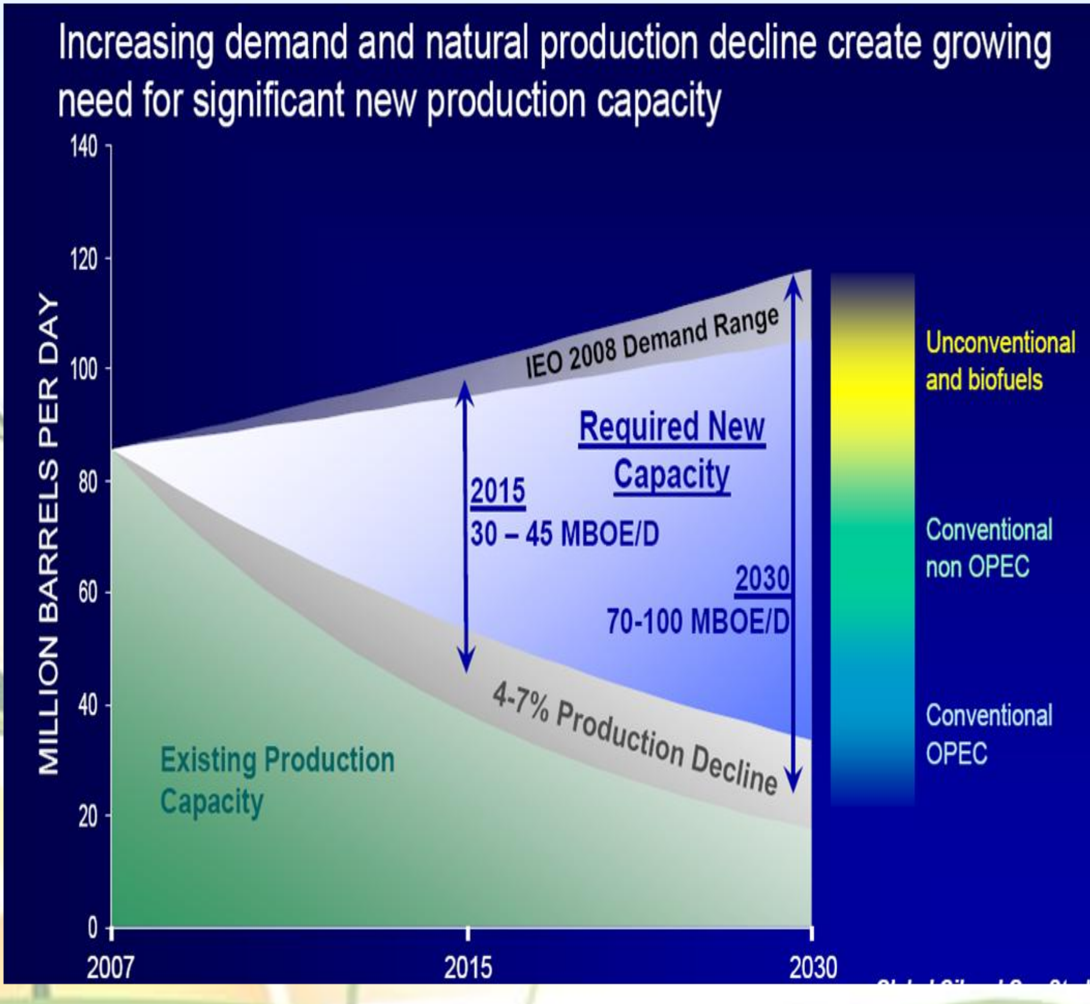
Solid Biomass For Cogeneration
IPRO 349

December 5, 2008

Importance

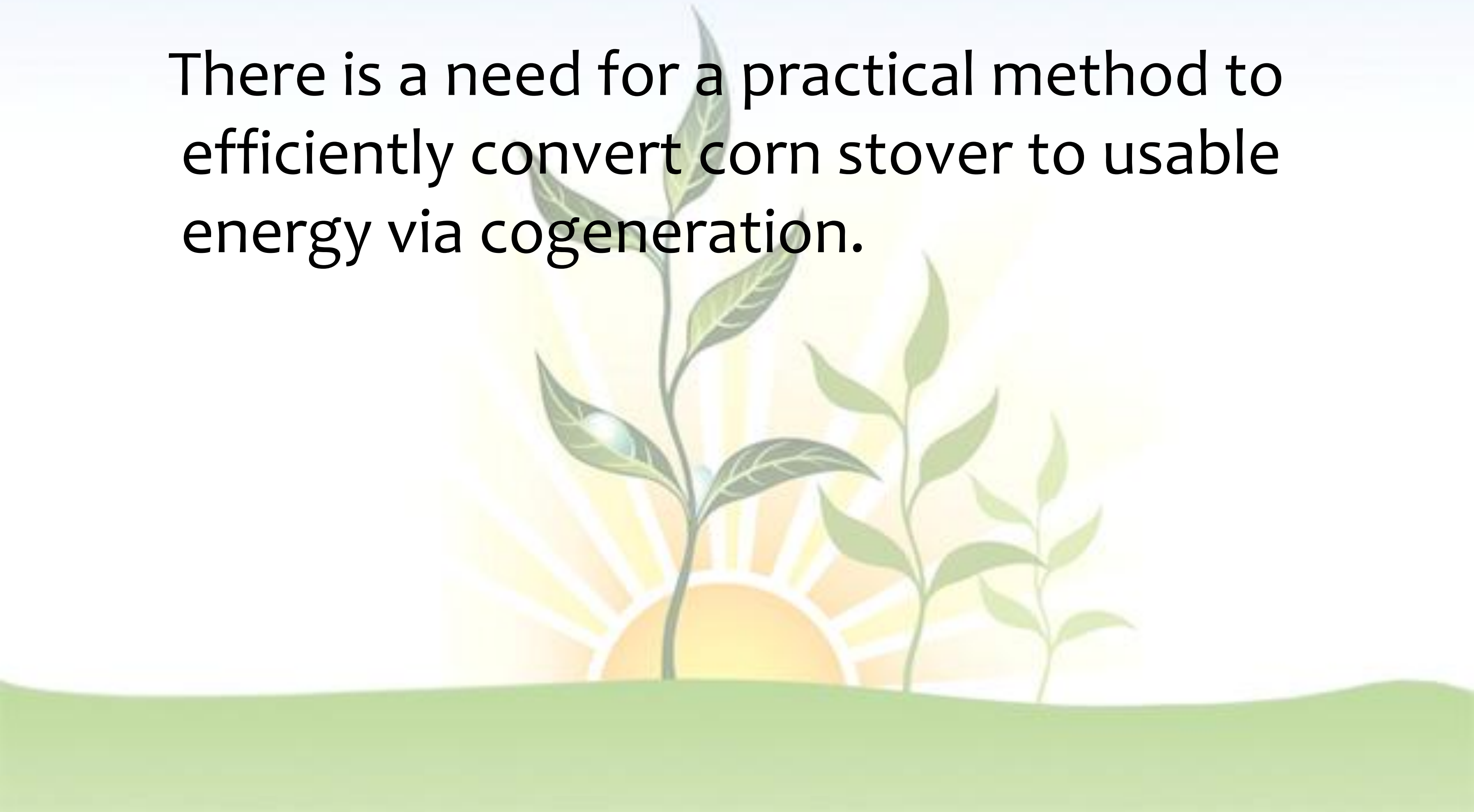
- The U.S. is moving towards sustainability.
- Biomass popular, but unexplored.
- Increase in demand and a decline in production of natural gas. [1]
- Potential energy from stover is greater than natural gas, propane, and heating oil. [2]
- Places value on stover which was once considered waste.



