How Good Is Our Bet on Biofuels?

RICE

Chemical and Biomolecular Engineering

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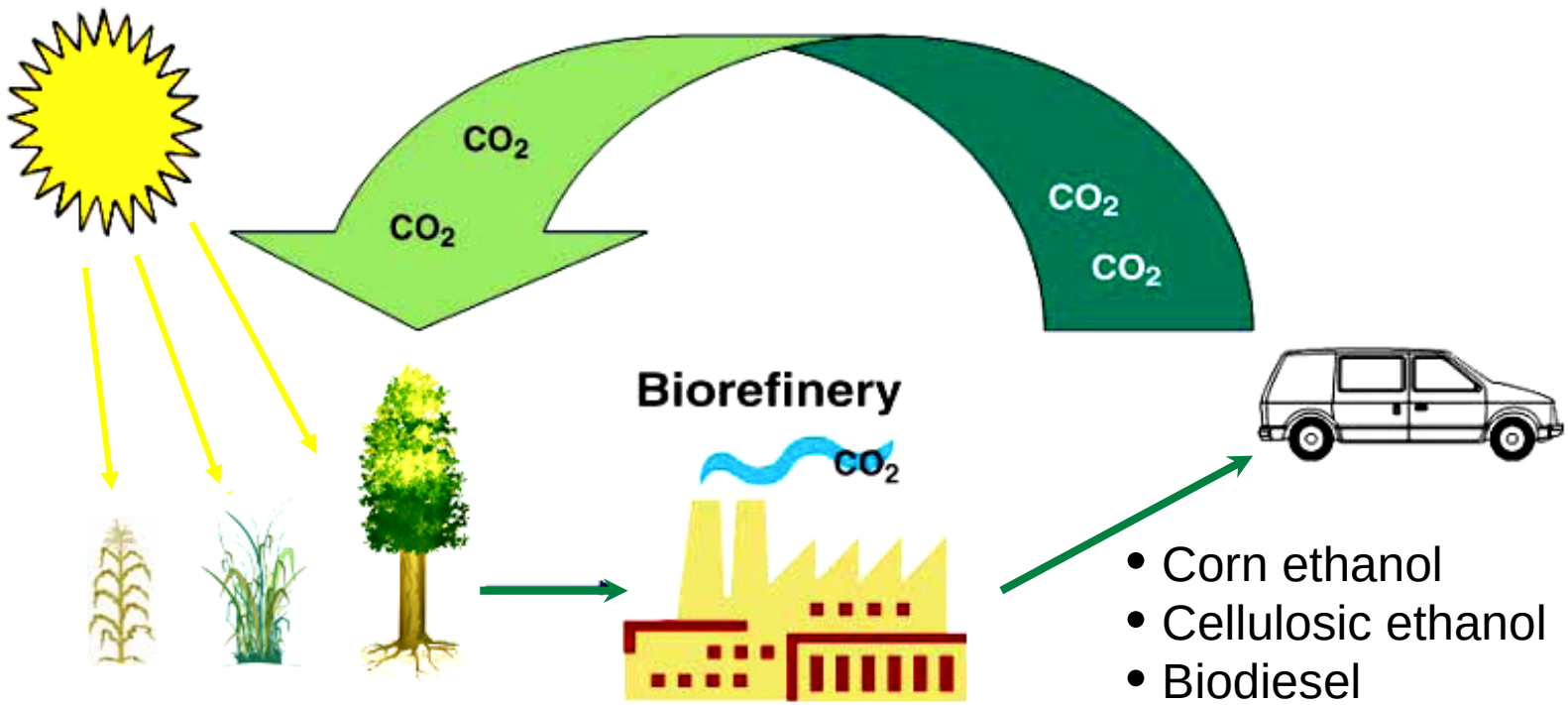
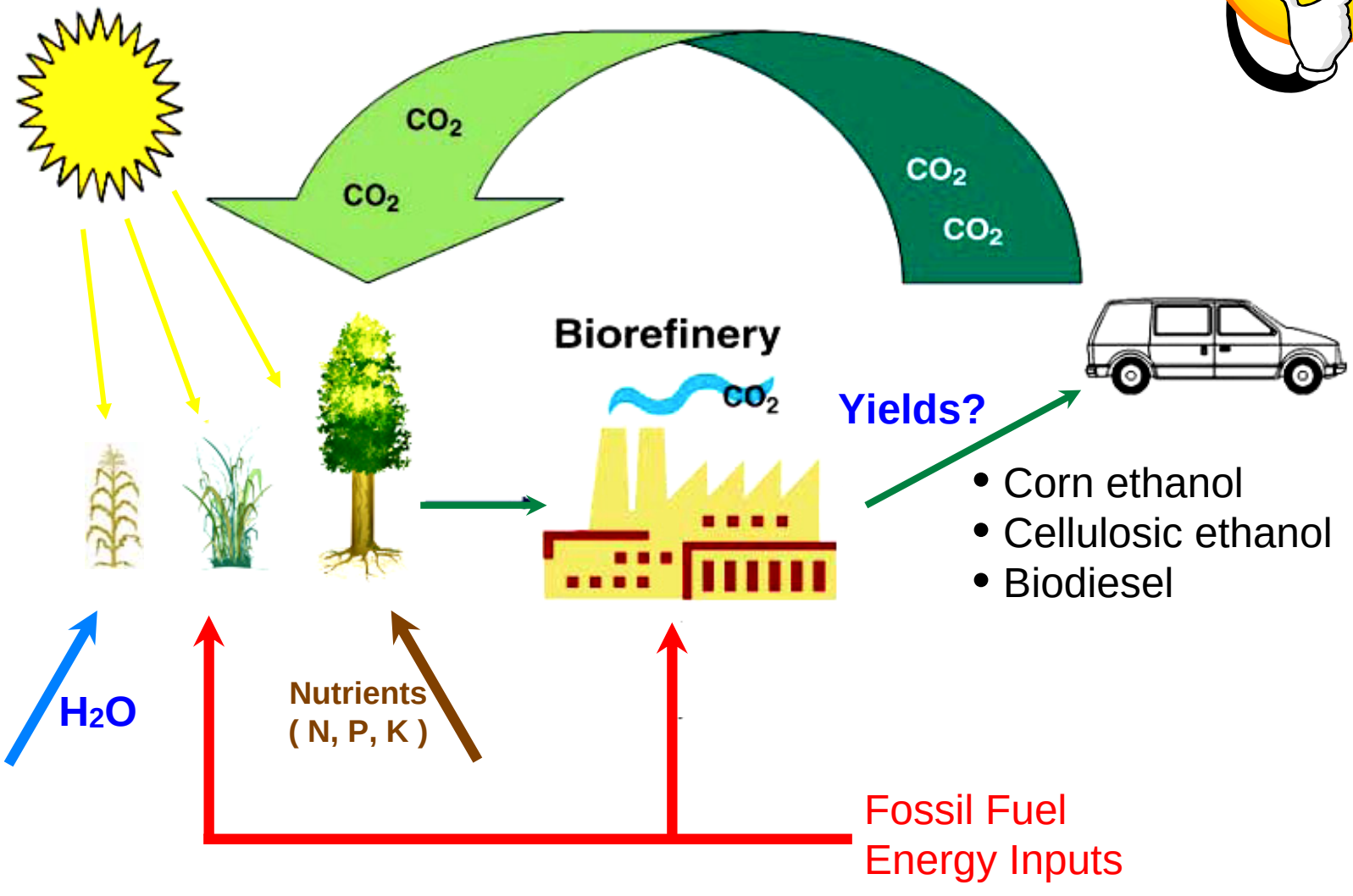
Production of Biofuels



Facts or Hype?

- Biofuels help us fight global warming by reducing greenhouse gas emissions!
- There is enough excess biomass or agricultural waste in the U.S. to produce more than 130 billion gallons of ethanol per year. This is equivalent to more than 50% of our 2005 gasoline consumption!
- Biofuels can reduce our dependence on fossil fuels and imported oil!

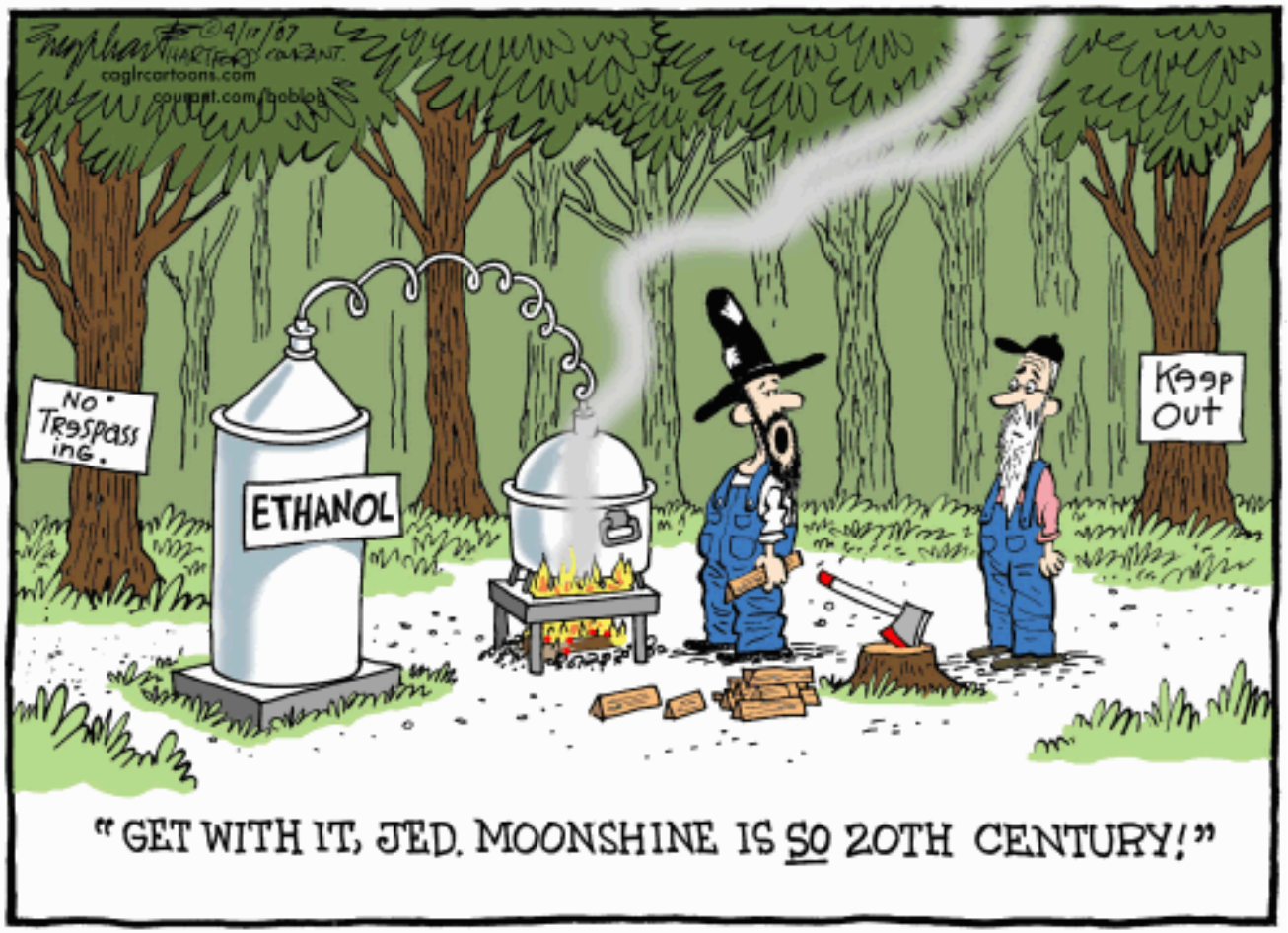
Complications...



