The Emergence of a Bioeconomy

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What is the Bioeconomy?

The bioeconomy is nothing less than a revolution in the way society will obtain vital sources of carbon and energy, in the process dramatically reducing our dependence on imported petroleum. Agriculture will make this transformation possible by providing biorenewable resources for the production of biobased products.

How are we doing?

- Iowa produces one-quarter of the U.S. supply of grain ethanol
- Iowa produces twice as much ethanol as any other state
- Capacity will double in less than five years
- Ethanol is blended with 40% of U.S. gasoline supply
- Corn prices have moved up from less than $2/bu to above $3/bu

But ethanol is not the goal!

The goals are…

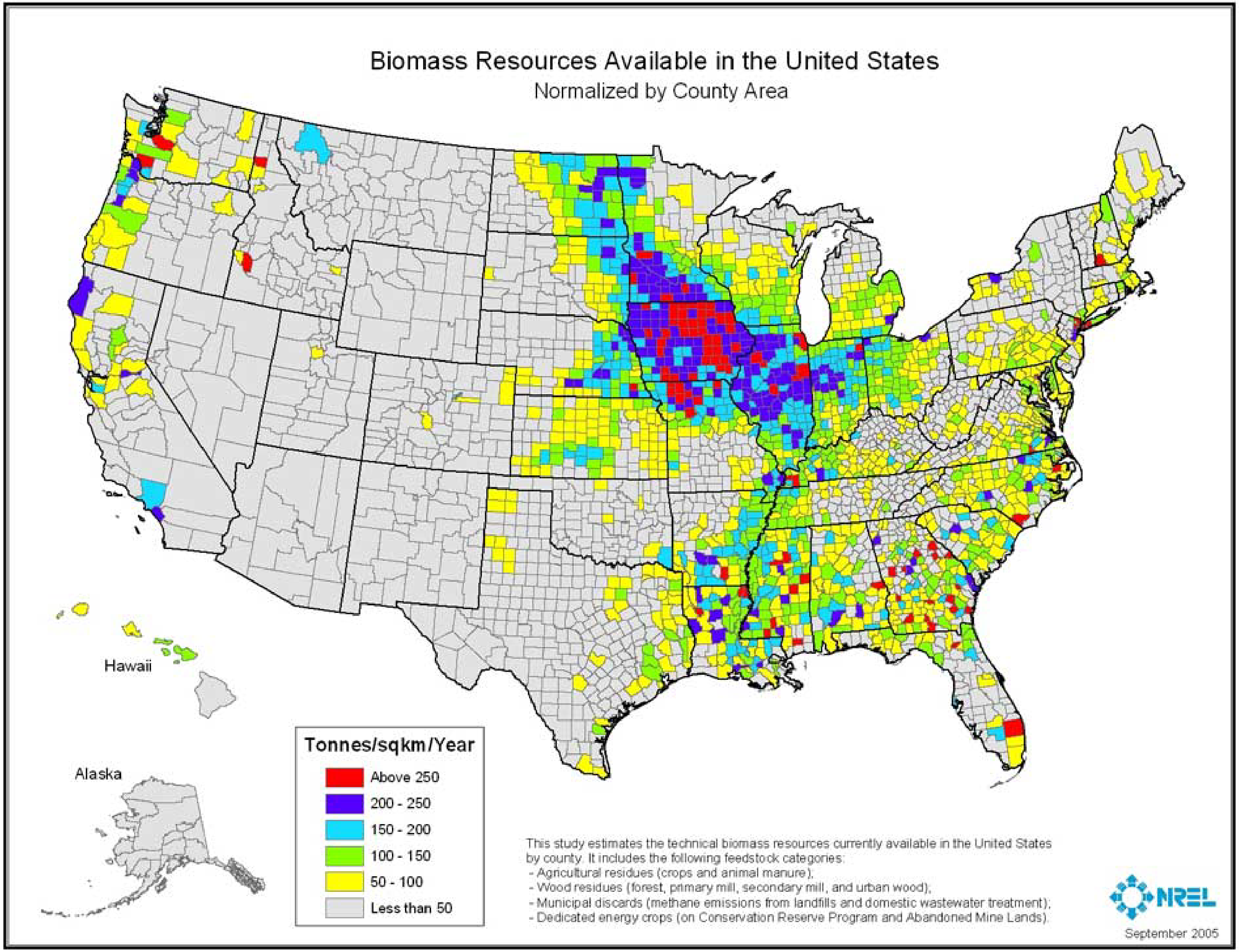
- Enhanced national security
  - Reducing dependence on imported petroleum
- Improved environmental quality
  - Including mitigation of global climate change
- Increased markets for agricultural crops
  - With the benefit of reducing need for crop support programs
- Advances in rural development
  - Creating economic opportunities where the resource is located

Courtesy USDA NRCS

Ethanol is just one pathway to our goals

Fuel	**Specific Gravity**	**LHV (MJ/kg)**	**Octane Number**	**Cetane Number**
Ethanol	**0.794**	**27**	**109**	**-**
Biodiesel	**0.886**	**37**	**-**	**55**
Methanol	0.796	20.1	109	-
Butanol	0.81	36	96 - 105	-
Mixed Alcohols	~0.80	27-36	96-109	-
Fischer-Tropsch Diesel	0.770	43.9	-	74.6
Hydrogen	0.07 (liq)	120	>130	-
Methane	0.42 (liq)	49.5	>120	-
Dimethyl Ether	0.66 (liq)	28.9	-	>55
Gasoline	0.72-0.78	43.5	91-100	-
Diesel	0.85	45	-	37-56

Iowa is the Saudi Arabia of biomass



Future for fibrous crops?

