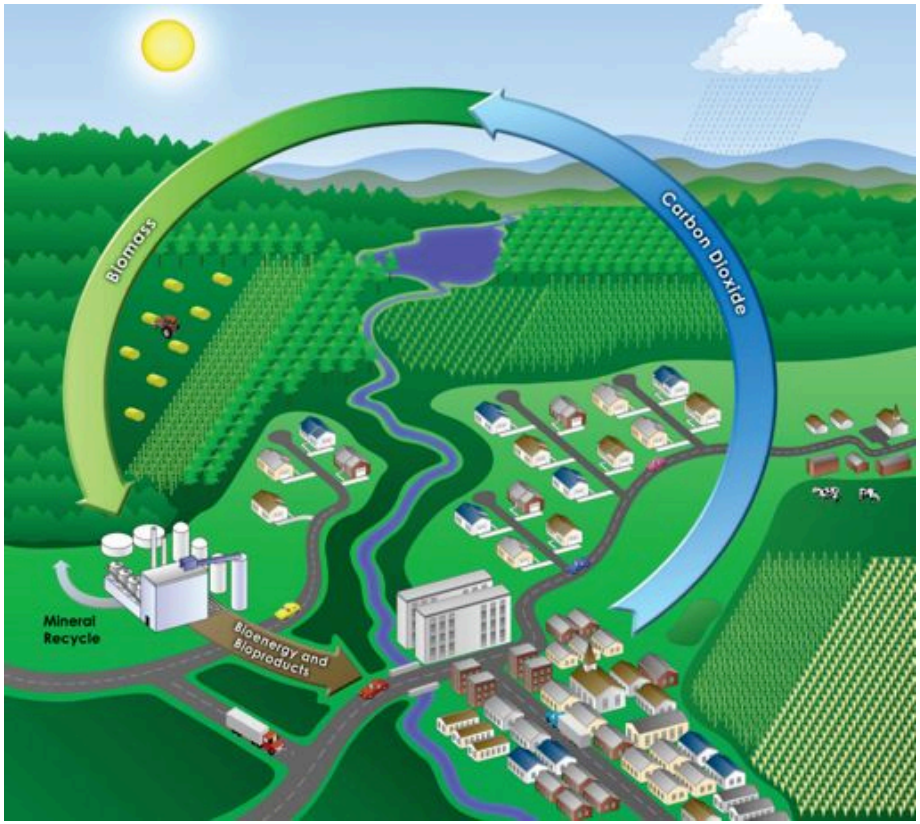
Development of Cellulosic Biofuels

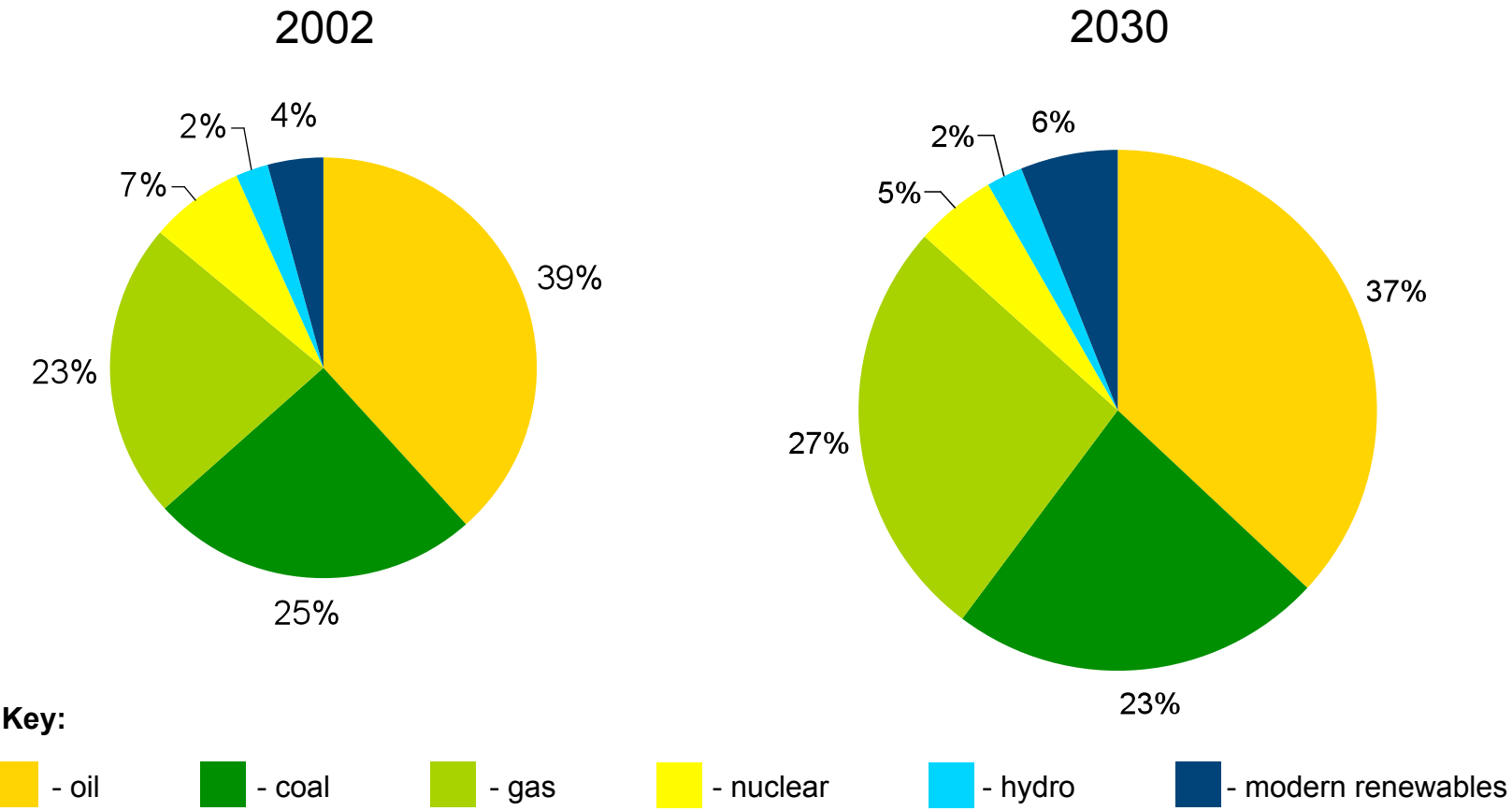


Chris Somerville
Energy Biosciences Institute
UC Berkeley, LBL, University of Illinois

Current and predicted energy use

Current use 13 TW

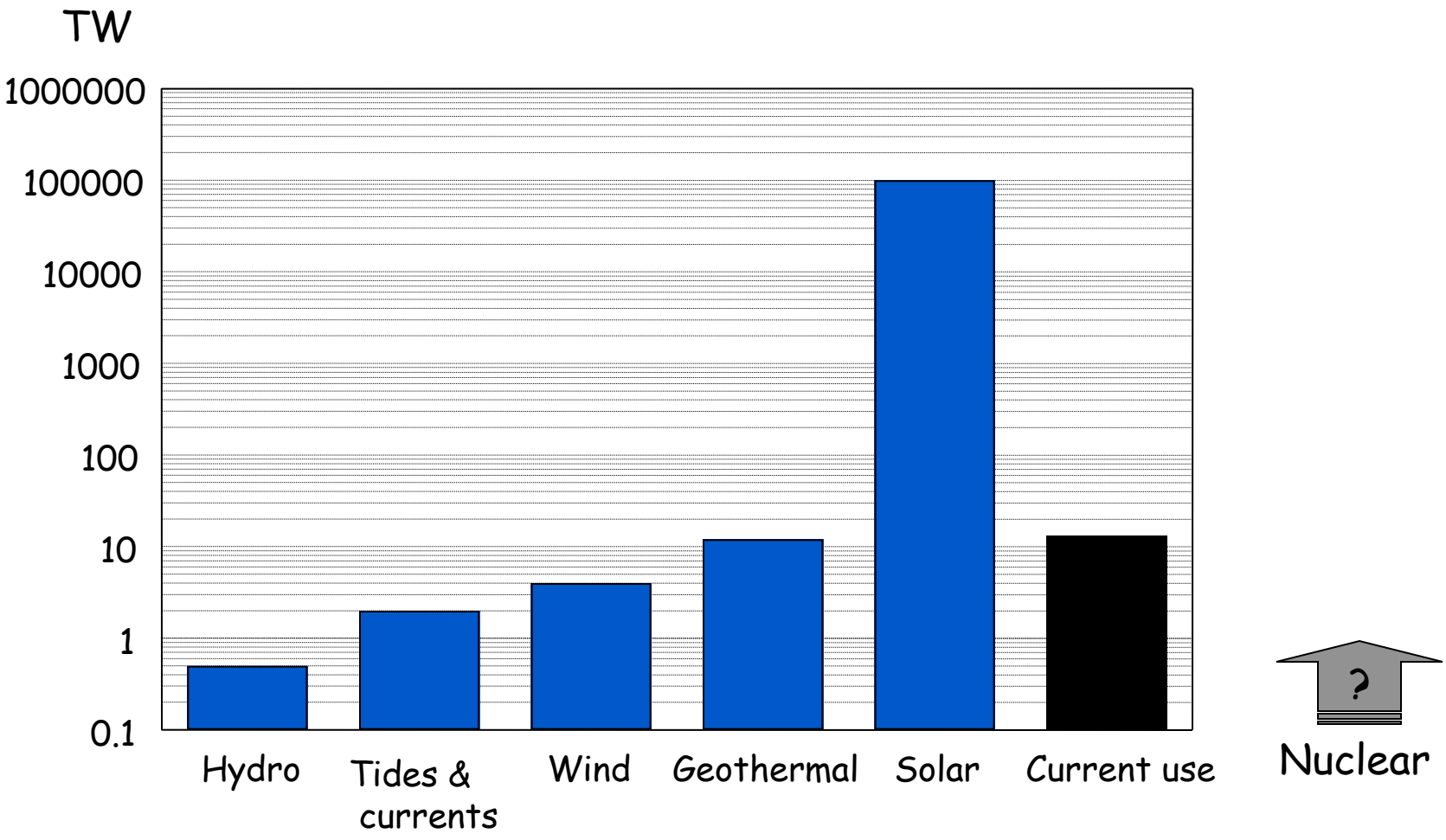
Global Primary Energy Supply by Fuel:*



* - excludes traditional biomass

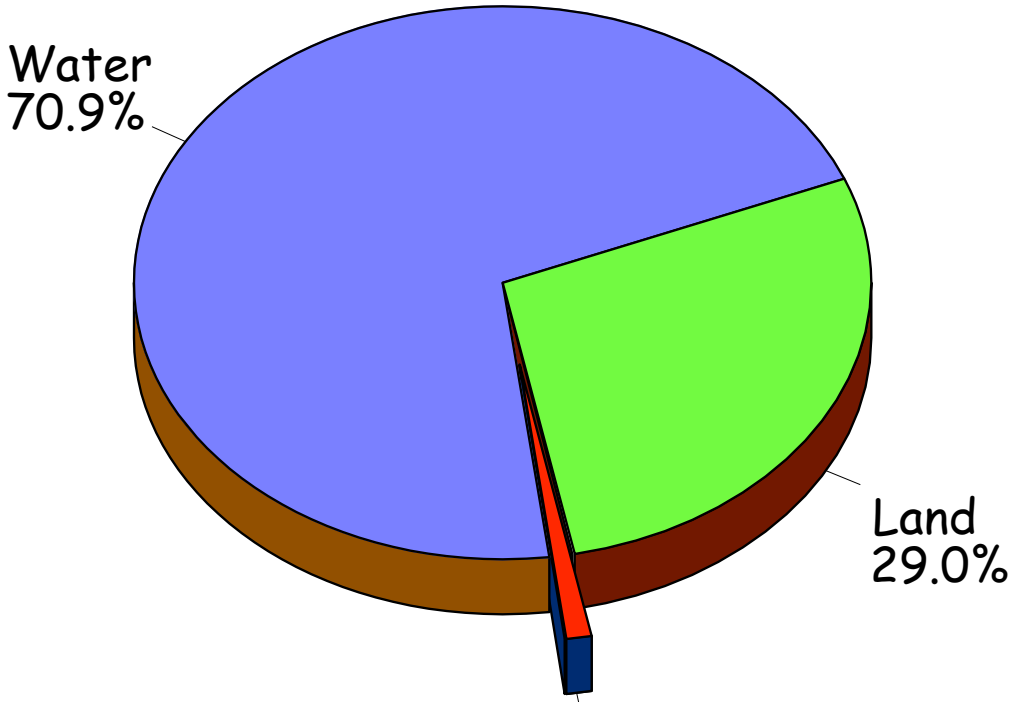
Source: IEA 2004 & Jim Breson

Potential of carbon-free energy sources



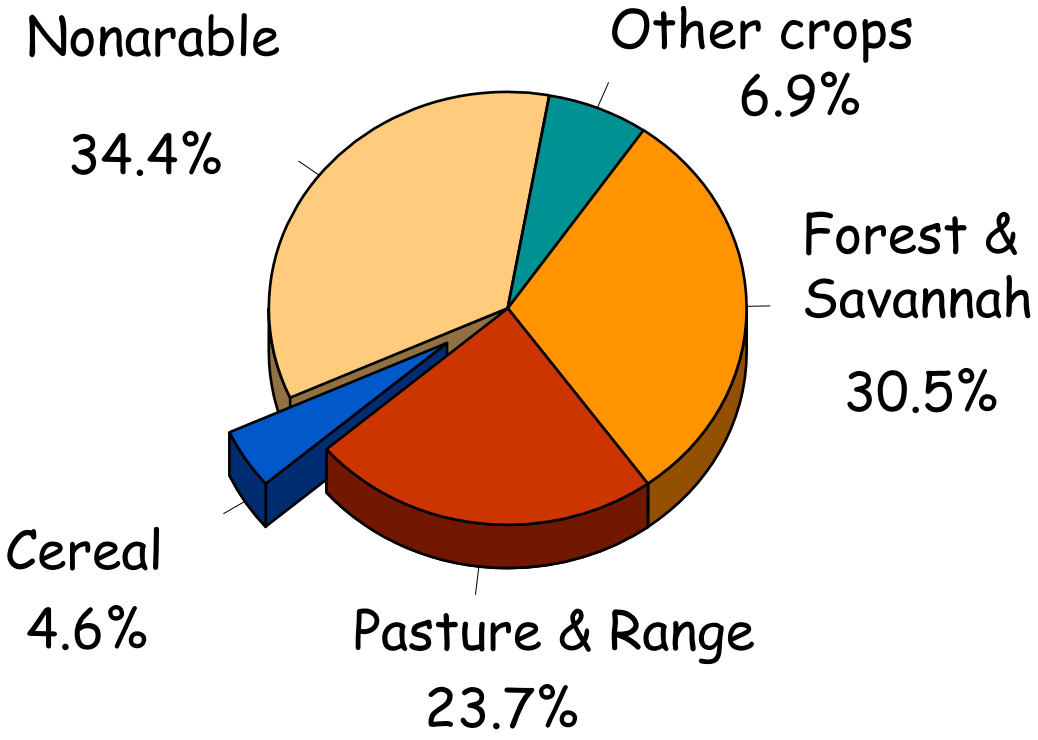
From: Basic Research Needs for Solar Energy Utilization, DOE 2005

~90,000 TW of energy arrives on the earths surface from the sun



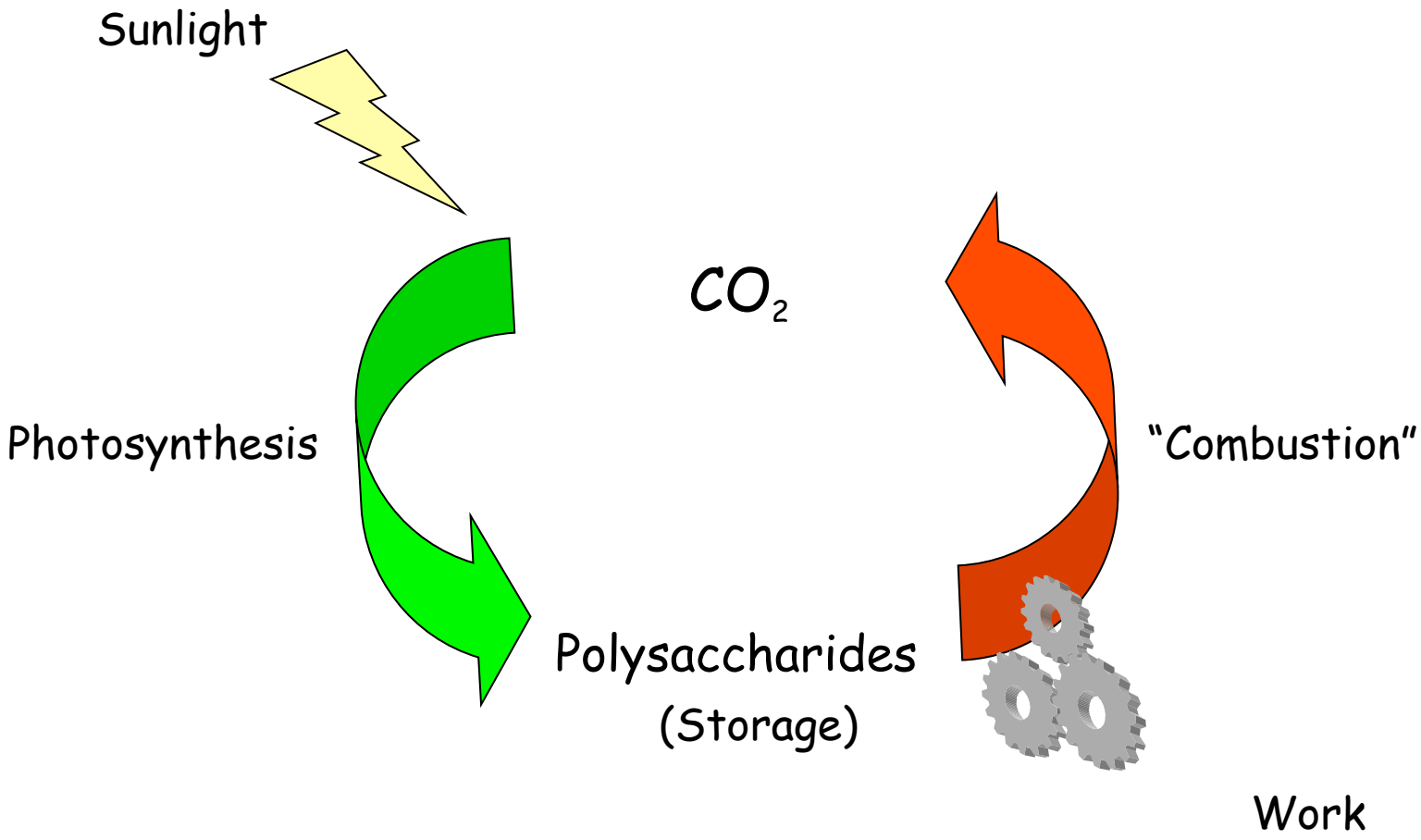
Amount of land needed for 13 TW at 1% efficiency
5% of land
650 MHa