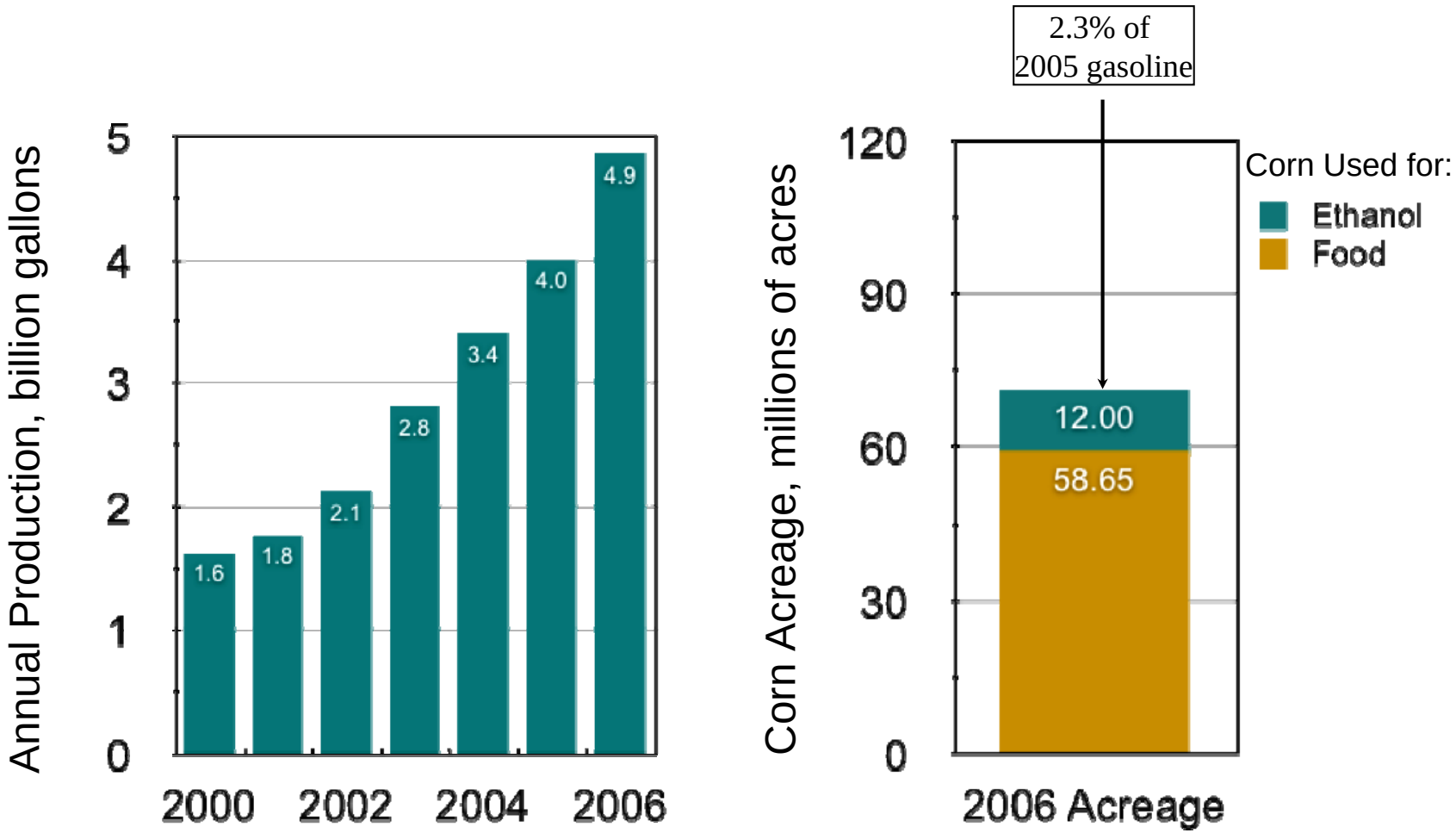
Questions

- How much fuel can we produce sustainably from each source?
- How much energy do we have to spend to produce a gallon of biofuel?
- Will we reduce carbon dioxide emissions by displacing gasoline (or petro-diesel) with this biofuel?
- Are there any other effects of biofuel production on the environment? On our water resources? On food production?

Corn Ethanol

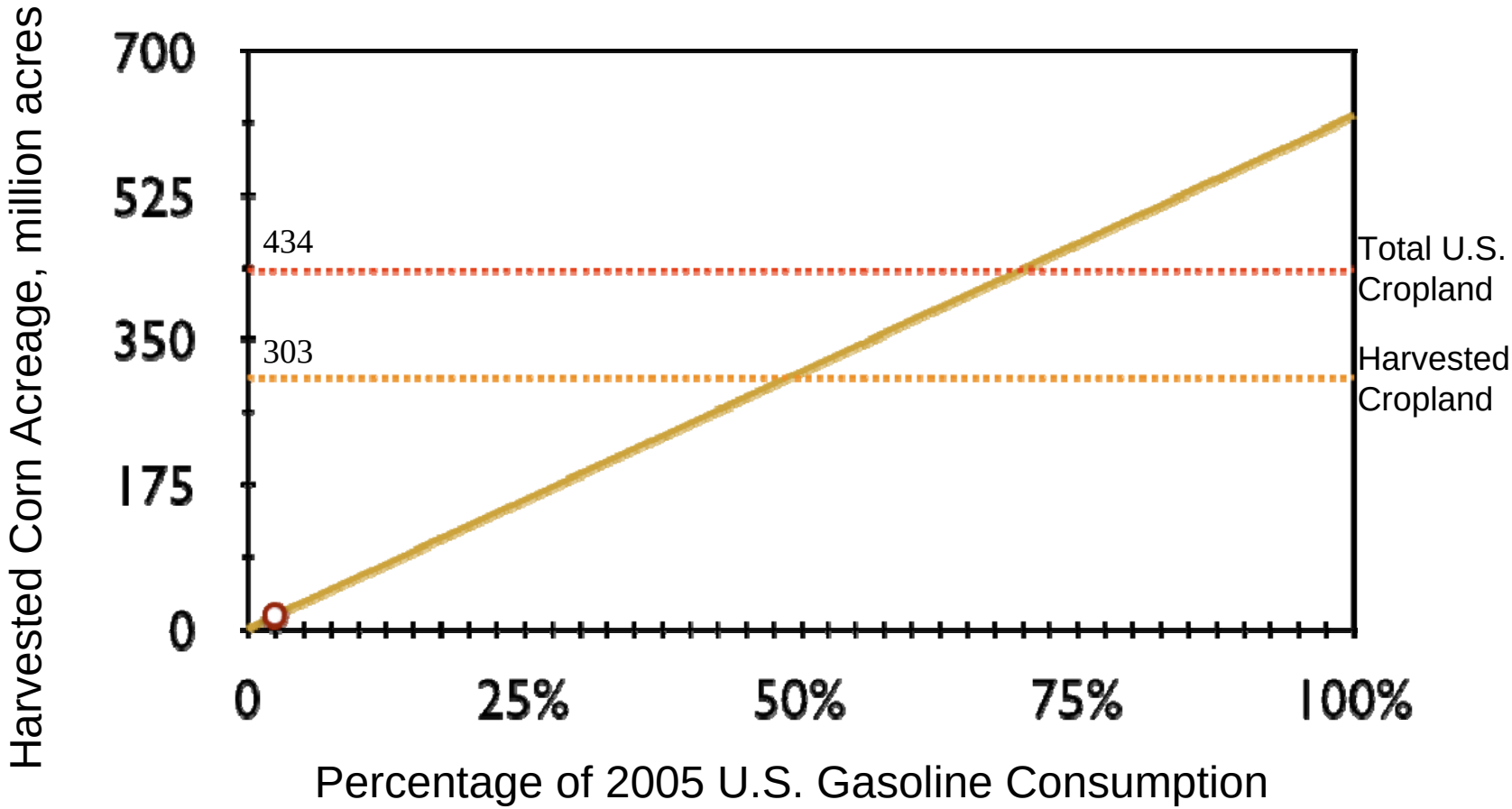


U.S. Corn Ethanol Production



Source: DOE, Energy Information Administration (EIA), 2007

Land Required to Meet U.S. Gasoline Needs with Corn Ethanol



Energy Balance for Corn Ethanol

Energy Metric

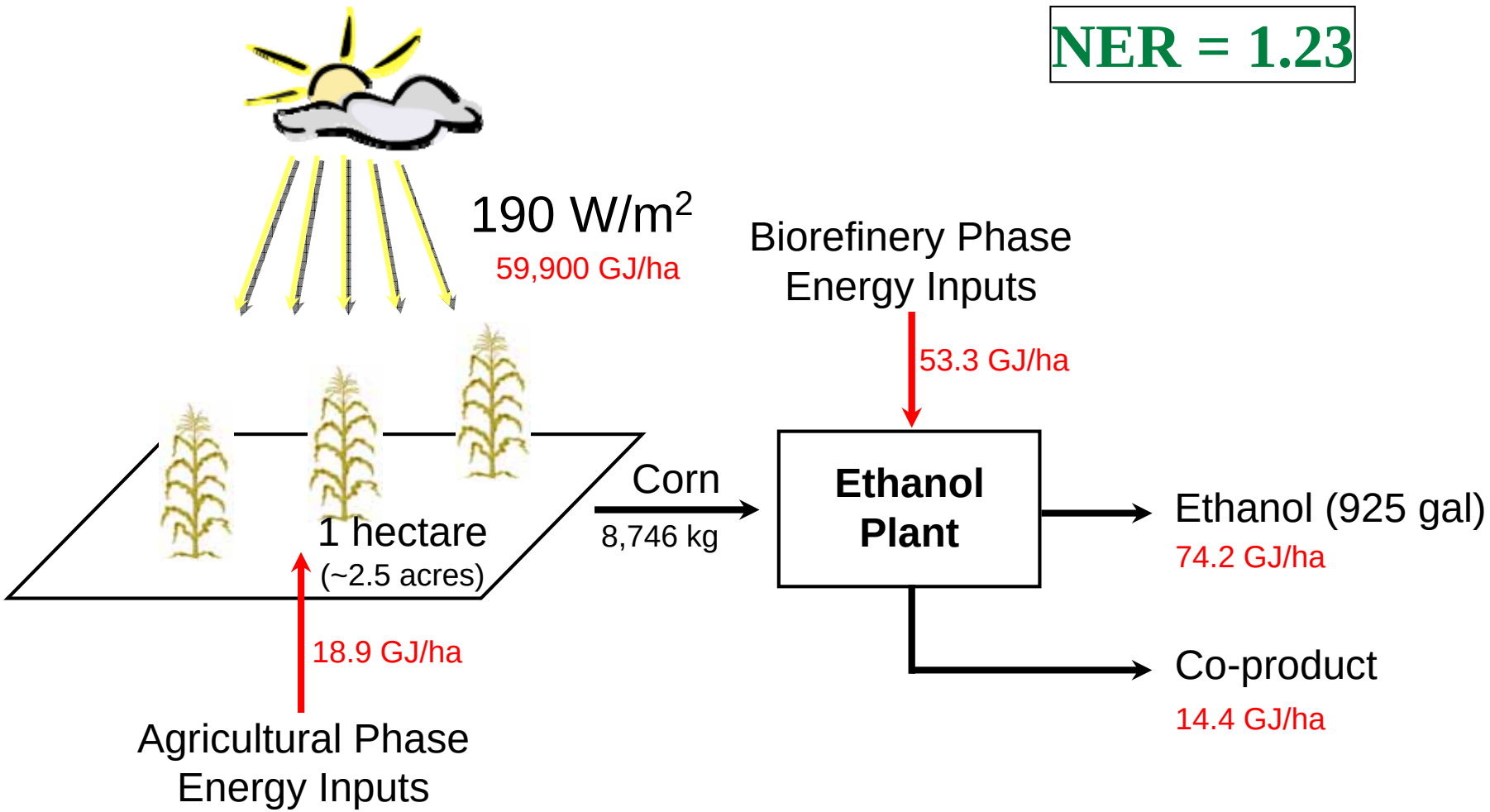
Net Energy Ratio (NER) :

$$NER = \frac{[\text{Energy Outputs}]}{[\text{Energy Inputs}]} = \frac{\left[\begin{array}{c}\text{Energy Content}\\ \text{of Fuel}\end{array}\right] + \left[\begin{array}{c}\text{Energy Content}\\ \text{of Co-product}\end{array}\right]}{\left[\begin{array}{c}\text{Energy Used in}\\ \text{Agricultural Phase}\end{array}\right] + \left[\begin{array}{c}\text{Energy Used}\\ \text{in Biorefinery}\end{array}\right]}$$

