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Biofuels from Cellulosic Biomass: An Overview of Current Technologies & Economic Feasibility

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Fueling the Future: The Role of Woody Biomass for Energy Workshop

April 29, 2009

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Why Biofuels Derived from Cellulosic Biomass ?

- Current energy economy prefers liquid and gaseous fuels that provide carbon as the energy source
- Liquid transportation fuels will be needed for a considerable time to come.
- Cellulosic based liquid biofuels are the next logical step beyond corn ethanol.
- This does not necessarily mean it will be ethanol!

Biofuels noise to signal ratio is high! Like a radio with lots of static.

- Many conflicting opinions about biofuels.
- Confusing data, especially on the internet and in the media.
- Competing interest groups with narrowly focused agendas.
- Lots of self-appointed experts.
- Everyone wants to get in on the act; even crankshaft!

The goal today is to increase the signal to noise ratio.

Seminar Outline

- Description of promising platforms for converting biomass to transportation fuels.
- Comparison of the platforms : Technical issues and economics. Is there a preferred platform?
- Biomass supply: How much, where is it , is there enough???

Conversion Platforms

- **Purpose** is to convert cellulosic biomass to **fuels such as ethanol, methanol, dimethyl ether, or gasoline**.
- Many platform technologies have been suggested
- Two important platforms are considered here:

  Biochemical and Thermochemical

What is Cellulosic Biomass?

Clean biomass:

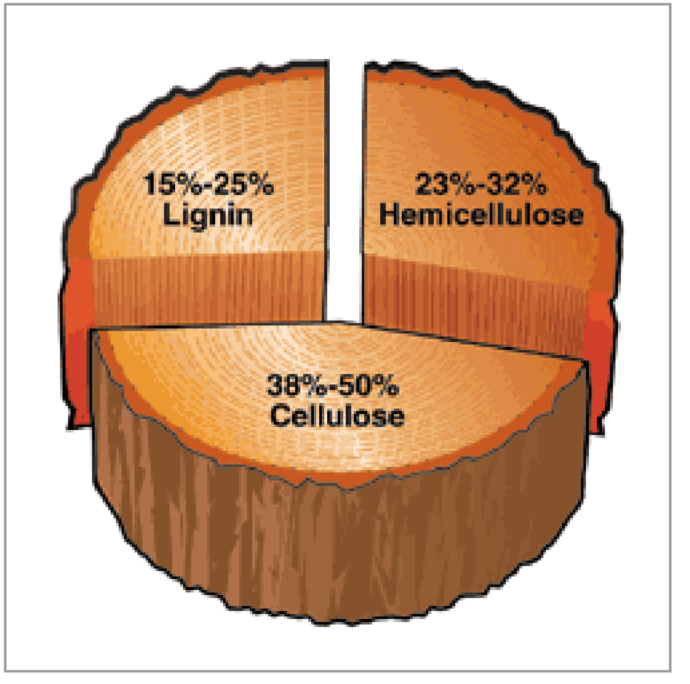
Forest
Hybrid poplar
Switch grass
Prairie Grass
Shrubs

Residual biomass:

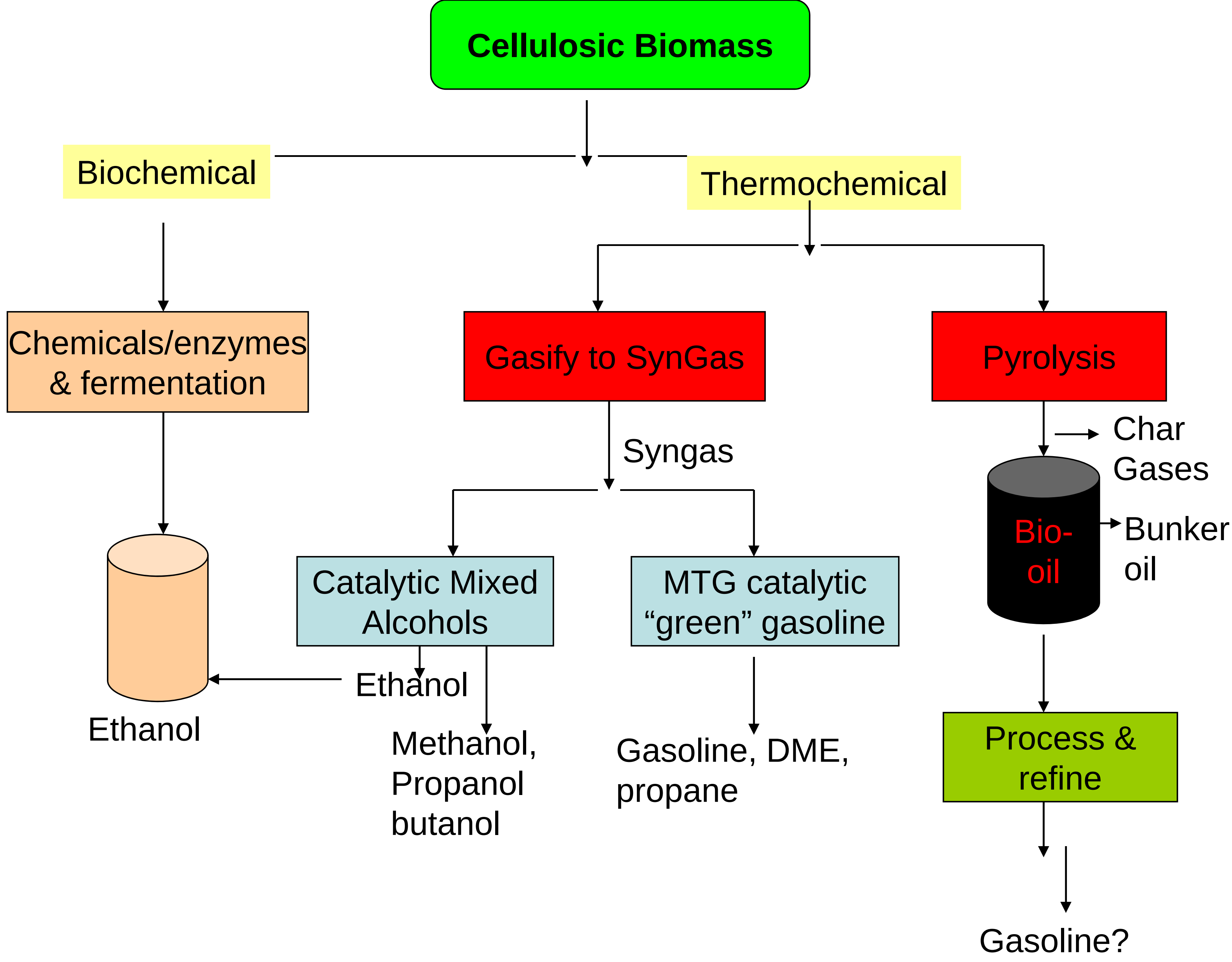
Forest & Ag Residues
    Corn stover
    Tops and branches
Process Residues
    Hulls
    Sawdust