Land Usage

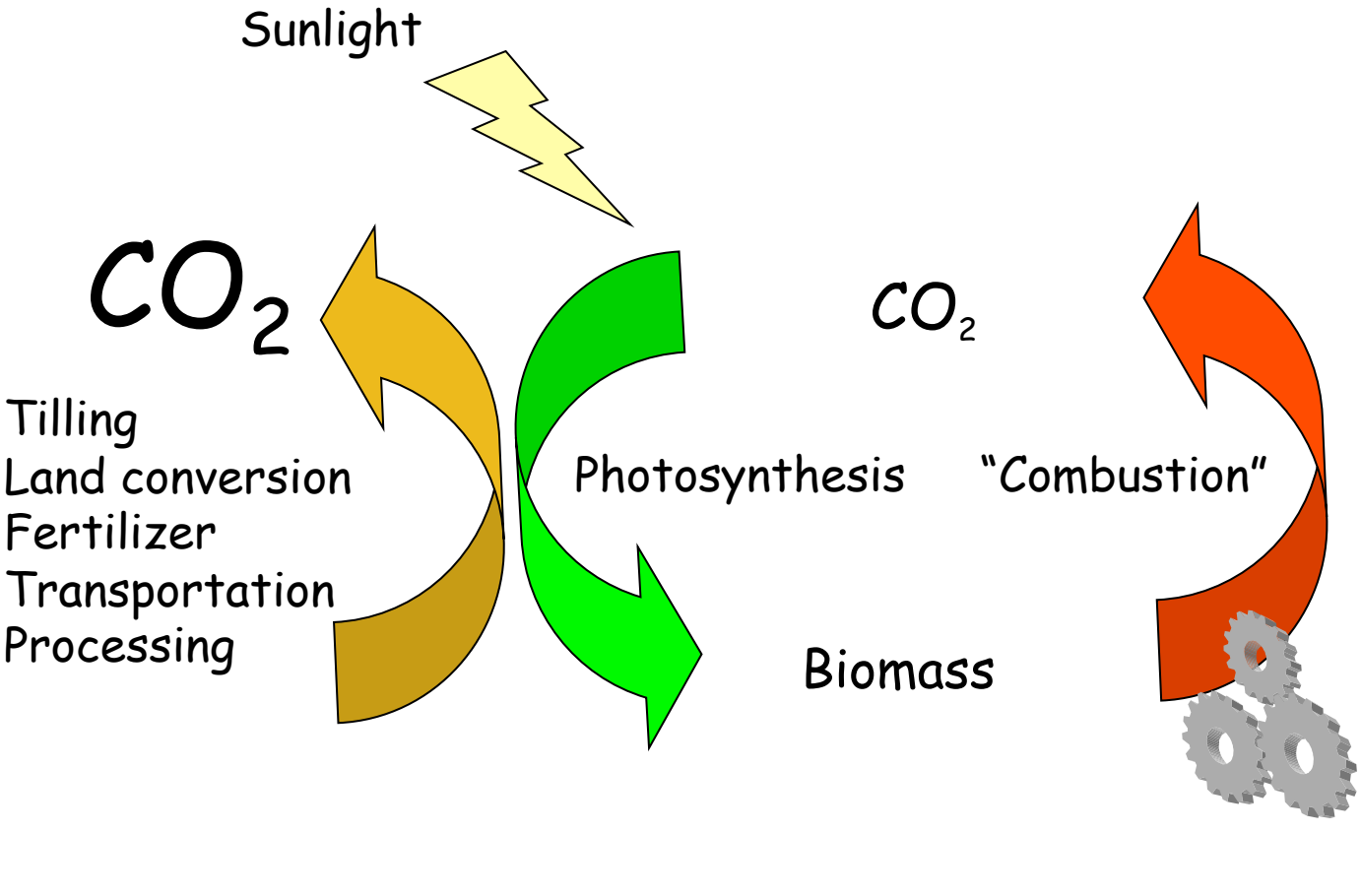


AMBIO 23,198 (Total Land surface 13,000 M Ha)

Combustion of biomass *can* provide carbon neutral energy

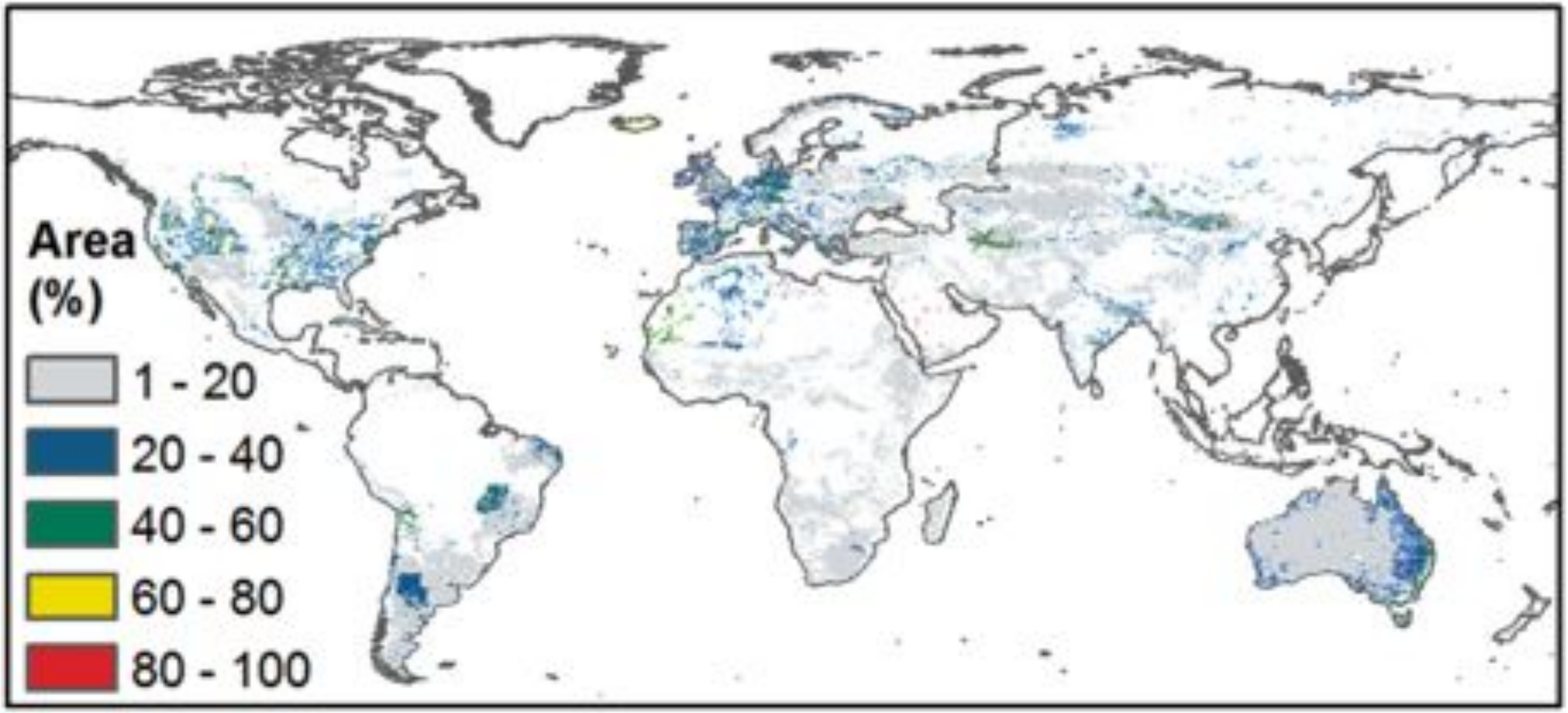


Combustion of biomass *can* provide carbon neutral energy



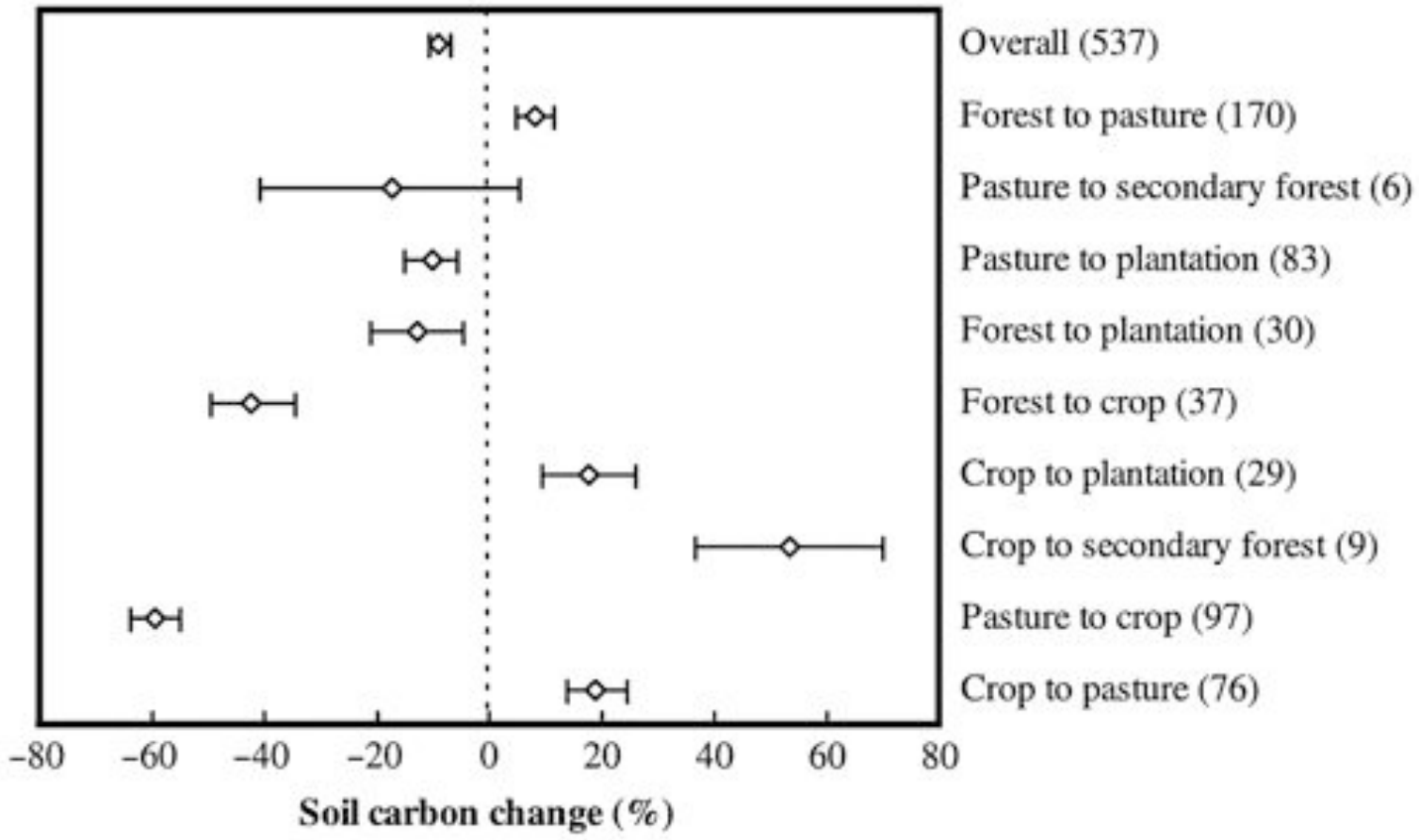
But it depends on how the biomass is produced and processed

>>A billion acres of agricultural land have been abandoned



Campbell et al., Env. Sci. Technol. (2008) **ASAP Article**, 10.1021/es800052w

Effect of land use change on soil carbon



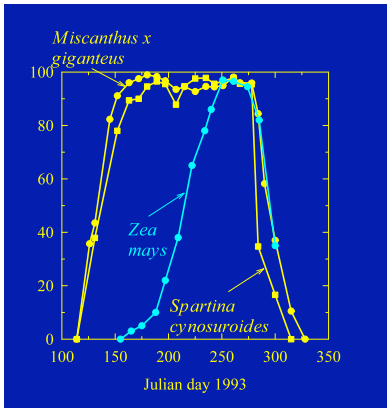
Guo & Gifford, Global Change Biology 8,345

>1% yield is feasible

Yield of 26.5 tons/acre observed by Young & colleagues in Illinois, without irrigation

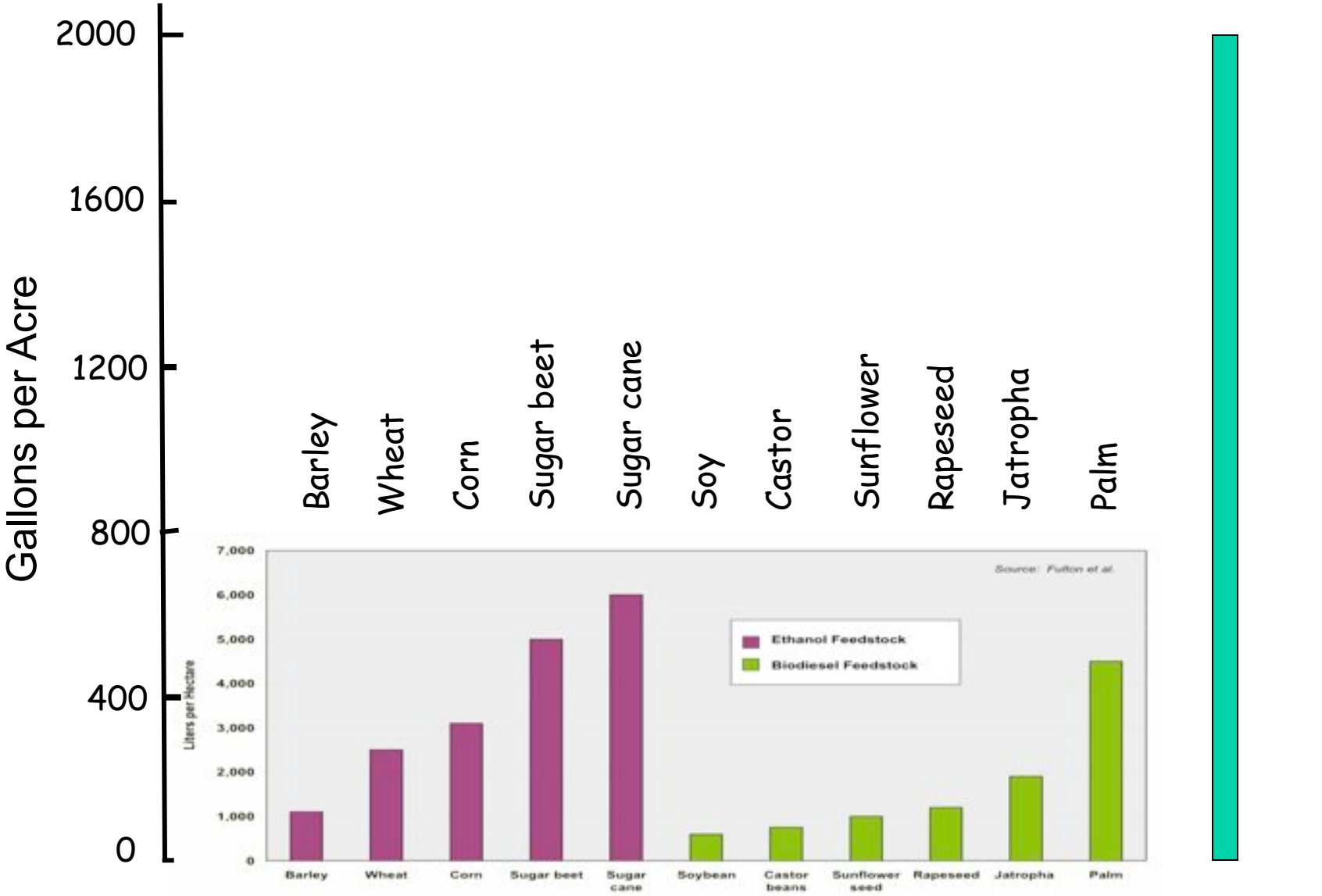
Courtesy of Steve Long et al

Perennials have more photosynthesis



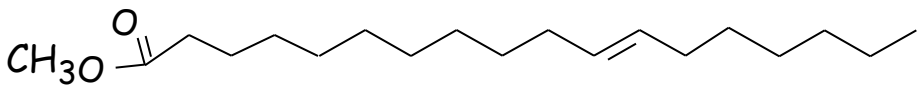
Courtesy of Steve Long, University of Illinois