NER > 1 **GOOD**

NER< 1 **BAD**

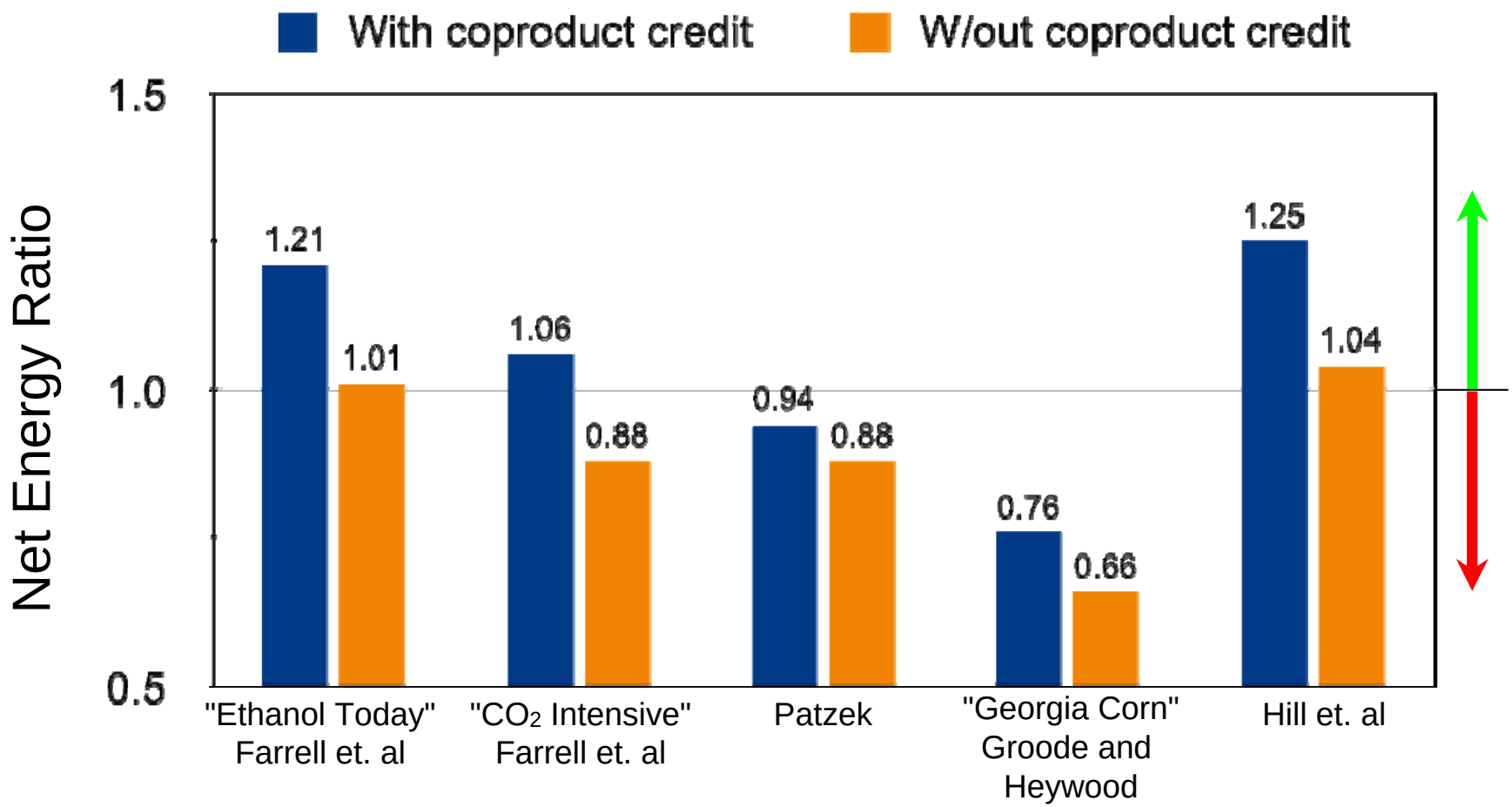
Energy Balance for Corn Ethanol



Efficiency of Solar Energy Conversion = 0.027%

Data from Farrell et al., *Science*, **181**, 506 (2006)

Energy Balance for Corn Ethanol



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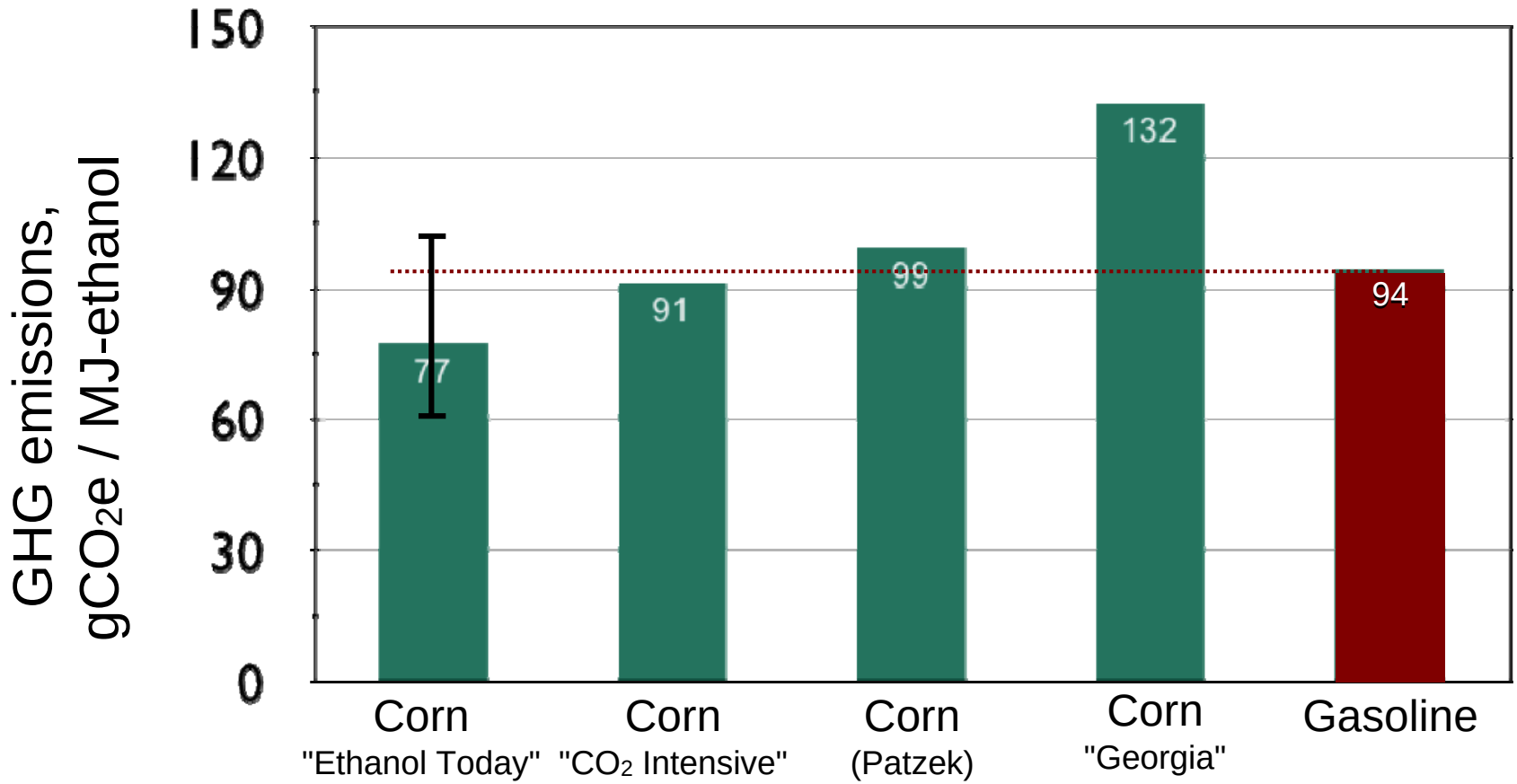
GHG Emissions for Corn Ethanol



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Cellulosic Ethanol

Ethanol produced from:

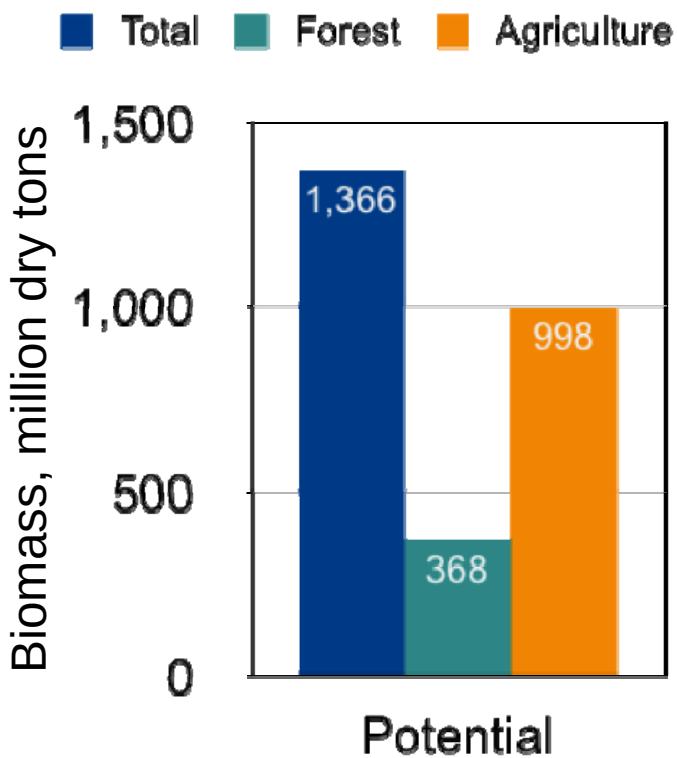
- agricultural waste (corn stover), or
- energy crops (switchgrass, poplar tree)

Corn Stover

Switchgrass

Poplar

1.3 Billion Ton Scenario



Source: U.S Department of Energy, 2005

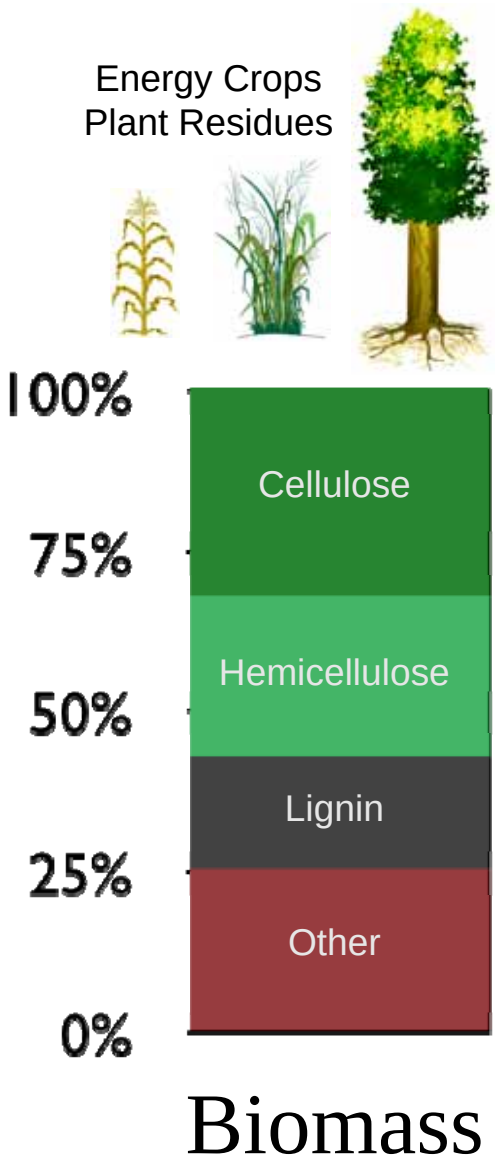
Goal

- By 2030, replace 30% of U.S. gasoline consumption in 2004 with cellulosic ethanol.
- DOE estimate: *750 million tons of dry biomass* will be needed to produce this amount of ethanol.

