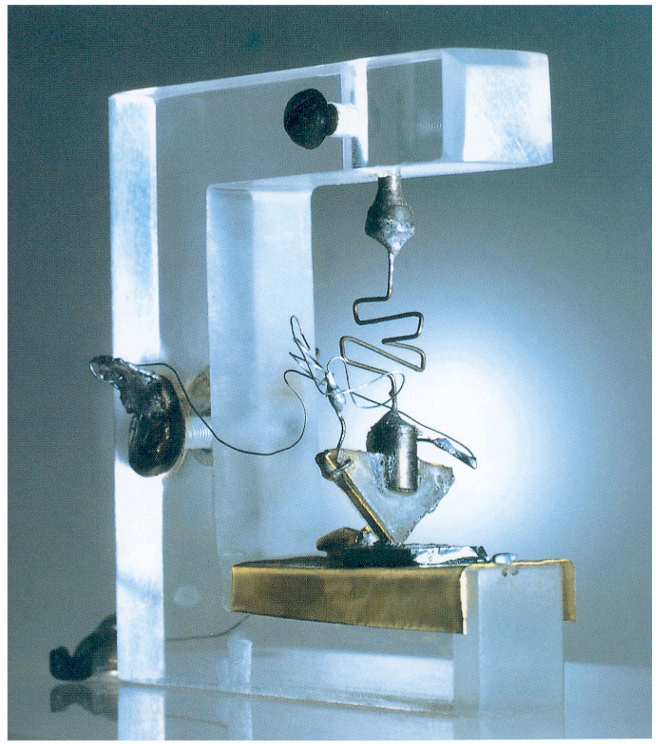
Development of Cellulosic Biofuels

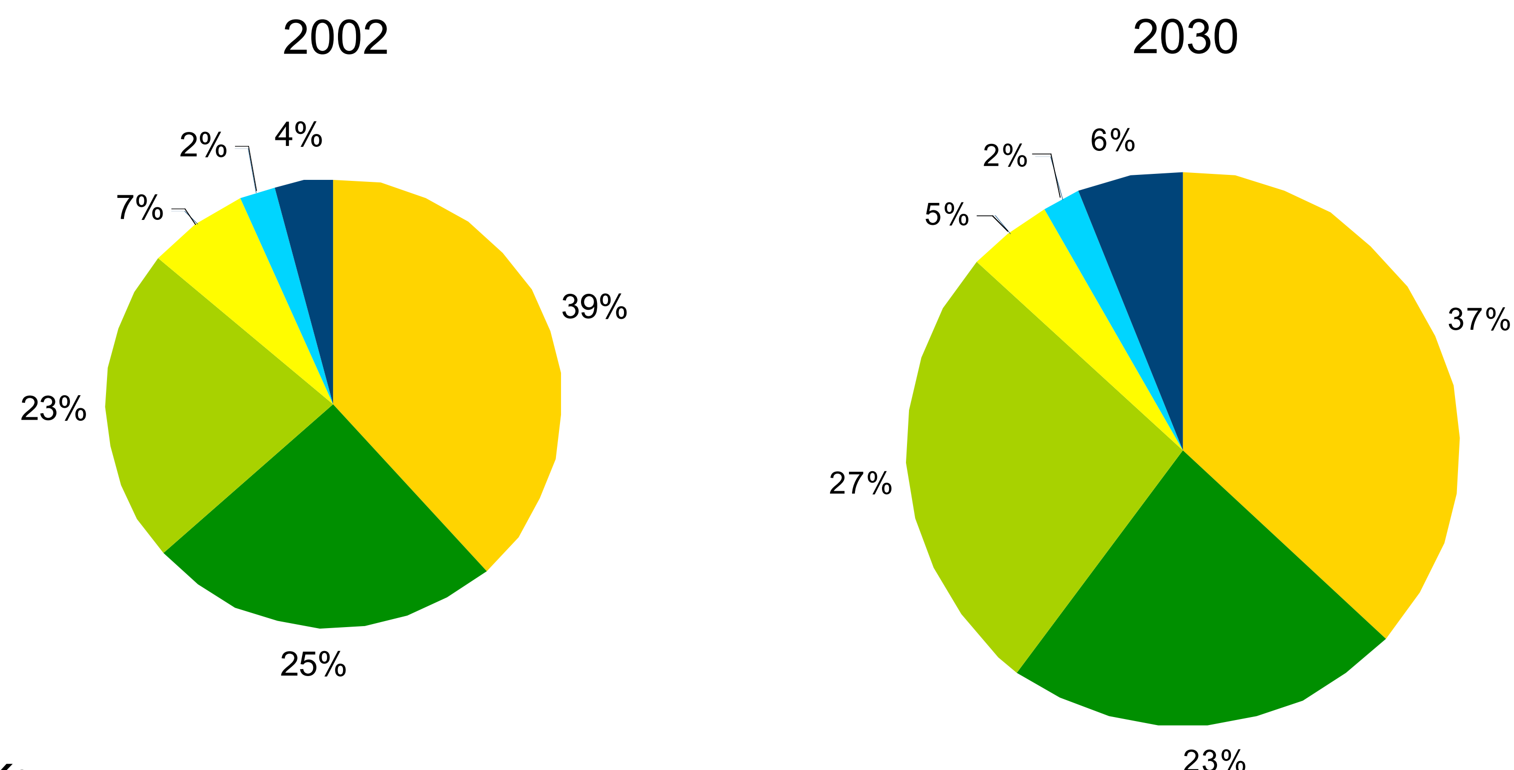


Chris Somerville
Energy Biosciences Institute
UC Berkeley, LBL, University of Illinois

Current and predicted energy use

Current use 13 TW

Global Primary Energy Supply by Fuel:*



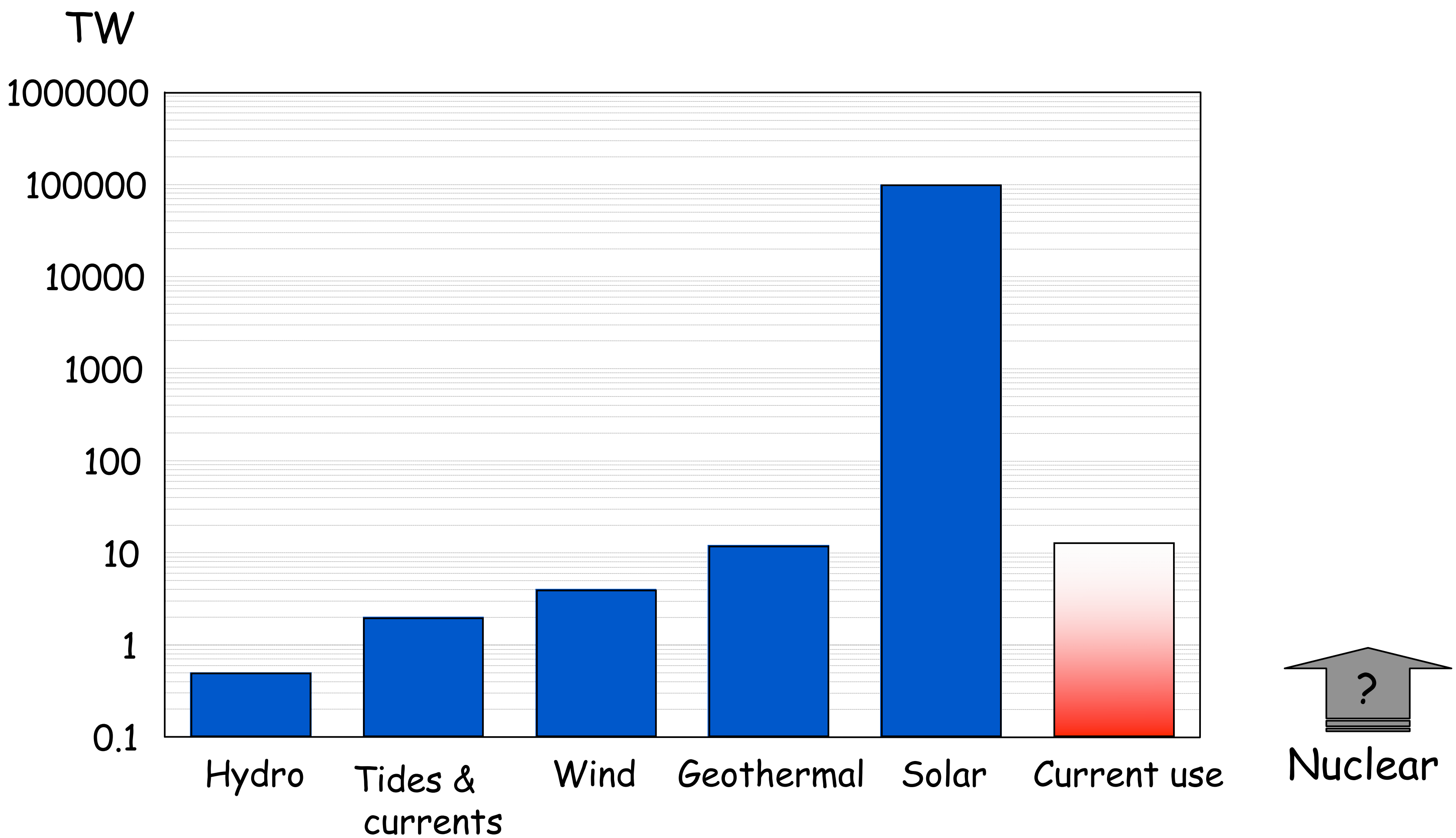
Key:

- oil - coal - gas - nuclear - hydro - modern renewables

* - excludes traditional biomass

Source: IEA 2004 & Jim Breson

Potential of carbon-free energy sources



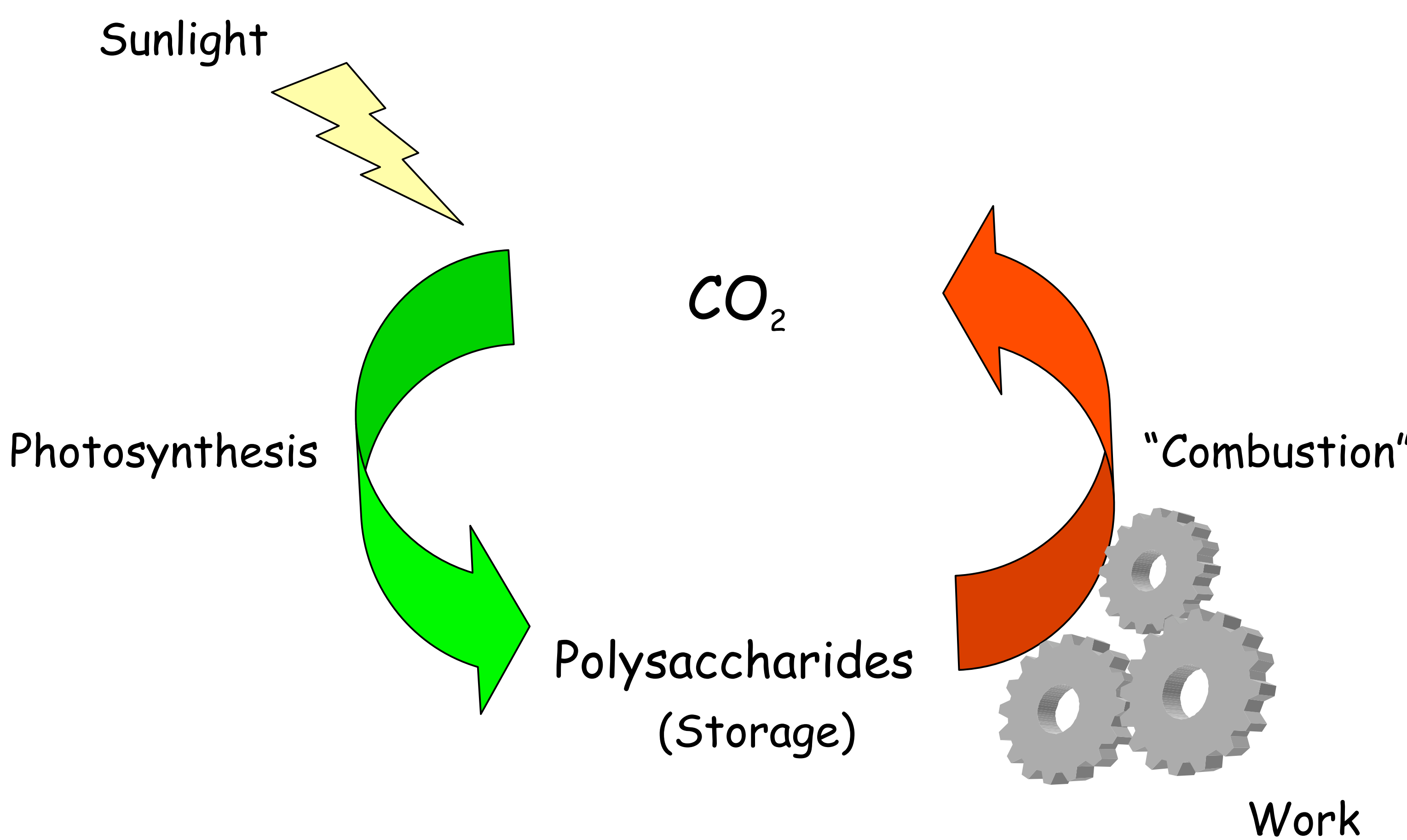
From: Basic Research Needs for Solar Energy Utilization, DOE 2005