Yield of various species varies widely

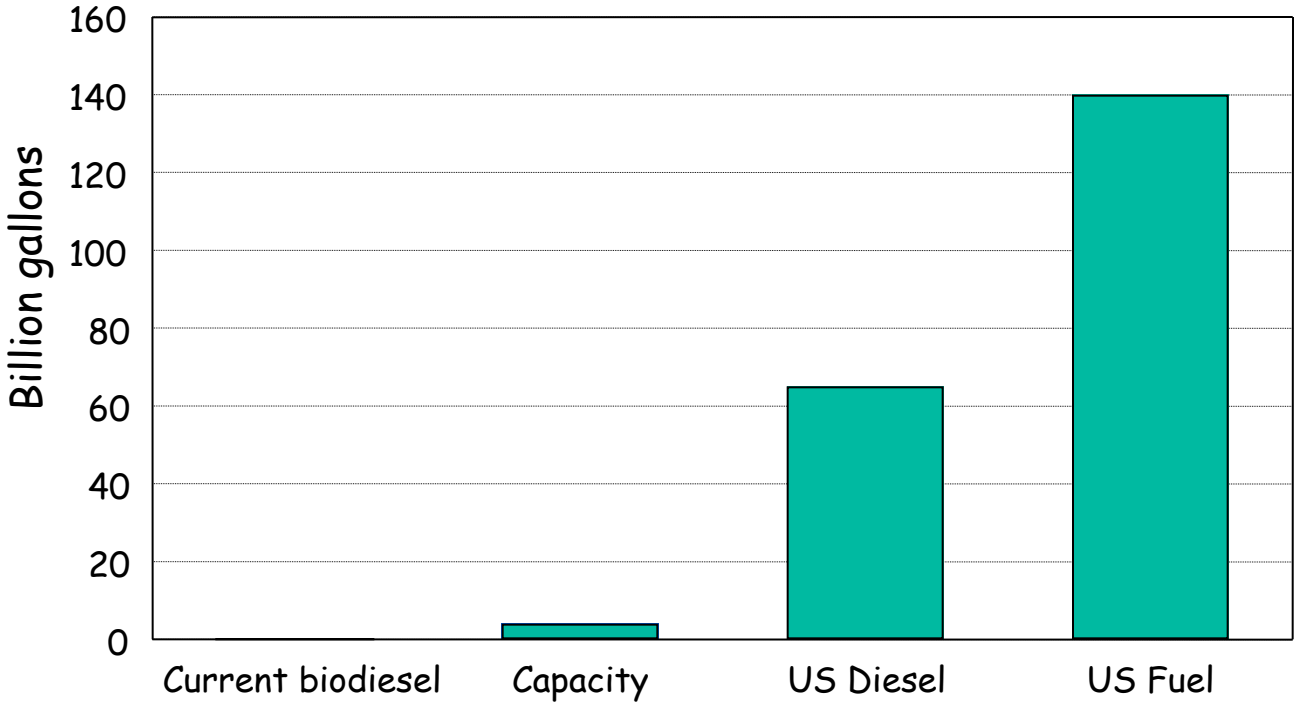


Worldwatch 2006

Limited potential of biodiesel



Biodiesel

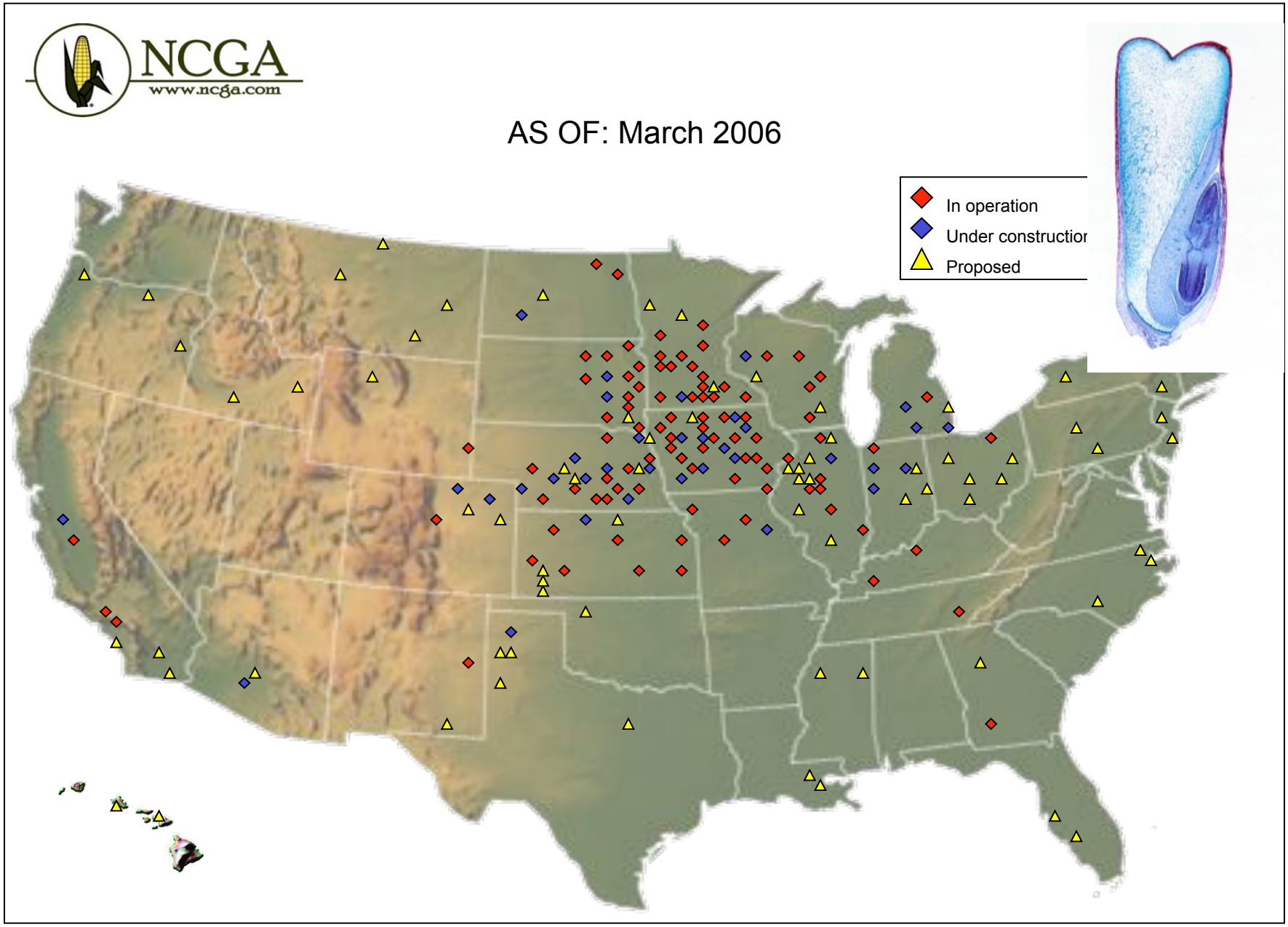


65 biodiesel companies in operation, 50 in construction 2006

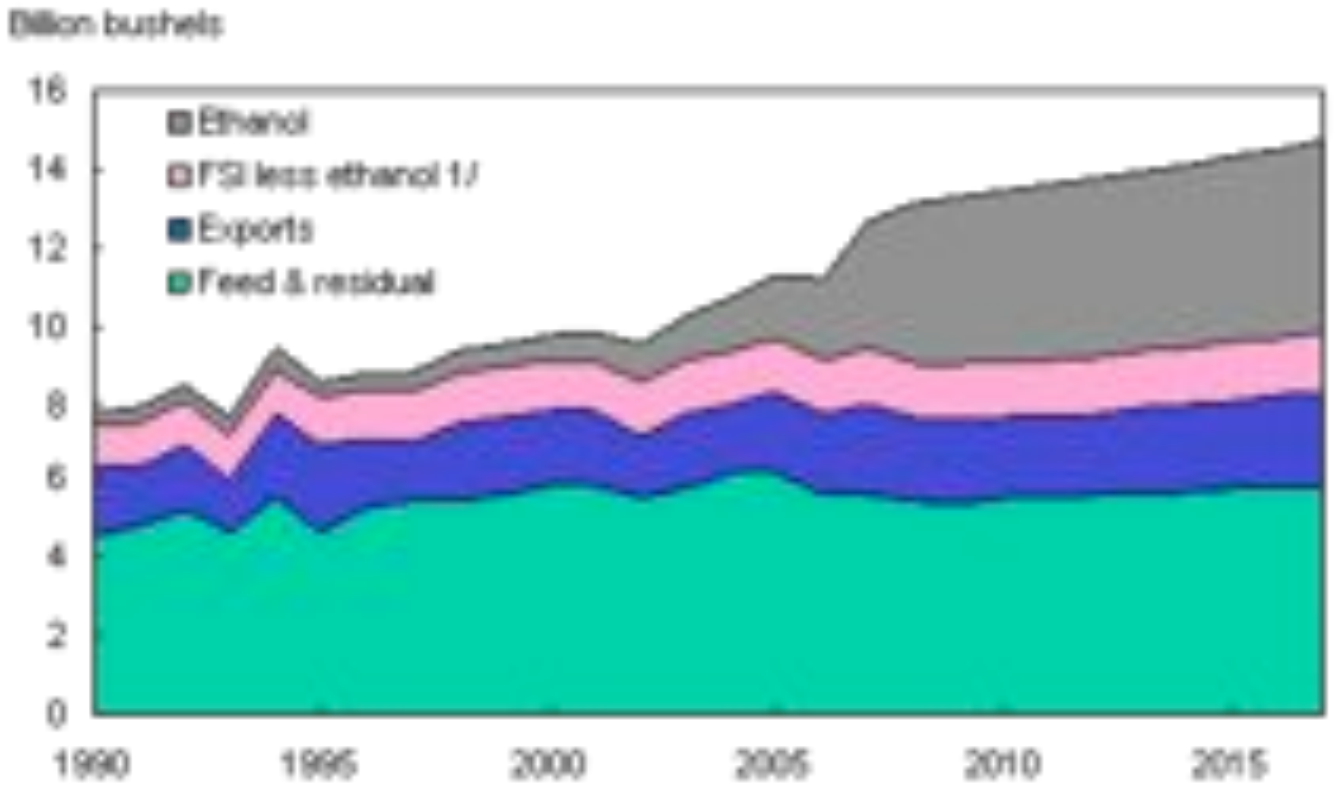
Overview of Brazil sugarcane

- 2007-08 harvest 528 MMT
- ~8 M Ha planted by 2008
- ~20 B liters ethanol, 2007
- ~80-120 T/Ha
- ~6400 L ethanol/Ha
- ~333 mills, 200 planned
- Plantings last 5 y, cut one per year
- Large mill
  - 22,000 tons/day
  - 1500 truck loads/day

US Biofuel Production has Expanded Rapidly



US Corn exports are projected to increase

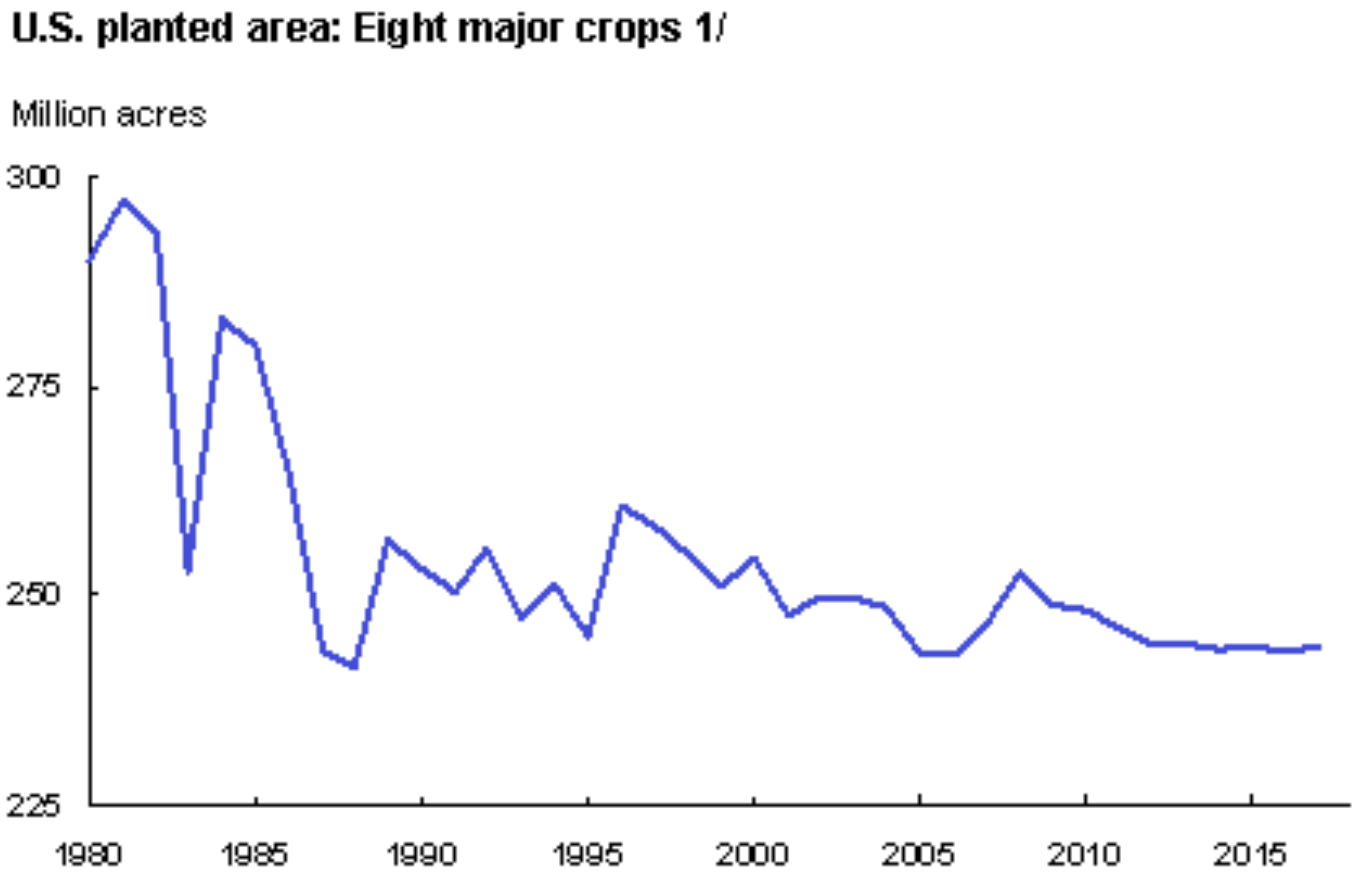


1/ Food, seed, and industrial less ethanol.

Source: USDA Agricultural Projections to 2017, February 2008.
USDA, Economic Research Service.

http://www.ers.usda.gov/briefing/Baseline/crops.htm

Agricultural land use has declined



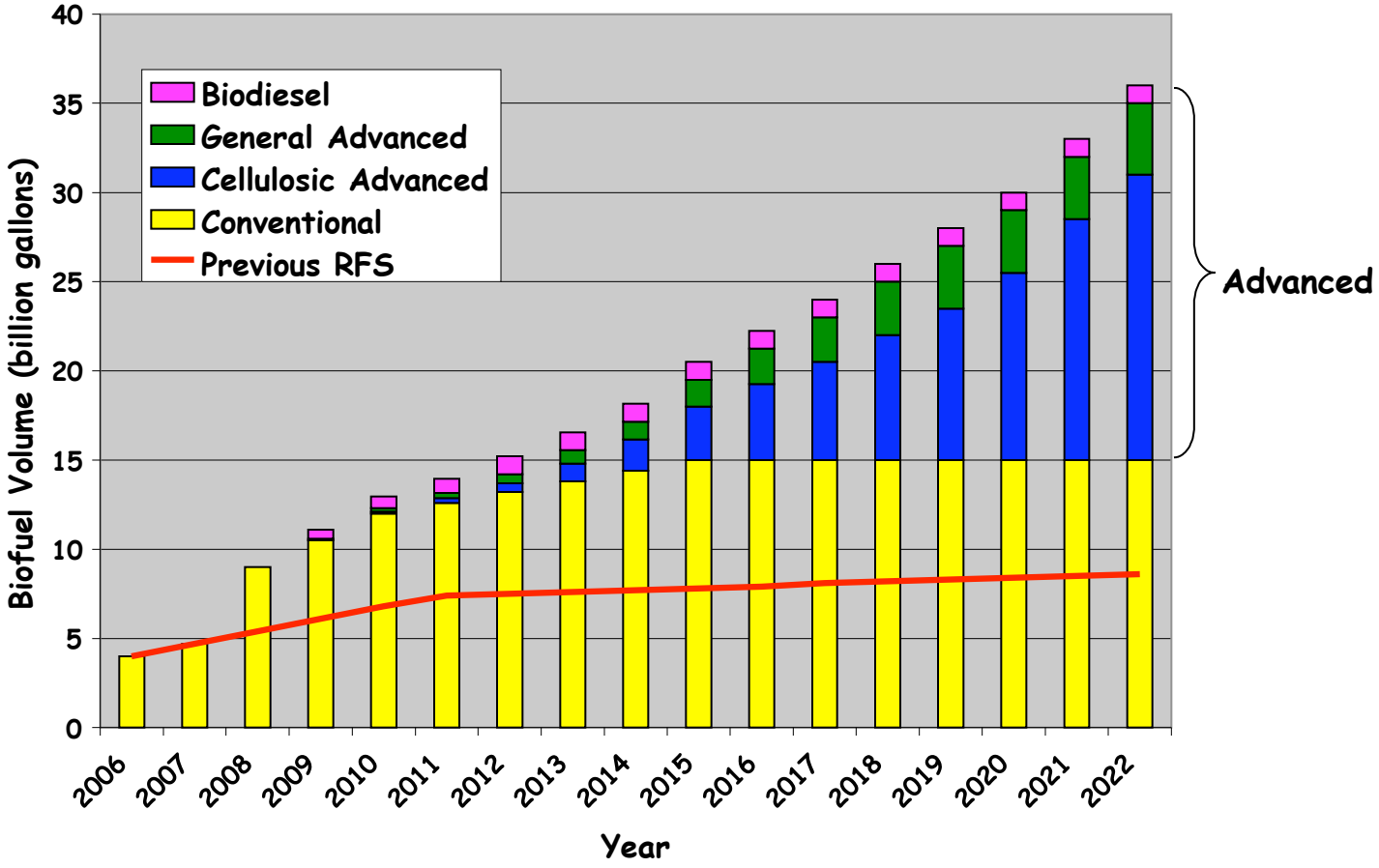
1/ The eight major crops are corn, sorghum, barley, oats, wheat, rice, upland cotton, and soybeans.

Source: *USDA Agricultural Projections to 2017*, February 2008. USDA, Economic Research Service.

