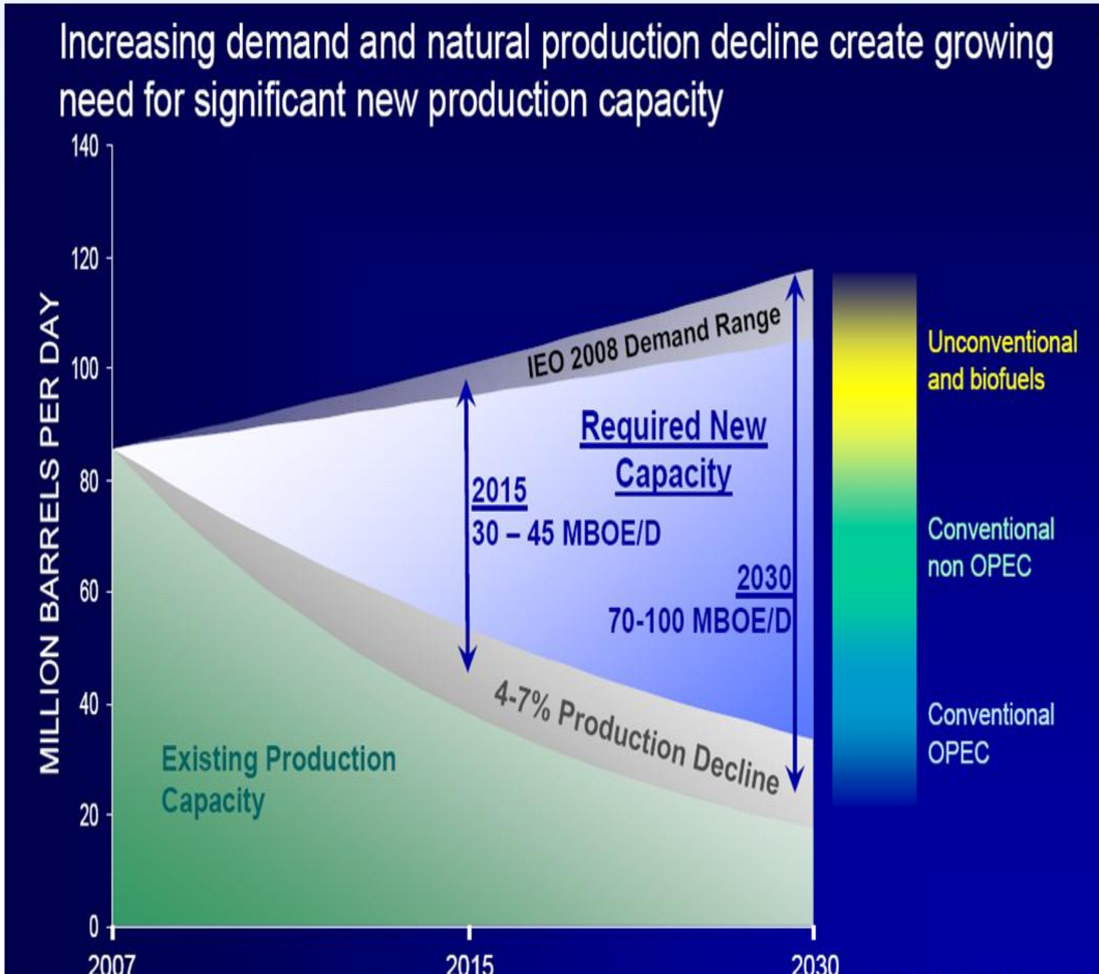
IPRO 349

Solid Fuel from Biomass for Cogeneration

Importance



Matlock, Mark, 2008 NWU Presentation

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.

What is CHP?

Combined
Heat
Power

A system that makes use of the heat generated during the generation of power

Overall system is 75% efficient compared to a non-CHP system which is 49% efficient.

IPRO 349 History Summary

Spring 2008

- Determined potential of using corn stover as a biomass fuel source in a CHP application
- Explored possible mechanism for stover processing and conversion

Fall 2008

- Determined feasibility of a single farm CHP system powered by stover
- Created detailed flow mechanism for stover processing and conversion

Statement of Problem

To determine the **feasibility** of using corn stover as a combined heat and power source for rural community colleges

Objectives

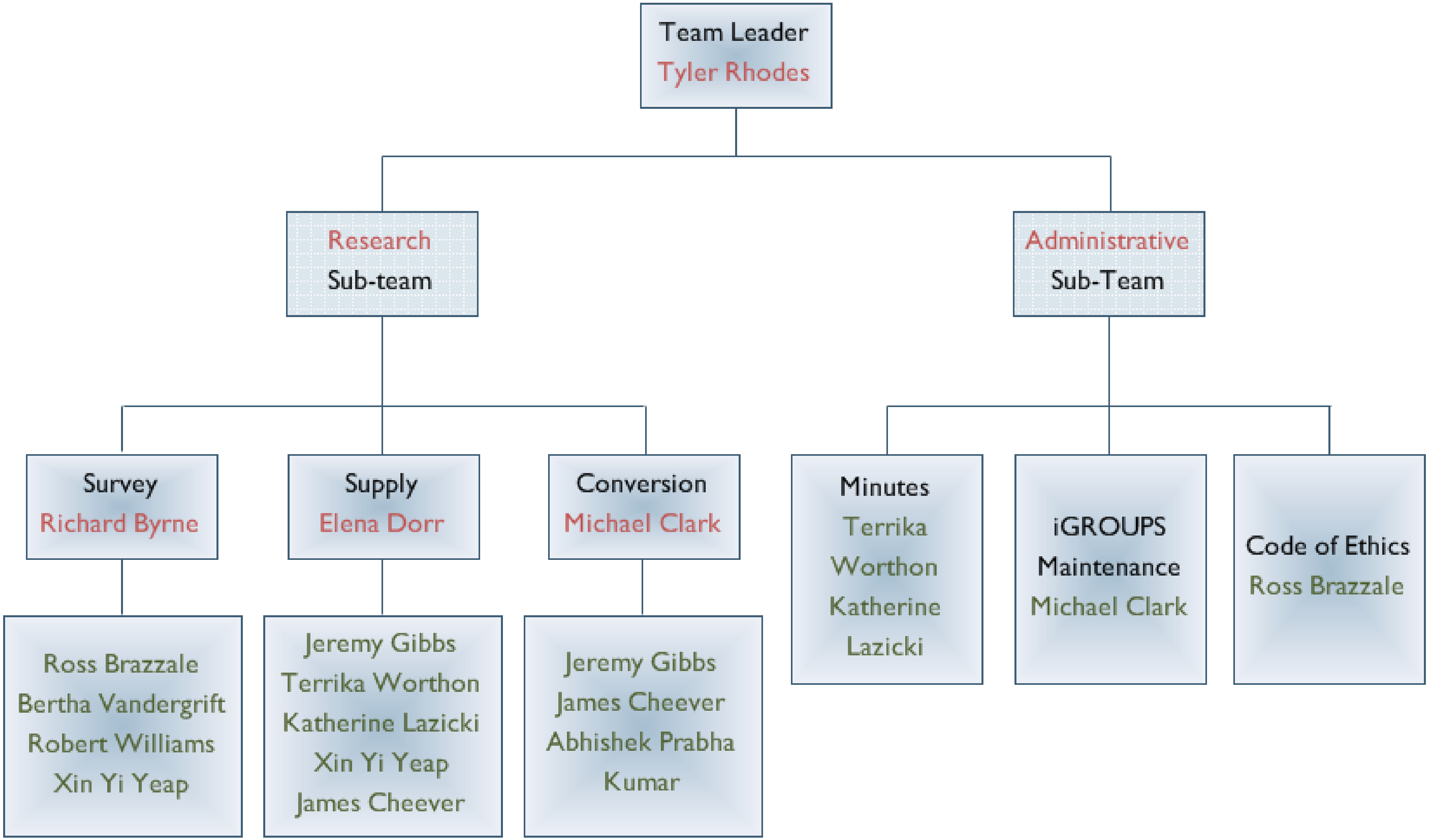
Survey the potential for CHP application

