Resources Needed to Establish Cellulosic Ethanol and Advanced Biofuels

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Future Stages for Rural Communities Depend Upon--

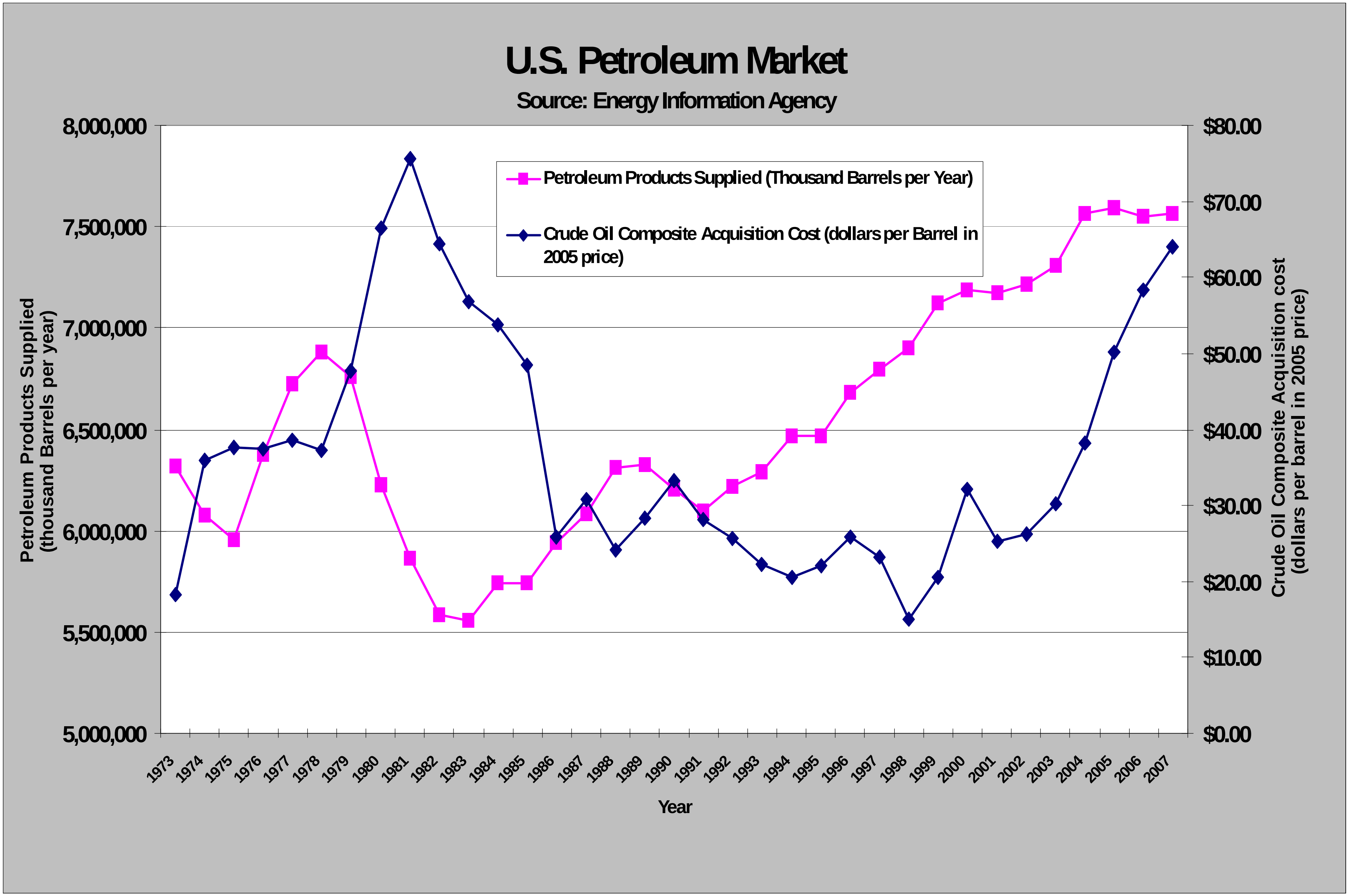
- Interplay of
  - technology developments
    - yeasts, enzymes, catalysts, pre-treatments
  - favorable economics
    - production economics of biofuel
    - relative levels of crude oil
  - facilitating policies
    - Low Carbon Fuel Standard
    - credits for sequestration of carbon
    - cost recognition of CO_2 emissions in power generation

Technology Developments

- Combined Heat and Power Using Biomass at Dry-Grind Plants---(can implement today)
- Cellulosic Ethanol---(Biochemical)—Aden et al.
- Cellulosic Ethanol---(Thermochem)-Phillips et al
- Important Technology Side Shows
  - Improved Harvest & Densification of Biomass
  - Korean High Oil Corn---may favor biodiesel
  - Pyrolysis Oils---any biomass, lower value markets
  - Torrefaction---any biomass, compatible with coal
  - Dimethyl Ether from gasified biomass, black liquor

Economic Factors

- Recognition of higher costs of coal-based electricity with sequestration
- Higher market prices should be expected for natural gas
- Will high crude oil prices persist?


U.S. Petroleum Market
Source: Energy Information Agency
Petroleum Products Supplied (Thousand Barrels per Year)
Crude Oil Composite Acquisition Cost (dollars per Barrel in 2005 price)
Petroleum Products Supplied (thousand Barrels per year)
Crude Oil Composite Acquisition cost (dollars per barrel in 2005 price)
8,000,000
7,500,000
7,000,000
6,500,000
6,000,000
5,500,000
5,000,000
$80.00
$70.00
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$0.00
Year
1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007

Facilitating Policies in Play

- Continuation of Energy Policy Act of 2007
  - -Emphasis on GHG reduction goals
- Preservation of Existing Ethanol Industry
  - -Rewards for Low Carbon Fuel Standards
  - -Reductions of CO_2 fr Power Generation

Requirements of a Biofuels Industry….

- Knowledge and Technology to Convert Feedstocks to Fuel
- Feedstock to Convert
- Business Model for Investors
- Business Plan that Bankers Can Finance
- Governmental Sponsorship—Risk Reduction
- ________________________________
- Government policies support the development and use of biofuels and will shape the technologies that will persist.

Key Features of 2007 Energy Bill

- Revised Renewable Fuels Standard Higher
- Capped the amount of ethanol from corn starch at 15 Billion Gallons
- Identified Carve-outs for Biodiesel, Advanced Biofuels and Cellulosic Ethanol
- Effectively Banned Additional Coal-fired plants
- Defined standards for biofuels in terms of GHG emissions reductions
  - greater than 20%----Conventional and Existing Plants
  - greater than 50%----Advanced Biofuels
  - greater than 60%----Cellulosic biofuels