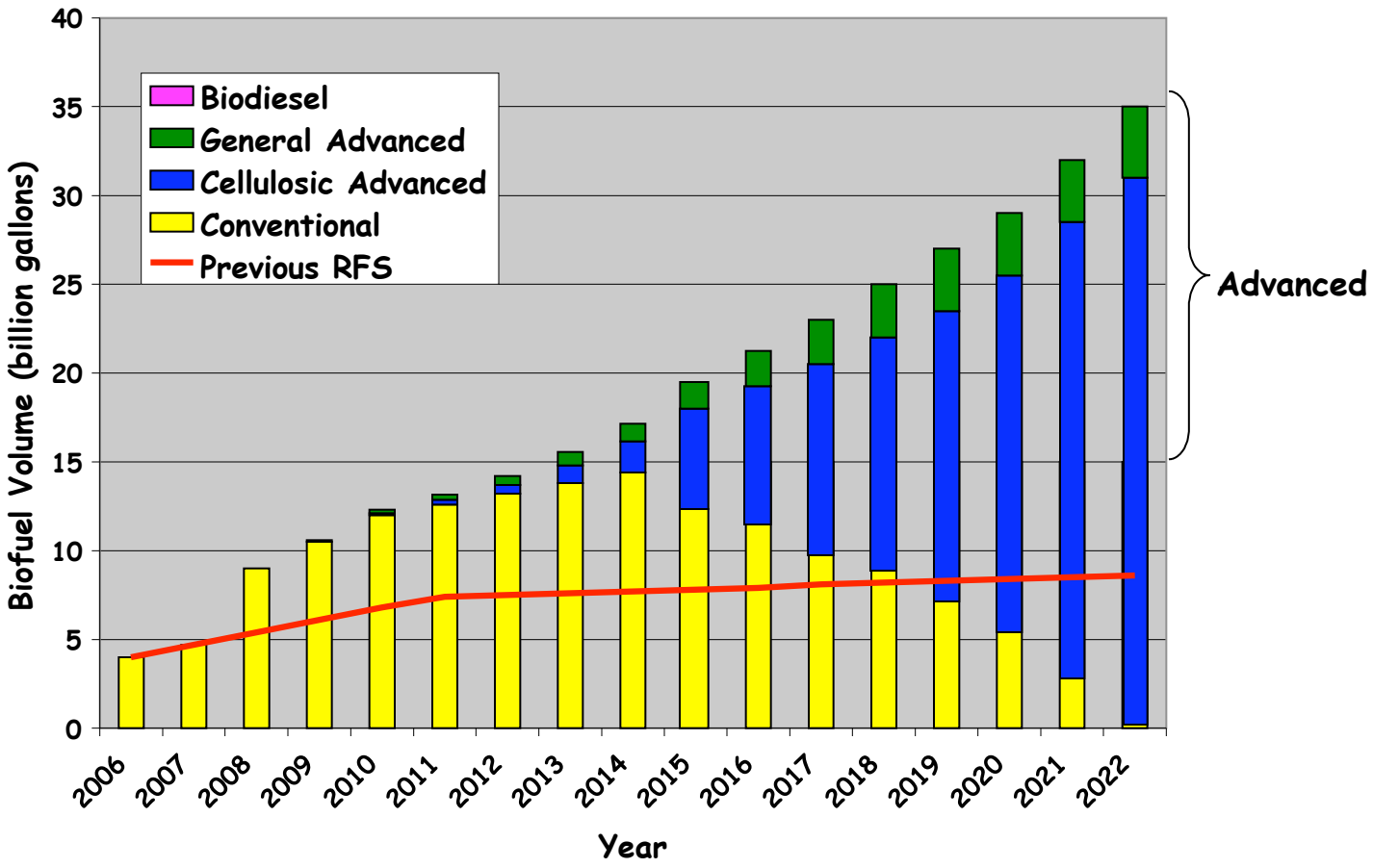
http://www.ers.usda.gov/briefing/Baseline/crops.htm

Renewable Fuel Standard

(Energy Independence and Security Act of 2007)

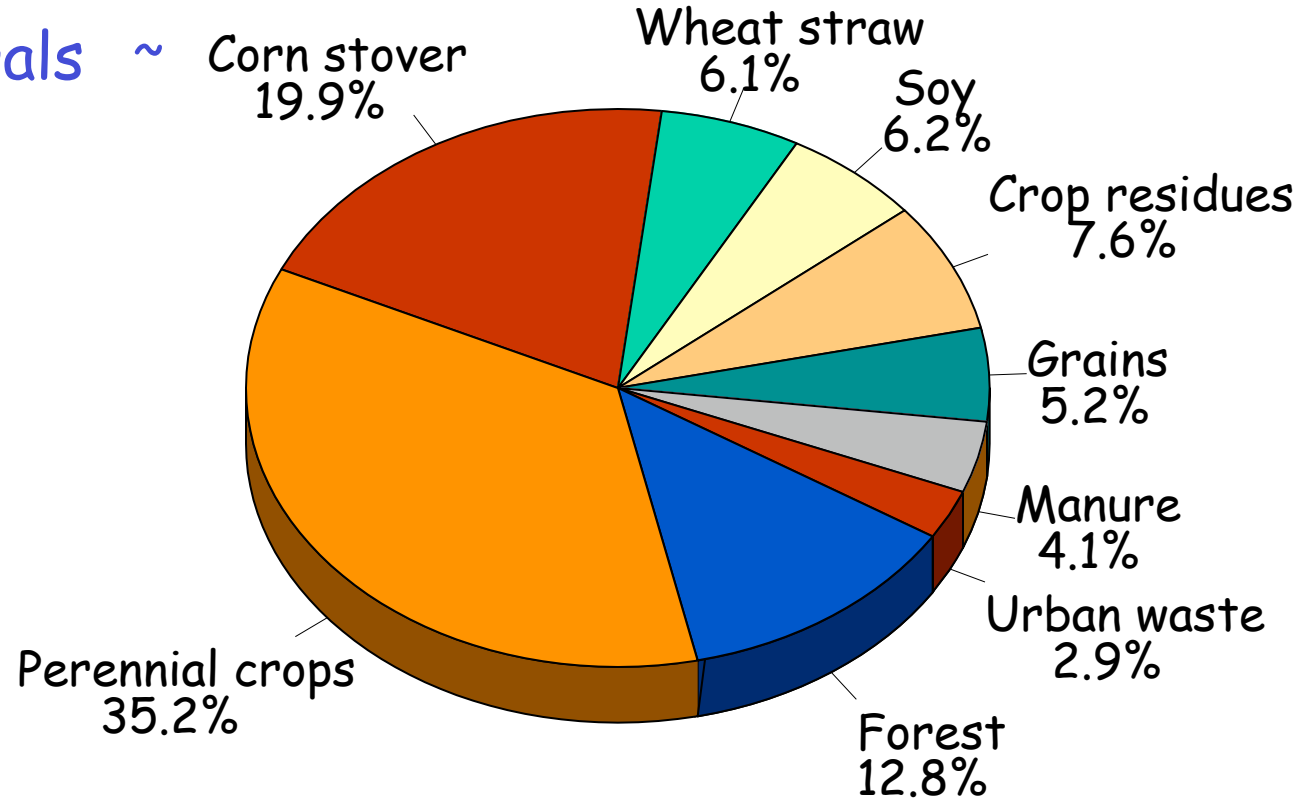


My Renewable Fuel Standard



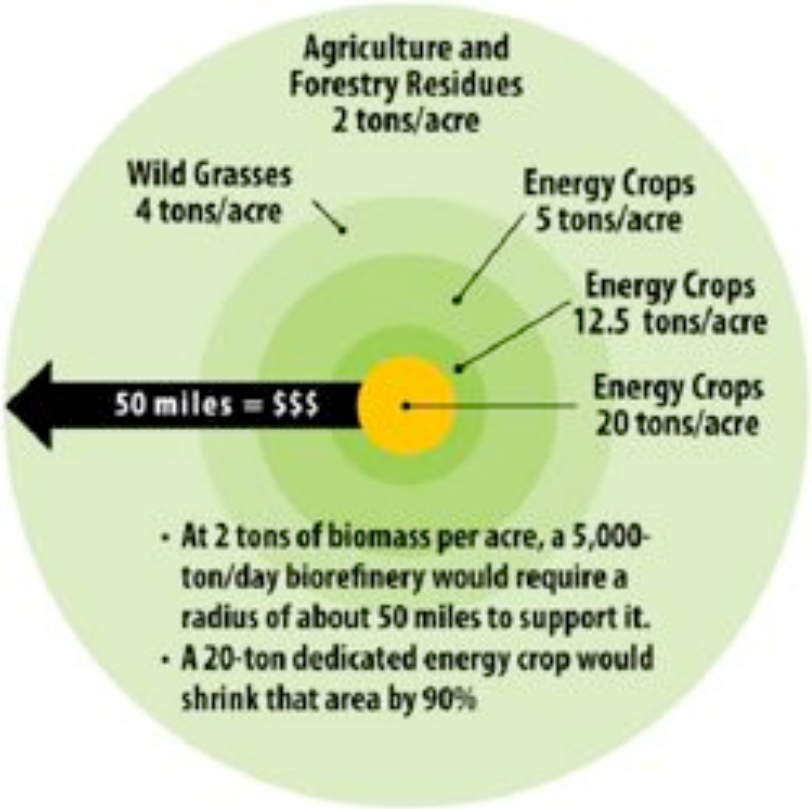
US Biomass inventory = 1.3 billion tons

26 B gals ~

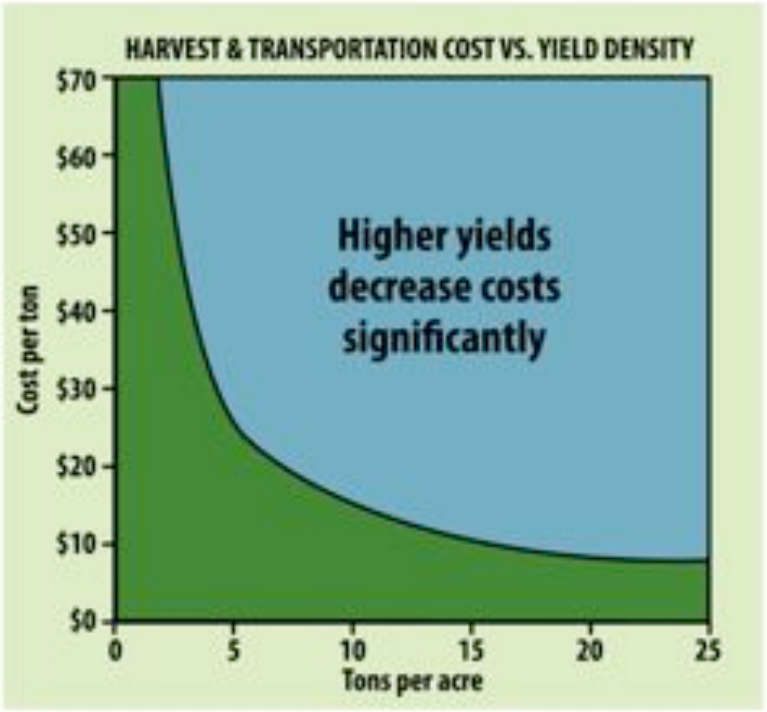


From: Billion ton Vision, DOE & USDA 2005

High yield decreases transportation and land costs

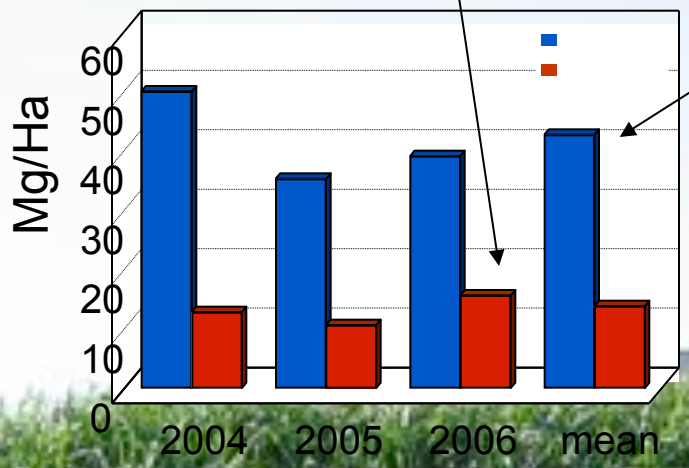


500,000 gal/day scenario



Richard Hamilton, Ceres

Switchgrass and Miscanthus at Illinois

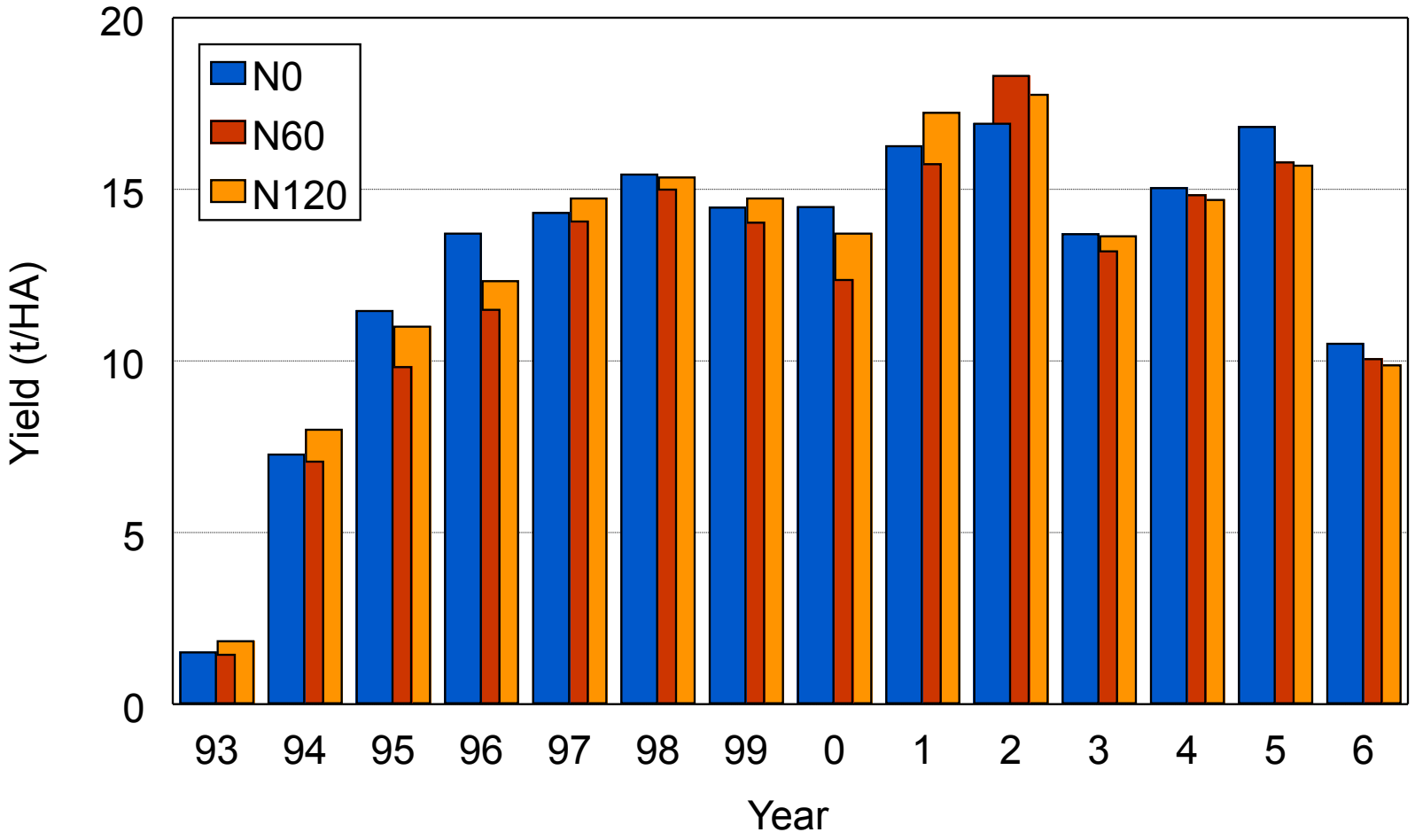


Heaton, Dohleman and Long, Climate Change Biology 2008

Harvesting Miscanthus

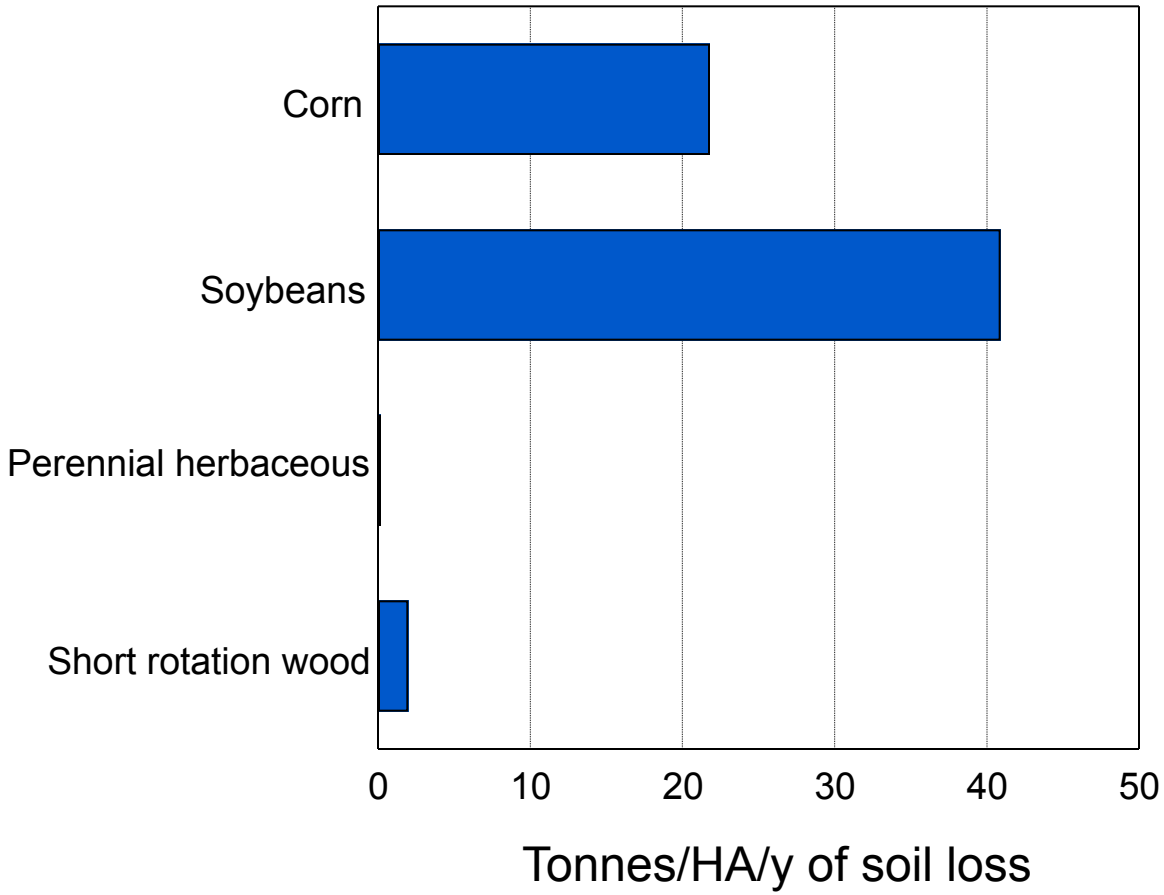
http://bioenergy.ornl.gov/gallery/index.html