~26,000 km^2 of photovoltaic devices would meet US energy

Turner, Science 285,687

Total shipped 1982-98 = 3 km^2

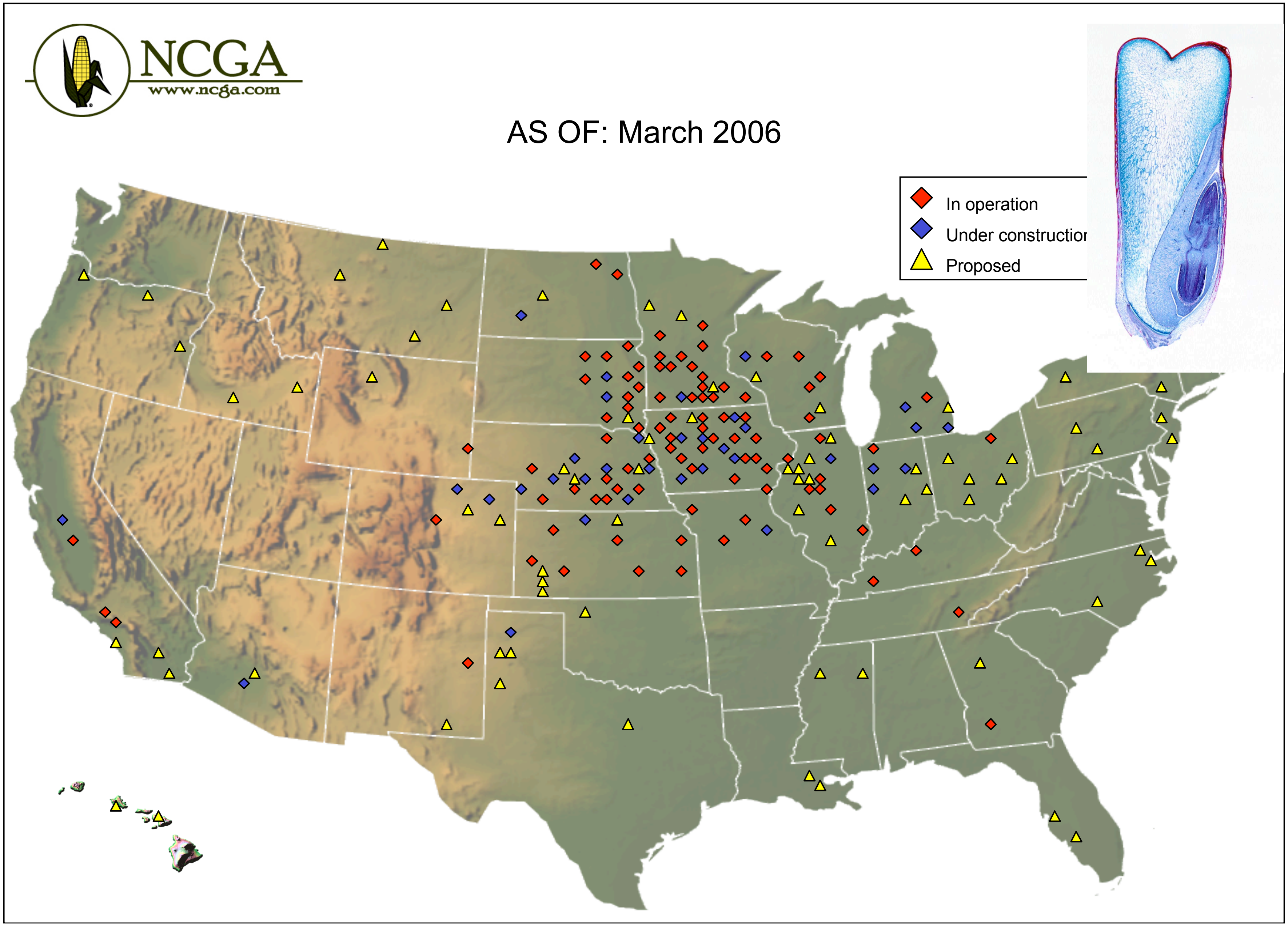
Combustion of biomass provides carbon neutral energy



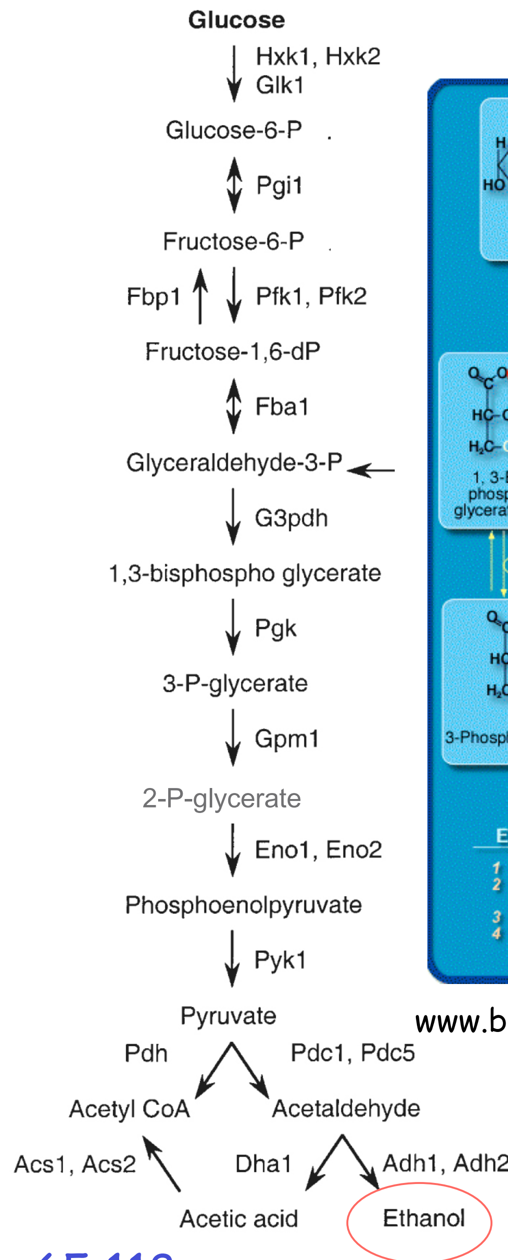
Overview of Brazil sugarcane

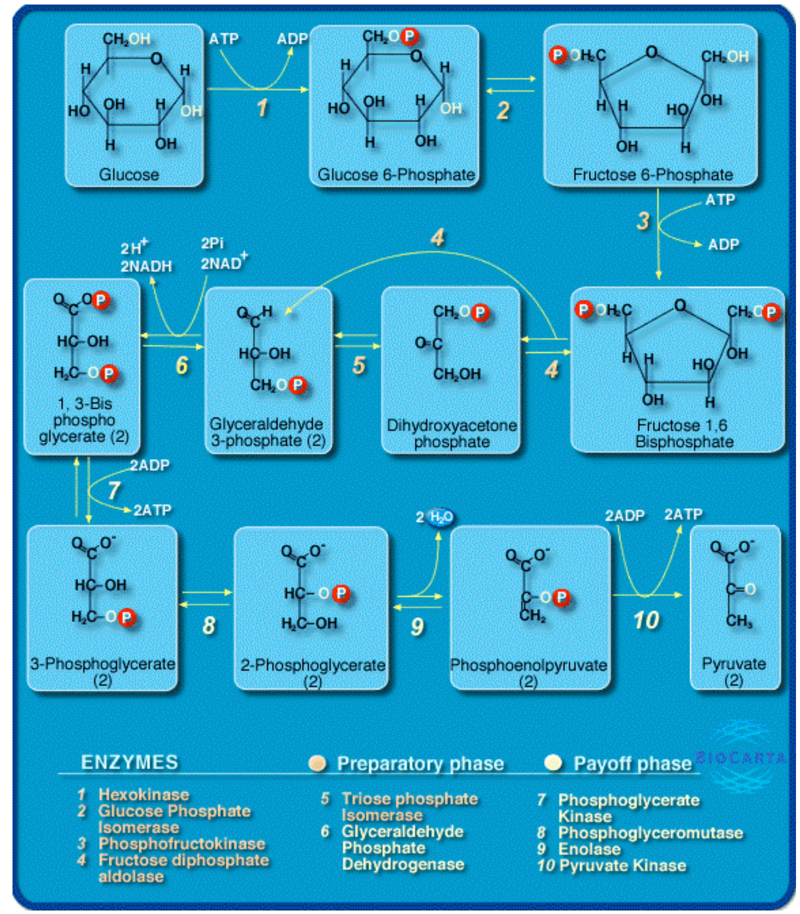
- 2007-08 harvest 528 MMT
- ~8 M Ha planted by 2008
- ~20 B liters ethanol, 2007
- ~80-120 T/Ha
- ~6400 L ethanol/Ha
- ~333 mills, 200 planned
- Plantings last 5 y, cut one per year
- Large mill
  - 22,000 tons/day
  - 1500 truck loads/day