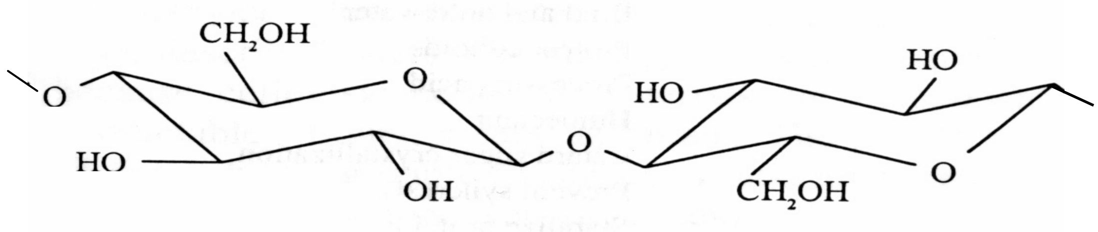
Crop	Fuel (GJ/acre)	Protein (kg/acre)
Soybeans	7.7	393
Corn	39	457
Switchgrass	61	300

- Soybeans: 38 wt% protein, 20 wt% oil, 38 bu/acre
- Corn: 10 wt% protein, 2.7 gal/bu, 180 bu/acre
- Switchgrass: 4 wt% protein, 100 gal/ton, 7.5 ton/acre

Why is cellulose more difficult to turn into fermentable sugars?

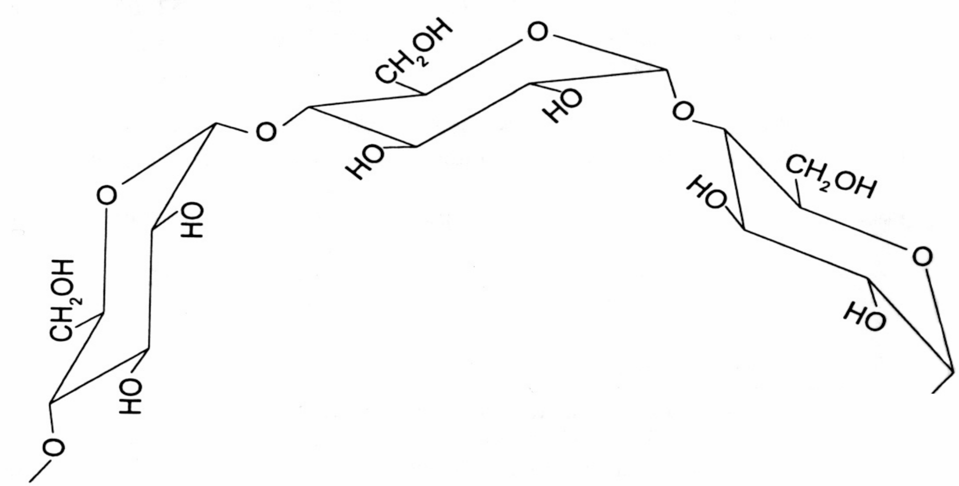
Cellulose

β 1-4 linked glucan

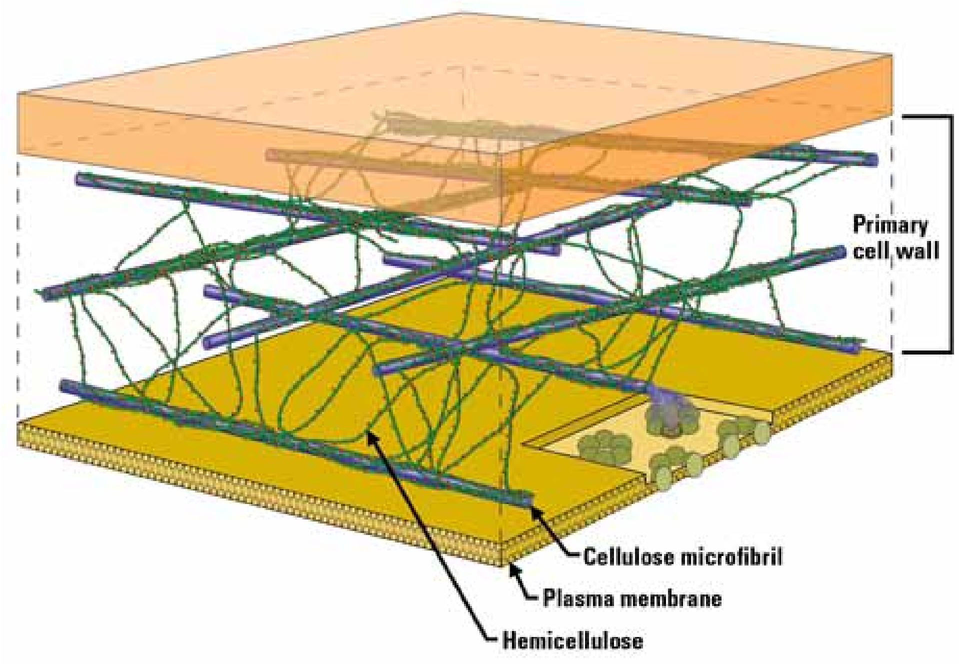


Starch

α 1-4 linked glucan



Why is cellulose more difficult to turn into fermentable sugars?