Urban biomass:

MSW (typically > 50% biomass)
Construction/Demolition wood



* 50% Carbon
* 6% Hydrogen
* 44% Oxygen


Cellulosic Biomass
Biochemical
Thermochemical
Chemicals/enzymes & fermentation
Gasify to SynGas
Pyrolysis
Syngas
Char
Gases
Bio-oil
Bunker oil
Catalytic Mixed Alcohols
MTG catalytic "green" gasoline
Ethanol
Ethanol
Methanol, Propanol butanol
Gasoline, DME, propane
Process & refine
Gasoline?

To assess economic feasibility you need information.

- Process description or **process flow diagram**
- **Equipment** list and **current prices**.
- **Installed capital cost** including site improvements, engineering, installation (piping, electrical, structural, mechanical), construction management, permitting, buildings and reasonable contingency.
- **Process yield** (gallons of biofuel/ton of biomass), **energy and water usage**, sewage charges.
- Fixed manufacturing costs (Plant overhead, management, property taxes).
- Variable manufacturing costs (labor, gas, electric, water, sewage disposal, and Biomass Cost)

This information is not readily available nor easy to obtain!!!

Process Models used for Analysis

- Models for the various platforms from NREL (National Renewable Energy Laboratory)

•NREL models contain ;

- ➢Material and energy balance from Aspen process software
- ➢Complete flow sheets and equipment costs
- ➢Labor and utility costs
- ➢Environmental impact

•Models were adjusted to reflect inflation, realistic install factors, engineering, construction management and permitting

But what metric should you use to assess economic viability??

How do you determine economic viability?

If you invest money in an enterprise you expect to earn a reasonable **return on the investment.**

There are several ways of reporting “return”such as;

- Average annual return, a simple ratio.

- Payback period, how long before you recover the invested capital.

- Business tends to take into account the time value of money and use metrics based on discounted cash flow. These are ;
  - Internal Rate of Return (IRR)
  - Net Present Value (NPV)

Consistent with NREL, **IRR and NPV** (with a hurdle rate of 10%) have been used as the metrics in our spread sheet calculations.

How do you use IRR and NPV?

- IRR is used to determine if a specific project meets a minimum rate or “hurdle rate “ that is set by the corporation as meeting minimum corporate financial objectives.
- IRR will tell you if a given project meets minimum requirements but not which of several projects is best if they all meet the hurdle rate.
- IRR measures only one dimension since it is a simple ratio and does not indicate the absolute magnitude of the opportunity.