US Biofuel Production has Expanded Rapidly



Fermentation of glucose to ethanol

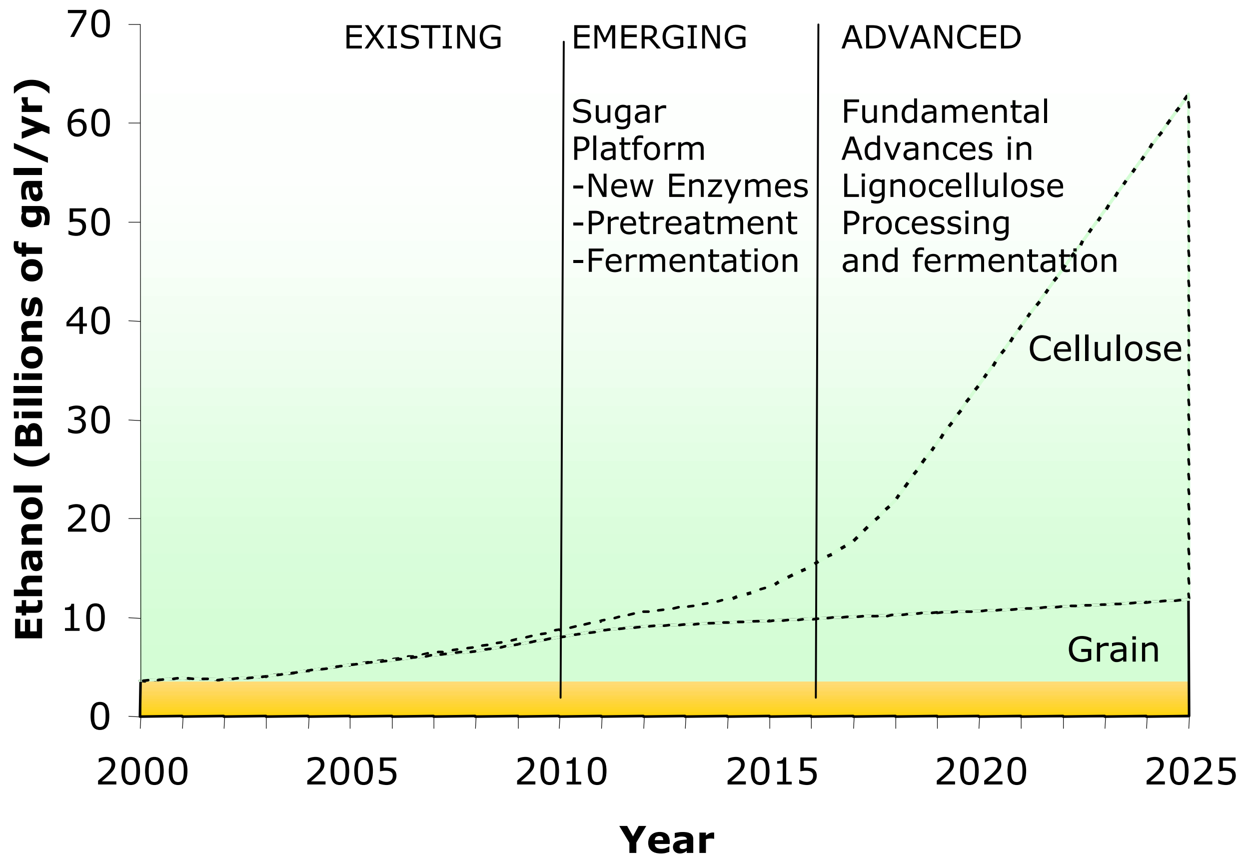




www.biocarta.com/pathfiles/h_glycolysisPathway.asp

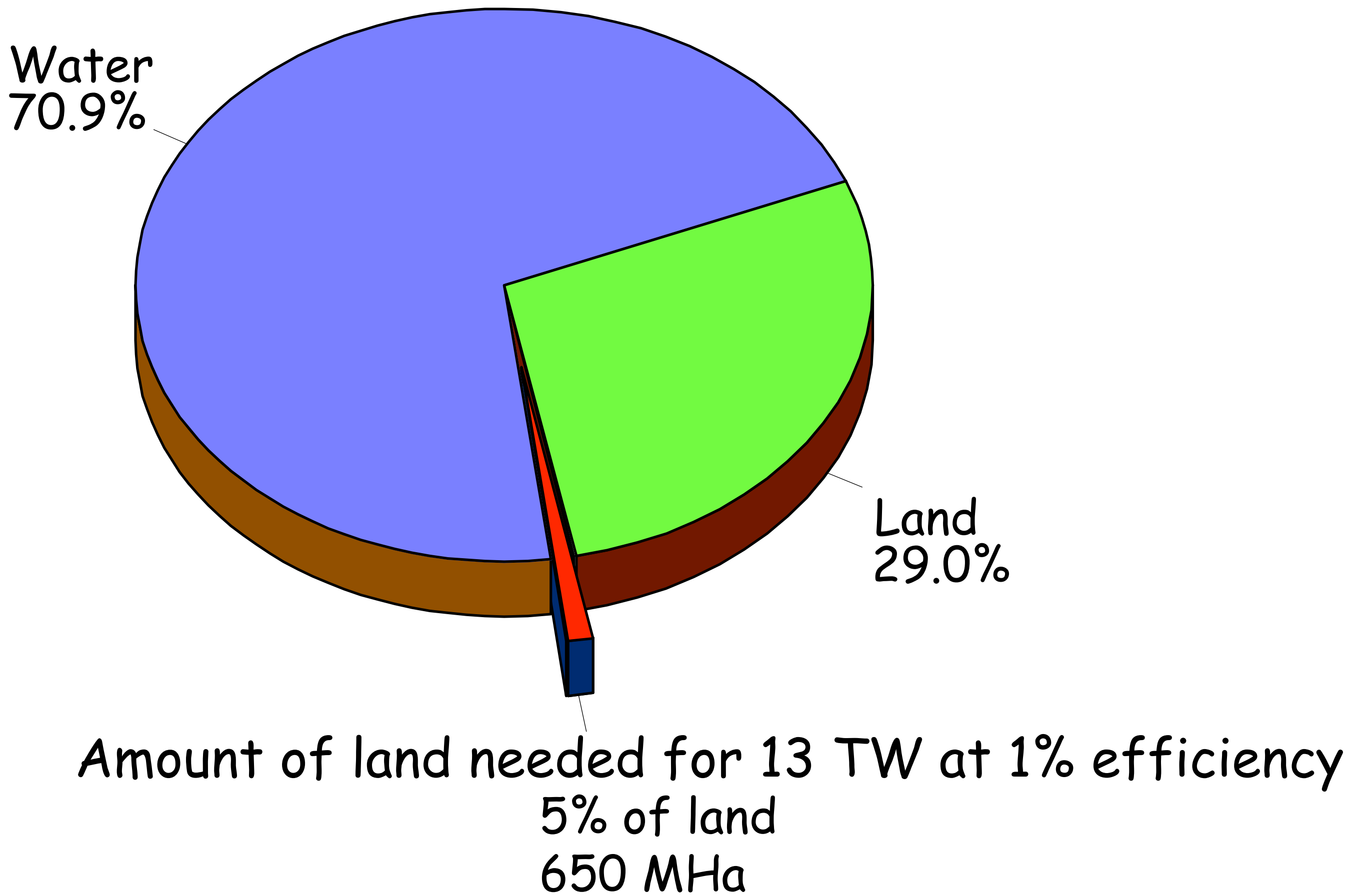
Jeffries & Shi Adv Bioch Eng 65,118

Cellulosic fuels are expected to become the dominant source of biofuels

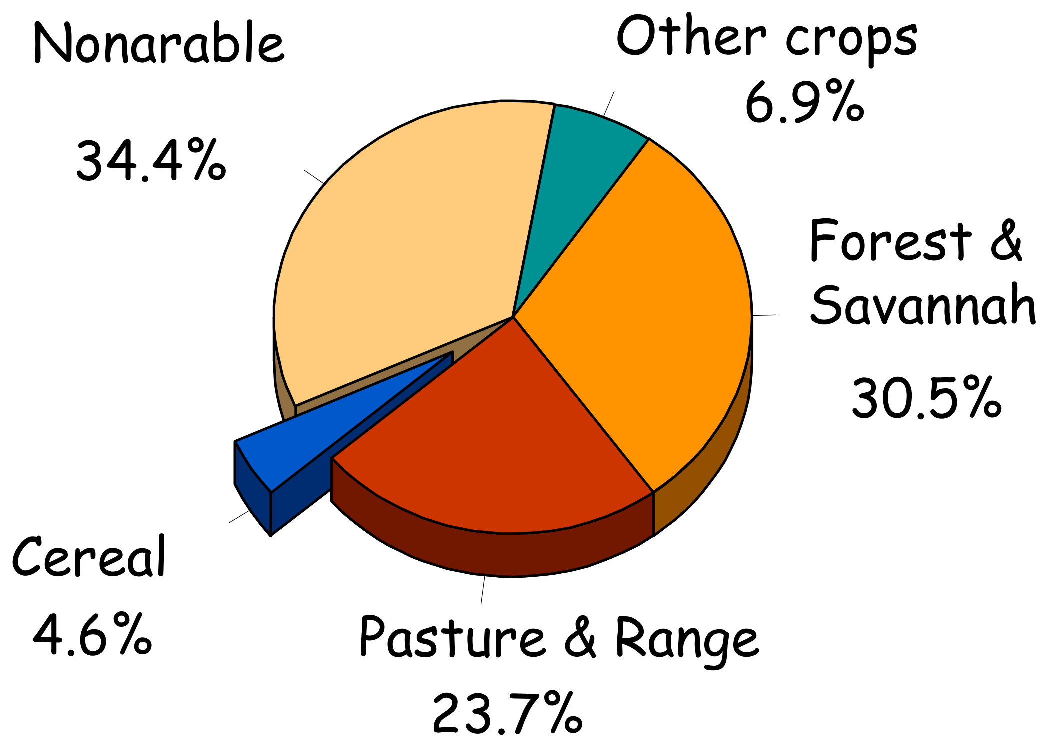


Modified from Richard Bain, NREL

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



Land Usage



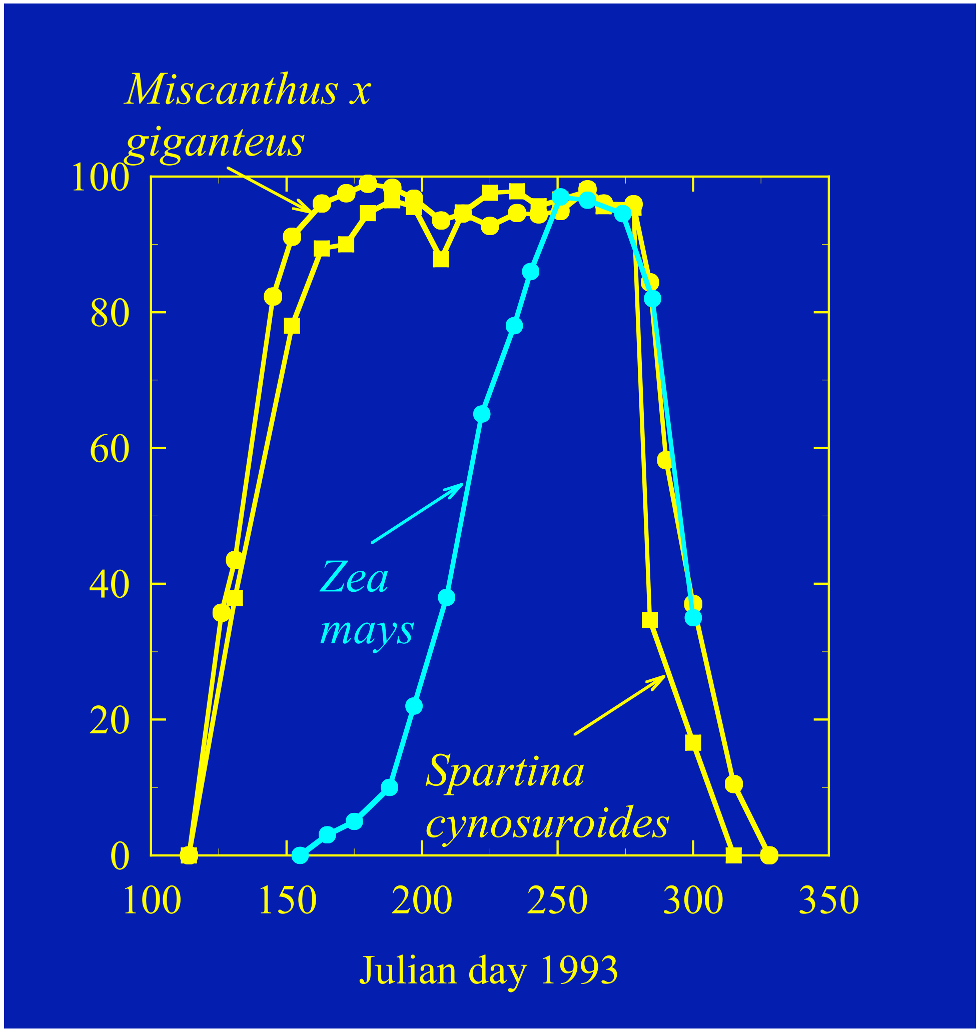
AMBIO 23,198 (Total Land surface 13,000 M Ha)

>2% 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

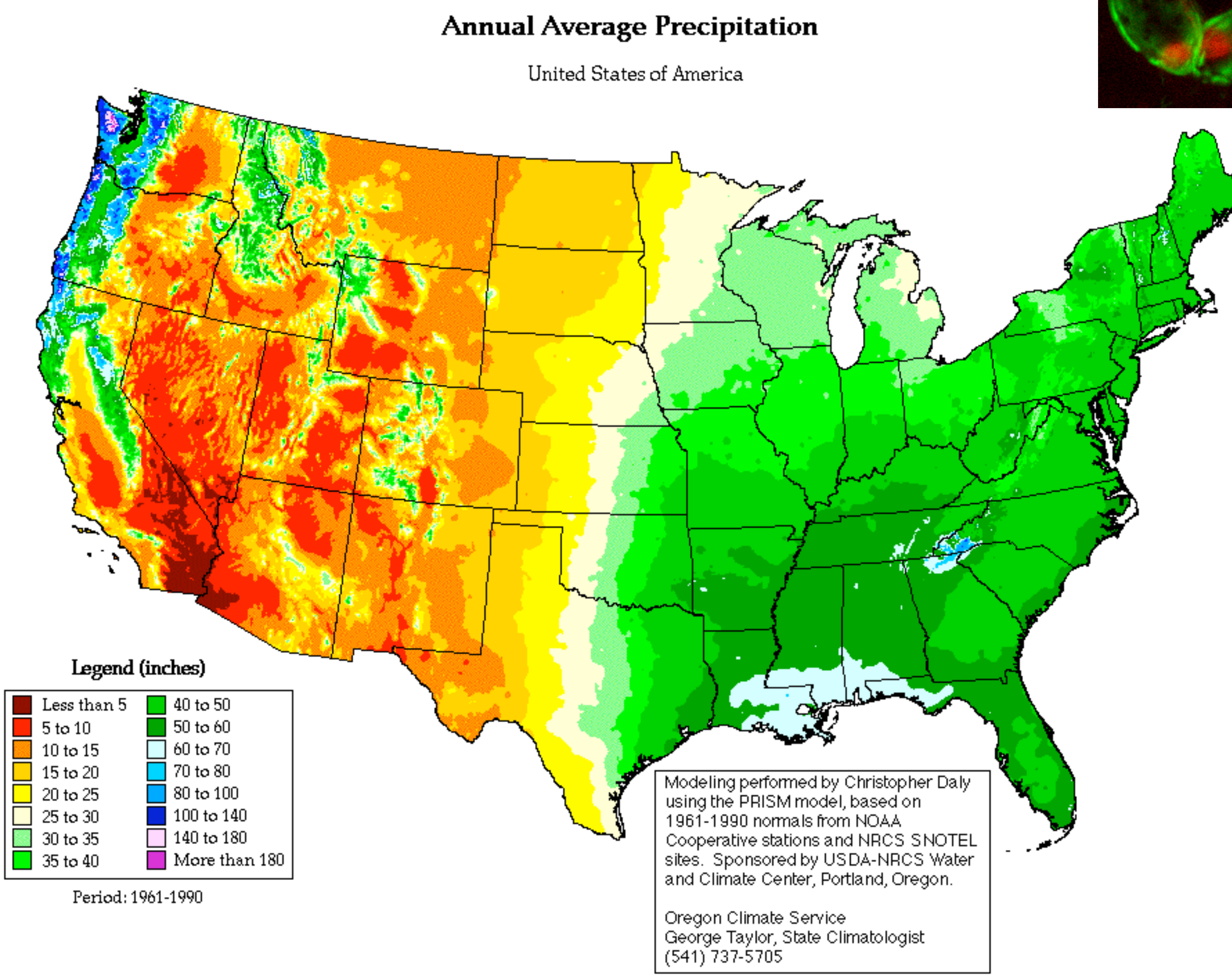


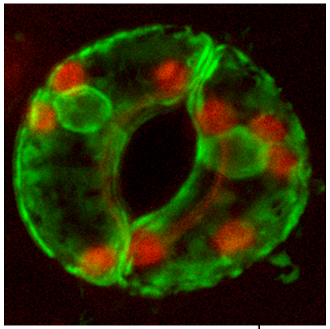
Courtesy of Steve Long, University of Illinois