Scale up from single to multiple farm system

Identify future stover CHP options

Investigate creation of an online database of our research

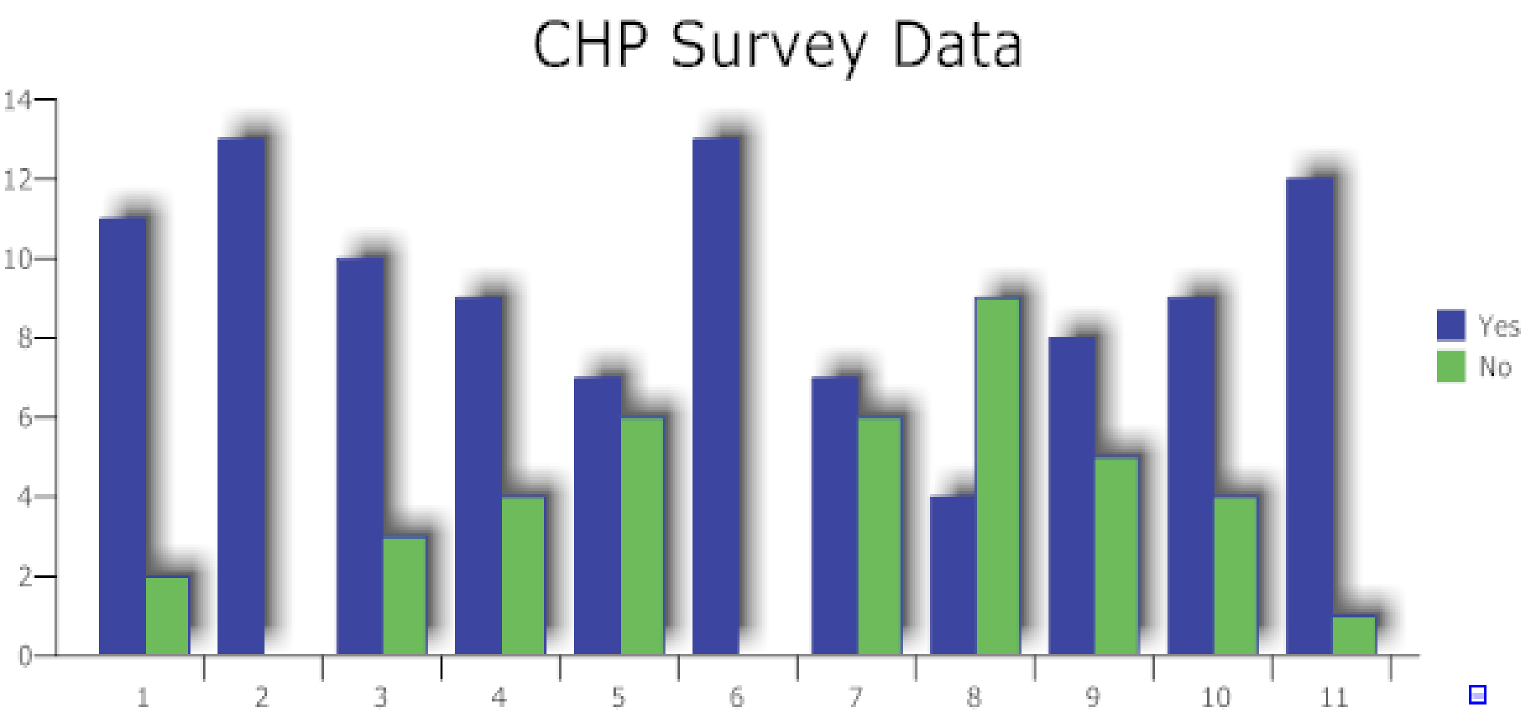
Team Organization



Research Methodology

- **Contacted different companies**
  - Freedom Equip.
  - Somes Nick
  - Hammellmann
  - CPM
  - AGICO
  - Andritz Sprout
  - Rotex
  - Primenergy
  - GTI
  - Graham Corp.
  - Sinotech Ind. Group Ltd.
- **Internet**
  - Illinois Corn Grower Association
  - Minnesota State University
- **Research Articles**
  - EPA CHP
  - AURI
  - Environmental
- **Survey Community Colleges**
  - 46 Illinois & Indiana rural community colleges
- **Phone Conference**
  - Paul DuCharme
- **Visit**
  - GTI Tour

Survey Data



☐	Does your facility have an existing central plant?
☐	Do you expect to replace, upgrade, or retrofit central plant equipment within the next 3-5 years?
☐	Do you anticipate a facility expansion or new construction project within the next 3-5 years?
☐	Have you already implemented energy efficiency measures and still have high energy costs?
☐	Are you interested in reducing your facility's impact on the environment?

