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

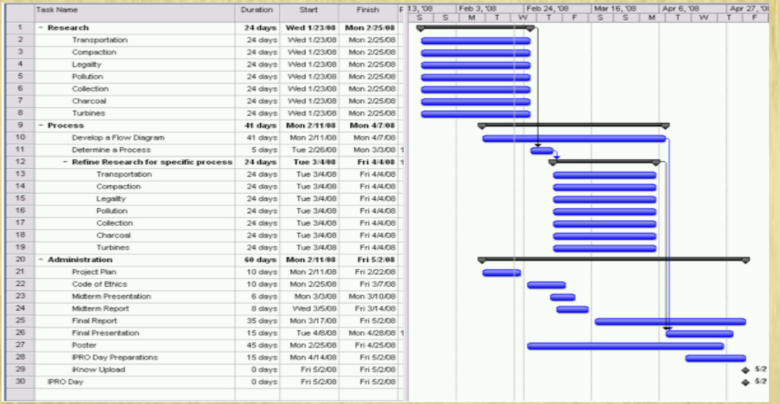
Exploratory Project
Providing the Basis for Further Study

- **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.**



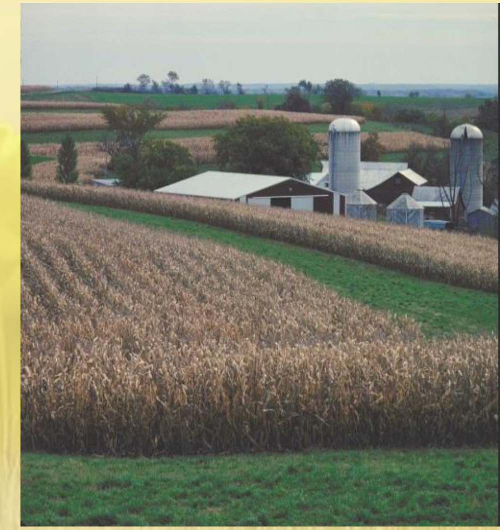
	Task Name	Duration	Start	Finish
1	− Research	24 days	Wed 1/23/08	Mon 2/25/08
2	Transportation	24 days	Wed 1/23/08	Mon 2/25/08
3	Compaction	24 days	Wed 1/23/08	Mon 2/25/08
4	Legality	24 days	Wed 1/23/08	Mon 2/25/08
5	Pollution	24 days	Wed 1/23/08	Mon 2/25/08
6	Collection	24 days	Wed 1/23/08	Mon 2/25/08
7	Charcoal	24 days	Wed 1/23/08	Mon 2/25/08
8	Turbines	24 days	Wed 1/23/08	Mon 2/25/08
9	− Process	41 days	Mon 2/11/08	Mon 4/7/08
10	Develop a Flow Diagram	41 days	Mon 2/11/08	Mon 4/7/08
11	Determine a Process	5 days	Tue 2/26/08	Mon 3/3/08
12	− Refine Research for specific process	24 days	Tue 3/4/08	Fri 4/4/08
13	Transportation	24 days	Tue 3/4/08	Fri 4/4/08
14	Compaction	24 days	Tue 3/4/08	Fri 4/4/08
15	Legality	24 days	Tue 3/4/08	Fri 4/4/08
16	Pollution	24 days	Tue 3/4/08	Fri 4/4/08
17	Collection	24 days	Tue 3/4/08	Fri 4/4/08
18	Charcoal	24 days	Tue 3/4/08	Fri 4/4/08
19	Turbines	24 days	Tue 3/4/08	Fri 4/4/08
20	− Administration	60 days	Mon 2/11/08	Fri 5/2/08
21	Project Plan	10 days	Mon 2/11/08	Fri 2/22/08
22	Code of Ethics	10 days	Mon 2/25/08	Fri 3/7/08
23	Midterm Presentation	6 days	Mon 3/3/08	Mon 3/10/08
24	Midterm Report	8 days	Wed 3/5/08	Fri 3/14/08
25	Final Report	35 days	Mon 3/17/08	Fri 5/2/08
26	Final Presentation	15 days	Tue 4/8/08	Mon 4/28/08
27	Poster	45 days	Mon 2/25/08	Fri 4/25/08
28	IPRO Day Preparations	15 days	Mon 4/14/08	Fri 5/2/08
29	iKnow Upload	0 days	Fri 5/2/08	Fri 5/2/08
30	IPRO Day	0 days	Fri 5/2/08	Fri 5/2/08

- **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?