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:** Sankyoung Lee, Ken Ogata
  - **iGroup Maintenance:** Funso Ajigbo

Methods

- Contact Different Companies
  - ADM
  - Monsanto
  - John Deere
  - Vermeer
- Internet
  - Department of Energy
  - Iowa State University
- Research Articles
  - 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.
- 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

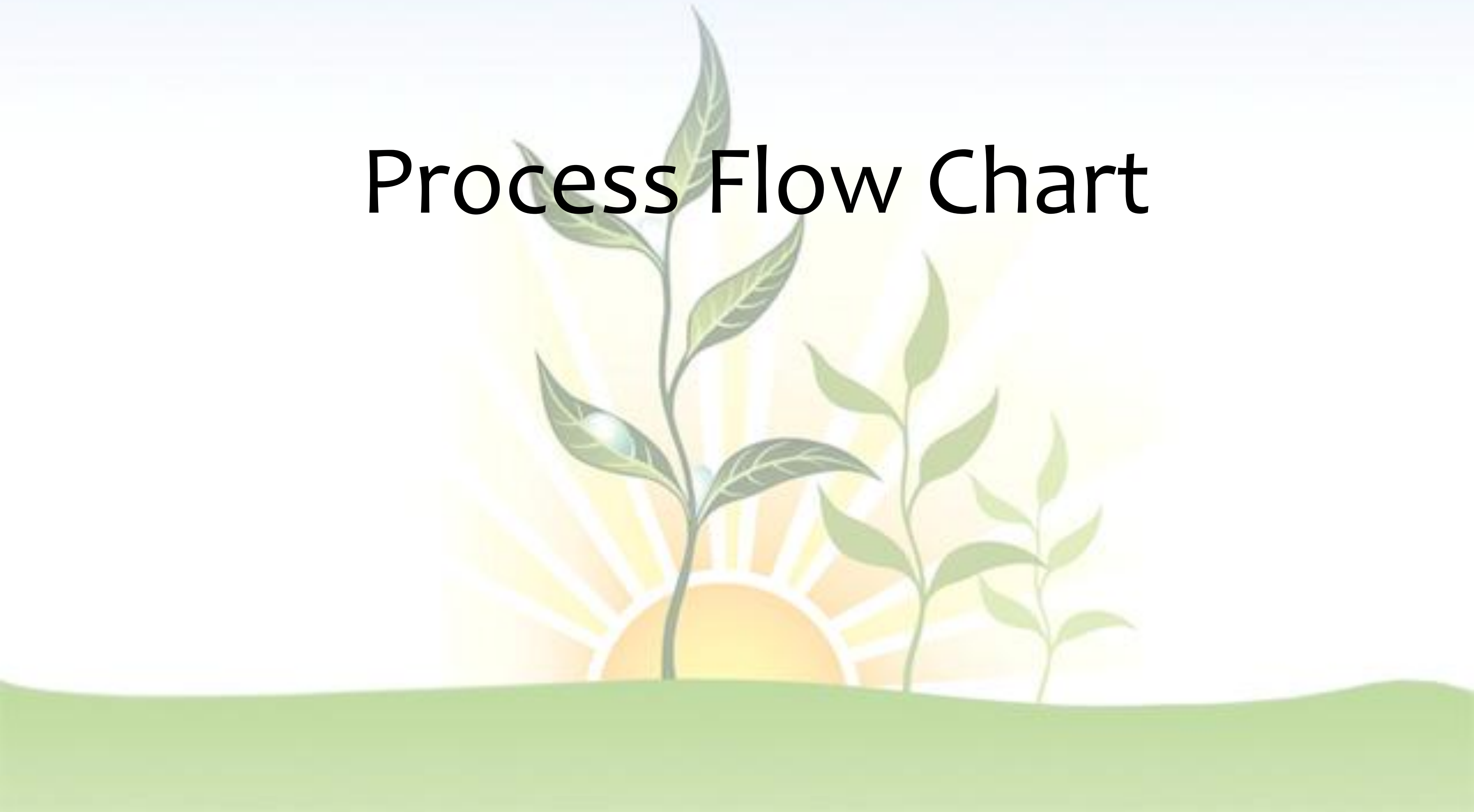
- **Small Scale Benefits**
  - Conventional
  - Transportation
  - Simpler equipment
  - Smaller investment
  - Profitability

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

- **Large Scale Benefits**
  - Create jobs
  - Large localized facility
  - Gasification
    - Higher energy yields [3]
    - Easier to transport/store
    - More efficient operation