Integrating Biomass to Produce Heat and Power at Ethanol Plants

Project Partners

Xcel Energy

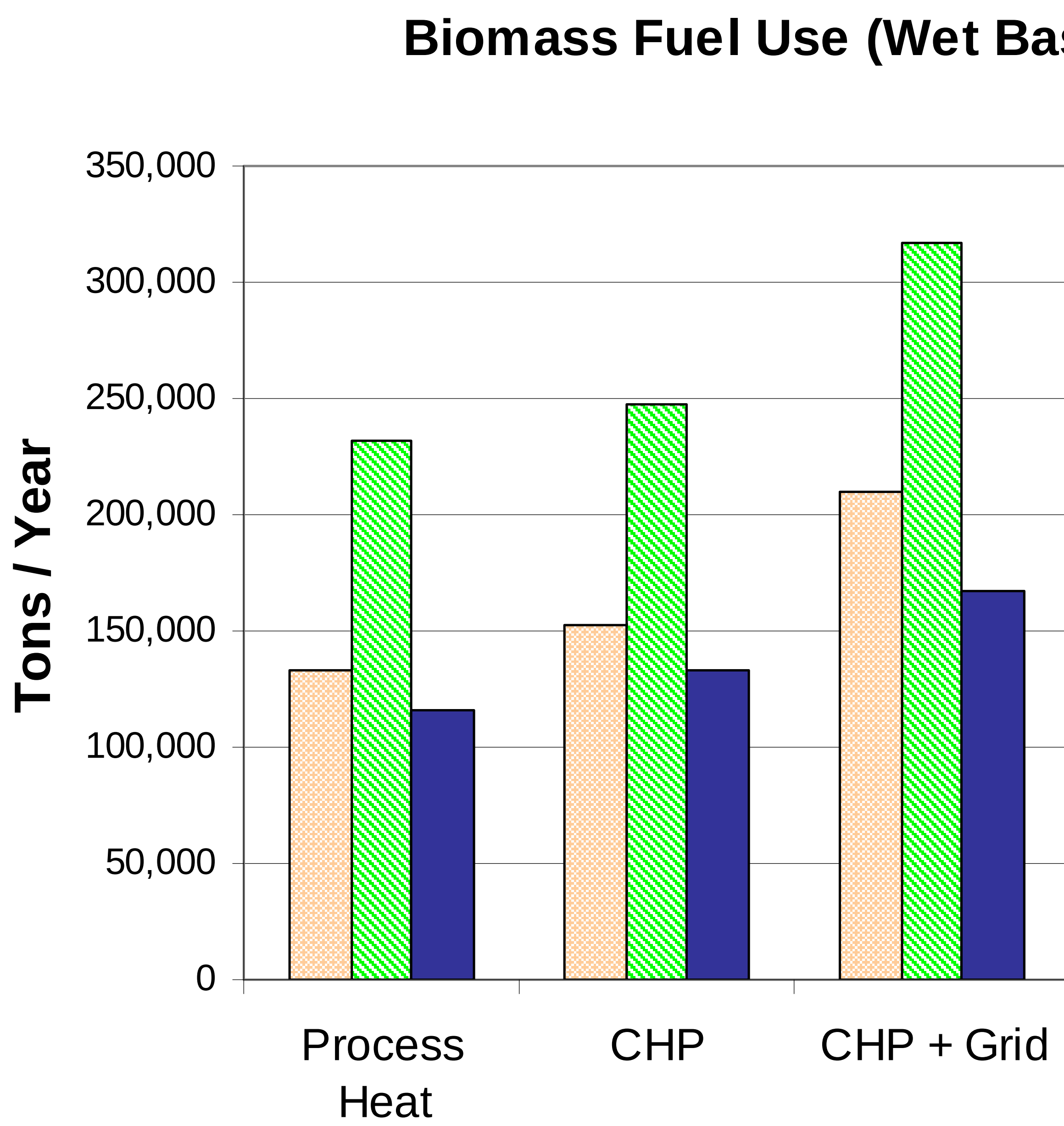
RMT

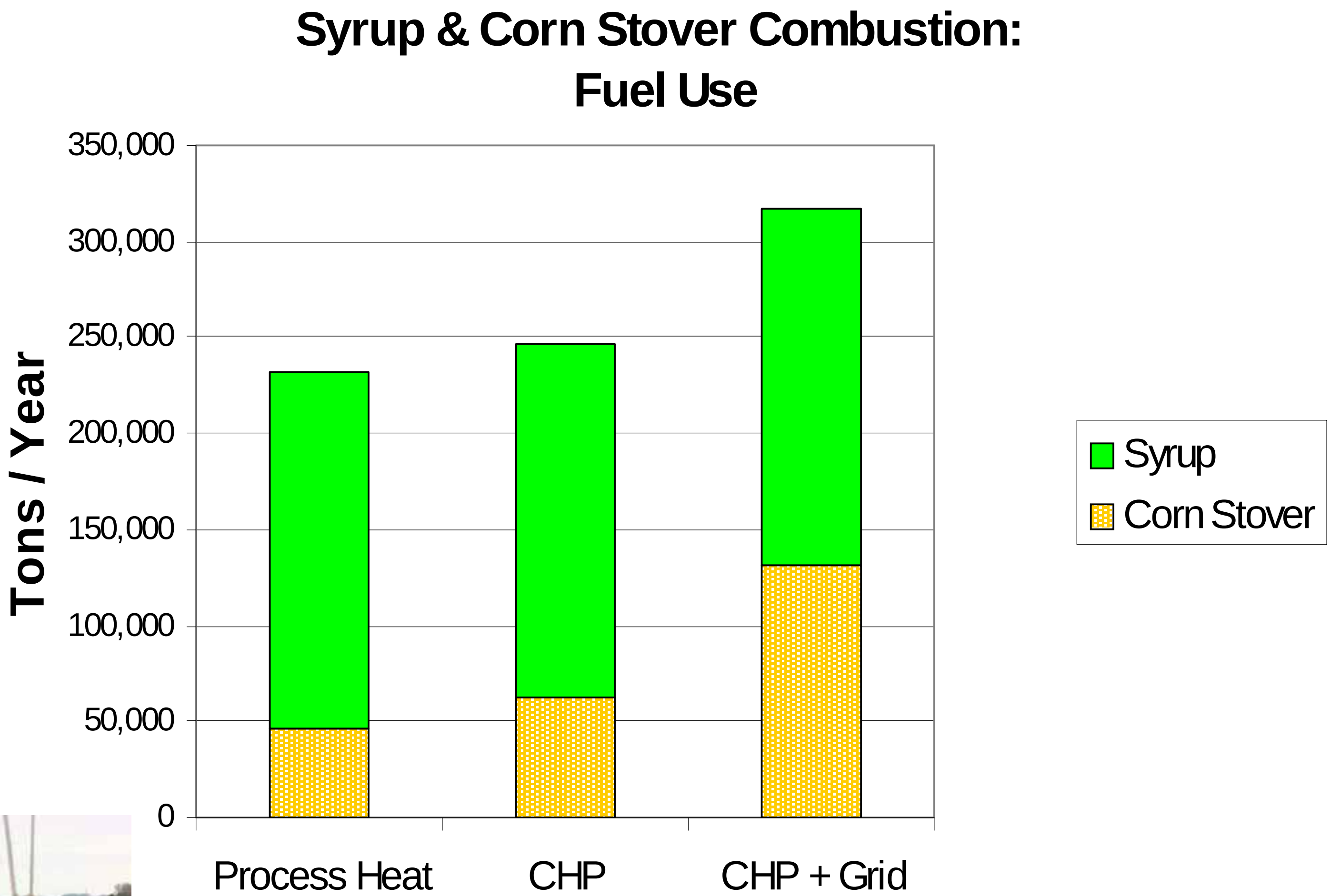
amec

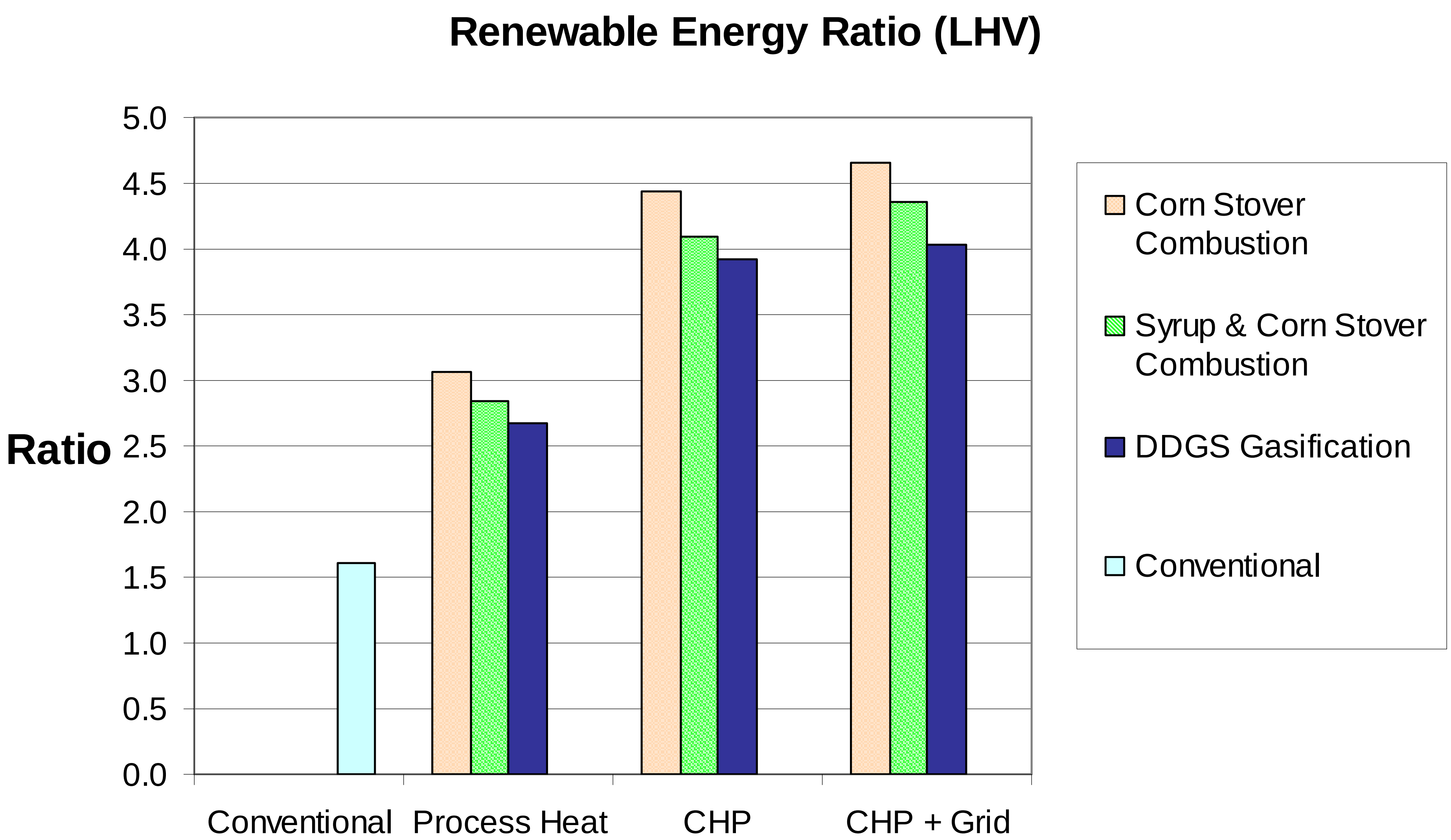
ota

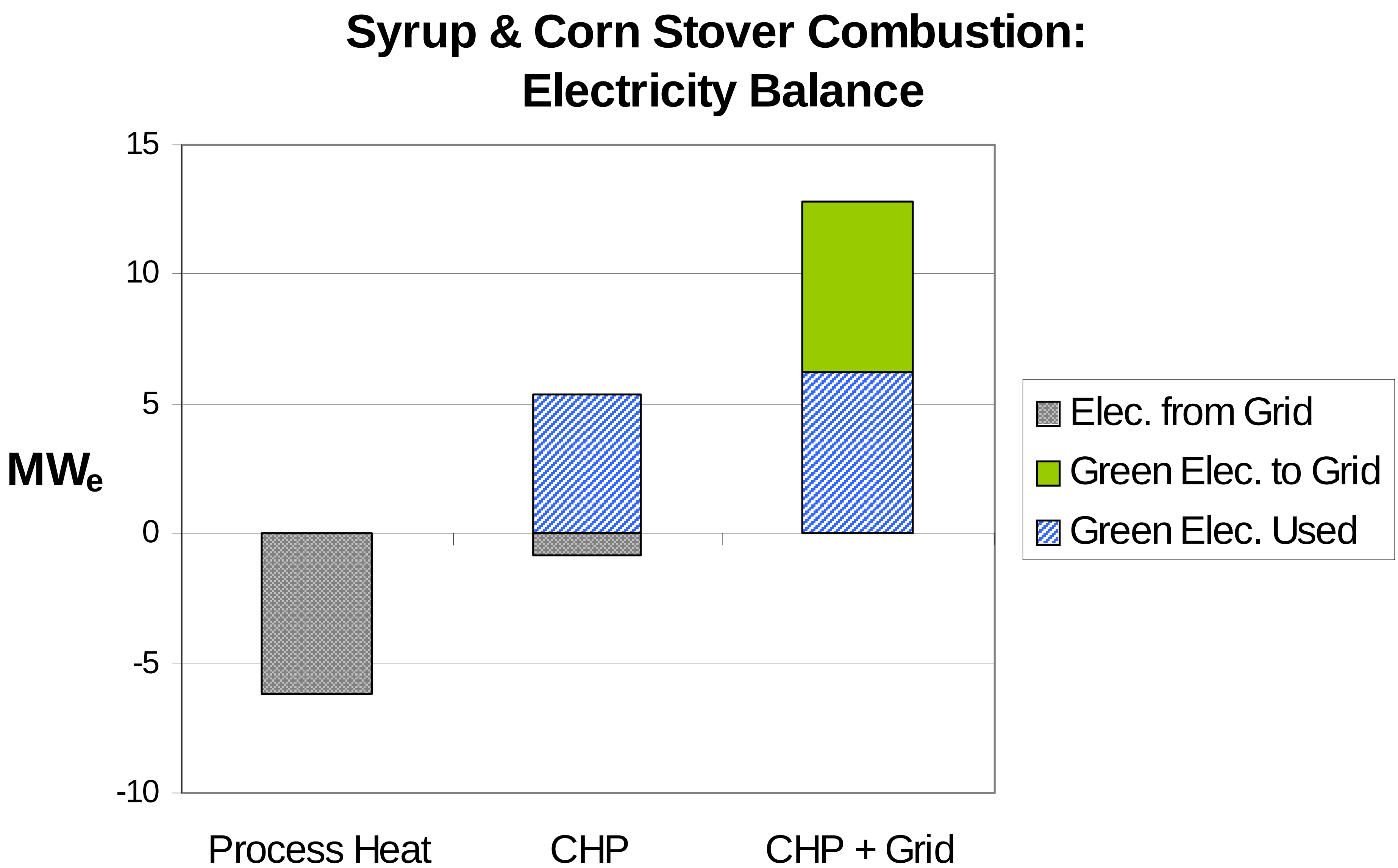
Issues of Biomass in Combustion

- NOx , SOx
- Ash Fusion Temperatures --- due to content of alkali metals--- K, Cl
- Moisture levels are important
- Temperature ranges are the key
- Ash characteristics—can be corrosive


Biomass Fuel Use (Wet Basis)
Tons / Year
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Process Heat
CHP
CHP + Grid
Combust Corn Stover
Combust Syrup & Corn Stover
Gasify DDGS


Syrup & Corn Stover Combustion:
Fuel Use
Tons / Year
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Process Heat
CHP
CHP + Grid
Syrup
Corn Stover


Renewable Energy Ratio (LHV)
Ratio
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Conventional
Process Heat
CHP
CHP + Grid
Corn Stover Combustion
Syrup & Corn Stover Combustion
DDGS Gasification
Conventional


Syrup & Corn Stover Combustion:
Electricity Balance
15
10
5
0
-5
-10
MWe
Process Heat
CHP
CHP + Grid
Elec. from Grid
Green Elec. to Grid
Green Elec. Used

It’s great to have a higher net energy balance, but can anyone make profits by these methods?

- Plants using biomass would cost more to build, but we know how to build them.
- Capital Costs be higher than a conventional dry-grind plant
  - Process Heat------- + 21 - 31%
  - CHP ------ + 34 - 45%
  - CHP with Sales to the Grid------ + 50 – 60%

Revenue Gains / Cost Savings

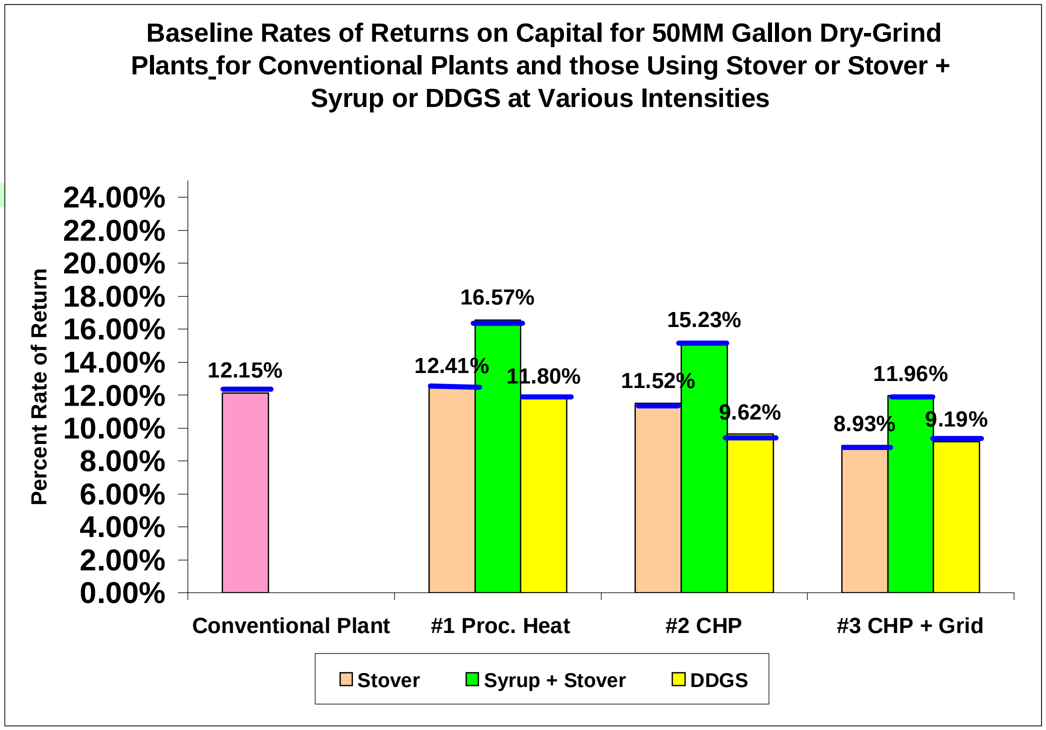
- Reduced Natural Gas Purchases
- Reduced Electricity Purchases
- Premium for “Low Carbon” Ethanol Produced ($.20- $.40) per gallon
- Sales of Nutrients in Ash of 0-18-28 ($200/T.)
- Sale of Renewable Electricity to the Grid ($.06/KWH)
- Credit for Renewable Electricity of ($.02 /KWH)
- Potential for More Valuable DDG product without solubles (10% premium assumed)

Additional Operating Costs with Biomass

- Biomass Costs of $80 per delivered ton include:
  - Procurement Activities for Corn Stover
  - Drying of Corn Stover / DDGS before Storage or Use
  - Densification of Stover for Transportation & Handling
  - Storage of Biomass
- Additional Labor and Maintenance at Plant
- Use of Limestone for Sulfur Capture @ $25/T.
- Use of Ammonia to reduce NOx @ $500/T.

