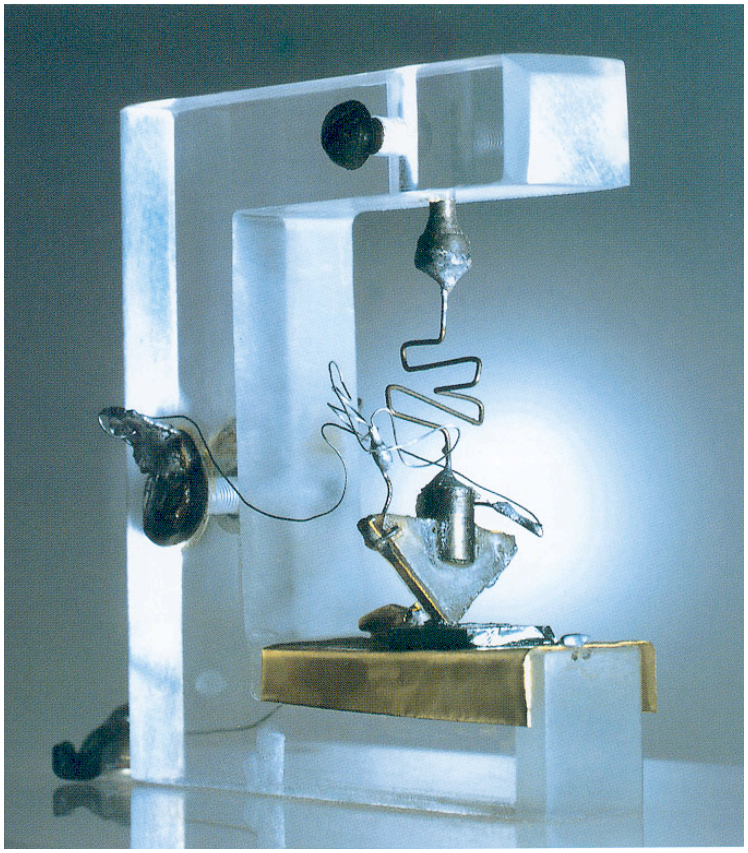
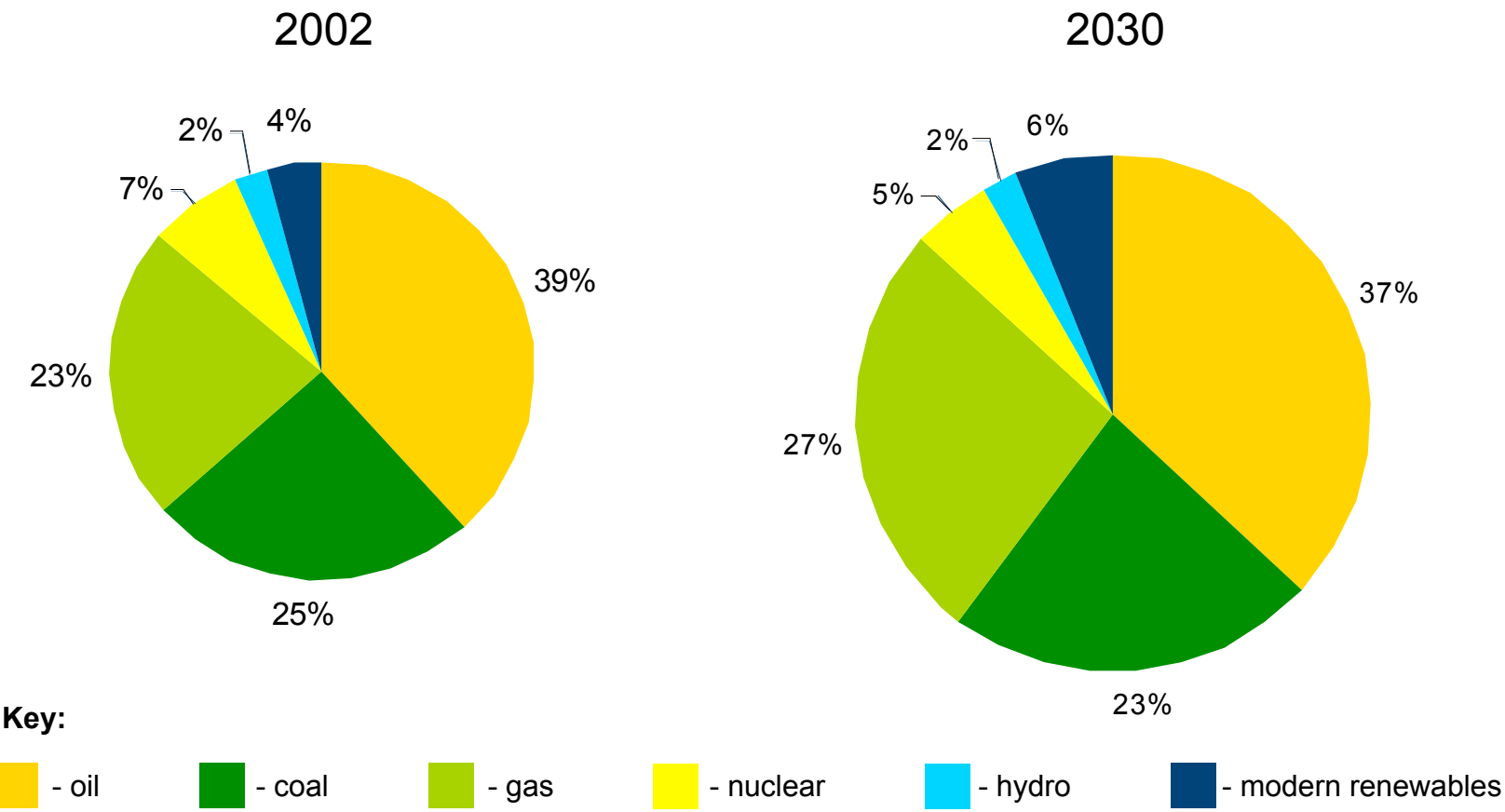
Development of Biofuels



Chris Somerville
Carnegie Institution, Stanford University, LBNL

We are not running out of fossil fuels

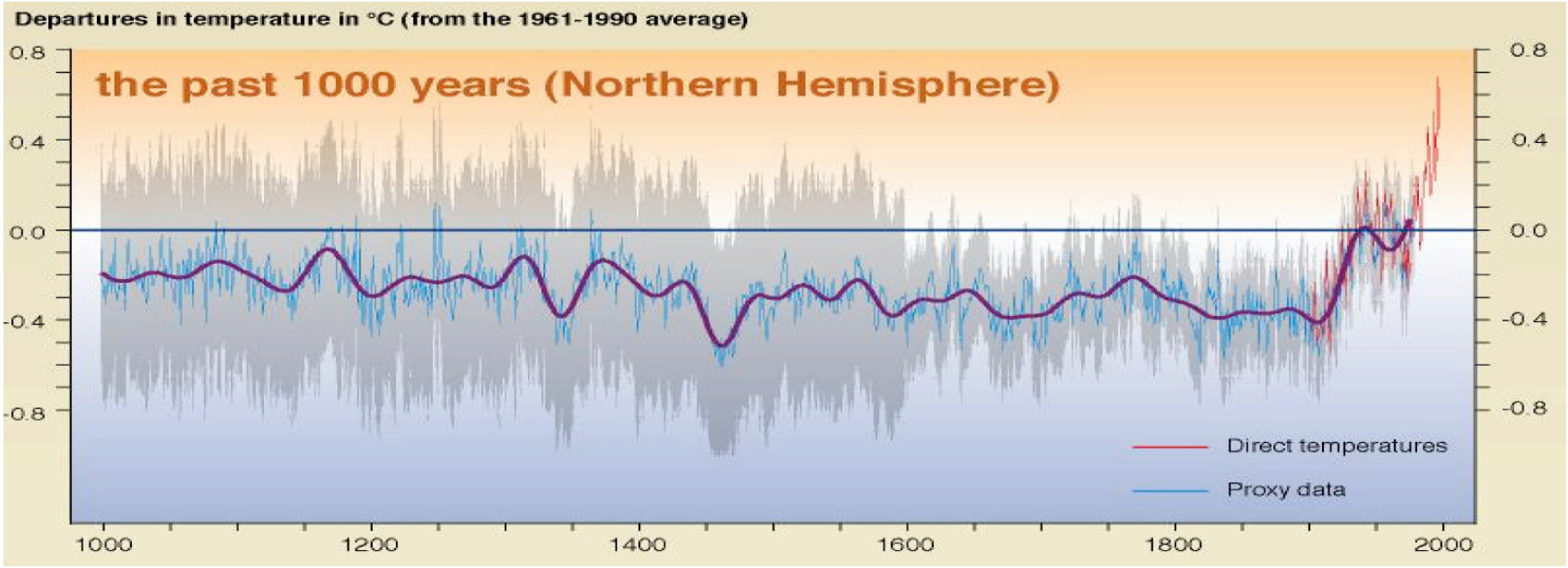
Global Primary Energy Supply by Fuel:*



* - excludes traditional biomass

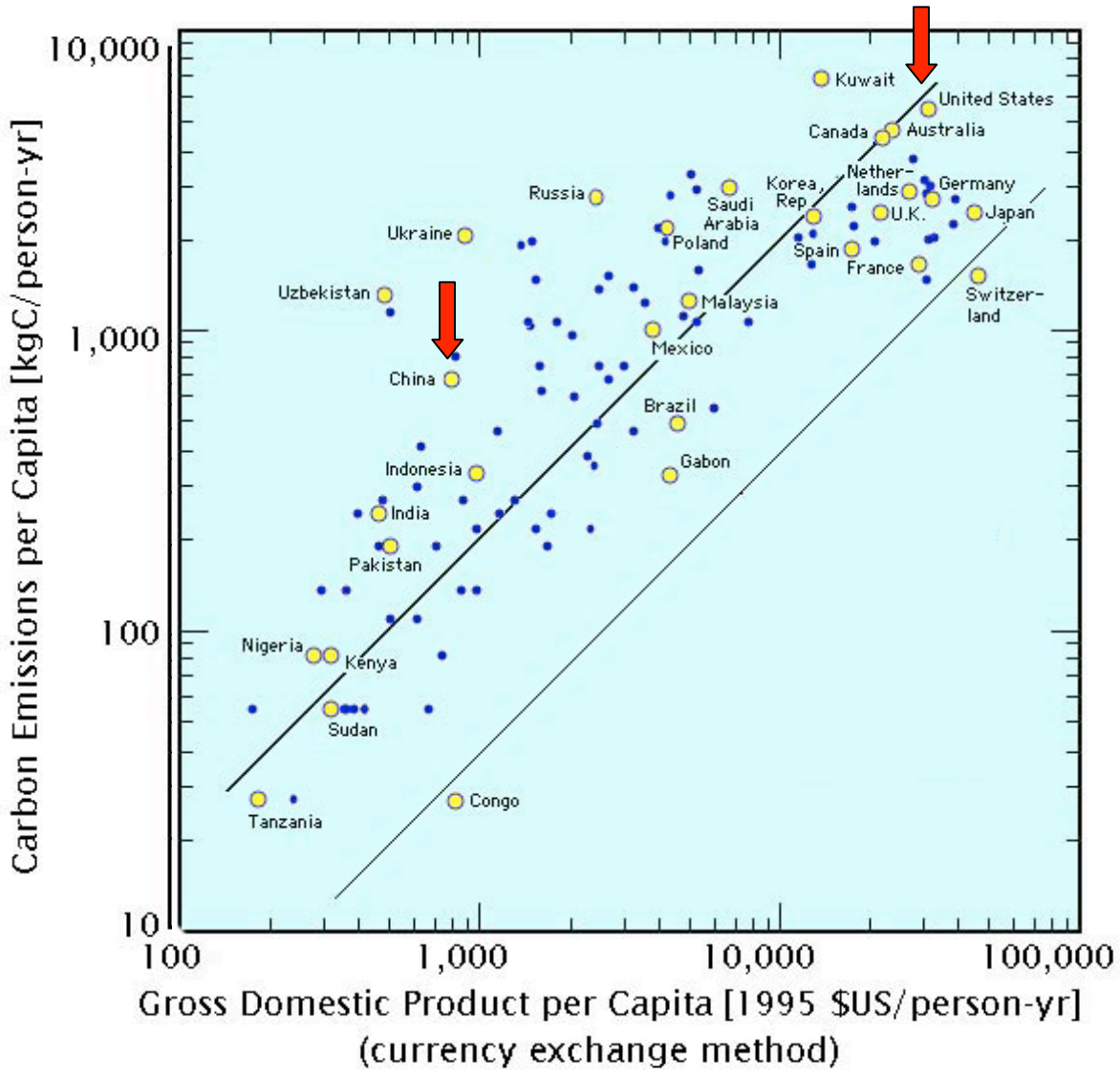
Source: IEA 2004, Jim Breson BP

The world is warming



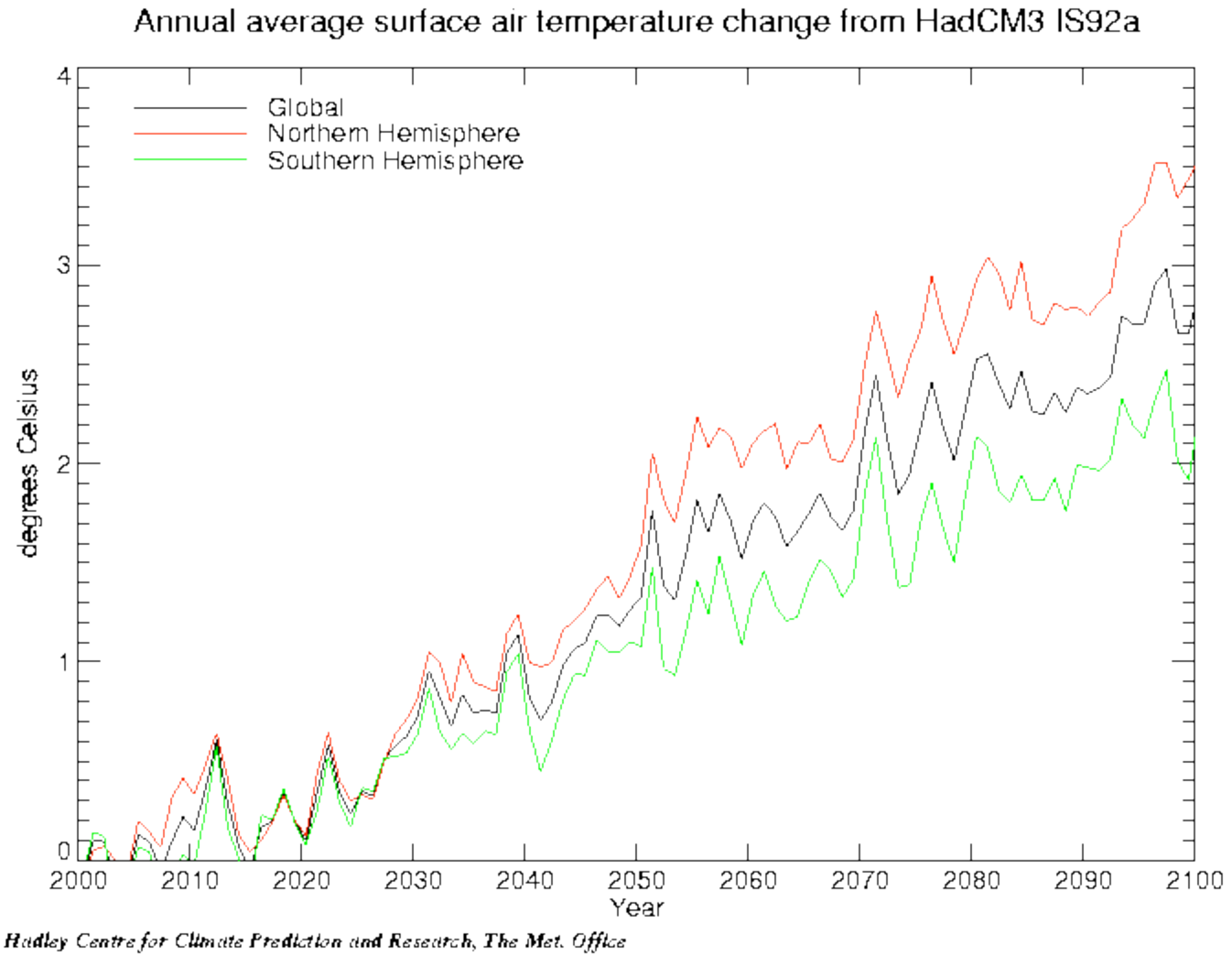
From: Anders Röj (Volvo Inc.) Agenda 2020 Technology Summit (2004)