- **Disadvantages**
  - Complicated logistics
  - Large investment
  - More complicated processes

Process Flow Chart

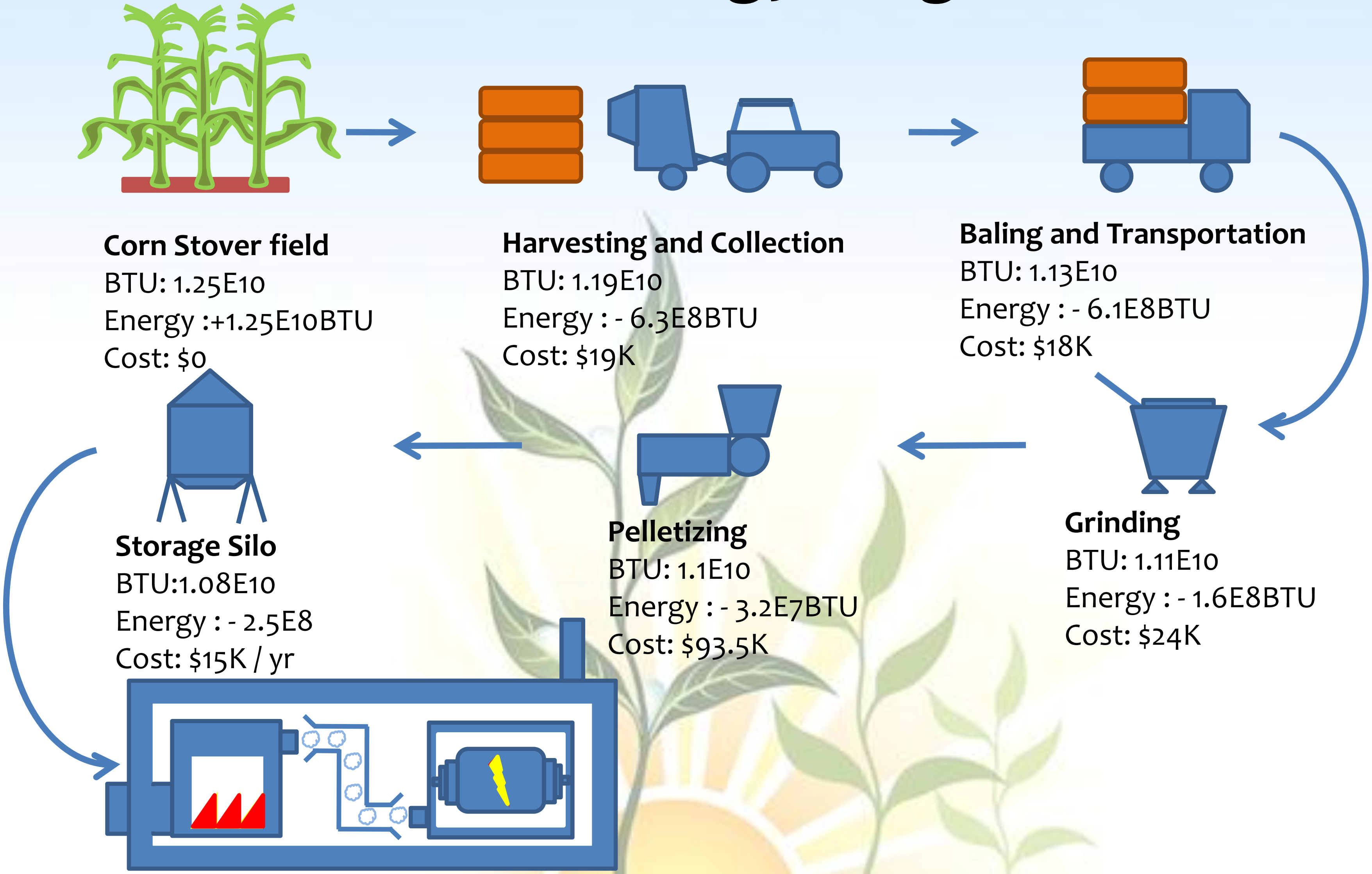


Harvest& Collection

BTU Loss 6.3E8

Cost $19K

Process & Energy Diagram



Corn Stover field
BTU: 1.25E10
Energy :+1.25E10BTU
Cost: $0

Harvesting and Collection
BTU: 1.19E10
Energy : - 6.3E8BTU
Cost: $19K