Baseline ROR's Using Installed Capital Costs for 50 MM Gallon Plant

Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid	50MM Gal
12.15%	12.41%	11.52%	8.93%	Stover
	16.57%	15.23%	11.96%	Syrup + Stover
	11.80%	9.62%	9.19%	DDGS



Years to Payback Additional Investment

Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid	50MM Gal
Not Applicable	7.5	9.9	27.6	Stover
	2.7	4.1	8.6	Syrup + Stover
	9.5	31.9	28.0	DDGS

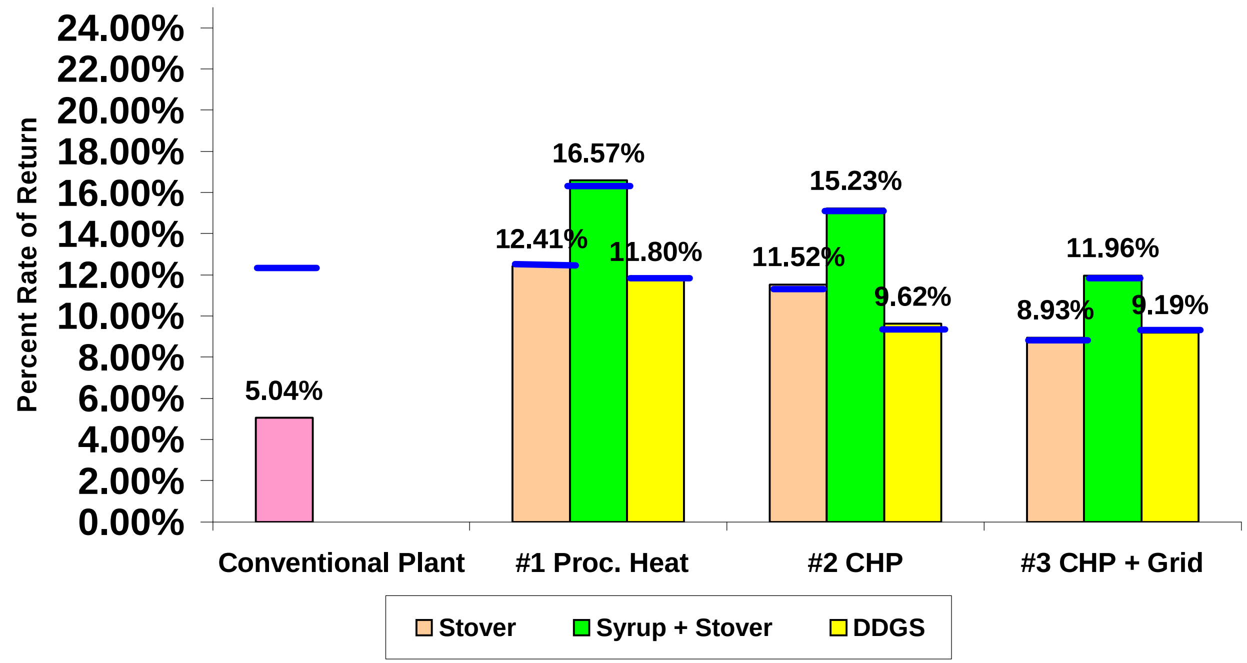
Testing Sensitivity of Technology Bundles

- **--**DDGS price
- --Corn Stover price
- --Natural gas price
- --Ethanol Price
- -- Premiums for Low-Carbon Imprint
- --Electricity Selling Price
- --Corn Price

Natural Gas Rises from $8.00 to $12.00 per DkTh

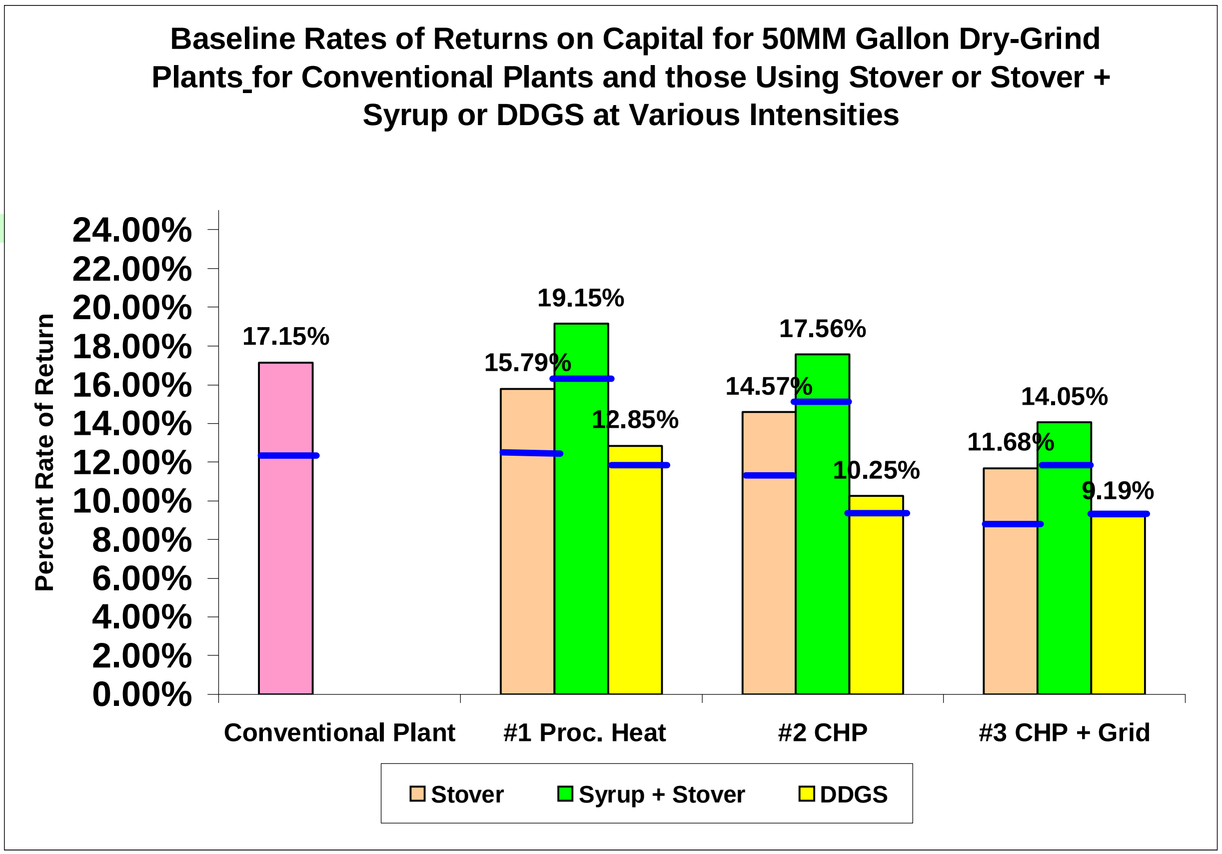
[redacted]	Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid		50MM Gal
	5.04%	12.41%	11.52%	8.93%	Stover	
	[redacted]	16.57%	15.23%	11.96%	Syrup + Stover	
		11.80%	9.62%	9.19%	DDGS	

Baseline Rates of Returns on Capital for 50MM Gallon Dry-Grind Plants for Conventional Plants and those Using Stover or Stover + Syrup or DDGS at Various Intensities



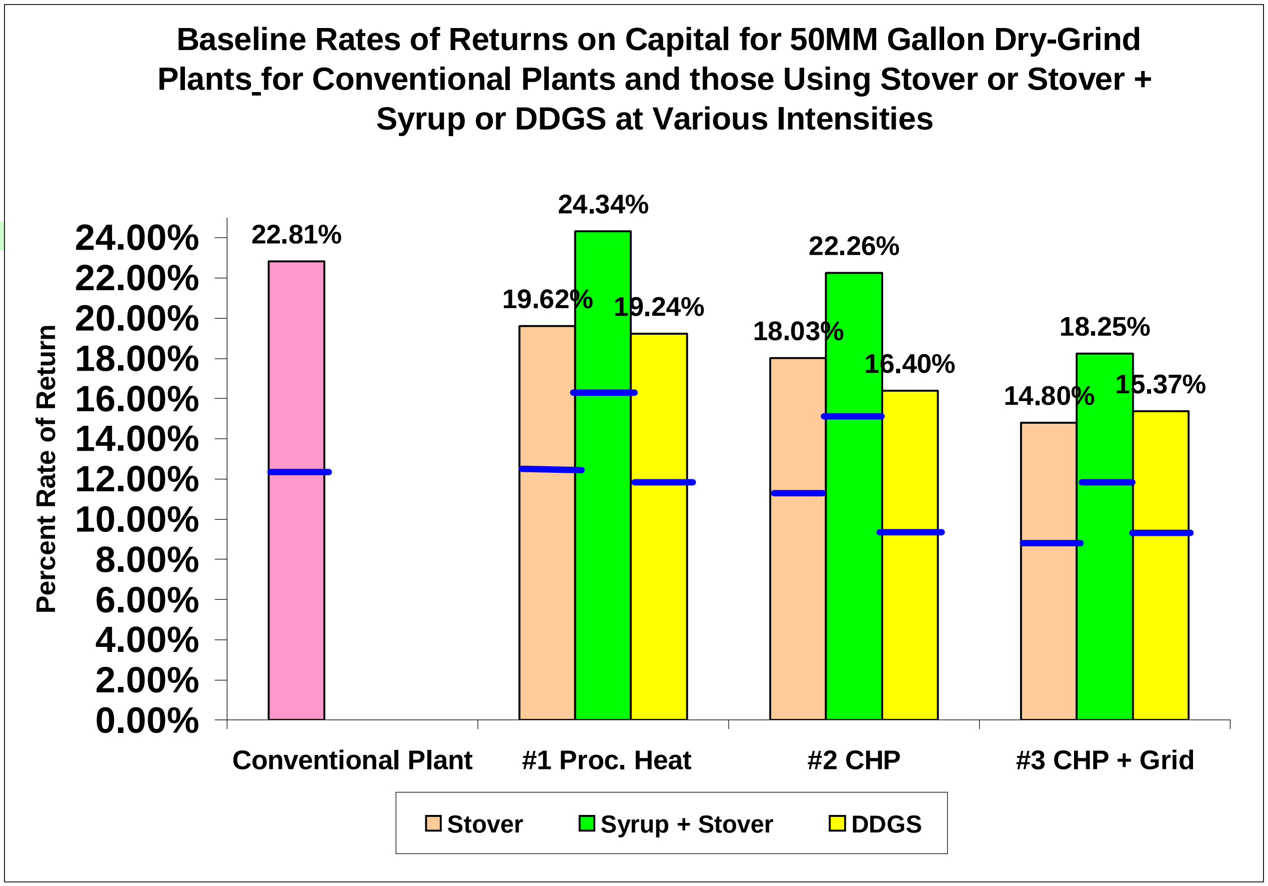
DDGS Price Rises from $100 to $130 per ton

Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid		50MM Gal
17.15%	15.79%	14.57%	11.68%	Stover	
	19.15%	17.56%	14.05%	Syrup + Stover	
	12.85%	10.25%	9.19%	DDGS	



Ethanol Price Rises from $1.80 to $2.00/ gal. at Plant

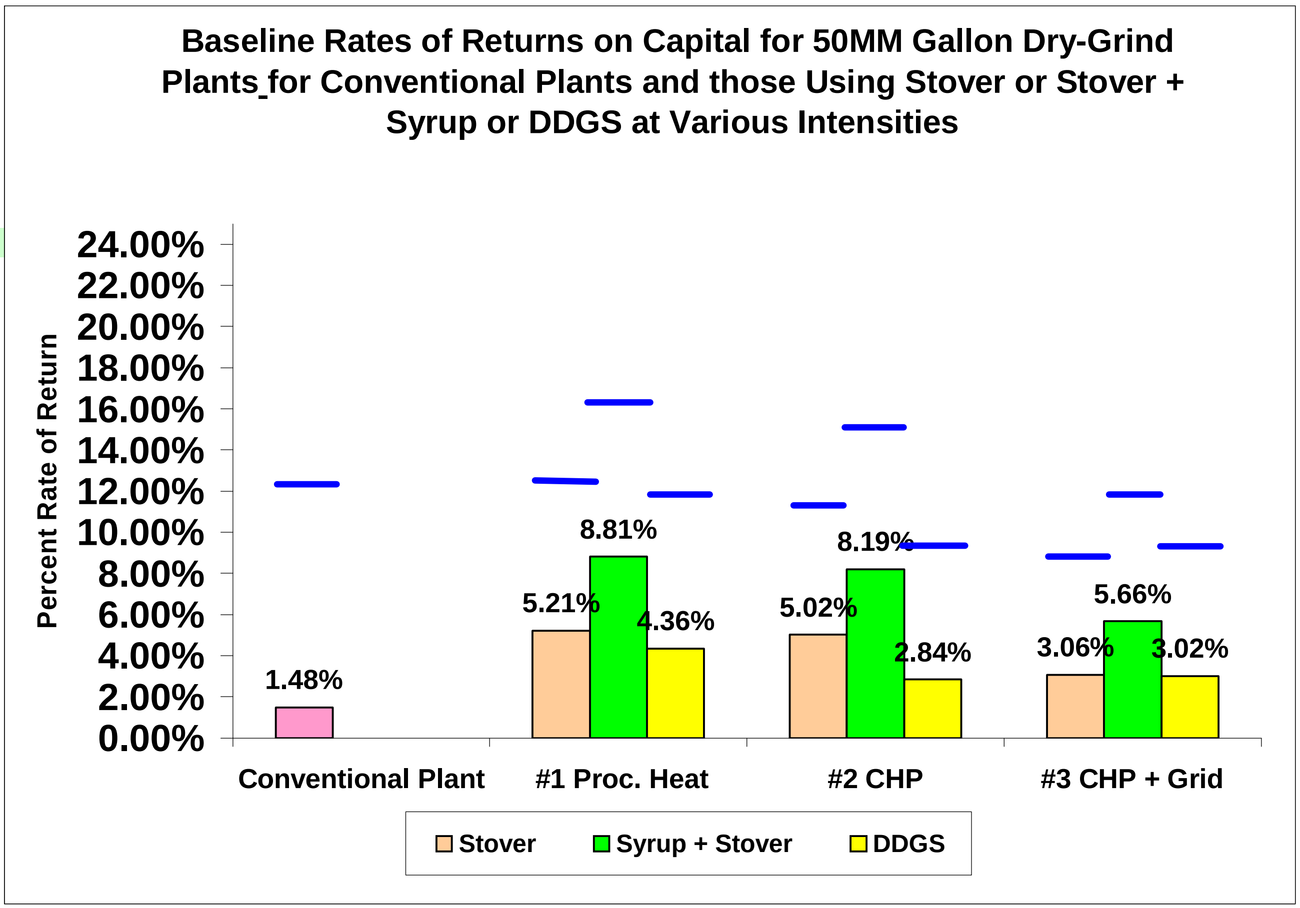
Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid		50MM Gal
22.81%	19.62%	18.03%	14.80%	Stover	
	24.34%	22.26%	18.25%	Syrup + Stover	
	19.24%	16.40%	15.37%	DDGS	



Ethanol Price Shifts from $1.80 to $1.60/ gal. at Plant

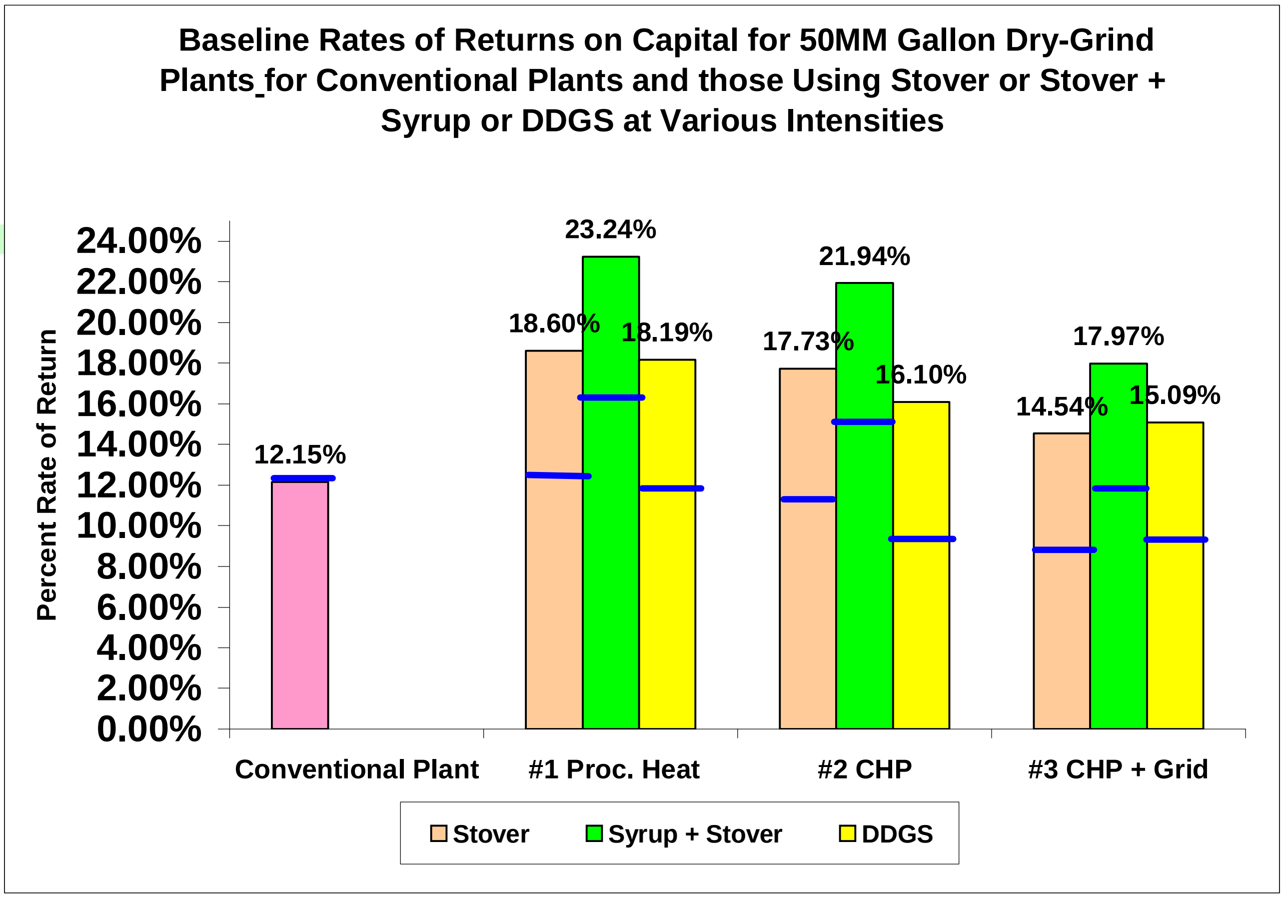
50MM Gal

Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid	
1.48%	5.21%	5.02%	3.06%	Stover
	8.81%	8.19%	5.66%	Syrup + Stover
	4.36%	2.84%	3.02%	DDGS



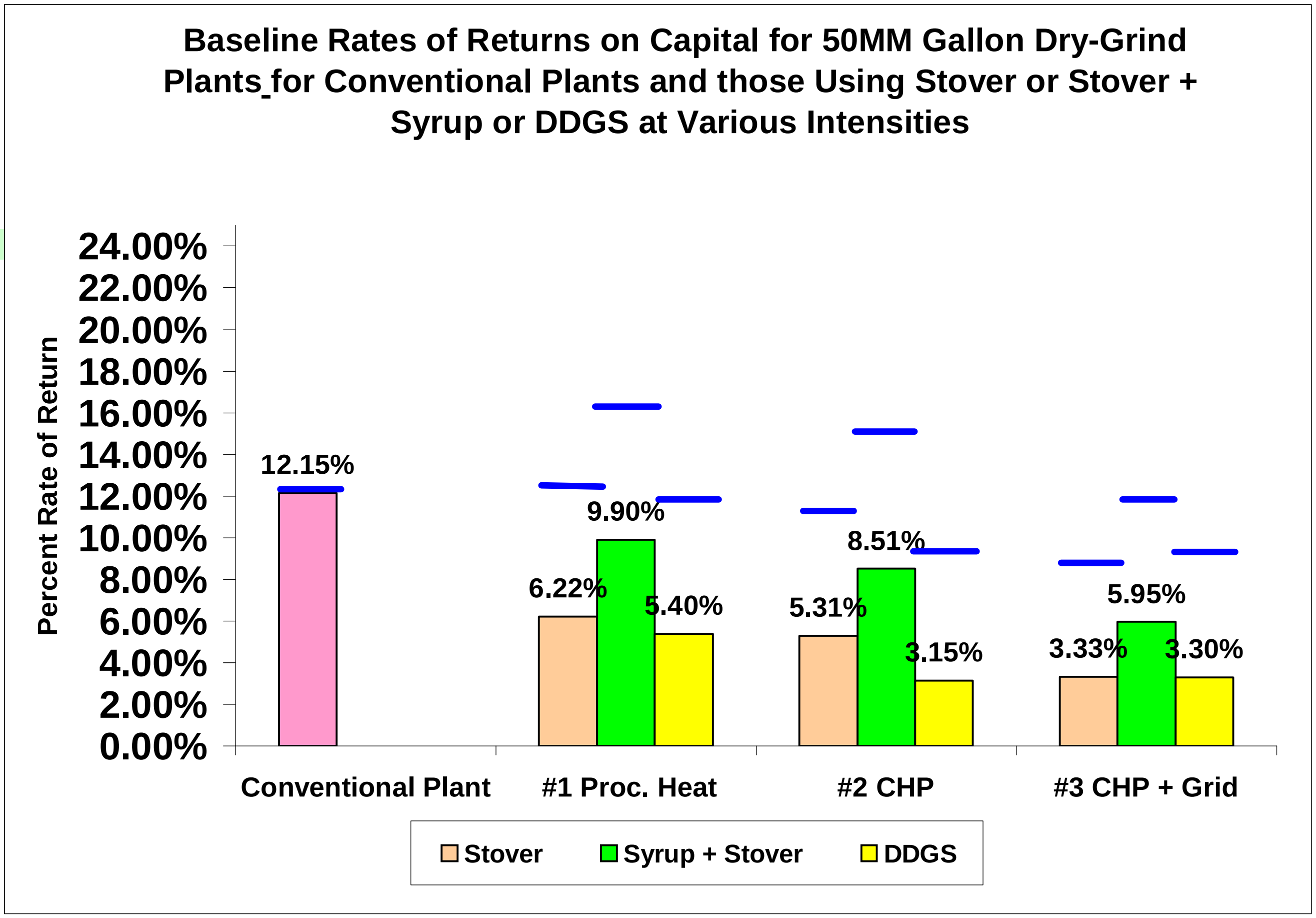
Low Carbon Premium Rises from $.20 to $.40/Gal.

	Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid	50MM Gal
	12.15%	18.60%	17.73%	14.54%	Stover
		23.24%	21.94%	17.97%	Syrup + Stover
		18.19%	16.10%	15.09%	DDGS



Low Carbon Premium is Zero

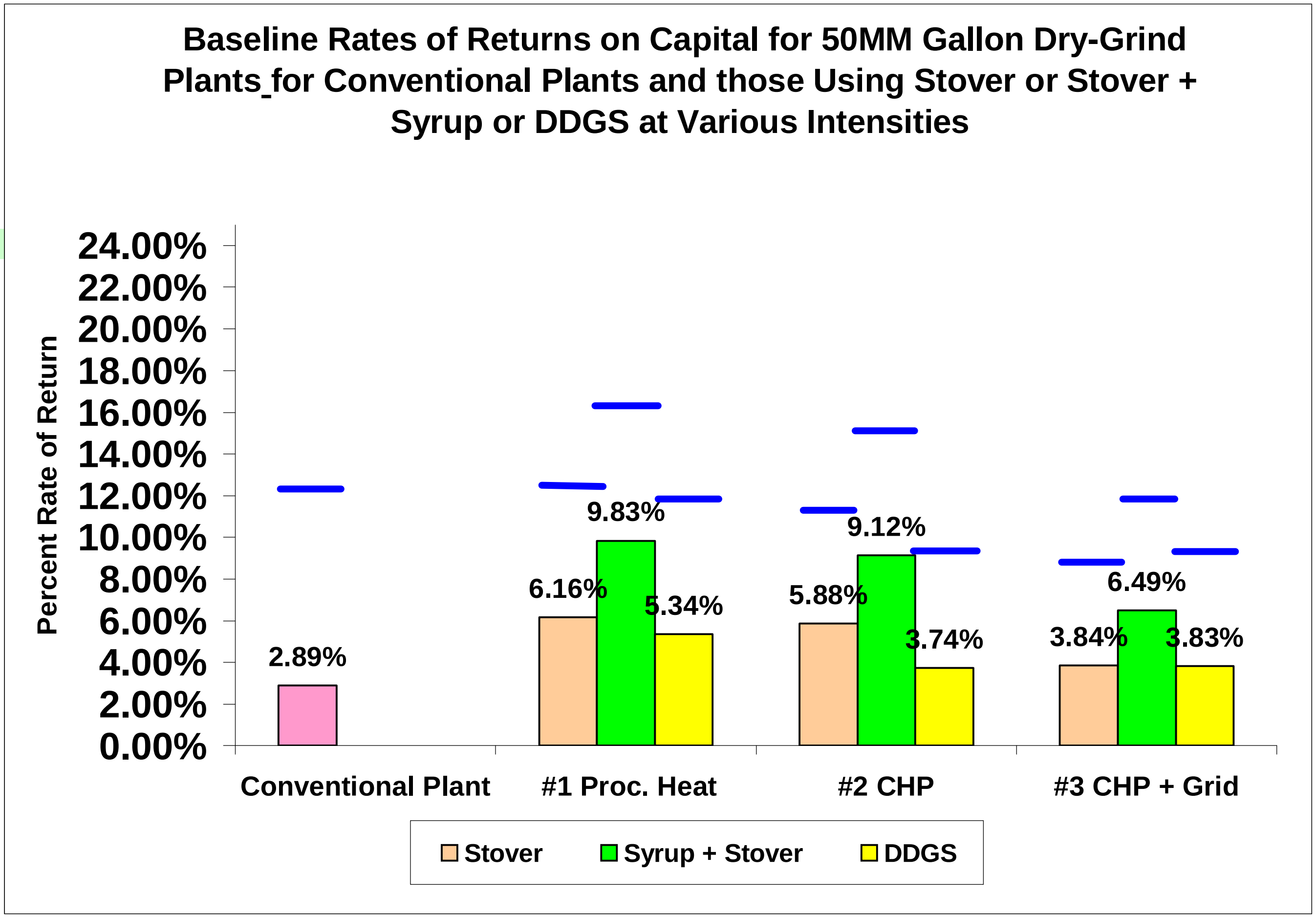
	Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid		50MM Gal
	12.15%	6.22%	5.31%	3.33%	Stover	
		9.90%	8.51%	5.95%	Syrup + Stover	
		5.40%	3.15%	3.30%	DDGS	



Corn Price Shifts from $3.50 to $4.00/bushel

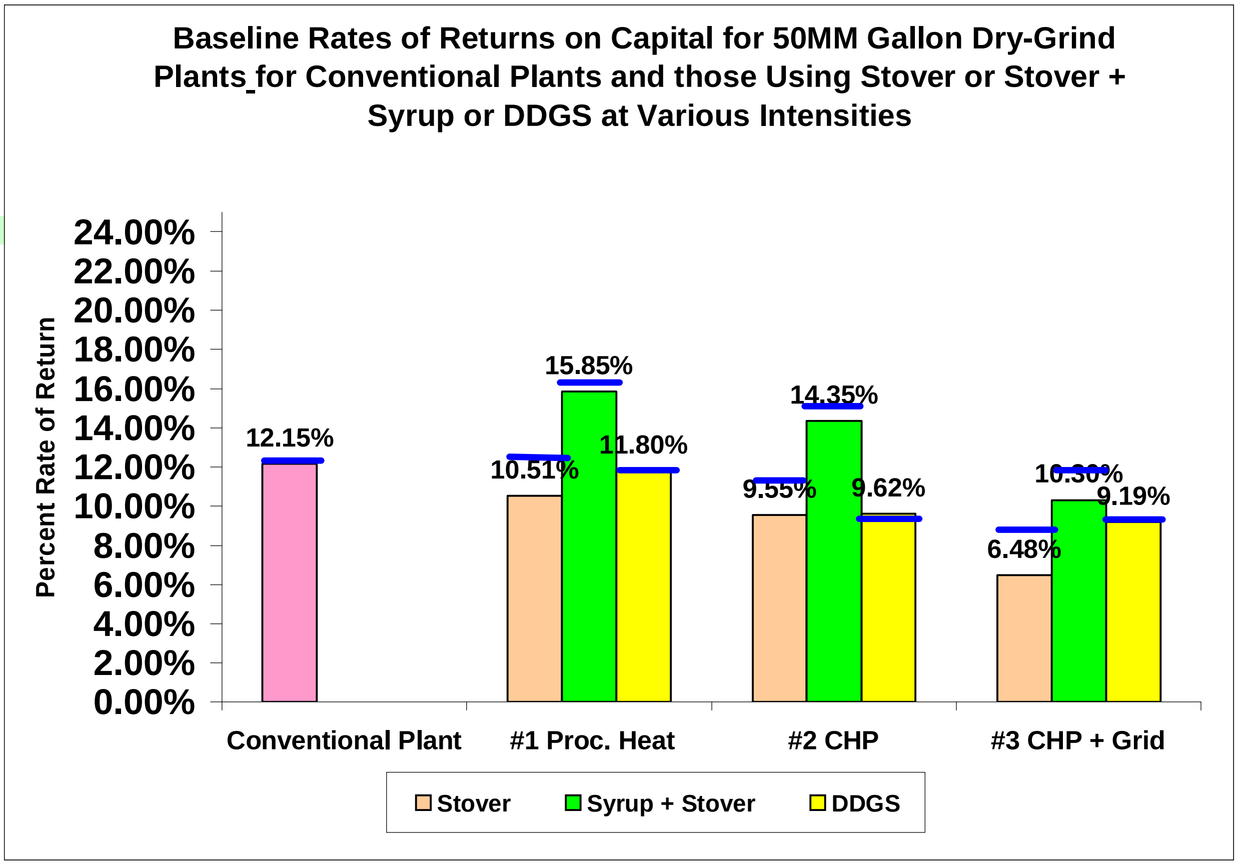
50MM Gal

Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid	
2.89%	6.16%	5.88%	3.84%	Stover
	9.83%	9.12%	6.49%	Syrup + Stover
	5.34%	3.74%	3.83%	DDGS



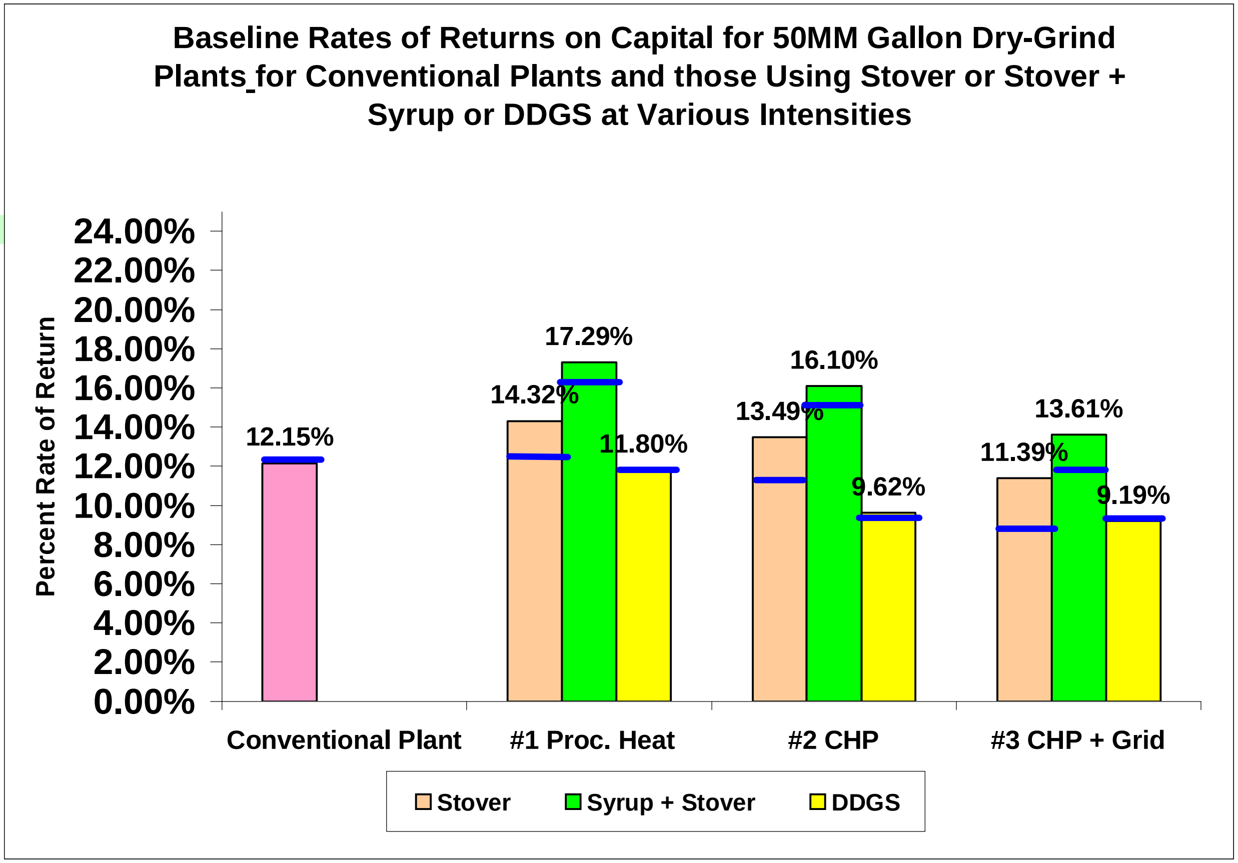
Stover Price Rises from $80 to $100 per Ton

Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid	50MM Gal
12.15%	10.51%	9.55%	6.48%	Stover
	15.85%	14.35%	10.30%	Syrup + Stover
	11.80%	9.62%	9.19%	DDGS