CO_2 release rises with per capita GDP



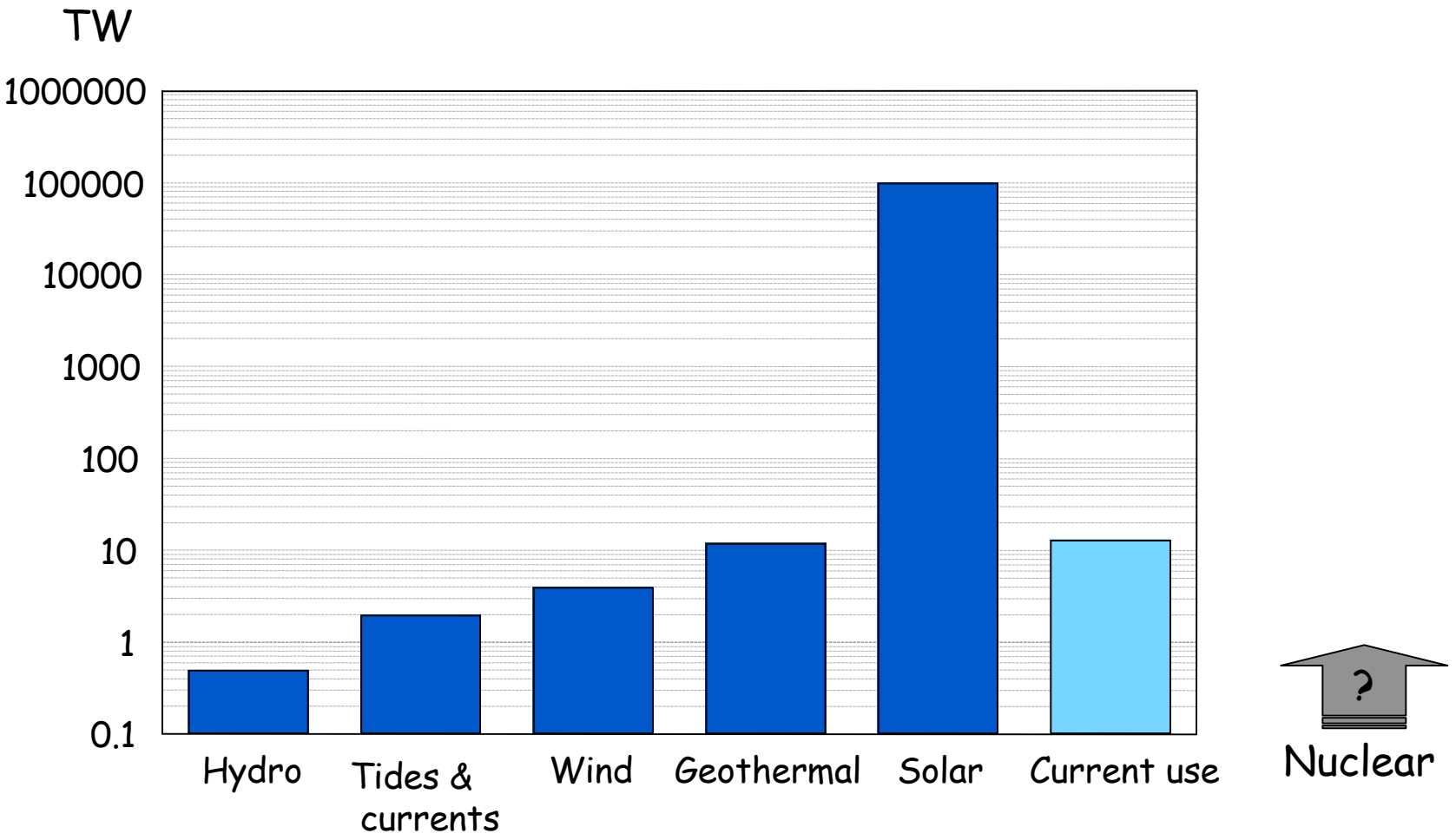
M Hoeffert

Predicted increase in global mean temperature due to CO_2 accumulation



www.metoffice.com/research/hadleycenter

Potential of underused renewable energy sources

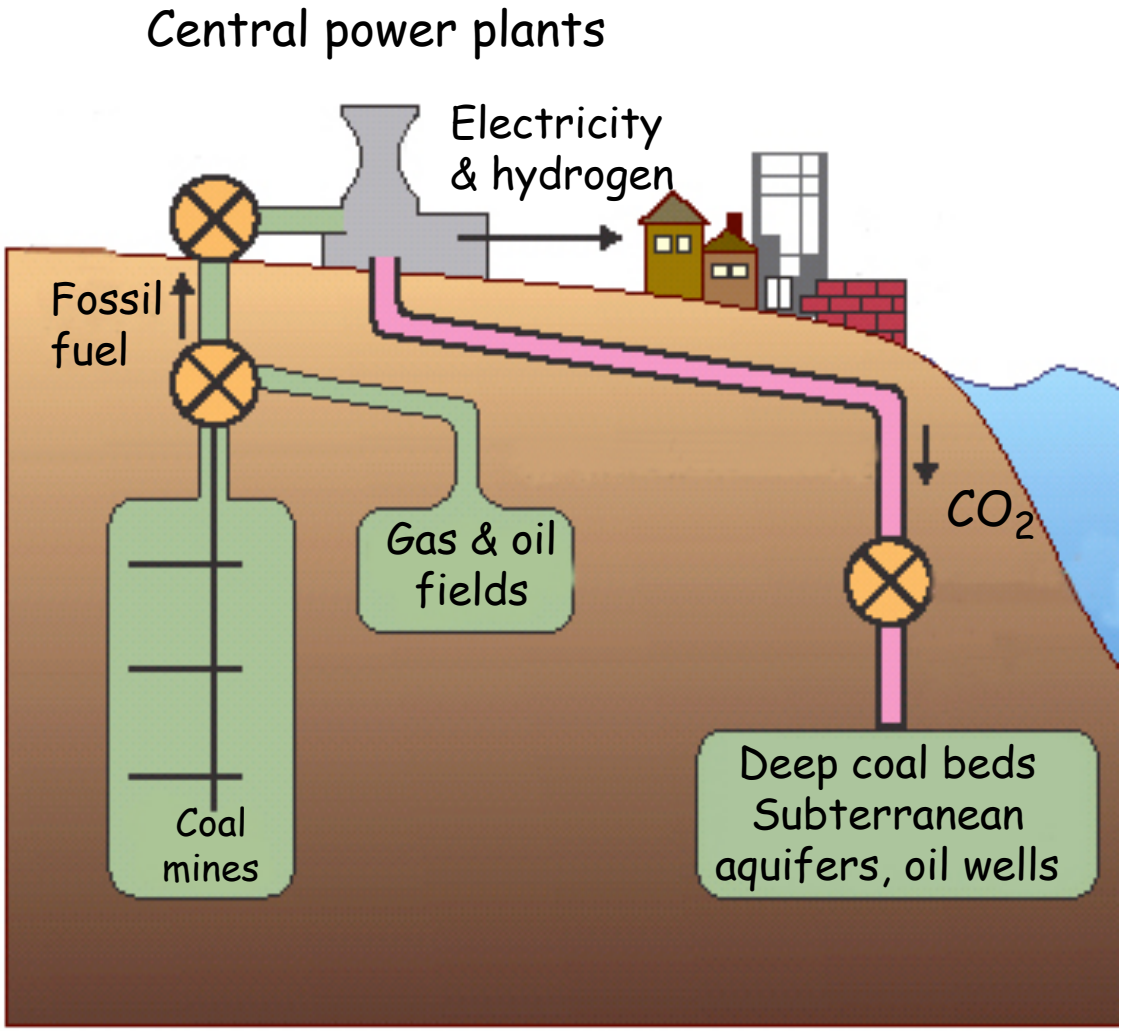


From: Basic Research Needs for Solar Energy Utilization, DOE 2005

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

N. Lewis, Caltech

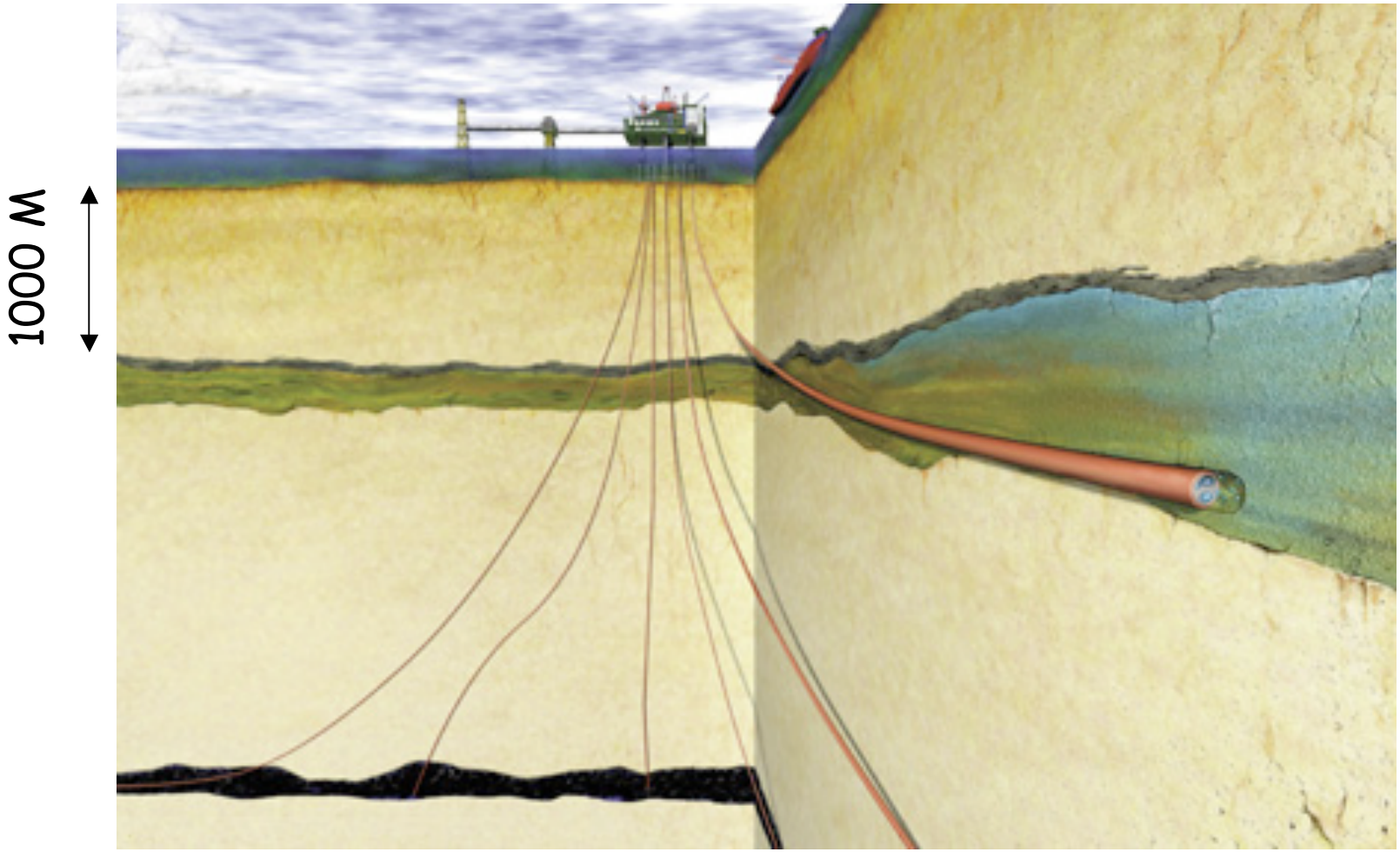
Sequestration vision



Modified from Hoffert et al. Science 298,981

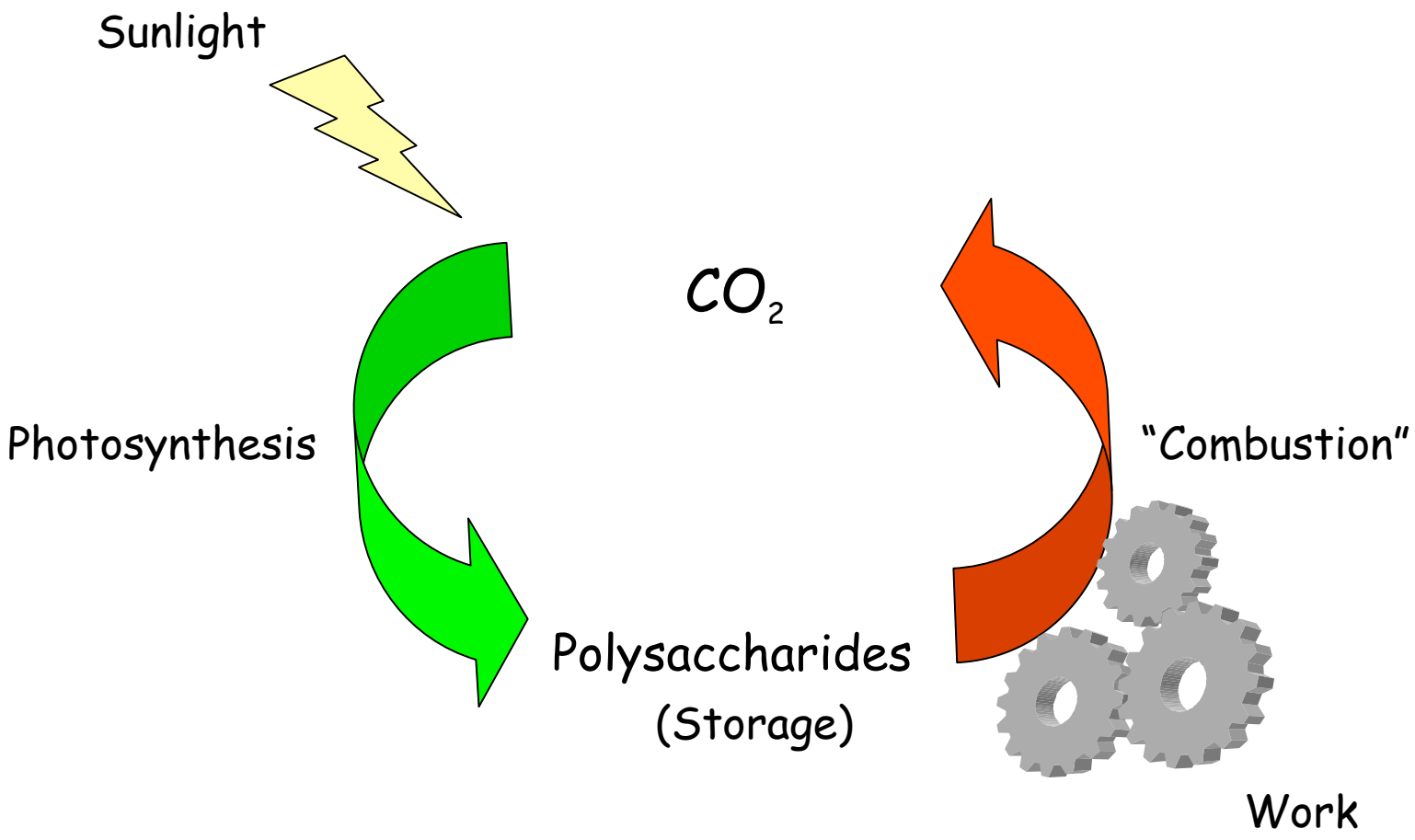
The Sleipner Experiment

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

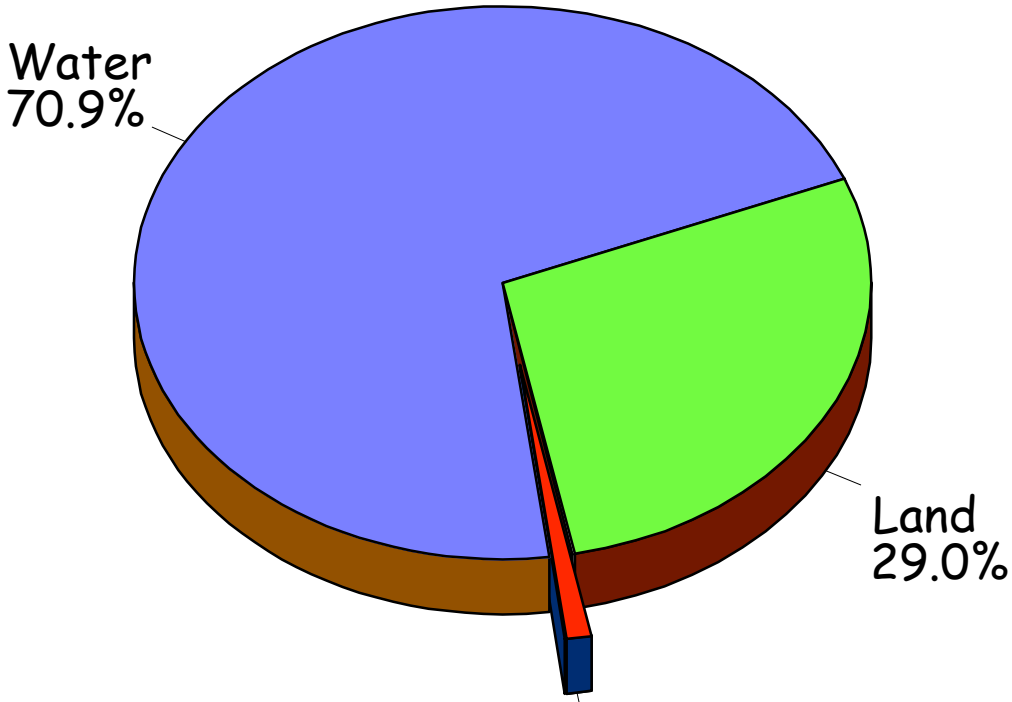


www.agiweb.org/geotimes

Combustion of biomass provides carbon neutral energy



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



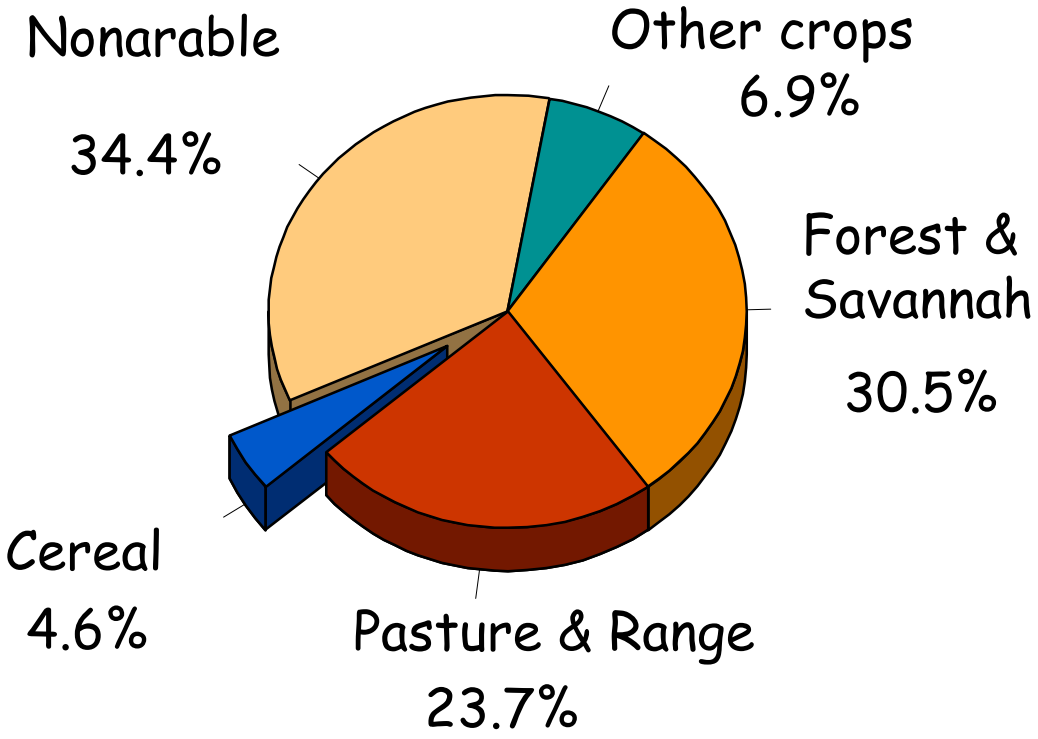
Amount of land needed for 13 TW at 1% efficiency
5% of land
650 MHa