Baling and Transportation
BTU: 1.13E10
Energy : - 6.1E8BTU
Cost: $18K

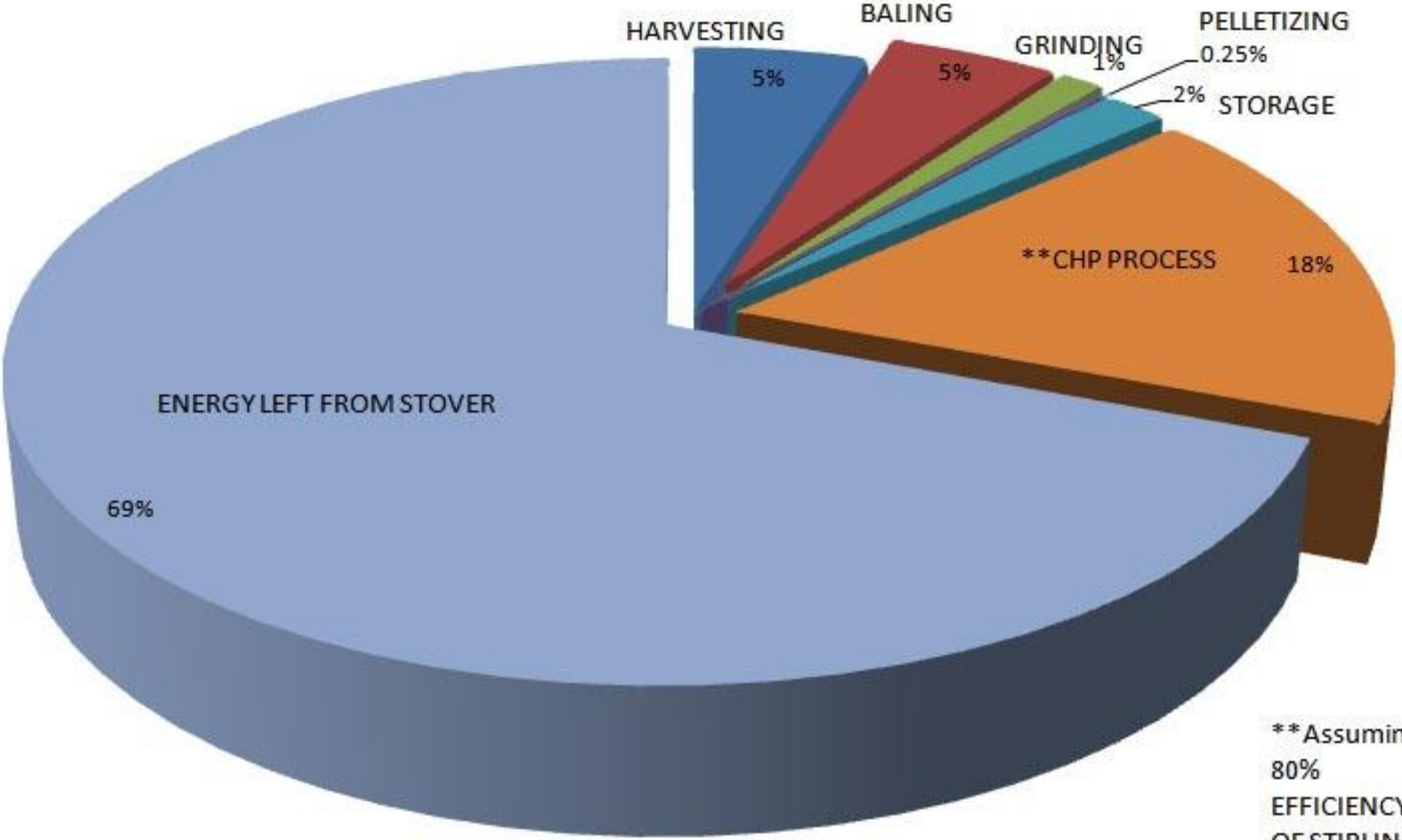
Grinding
BTU: 1.11E10
Energy : - 1.6E8BTU
Cost: $24K

Pelletizing
BTU: 1.1E10
Energy : - 3.2E7BTU
Cost: $93.5K

Storage Silo
BTU:1.08E10
Energy : - 2.5E8
Cost: $15K / yr

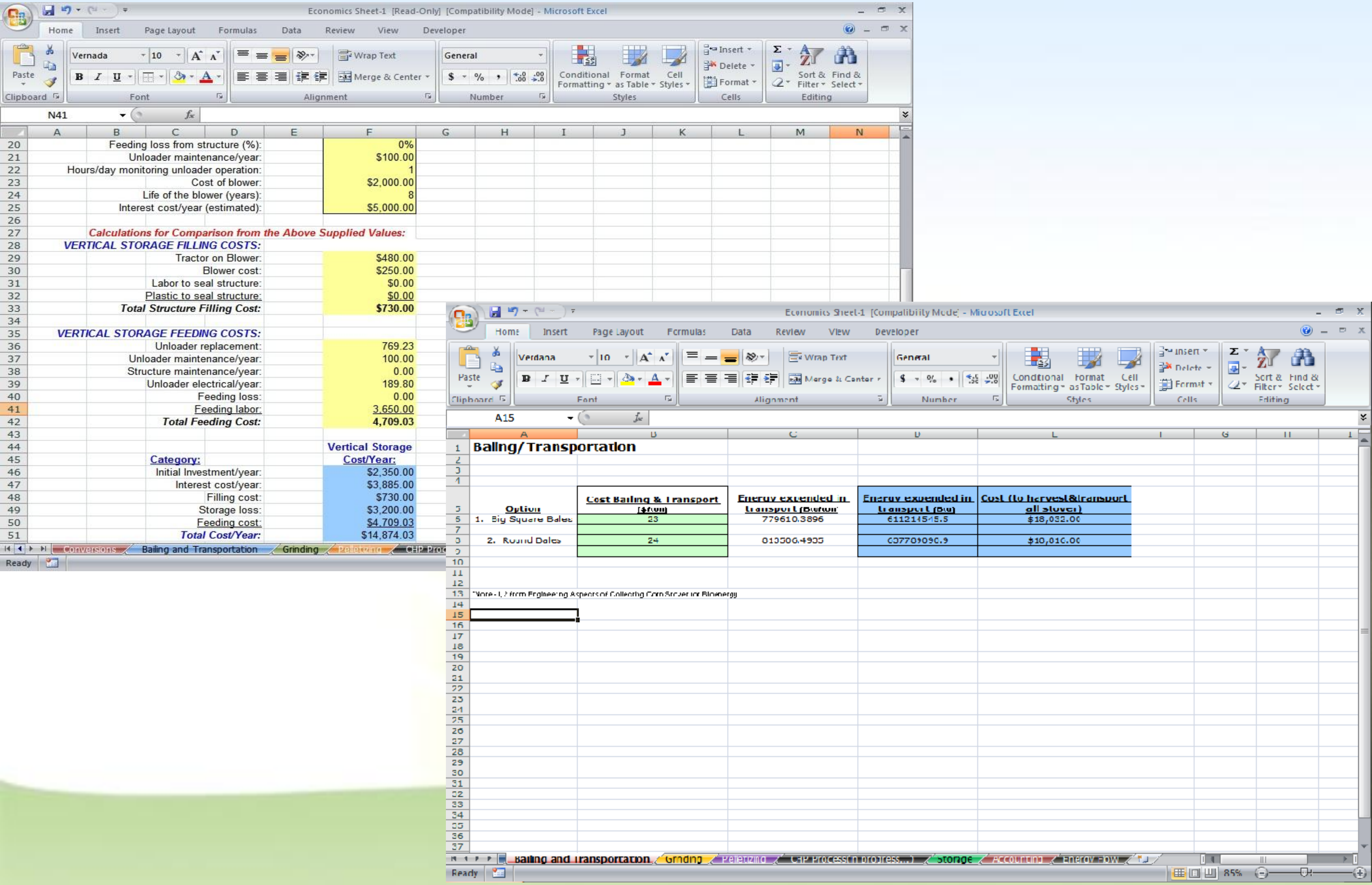
CHP Process
BTU : 8.6E9
Energy: - 2.2E9
Cost : $100k