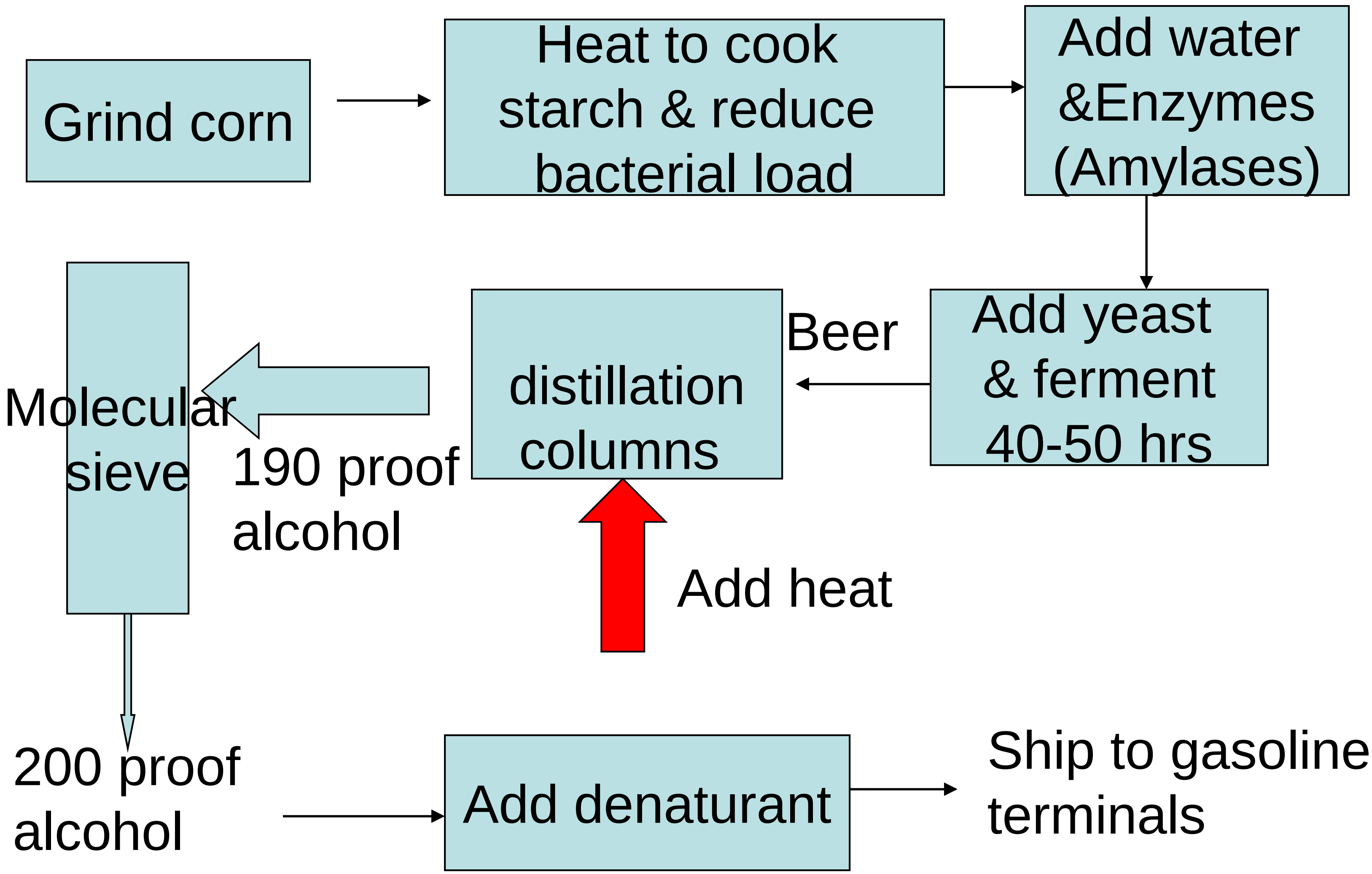
NPV is a way of measuring the cash flow generated at the required hurdle rate

NPV = Cumulative discounted cash flow (computed @ the hurdle rate) - Investment

The hurdle rate selected for this study was 10%.