>2% yield is feasible

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

Courtesy of Steve Long et al

Land Usage

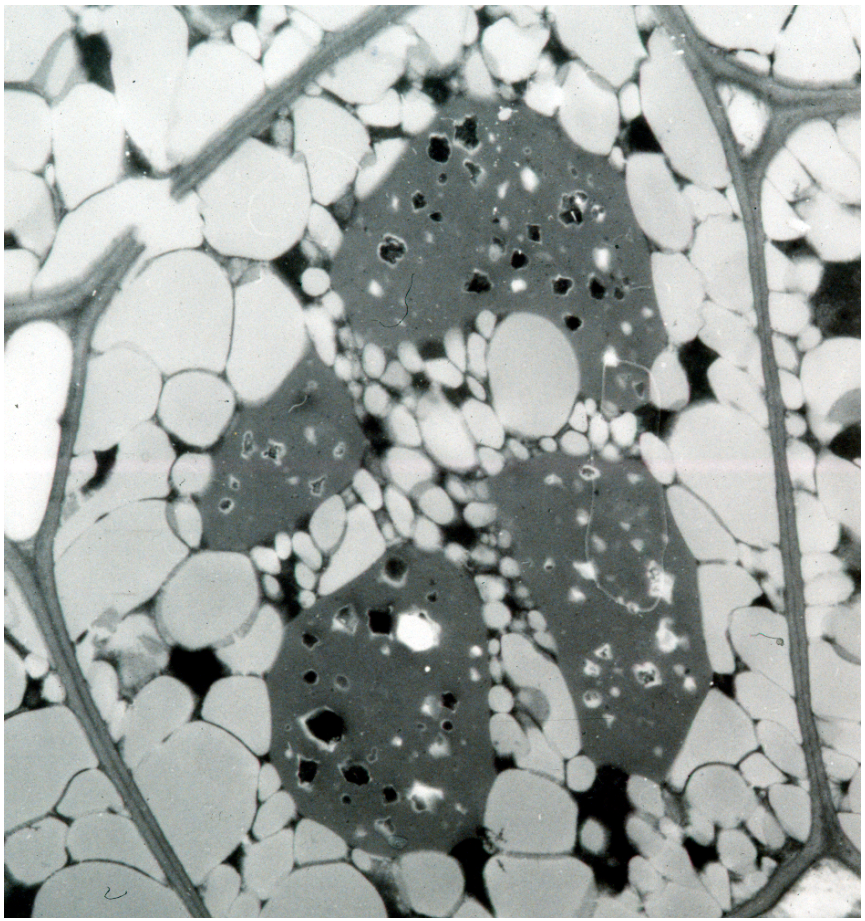


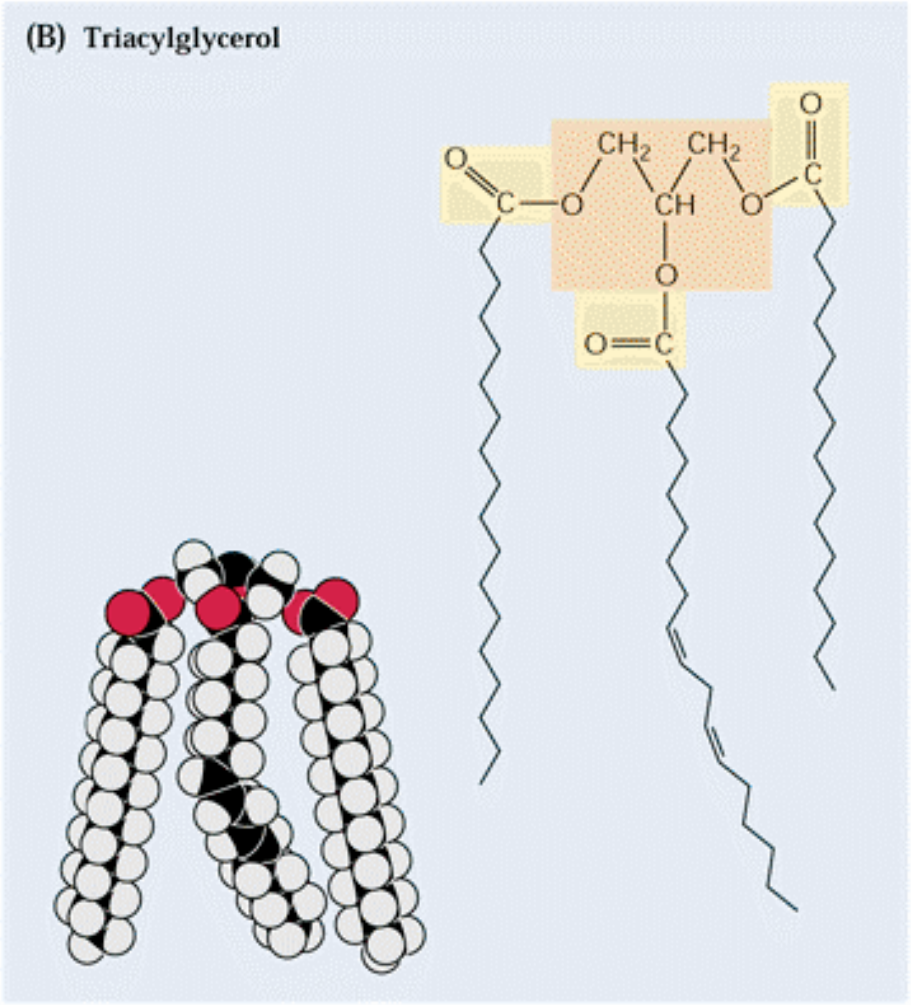
AMBIO 23,198 (Total Land surface 13,000 M Ha)

Types of biofuels

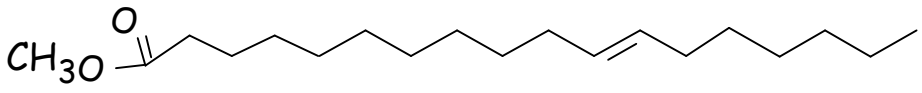
- Solid, burned directly
- Diesel
- Sugar to ethanol
- Cellulose to ethanol

Some plants accumulate oil

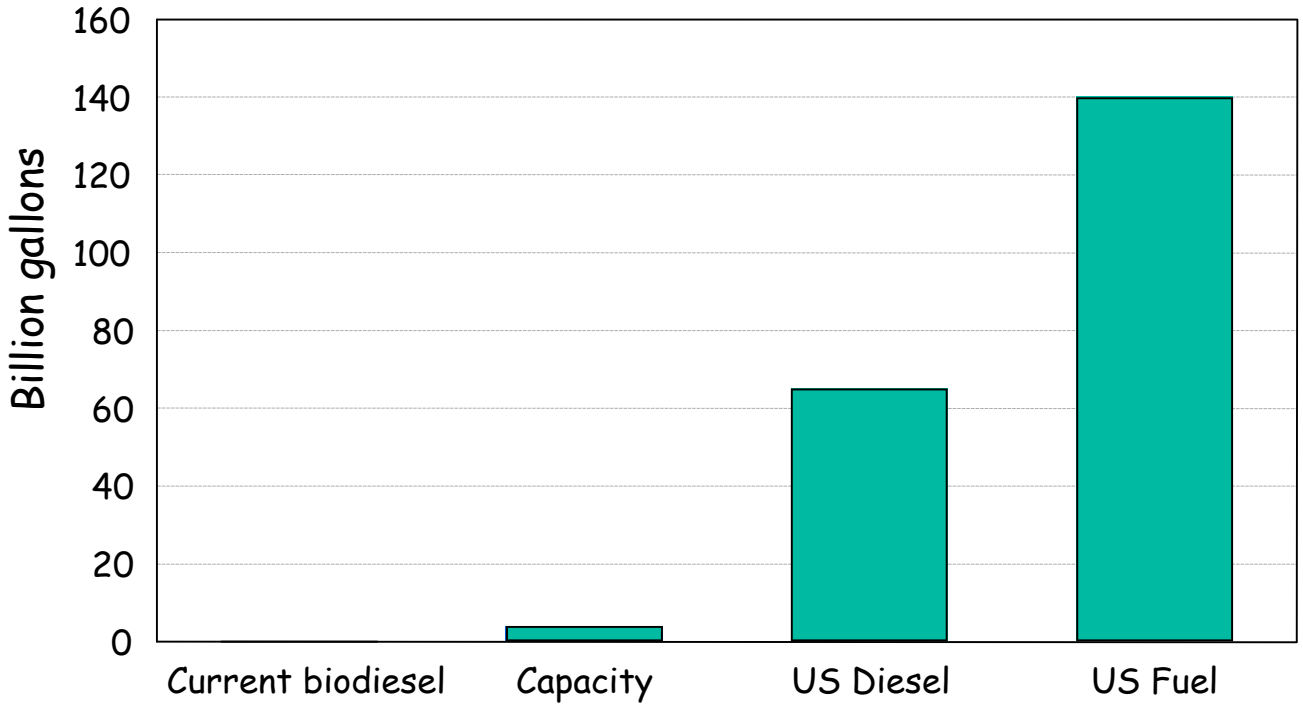




Limited potential of biodiesel



Biodiesel



65 biodiesel companies in operation, 50 in construction 2006

Oil palm is highly productive

(Best yields ~ 10 tonnes/HA)