Potential

- More than *1.3 billion tons of dry biomass* from forest and agricultural resources through:
- Increased yields
- No-till cultivation
- Perennial crops on 55 million acres (switchgrass, poplar trees)

Cellulosic Ethanol Production



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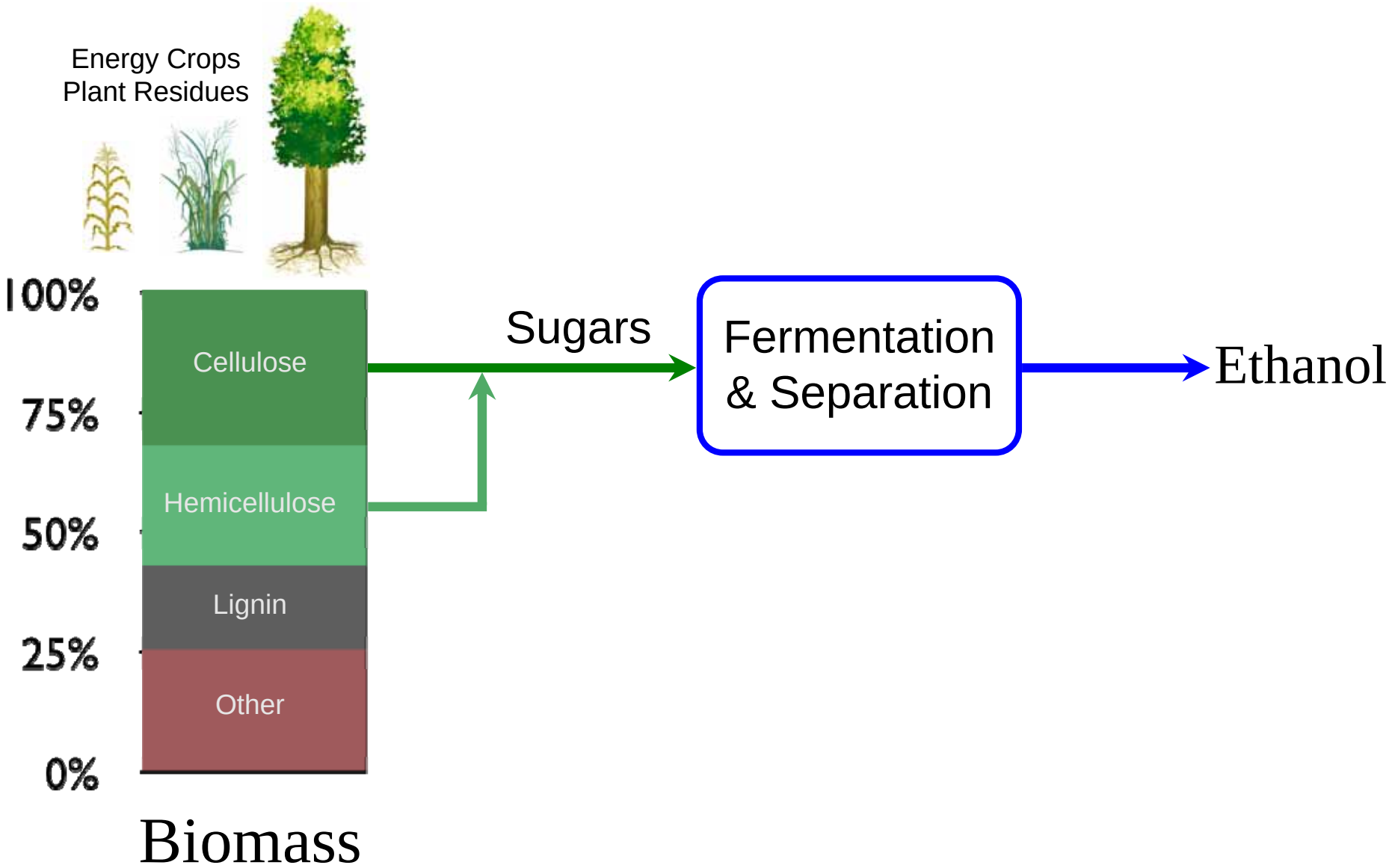

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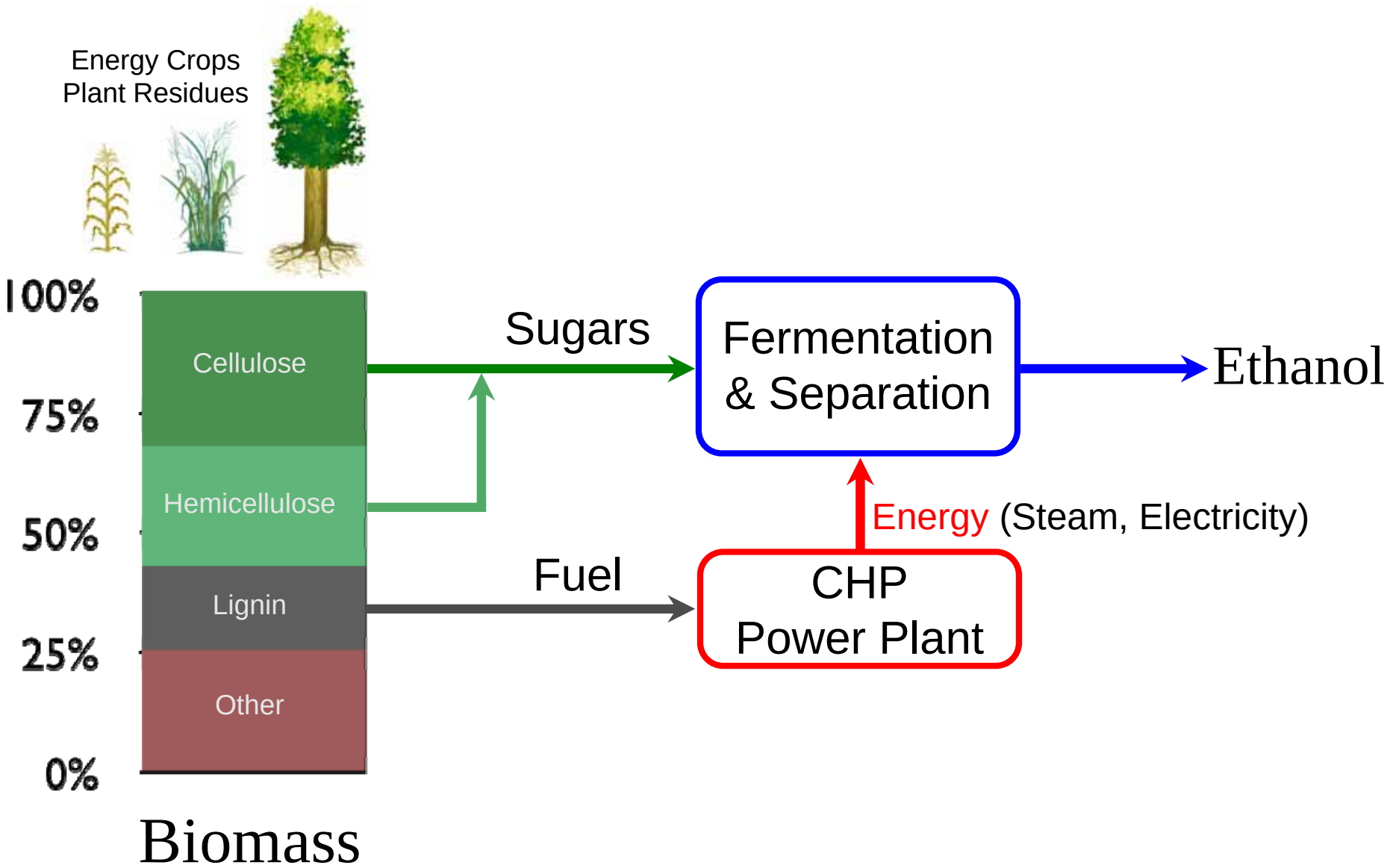

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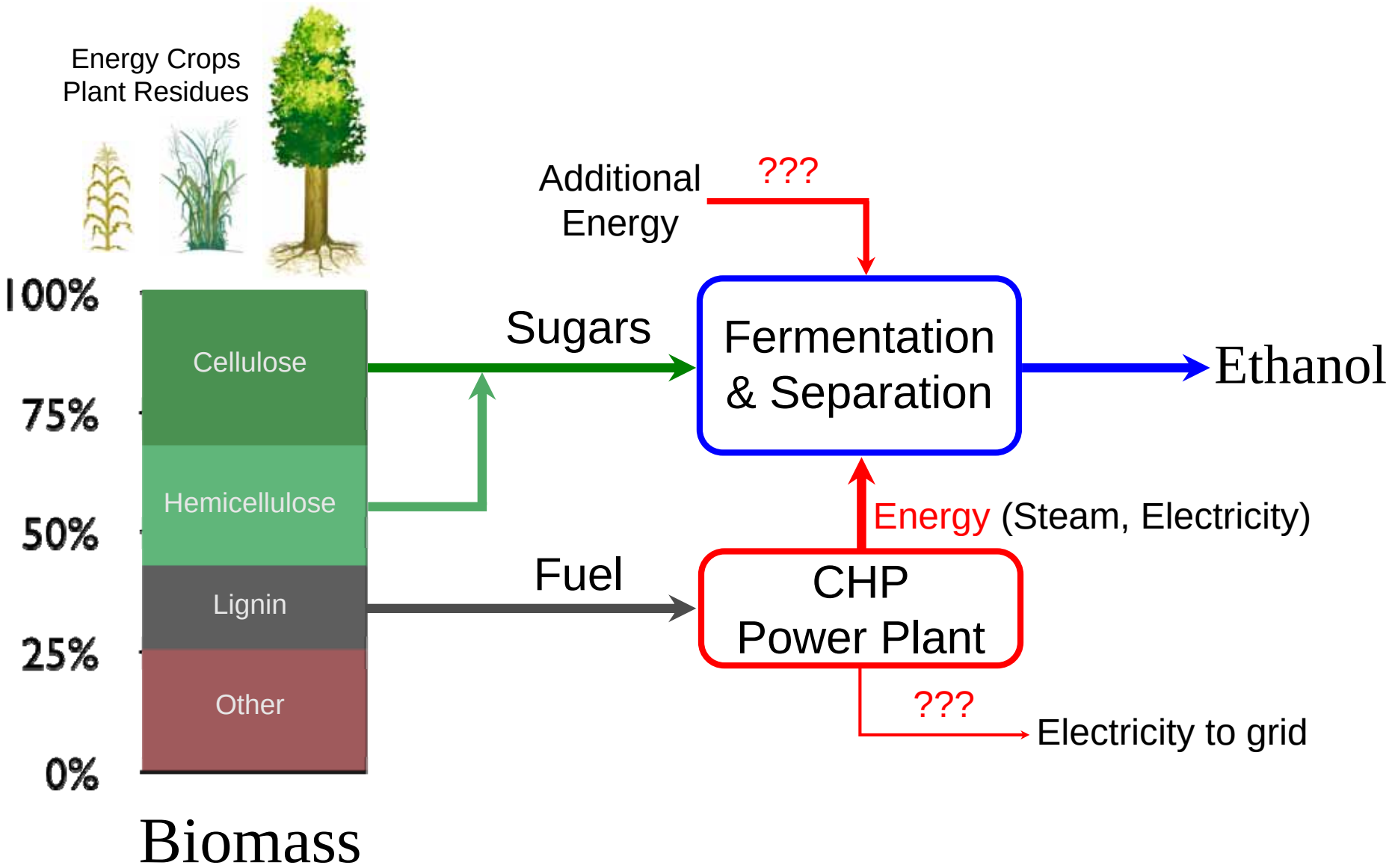
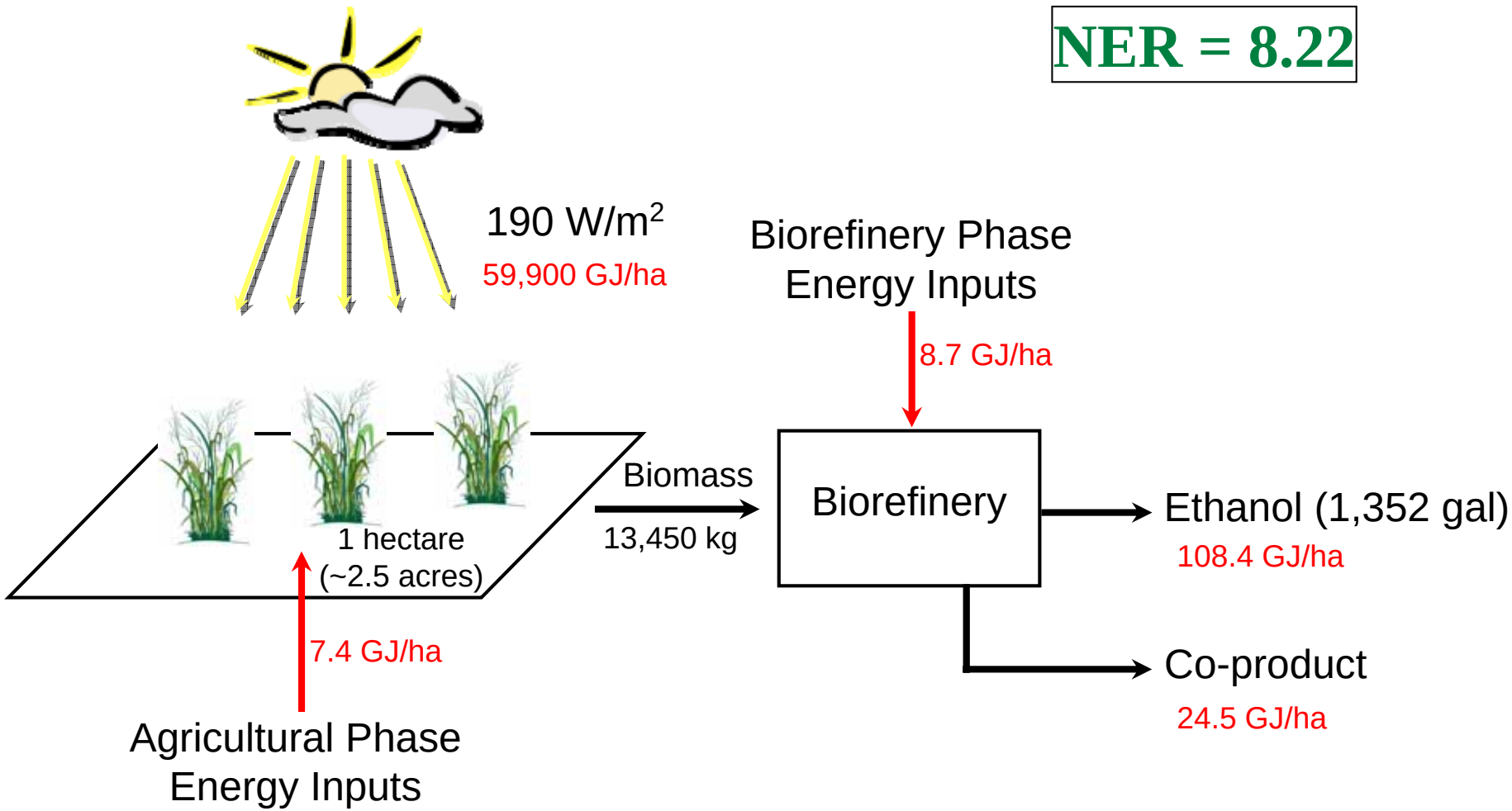