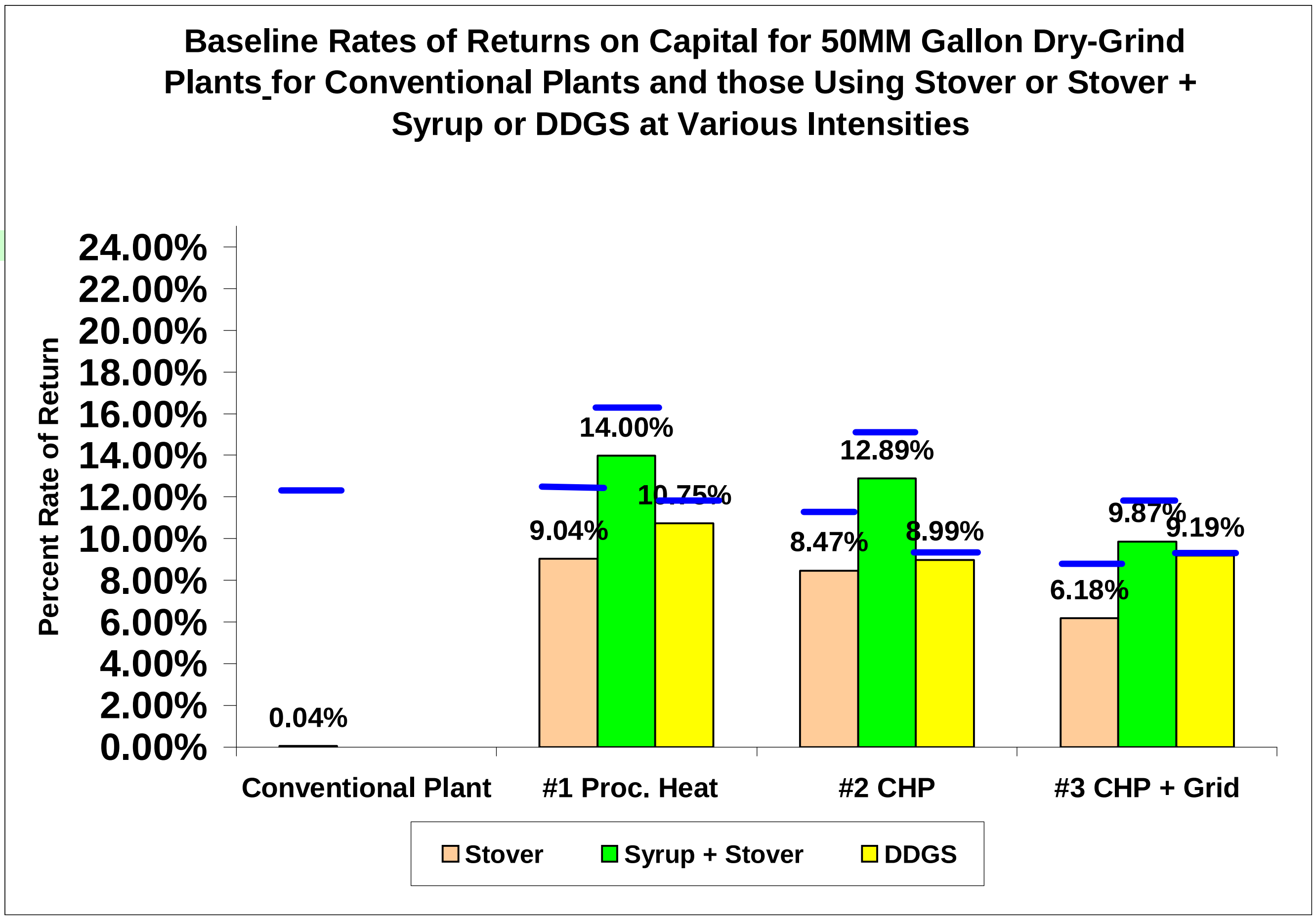
Stover Price Drops from $80 to $60 per Ton

Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid	50MM Gal
12.15%	14.32%	13.49%	11.39%	Stover
	17.29%	16.10%	13.61%	Syrup + Stover
	11.80%	9.62%	9.19%	DDGS



Multiple Factors: $70 DDGS, $12.00 N.G.

Conventional Plant	#1 Proc. Heat	#2 CHP	#3 CHP + Grid		50MM Gal
0.04%	9.04%	8.47%	6.18%	Stover	
	14.00%	12.89%	9.87%	Syrup + Stover	
	10.75%	8.99%	9.19%	DDGS	



Potential GHG Reductions Versus Gasoline Using Corn and Dry-Grind Technology

Technology	GHG Reduction	Cumulative GHG Reduction
Natural gas with DDGS drying	30 – 45%	30 – 45%
Biomass CHP	30 – 35%	60 – 80%
Electricity to grid	30 – 50%	90 – 130%
Nitrogen fertilizer from wind	5%	95 – 135%
Sequester CO_2 from fermentation	35 – 40%	130 – 175%

Project Summary

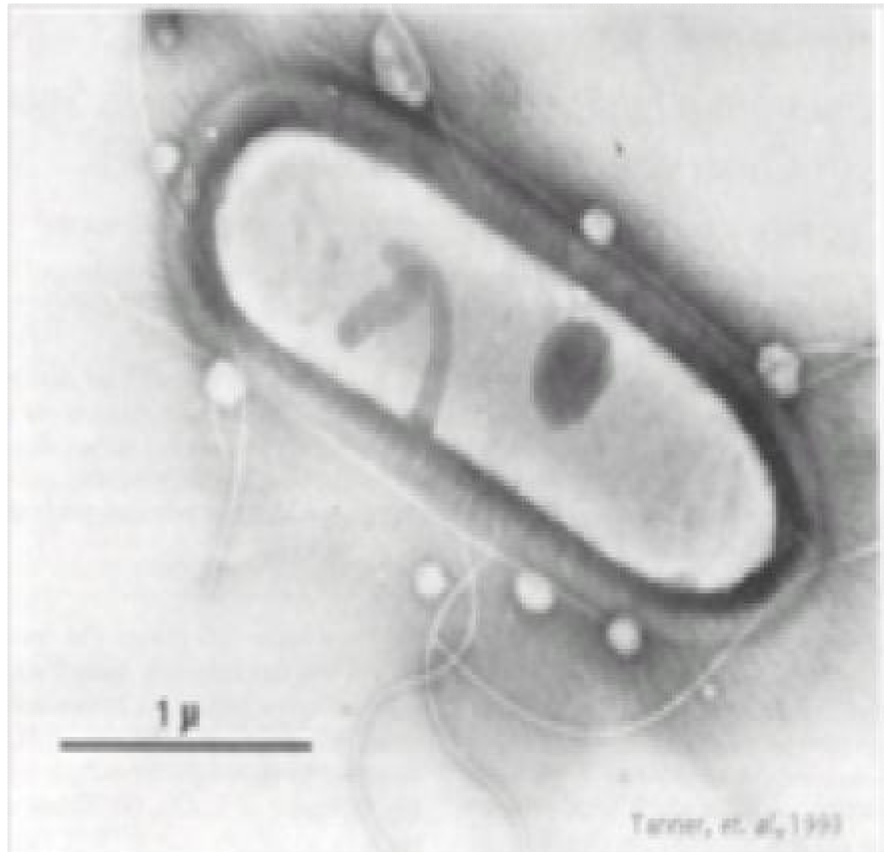
- Use of by-product syrup and corn stover at dry-grind ethanol plants is **technically feasible and fiscally prudent**, especially if we have policies favoring low carbon fuel standards.
- Use of biomass improves energy balance and **drastically reduces the carbon footprint** of ethanol produced from corn.
- Dry-grind ethanol plants of 50MM gal. per year capacity can produce and sell 5-7 MW of electricity for the grid. (140 MW capacity for MN)

Two Approaches to Make Ethanol from Biomass

- Thermochemical
  - Using high temperatures, pressure and in atmosphere starved of oxygen drive off Synthesis Gas (H_2, CO, CO_2)
  - Use organisms or catalysts to assemble fuels or chemicals
- Biochemical
  - Use pre-treatments to prepare biomass
  - Use organisms to produce biofuel
  - Use catalysts via Fischer-Tropsch

Thermochemical Processes: Organisms or Catalysts

- BRI –Dr. James Gaddy
- Coskada—Oklahoma St. University + partners
- Feed Synthesis Gas to Clostridia that can make ethanol



- Pearson Process with Iron catalysts
- Mixed Catalysts NREL--Phillips et. al.

BRI & Coskata Processes

- Gasification of Biomass
- Clean-up of Synthersis Gas
- Sparge H, CO, and CO2 through media with Clostridium to produce ethanol
- Anticipates Sale of Power from extraction turbine

Pearson Process

- Gasification of Biomass
- Clean-up of Synthesis Gas
- Use Iron Catalysts to Produce Hydrocarbons

Biochemical: Ligno-Cellulosic Ethanol

- Cellulose and Hemicellulose are made from carbohydrates.
- Lignin, with energy density nearly equal to coal, would produce process heat & electricity with electricity to sell to grid. Produces 3.7 kWH per gallon of anhydrous ethanol, use 1.42 in the plant and sell

  2.72 kwh @ $.041---equal to about 10% of revenues.
- Acid pre-treatments are needed to prepare cellulosic feedstocks for enzymatic processing.
- Bacteria may to be used for fermentation of C5 sugars; yeasts for C6 sugars.

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Factors for Ligno-Cellulosic Ethanol Production Cost

- Capital Costs are Triple the Costs of Dry-Mills per Unit of Capacity. (Perhaps difficult to raise capital, >sensitivity to interest rates.)

- Conversion Rates with Cellulosic Crops

  Near Term: 69.7 gallons/Ton (5-7 days saccharification & fermentation)

  Future Term: 89.7 gallons/Ton (3-3.5 days saccharification & fermentation)

  Theoretical: 112.7 gallons/Ton

Dry-Grind (Corn): 114 gallons/Ton + 643 lb. DDGS

- Cellulosic Enzyme Costs Range from $.40--$.25--$.10 per gal. denatured ethanol produced.
- Processing time to achieve conversion rates has not been disclosed.

Novel Cellulosic Plants to be Built with U.S. Govt. Sponsorship

Company	Location	Feedstock	Technology
Abengoa Bioenergy	Colwich, KS	Corn stover, wheat straw, milo stubble, switchgrass	Thermochemical & biochemical
ALICO	LaBelle, FL	Yard, wood , and vegetable wastes	Thermochemical & biochemical
BlueFire Ethanol	Corona , CA	Green waste and wood wast from landfills	Biochemical
Poet (Broin)	Emmetsburg, IA	Corn fiber, cobs, and stalks	Biochemical
Iogen	Shelley , ID	Wheat barley & rice straw, corn stover, switchgrass	Biochemical
Range Fuels	Treutlin Co, GA	Wood residues & wood based energy crops	Thermochemical

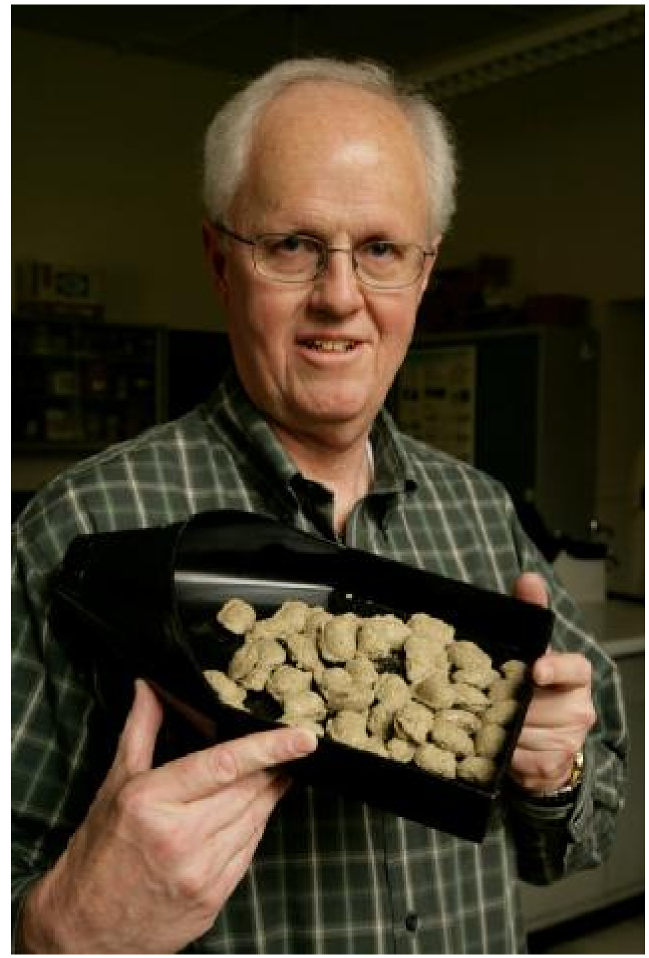
Process Comparisons

	Annual Production (Gallons)	Feedstock Required to Convert (Tons)	Additional Biomass Trucked in	Natural Gas Used per Gallon of Ethanol	Electricity Purchased per Gallon of Ethanol	Water Usage per Gallon of Ethanol	DDG(S) Sold (Tons)
Dry-Grind (Tiffany and Eidman)	60,000,000	605,769 T.	0	34,000 BTU	.75 kWh	3-4 gal.	194,711
Dry-Grind using Syrup & Stover CHP (Morey et al.)	53,000,000	515,107 T.	Stover 72,898 T.	0	-0.44	4.22	98,447
Dry-Grind using Stover CHP (Morey et al.)	53,000,000	515,107 T.	Stover 156,709 T.	0	-0.724	4.24	166,968
Biochemical (Aden et al.)	57,750,000	905,882 T.	0	0	-2.72	6 gal.	0
Thermochemical (Phillips et al.)	57,750,000	1,540,000 T.	0	0	0	1.9 gal.	0