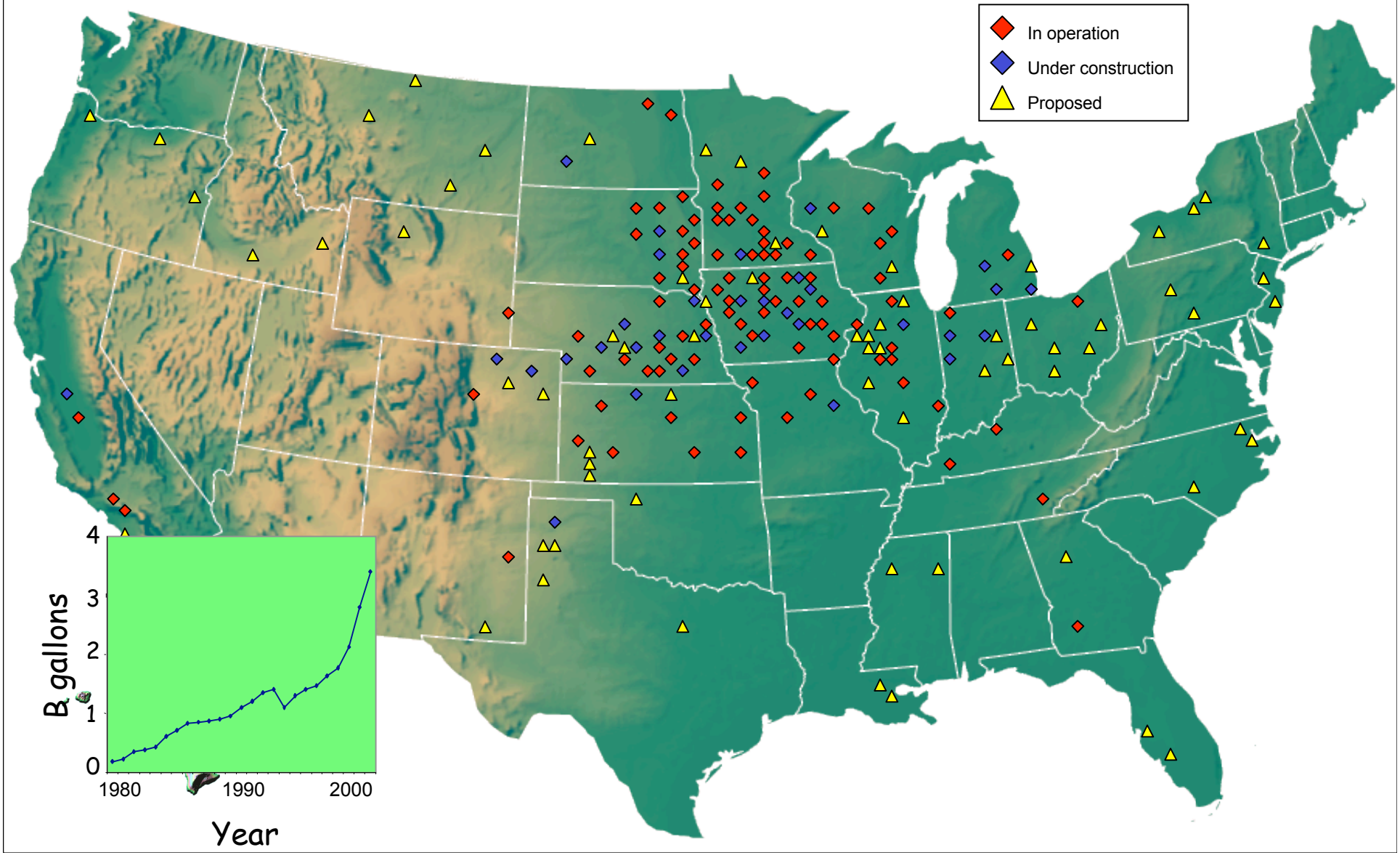
Greenfuel bioreactor

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

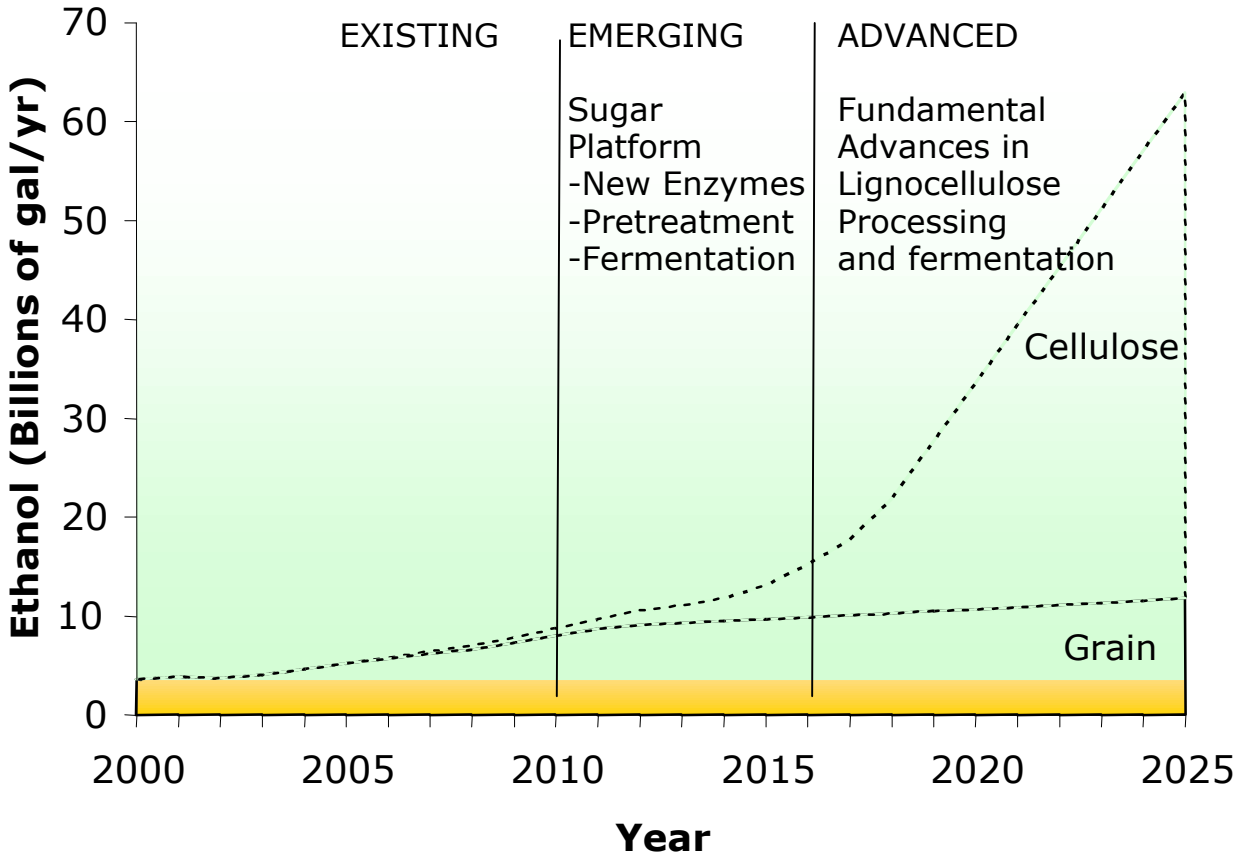
NCGA
www.ncga.com

US Corn Grain Ethanol Plants

AS OF: March 2006

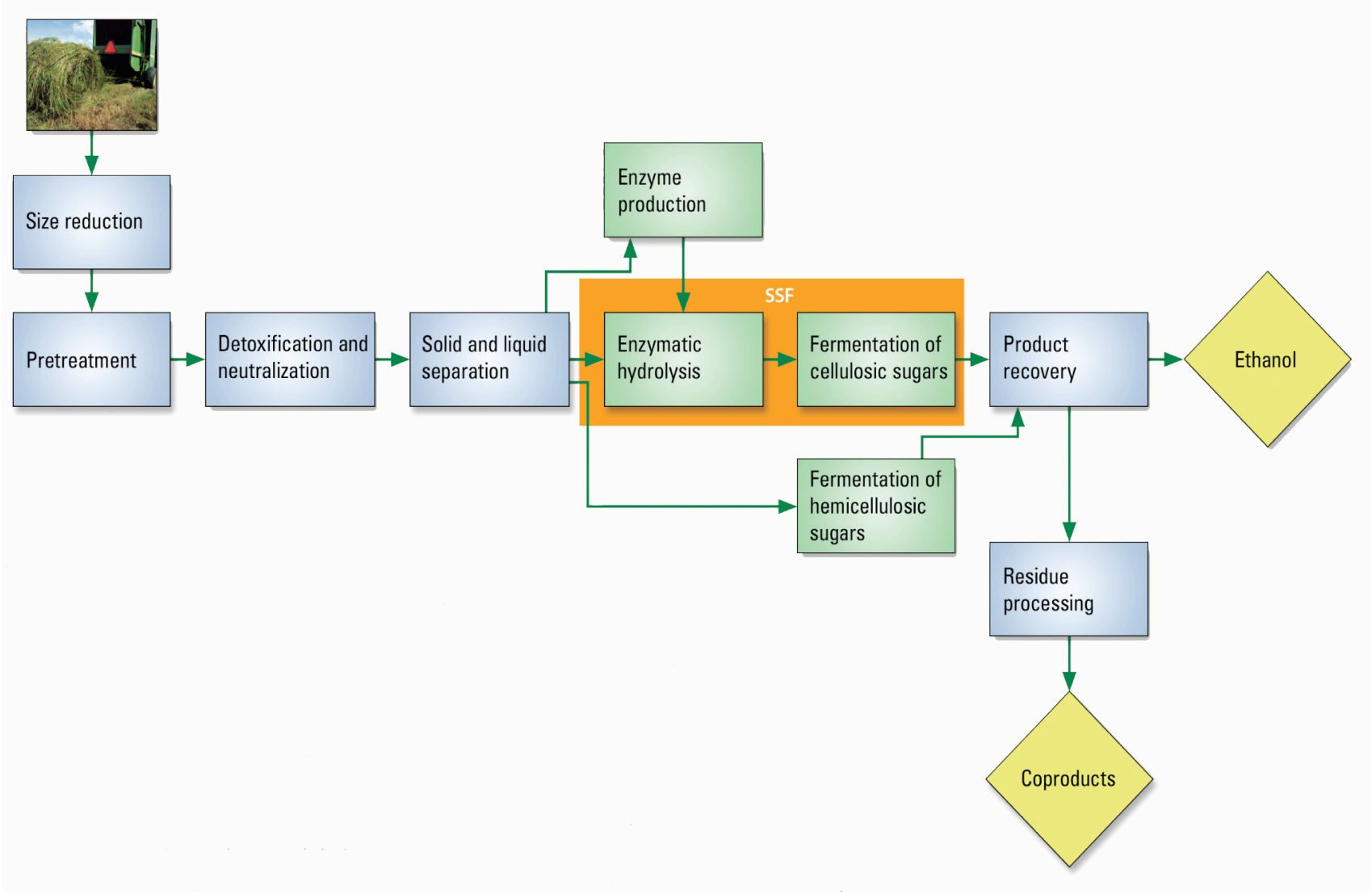


A DOE Ethanol Vision



Modified from Richard Bain, NREL

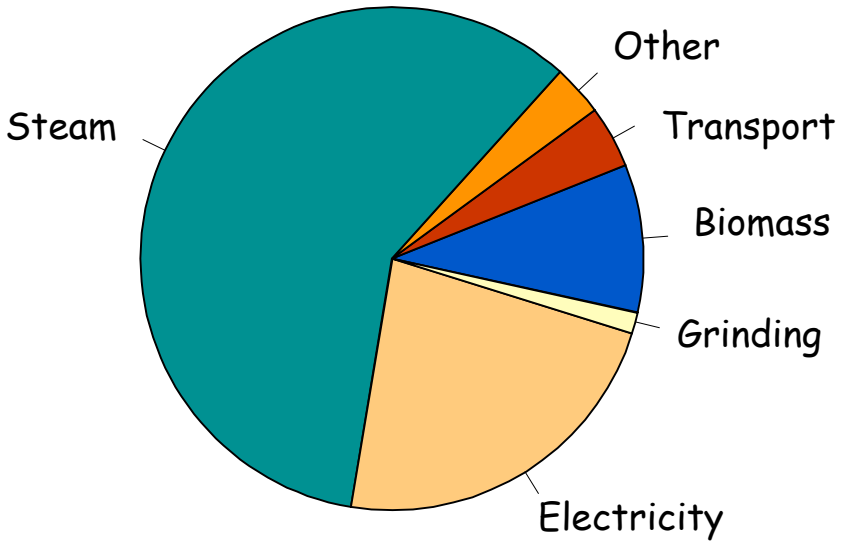
Steps in cellulosic ethanol production



From: Breaking the Biological Barriers to Cellulosic Ethanol

The challenge is efficient conversion

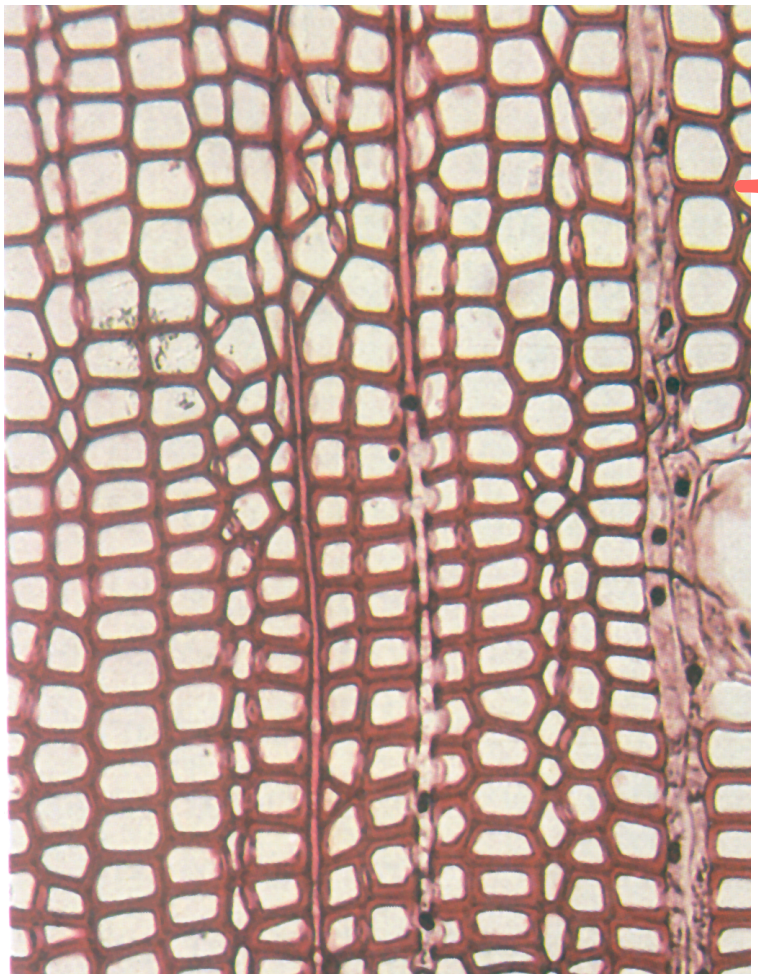
- Burning switchgrass (10 t/ha) yields 14.6-fold more energy than input to produce*
- But, converting switchgrass to ethanol calculated to consume 45% more energy than produced



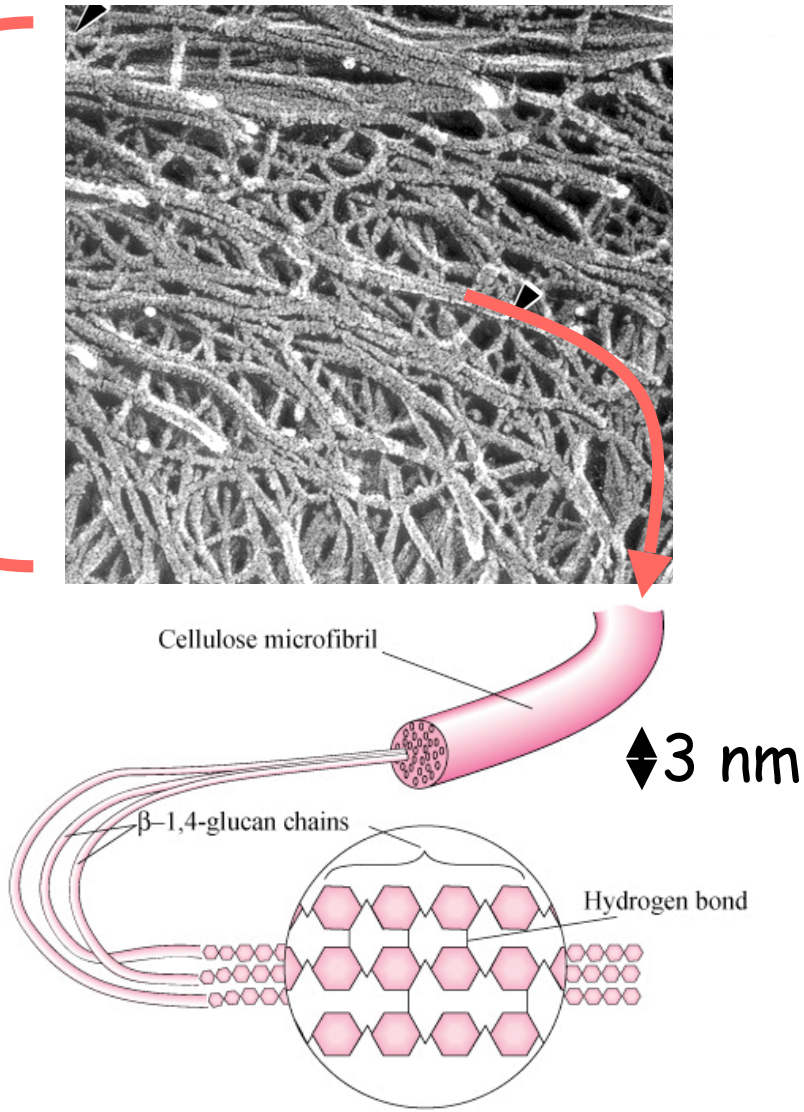
Energy consumption

*Pimentel & Patzek, Nat Res Res 14,65 (2005)