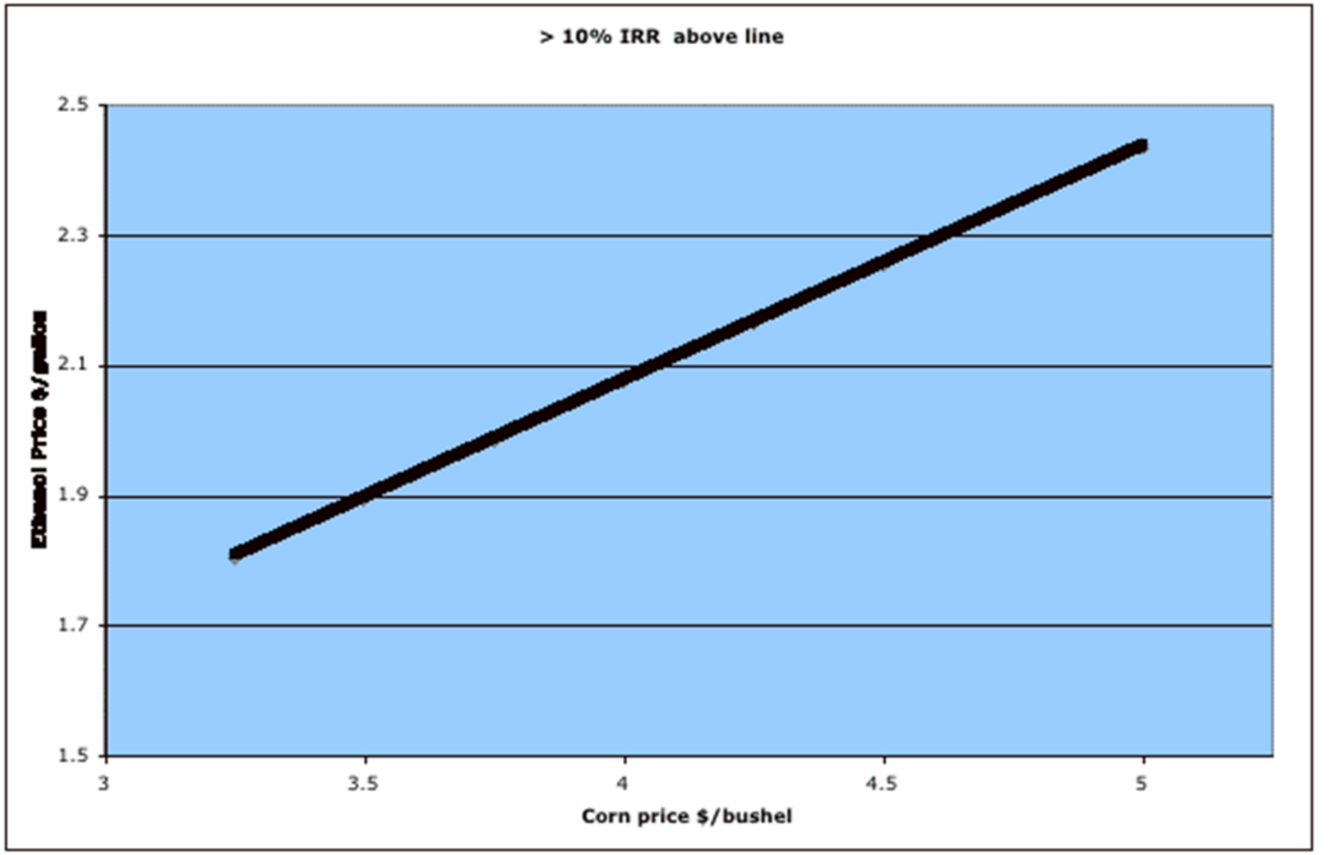
Corn Ethanol Plant

Corn Ethanol process - dry milling
A baseline for comparison



Corn Ethanol Parameters

- Profitability is highly leveraged against corn prices.
- For a 50million gal/yr plant with a capital cost of $100 million and ethanol at $2.00/gal. the IRR is 10.5% (after tax) for corn @$3.75/bu and drops to <10.4%> for corn @$4.50/bu.!



Corn Ethanol Issues/Concerns

- Reduction in carbon footprint vs. fossil fuels is 25-30% for plants heating with fossil fuels and 40-50% for plants heating with cellulosic biomass.(Wang, et. al., Environ. Res. Lett. 2, 2007)

- Plowing prairie land to grow more corn releases sequestered carbon to the extent that it would take about 80 years to recover based on the carbon footprint reduction associated with corn ethanol (Fargione, J; Tilman, D.; Polasky, S; and P. Hawthorne; Science, 2008)

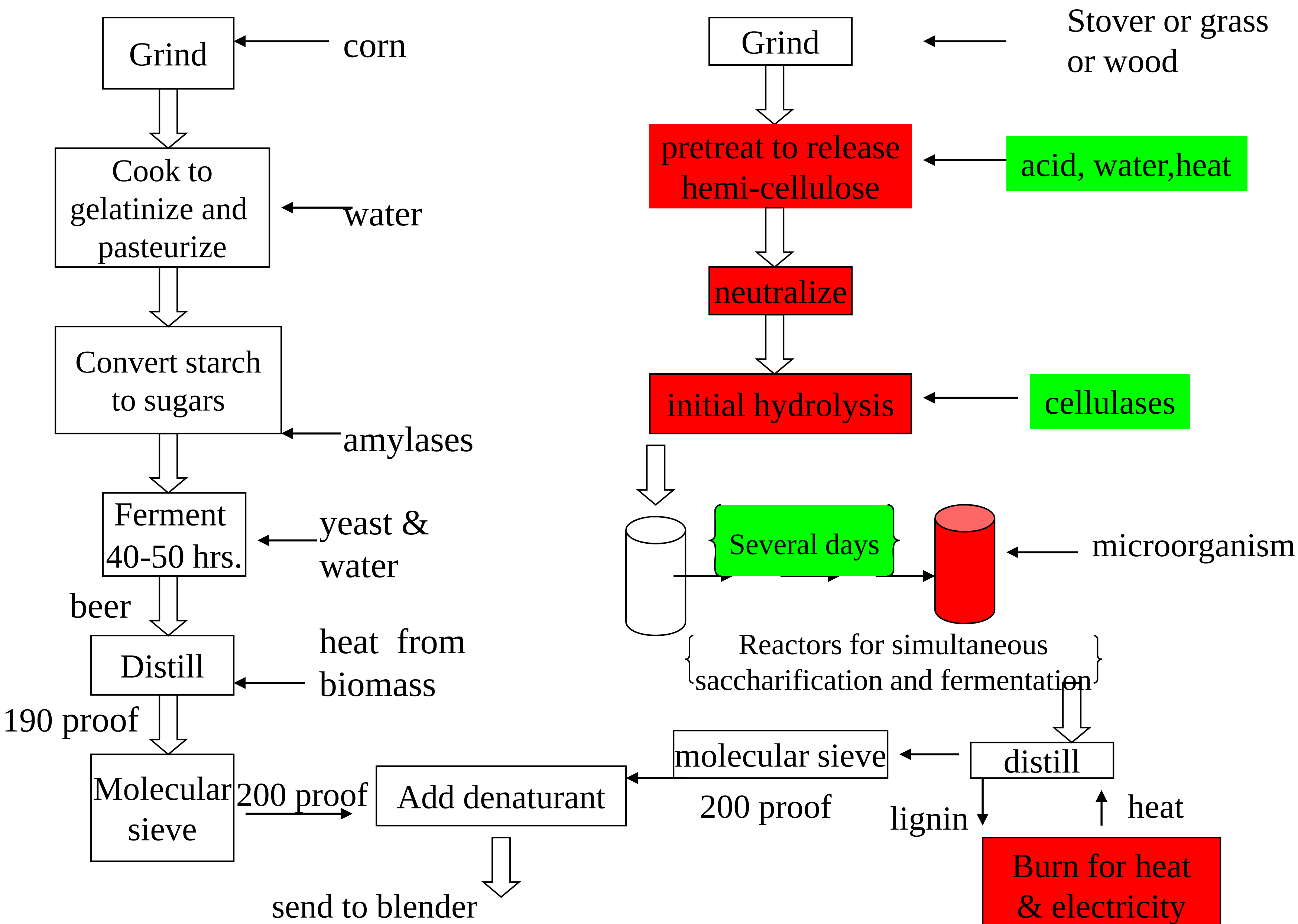
- Controversy over alleged competition between corn for fuel vs. food.