Energy



**Assuming 80% EFFICIENCY OF STIRLING ENGINE

Excel Screenshot



Economics Sheet-1 [Read-Only] [Compatibility Mode] - Microsoft Excel

Feeding loss from structure (%):	0%
Unloader maintenance/year:	$100.00
Hours/day monitoring unloader operation:	1
Cost of blower:	$2,000.00
Life of the blower (years):	8
Interest cost/year (estimated):	$5,000.00

Calculations for Comparison from the Above Supplied Values:

VERTICAL STORAGE FILLING COSTS:	
Tractor on Blower:	$480.00
Blower cost:	$250.00
Labor to seal structure:	$0.00
Plastic to seal structure:	$0.00
Total Structure Filling Cost:	**$730.00**

VERTICAL STORAGE FEEDING COSTS:	
Unloader replacement:	769.23
Unloader maintenance/year:	100.00
Structure maintenance/year:	0.00
Unloader electrical/year:	189.80
Feeding loss:	0.00
Feeding labor:	3,650.00
Total Feeding Cost:	**4,709.03**

Category:	**Vertical Storage Cost/Year:**
Initial Investment/year:	$2,350.00
Interest cost/year:	$3,885.00
Filling cost:	$730.00
Storage loss:	$3,200.00
Feeding cost:	$4,709.03
Total Cost/Year:	$14,874.03

Economics Sheet-1 [Compatibility Mode] - Microsoft Excel

Baling/Transportation

Option	Cost Baling & Transport ($/ton)	Energy expended in transport (Btu/ton)	Energy expended in transport (Btu)	Cost (to harvest&transport all stover)
1. Big Square Bales	23	779610.3896	611214545.5	$18,032.00
2. Round Bales	24	813506.4935	637789090.9	$18,816.00

*Note - 1,2 from Engineering Aspects of Collecting Corn Stover for Bioenergy

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

http://www.newhollandmediakit.com/images/newsreleases/H9880_ABW_1.jpg

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

Shenk Livestock - 760 Rotogrind

- http://www.shenklivestock.com

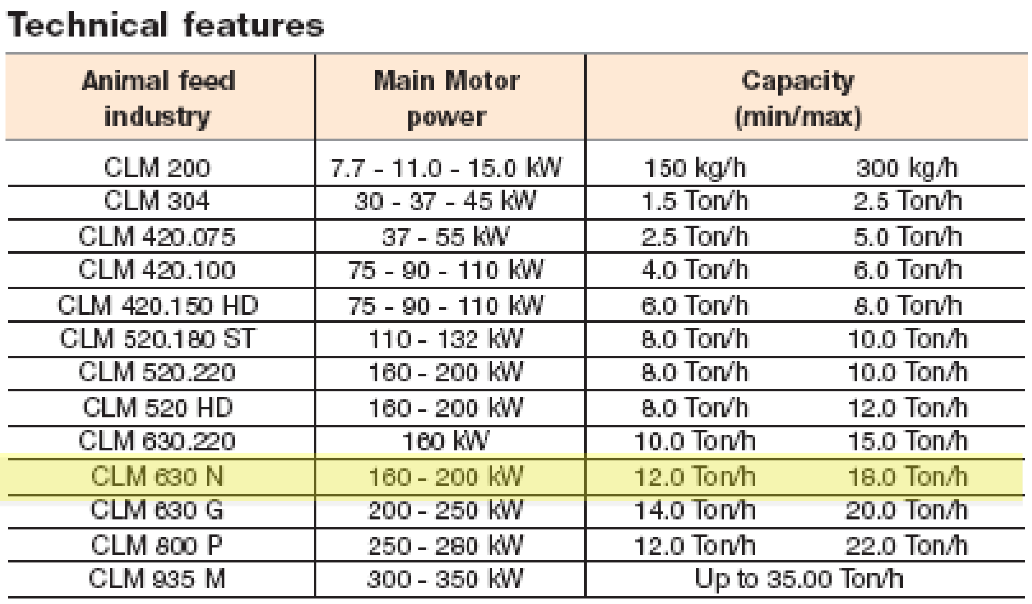
- Price : ~ $19,800
- Minimum HP of Tractor : 65HP
- Average HP : 80HP
- Grinder Weight : 3500lb
- Capacity : 5 - 30 ton/hour

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

La Meccanica - CLM 630N

http://www.lameccanica.it

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



Technical features

Animal feed industry	Main Motor power	Capacity (min/max)	
CLM 200	7.7 - 11.0 - 15.0 kW	150 kg/h	300 kg/h
CLM 304	30 - 37 - 45 kW	1.5 Ton/h	2.5 Ton/h
CLM 420.075	37 - 55 kW	2.5 Ton/h	5.0 Ton/h
CLM 420.100	75 - 90 - 110 kW	4.0 Ton/h	6.0 Ton/h
CLM 420.150 HD	75 - 90 - 110 kW	6.0 Ton/h	8.0 Ton/h
CLM 520.180 ST	110 - 132 kW	8.0 Ton/h	10.0 Ton/h
CLM 520.220	160 - 200 kW	8.0 Ton/h	10.0 Ton/h
CLM 520 HD	160 - 200 kW	8.0 Ton/h	12.0 Ton/h
CLM 630.220	160 kW	10.0 Ton/h	15.0 Ton/h
CLM 630 N	160 - 200 kW	12.0 Ton/h	18.0 Ton/h
CLM 630 G	200 - 250 kW	14.0 Ton/h	20.0 Ton/h
CLM 800 P	250 - 280 kW	12.0 Ton/h	22.0 Ton/h
CLM 935 M	300 - 350 kW	Up to 35.00 Ton/h	