**Thermochemical method also yields an additonal 15% as mixed alcohols.

Technology Sideshows

Harvest and Densification of Biomass



Loading 3X4X8 Switchgrass Bales

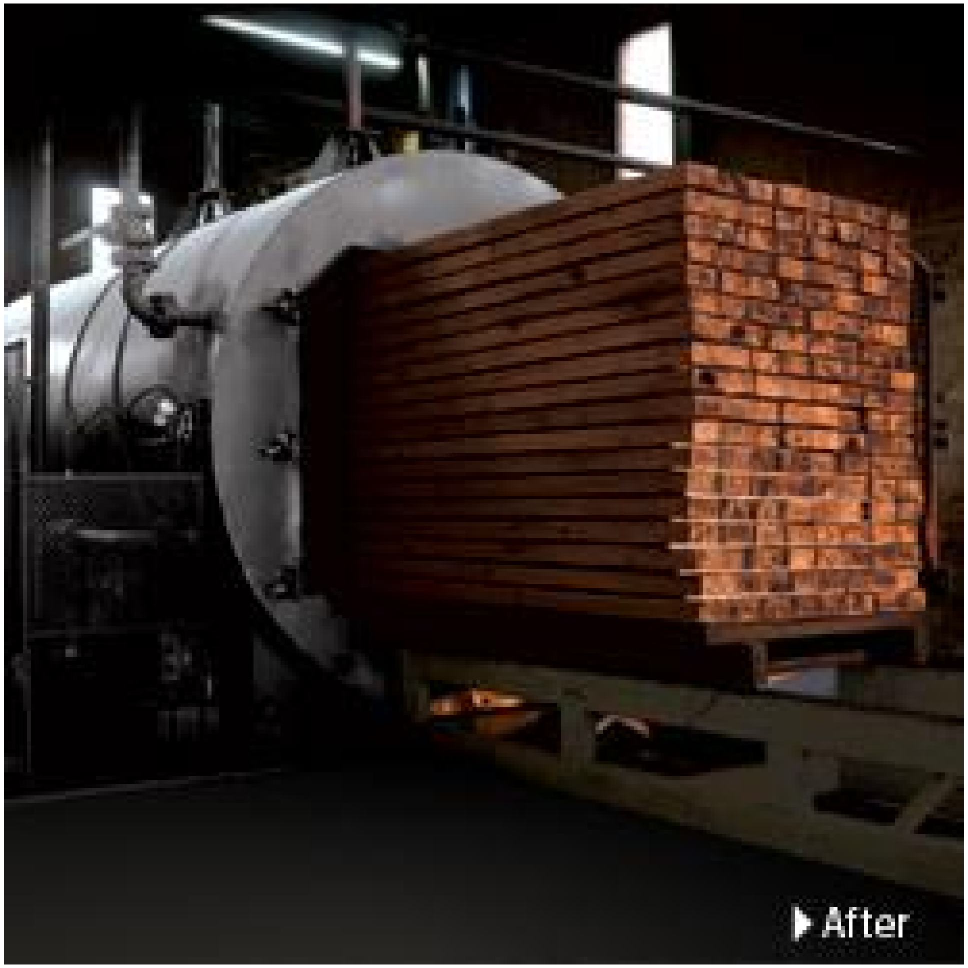
Estimated Delivered Costs of Corn Stover Based on---

- 40% harvest efficiency and 50% farmer participation on safe soils of Southern Minnesota

- Total delivered costs =
- Collection costs
- + transportation cost
- + fertility replacement cost
- + unloading and stacking
- + storage cost
- Collection methods evaluated
- - Large rectangular bales (1342 lbs.)
- - Large Round Bales (739 lbs.)
- - Densification of both rectangular and round bales

- ***The Economics of Harvesting and Transporting Corn Stover for Conversion to Fuel Ethanol: A Case Study for Minnesota***
  Petrolia, Daniel R.

Torrefaction

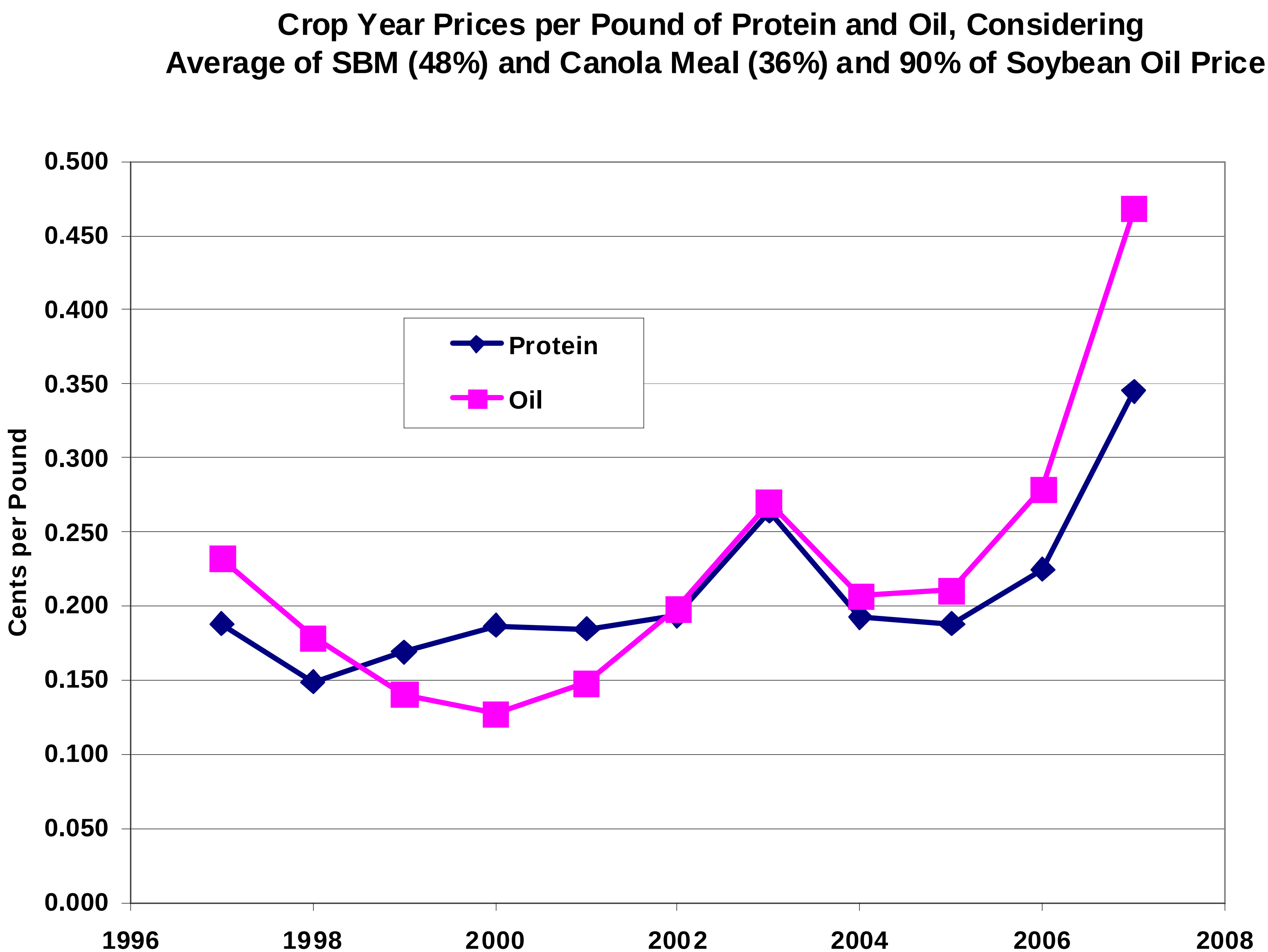


Torrefaction

- Roasting biomass at 450-550 degrees F.
- Process takes 5-15 minutes
- Absence of oxygen
- Increases Energy Density of Pellets
- Hydrophobic, non-reactive in atmosphere
- 2 X energy density of wood pellets
- Can blend with coal
- Favors transportation of fuel
- Sources: Berman and Kiel, Energy Centre of the Netherlands
- Zani et al, Dept. of Chem Engiineering and Technology

Genetic Manipulation to Produce Corn with Higher Oil

- Goal of Ron Phillips and team: Raise Oil from 4% to 20% by Plant Breeding
- Very Valuable when used w/ Wet-Milling ,Fractionation
- Potential for ethanol and more biodiesel from corn oil


Crop Year Prices per Pound of Protein and Oil, Considering
Average of SBM (48%) and Canola Meal (36%) and 90% of Soybean Oil Price
Cents per Pound
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
1996
1998
2000
2002
2004
2006
2008
Protein
Oil

Comparing Conventional and Korean High Oil Corn in Fractionation

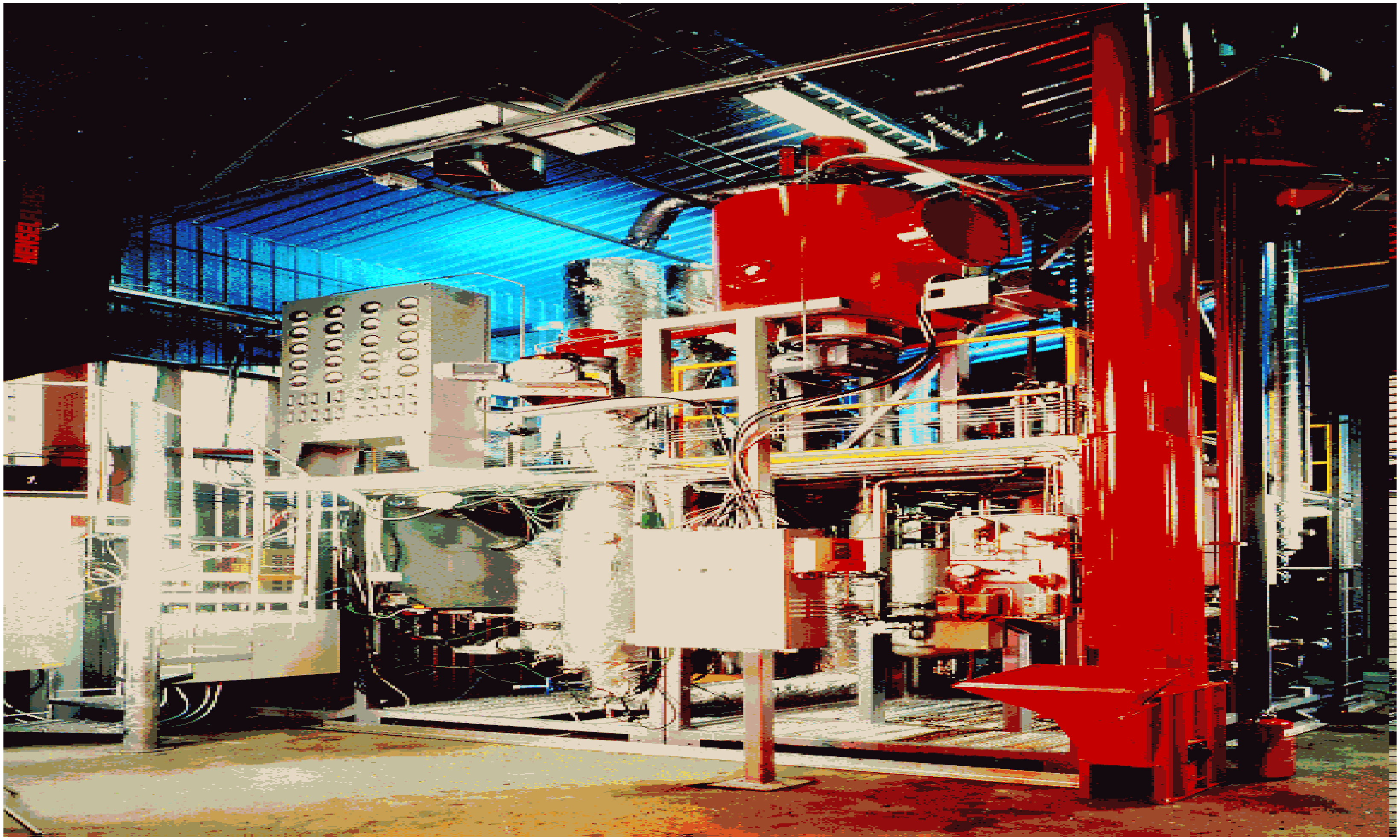
Constituents	Convent. Corn	Pounds/Bu.	Low Eth. Margin Value @$.25 Oil	High Eth. Margin Value @$.25 Oil	Low Eth. Margin Value @ $.50 Oil	High Eth. Margin Value @ $.50 Oil
Oil	0.038	2.13	$ 0.53	$ 0.53	$ 1.06	$ 1.06
Starch	0.613	34.33	$ 0.54	$ 1.25	$ 0.54	$ 1.25
Protein	0.081	4.54	$ 0.18	$ 0.18	$ 0.18	$ 0.18
Fiber	0.113	6.33	$ 0.25	$ 0.25	$ 0.25	$ 0.25
Moisture	0.155	8.68	$ 0.34	$ 0.34	$ 0.34	$ 0.34
	1.000	56.00	$ 1.84	$ 2.55	$ 2.38	$ 3.08