Harvesting Miscanthus

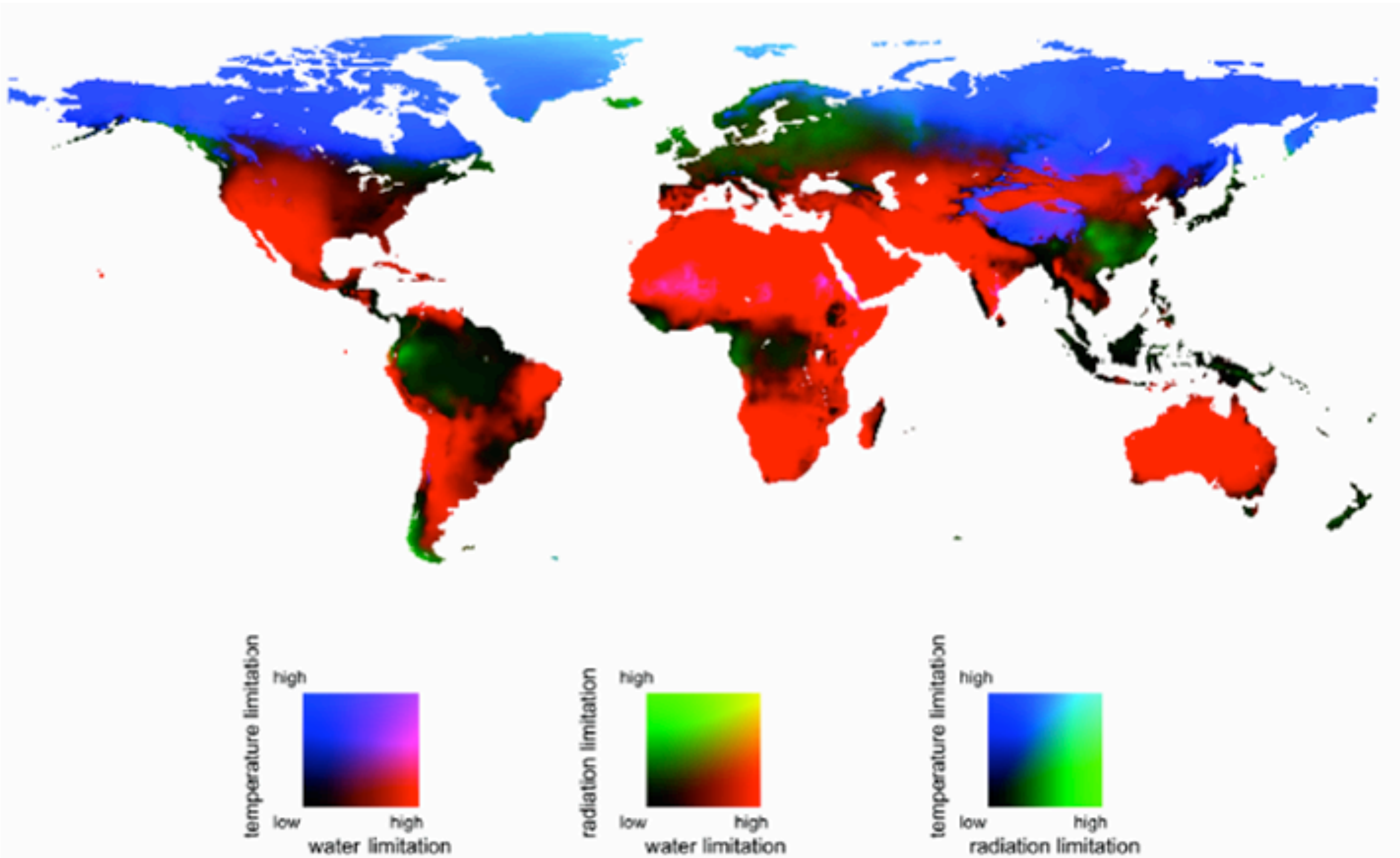
http://bioenergy.ornl.gov/gallery/index.html