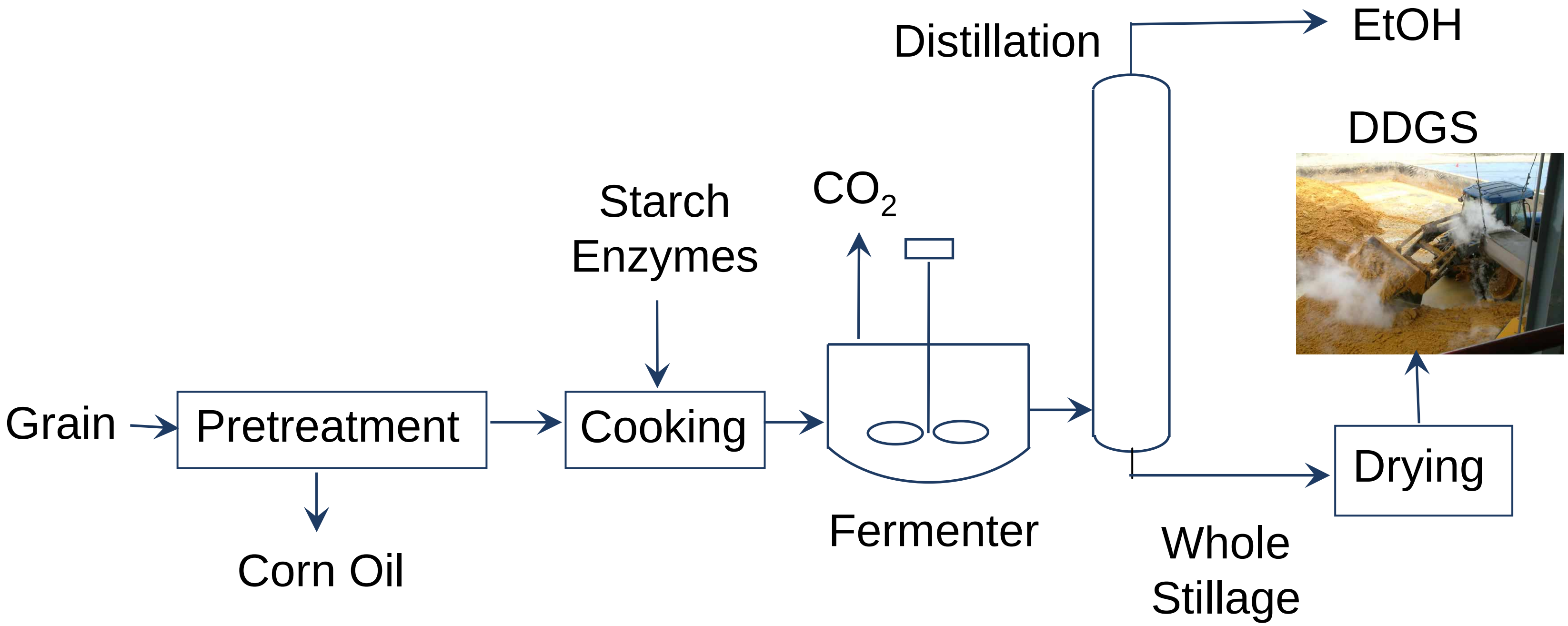


- Starch is a storage polysaccharide designed by nature as a food reservoir
- Cellulose is part of a lignocellulosic composite designed by nature to resist degradation