Plants are mostly composed of sugars

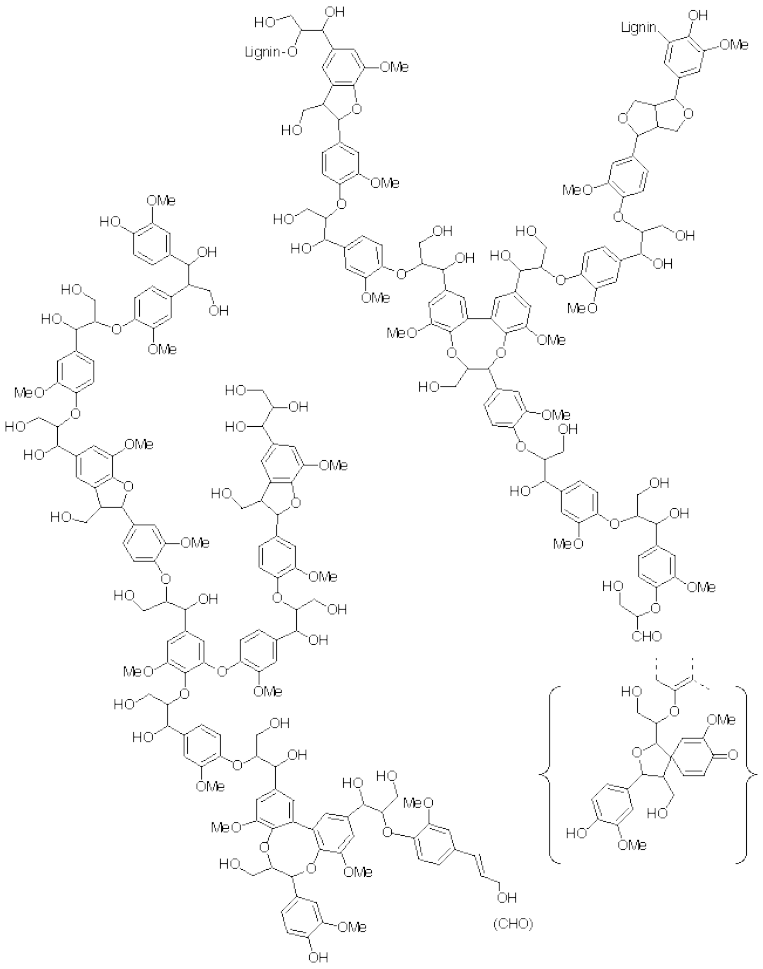


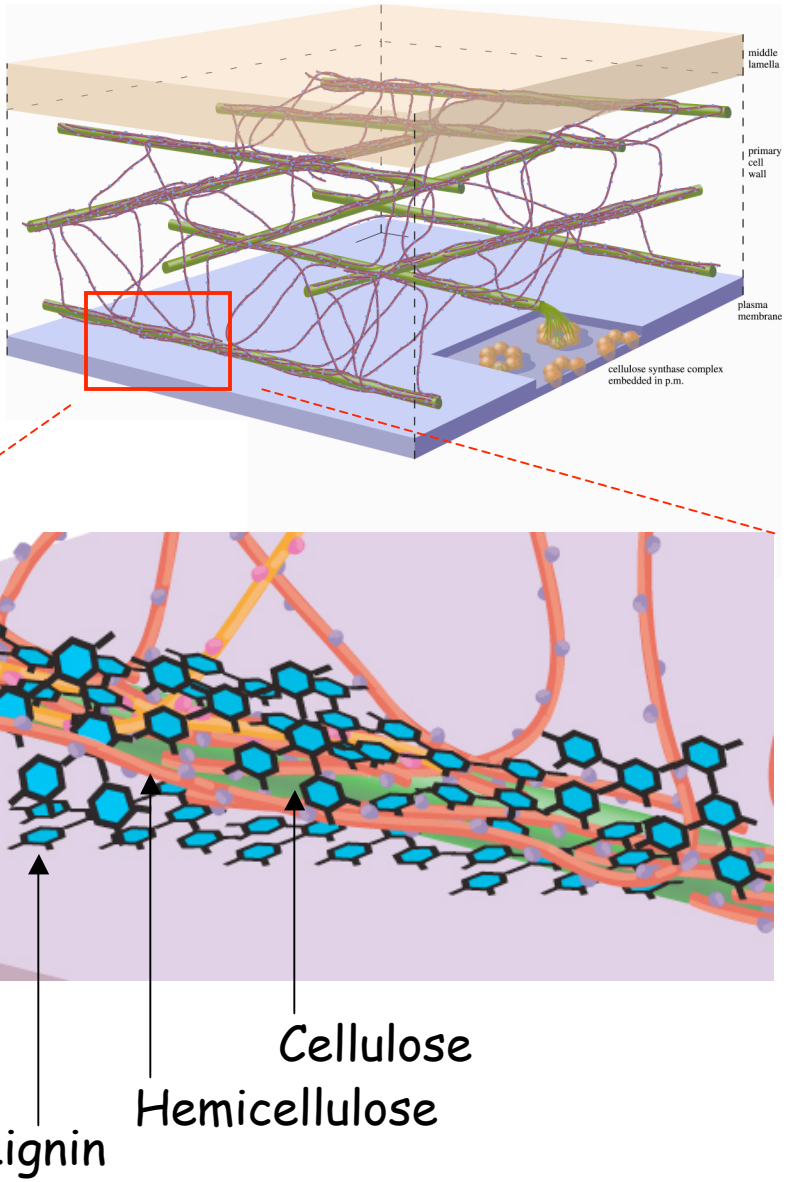
Section of a pine board



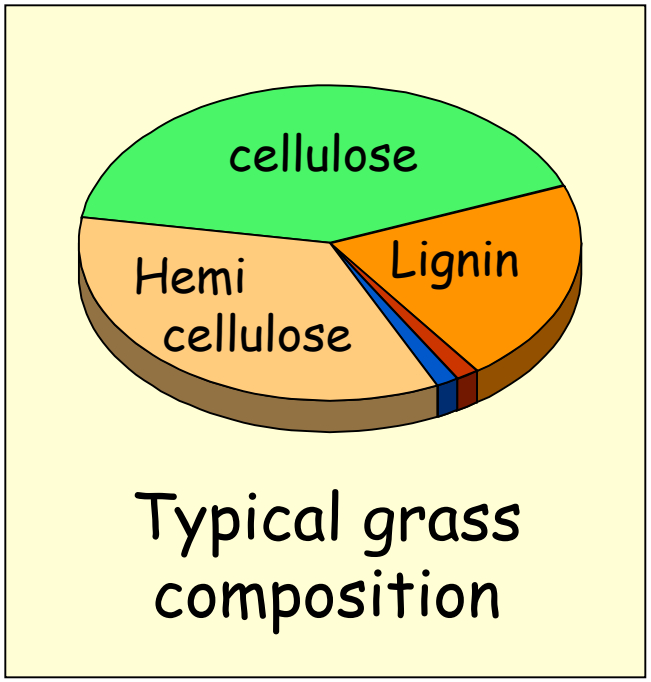
Polymerized glucose

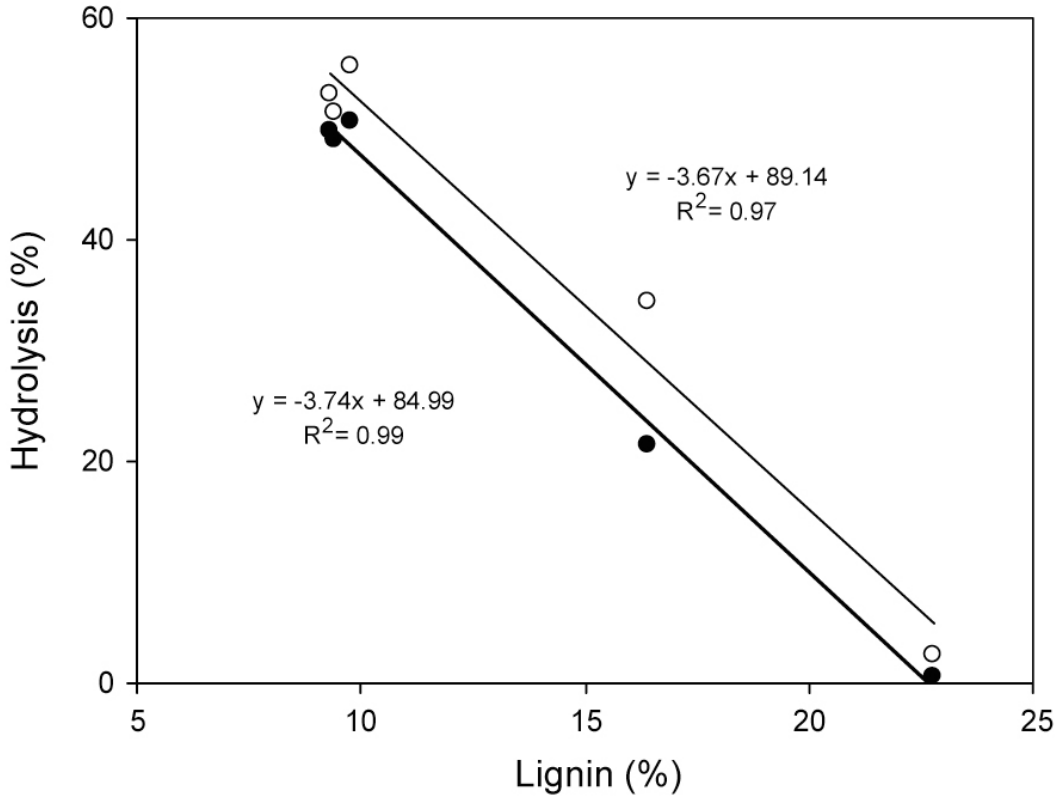
Lignin occludes polysaccharides





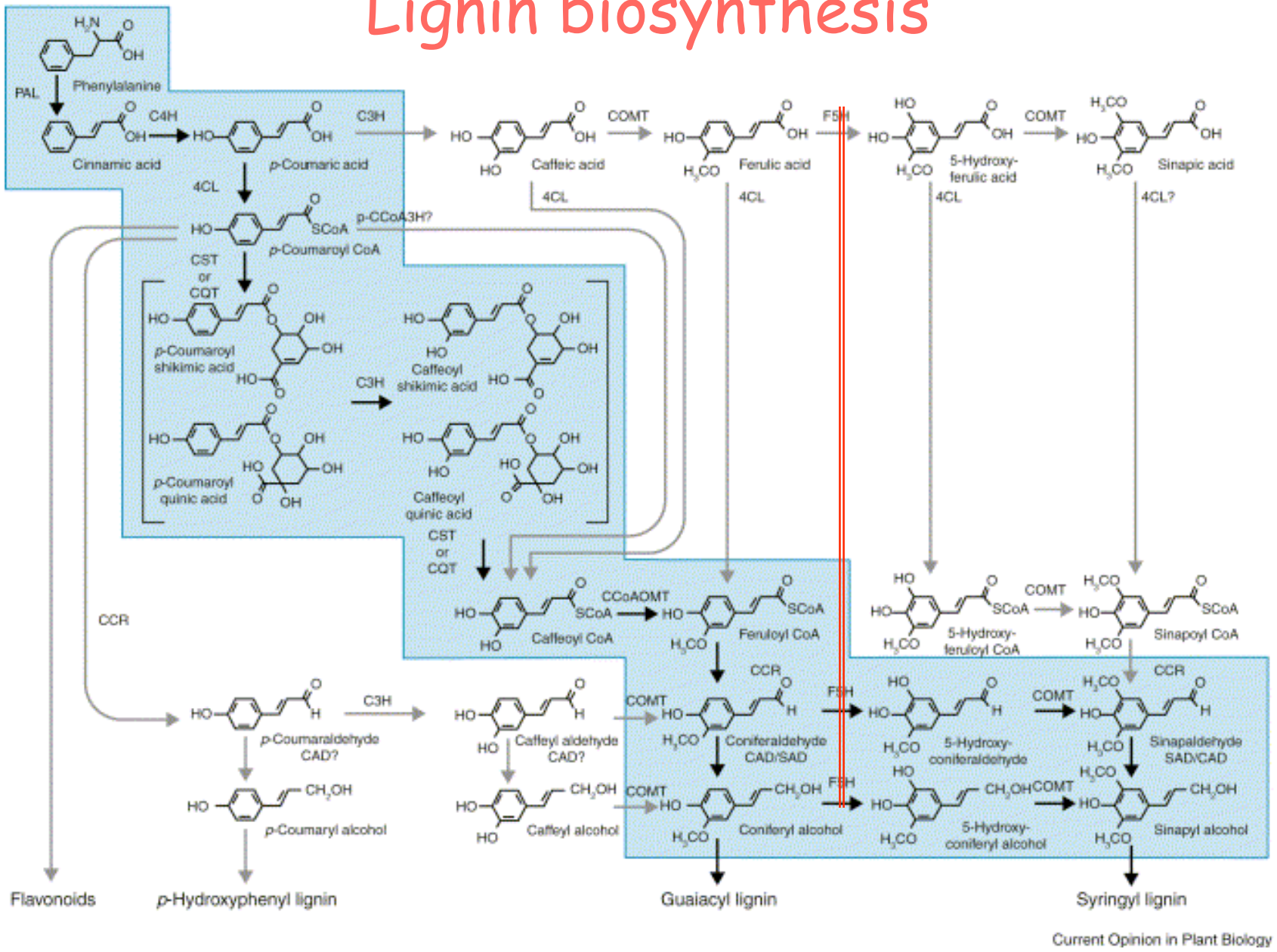
Effect of lignin content on enzymatic recovery of sugars from Miscanthus





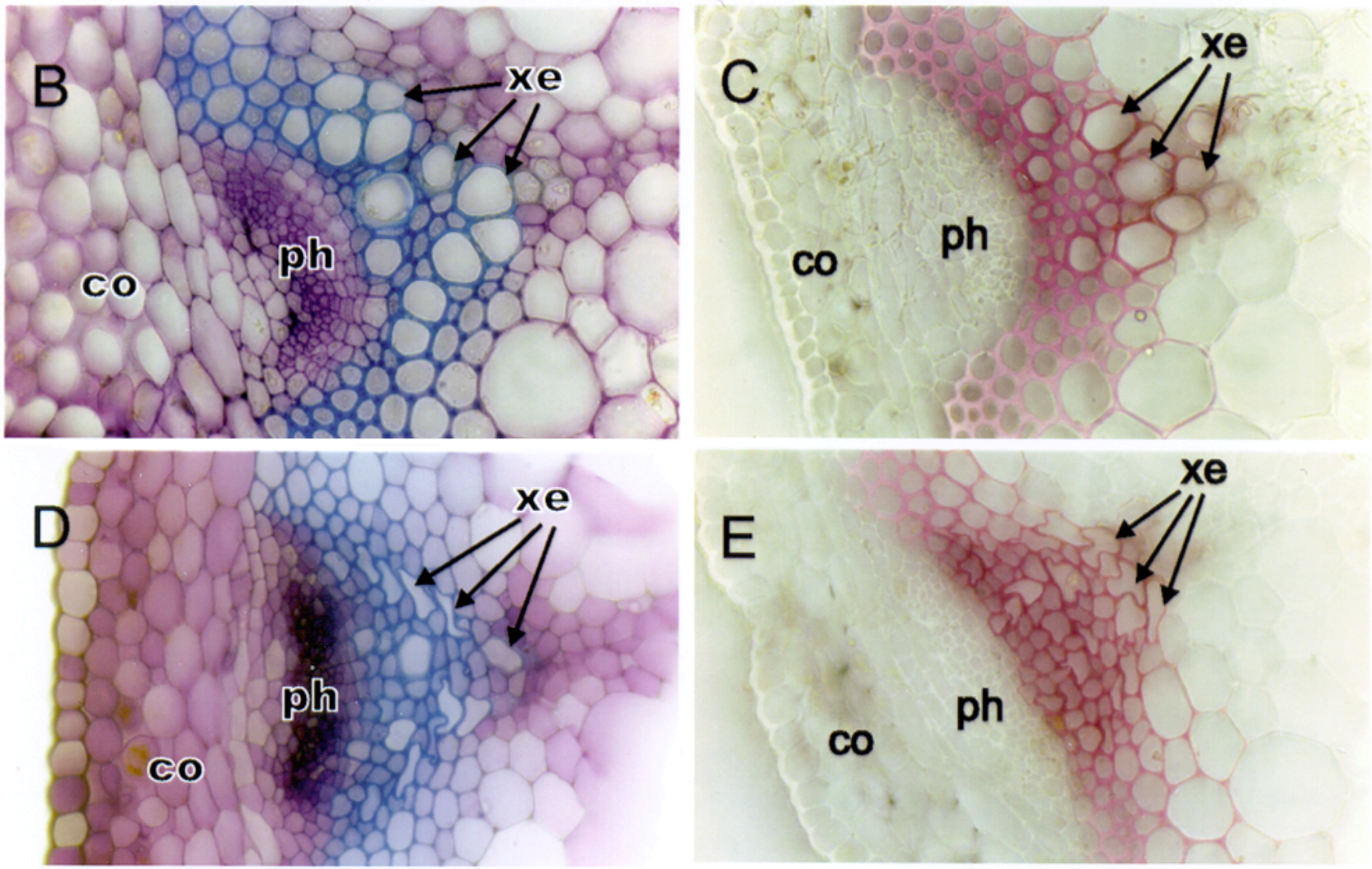
D Vrije et al (2002) Int J Hydrogen Energy 27,1381

Lignin biosynthesis



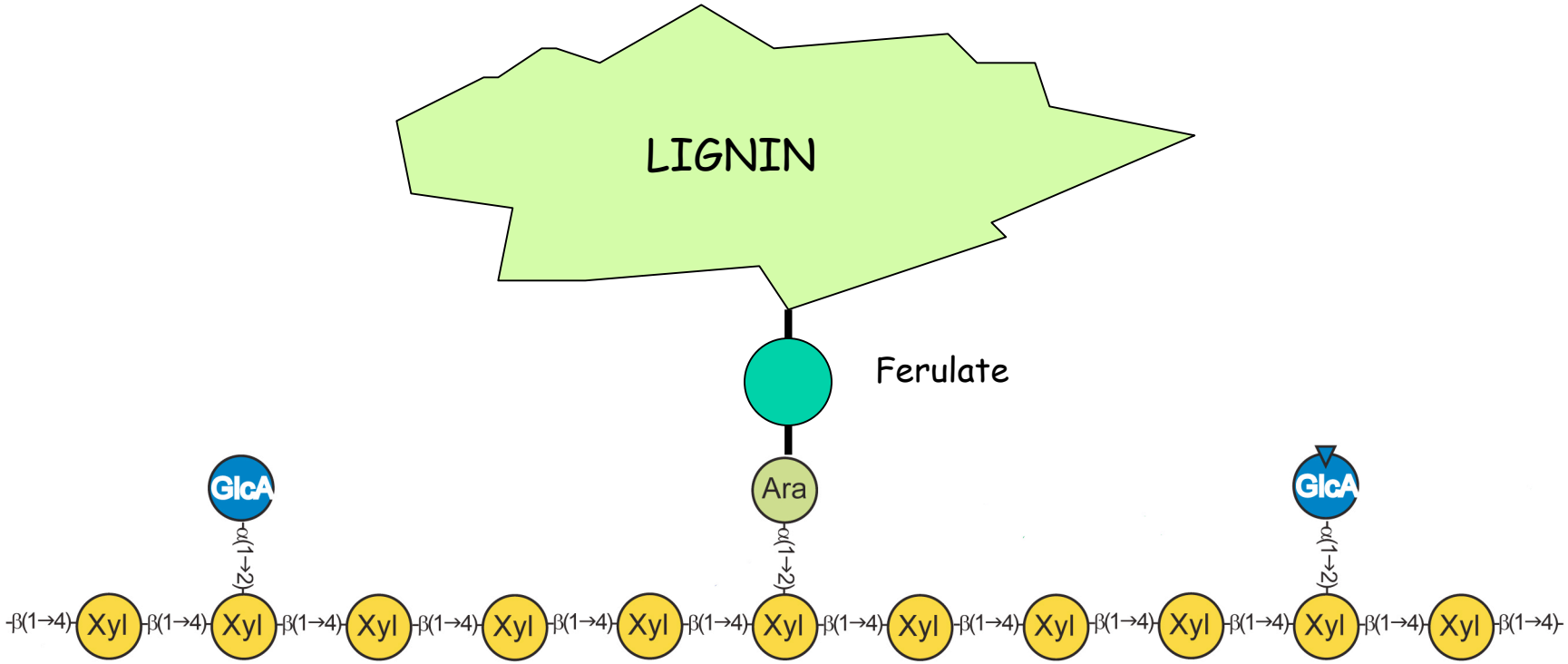
Humphreys and Chapple, Curr Opin Plant Biol 5,224

Irregular xylem (*irx*) mutants



Turner and Somerville Plant Cell 9,689

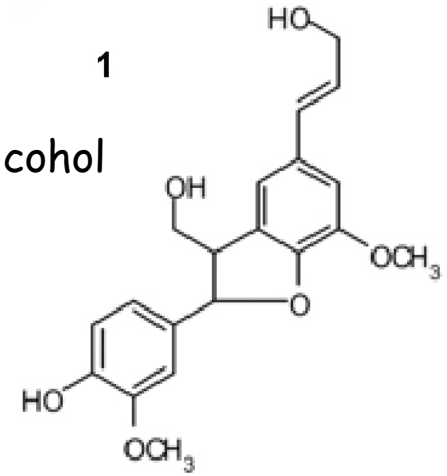
Lignin is covalently linked to hemicellulose (xylans)



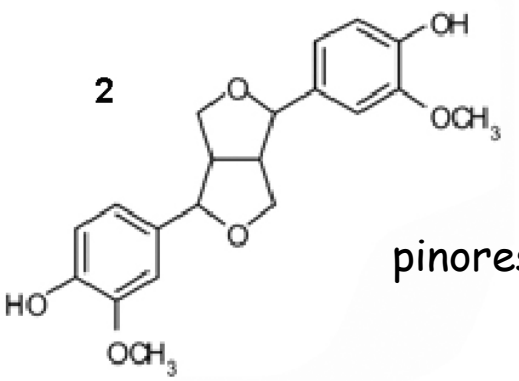
A cleavable lignin precursor would fundamentally alter preprocessing

1

dehydrodiconiferyl alcohol

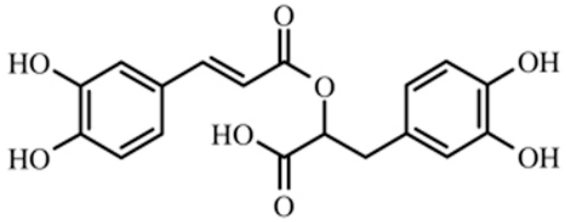


2



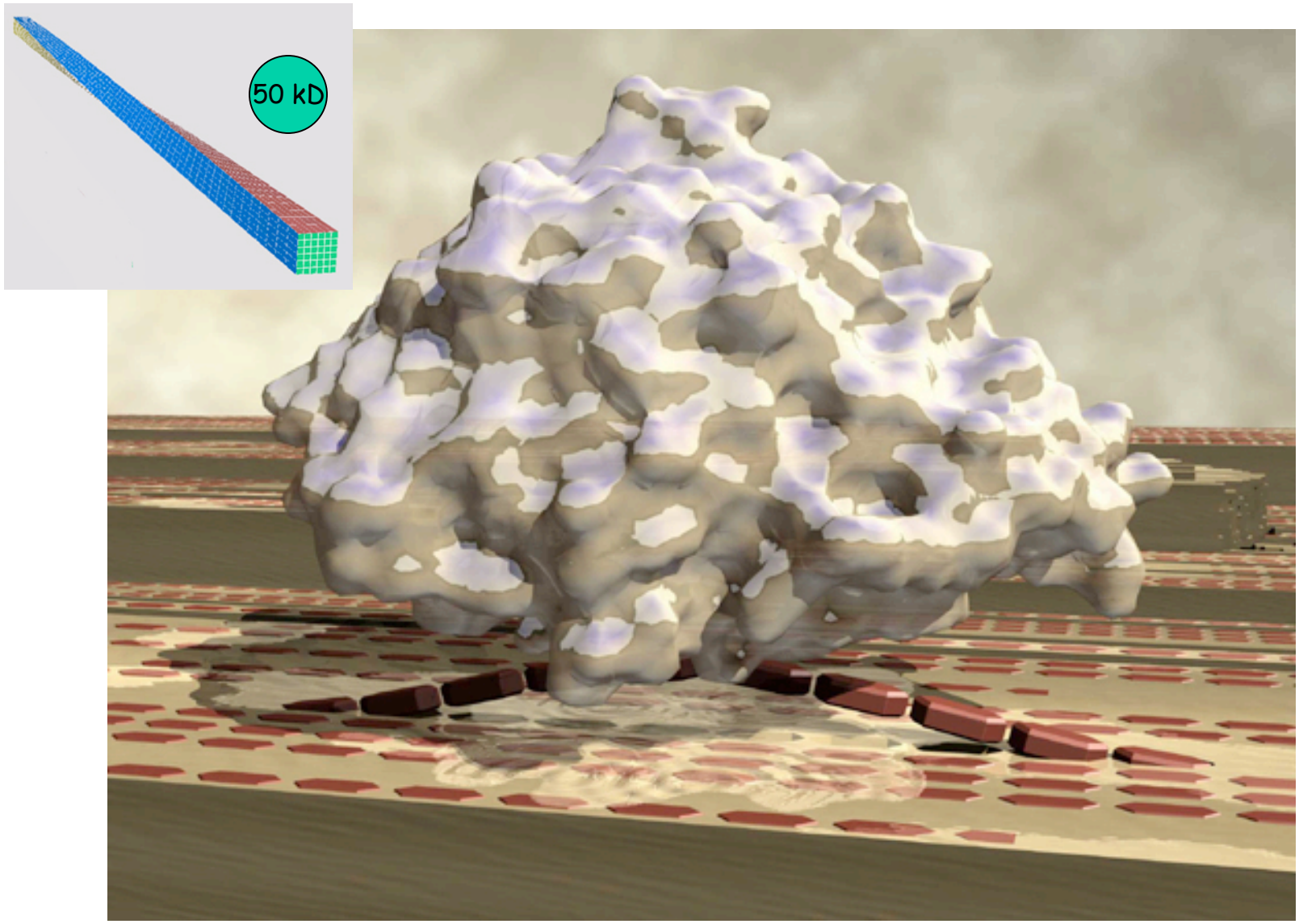
pinoresinol

3



rosmarinic acid

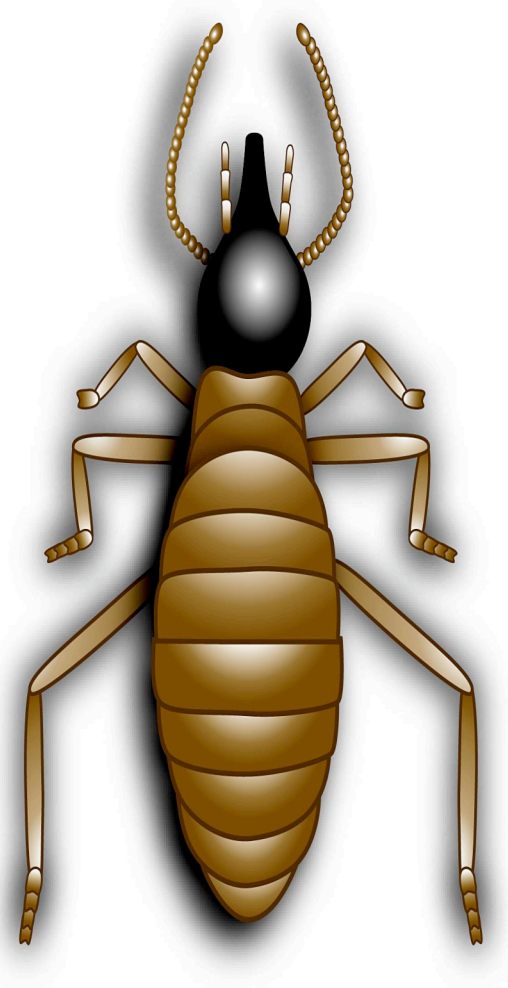
Cellulose is recalcitrant to hydrolysis



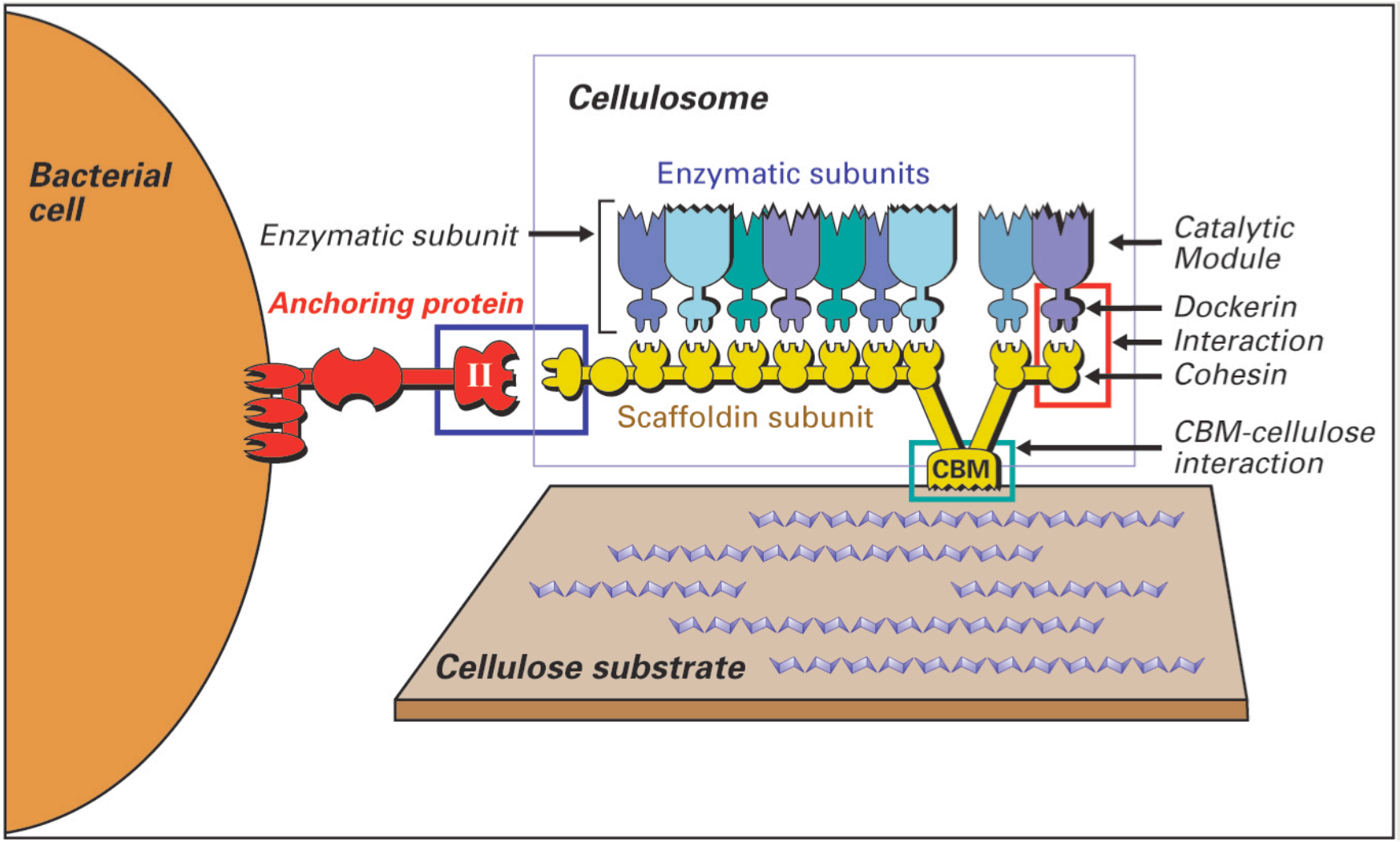
NREL

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)