Annual precipitation



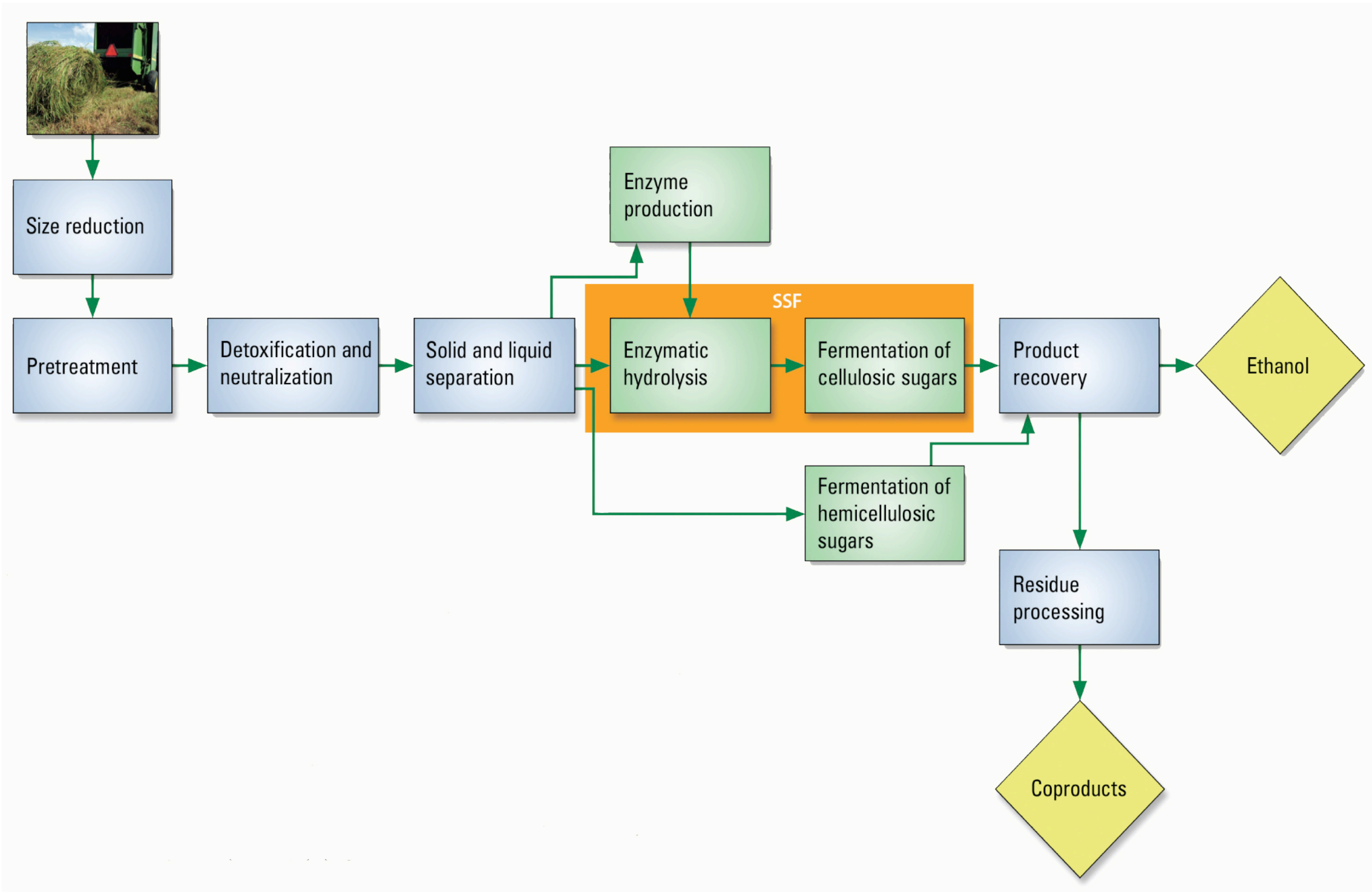


Limiting factors for global NPP



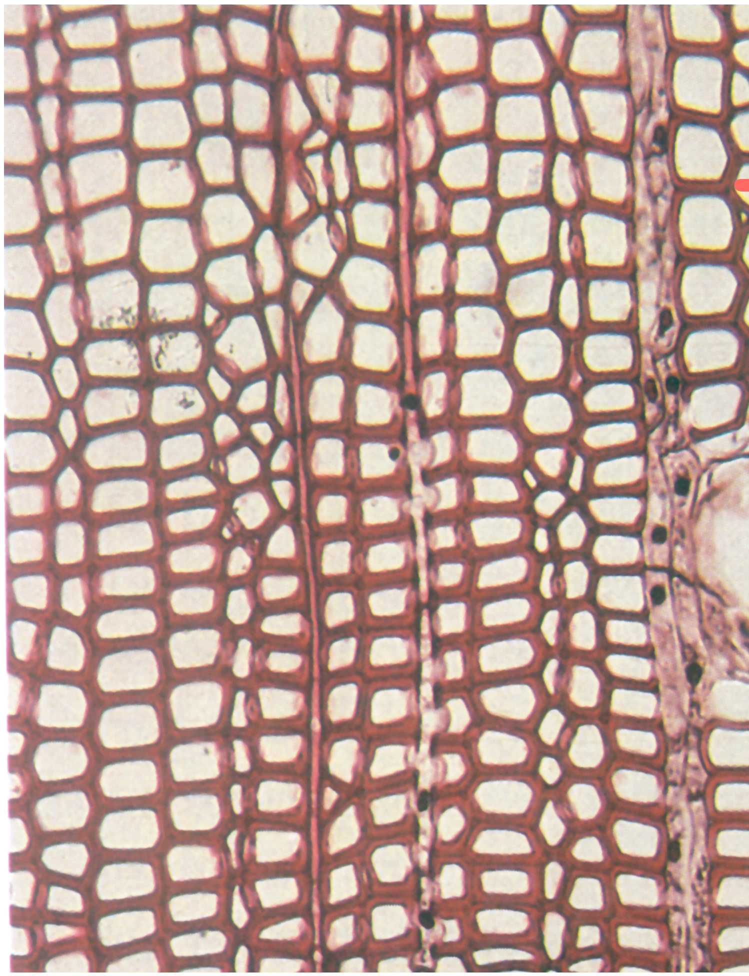
Baldocchi et al. 2004 SCOPE 62

Steps in cellulosic ethanol production

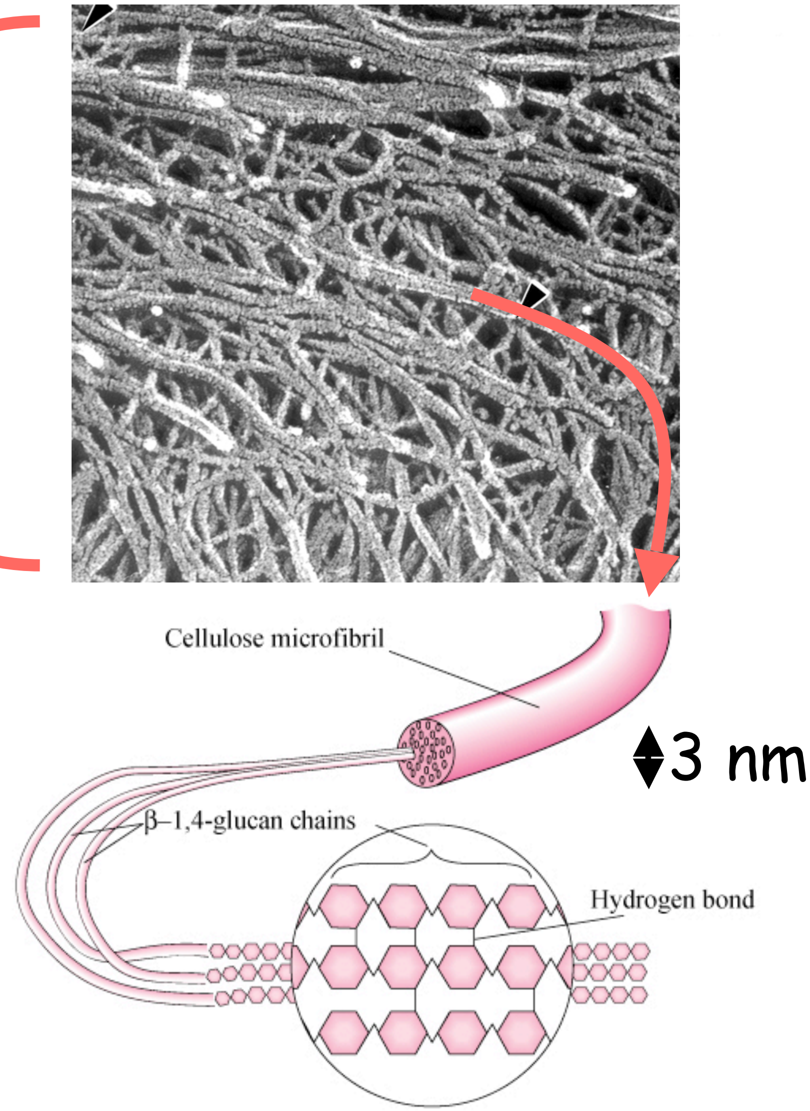


From: Breaking the Biological Barriers to Cellulosic Ethanol

Plants are mostly composed of sugars



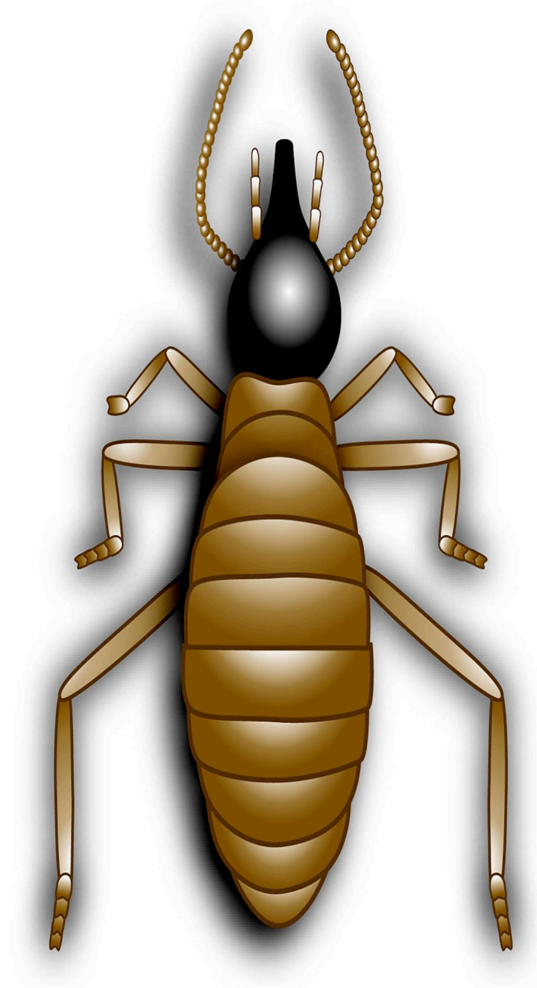
Section of a pine board



Polymerized glucose

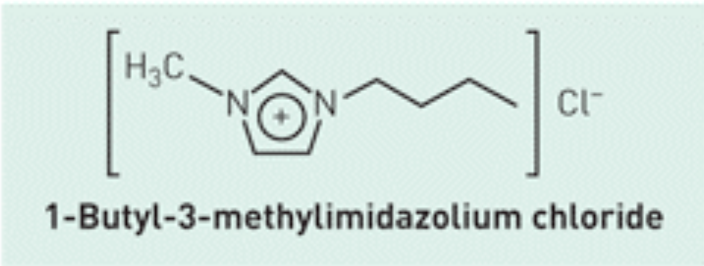
Possible routes to improved catalysts

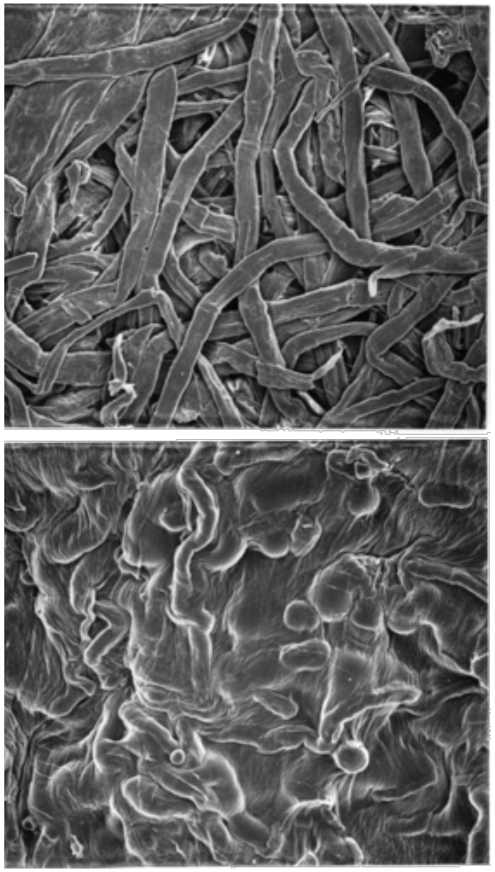
- Explore the enzyme systems used by termites (and ruminants) for digesting lignocellulosic material
- Compost heaps and forest floors are poorly explored
- In vitro protein engineering of promising enzymes
- Develop synthetic organic catalysts (for polysaccharides and lignin)



Dissolution of cellulose in an ionic liquid

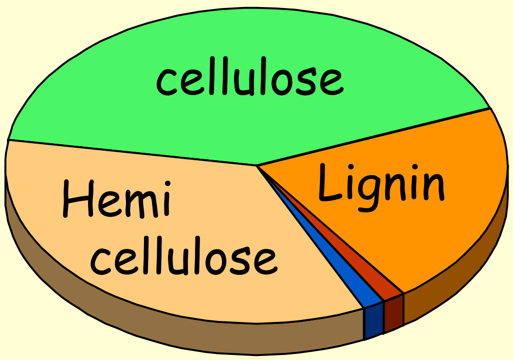
(novel pretreatment methods may create fundamental changes)



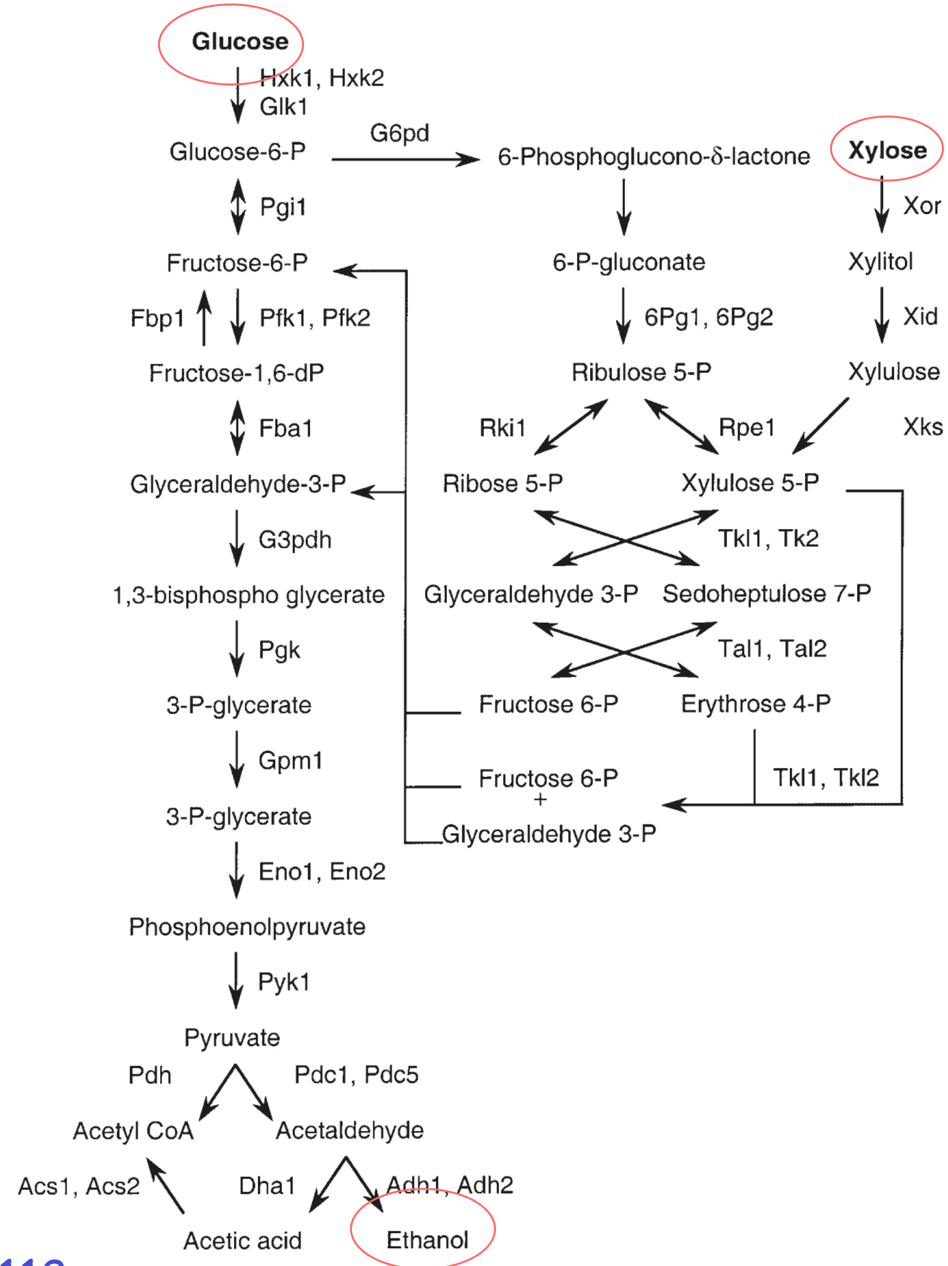


Swatloski, Spear, Holbrey, Rogers *J. Am. Chem. Soc.*, 124 (18), 4974 -4975, 2002