http://www.pelletmills.com

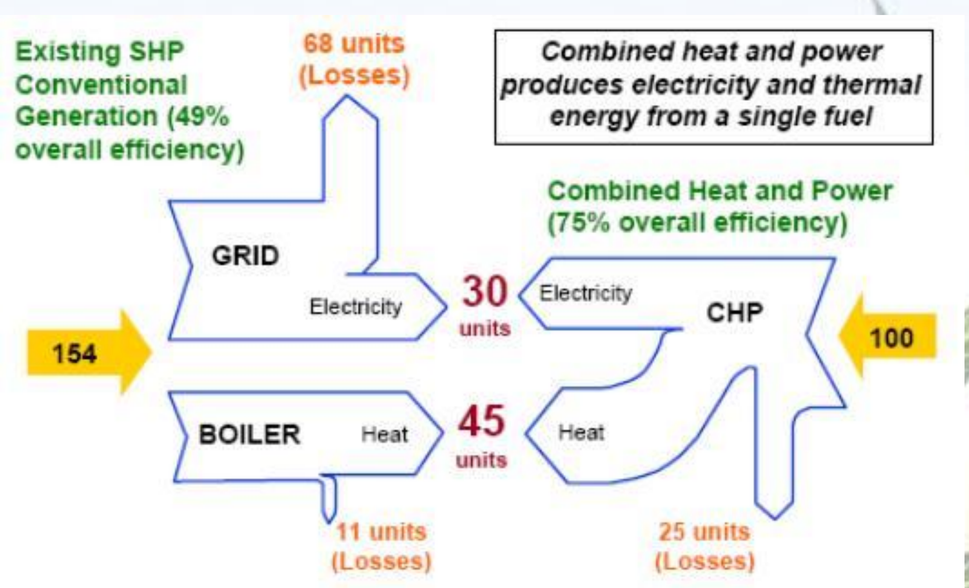
Harvestore Silo

- Steel Silo
- Material : glass-fused-to-steel sheets
- Capacity : 1000 tons ~ 43000 ft^3

http://www.harvestore.com

http://www.harvestore.com

Why use CHP?



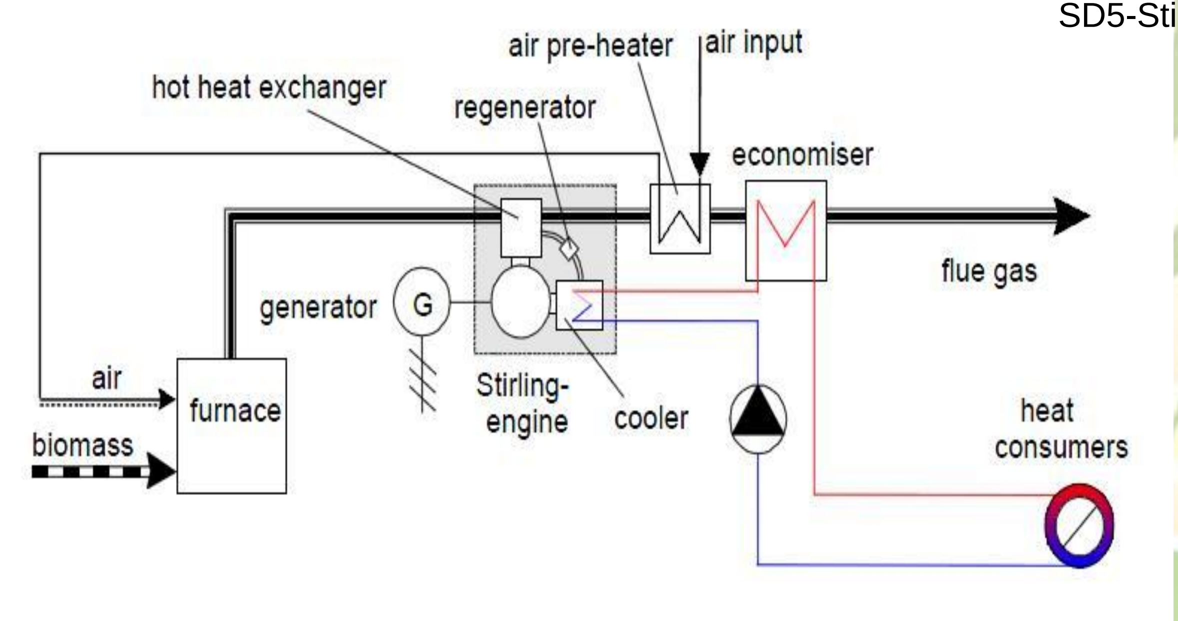
Vartiainen, E et al, 2002; Gaia Group Oy, 2004; Obernberger, I., 2004

- 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

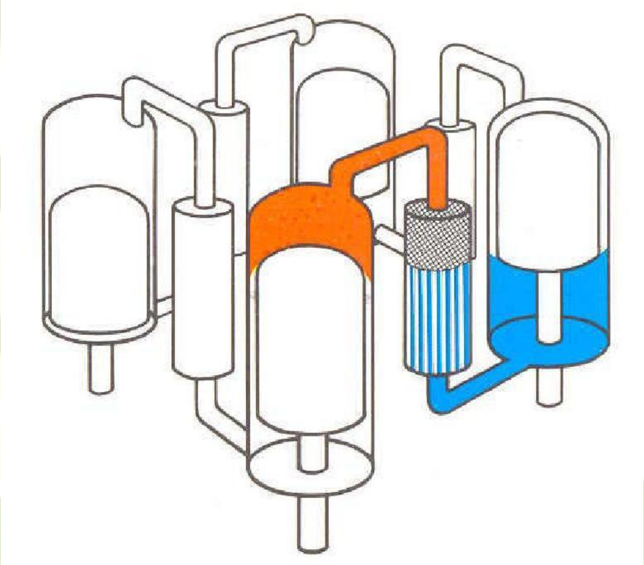
Stirling Denmark - SD 5 Stirling Engine

- 80% energy efficient
  - 10 kWe capacity
  - 40 kWth capacity
- $100,000 for plant construction
- input 24 to 32 pounds/hour[5]