Corn - US cash crop currently used in most ethanol production

≠ 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…

Why Cogeneration?

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

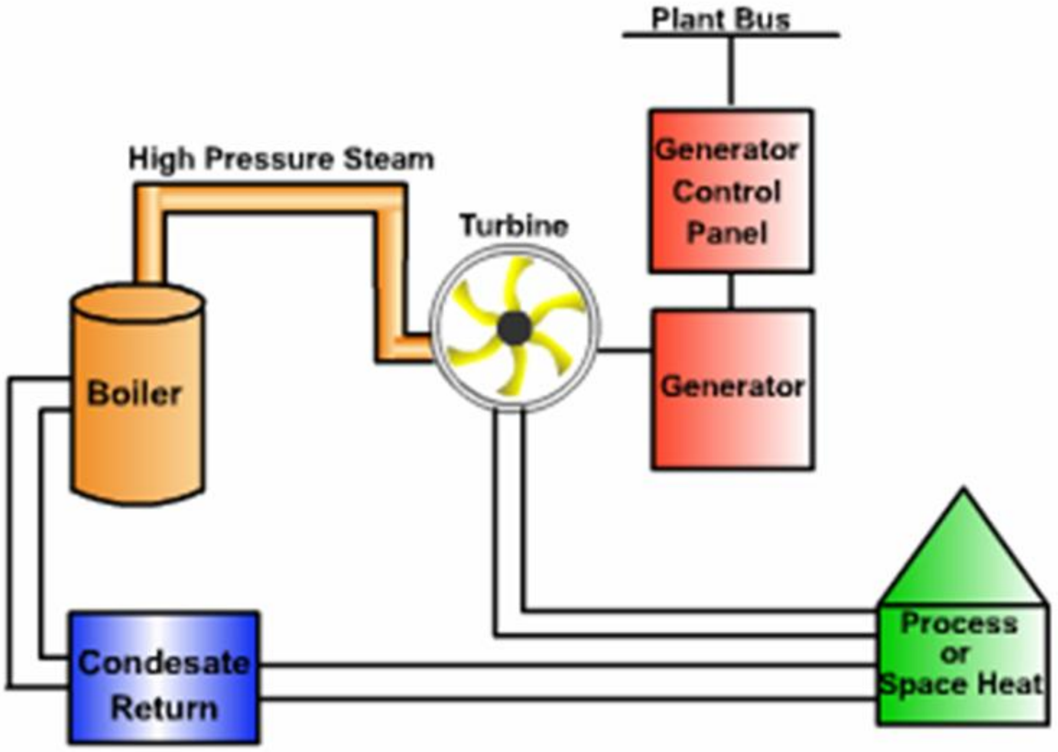


Diagram1

Comparison

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

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

Pure Potential – Small Scale

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

Pure Potential – Small Scale

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 <u>3.4 x 10^8 watt-hours</u> and <u>1.8 x 10^9 watt-hours</u> in a year.

Pure Potential – Small Scale

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

Pure Potential – Large Scale

- Factoring in the efficiency of the turbine. 6% or 32% respectively 19,993.8Acre/Year or 3,748Acre/Year