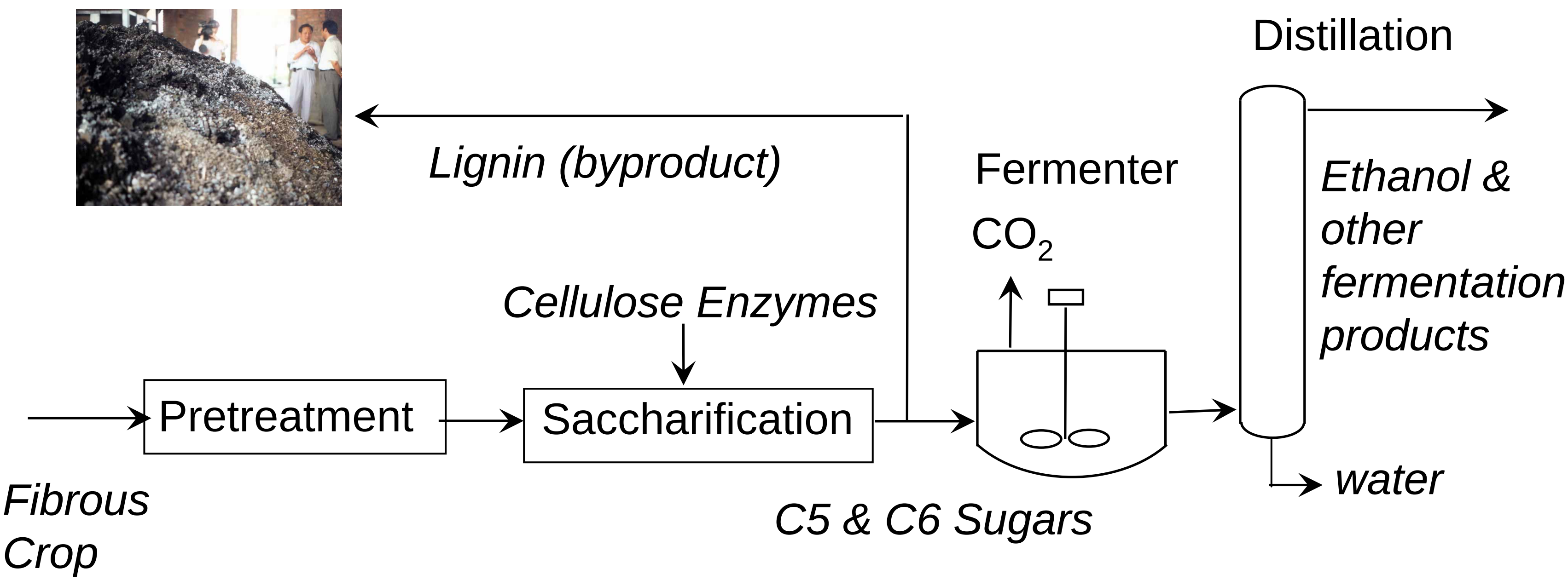
Options for biorefineries

- Oleochemical (biodiesel)
- Biochemical (sugar platform)
  - Starch
  - Cellulose
- Thermochemical
  - Gasification
  - Fast pyrolysis
- Hybrid biochemical/thermochemical