Energy Balance for Switchgrass [1]

NER = 8.22



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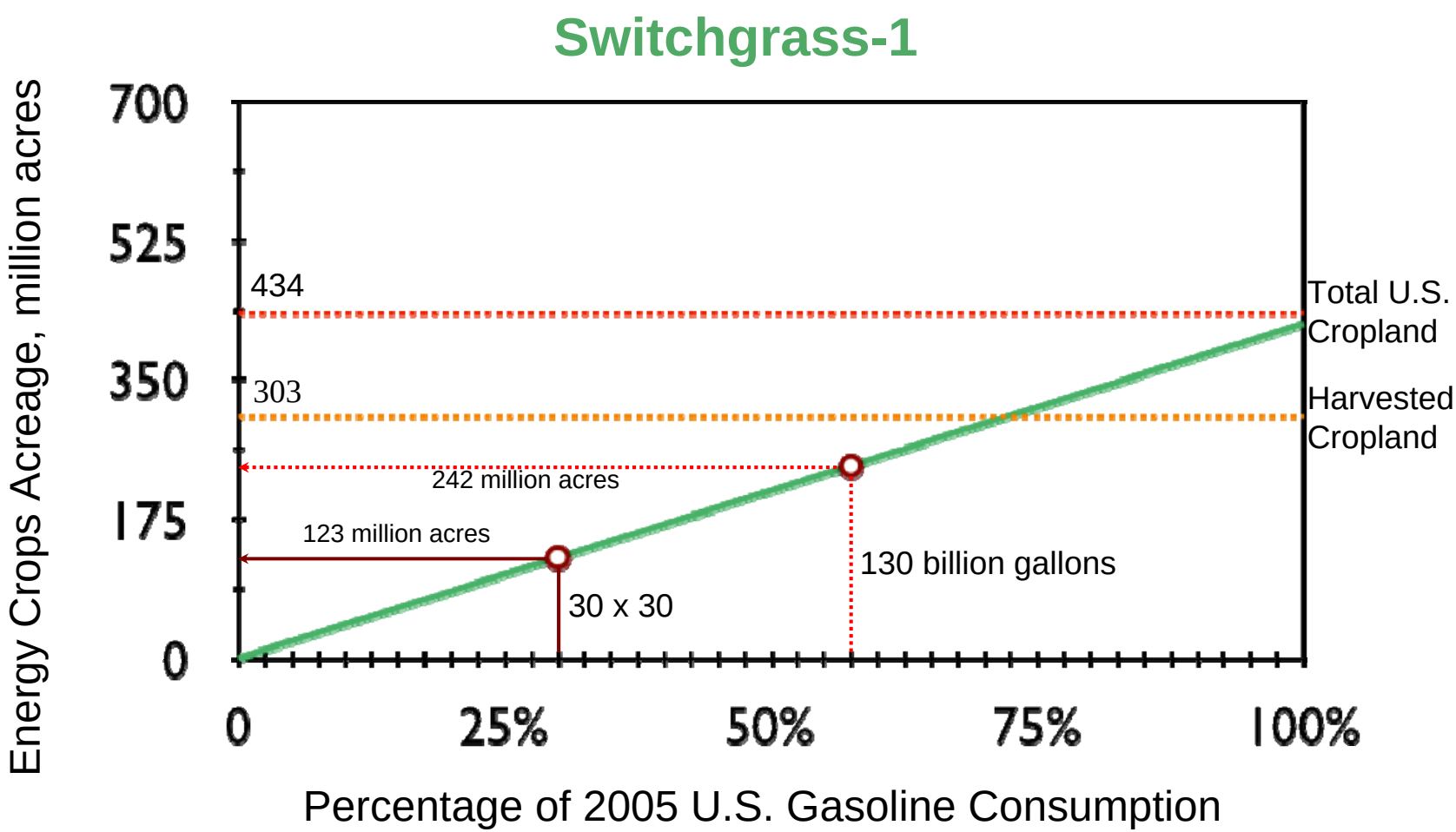
Land Required to Meet U.S. Gasoline Needs w/ Cellulosic Ethanol



Data from Farrell et al., *Science*, **181**, 506 (2006)

How much land will we need?