To put things into proper perspective: Corn is but the first step on the long road to significant levels of renewable energy <u>but still an important step</u>.

Comparison of Corn Ethanol and Cellulosic Ethanol Platforms

Corn Ethanol

Cellulosic Ethanol
(hemicellulose,cellulose and lignin)



Major differences between Corn Ethanol and Biochemical Cellulosic Ethanol

- **Capital for Biochemical** Platform is **$340MM** vs. **Corn Ethanol** at **$143MM** for 50 million GPY. Both use biomass for process heat. Biochemical is much more complex than corn ethanol.

- **Enzymes, acids, and bases** add to the operating cost which are **$0.26/gal for biochemical and $0.156 for corn ethanol**. For a **50MM gallon** plant that amounts to **$5.2MM per year** difference!

- Acid pretreatment produces chemical by-products that are **fermentation inhibitors.**

Comparison of Conversion Platforms Baseline conditions

- **Plant capacity of 50 million gallons per year**
- **Corn @ $3.75/ bu.**
- **Ethanol @ $2.00/ gal. rack price (wholesale)**
- **Cellulosic biomass @ $90/ton (15% moisture), delivered to conversion plant gate.**
- **Gasoline @$1.69/gal. rack price ($2.55 at the pump)**
- **Ethanol and gasoline rack prices based on inflation(3%/year) adjusted average prices from 2003-2007.**

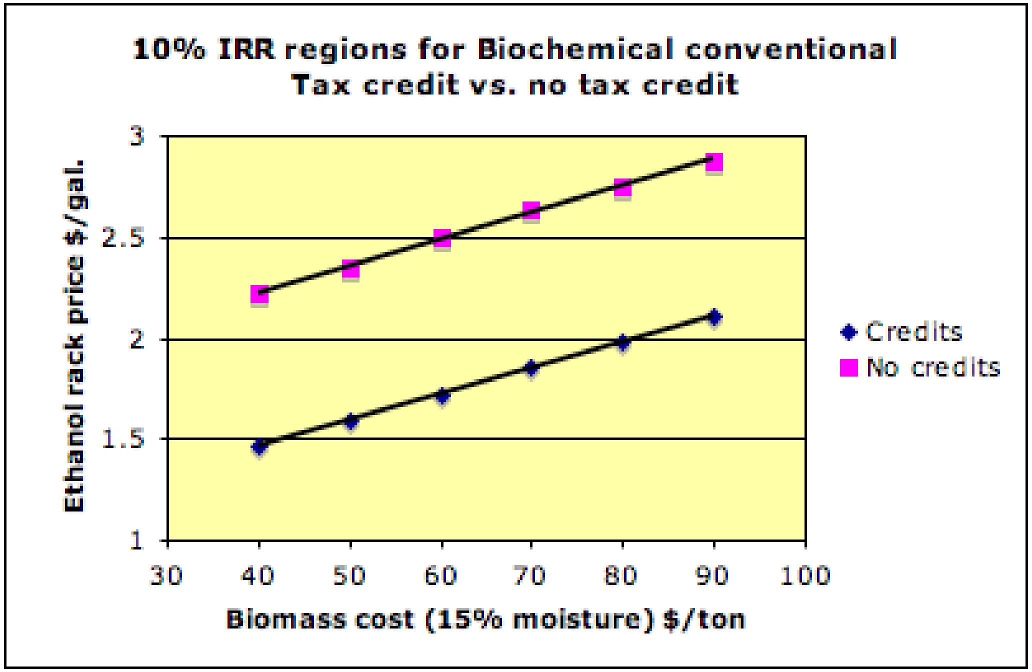
Effect of ethanol rack price & tax credits for cellulosic ethanol platform @ baseline conditions

	Rack price $/gallon	$1.80	$2.00	$2.20
No credits Cellulosic	IRR %	<21.6>	<10>	<3>
	NPV- $MM	<272>	<211>	<150>
Producer tax credit Cellulosic $0.56/gal.	IRR %	2	7	11.5
	NPV - $MM	<101>	<40>	20
Corn Ethanol	IRR %	<1.8>	10.5	19.5
	NPV - $MM	<42>	2	45

Red = negative IRR; Yellow = IRR below hurdle rate; Green = in the money

- **Cellulosic ethanol dependent on tax credits for profitability**
- **Corn ethanol swings from very profitable to negative profits with only 18% change in ethanol price! Highly leveraged**

Biomass cost drives profitability.