Fermentation of all sugars is essential

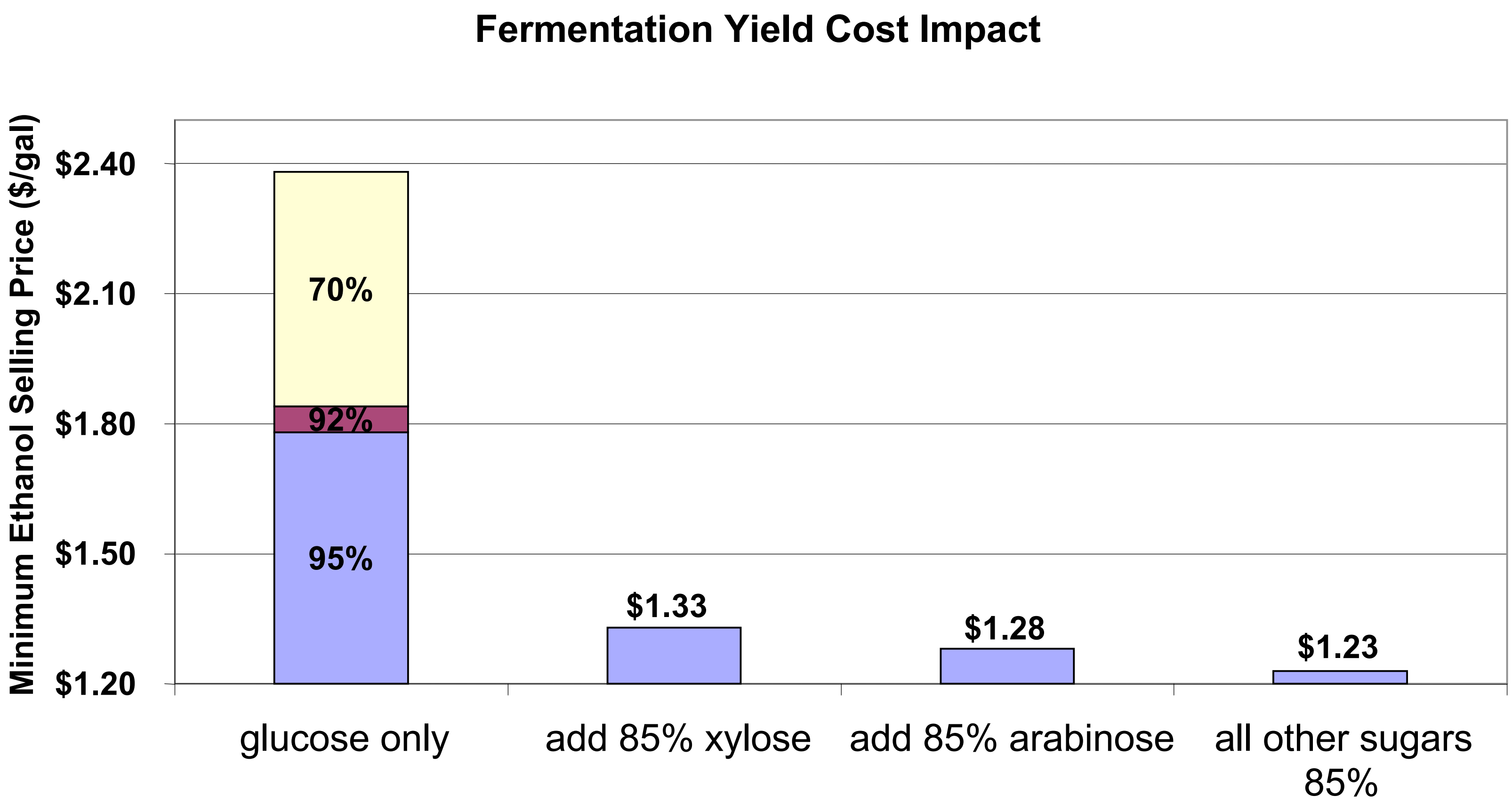


Typical grass composition



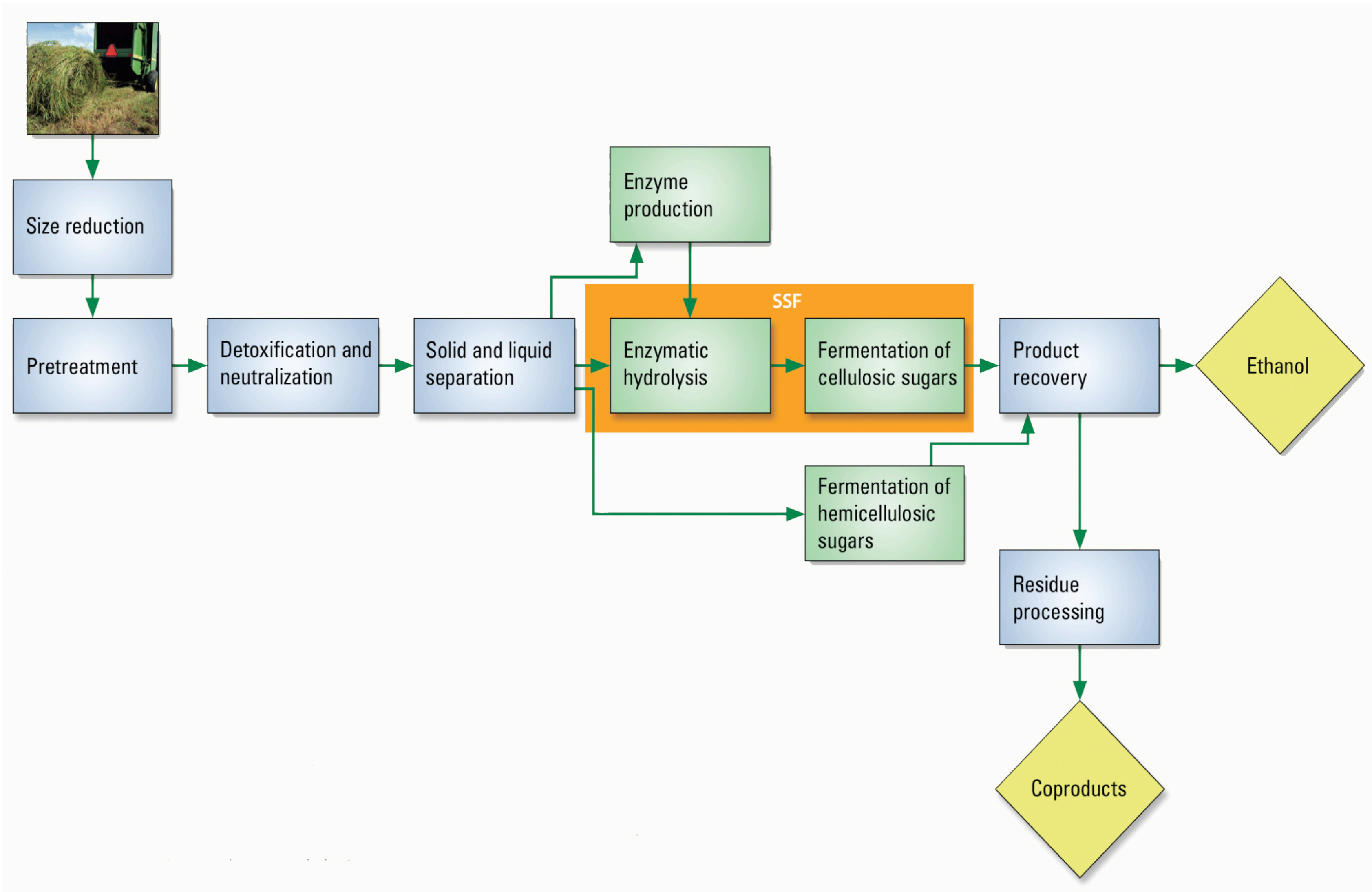
Jeffries & Shi Adv Bioch Eng 65,118

Saccharification & Fermentation



NREL

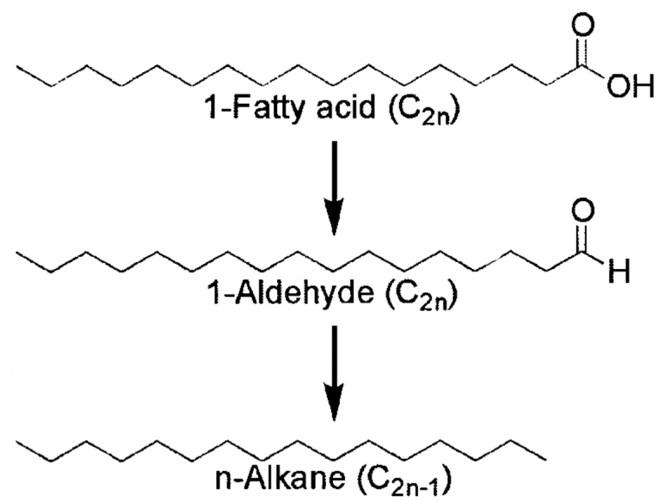
Steps in cellulosic ethanol production



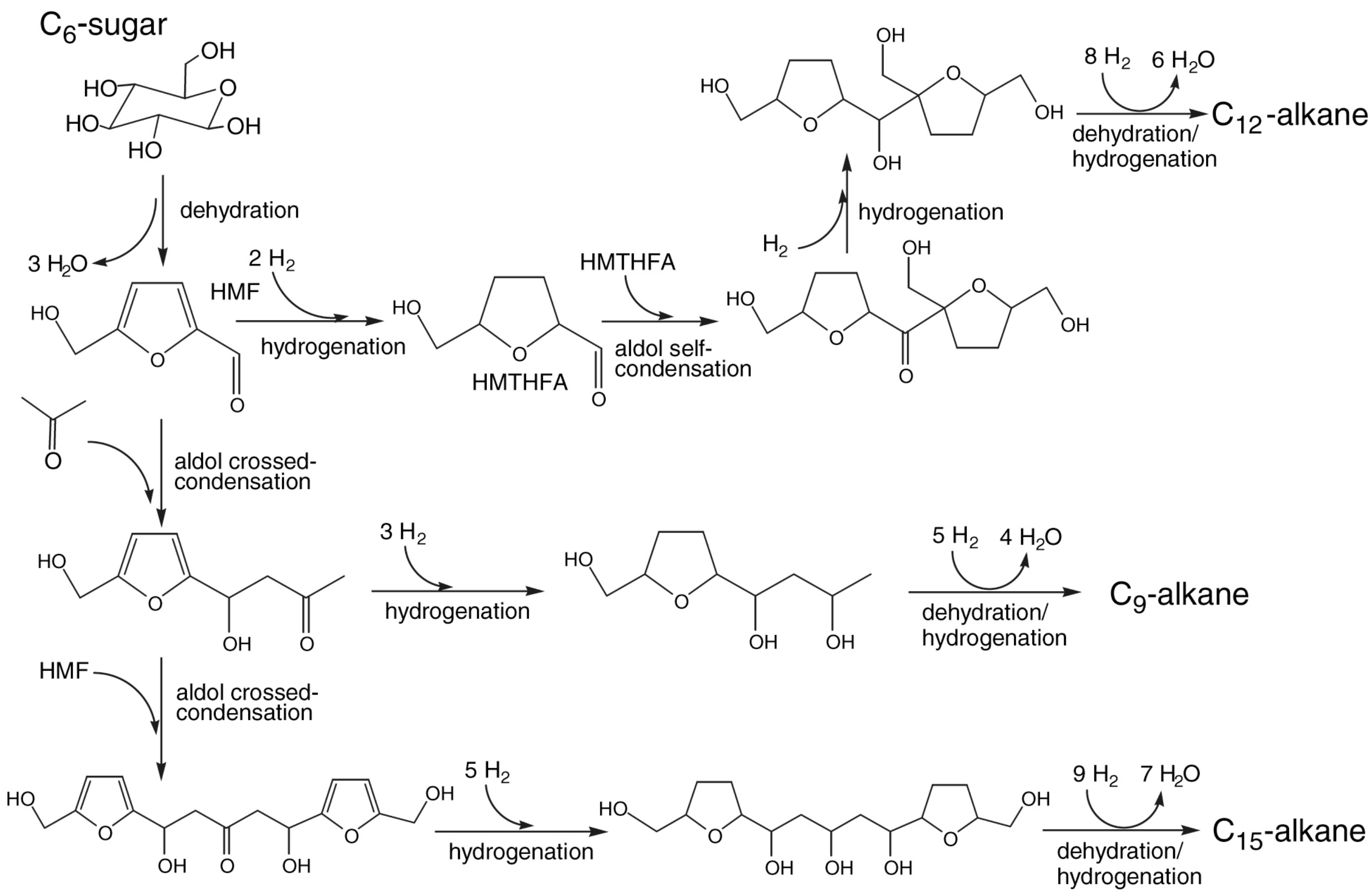
From: Breaking the Biological Barriers to Cellulosic Ethanol

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

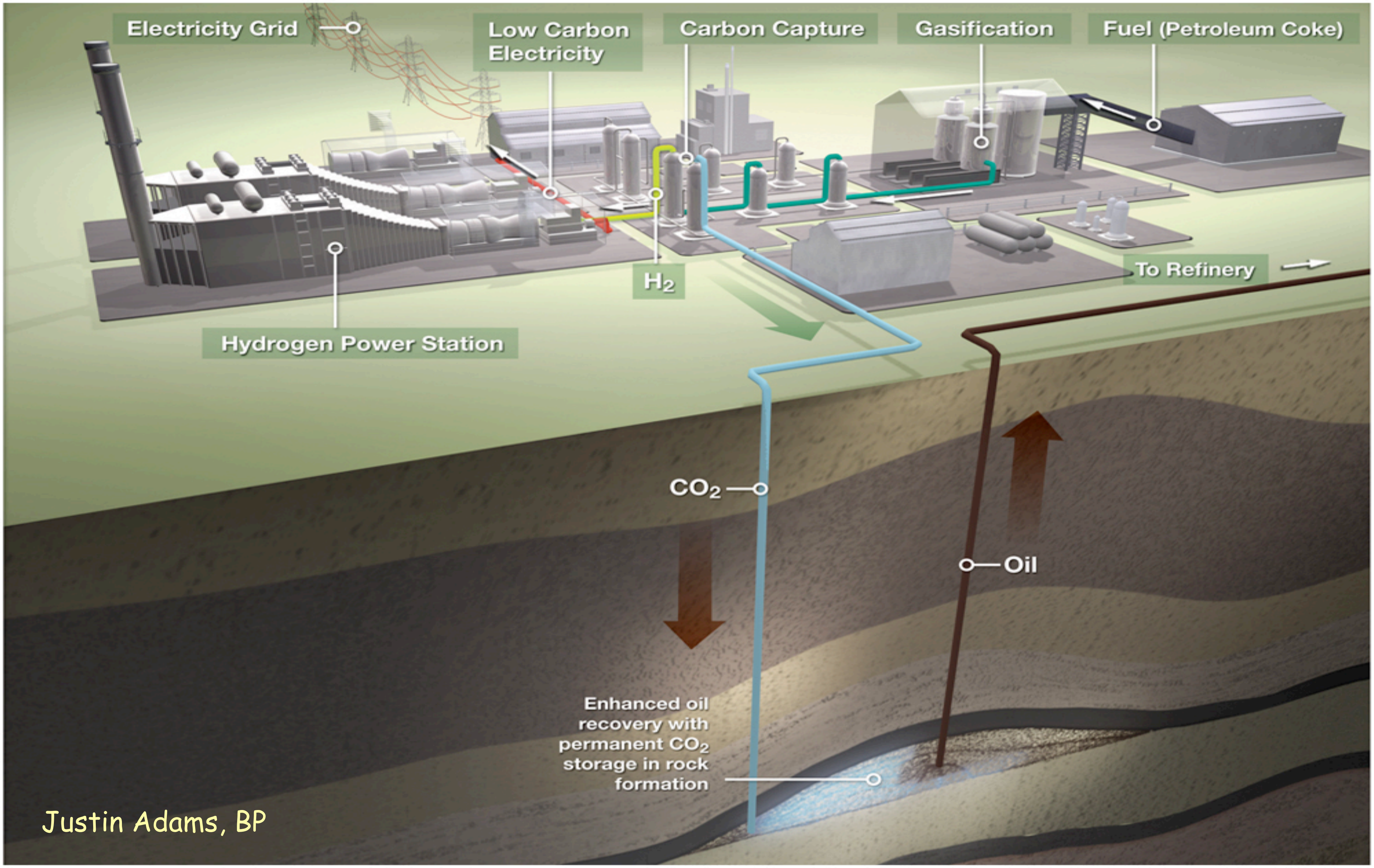


Conversion of sugar to alkanes



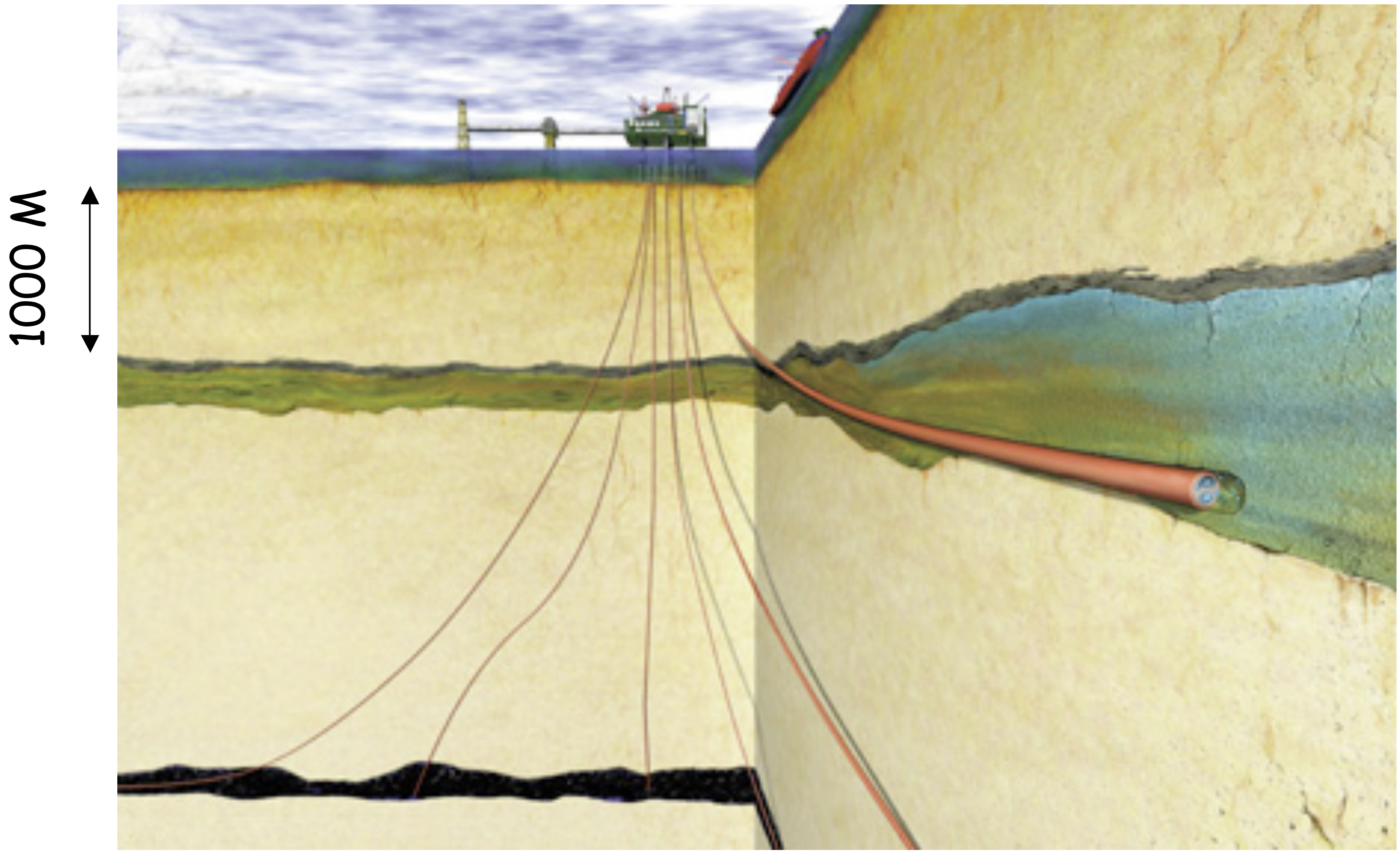
Huber et al., (2005) Science 308,1446

The “hydrogen economy”