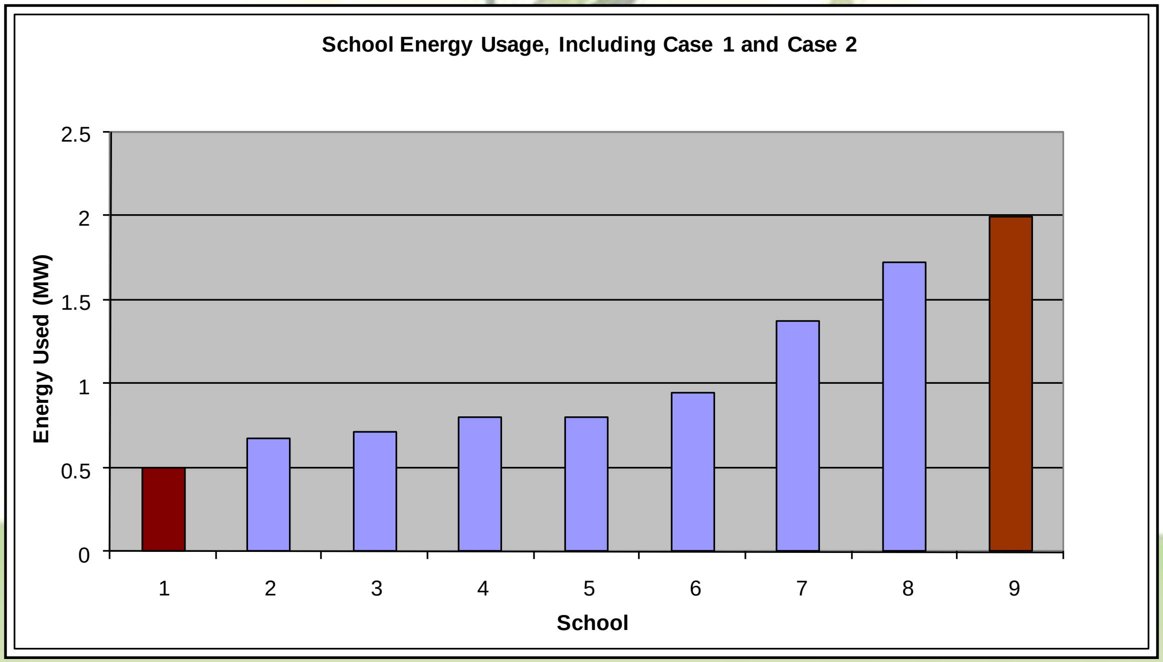
Survey Analysis

- 30% of the schools contacted are a good candidate for CHP according to EPA guideline
- Only 20% of schools that replied are planning to develop power facilities within 5 years
- Schools are generally concerned about reducing the current and future energy costs

Follow up from schools

School Name	Power Bought (kWh)	Electricity Usage (MW)	Heating demand (Therms)	On-campus residency	Size of student body	Campus Area (Acres)
SCHOOL 1	5,900,000	0.67	107,000	No	7400	310
SCHOOL 2	6,200,000	0.71	286,000	No	3370	170
SCHOOL 3	7,000,000	0.80	438,000	No	4940	120
SCHOOL 4	7,000,000	0.80	190,000	No	4760	160
SCHOOL 5	8,300,000	0.95	535,000	No	1600	50
SCHOOL 6	12,000,000	1.37	540,000	No	18000	390
SCHOOL 7	15,100,000	1.72	340,000	No	12400	430

STATISTICS OF RECORDED SCHOOL DATA						
Average	8,786,000	1.00	341,500		7,500	232
Max	15,100,000	1.72	540,000		18,000	430
Min	5,900,000	0.67	107,000		1,600	50
Range	2,400,000	1.05	433,000		16,400	380