- Ethanol prices tend to track the rack price of gasoline/diesel.
- However, rising fuel prices mean higher cost for growing and harvesting biomass.
- It is unrealistic to use artificially low prices for biomass in financial projections.
- Corn stover **will cost more** than the $40 or $50 per ton used by many analysts.

Current Activity on Biochemical Cellulosic Platforms

- Private companies and Universities are engaged in research to solve some of the technical issues.

- Scalability of the platform is major concern of DOE and private companies.

- One operating pilot scale plant(1MGY) in N. America, Iogen in Ottawa,Canada operating on **wheat straw.**

- Another 1.6MGY pilot plant by Verenium in Louisiana operated on **sugar cane bagasse** under construction.

- Three semi-works plants in design phase. Two are connected to existing corn ethanol plants, Poet’s Project Liberty in Emmetsburg, Iowa and Abengoa Bioenergy’s facility in Kansas. These are based primarily on **corn stover.** The third by Iogen in Saskatchewan is based on **wheat straw**.

- All of these semi-works demonstration plants receive significant government funding.

Research activity for cellulosic ethanol via fermentation

- Organisms that will **simultaneously hydrolyze cellulose and ferment** resultant 5 and 6 carbon sugars. (Consolidated bioproceesing, Lynd, L.R., et. al. Current Opinion in Biotechnology, 2005)

- Organisms that will simultaneously ferment 5 and 6 carbon sugars (Capital implications)

- Elimination or removal of **fermentation inhibitors**.

- **Cost** reduction **of enzyme** production.

- Evaluation and **optimization of various feedstocks** (corn stover, switch grass, prairie grasses, hybrid poplar and the like.

Consolidated Bioprocessing - the whole organism approach

The concept is to find and develop organisms that are capable of simultaneously performing saccharification (make sugars from cellulose) and fermenting these to ethanol in a single reactor.

- **This would significantly reduce two major cost factors.**
  - **No enzymes to purchase**
  - **Significantly fewer vessels and capital**

The NREL cellulosic model has been modified to get some idea of how such improvements might affect the economics.

The NREL model was adjusted by removing all enzyme cost and reducing the capital by removing equipment that would be redundant. This is a best case or "ideal "biochemical platform scenario!!

Financial Impact of “Ideal” Biochemical Platform.

- Elimination of enzymes reduces variable operating cost from $0.26/gal to $0.16/gal. This is $5.0MM per year on a 50MM gal. plant
- Removal of some vessels reduces capital from $340MM to $318MM
- Table 4.5 is a comparison of IRR and NPV for corn ethanol, biochemical and ideal biochemical platforms.

		CAPITAL $MM	IRR% AFTER TAX	NPV $MM
Corn ethanol	stover@ $60/ton	143	12	12
Biochemical conventional	$0.56 tax credit	340	7	<40>
	No credit	340	<10>	<211>
"Ideal" biochemical	$0.56 tax credit	318	11.5	20
	No credit	318	<4>	<151>

▲ **Table 4.5. IRR and NPV for Ideal cellulosic ethanol platform**

There is an improvement over conventional biochemical and similar economics to corn ethanol with biomass heat source.

Production Costs for Biochemical Platforms

BIOMASS $/TON	90	70	60	50
Conventional biochemical	2.34	2.09	1.96	1.83
"ideal" - no enzymes	2.18	1.92	1.78	1.65
Corn ethanol base case	1.82	1.82	1.82	1.82
Corn ethanol with biomass energy source	1.79	1.75	1.73	1.70

▲ **Table 4.6. Production costs ($/gallon) of ethanol for biochemical cellulosic platforms with corn ethanol platform as base case (corn @ 3.75/bu.).**

- Ideal platform has an operating cost benefit of about $8.5MM/yr over the conventional biochemical platform.

- At biomass cost < $60/ton the ideal biochemical platform is competitive vs. corn ethanol with biomass energy source.

Thermochemical Conversion Platforms

- Gasification of biomass to create syngas is the first step in the conversion platforms considered here.
- What is gasification and how does it differ from combustion?

Gasification vs. Combustion

GASIFICATION
Chemical conversion using limited amounts of oxygen:
C to CO
H to H_2
S to H_2S, then pure S
N to N_2

High temps (1300-2700 F) and high pressure

COMBUSTION
Complete oxidation using excess air:

C to $C0_2$
H to H_20
S to SO_2
N to Nox

Lower temps (1500-1800 F) and atmospheric pressure (0 psig)