The Sleipner Experiment

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

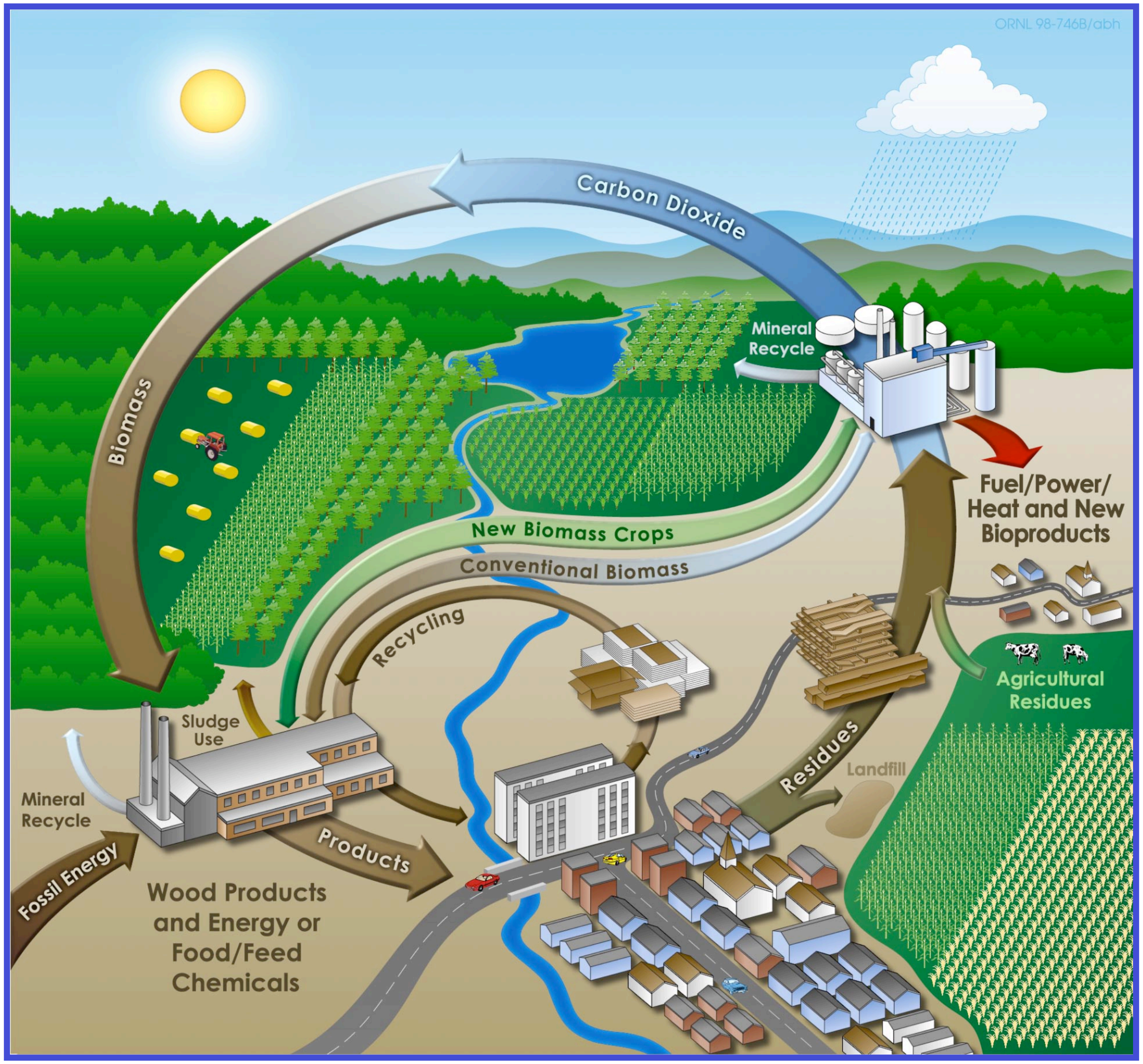


www.agiweb.org/geotimes

Summary of priorities

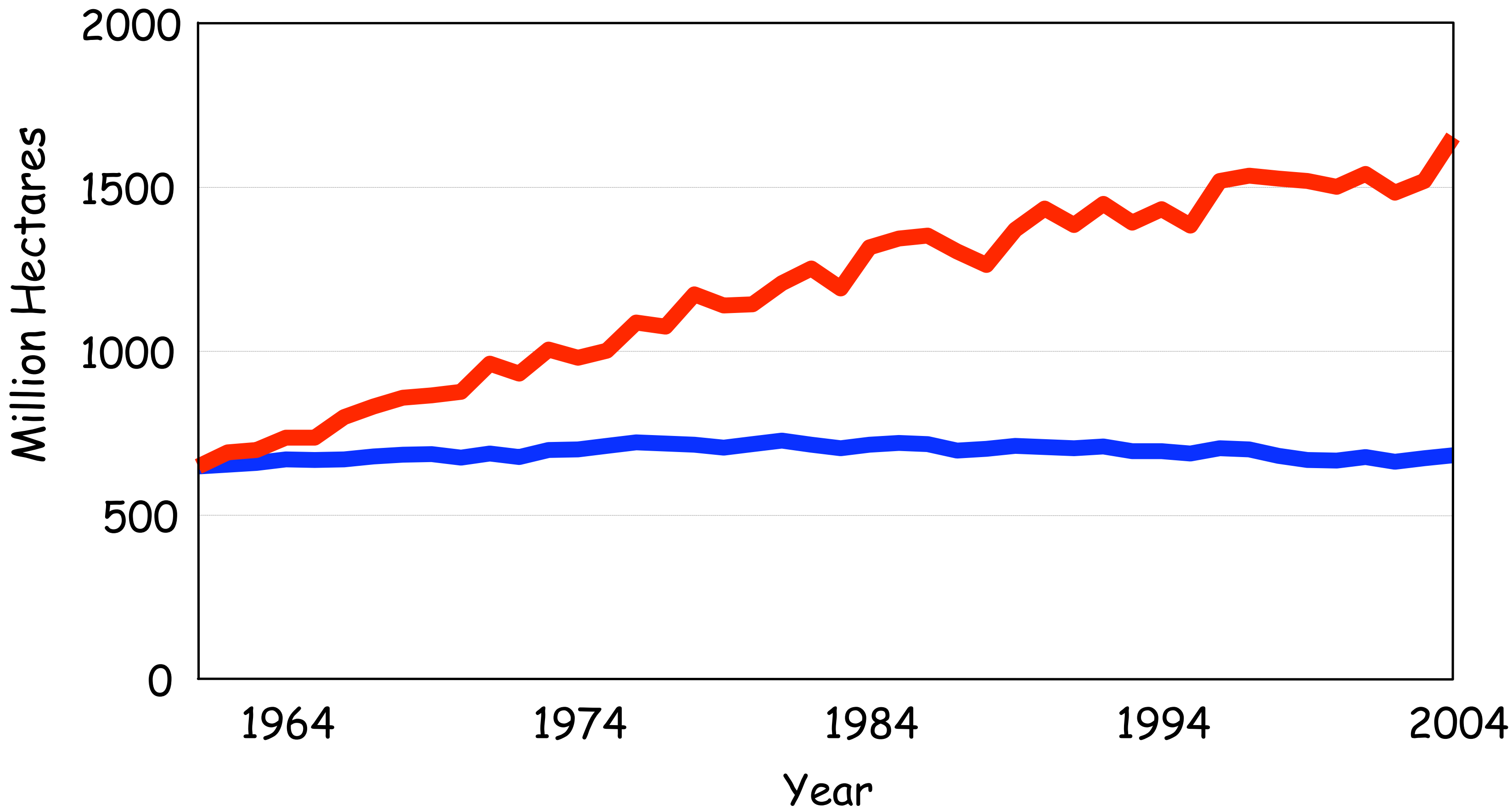
- Develop energy crops and associated agronomic practices
- Identify or create more active catalysts for conversion of biomass to sugars
- Develop industrial microorganisms that ferment all sugars
- Develop new types of microorganisms that produce and secrete hydrophobic compounds

A vision of the Future



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

Global grain production with and without yield enhancements



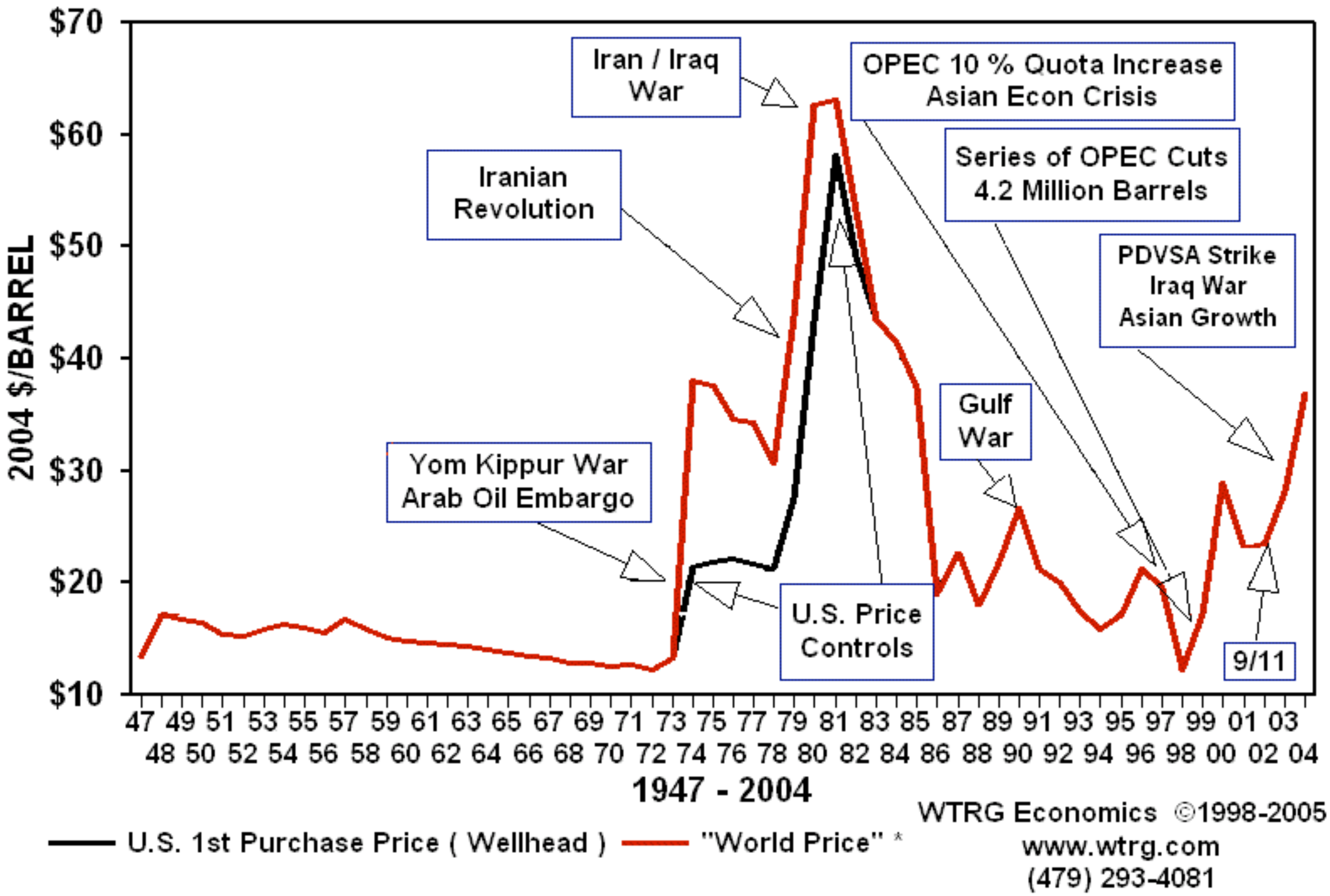
Data from worldwatch

Economics of Perennials are Favorable

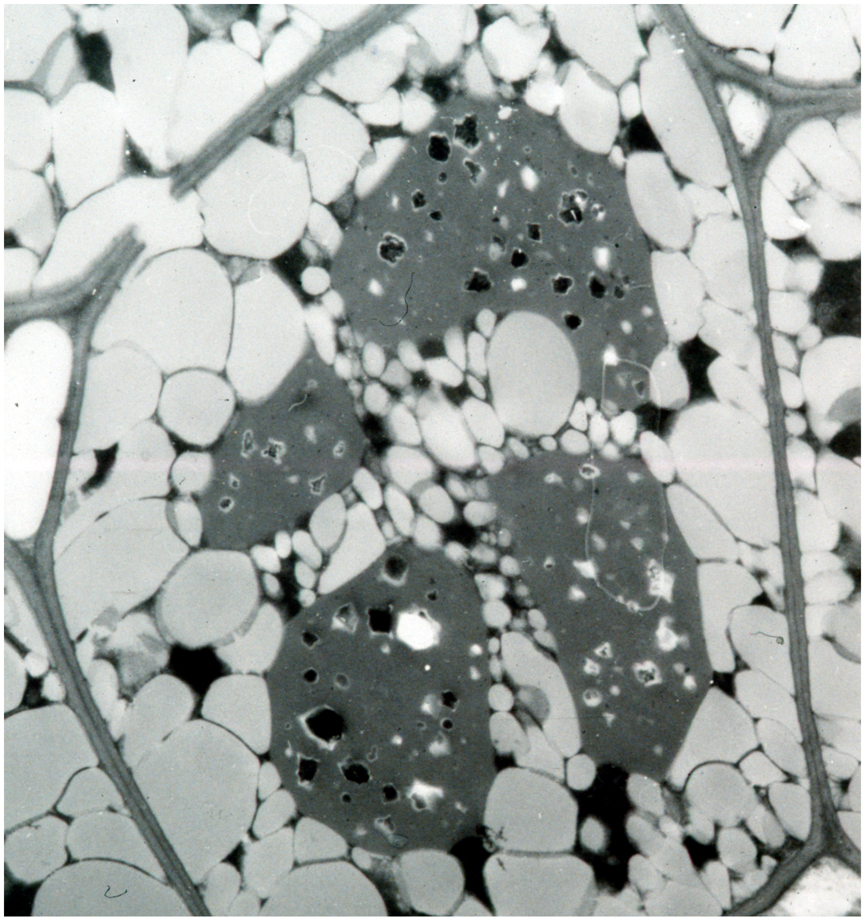
CROP	Yield per Acre	Value $	Cost $	Profit $
Corn ($4.2/bu) ($150/t)	160 bu	672	193*	479
Switchgrass ($50/t)	10 tons	500	138**	362
Miscanthus ($50/t)	15 tons	750	138**	612