Response of Miscanthus to nitrogen fertilizer



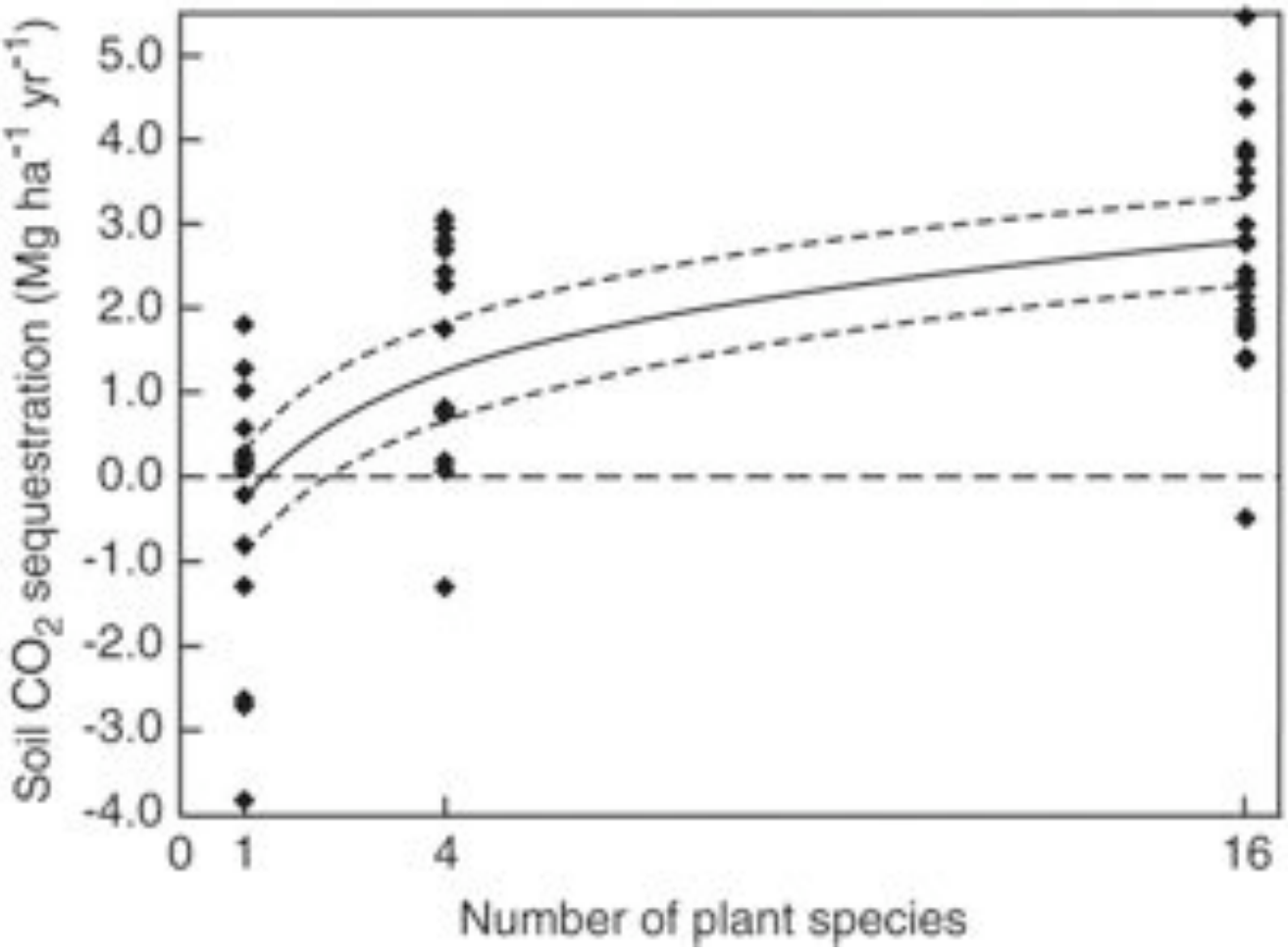
Christian, Riche & Yates Ind. Crops Prod. (2008)

Perennials have little or no erosion



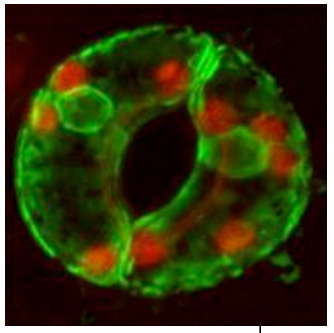
From Oliveira et al in: Jones and Walsh (eds) Miscanthus for Energy and Fibre, 2001

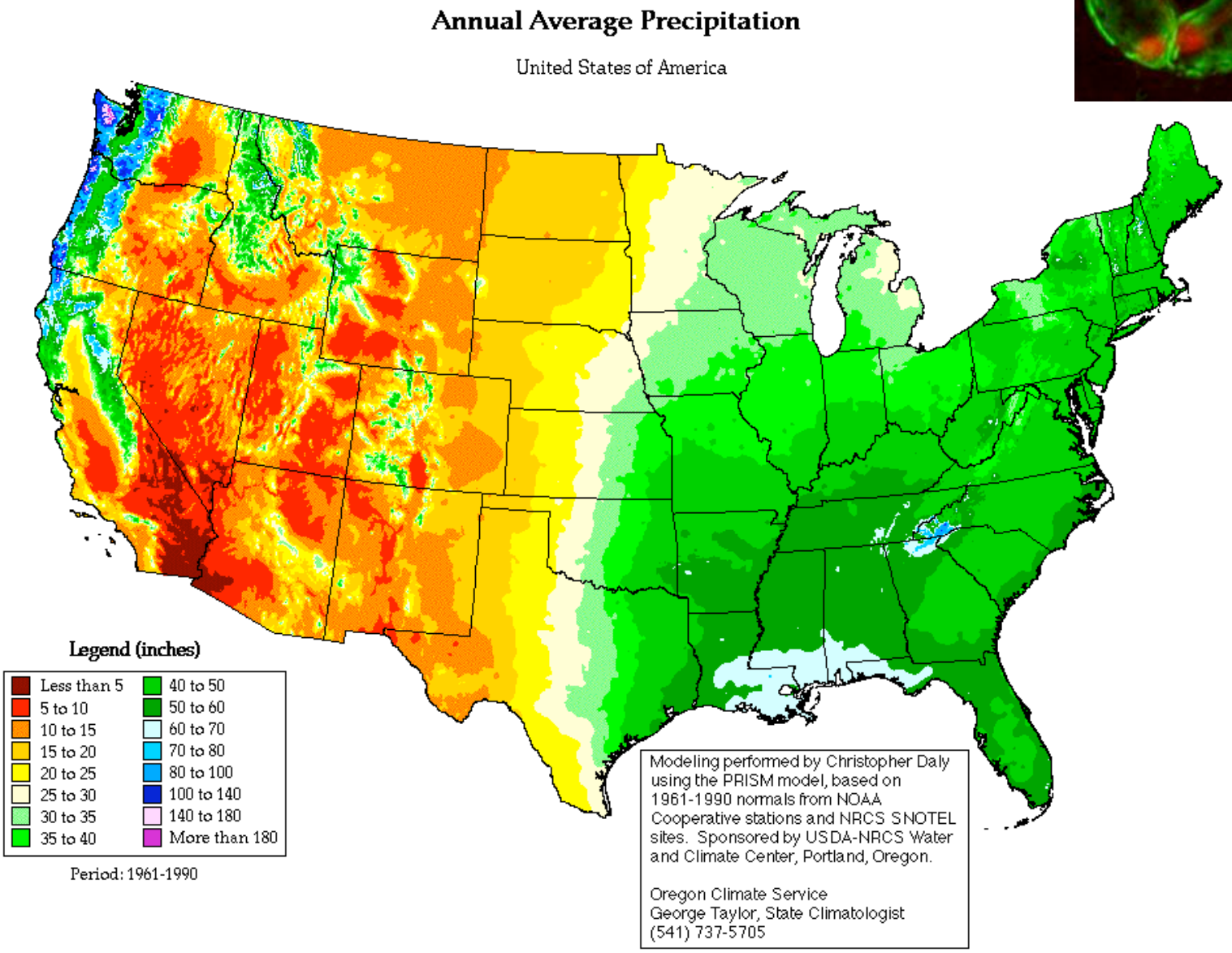
Soil carbon increases in perennial crops with all aboveground biomass removed