~ 126 million acres needed for 69 billion gallons of ethanol

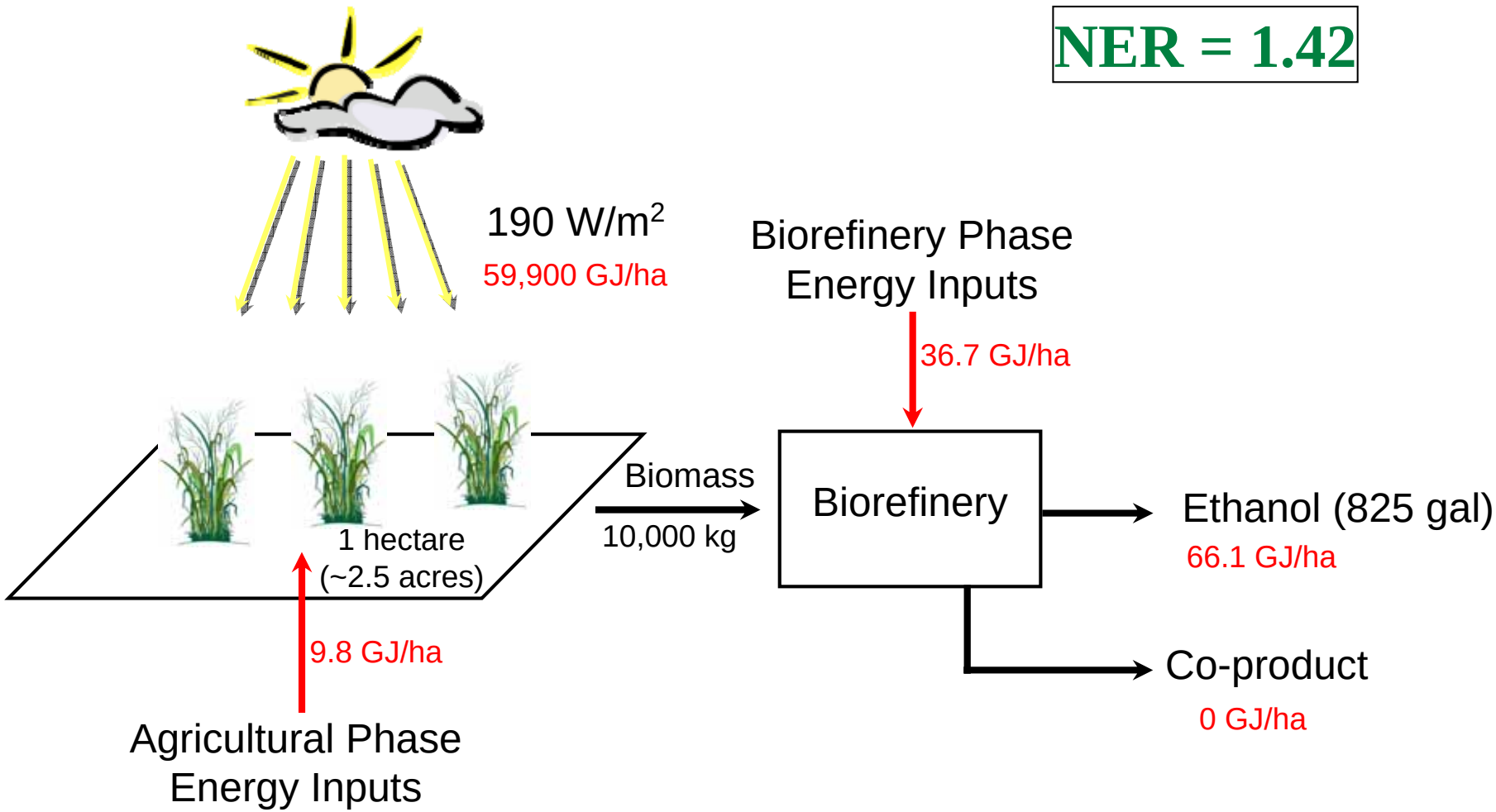
US Statistics

Total Farmland = 938 million acres

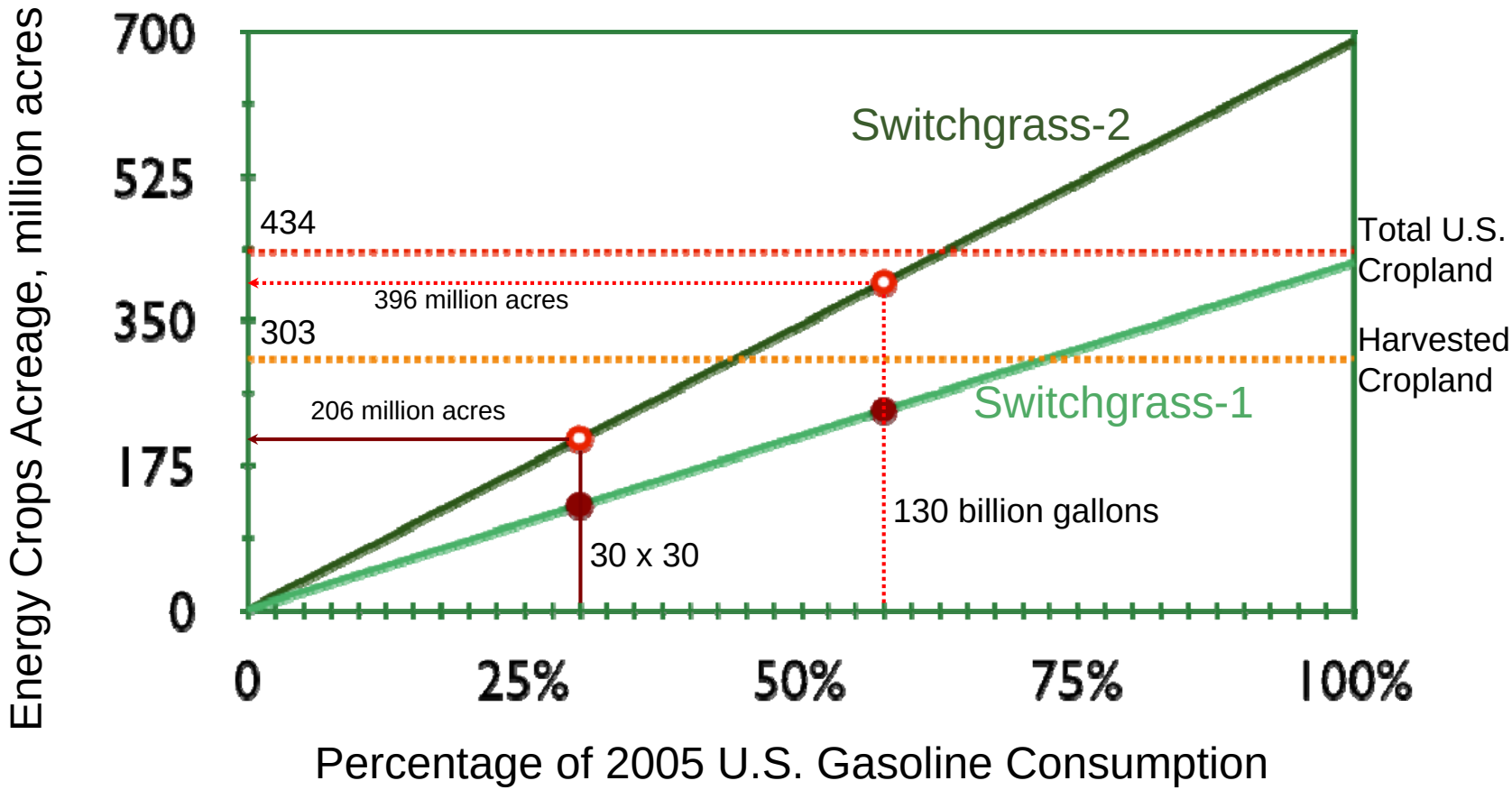
Total Cropland = 434 million acres

Harvested Cropland = 303 million acres

Energy Balance for Switchgrass [2]



Land Required to Meet U.S. Gasoline Needs w/ Cellulosic Ethanol



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~ 206 million acres needed for 69 billion gallons of ethanol

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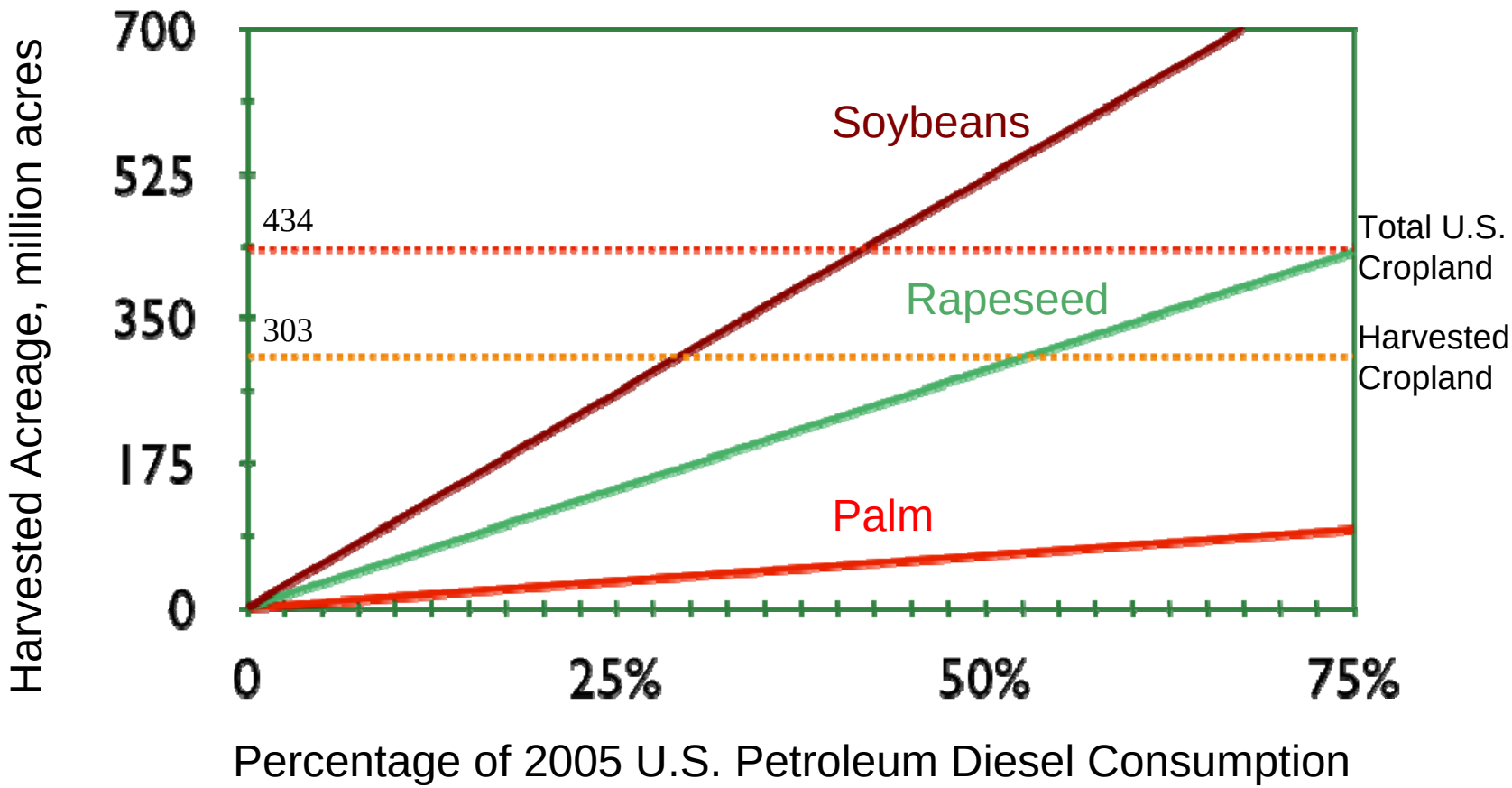
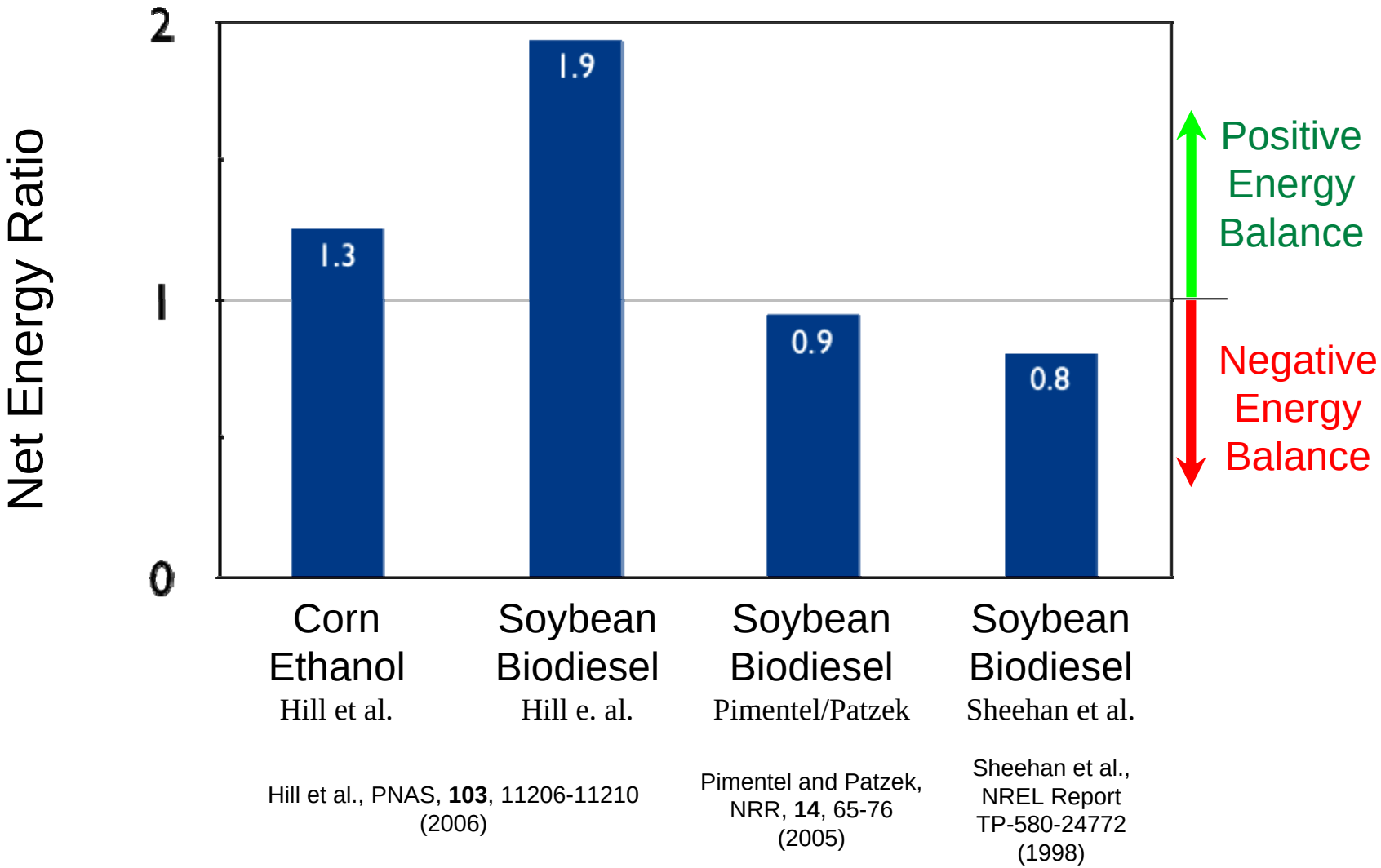
Biodiesel