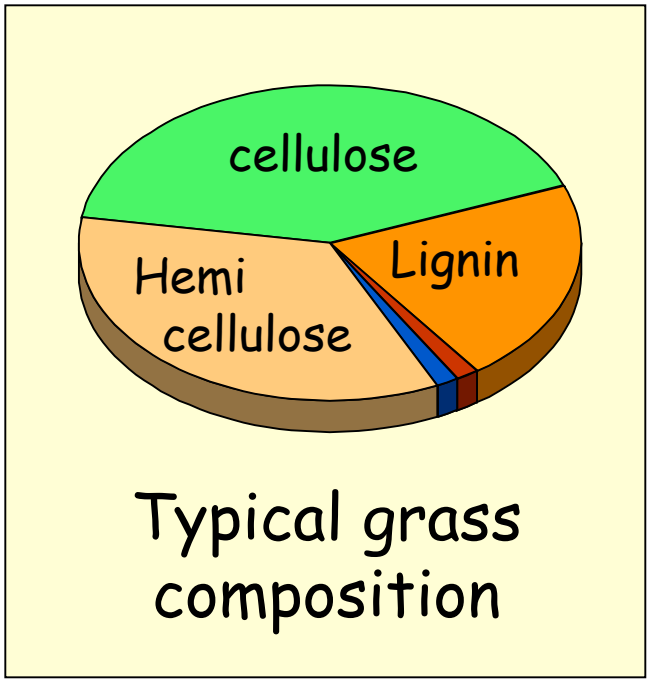


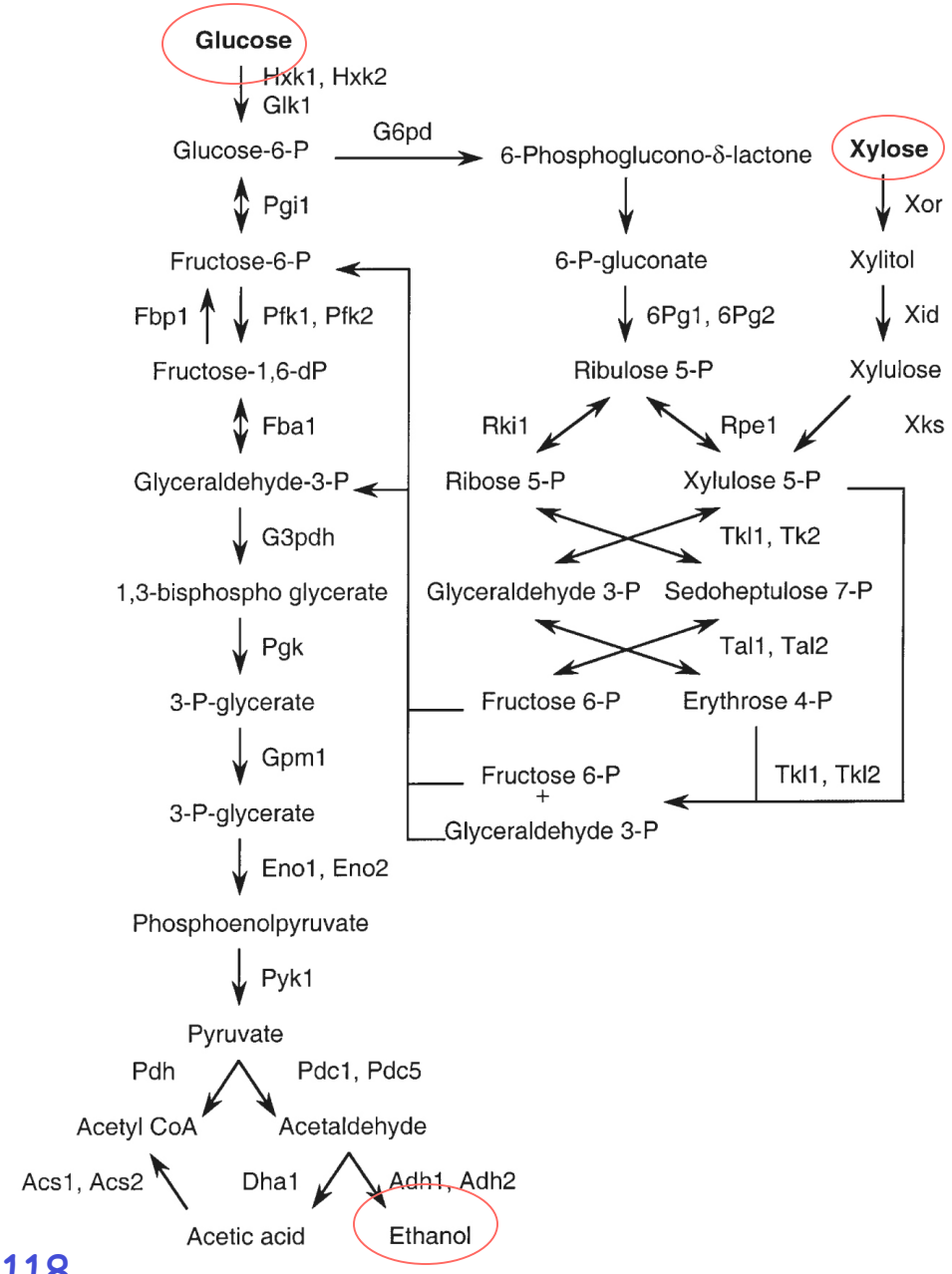
Some cellulytic enzymes are components of a "molecular machine"



From: Breaking the Biological Barriers to Cellulosic Ethanol

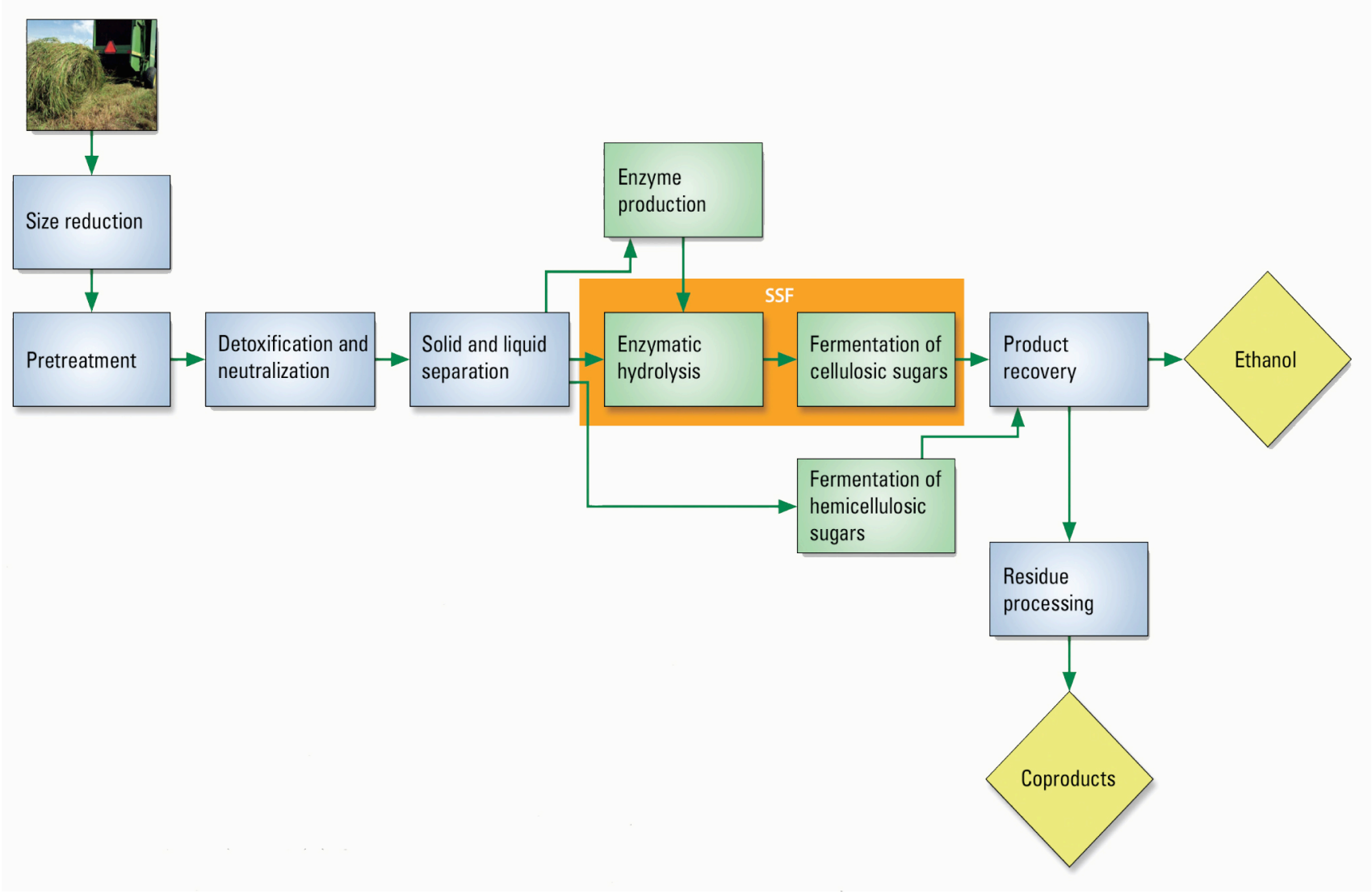
Fermentation of all sugars is essential





Jeffries & Shi Adv Bioch Eng 65,118

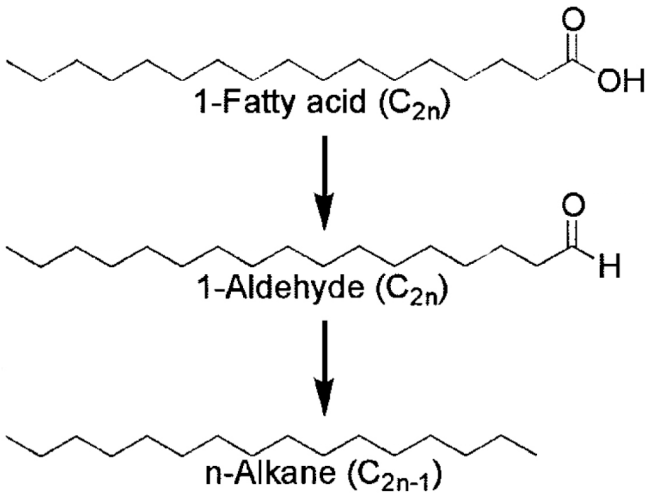
Steps in cellulosic ethanol production



From: Breaking the Biological Barriers to Cellulosic Ethanol

Nature offers many alternatives to ethanol

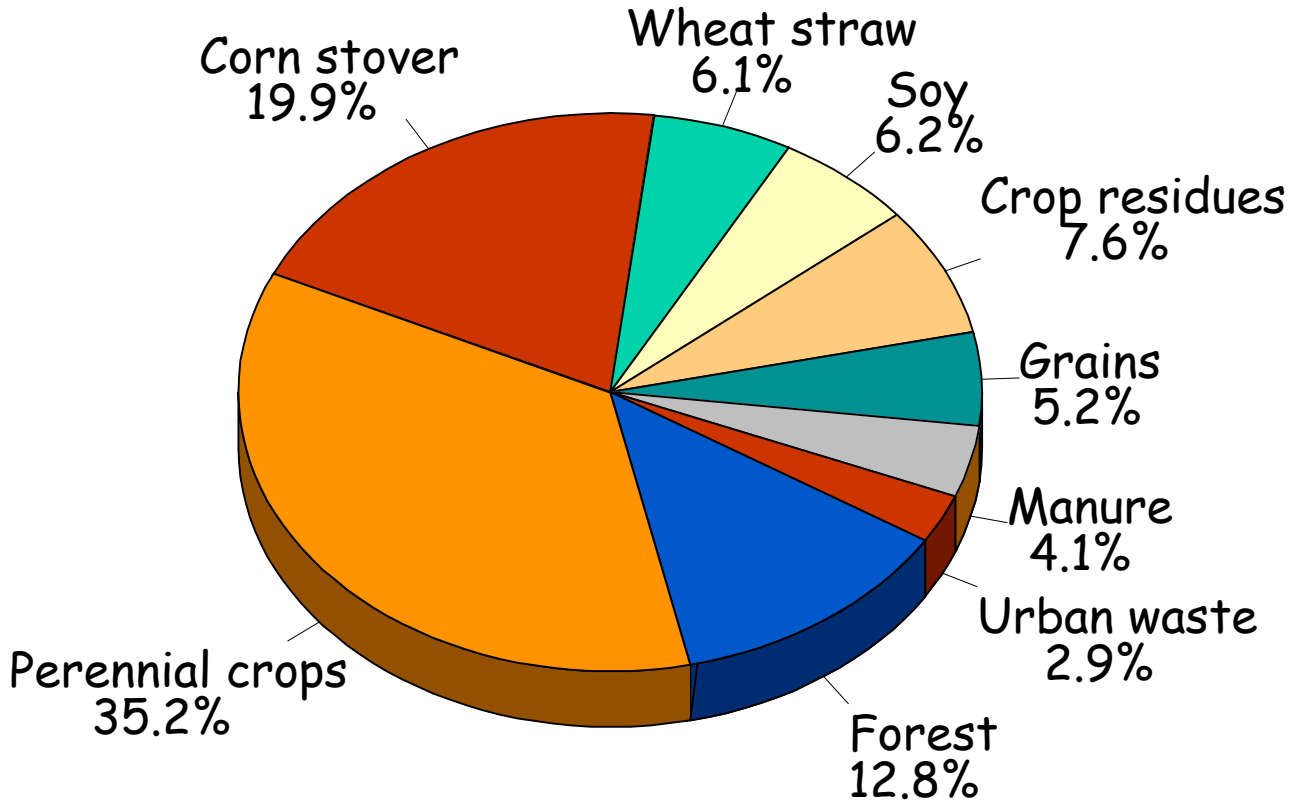
- Plants, algae, and bacteria synthesize alkanes, alcohols, waxes
- Production of hydrophobic compounds would reduce toxicity and decrease the energy required for dehydration



Summary of priorities

- Modify plant composition to minimize energy required for depolymerization
- 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

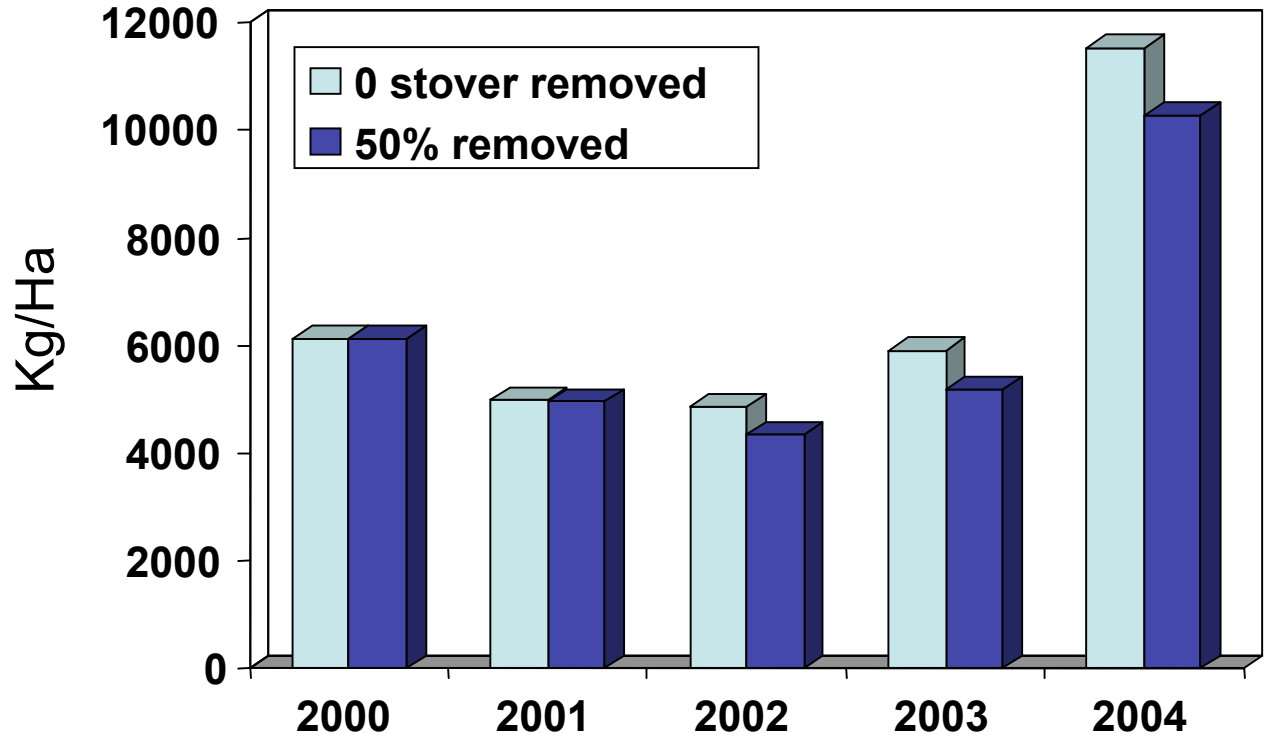
US Biomass inventory = 1.3 billion tons



From: Billion ton Vision, DOE & USDA 2005

Effect of 50% stover removal on corn grain yields in eastern NE.