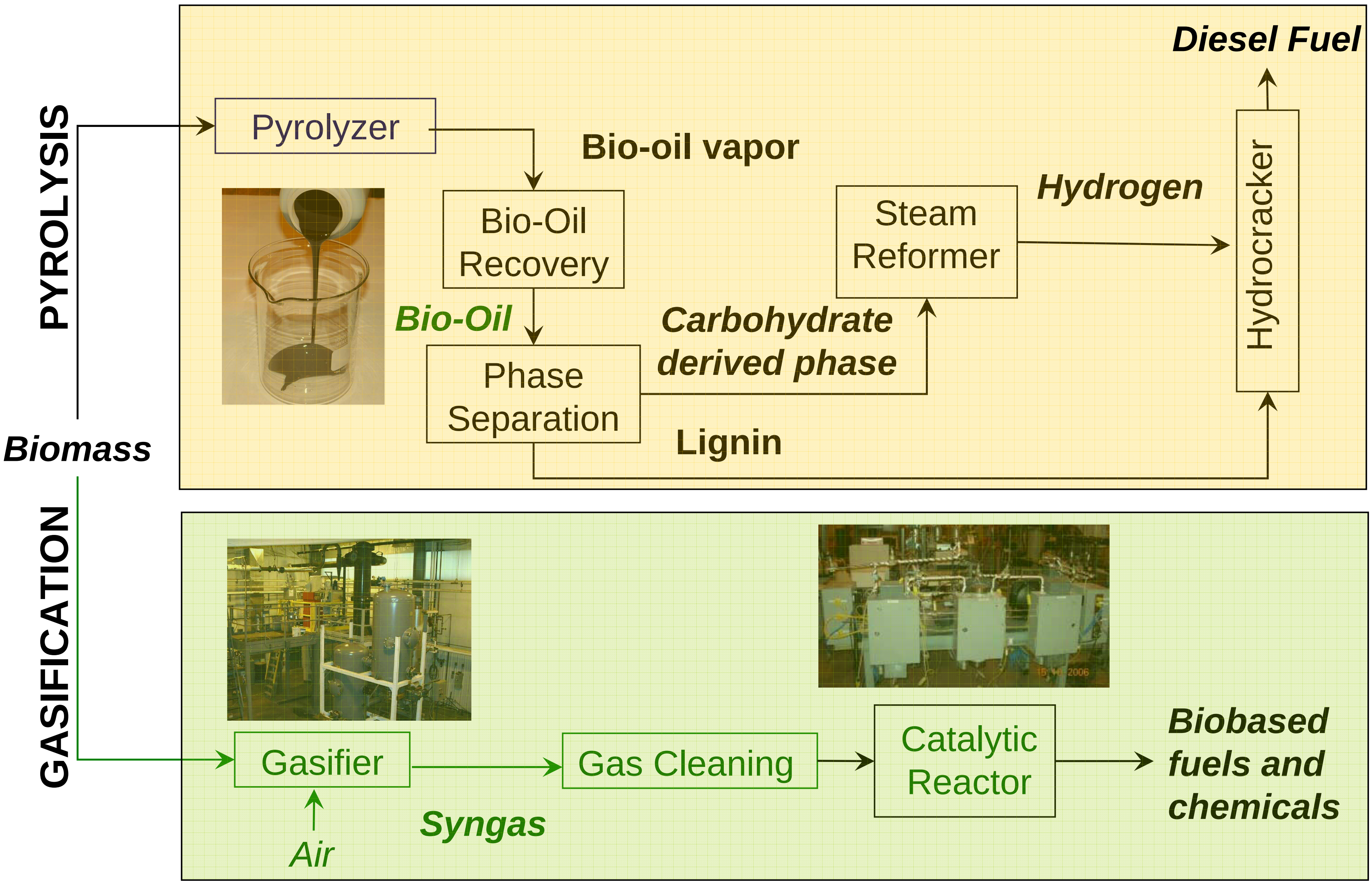
Starch-based biochemical biorefinery



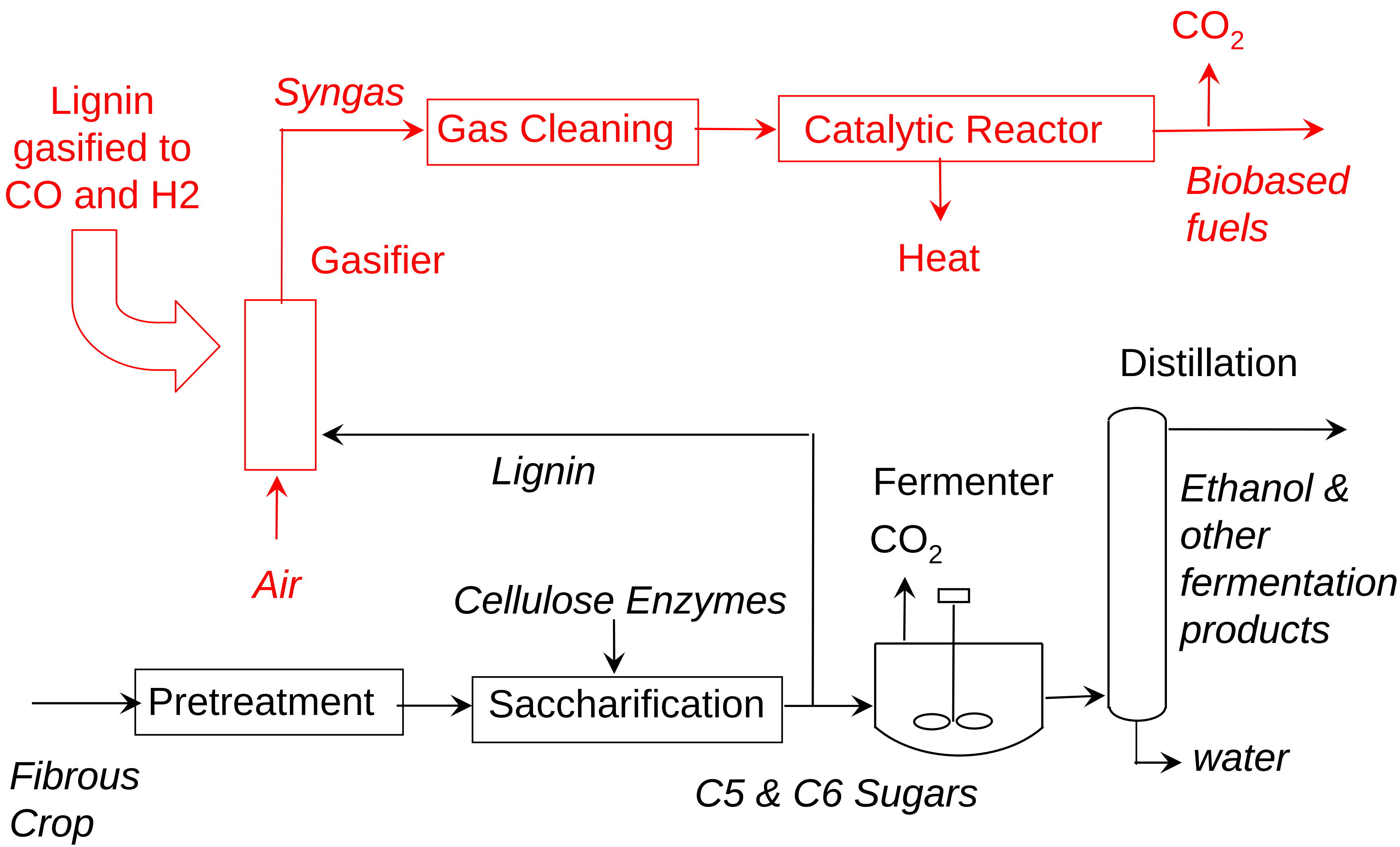
Cellulose-based biochemical biorefinery



Thermochemical routes



Hybrid biochemical/thermochemical biorefinery



