficient
  - Gasification too complex and impractical

- **Large Scale Benefits**
  - Create jobs
  - Large localized facility
  - Gasification
    - Higher energy yields
    - Easier to transport/store
    - More efficient operation

- **Disadvantages**
  - Complicated logistics
  - Large investment
  - More complicated processes
Process Flow Chart
Energy

- Energy Left from Stover: 69%
- Harvesting: 5%
- Baling: 5%
- Grinding: 1%
- Pelletizing: 0.25%
- Storage: 2%
- **CHP Process**: 18%

**Assuming 80% Efficiency of Stirling Engine**
Proposal of Best Combination

- Large square bales
- Shenk Rotogrinder for bale grinding
- La Meccanica for pelletizing
- Harvestore silo for pellet storage
- Stirling engine for CHP
Large Square Bales

- Dimensions: 4ft x 4ft x 8ft
- 1200 lbs
- Variable Loading Mechanisms

http://www.newhollandmediakit.com/images/newsreleases/H9880_ABW_1.jpg
Shenk Livestock - 760 Rotogrind

- Price: ~ $19,800
- Minimum HP of Tractor: 65HP
- Average HP: 80HP
- Grinder Weight: 3500lb
- Capacity: 5 - 30 ton/hour

※ capacity depends on the type and condition of material, how finely it is being ground, and the size of the tractor.

http://www.shenklivestock.com
La Meccanica - CLM 630N

• Main Motor Power: 160 – 200 kW
• Capacity: 12/18 (min/max, ton/hr)

Technical features

<table>
<thead>
<tr>
<th>Animal feed industry</th>
<th>Main Motor power</th>
<th>Capacity (min/max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLM 200</td>
<td>7.7 - 11.0 - 15.0 kW</td>
<td>150 kg/h - 300 kg/h</td>
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<tr>
<td>CLM 304</td>
<td>30 - 37 - 45 kW</td>
<td>1.5 Ton/h - 2.5 Ton/h</td>
</tr>
<tr>
<td>CLM 420.075</td>
<td>37 - 55 kW</td>
<td>2.5 Ton/h - 5.0 Ton/h</td>
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<tr>
<td>CLM 420.100</td>
<td>75 - 90 - 110 kW</td>
<td>4.0 Ton/h - 6.0 Ton/h</td>
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<tr>
<td>CLM 420.150 HD</td>
<td>75 - 90 - 110 kW</td>
<td>6.0 Ton/h - 8.0 Ton/h</td>
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<tr>
<td>CLM 520.180 ST</td>
<td>110 - 132 kW</td>
<td>8.0 Ton/h - 10.0 Ton/h</td>
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<tr>
<td>CLM 520.220</td>
<td>160 - 200 kW</td>
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<tr>
<td>CLM 520 HD</td>
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<td>8.0 Ton/h - 12.0 Ton/h</td>
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<td>CLM 630.220</td>
<td>180 kW</td>
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<tr>
<td>CLM 630 N</td>
<td>160 - 200 kW</td>
<td>12.0 Ton/h - 18.0 Ton/h</td>
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<tr>
<td>CLM 630 G</td>
<td>200 - 250 kW</td>
<td>14.0 Ton/h - 20.0 Ton/h</td>
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<tr>
<td>CLM 600 P</td>
<td>250 - 260 kW</td>
<td>12.0 Ton/h - 22.0 Ton/h</td>
</tr>
<tr>
<td>CLM 935 M</td>
<td>300 - 350 kW</td>
<td>Up to 35.00 Ton/h</td>
</tr>
</tbody>
</table>
Harvestore Silo

• Steel Silo
• Material: glass-fused-to-steel sheets
• Capacity: 1000 tons ~ 43000 ft³
Why use CHP?

- Increased efficiency of energy conversion and use
- Lower emissions to environment, in particular of CO2, the main greenhouse gas
- An opportunity to move towards more decentralized forms of electricity generation
- High efficiency by avoiding transmission losses and increasing flexibility in system use

Vartiainen, E et al, 2002; Gaia Group Oy, 2004; Obernberger, I., 2004
Stirling Denmark - SD 5 Stirling Engine

- 80% energy efficient
- 10 kWe capacity
- 40 kWth capacity
- $100,000 for plant construction
- input 24 to 32 pounds/hour