SD5-Stirling Engine from Stirling Denmark



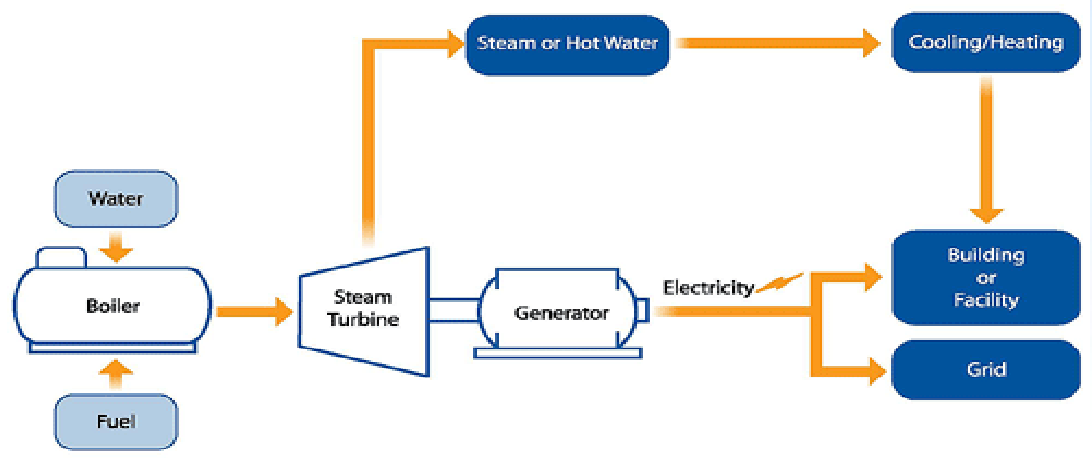
Henrik Carlsen, Technical University of Denmark



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]