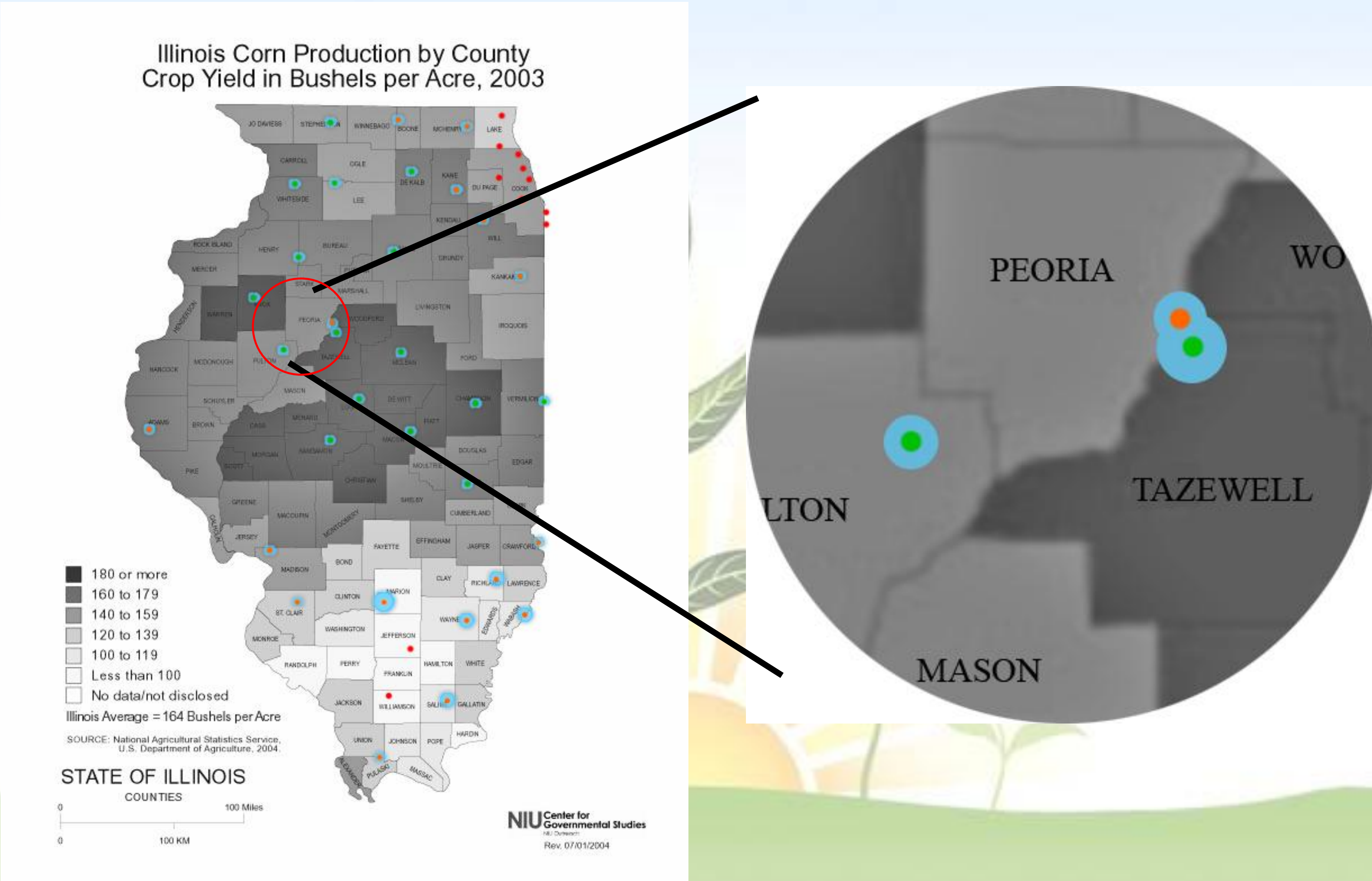
Farmer survey

13

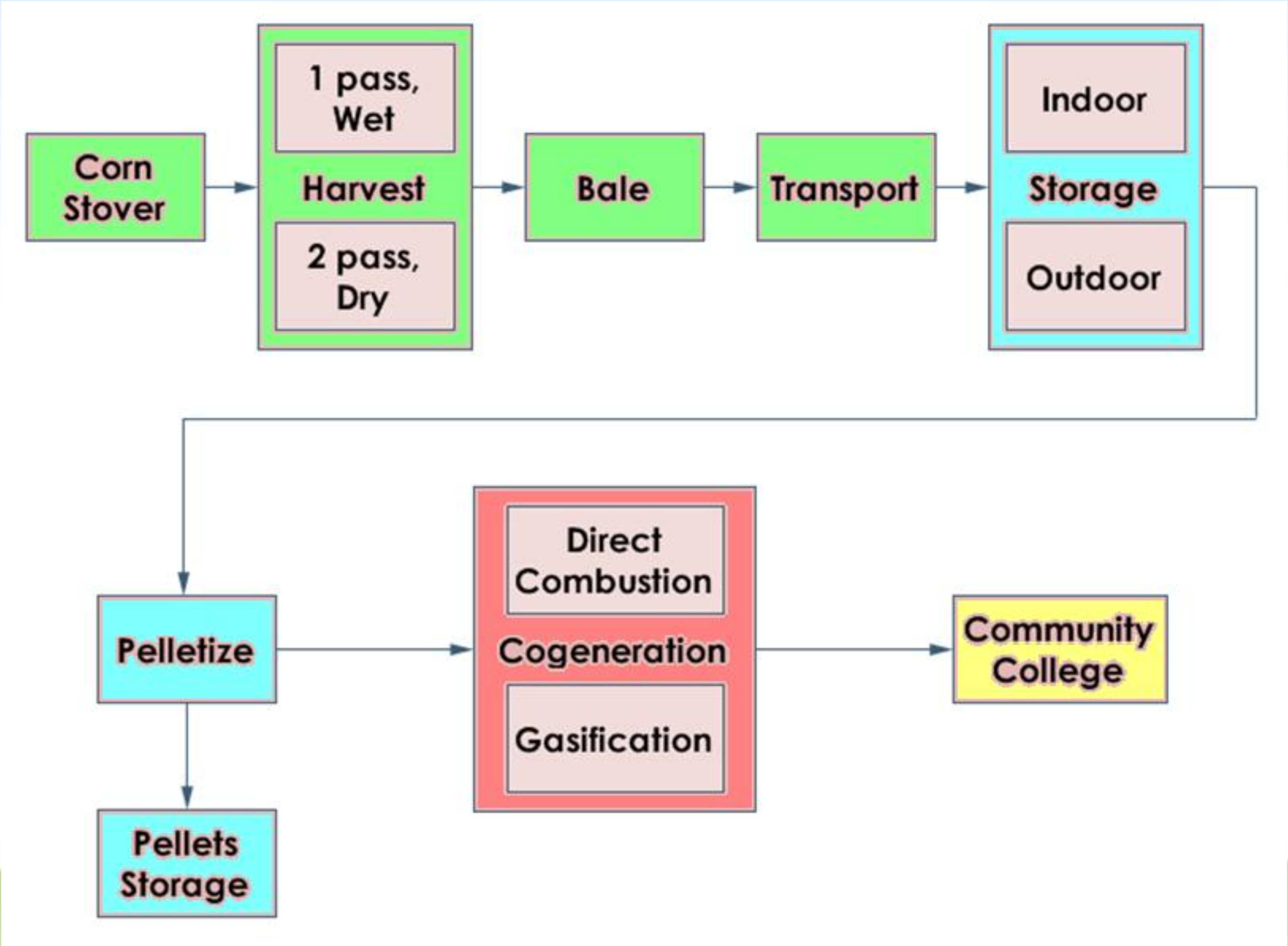
- 9 out of 13 who are willing to participate:
  - All are willing to sell corn stover at a **good price**
  - 5 are willing to harvest corn stover with provided equipment (part of profit)
  - 1 have storage facility for corn stover (some stored outside)
  - 7 are willing to transport the corn stover at a **good price**

Good price = $35 - $42

Geography


Illinois Corn Production by County
Crop Yield in Bushels per Acre, 2003
180 or more
160 to 179
140 to 159
120 to 139
100 to 119
Less than 100
No data/not disclosed
Illinois Average = 164 Bushels per Acre
SOURCE: National Agricultural Statistics Service, U.S. Department of Agriculture, 2004.
STATE OF ILLINOIS
COUNTIES
0
100 Miles
0
100 KM
NIU Center for Governmental Studies
Rev. 07/01/2004
PEORIA
WO
TAZEWELL
LTON
MASON

Overall Process Flow



Harvest and Baling

2 Pass Harvest (Dry)

Combine Windrow

- Easy
- Long dry time

Raker Windrow

- Even coverage
- A third step

Bales

Round

- Good water management
- Added labor

Square

- Efficient transport and stacking
- Poor water management

Transportation

JCB tractor with trailer
http://www.jcb.com/

Distance between farm and school:

Average = 16 miles
Shortest = 5 miles

0.5 MW

- 1,100 loads/yr
- 36,000 average miles traveled/yr
- 221,000 kWh/yr

2 MW

- 4,900 loads/yr
- 158,000 average miles traveled/yr
- 971,000 kWh/yr

Pelletizing

- High Density
- Longer Durability
- Smaller in size
- More drying time required

http://www.cfuel.com

Grinders

Primary/Secondary

- Reduce bales to smaller chunks of stover
- Reduce stover down to pelletizing size

CPM 15 x 44 Hammermill
http://www.cpmroskamp.com/

- Electricity Usage: 2 x 93 kW
- Cost: 2 x $58,200

Pellet Mill

http://www.cpmroskamp.com/

- Compress stover into denser pellets
- Often used in tandem with a conditioner and cooler

0.5 MW

- CPM 1116-4
- Electricity Usage: 37kW
- Cost: $112,000

2 MW

- CPM 7722-6
- Electricity Usage: 186kW
- Cost: $240,000

Storage

Raw Storage

Round bales
- 5 ft diameter
- 5 ft length

Pyramid stacking
- 5 on bottom row

0.5 MW - 42,000 ft^2
2 MW - 167,000 ft^2

http://www.freefoto.com/

Pellet Storage

Harvestore Structure Silo Model 3189
- Volume capacity: 1750m_3
- Cost: $192,650 each