Henrik Carlsen, Technical University of Denmark

SD5-Stirling Engine from Stirling Denmark

www.epa.gov
Hurst Boiler & Welding Co., Inc. - CAT # B-08

- 60% energy efficient
- 50 kWe capacity
- 250 kWth capacity
- $250,000*(estimated)
- Currently larger scale operation/multiple farm investment
- Research for smaller scale is concurrent (1-10kW)[6]

50 kW GE Steam Turbine
Hurst RG Biomass Fired Boiler
Cost of Biomass CHP-Plants

<table>
<thead>
<tr>
<th>Technology</th>
<th>EUR/kWe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam turbine/-engine</td>
<td>2.000</td>
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<tr>
<td>ORC</td>
<td>4.000</td>
</tr>
<tr>
<td>Gasification + Fuel Cell</td>
<td>6.000</td>
</tr>
<tr>
<td>Gasification + Turbine</td>
<td>8.000</td>
</tr>
<tr>
<td>Gasification + Engine</td>
<td>10.000</td>
</tr>
<tr>
<td>STIRLING</td>
<td>12.000</td>
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<td></td>
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Comparison of Technologies - Power Output Potential

<table>
<thead>
<tr>
<th>Technology</th>
<th>kW elektric</th>
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<tbody>
<tr>
<td>Steam turbine/-engine</td>
<td>10</td>
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<tr>
<td>ORC</td>
<td>50</td>
</tr>
<tr>
<td>Gasification + Fuel Cell</td>
<td>100</td>
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<tr>
<td>Gasification + Turbine</td>
<td>500</td>
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<tr>
<td>Gasification + Engine</td>
<td>1.000</td>
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<tr>
<td>STIRLING</td>
<td>5.000</td>
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<tr>
<td></td>
<td>10.000</td>
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</table>

<table>
<thead>
<tr>
<th>Technology</th>
<th>Diesel/gas engine</th>
<th>Micro turbine</th>
<th>Stirling engine</th>
<th>ORC turbine</th>
<th>Steam engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity range (kWₑ)</td>
<td>15-10000</td>
<td>25-250</td>
<td>10-150</td>
<td>200-1500</td>
<td>20-1000</td>
</tr>
<tr>
<td>Electrical efficiency (%)</td>
<td>30-38</td>
<td>15-35</td>
<td>15-35</td>
<td>10-20</td>
<td>10-20</td>
</tr>
<tr>
<td>Thermal efficiency (%)</td>
<td>45-50</td>
<td>50-60</td>
<td>60-80</td>
<td>70-85</td>
<td>40-70</td>
</tr>
<tr>
<td>Overall efficiency (%)</td>
<td>75-85</td>
<td>75-85</td>
<td>80-90</td>
<td>85-95</td>
<td>75-85</td>
</tr>
<tr>
<td>Heat production (°C)</td>
<td>85-100</td>
<td>85-100, steam</td>
<td>60-80</td>
<td>80-100</td>
<td>85-120</td>
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<tr>
<td>Lifetime (h)</td>
<td>50000-60000</td>
<td>50000-75000</td>
<td>50000-60000</td>
<td>?</td>
<td>&gt; 50000</td>
</tr>
</tbody>
</table>

Vartiainen, E et al, 2002; Gaia Group Oy, 2004; Obernberger, I., 2004
Problems

- **Correspondence**
  - Information is still being researched by companies that have been contacted
  - “Smart” relations

- **Size Reduction**
  - Properly scaling model for 400 acre farm
  - Current equipment ideal for large scale operations

- **Standardization**
  - Size consistencies between input and output of processes
  - Consistent units of measure
To Do - Recommendations

- Equipment ordering specifications & conditions for test installation
- Unit operations safety review
- Website and interactive database

Examine options:
1. Possible piping of stover slurry for transport
2. Nitrogen byproduct use (cost/benefit)
3. Look into gasification (energy potential is 9:1)
4. Expand models: Small to large scale

http://openlearn.open.ac.uk/file.php/2457/T210_1_044i.jpg
References

1. Matlock, Mark, 2008, Northwestern University Presentation
4. Engineering Aspects of harvesting corn stover for bioenergy, Sokansanj
5. BIOS Bioenergy Systems, Austria 2003
Acknowledgements

- Mark Matlock – Archer Daniels Midland
- Peter J. Schubert, Ph.D – Packer Engineering
- John McKinney – Packer Engineering
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- Jay Van Roekel – Vermeer
- Dave Shenk – Shenk Livestock
- Christopher Scott – Pelheat
- Larry Bubb – California Pellet Mills
- Jennifer Keplinger - IPRO
Questions?