Steam or Hot Water

Cooling/Heating

Water

Boiler

Fuel

Steam Turbine

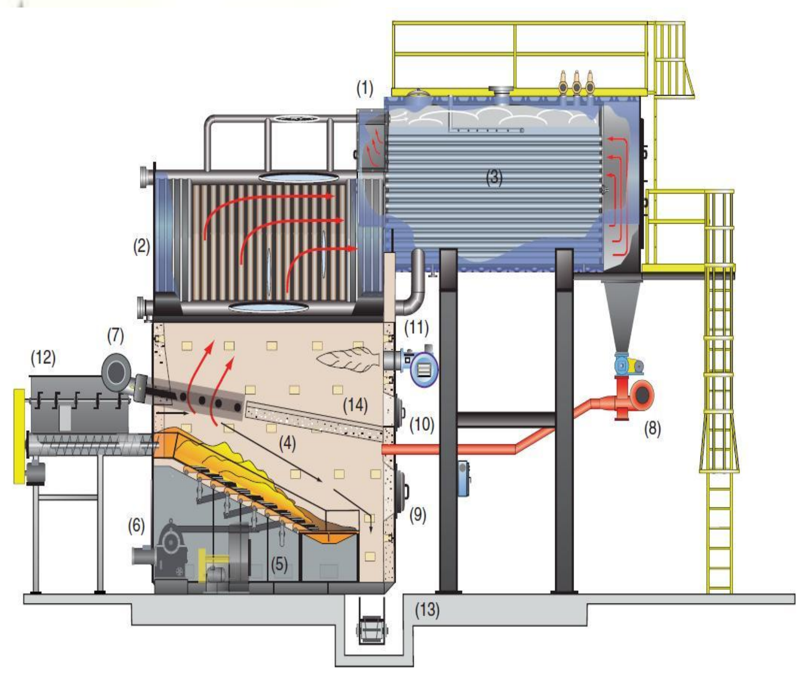
Generator

Electricity

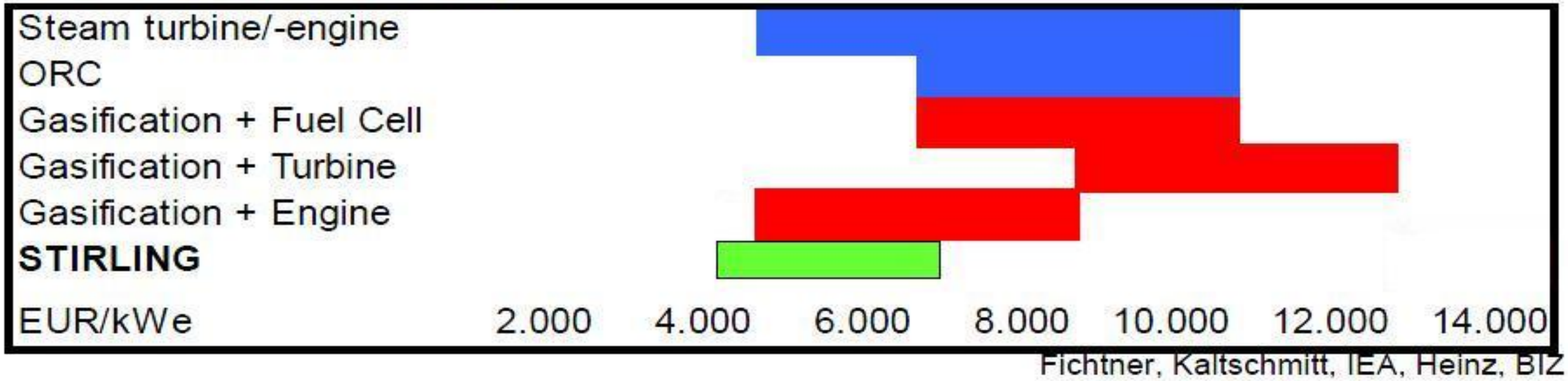
Building or Facility

Grid

50 kW GE Steam Turbine

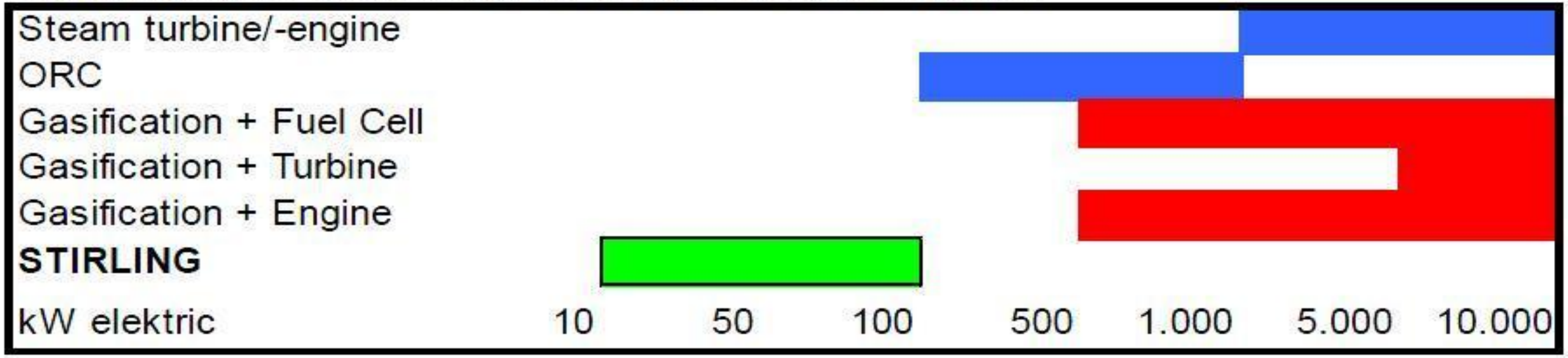


Hurst RG Biomass Fired Boiler

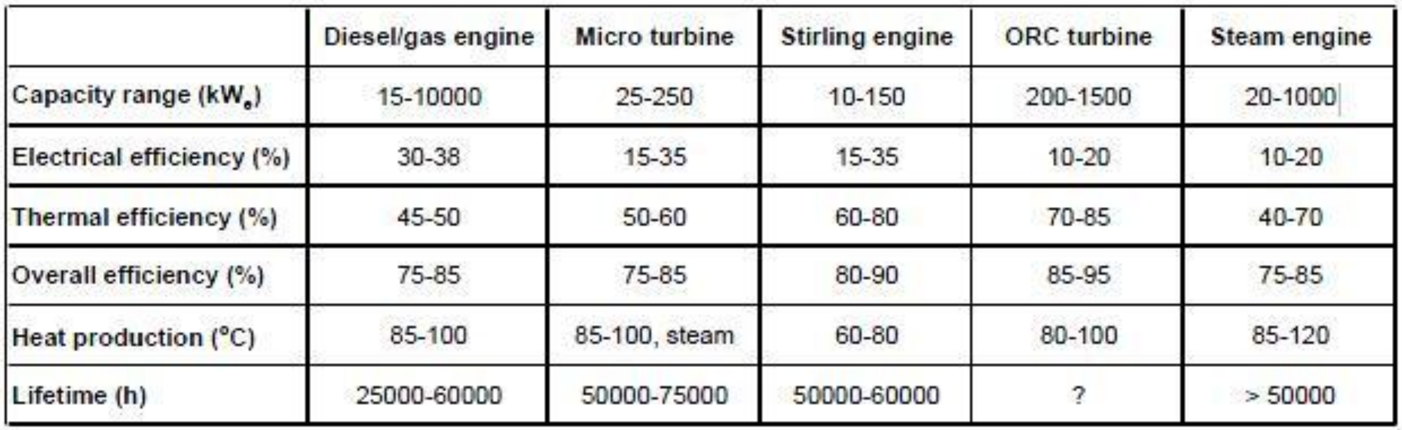


Cost of Biomass CHP-Plants

Fichtner, Kaltschmitt, IEA, Heinz, BIZ



Comparison of Technologies - Power Output Potential



	Diesel/gas engine	Micro turbine	Stirling engine	ORC turbine	Steam engine
Capacity range (kW_e)	15-10000	25-250	10-150	200-1500	20-1000
Electrical efficiency (%)	30-38	15-35	15-35	10-20	10-20
Thermal efficiency (%)	45-50	50-60	60-80	70-85	40-70
Overall efficiency (%)	75-85	75-85	80-90	85-95	75-85
Heat production (°C)	85-100	85-100, steam	60-80	80-100	85-120
Lifetime (h)	25000-60000	50000-75000	50000-60000	?	> 50000

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

Problems

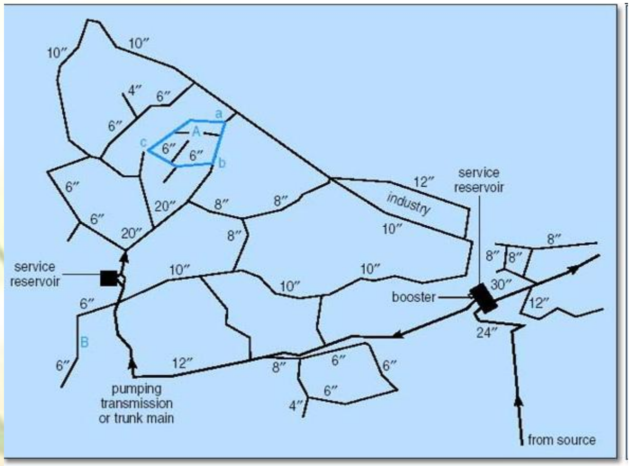
- **Correspondence**
  - Information is still being researched by companies that have been contacted
  - “Smart” relations
- **Size Reduction**
  - Properly scaling model for 400 acre farm
  - Current equipment ideal for large scale operations
- **Standardization**
  - Size consistencies between input 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)*



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

3. *Look into gasification (energy potential is 9:1)*
4. *Expand models: Small to large scale*

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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- *Peter J. Schubert, Ph.D* – 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?