WOULD YOU LIKE FRIES WITH THAT?!
FISH and CHIPS
HAMBURGERS
THIS TRUCK RUNS ON BIODIESEL!
4X4
BIO DIESEL

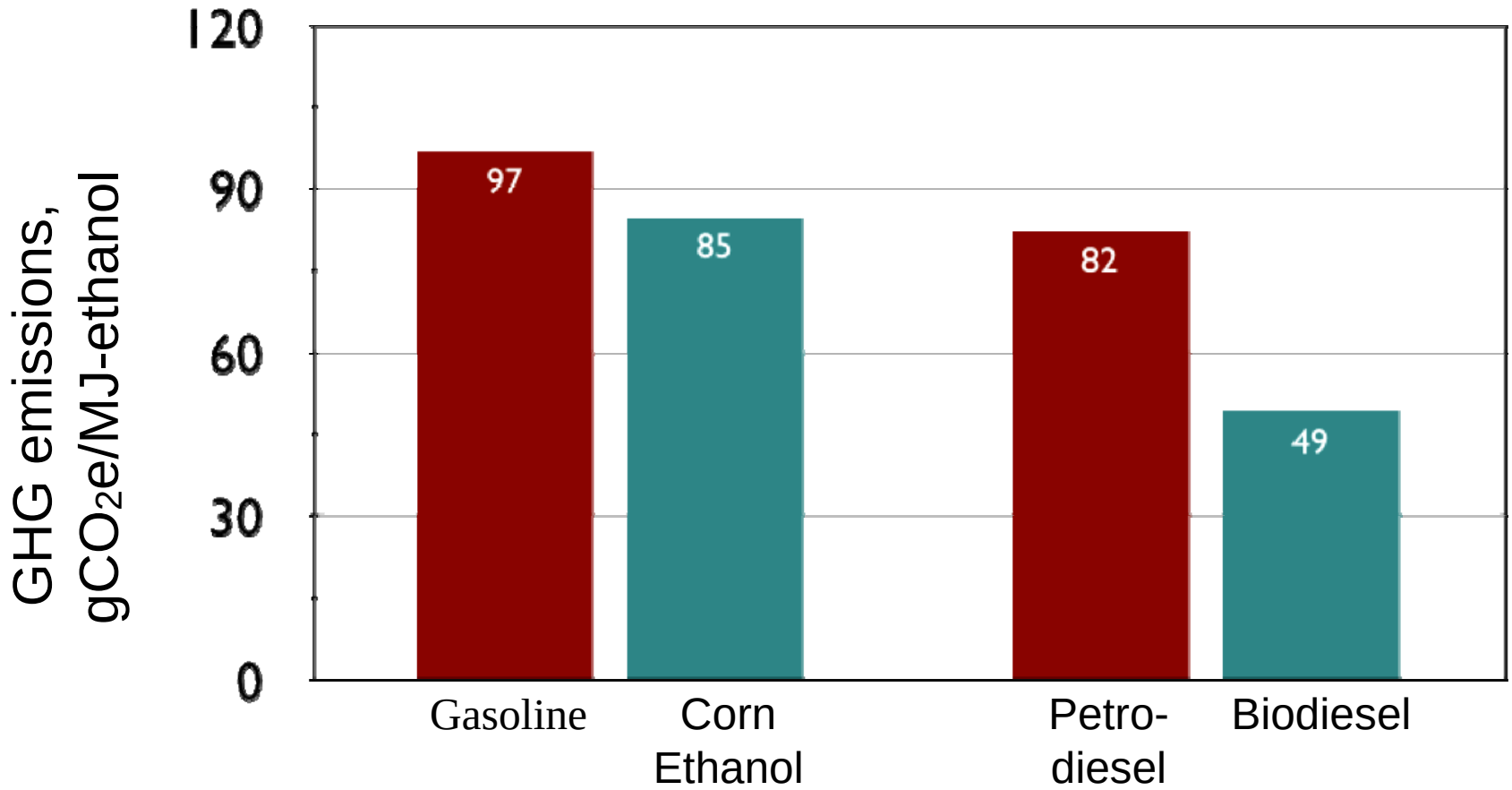
Land Required to Meet U.S. Diesel Needs with Biodiesel



Energy Balance for Biodiesel



GHG Emissions for Biodiesel



Data from Hill et al., *PNAS*, **103**, 11206-11210 (2006)

Biodiesel vs. Cellulosic Ethanol

	Cellulosic Ethanol	Biodiesel
Technology	Under development Large capital investment	Here now Low capital investment
Yield (gallons / acre)	High	Low
Small Scale?	No	Yes

Some Remarks

- Both corn ethanol and biodiesel can only meet a small fraction of the U.S. needs for liquid transportation fuels.
- GHG emissions from corn ethanol are similar to those of gasoline and its energy balance is marginal at best.
- GHG emissions from biodiesel are lower than petro-diesel and it can be easily produced and deployed locally. But, doubts about its energy balance remain.
- Significant uncertainties still remain about cellulosic ethanol. Major technical challenges lie ahead and its energy balance may not be as favorable as claimed by proponents.

Thank you. Questions?

U.S. Corn Ethanol Statistics

2006 U.S. corn production:	267.6 million tons
2006 harvested corn acreage:	70.65 million
Fraction of corn converted to ethanol:	17.1% (~12 million acres)
2007 corn acreage planted (estimate):	90.5 million acres
2006 Ethanol production:	4.85 billion gallons
2017 target:	35 billion gallons
Number of ethanol plants:	105
Current ethanol production capacity:	5 billion gallons
Ethanol plants under construction:	42
Additional production capacity:	3 billion gallons
Business proposals for more plants:	300

Source: Renewable Fuels Association, 2007

U.S. and Brazil

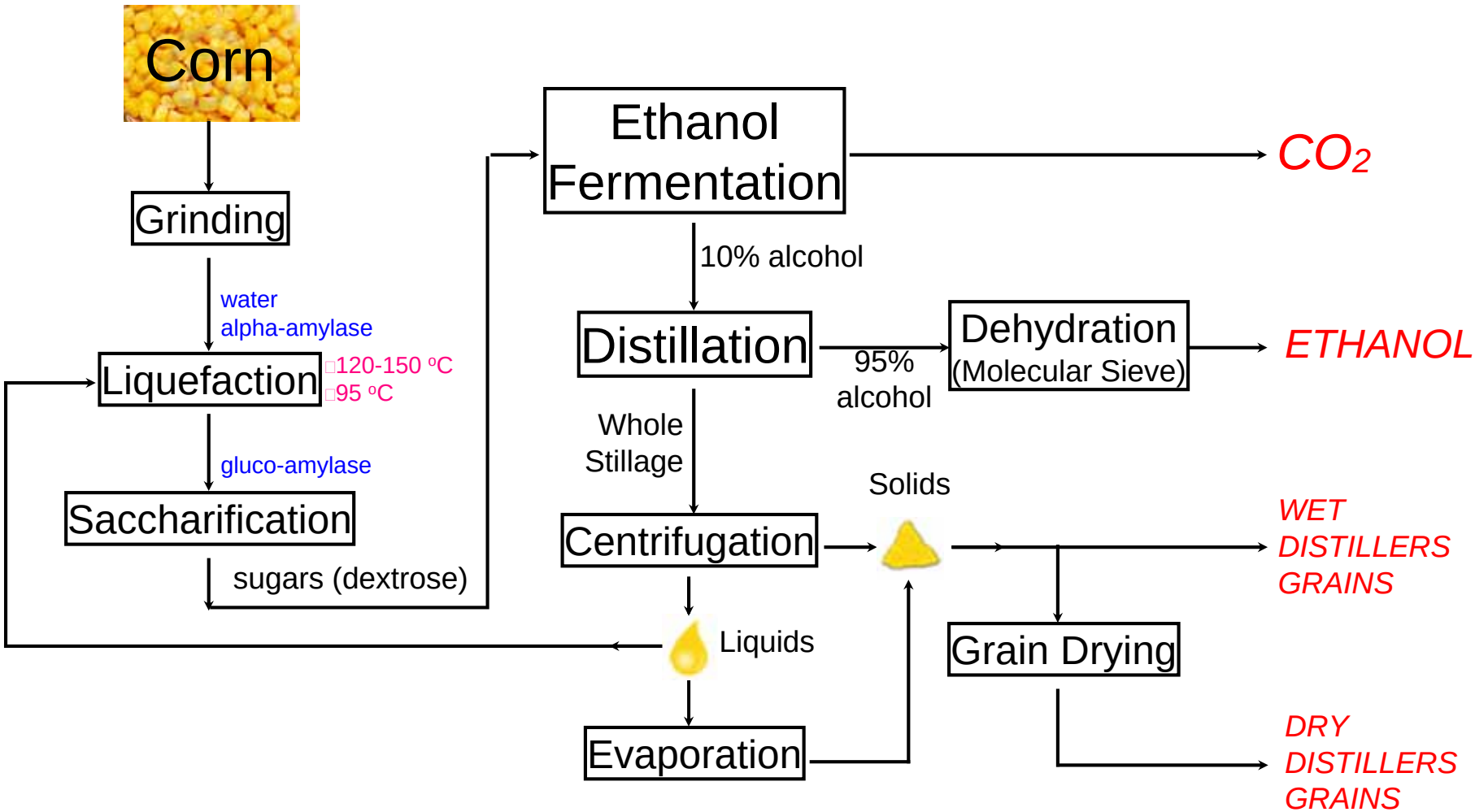
	U.S	**Brazil**
Population, million inhabitants	300	184
Total fleet of vehicles	230	28
Vehicles per inhabitant	0.77	0.15
Ethanol production, billion gallons per year	4.85	4.8
Gasoline replaced, percentage	2.5%	50%
30% of U.S. gasoline contains 10% ethanol (4.2 billion gallons)		

Switchgrass Annual Yields

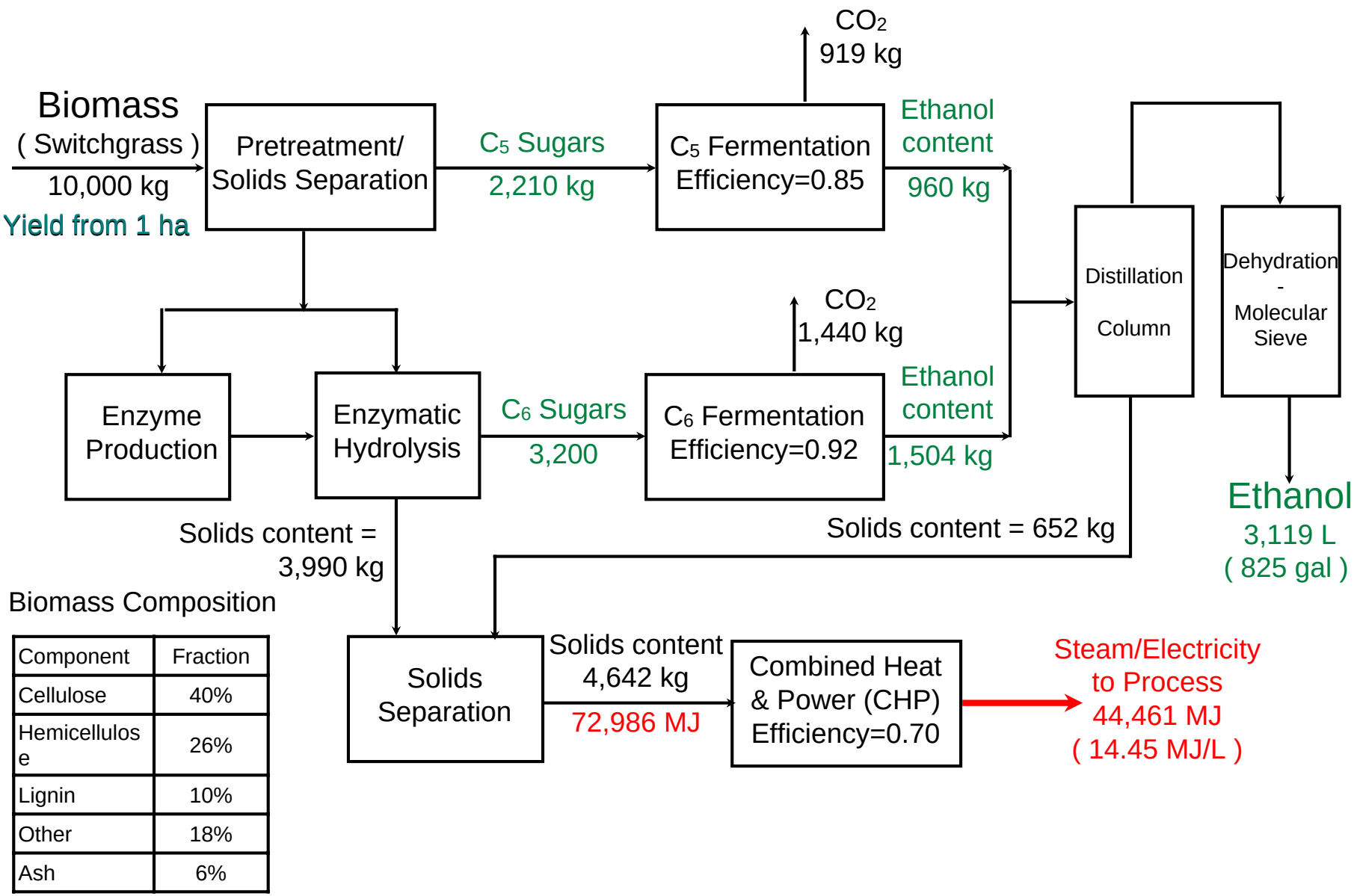
	Crop Yield (dry tons) / ha		Crop Yield (dry tons) / ha
Industry claim - Now [a]	12.5	Lemus et al., 2002 [d] Biomass Bioenergy, 23, 433-442	6.8 - 13.1
Industry claim - Future [a]	25.0	Lewandowski et al., 2003 Biomass Bioenergy, 25, 335-361	5 - 23 Europe
Cassida et al., 2005 [b] Crop Science, 45, 673-681 and 682-692	5.82 - 14.97	McLaughlin et al., 2005 [e] Biomass Bioenergy, 28, 515-535	9.8 - 16.6 VA, TN, WV, KY, NC
Lee and Boe, 2005 [c] Crop Science, 45, 2583-2590	2 - 12	ibid	5.5-13.3 TX
Berdahl et al., 2005 Agronomy J., 97, 549-555	3.20 - 12.48	ibid	10.7-19.5 TX, AK, LA