0.5 MW - 5 Silos
2 MW - 22 Silos

http://www.busn.uco.edu

Summary of Requirements

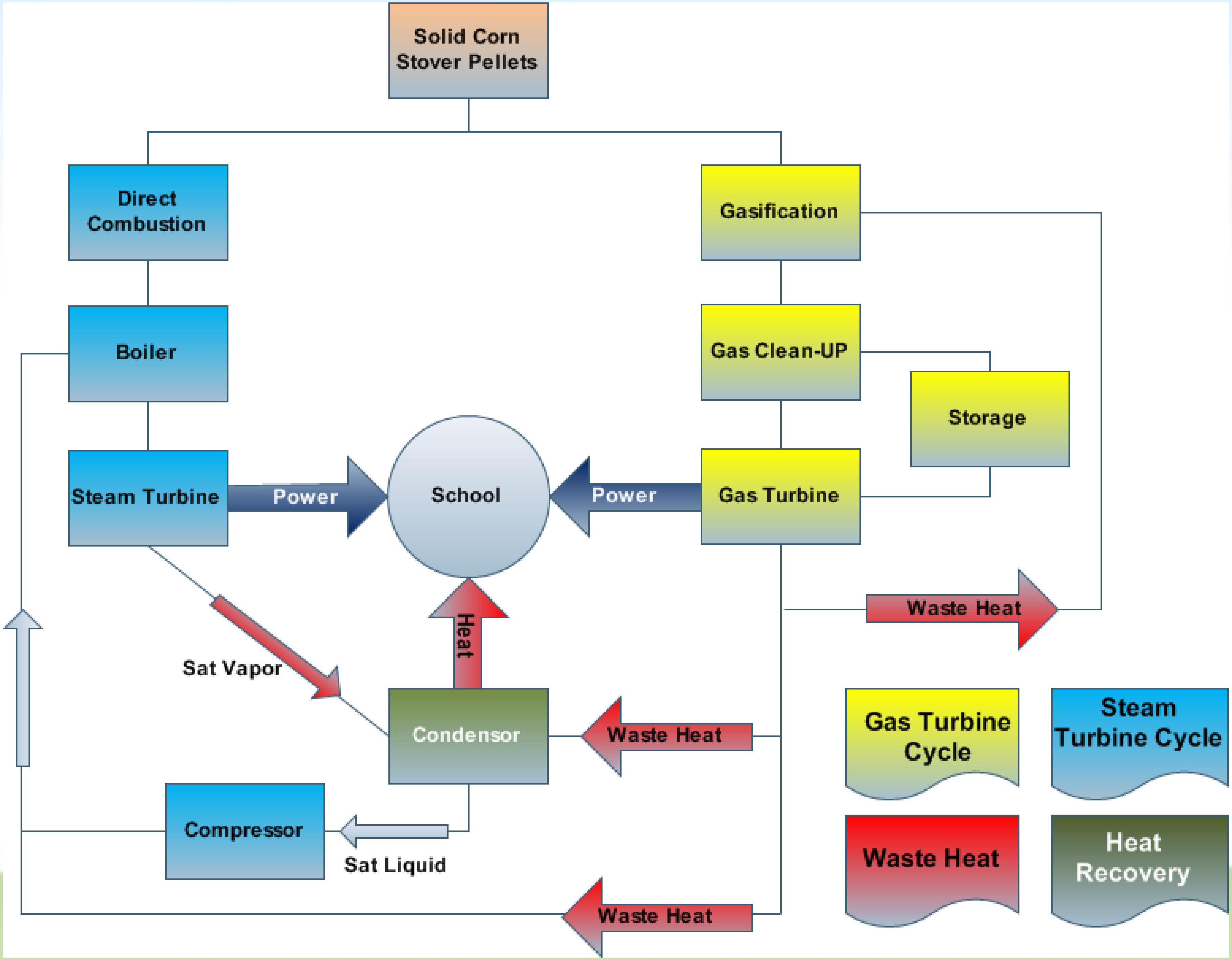
0.5 MW case study

- 12 farms/yr with 40% pick up of stover
- 10,400,000 lb stover/yr
- 4,800 tons pellets/yr

2 MW case study

- 51 farms/yr with 40% pick up of stover
- 45,600,000 lb stover/yr
- 21,100 tons pellets/yr

CHP Process Flow



Power Generation

TiMSAN biomass boiler
http://www.timsan.com.tr

- Pellets are burned to produce heat
- Heat converts water to steam

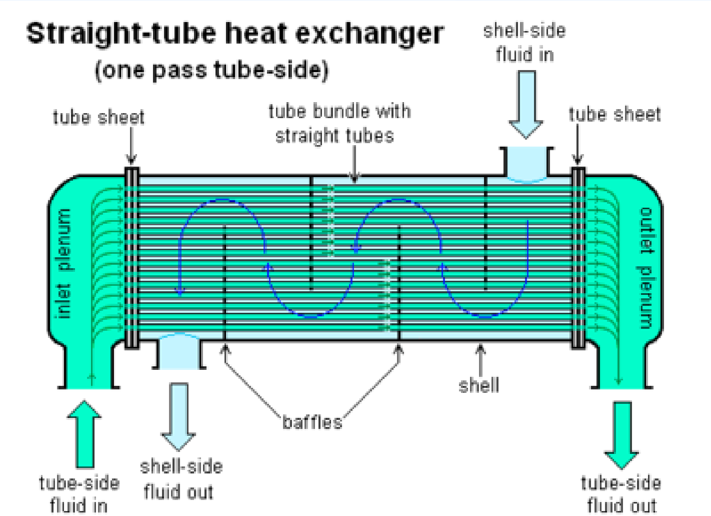
0.5 MW	2 MW
1180 lb pellets/hr	5195 lb pellets/hr
9.68 GJ/hr heat	41.9 GJ/hr heat

- Turbine allows steam to expand
- Expansion work produces power

0.5 MW	2 MW
6,173 lb steam/hr	26,675 lb steam/hr
9680 MJ/hr heat	41.9 GJ/hr heat

General Electric
http://www.equipnet.com

Heat Recovery



http://images.absoluteastronomy.com

- Steam and cooling water flow countercurrent
- Cooling water absorbs heat from steam
- Steam condenses