Constituents	Korean High Oil	Pounds/Bu.	Low Eth. Margin Value @ $.25 Oil	High Eth. Margin Value @ $.25 Oil	Low Eth. Margin Value @ $.50 Oil	High Eth. Margin Value @ $.50 Oil
Oil	0.230	12.88	$ 3.22	$ 3.22	$ 6.44	$ 6.44
Starch	0.430	24.08	$ 0.38	$ 0.87	$ 0.38	$ 0.87
Protein	0.072	4.03	$ 0.16	$ 0.16	$ 0.16	$ 0.16
Fiber	0.113	6.33	$ 0.25	$ 0.25	$ 0.25	$ 0.25
Moisture	0.155	8.68	$ 0.34	$ 0.34	$ 0.34	$ 0.34
	1.000	56.00	$ 4.35	$ 4.84	$ 7.57	$ 8.06

Objectives for Fractionation Technologies

- Reasonable capital costs
- Lower operating costs—lower enzyme costs, less drying of by-products
- Greater throughput of plant (+10%)—higher starch levels placed in fermentor (83% vs. 74%)
- More valuable co-products– oil, high protein, low-fiber feeds– for poultry and swine
- Lower carbon footprint by reducing energy used for ethanol production-reduced emissions of VOC's

Fast Pyrolysis Unit at Ensyn



A fast pyrolysis PDU unit built by Ensyn Technologies Inc. 20 kg/h

Pyrolysis to Produce Bio-Oil

- Description of Pyrolysis
  - Very Fine grind
  - High Temp. (500 ° C), Short Duration(<1 sec.), and Zero Oxygen
  - Rapid Quenching and Removal of Bio-Oil
  - Yields from 50-70% of biomass D.M. as Bio-Oil
- Products of Pyrolysis
  - Hydroxyacetaldehydes (HA) for food flavoring
  - Phenolics for Resins and Adhesives
  - Anhydroglucose (AHG) for potential Ethanol
  - Formic and Acetic Acid
  - Resins---- perhaps for fuel usage

Prices of Fuels per $/MMBTU

Energy Source	***Theoretical Price***	***Average 2005 Electric Utility Price ($/MMBTU)***	***Average 2005 Price, all sectors ($/MMBTU)***
Gasoline			$17.32
No. 2 Fuel Oil		$11.30	$12.74
Natural Gas		$7.50	$7.67
Residual Fuel Oil		$6.57	$7.53
Coal		$1.52	
Petroleum Coke		$1.10	
Bio-oil	$ 8.60 [1]		
Switchgrass	$ 2.50 [2]		

[1] Assumes $40/ton Switchgrass, 20 ton per hour plant.

[2] Assumes $40/ton Switchgrass.

Conclusions– Economic

- Bio-Oil is Competitive with petroleum for production of fuel oil in boilers
- Research is needed to improve stability of bio-oil.
- Improvements that make Sugars derived from AHG fermentable would improve gross margins by $17.58 per T. in Big Bluestem, $9.50 /T. in Switchgrass

Pyrolysis of Biomass

- Feedstocks investigated—wood, corn stover, DDGS, hog manure
- Pyrolysis paths----

- Thermal
- Catalytic
- Microwaves

Pilot Scale Continuous Microwave Pyrolysis System

Figure 1. “Bale to Barrel” – on-farm biomass conversion approach

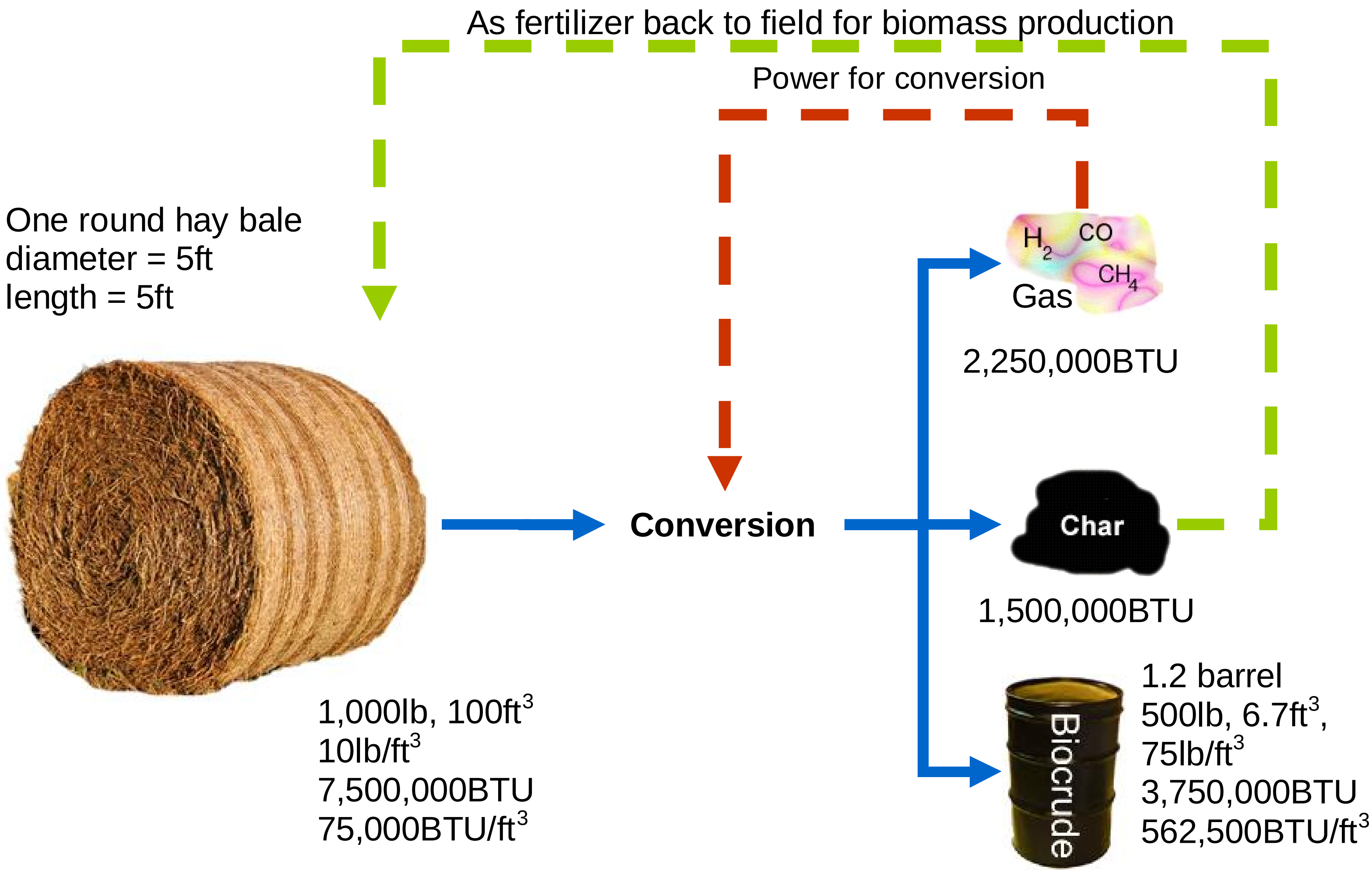
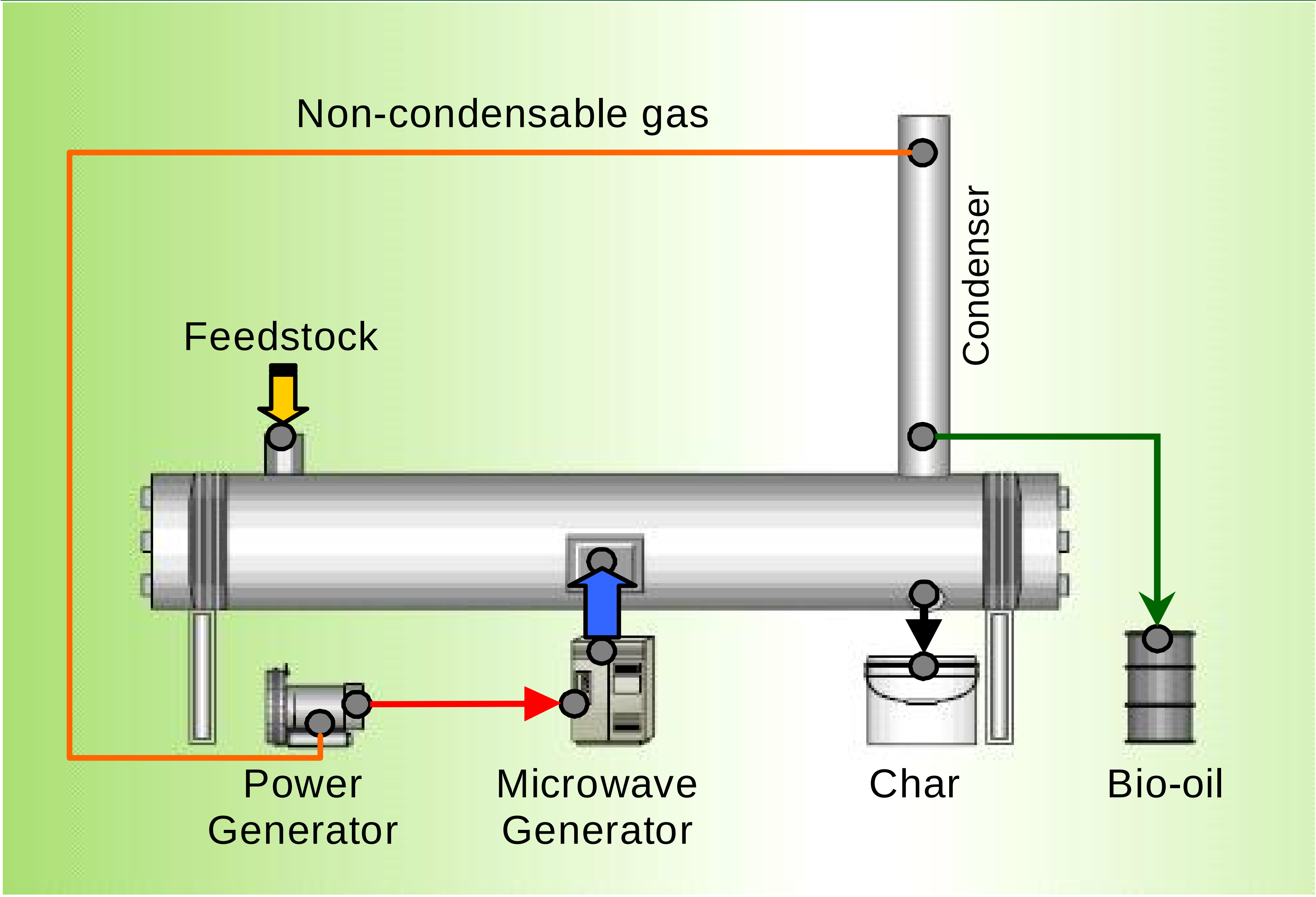


Figure 3. Microwave Assisted Pyrolysis System



Pro forma for Distributed Pyrolysis Oil Production

Table 1. Income and costs estimate.*

Items	Amount	Notes
Income		
Sale of bio-oil	$168,000	$1/gallon
Sale of char	$15,000	$50/ton
Total sales	$183,000	
Costs		
Feedstock	$45,000	$30/ton
Machine depreciation	$30,000	10 years life time, 8% interest
Electricity	$8,640	$0.072/kWh
Consumables	$9,150	5% of total sales
Maintenance	$10,000	5% of Capital
Other expenses	$18,300	10% of total sales
Total costs	$121,090	
Net income	$61,910	

*Calculations are based on data from references (*5*, *9*, *11*).

Dimethyl Ether

- Produced from gasified biomass
- Works well with black liquor, stover,cobs
- Synthesis gas is cleaned and converted catalytically to DME
- Resulting fuel can be used in diesel engines or used like propane for heating
- Permits high density storage when chilled and under pressure, vaporizes when released

Thanks!

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