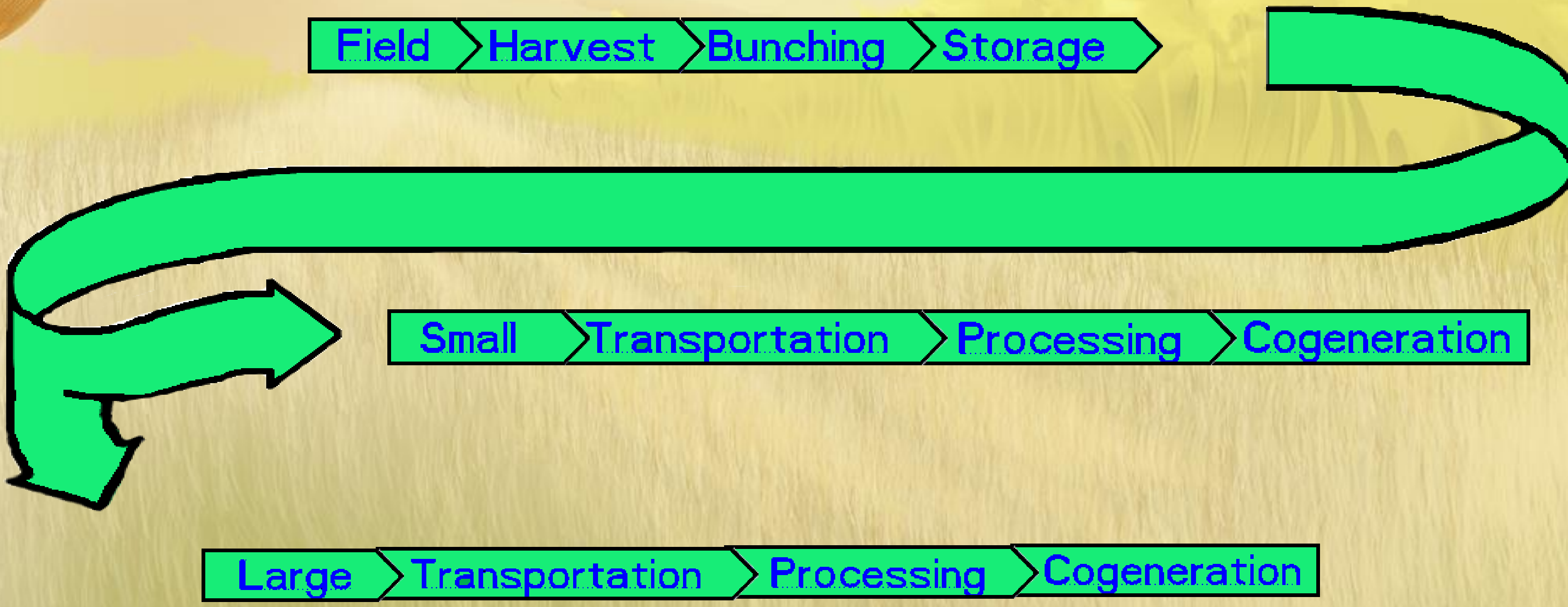
↓

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

↓

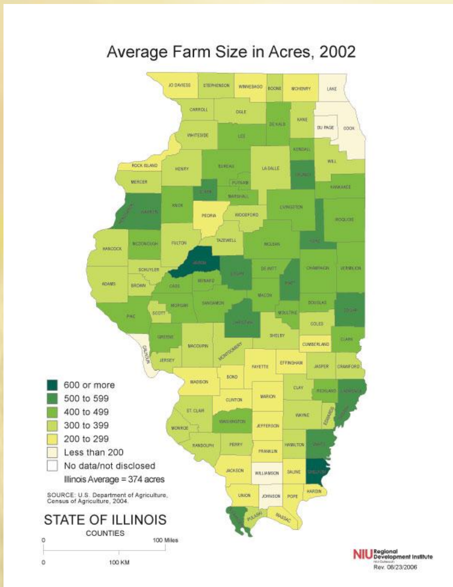
- Meaning it would be possible to supply a 50MW-hrs/Day plant on a Btu / county basis.

Flowchart



Field
Harvest
Bunching
Storage
Small
Transportation
Processing
Cogeneration
Large
Transportation
Processing
Cogeneration

Field



- No stover can be collected from tilled fields (83% of Illinois corn fields)
- Accounting for tilled fields and 30% coverage for erosion preventions, 2.7×10^8 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

Processing

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

Processing

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 900-1150oC
  - Turbine entry temperature 700-850oC
  - Net electrical output testing range 18-35kW
  - Heat exchanger efficiency 71%
  - Exhaust gas temperature 300-330oC (for CHP)
  - Compressor isentropic efficiency 62%
  - Turbine isentropic efficiency 80%
  - Measured emissions:
    - CO 0.001 to 0.01 vol %
    - CO_2 7.4 to 7.5 vol %
    - NO_x 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 x 1300 x 7540 = **2.54 x 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)/42.8 (kw*hr)/G = **1745 G diesel**
- 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% O , dry)
    - CO <10 mg/ Nm (15% O , dry)

CARBON ZERO NET GAIN

CO_2 RELEASED DURING BURNING OF BIOMASS

IS LATER ABSORBED BY THE GROWING CROP

CO_2 =

Large Scale Energy Loss

Field	Harvest	Bunching	Storage
1832.6 tons 2.76e10 btu	-30%	-3.22e5 btu/ton	-0%

Transportation	Processing	Cogeneration
-1.01e5 btu/ton	-3.24e5 btu/ton	-40%

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

Questions?