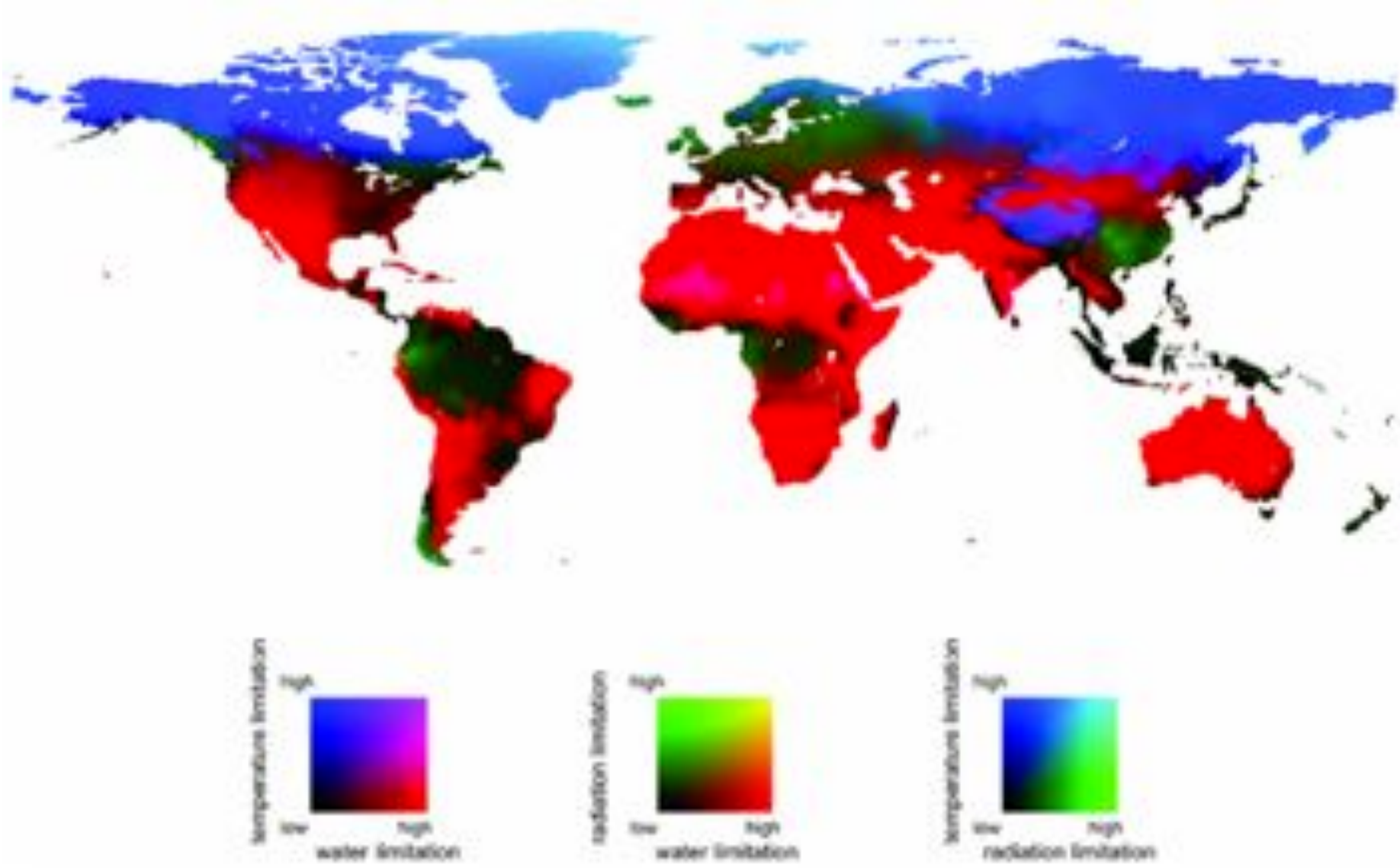
Tilman, Hill & Lehman Science 314,1598

Annual precipitation



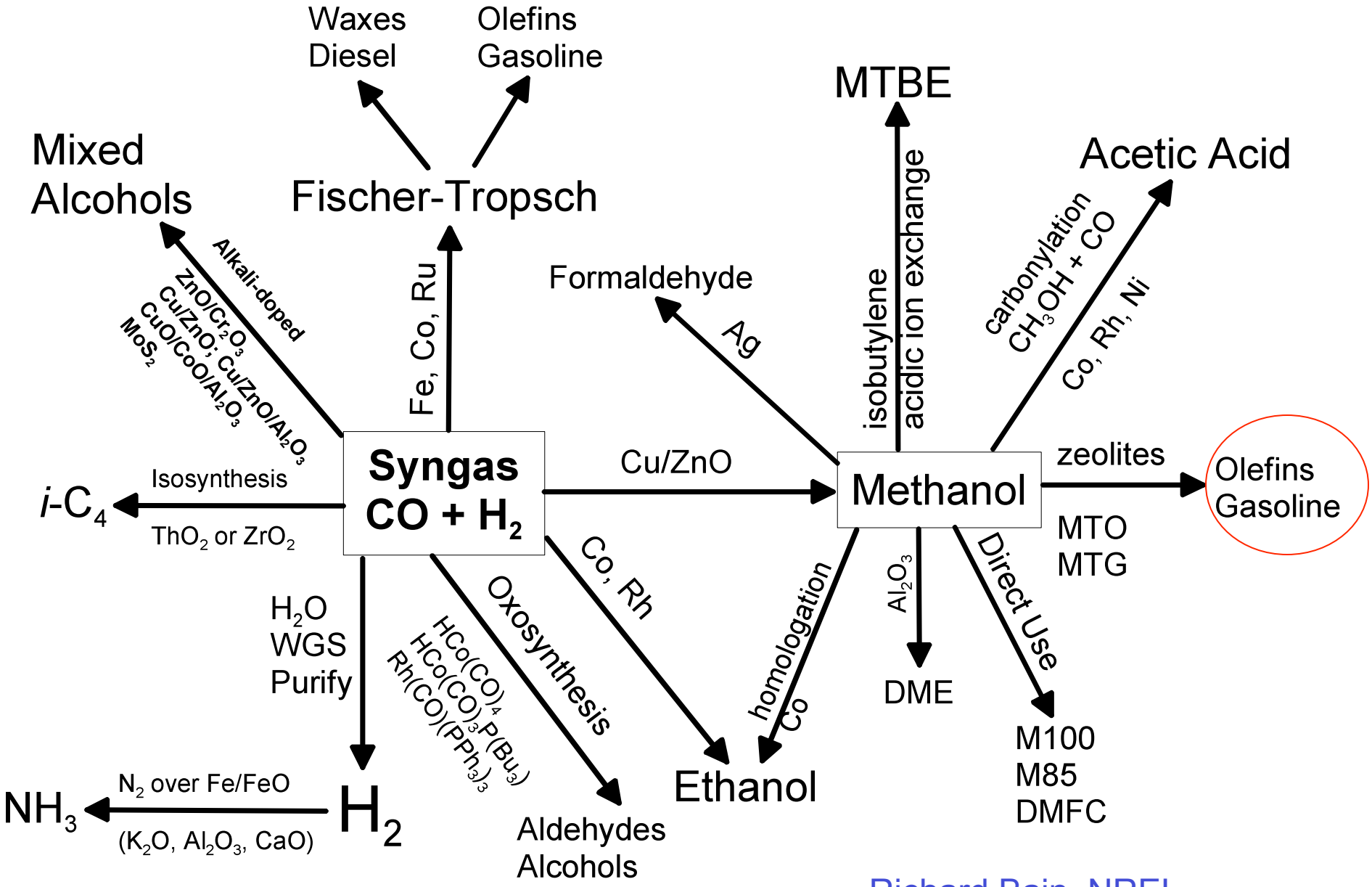


Limiting factors for global NPP



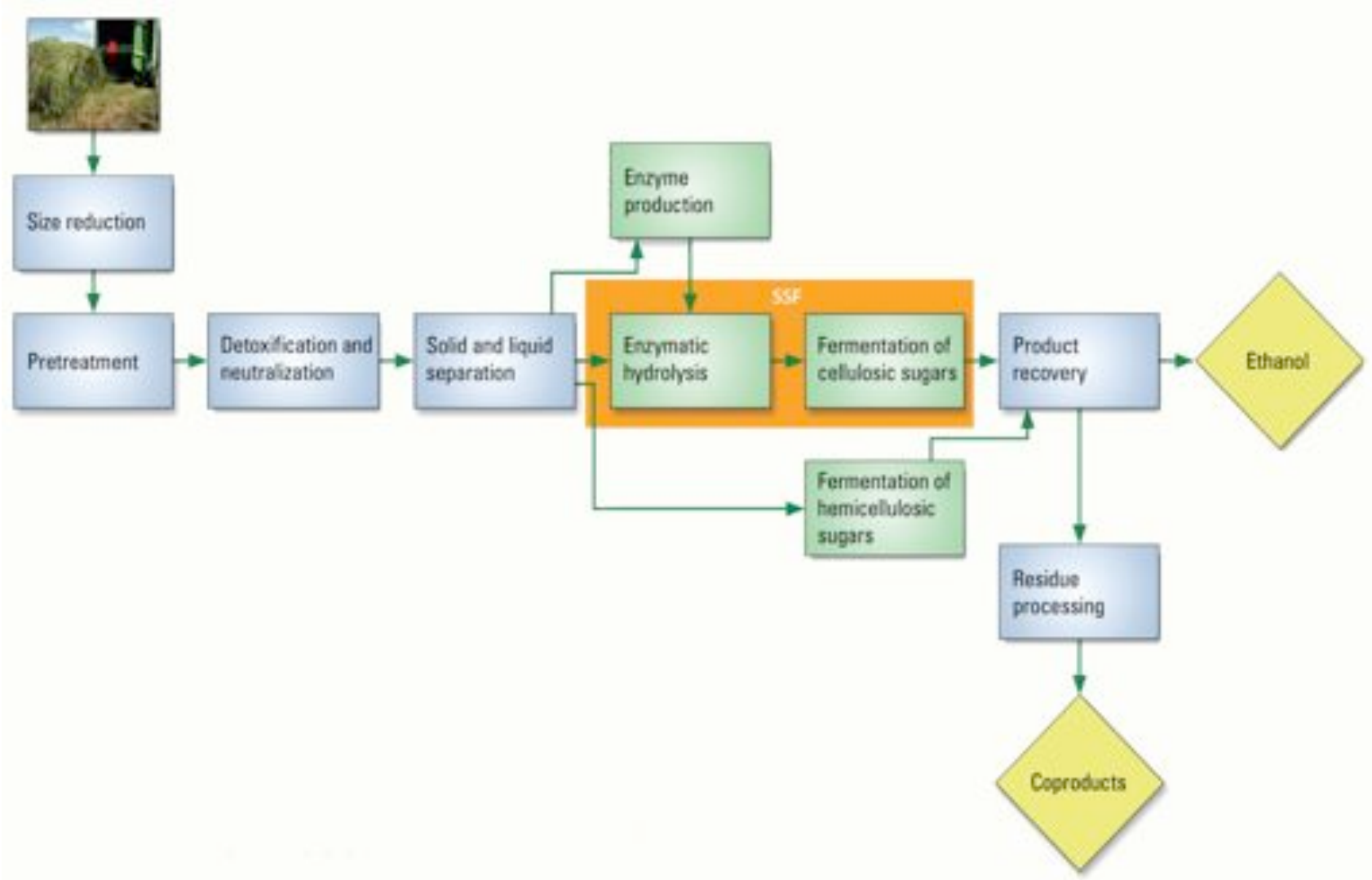
Baldocchi et al. 2004 SCOPE 62

Summary of Syngas-Liquids Processes



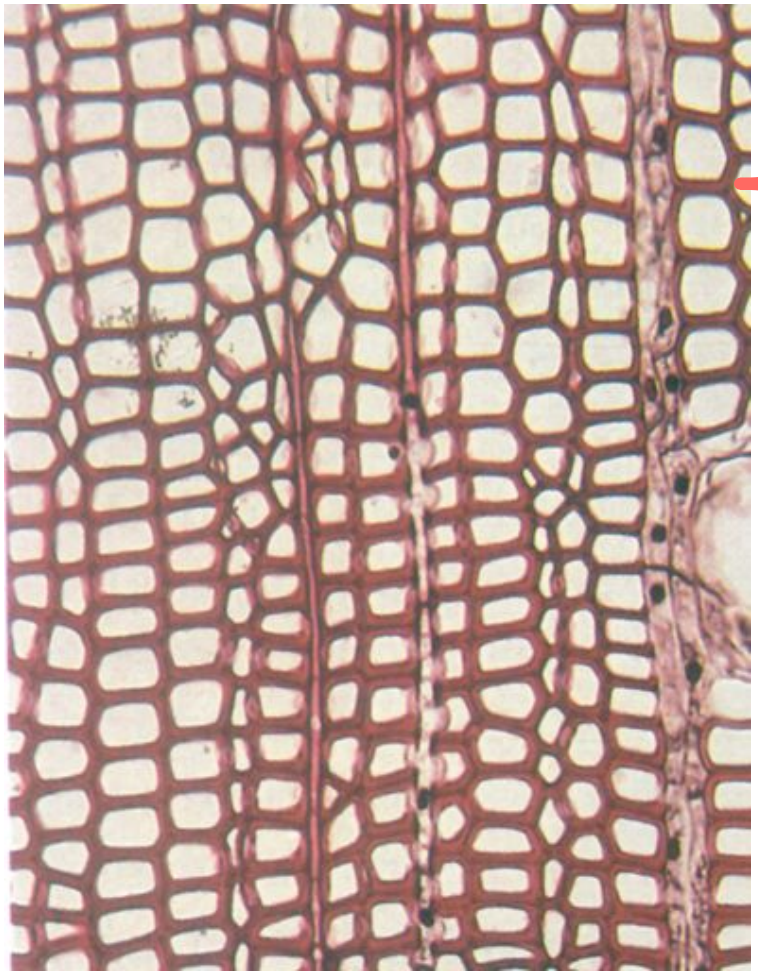
Richard Bain, NREL

Steps in cellulosic ethanol production

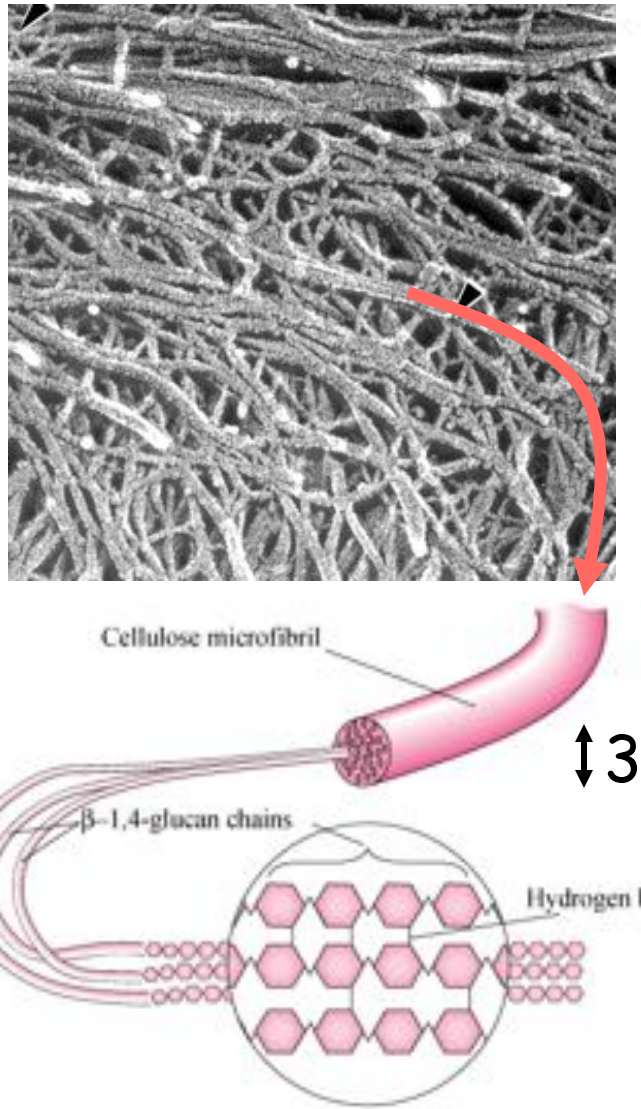


From: Breaking the Biological Barriers to Cellulosic Ethanol

Plants are mostly composed of sugars

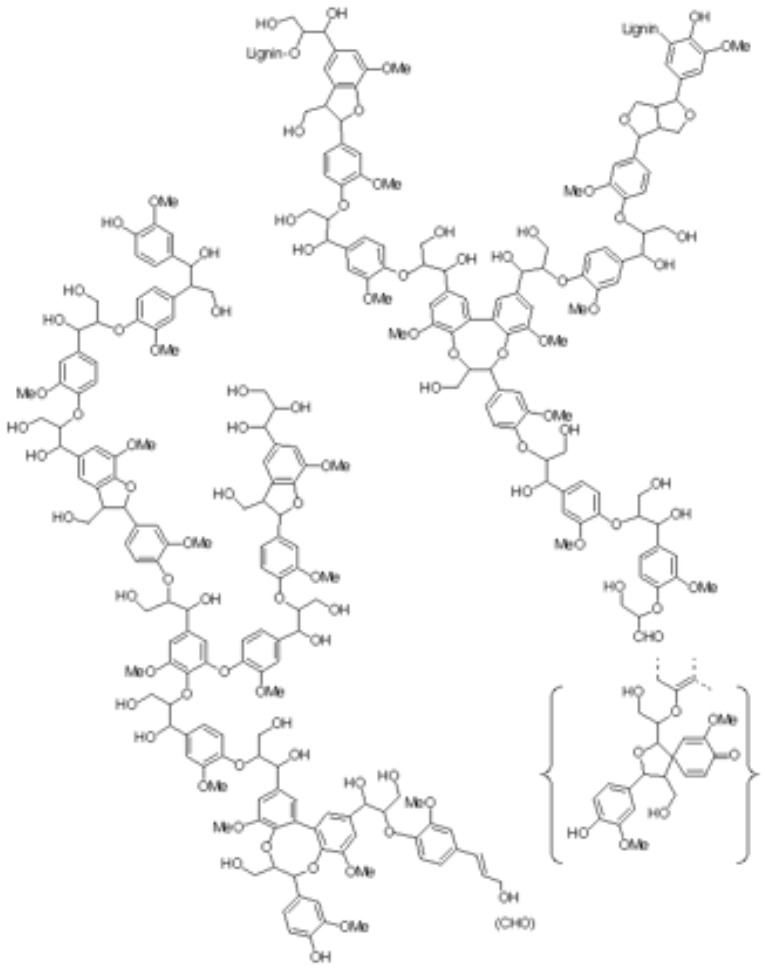


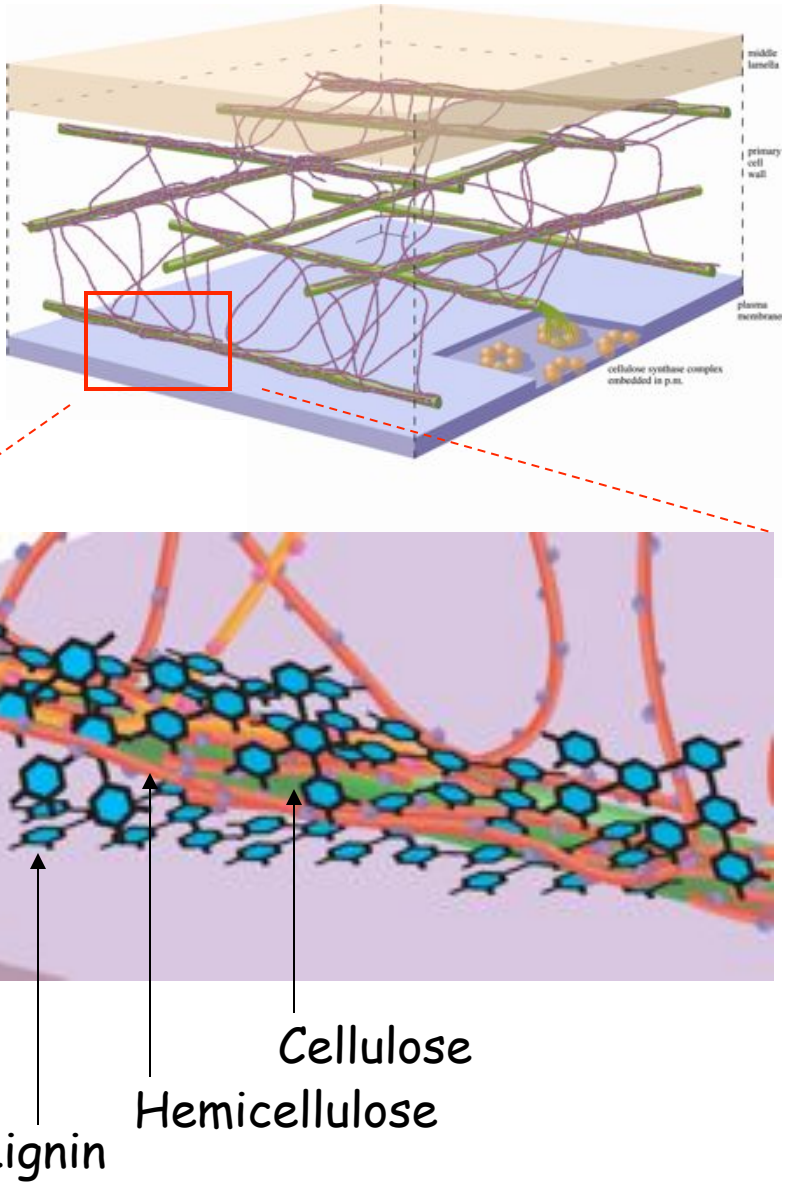
Section of a pine board



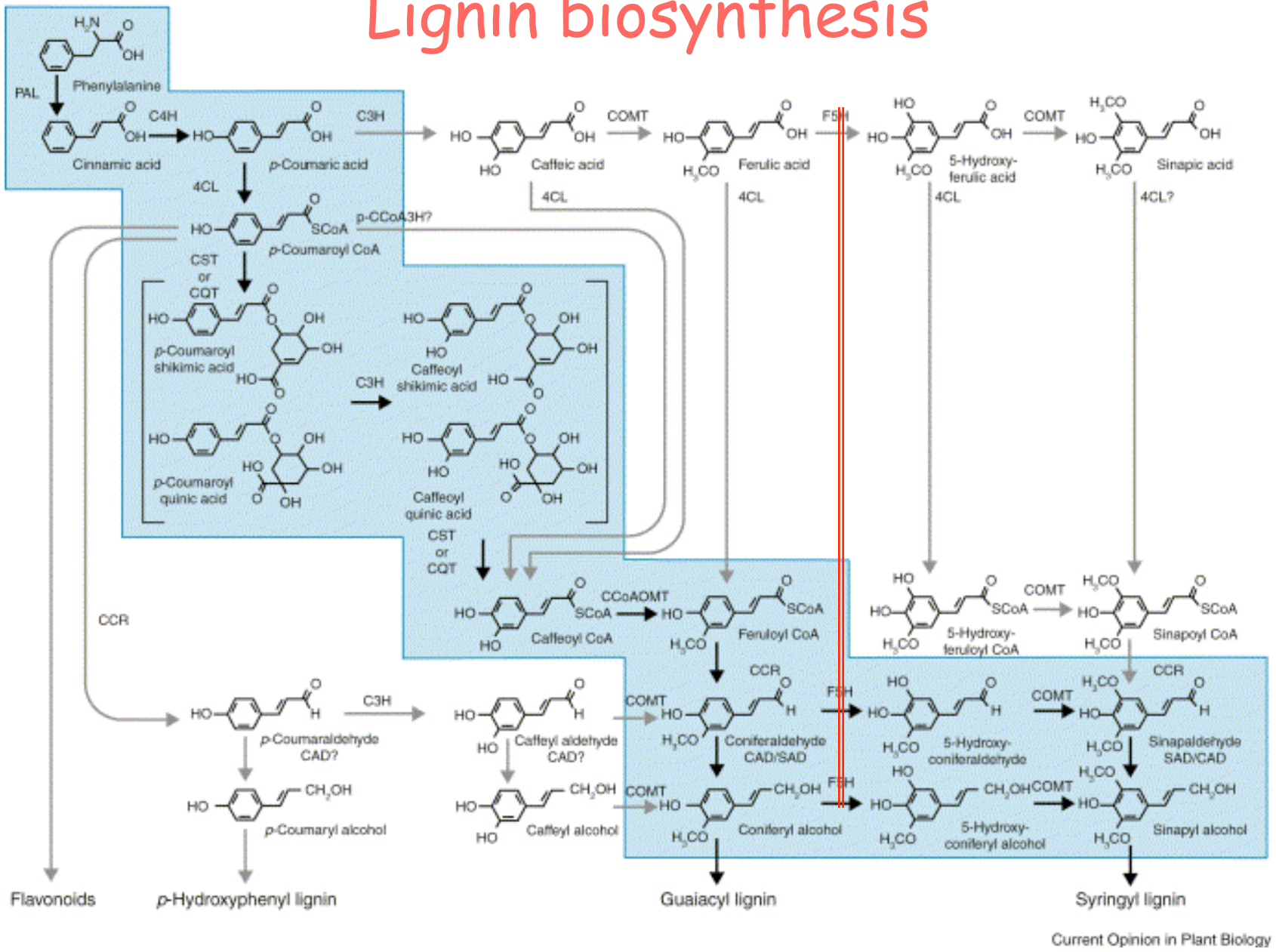
Polymerized glucose

Lignin occludes polysaccharides





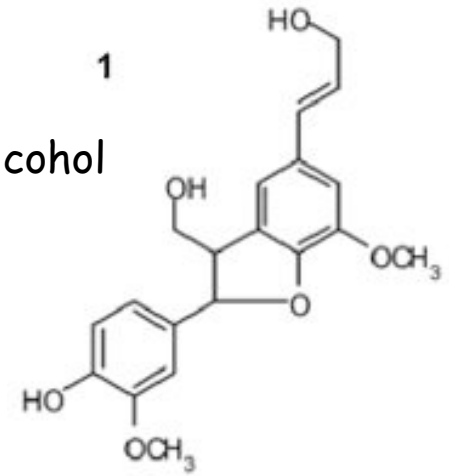
Lignin biosynthesis

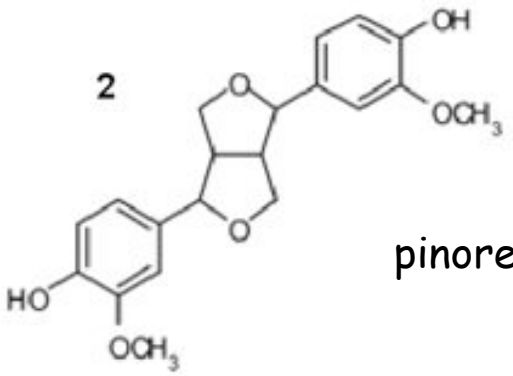


Humphreys and Chapple, Curr Opin Plant Biol 5,224

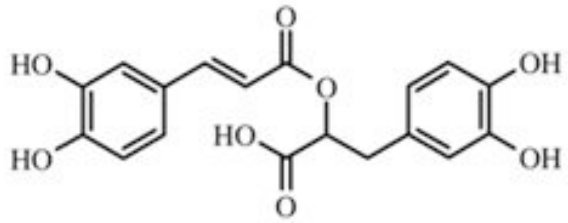
A cleavable lignin precursor would fundamentally alter preprocessing