0.5 MW	2 MW
182 m^3 water/hr	750 m^3 water/hr
Tout @ 52.4^{0}C	Tout @ 72.39^{0}C

Baltimore Aircool Company

http://cset.mnsu.edu

- Excess heat released to atmosphere
- Reservoir for cooling water

0.5 MW	2 MW
2,000 ft^2	5,030 ft^2

Gas Cycle

http://www.mam.gov.tr

http://www.cfaspower.com

Pellets to syngas

$CO_2 + C \rightarrow 2CO - 172.6$ kJ/mol

$C + H_2O \rightarrow CO + H_2 - 131.4$ kJ/mol

$CO_2 + H_2 \rightarrow CO + H_20 + 41.2$ kJ/mol

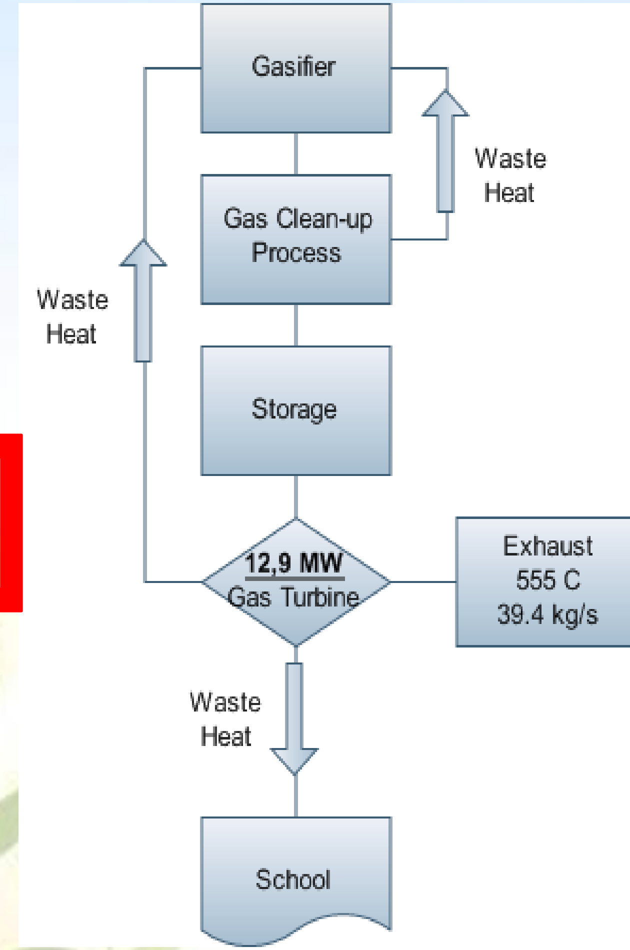
$C + O_2 \rightarrow CO_2 + 406$ kJ/mol

$H_2 + 0.5O_2 \rightarrow H_2O + 242$ kJ/mol

$CO_2 + 3C + H_2 \rightarrow 4CO + H_2O + 730.4$ kJ/mol

- Less stover (26+%)
- Smaller plant size
- Combined cycle

- No technology for scale
- Complicated process
- Higher equipment cost

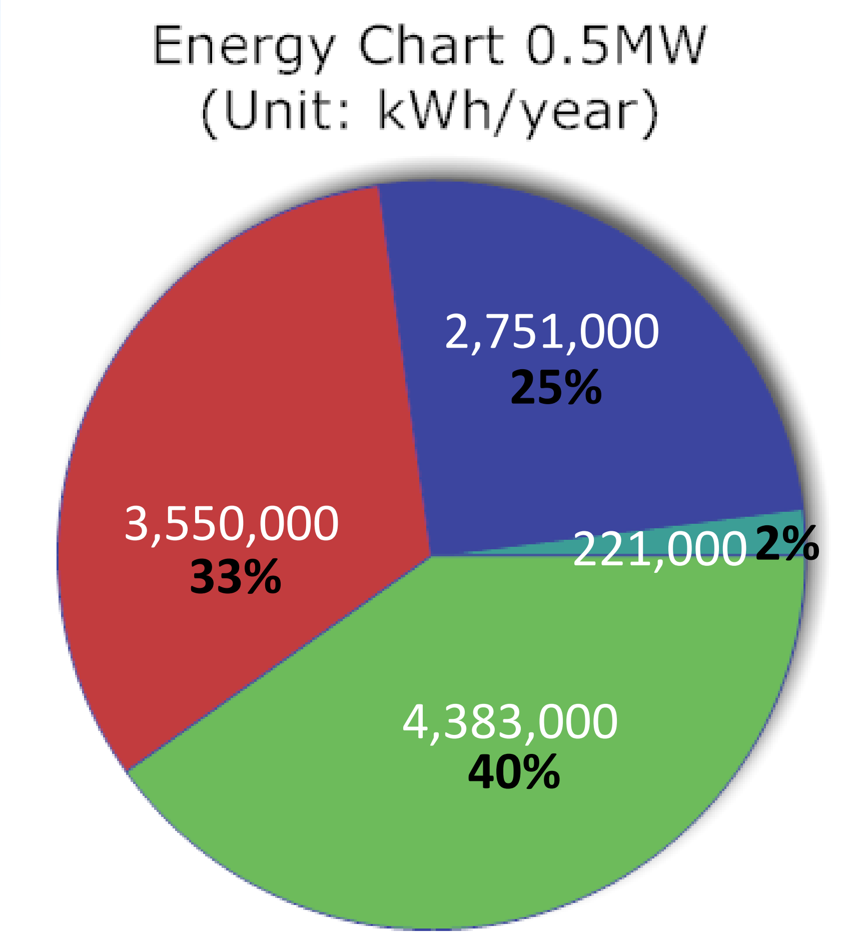


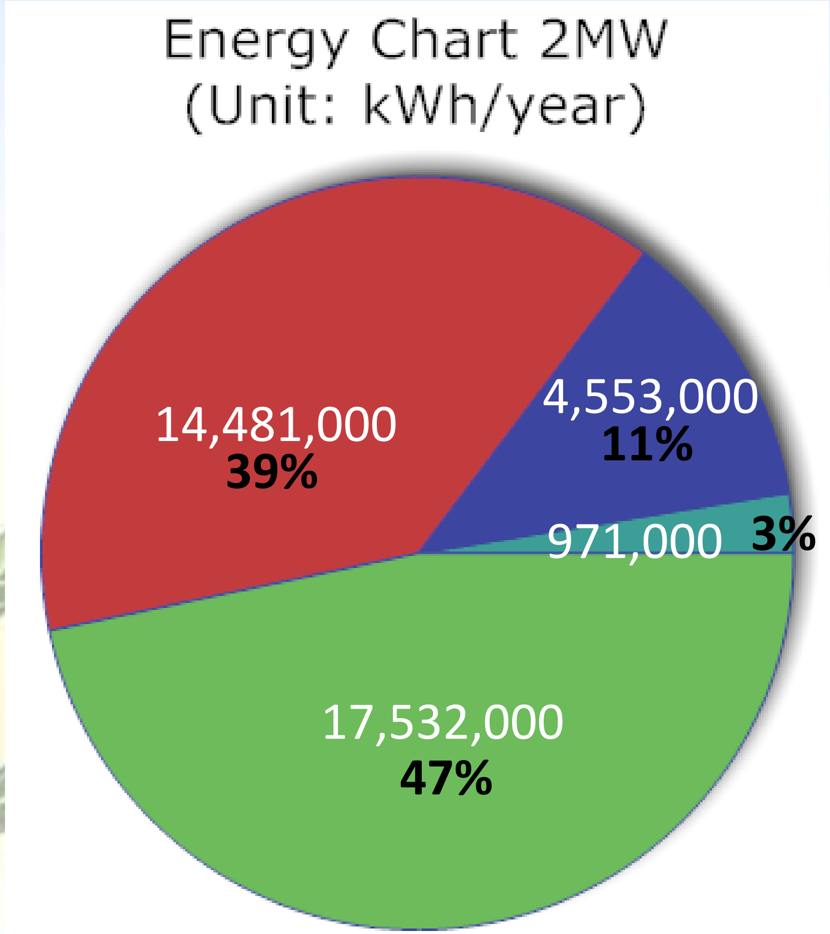
Total Cost

0.5 MW case study		2 MW case study
$6,677	Windrower	$6,677
$28,359	Baler	$28,359
$116,400	Grinder	$116,400
$80,000	Dryer	$102,960
$112,000	Pellet Mill	$240,000
$11,900	Pellet Cooler	$15,900
$13,000	Screener	$13,000
$963,250	Silo	$4,238,300
$500,000	Steam Turbine	$500,000
$250,000	Condenser	$250,000
$17,500	Pump	$17,500
$340,000	Boiler	$340,000

$2,421,586 $5,851,596

Energy Balance





Transportation E Usage
Pelletizing Process E Usage
Conversion Process E Usage
Net Energy Output (Efficiency)

Ethics

7 layers of ethics

EPA guidelines

Must not represent our team falsely

– Be smart

Special attention to environmental concerns

- Soil nutrient removal