(120kg N/ha)



K. Vogel et al., unpublished

Prospective energy crops have not been subject to intensive breeding

Miscanthus sp.

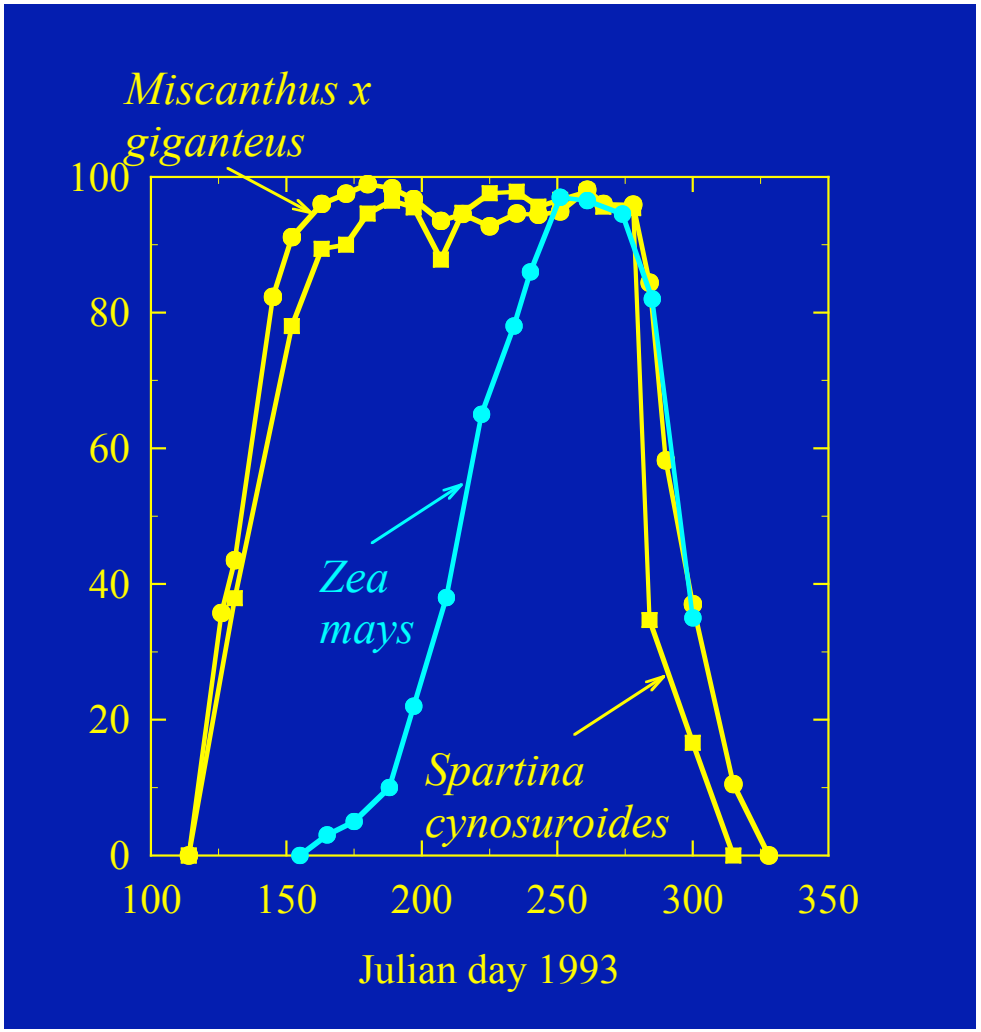
Switchgrass (Panicum virgatum)

Courtesy of Steve Long & Emily Heaton. USDA-NRCS PLANTS Database / Hitchcock, A.S. (rev. A. Chase). 1950. *Manual of the grasses of the United States*. USDA Misc. Publ. No. 200. Washington, DC.

Harvesting Miscanthus

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

Perennials have more photosynthesis

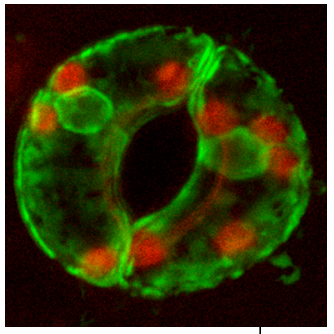


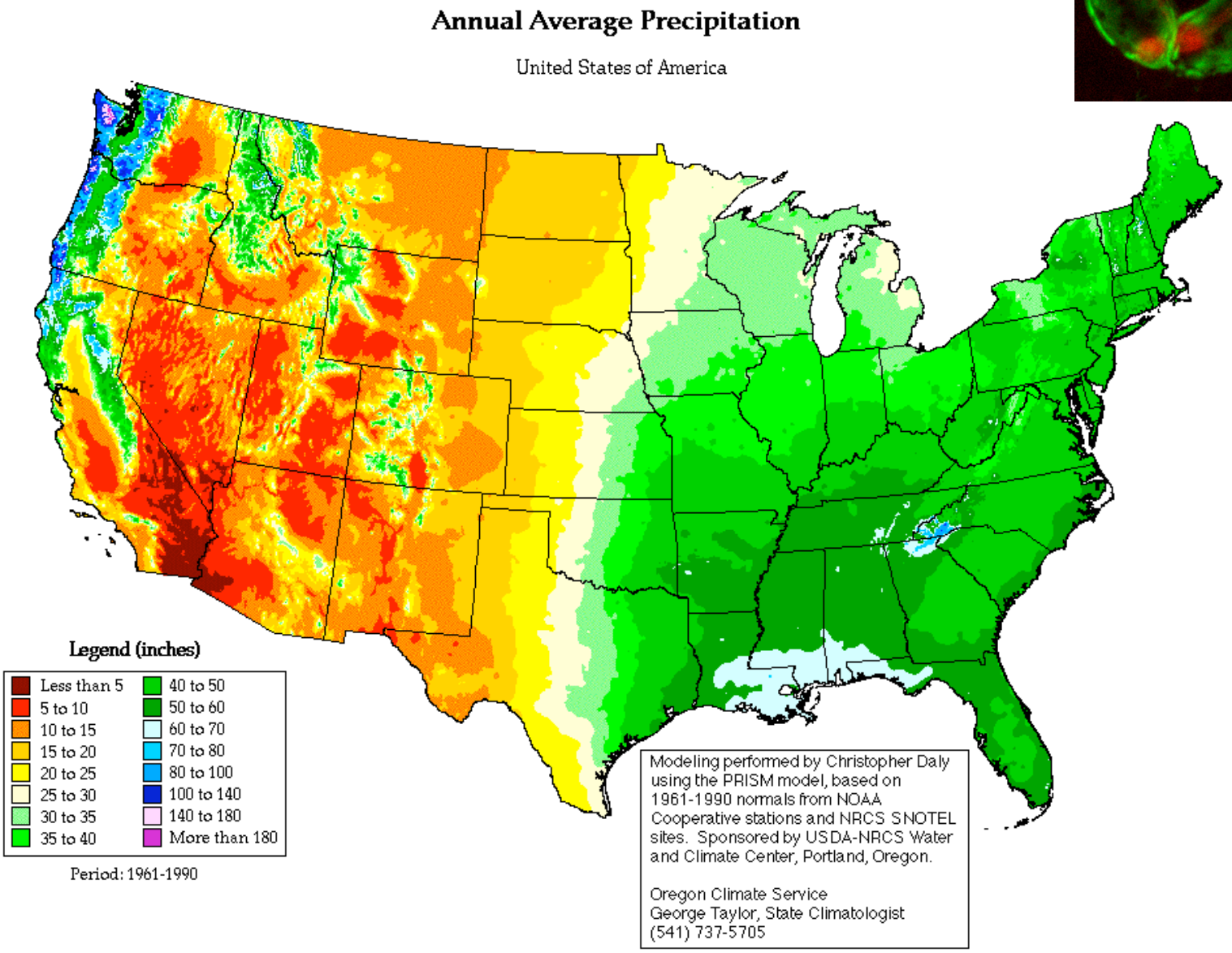
Courtesy of Steve Long, University of Illinois

Geographic distribution of biomass

Wright et al DOE-ORNL-EERE

Annual precipitation





Comments

- Energy crops are expected to be more environmentally benign than production agriculture
  - Low fertilizer and chemical inputs
  - Late-harvest supports biodiversity
  - Mixed cultures possible
  - Many species can be used

Research goals for feedstock improvement

- Minimize inputs
  - Perennial energy crops
  - Biotic and abiotic stress tolerance
- Improve propagation
- Maximize biomass yield
  - Establish breeding tools
  - Develop genetic maps
  - Survey genetic diversity
  - Establish orthology to models
- Optimize composition
  - Facile deconstruction
  - Minimal inhibitor production
  - Maximal productivity

Asian soy rust

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

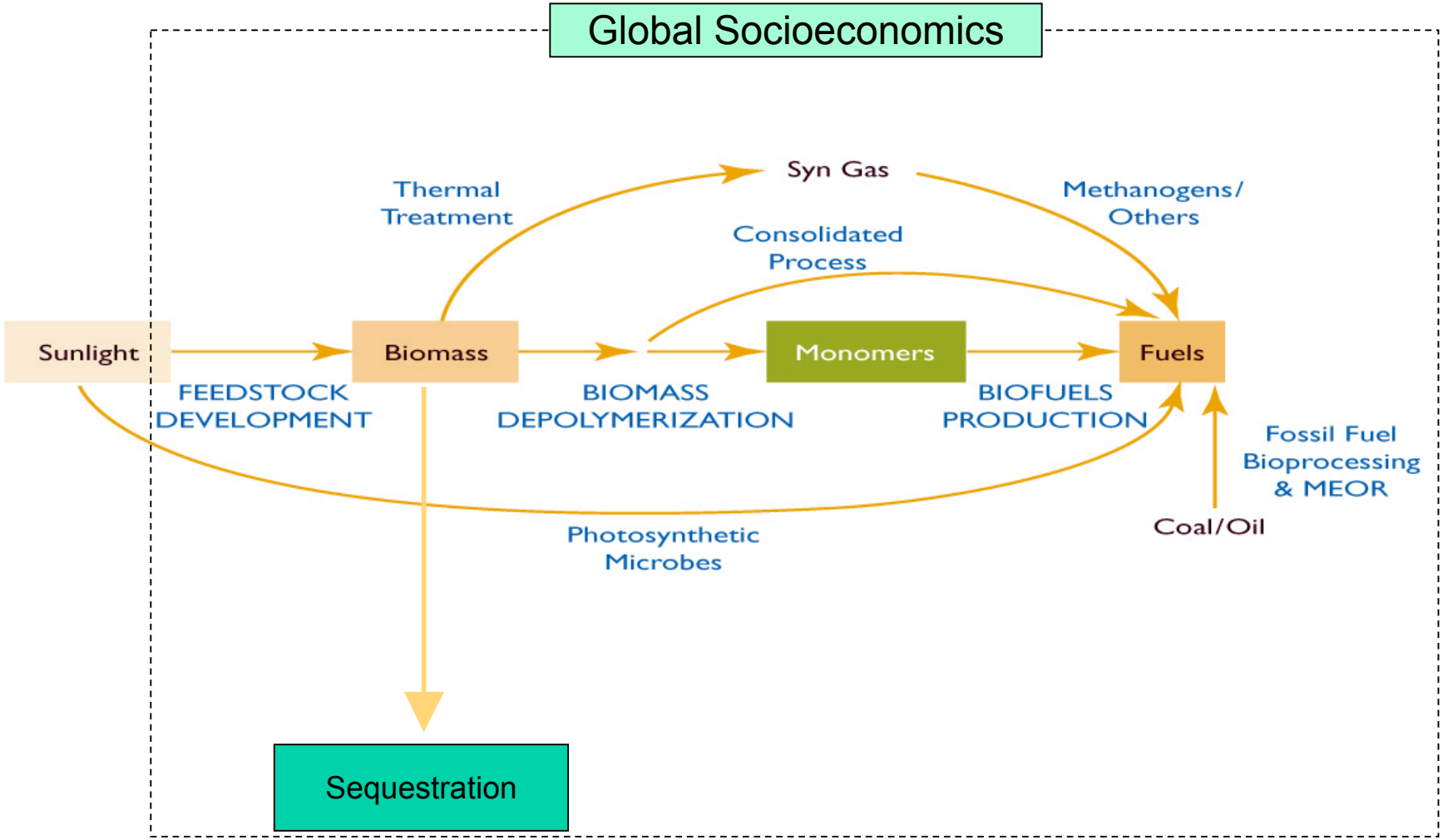
Conclusions

- Biofuels are expected be an important part of a carbon neutral energy economy
- There are no insurmountable problems
- Many improvements are possible
- The revolution in mechanistic biology offers enormous untapped potential to make fundamental changes in solar harvesting with plants

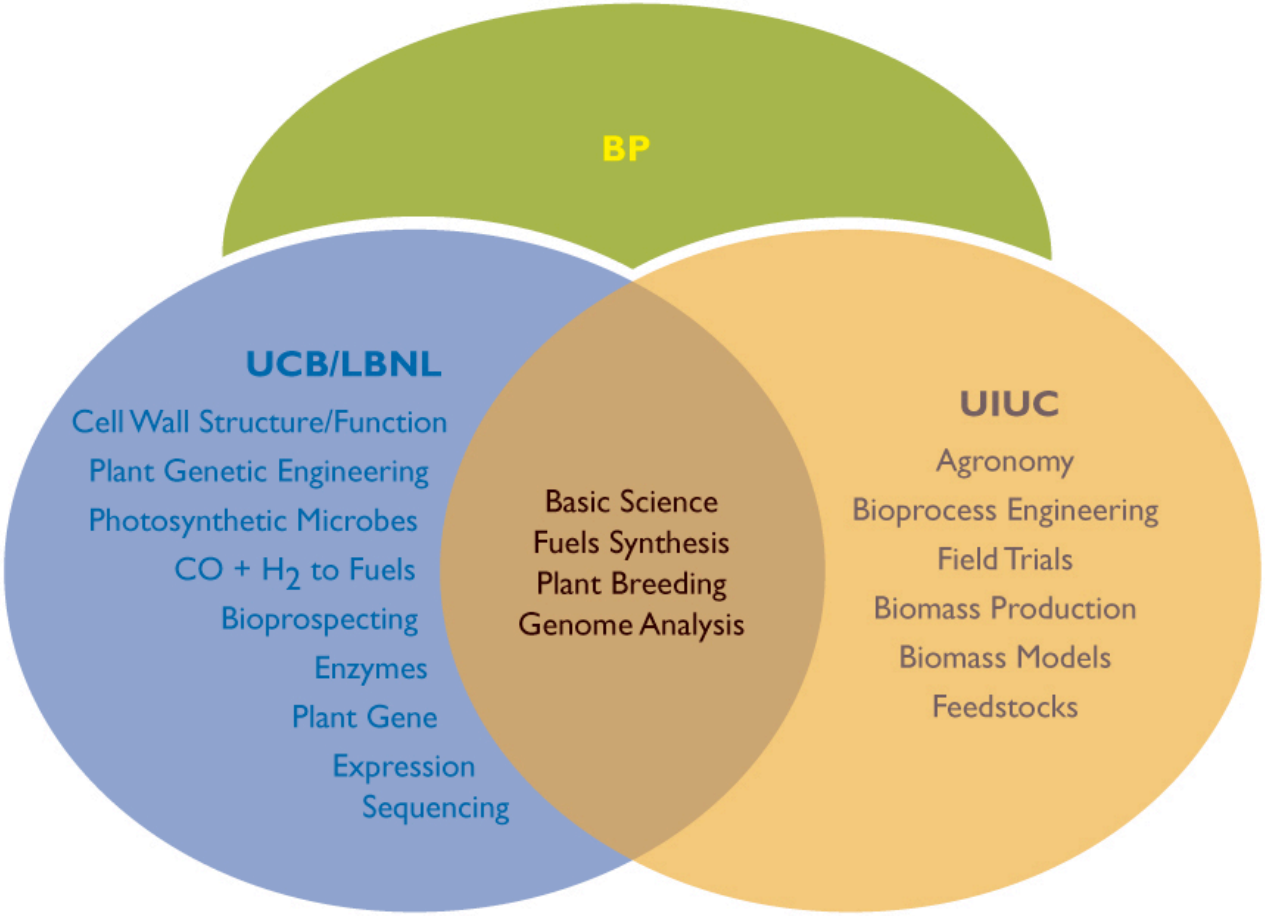
The Energy Bioscience Institute

- Partnership between UCB, UI, LBL
- BP has committed $500M over 10 years
- Goals include elimination of bottlenecks to biofuels, development of improved biotechnologies for fuel production, and education of scientists and engineers across the relevant disciplines