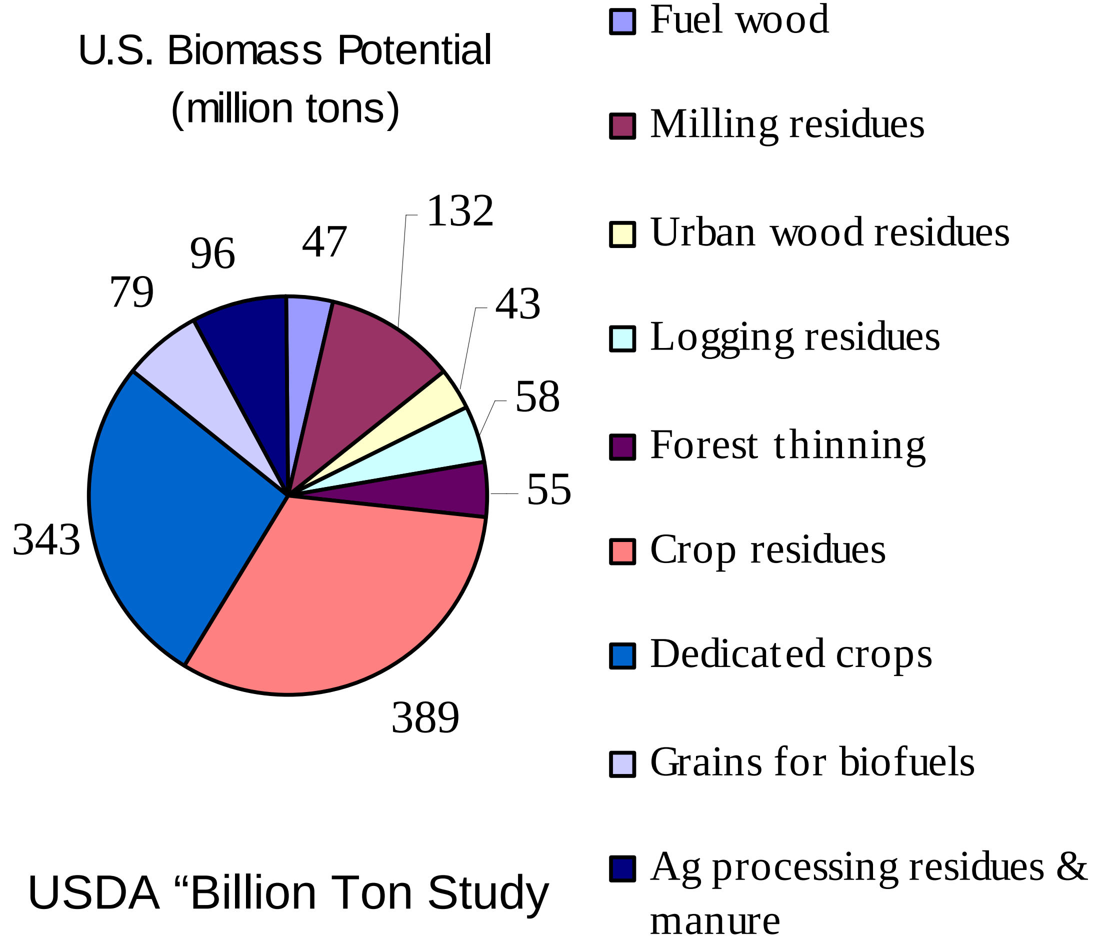
Hybrid thermochemical/biochemical biorefinery

Barriers to biorefineries

- Feedstock supply
- Fossil fuel consumption
- Energy efficiency
- Capital cost of biorefinery