- Ash and sulfur content produced from burning stover as biomass fuel
- Carbon emissions

Impact on Nutrient Removal

- With current harvesting technology, only 40% of stover can be collected from fields
- Major nutrients are contained in the ear of corn which is harvested
  - Farmers will buy fertilizers to replace this anyway
- EPA requires that only 30% be left on the field for erosion prevention

Carbon Emission

- Our process is a net zero carbon cycle
  - Corn pulls CO_2 our of air while its growing
- Decomposing corn stover releases CO_2 while laying on the field

Ash, Chlorine, and Sulfur

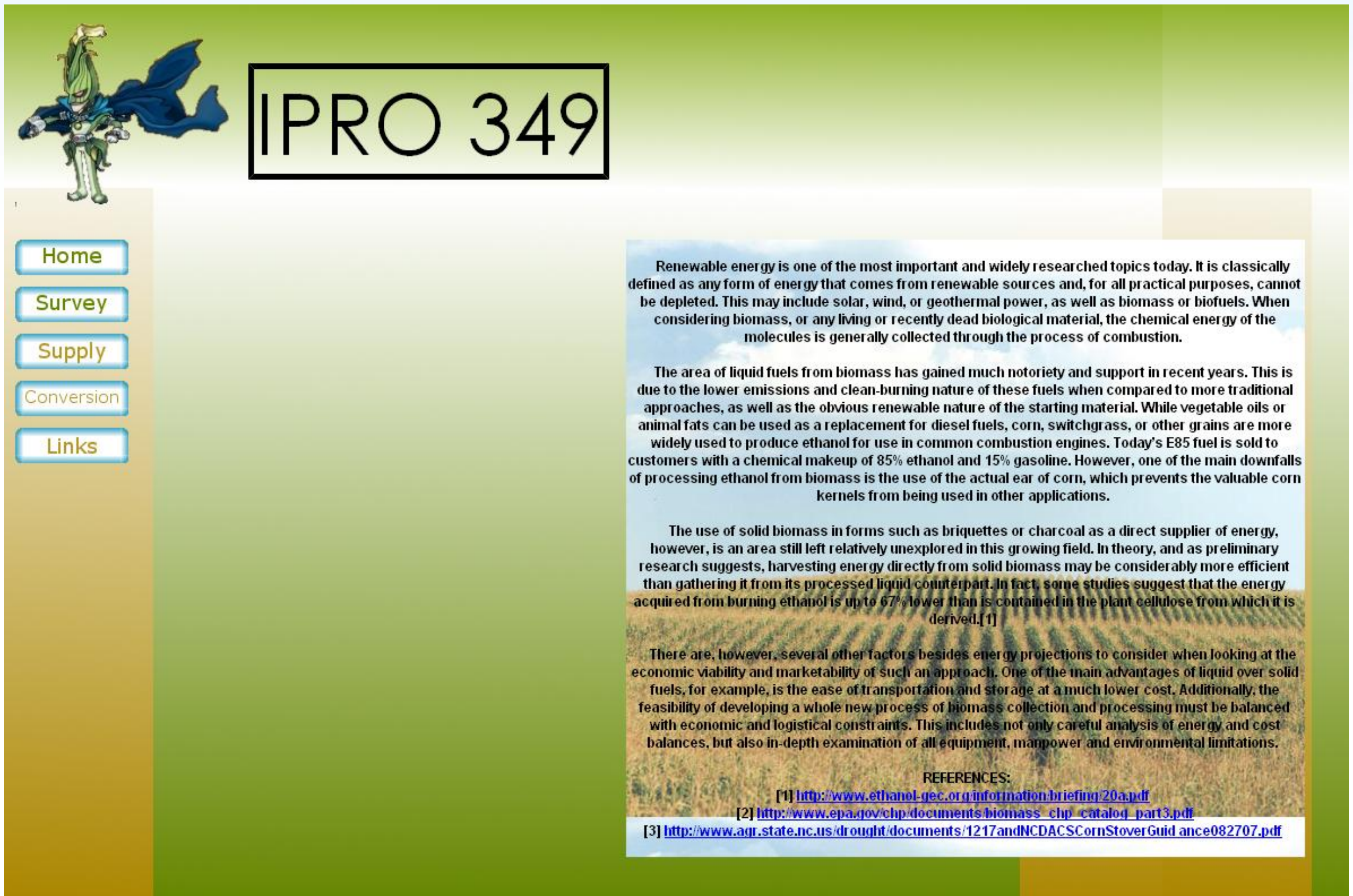
Biomass	Ash content
Corn stover	5.01%
Soybean straw	3.65%
Wheat straw	7.82%
Switchgrass	5.51%
Blue stem grass	6.00%

Feedstock	Chlorine (ppm)
Corn stover	1,030
Soybean straw	1,430
Wheat straw	298
Switchgrass	1,950
Blue stem grass	2,010

* Both charts are based on dry matter basis

Sulfur content from burning corn stover is very low: **0.04g/kg**

Online database



IPRO 349

Home
Survey
Supply
Conversion
Links

Renewable energy is one of the most important and widely researched topics today. It is classically defined as any form of energy that comes from renewable sources and, for all practical purposes, cannot be depleted. This may include solar, wind, or geothermal power, as well as biomass or biofuels. When considering biomass, or any living or recently dead biological material, the chemical energy of the molecules is generally collected through the process of combustion.