dehydrodiconiferyl alcohol



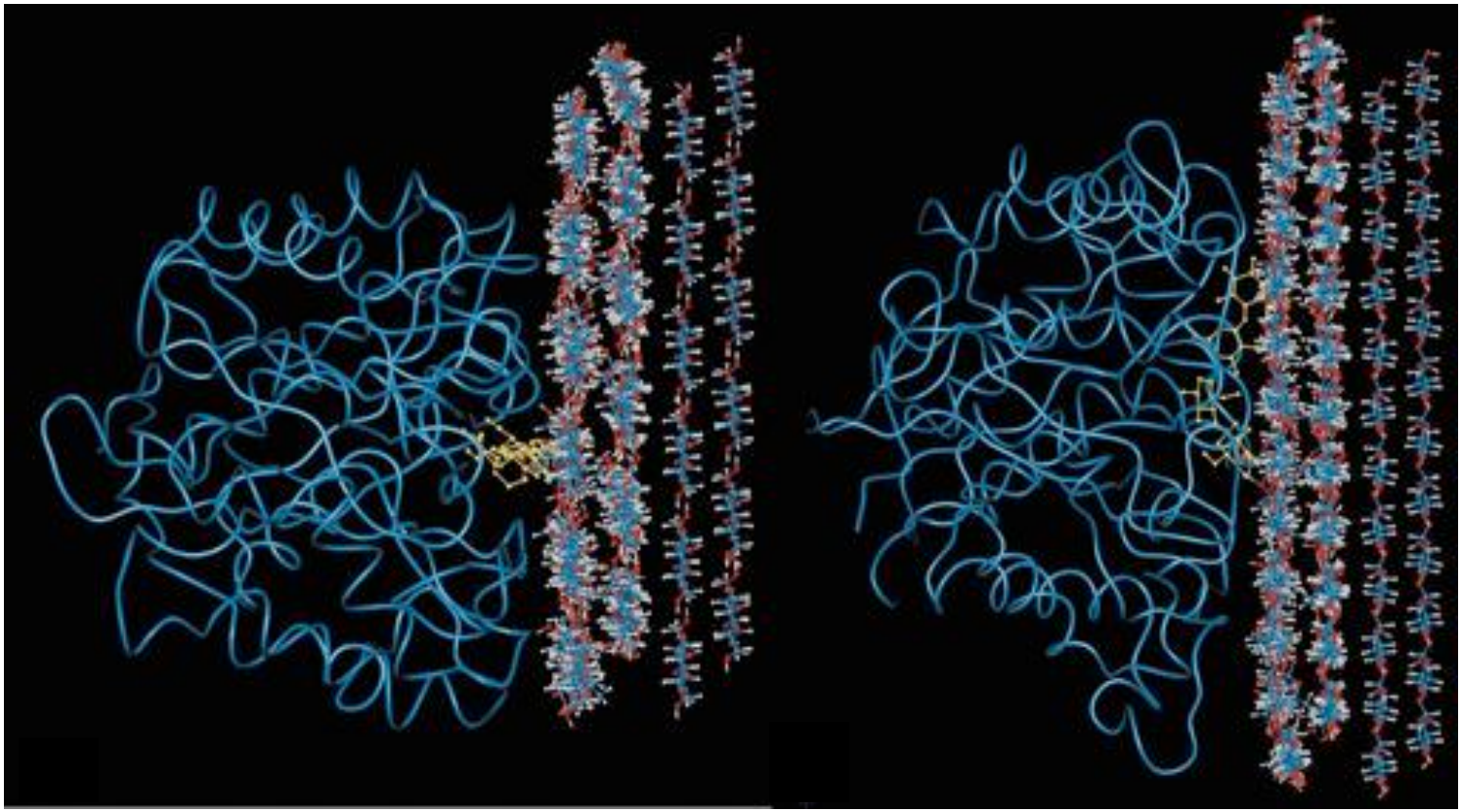


pinoresinol



rosmarinic acid

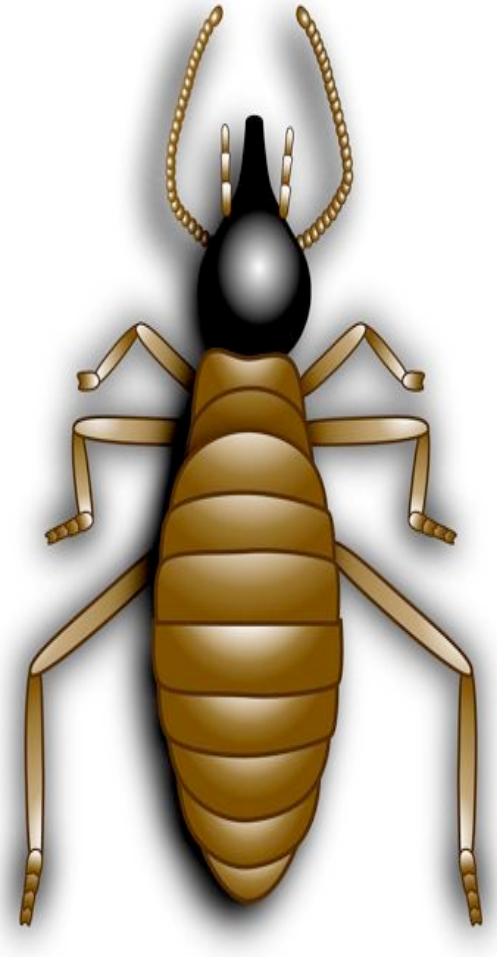
Enzymatic hydrolysis of cellulose is slow



Skopec, Himmel, Matthews, Brady Protein Engineering 16, 1005

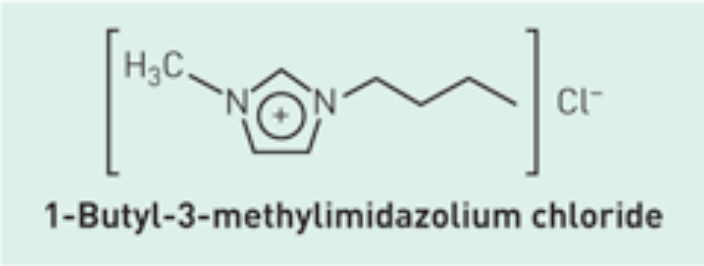
Possible routes to improved catalysts

- Explore the enzyme systems used by termites (and ruminants) for digesting lignocellulosic material
- Compost heaps and forest floors are poorly explored
- In vitro protein engineering of promising enzymes
- Develop synthetic organic catalysts (for polysaccharides and lignin)

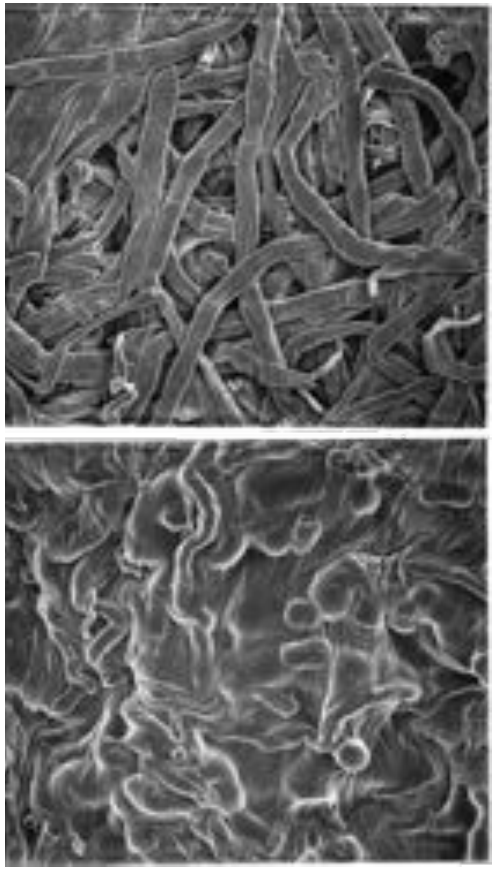


Dissolution of cellulose in an ionic liquid

(novel pretreatment methods may create fundamental changes)



1-Butyl-3-methylimidazolium chloride

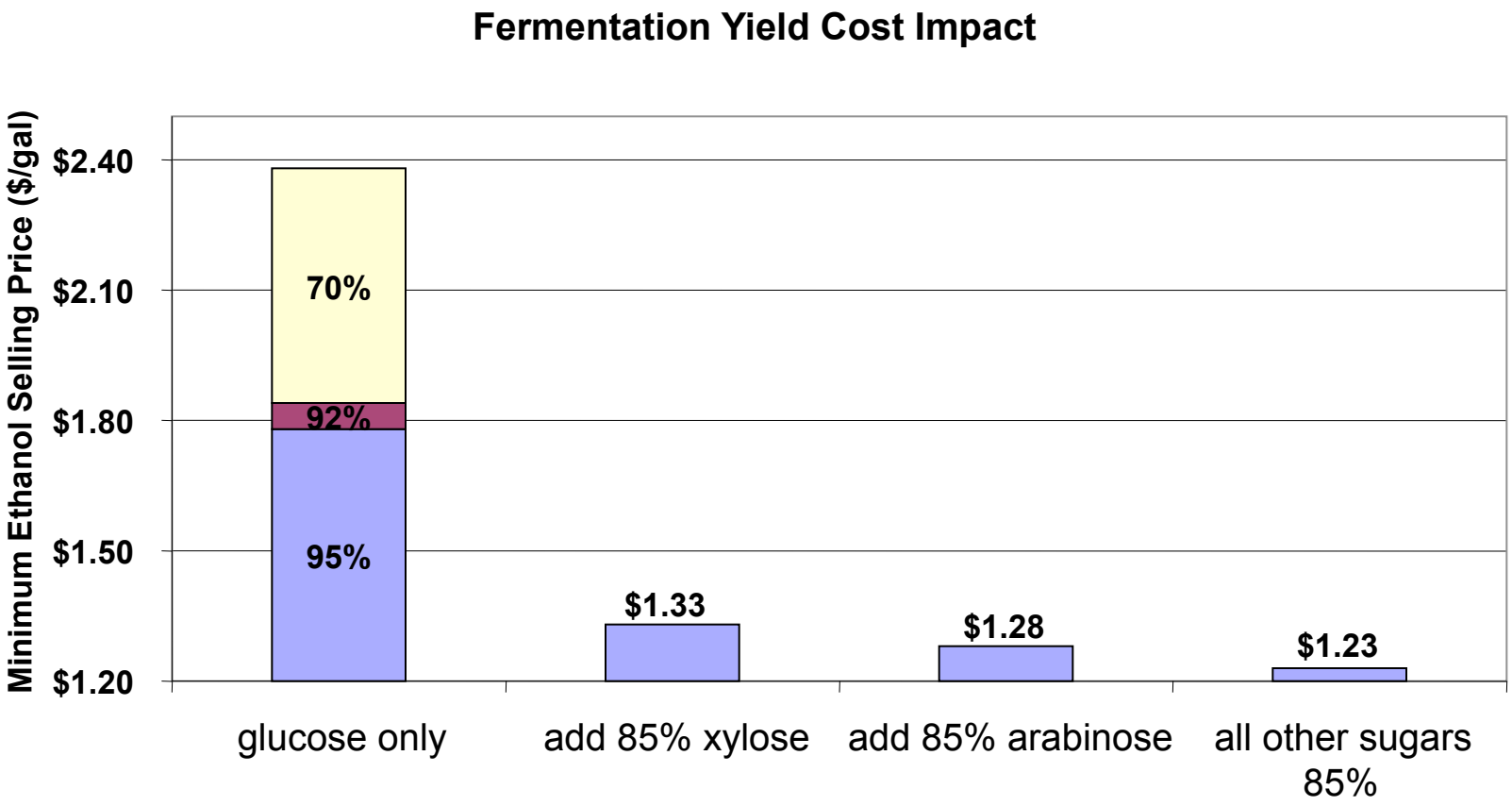


Untreated

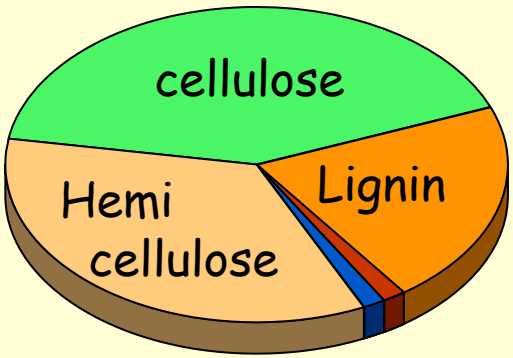
Treated

Swatloski, Spear, Holbrey, Rogers *J. Am. Chem. Soc.*, 124 (18), 4974 -4975, 2002