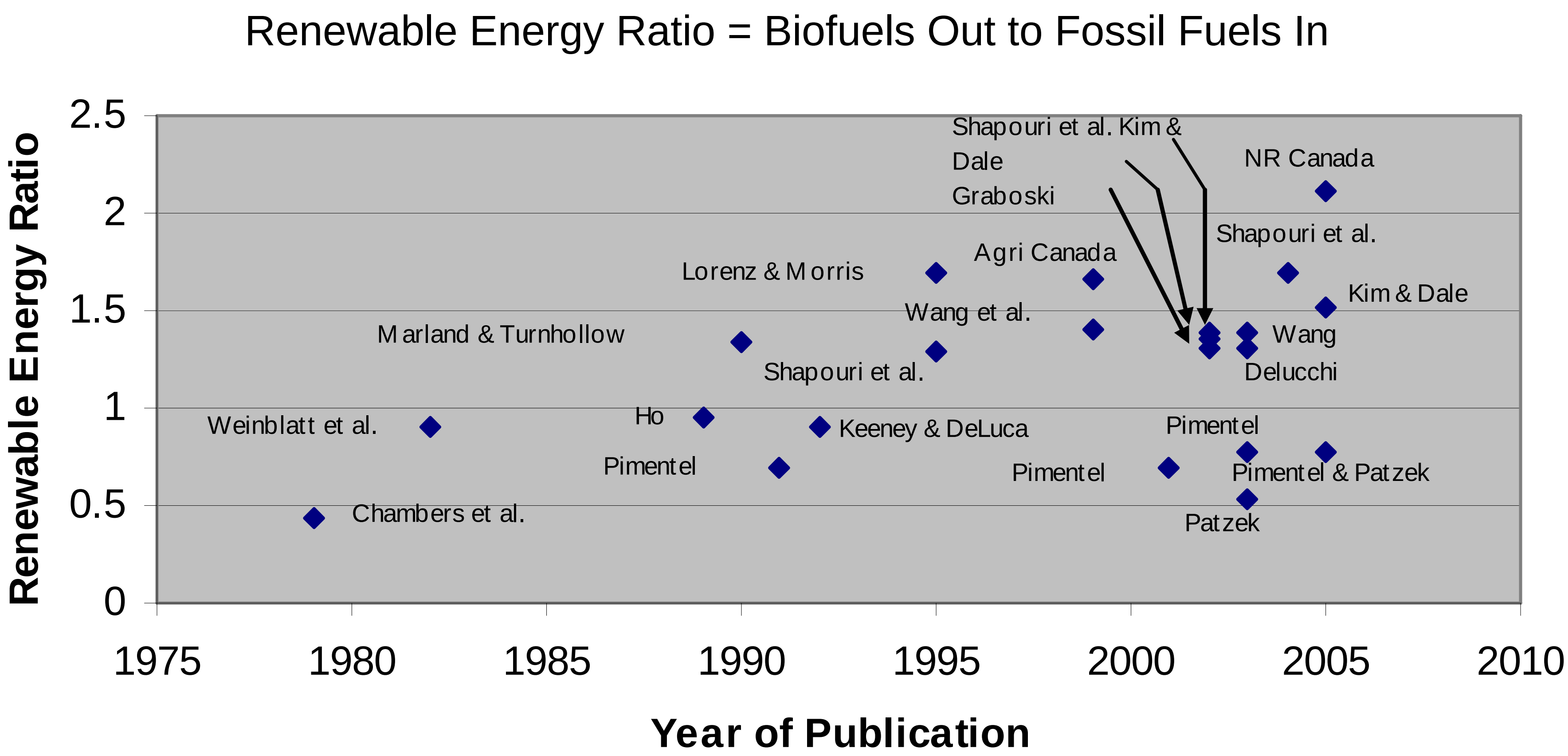
Grains represent only a small fraction of potential U.S. supply of biomass

- Total potential in U.S. is in excess of 1.3 billion tons (about 21 EJ)
- Could replace up to 66% of U.S. gasoline demand
- Grain ethanol represents less than 10% of this replacement



USDA "Billion Ton Study

The energy ratio is positive…But we could do better!



Adapted from Wang (2005)

Comparing Efficiencies

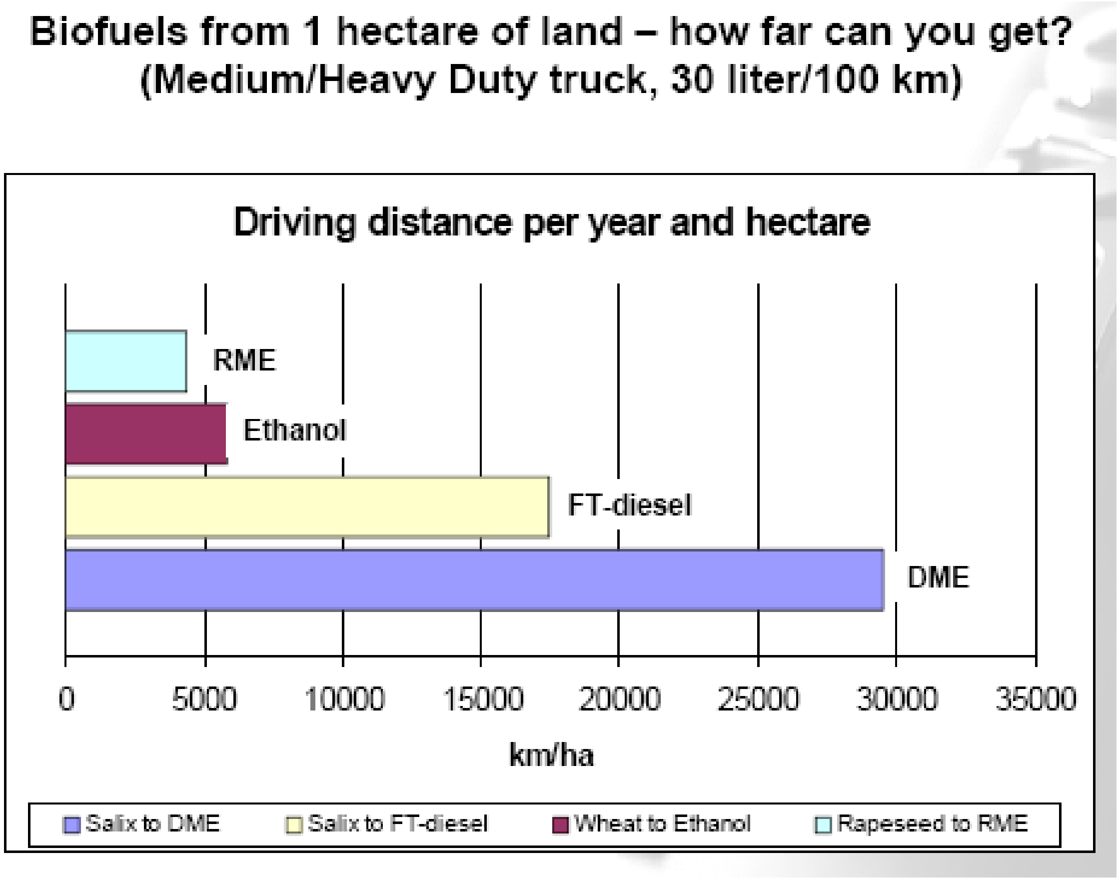
150 MMGPY* Capacity	Fuel Production Efficiency	
Grain Ethanol[1]	38%	Biochemical
Lignocellulosic Ethanol[2]	35%	
Methanol[3]	45%	Thermochemical
Hydrogen[3]	50%	
Fischer-Tropsch[4]	45%	