The area of liquid fuels from biomass has gained much notoriety and support in recent years. This is due to the lower emissions and clean-burning nature of these fuels when compared to more traditional approaches, as well as the obvious renewable nature of the starting material. While vegetable oils or animal fats can be used as a replacement for diesel fuels, corn, switchgrass, or other grains are more widely used to produce ethanol for use in common combustion engines. Today's E85 fuel is sold to customers with a chemical makeup of 85% ethanol and 15% gasoline. However, one of the main downfalls of processing ethanol from biomass is the use of the actual ear of corn, which prevents the valuable corn kernels from being used in other applications.

The use of solid biomass in forms such as briquettes or charcoal as a direct supplier of energy, however, is an area still left relatively unexplored in this growing field. In theory, and as preliminary research suggests, harvesting energy directly from solid biomass may be considerably more efficient than gathering it from its processed liquid counterpart. In fact, some studies suggest that the energy acquired from burning ethanol is up to 67% lower than is contained in the plant cellulose from which it is derived.[1]

There are, however, several other factors besides energy projections to consider when looking at the economic viability and marketability of such an approach. One of the main advantages of liquid over solid fuels, for example, is the ease of transportation and storage at a much lower cost. Additionally, the feasibility of developing a whole new process of biomass collection and processing must be balanced with economic and logistical constraints. This includes not only careful analysis of energy and cost balances, but also in-depth examination of all equipment, manpower and environmental limitations.

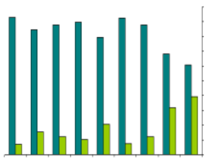
REFERENCES:

[1] http://www.ethanol-gec.org/information/briefing/20a.pdf
[2] http://www.epa.gov/chp/documents/biomass_chp_catalog_part3.pdf
[3] http://www.agr.state.nc.us/drought/documents/1217andNCDACSCornStoverGuid ance082707.pdf

Obstacles

Contacting schools and manufacturers

- Getting and maintaining contact for surveys and information



Making sense of data given & using it effectively

- Converting units
- Reasonable estimates
- Calculating proper input/output to find best equipment

Determining scale

- Varying facility size and student body populations

Recommendations

- Investigate specific case study of community college
  - Look at CHP needs and surrounding area
  - Cost effectiveness and payback analysis
- Investigate feasibility of modular systems
  - Stirling Engine
- International Humanitarian Applications
  - Energy effective farming, biodiversity
  - Adapt processes to geographical limitations
- Develop user friendly equipment database

Conclusion

- CHP is feasible for the researched:
    - heat requirement
    - power requirement
    - stover production and storage
- 75% of farmers would be willing to participate in a CHP project
- 100% of schools which responded would be good candidates for CHP*
- Current gas turbine options not fit for this scale

*according to EPA guidelines

References

1. Matlock, Mark, 2008, Northwestern University Presentation
2. Jannasch, R. “Switchgrass Fuel Pellet Production in Eastern Ontario: A Market Study.” Resource Efficient Agricultural Production (REAP). Canada, Dec. 2001.
3. “The GTI Gassification Process” Sept. 2007
4. Engineering Aspects of harvesting corn stover for bioenergy, Sokansanj
5. BIOS Bioenergy Systems, Austria 2003
6. Tina Kaarsberg and Joseph Roop, “Combined Heat and Power: How Much Carbon and Energy Can It Save for Manufacturers?”

Acknowledgements

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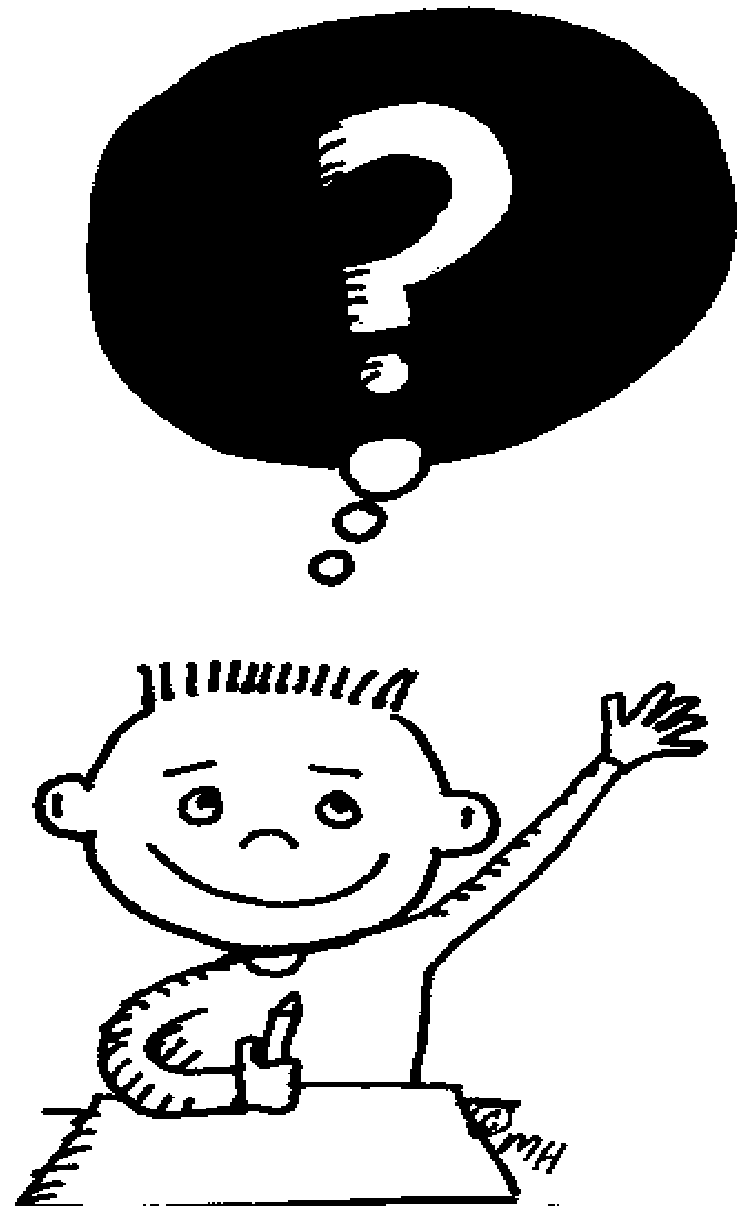
- *Dave Shenk* – Shenk Livestock
- *Christopher Scott* – Pelheat
- *Larry Bubb* – California Pellet Mills
- *Jennifer Keplinger* - IPRO



QUESTIONS