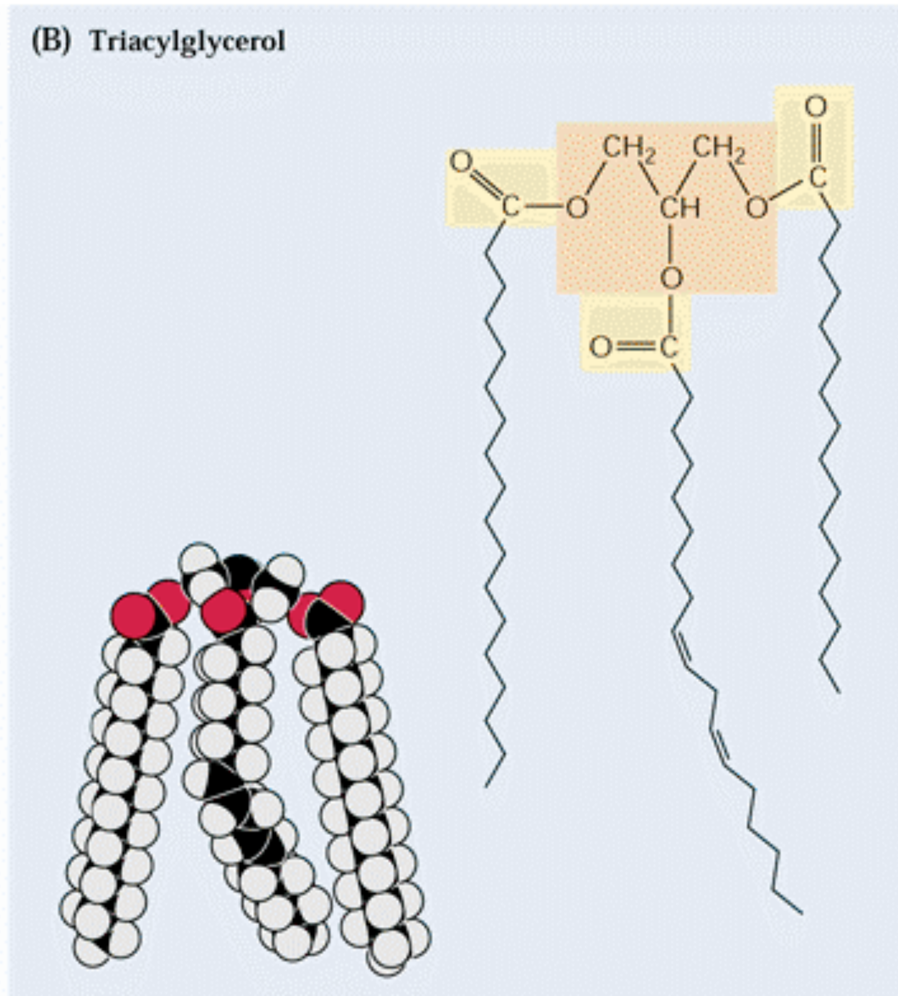
*USDA economic research service 2004
**50% as much fertilizer, no chemicals

Risks: Historical Price of Oil

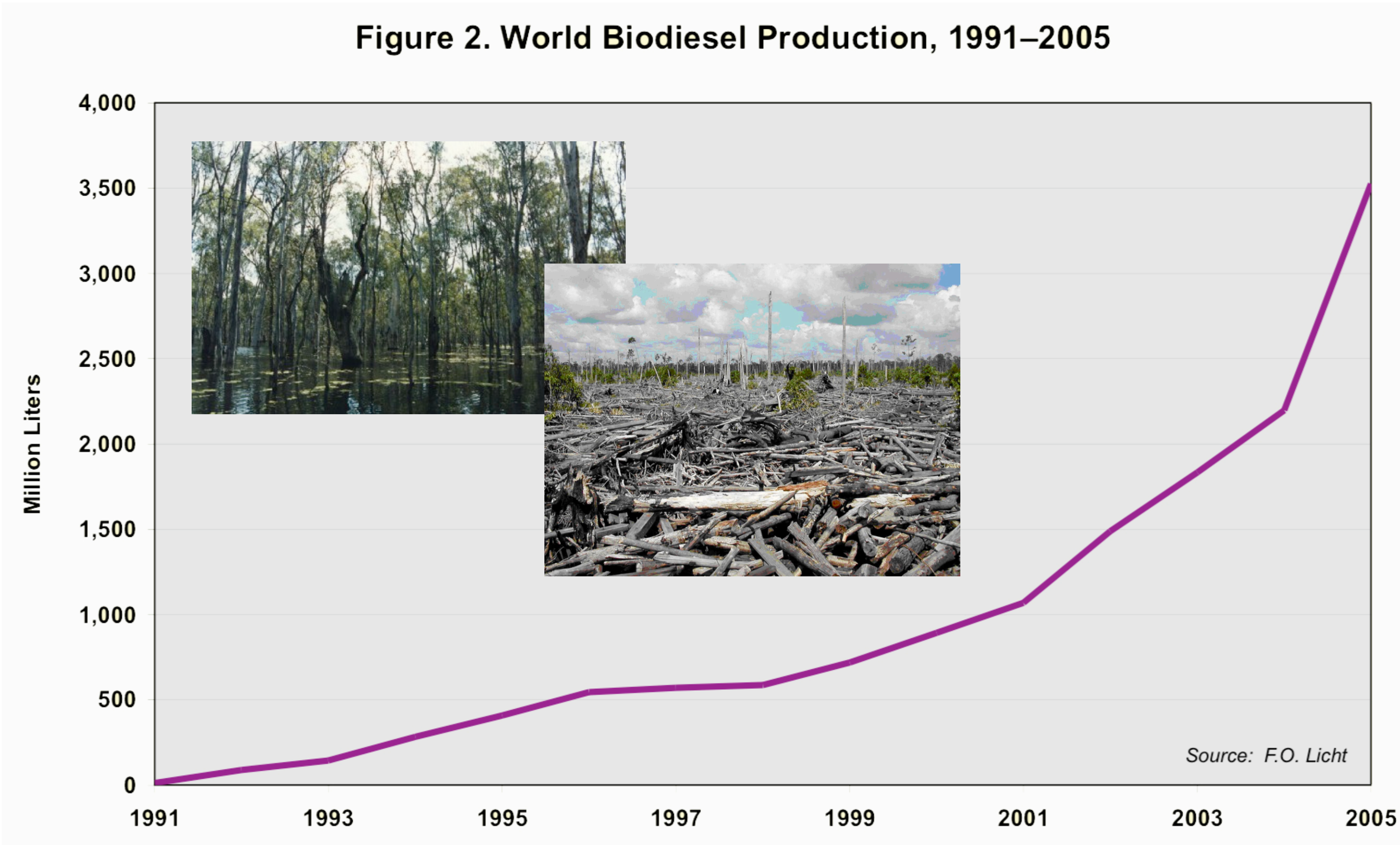


Some plants accumulate oil



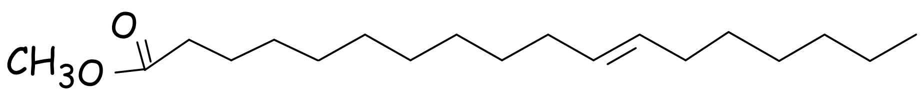


Biodiesel has been expanding rapidly

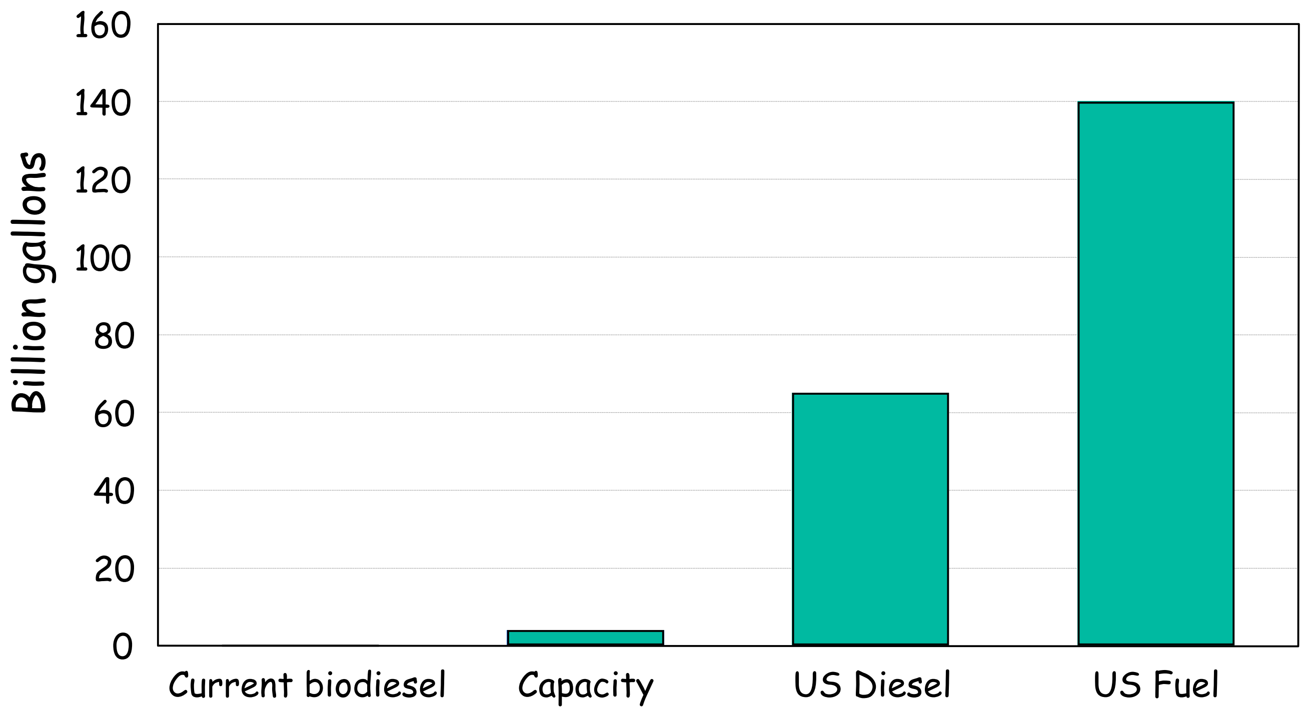


Worldwatch 2006 & Louise Fresco

Limited potential of biodiesel



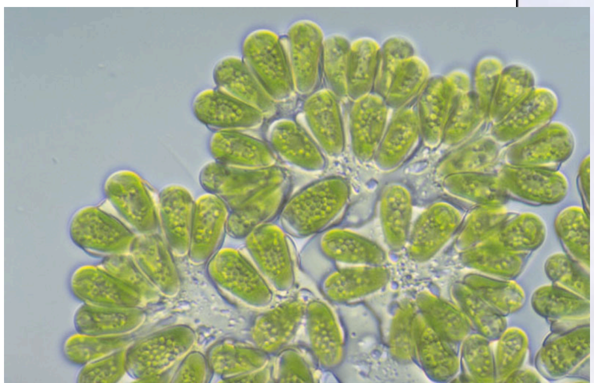
Biodiesel



65 biodiesel companies in operation, 50 in construction 2006

Use of algae could enable saline cultivation

Greenfuel bioreactor



http://news.com.com/Photos+Betting+big+on+biodiesel/2009-1043_3-5714336.html?tag=st.prev

How Much Ethanol Could the Municipal Solid Waste from a City With 1 Million People Produce?

The average person in the United States generates approximately 1.8 kilograms of municipal solid waste (MSW) every day. Of this, typically about 75 percent is predominantly cellulosic organic material, including waste paper, wood wastes, cardboard, and waste food scraps. Thus, a city with 1 million people produces around 1,800 tonnes of MSW in total, or about 1,300 tonnes per day of organic material. Using technology that could convert organic waste to ethanol, roughly 330 liters of ethanol could be produced per tonne of organic waste. Thus, organic waste from a city with 1 million people would be enough feedstock to produce about 150 million liters per year. This is enough fuel to meet the needs of more than 58,000 people in the United States; 360,000 people in France; or nearly 2.6 million people in China at current rates of per capita fuel use.

Worldwatch, 2006