Purpose: Create usable syngas

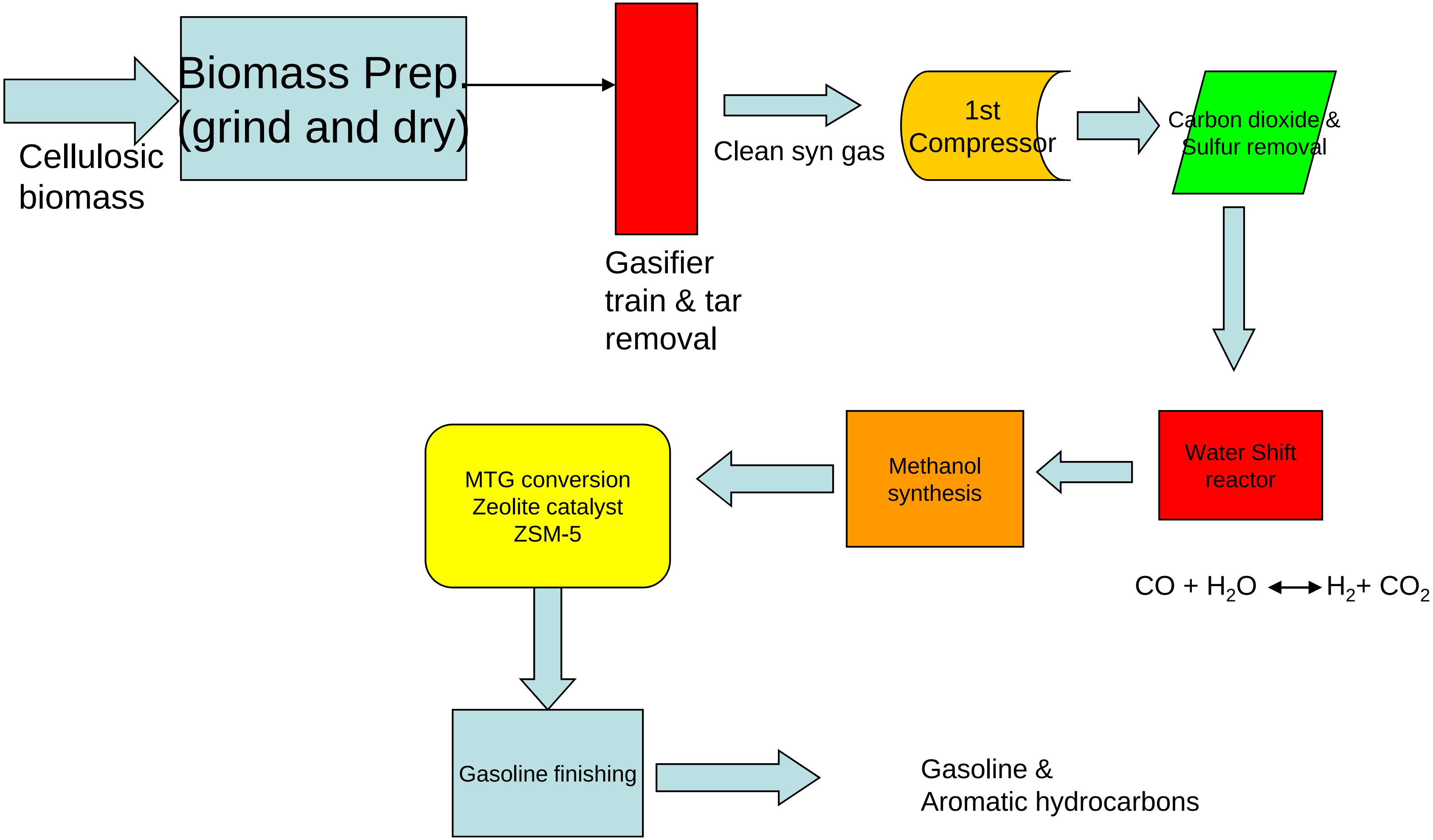
Generate heat


Biomass Gasification
Biomass Feed
Pyrolysis Zone
Biomass + Heat → C (char/tar)
Air
Air
Combustion Zone
$C + O_2 \rightarrow CO_2 + Heat$
SynGas
Reduction Zone
$C + H_2O + Heat \rightarrow CO + H_2$
$H_2O + CO \rightarrow CO_2 + H_2 + Heat$
H_2O 8 - 10 %
CO_2 17 - 12 %
CO 13 - 15 %
N_2 44 - 42 %
H_2 18 - 19 %
CH_4 2 %

“Green” Gasoline - Gasification based MTG Platform for Converting Biomass to Gasoline

- Commercially proven syngas/catalytic process currently in use in New Zealand and China.
- Converts syngas to methanol and subsequently to products such as dimethyl ether (DME) ,and gasoline with propane as a by-product.
- Based on a zeolite catalyst developed by Mobil Oil in 1970’s.
- Originally designed for conversion of methane or coal to syngas.
- Will work for cellulosic biomass with suitable adjustments (not a slam dunk) to the gasification unit.
- Smaller scale than Fischer-Tropsch process.
- Original driver was high crude prices.
- This is a chemical plant that coincidentally uses cellulosic biomass as its feedstock.

Gasification of biomass and catalytic conversion to gasoline



Financial parameters for 50 MGY plants

	Capital $MM	IRR (after tax)	NPV $MM	Production cost $/gal.
Corn ethanol w/gasifier	143	12	12	1.79
Biochemical [1]	340	7	<40>	2.34
"Ideal" [1] Biochemical	318	11.5	20	2.18
MTG gasoline [1,2]	265	17.5	86	2.16

Biomass at $ 90/ton (15% moisture)and other variables at baseline. Cellulosic ethanol producer credit [1]of $0.56/gal and blender credit [2]of $0.45/gal applied where applicable.

•MTG green gasoline beats fermentation based ethanol for IRR and NPV.