*BPD – barrels per day **MMGPY – million gallons per year (gasoline equivalent)
Note: Efficiencies do not account for byproduct value or power production although production costs do.

References for Base Case Data:

1. A. McAloon, F. Taylor, W. Yee, K. Ibsen, and R. Wooley, “Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks,” National Renewable Energy Laboratory Report, October 2000.
2. C. N. Hamelinck, G. van Hooijdonk, and A. PC Faaij, “Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle-, and long-term,” Biomass and Bioenergy. 22, 384-410, 2005
3. C. N. Hamelinck, and A. Faaij, “Future prospects for production of methanol and hydrogen from biomass,” Journal of Power Sources 111, 1-22, 2002.
4. M. J.A. Tijmensen, A. P.C. Faaij, C. N. Hamelinck, and M. R.M. van Hardeveld, “Exploration of the possibilities for production of Fischer Tropsch liquids and power via biomass gasification,” Biomass and Bioenergy 23, 129-152, 2002.

Thermochemical synfuels have yield advantage

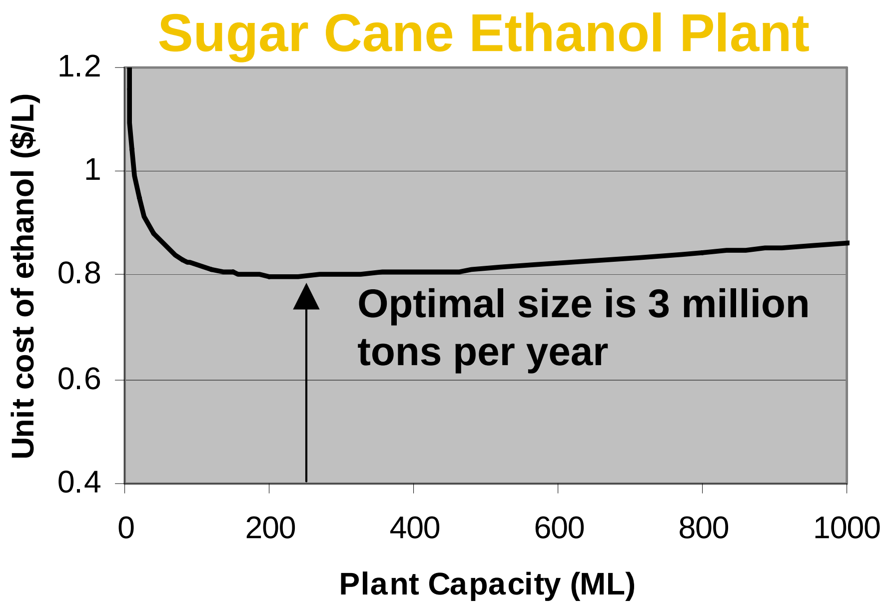


Source: Röj, A.*, Automotive Fuels from Biomass – What is the best road forward, First International Biorefinery Workshop, Washington, D.C., July 20-21, 2005, http://www.biorefineryworkshop.com/presentations/Roj.pdf

* Volvo Technology Corporation, anders.roj@volvo.com

How big do we build them?

- Trade-off between cost of biomass transportation and economies of scale of biorefinery



Comparing Costs

150 MMGPY* Capacity	Capital Cost ($/bpd)*	Operating Cost ($/gal)	Feedstock Cost
Grain Ethanol[1]	13,000	**$1.74/gal**	**$3.00/bu**
Lignocellulosic Ethanol[2]	76,000	1.76	$50/ton
Methanol[3]	66,000	1.19	$50/ton
Hydrogen[3]	59,000	1.07	$50/ton
Fischer-Tropsch[4]	86,000	1.87	$50/ton

*BPD – barrels per day **MMGPY – million gallons per year (gasoline equivalent)
Note: Operating costs include credit for byproduct utilization.

References for Base Case Data:

1. A. McAloon, F. Taylor, W. Yee, K. Ibsen, and R. Wooley, “Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks,” National Renewable Energy Laboratory Report, October 2000.
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Summary

- Biorefineries based on lignocellulosic biomass will be essential to meeting future renewable fuel demand
- Several options for lignocellulosic biorefineries
  - Biochemical (sugar platform)
  - Thermochemical
  - Hybrid systems
- Too early to pick the winners and losers