[a] Iogen presentation; [b] Average over 3 years for upland and lowland genotypes - Annual yield depends on precipitation; [c] Annual yield depends on precipitation; [d] Average over 3 years; [e] Best 1-year yield: 34.6 Mg/ha

Production of Corn Ethanol



Cellulosic Ethanol Process Steps



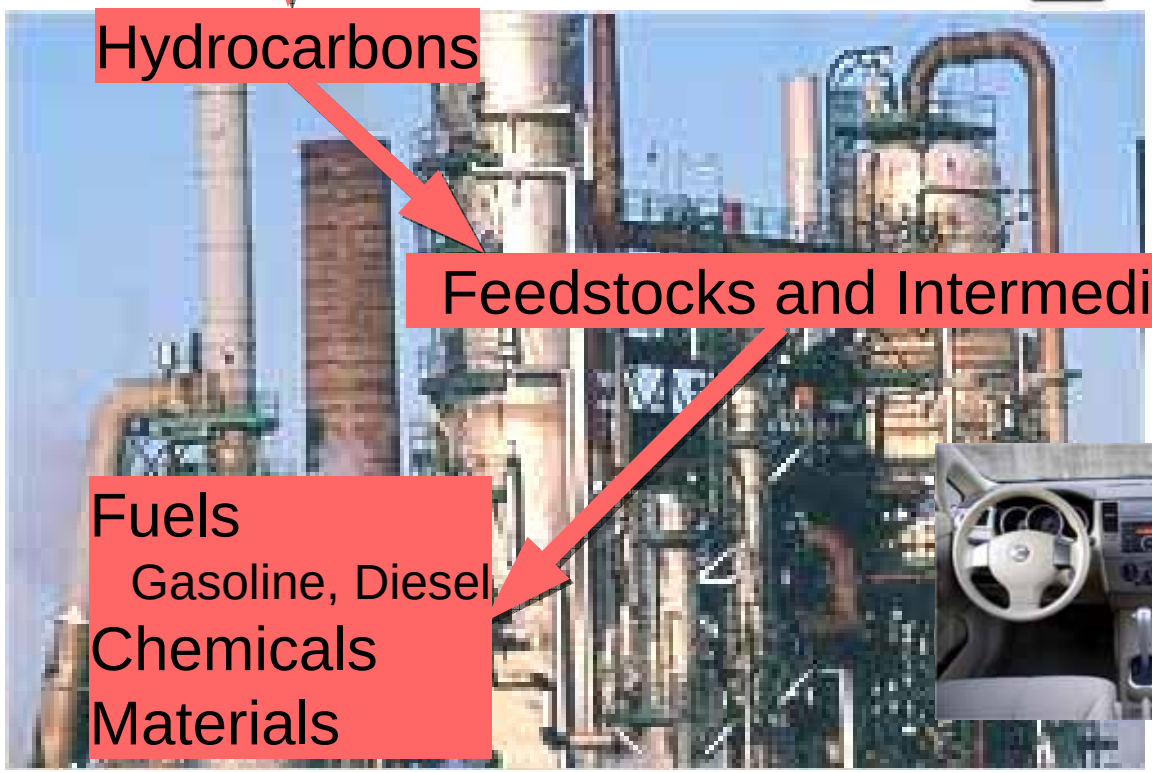
Biomass Composition

Component	Fraction
Cellulose	40%
Hemicellulose	26%
Lignin	10%
Other	18%
Ash	6%

Oil Provides More Than Fuels!

Crude Oil and Natural Gas

Hydrocarbons



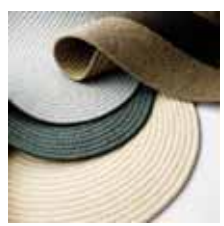
Feedstocks and Intermediates

Fuels

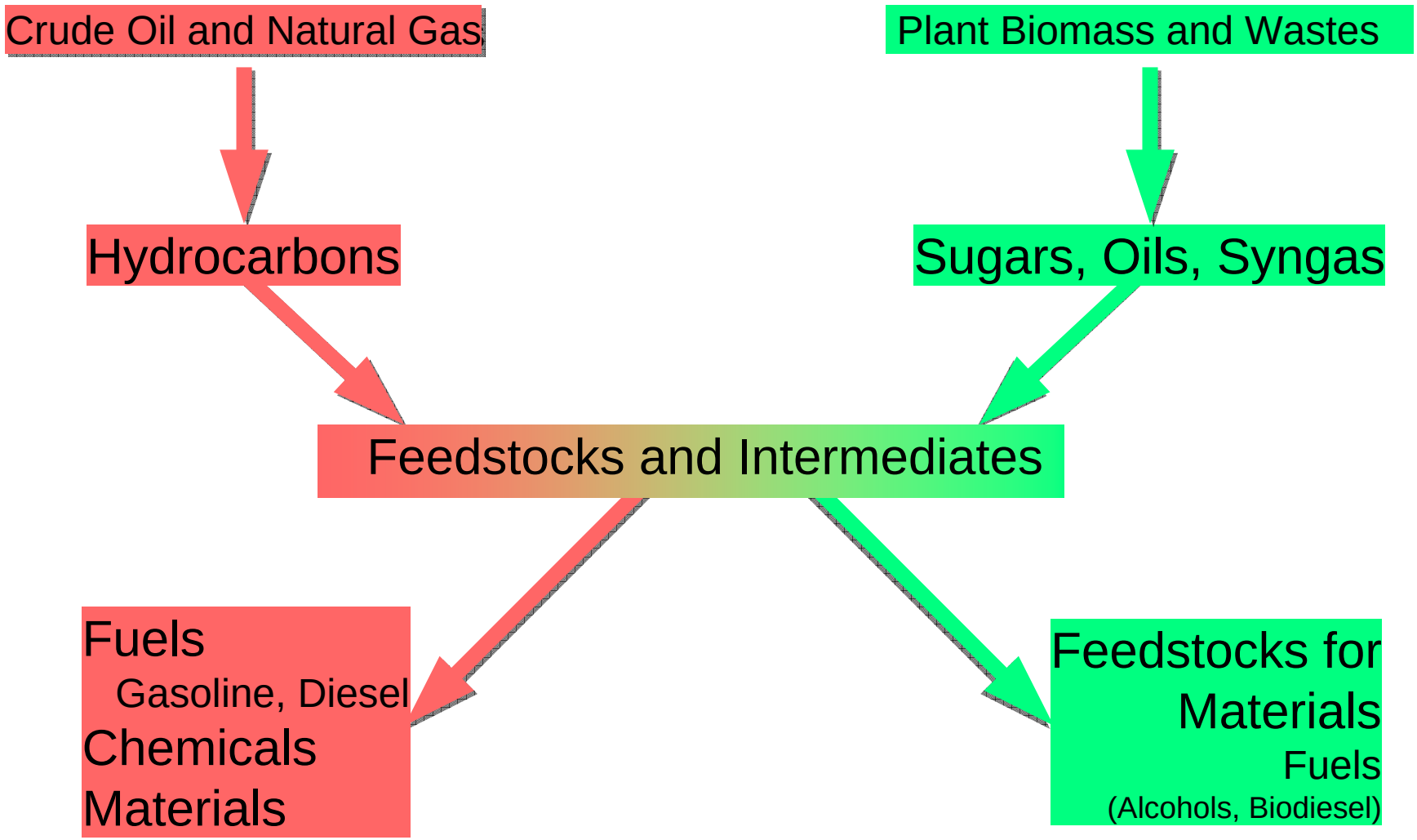
Gasoline, Diesel

Chemicals

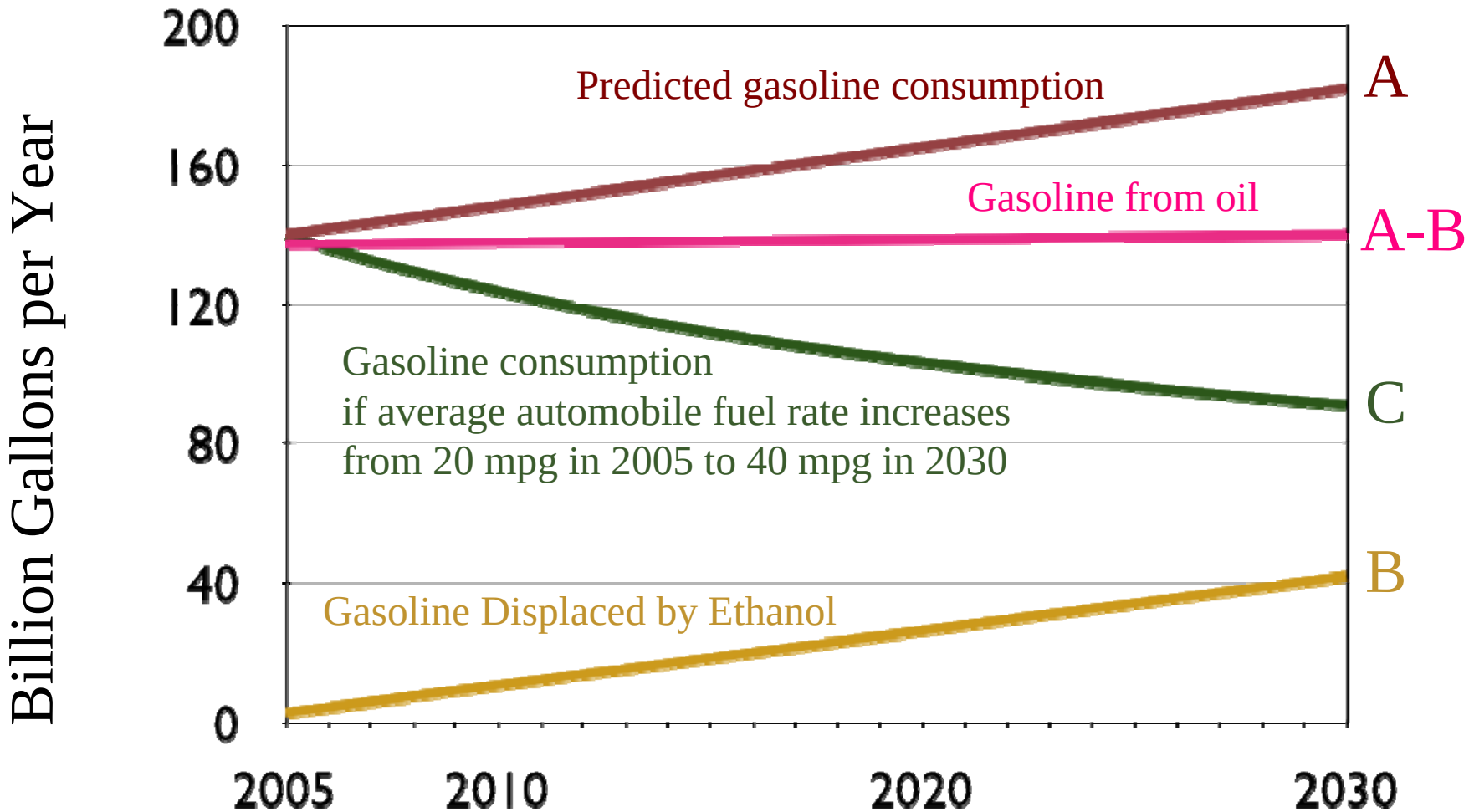
Materials



The Future of Biomass



How effective will be the cellulosic ethanol program?



Solar Energy

2007 Houston World Oil Conference

Proceedings

- Conference Program
- Conference DVD
- Video Highlights
- Peak Oil Review
- ASPO-USA