•MTG is gasoline and as such would receive both producer and blender credits. Note that 50MM gal. of gasoline is the equivalent of 76MM gal. of ethanol based on energy content.

Conclusions for Liquid Fuels from Cellulosic Biomass

Biochemical ethanol is:

- Not ready for commercialization
- In need of significant technological improvements
- Much more capital intensive($6.80/gal.) than corn ethanol ($2.80/gal.)
- Highly dependent on government subsidy for profitability

Ethanol should be viewed as a phase 1 biofuel with phase 2 being syngas catalytic conversion of cellulosic biomass to “green” gasoline.

Syngas to “green” gasoline appears to offer several advantages:

- Compatible with current use and distribution
- Commercially proven technology
- Good economics

What will it take to make it happen?

- Gasoline greater than $2.55 at the pump
- Commitment to reduced foreign oil dependence
- Emphasis on reducing green house gases
- Modification of gasifier to accommodate cellulosic biomass.
- **Availability of cellulosic biomass**

Focus on Biomass

- How much biomass does it take to make 50MM gallons of ethanol or gasoline?
- What are the potential sources of biomass in Minnesota?
- How much of Minnesota's transportation fuel needs could be provided with our current resources?

Biomass Requirements for Cellulosic Conversion Platforms

- The requirements are different for Biochemical and Thermochemical platforms for **50 million gallons per year of ethanol**
- **Biochemical** platforms (Aden model) use **655,000 tons /yr of corn stover** or **670,000 tons/yr of prairie grass**, both @ 15% moisture.
- Sustainable removal rate for corn stover is **1.5 - 2.0 tons/acre** which translates to **328,000 -437,000 acres** planted in corn.
- Sustainable yield from **prairie grass** depends on location, inputs, and mono vs. polylculture. In a recent study in the White Earth area and East Central Minnesota the yield ranged from **1.6 - 2.2 tons/acre** with low input. Hopefully this could be improved with **more research.** The acreage would be **304,000 to 418,000 acres**.
- **MTG green gasoline** platform requires **750,000 tons stover or 765,000 tons grass**. It produces **50MM gallons of gasoline** which is **equivalent to 76MM gallons of ethanol** in energy content. It also produces **7.4 million gallons of LPG**.

Biomass Supply

- Agricultural residues
  - •Corn Stover
  - •Wheat Straw & other small grains
- Forest Biomass
- Grasslands
- Brushlands

How much of Minnesota's transportation fuel needs could be provided with our current resources?

- Minnesota used 2.7 billion gallons of gasoline in 2007 (DOE). And 276 million gallons of ethanol (10%)
- In 2006 Minnesota produced 550 million gallons ethanol in 16 plants
- 5 new plants under construction in 2007/8.
- Projected total corn ethanol capacity 1,000 million gallons.
- Minnesota is mandating 20% ethanol by 2013. (552 million gallons)

- In 2008 corn prices went out of sight and this brought dramatic change to the corn ethanol business. Corn exceeded $8/bu.
- Vera Sun filed for bankruptcy because of a very unfavorable hedge position on corn which subsequently dropped in price in late 2008 (back to <$4/bu.).
- Other (than Vera Sun) plant construction was put on hold.
- Vera Sun's assets have been auctioned for a fraction of their value.

- **But what about the future and the use of cellulosic biomass for transportation fuel??**

As a first approximation let's look only at corn stover.

- Sustainable harvest potential is 14.332 million dry tons based on removal of 2 tons/acre.
- If the existing corn ethanol plants utilize corn stover to generate heat instead of fossil fuels they would consume 2.0 million TPY of stover.

- If all the remaining stover were used to make biochemical ethanol it would yield about 1,000 million gal/yr. This effectively doubles the state's capacity to 2,000 million gal/yr.
- The capital cost to build 10 -100MM gal. plants would be about **$5 billion.**

- **But, is this the "best" use of our biomass resource?**

- A gallon of **ethanol** has only **65% of the energy** content of a gallon of **gasoline.**

- **What impact could "green"gasoline make on stepping towards independence from foreign oil??**

Converting Corn Stover to “green” Gasoline

- The MTG platform would convert 12.43 million dry tons of corn stover to **828 million gallons /yr of gasoline** and **122 million gal. of propane.**
- The capital cost for 8 -100MM gal plants would be **$3.4billion.**
- This green gasoline could replace **30%** of our total gasoline consumption.
- The propane is an additional energy bonus.
- 828 million gallons of gasoline is the **equivalent of 1,266 million gallons of ethanol** in energy content.
- At the gas pump we purchase energy! What matters is the BTU content of the fuel.
- Which makes more sense **1,000 million gallons** (ethanol) and **$5.0 billion** capital or **1,266 million** (equivalent ethanol) gallons and **$3.4 billion** capital ????

How would this look on a national level?

- U.S. consumes about 140 billion GPY of gasoline.
- U.S. harvested corn acres are 77.7 million
- Setting 10% aside to run corn ethanol gasifiers this leaves 70 million acres
- Converted to gasoline by the MTG process this would yield about 9.3 billion GPY of gasoline and 1.4 billion GPY of propane.
- This is about 6.6% of the U.S. consumption rate!

86 % of the corn stover resource is in the midwest.

A potential boon for the midwest corn belt and corn growers?

Acknowledgements

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