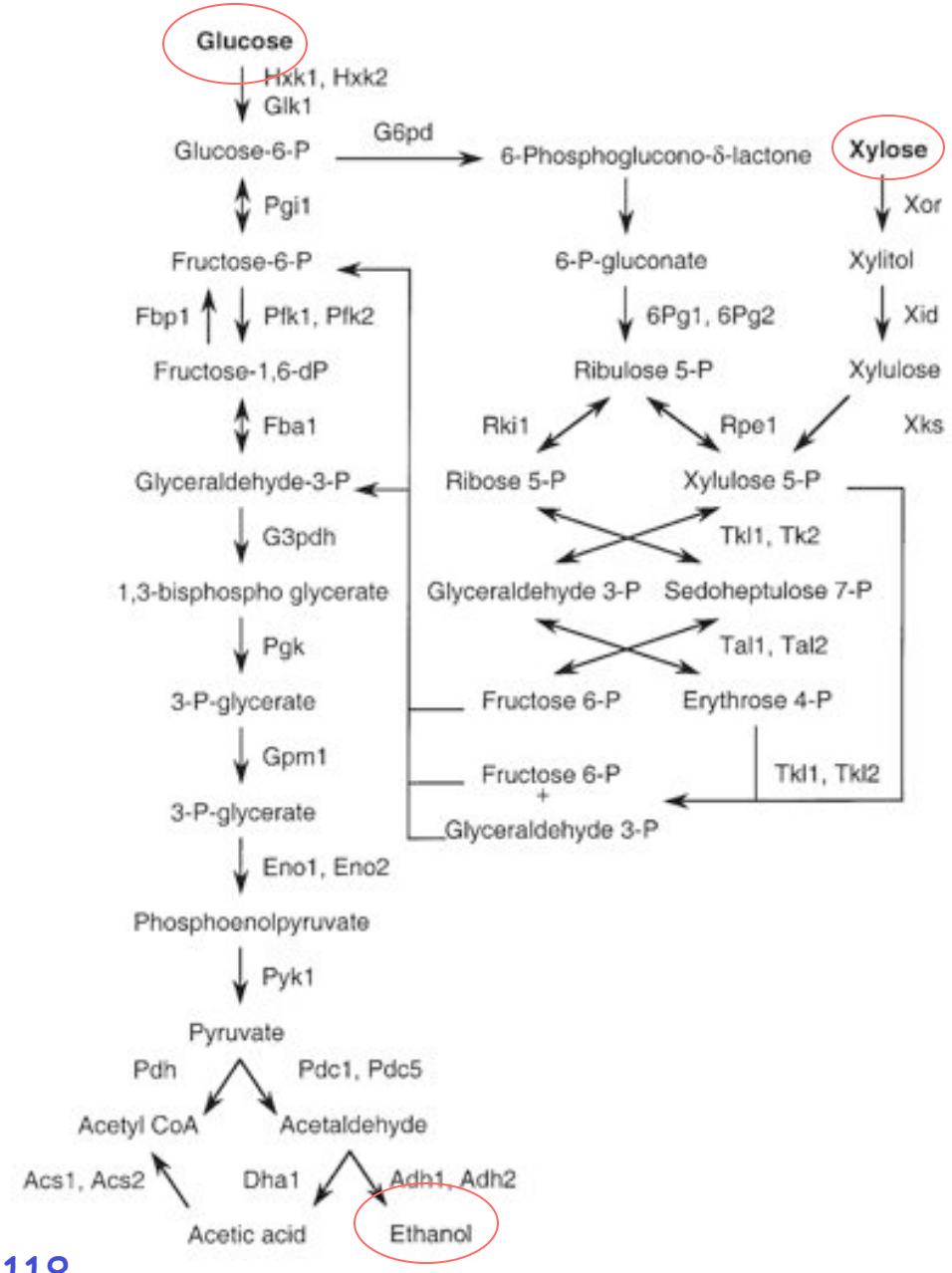
Saccharification & Fermentation



Fermentation of all sugars is essential

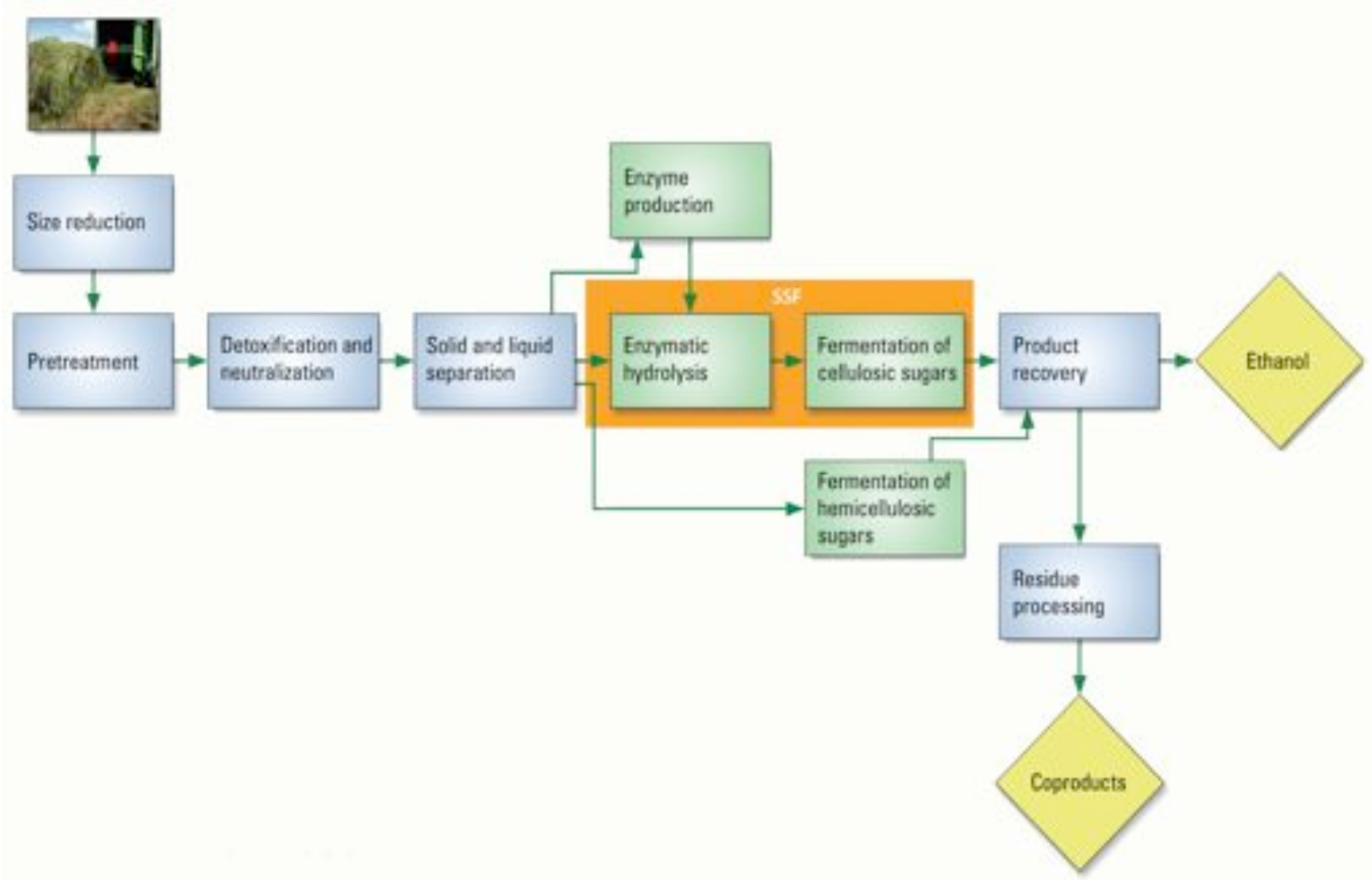


Typical grass composition



Jeffries & Shi Adv Bioch Eng 65,118

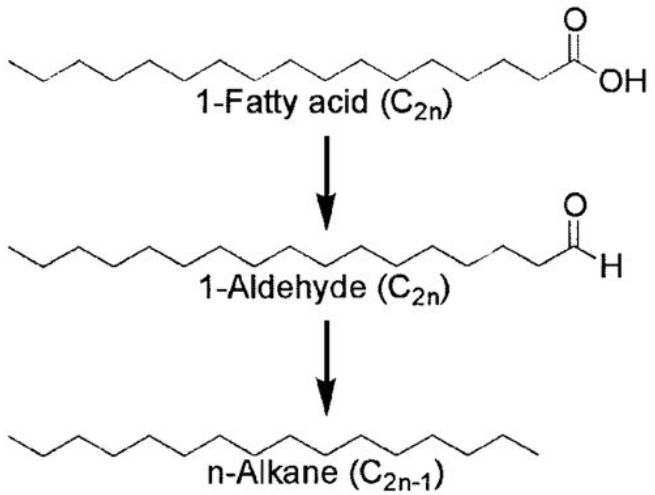
Steps in cellulosic ethanol production



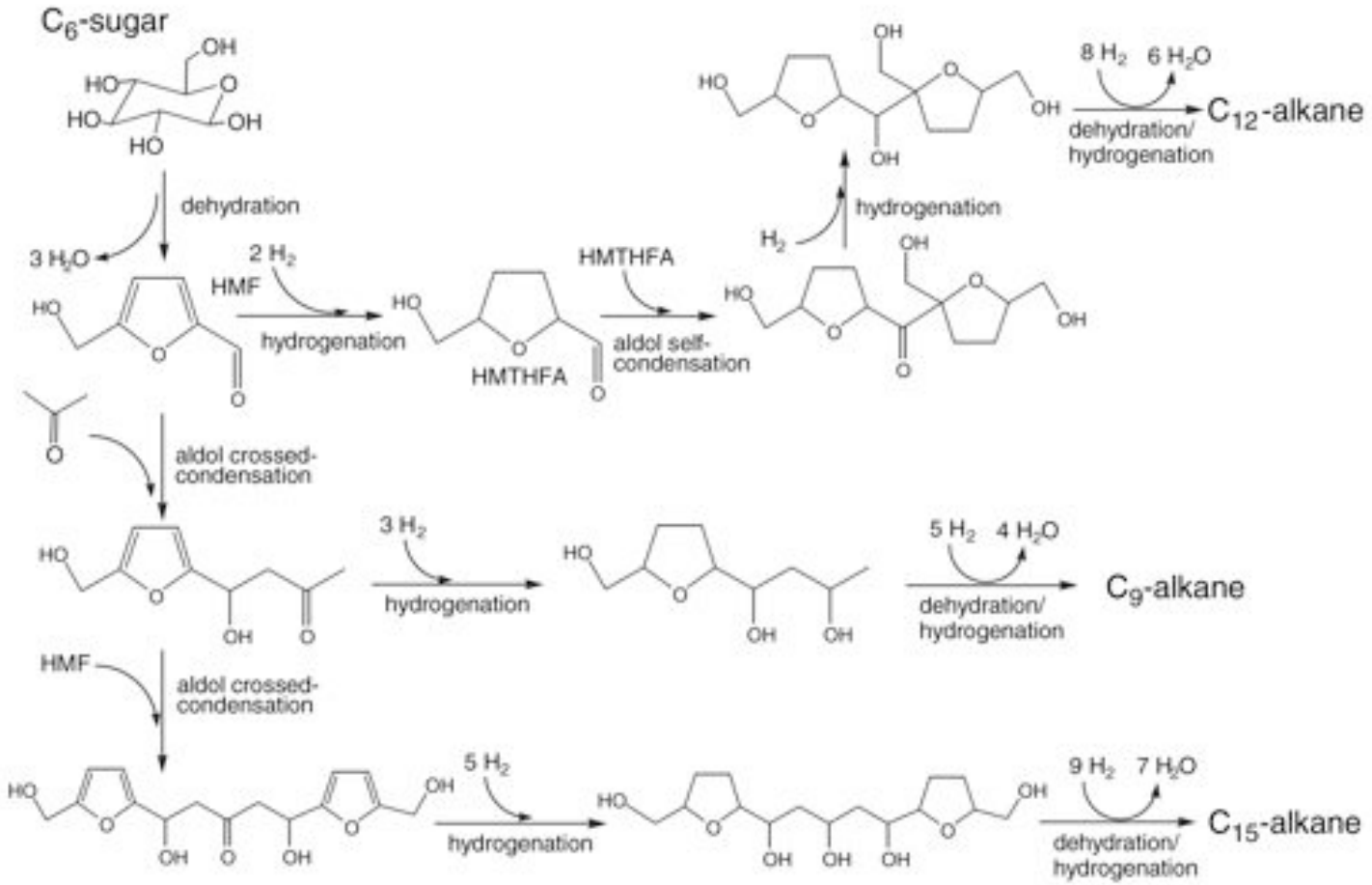
From: Breaking the Biological Barriers to Cellulosic Ethanol

Nature offers many alternatives to ethanol

- Plants, algae, and bacteria synthesize alkanes, alcohols, waxes
- Production of hydrophobic compounds would reduce toxicity and decrease the energy required for dehydration



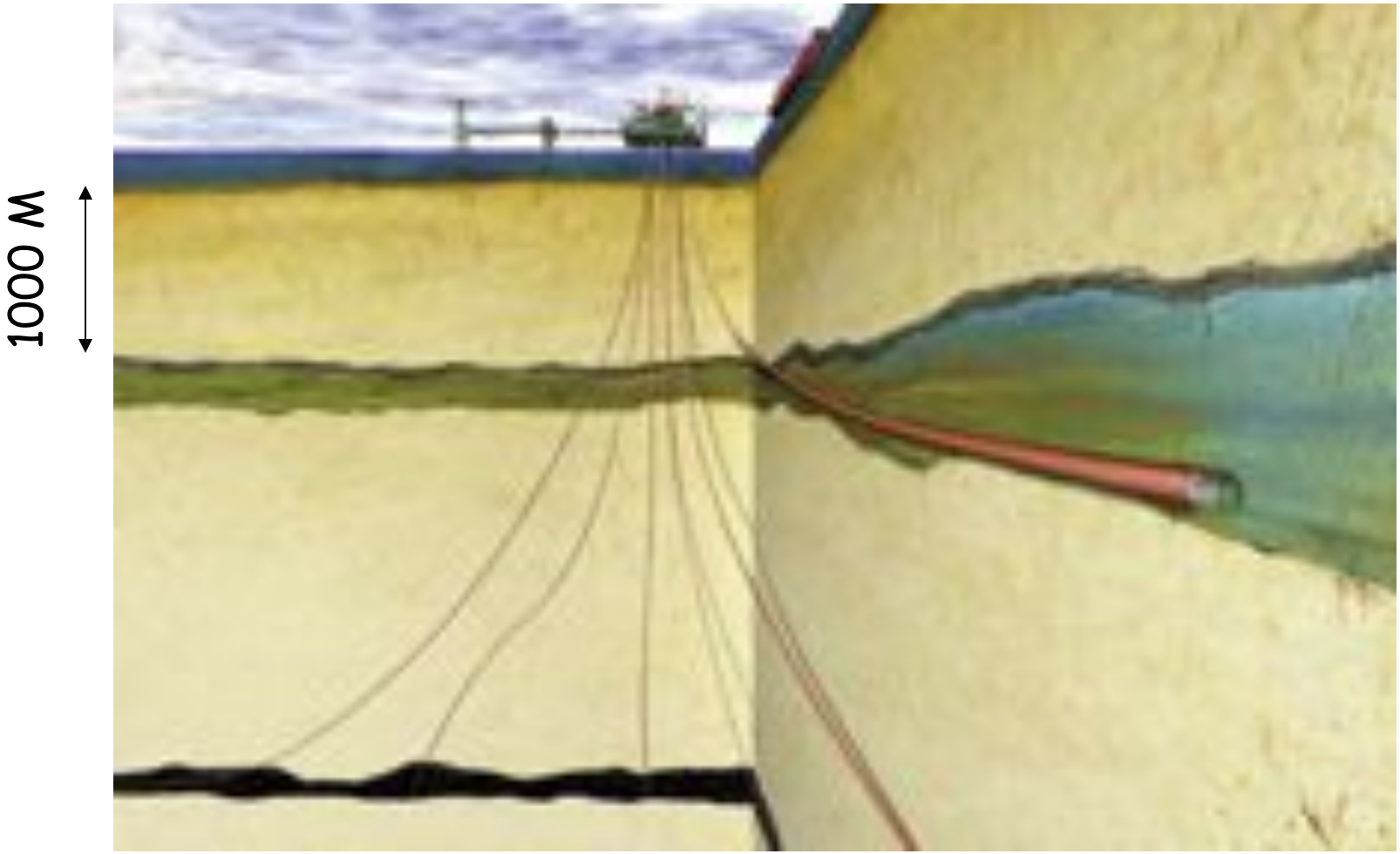
Conversion of sugar to alkanes



Huber et al., (2005) Science 308,1446

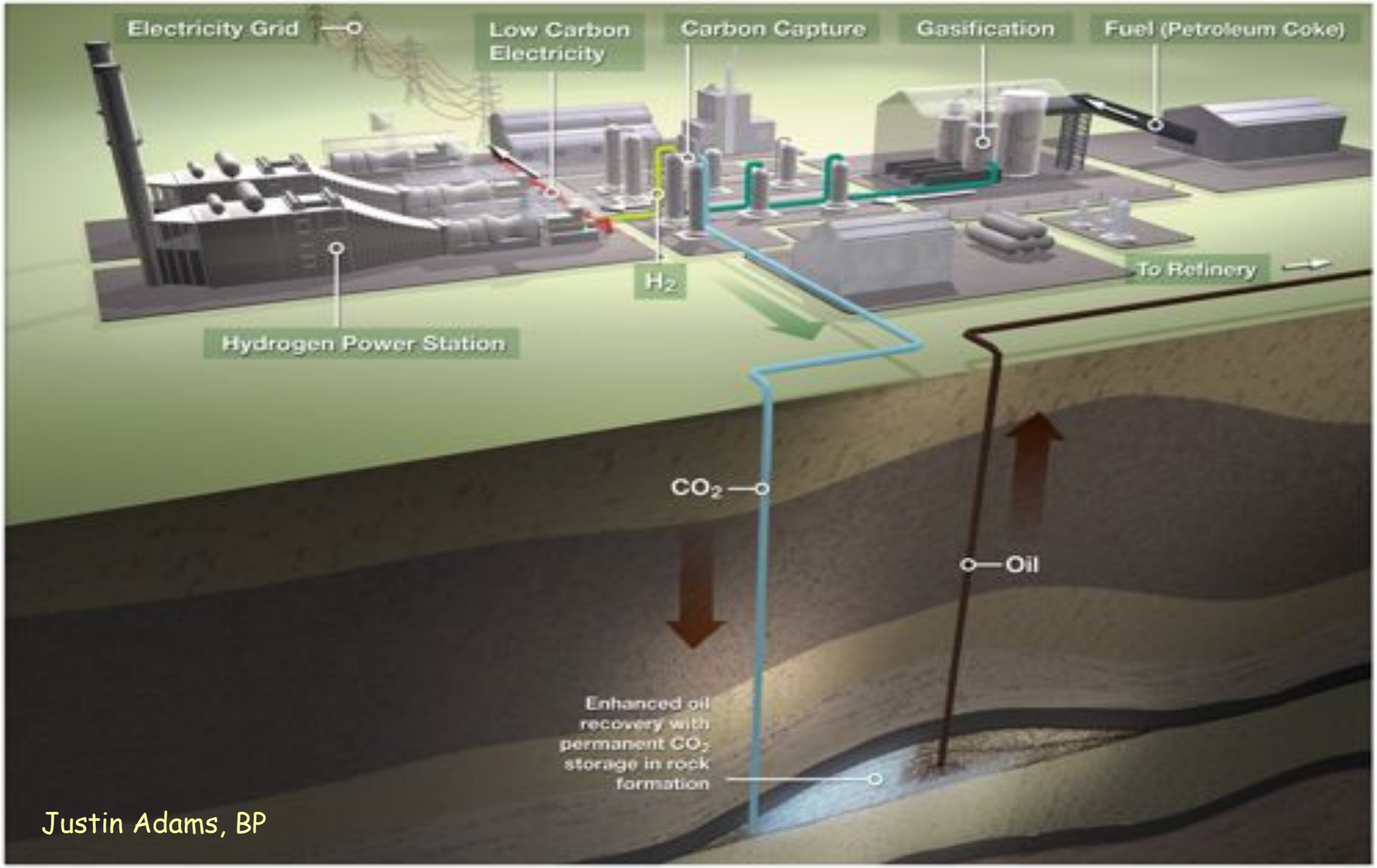
The Sleipner Experiment

1 million tons/y; capacity 600 B tons
7000 such sites needed



www.agiweb.org/geotimes

The "hydrogen economy"



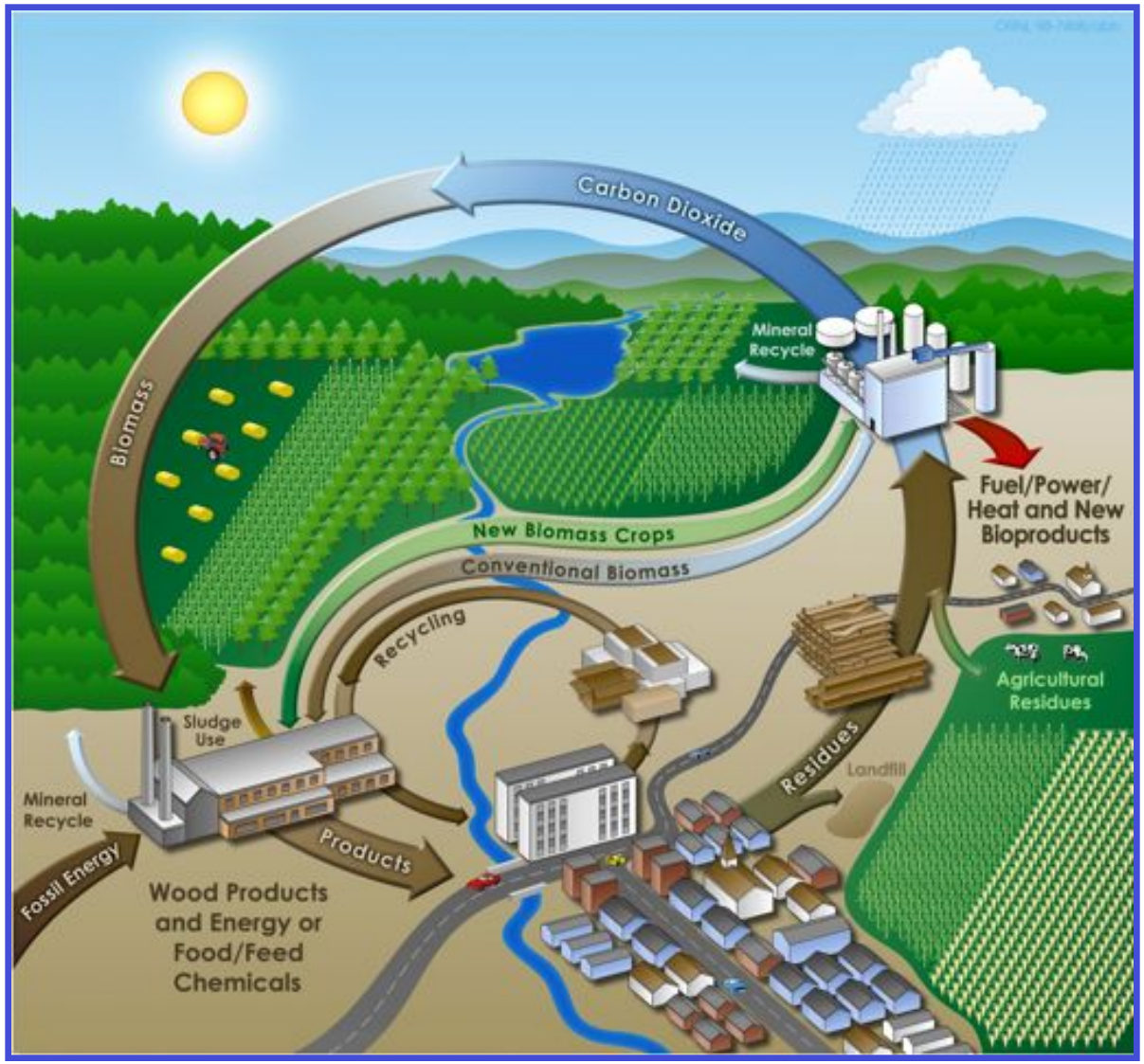
Visions

- Corn grain ethanol will be displaced by cellulosic fuels (~3-4X reduction in land use)
- Sugarcane use will expand to include both sugar and cellulose (~3-4x reduction in land use)
- Diesel replacements will be obtained from cellulosic materials rather than vegetable oils (~20-40x reduction in temperate acres)
- Ethanol will eventually be displaced by more highly reduced compounds (improved net energy efficiency)
- Synthetic catalysts could be game-changing

Summary of priorities

- Develop energy crops and associated agronomic practices
- Identify or create more active catalysts for conversion of biomass to sugars and sugars to fuels
- Develop industrial microorganisms that ferment all sugars
- Develop new types of microorganisms that produce and secrete hydrophobic compounds
- Understand the social, economic, and environmental implications

The Future



http://genomicsgtl.energy.gov/biofuels/index.shtml