The EBI has Goals Beyond Biofuels



Research Complementarity



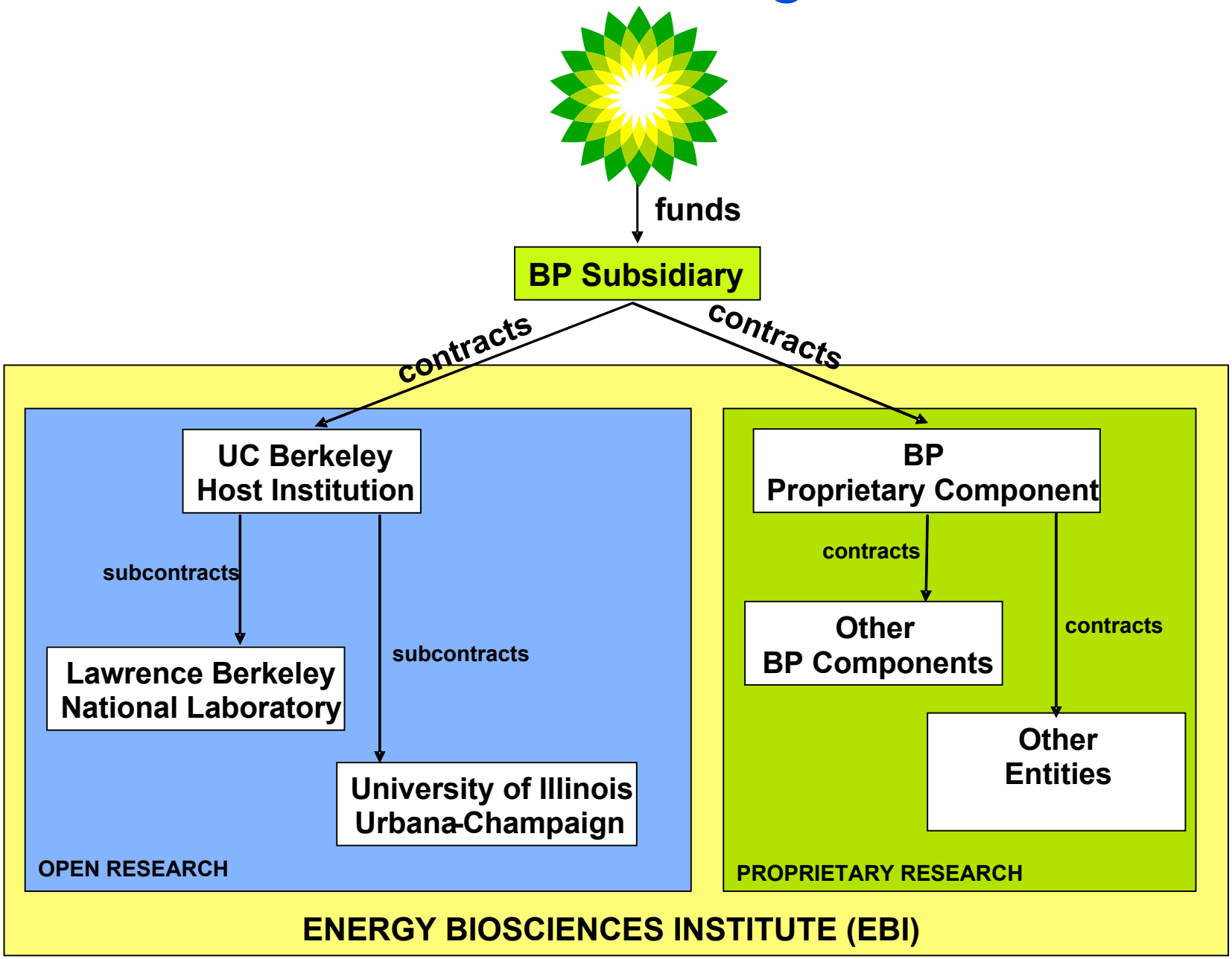
Status

- BP & UCB in discussion about terms of agreement, goal is completion by end of July
- Executive committee organizing operational aspects
- Grant competition currently running, expect to start funding research by October

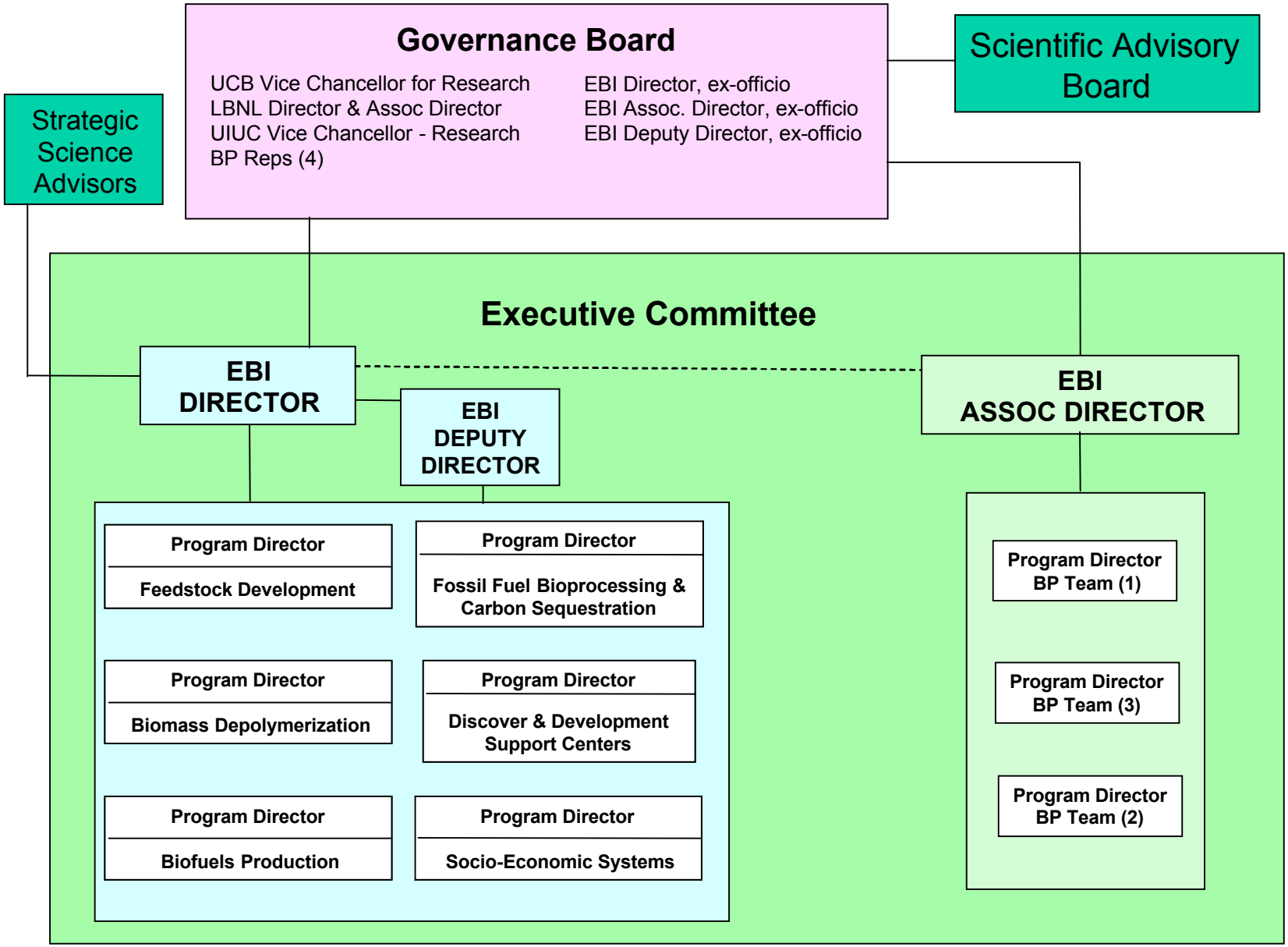
Goals of the EBI

- Envisioning the future
- Identifying and solving the scientific and technical problems required to enable the development of a cellulosic biofuels industry
- Developing new biotechnologies for enhanced oil recovery, fossil fuel processing & biosequestration
- Educating scientists, policymakers, and the public
- Training a new generation of students

EBI Funding


funds
BP Subsidiary
contracts
contracts
UC Berkeley
Host Institution
subcontracts
Lawrence Berkeley
National Laboratory
subcontracts
University of Illinois
Urbana-Champaign
OPEN RESEARCH
BP
Proprietary Component
contracts
Other
BP Components
contracts
Other
Entities
PROPRIETARY RESEARCH
ENERGY BIOSCIENCES INSTITUTE (EBI)

EBI Governance and Oversight

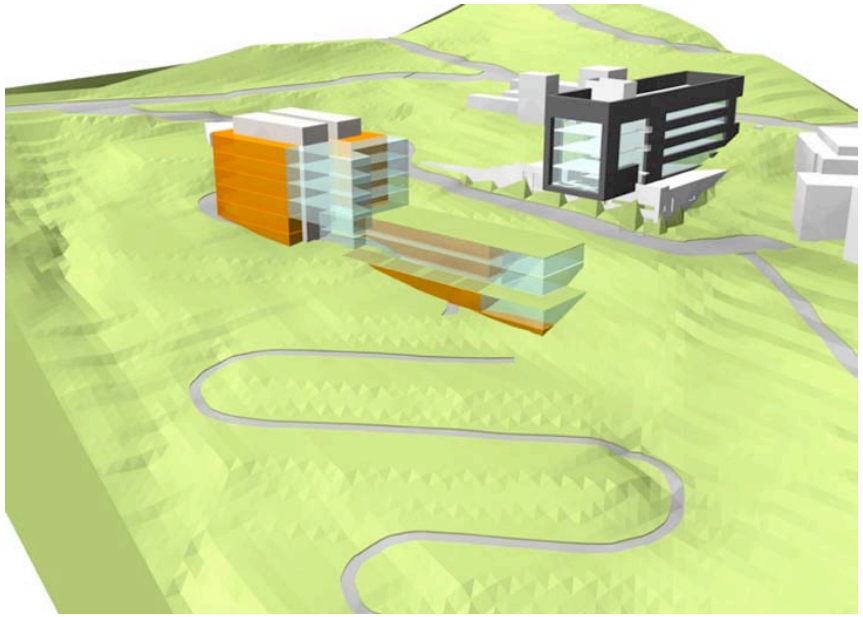


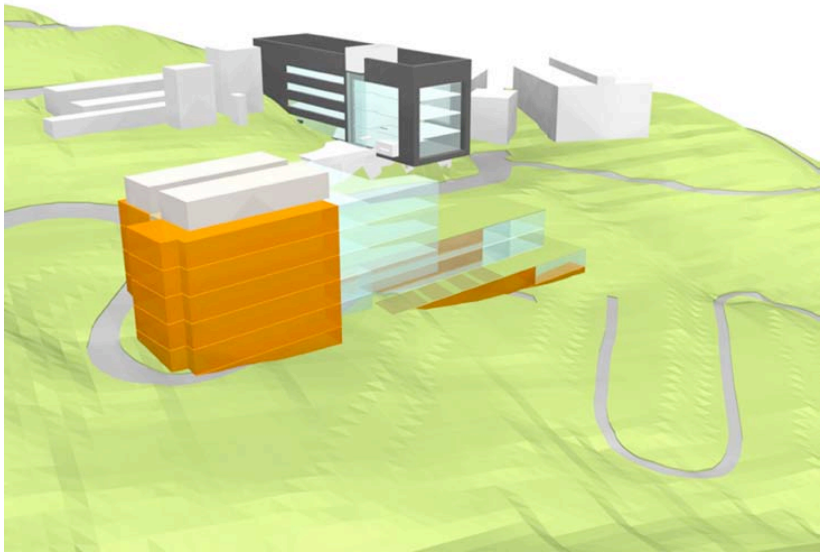
Implementing the program

- Open call for preproposals that address broad goals
- Based on preproposals, PIs will be invited to submit either a project or program proposal
  - Suggestions from executive committee may be attached.
  - Projects will be defined term (EBI associates)
  - Programs will be rolling 3 years with annual reviews (EBI investigators)
- Proposals will be peer reviewed
- EBI investigators will co-locate in EBI space
- EBI associates will have participation obligations

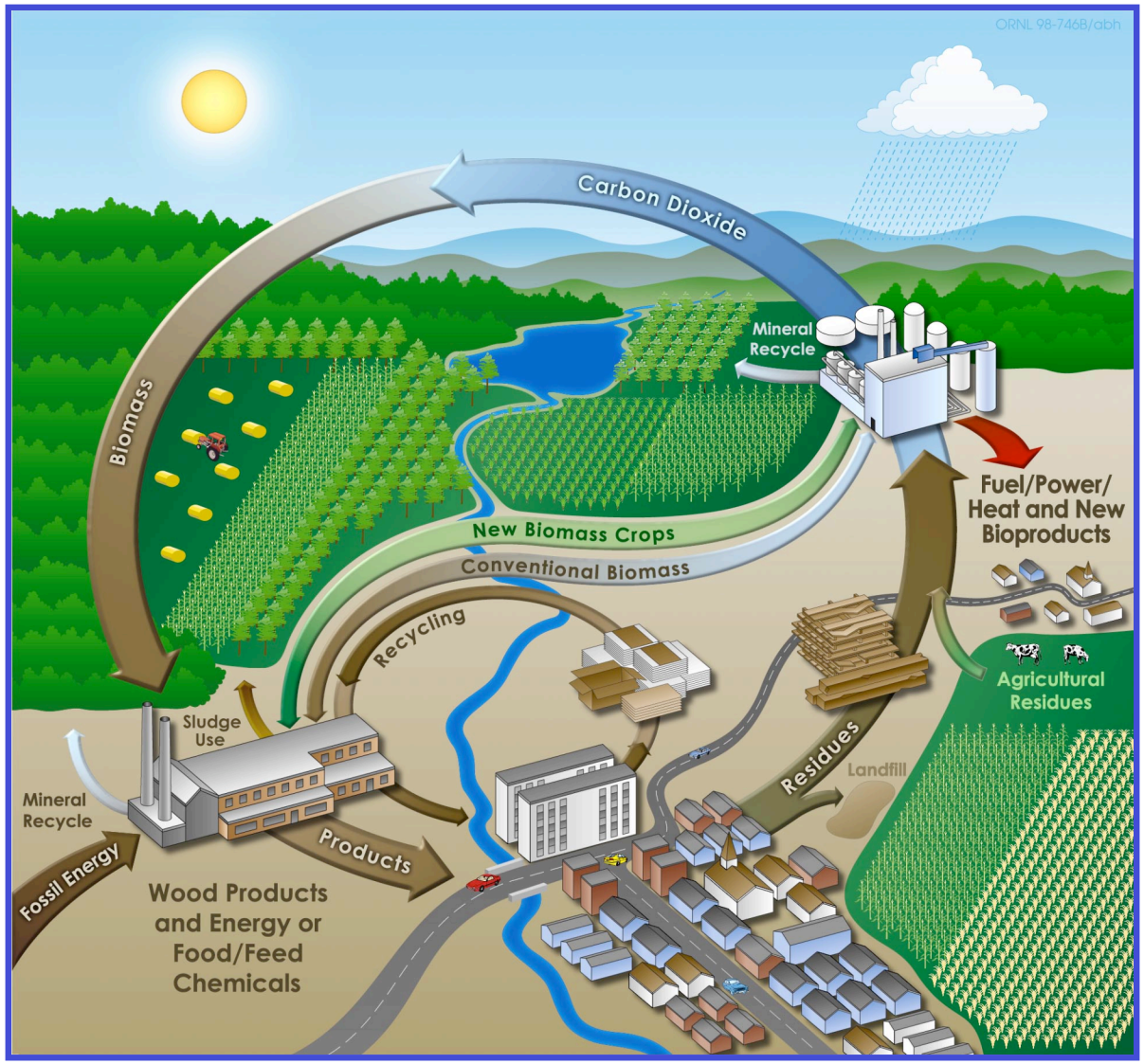

University of California at Berkeley and
Lawrence Berkeley National Laboratory
LBL
UC
Berkeley
Campus

Helios building is at conceptual design stage



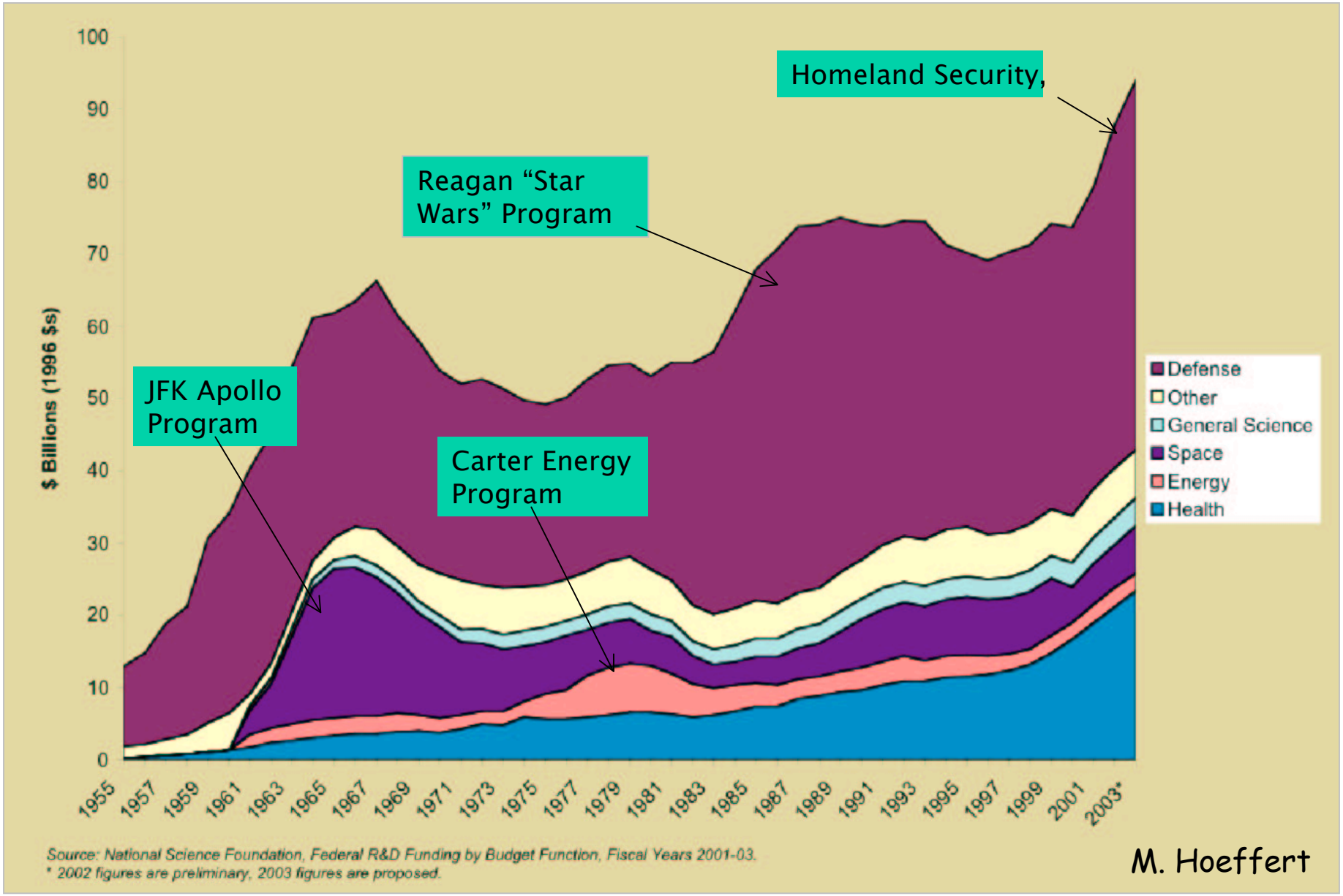


A vision of the Future



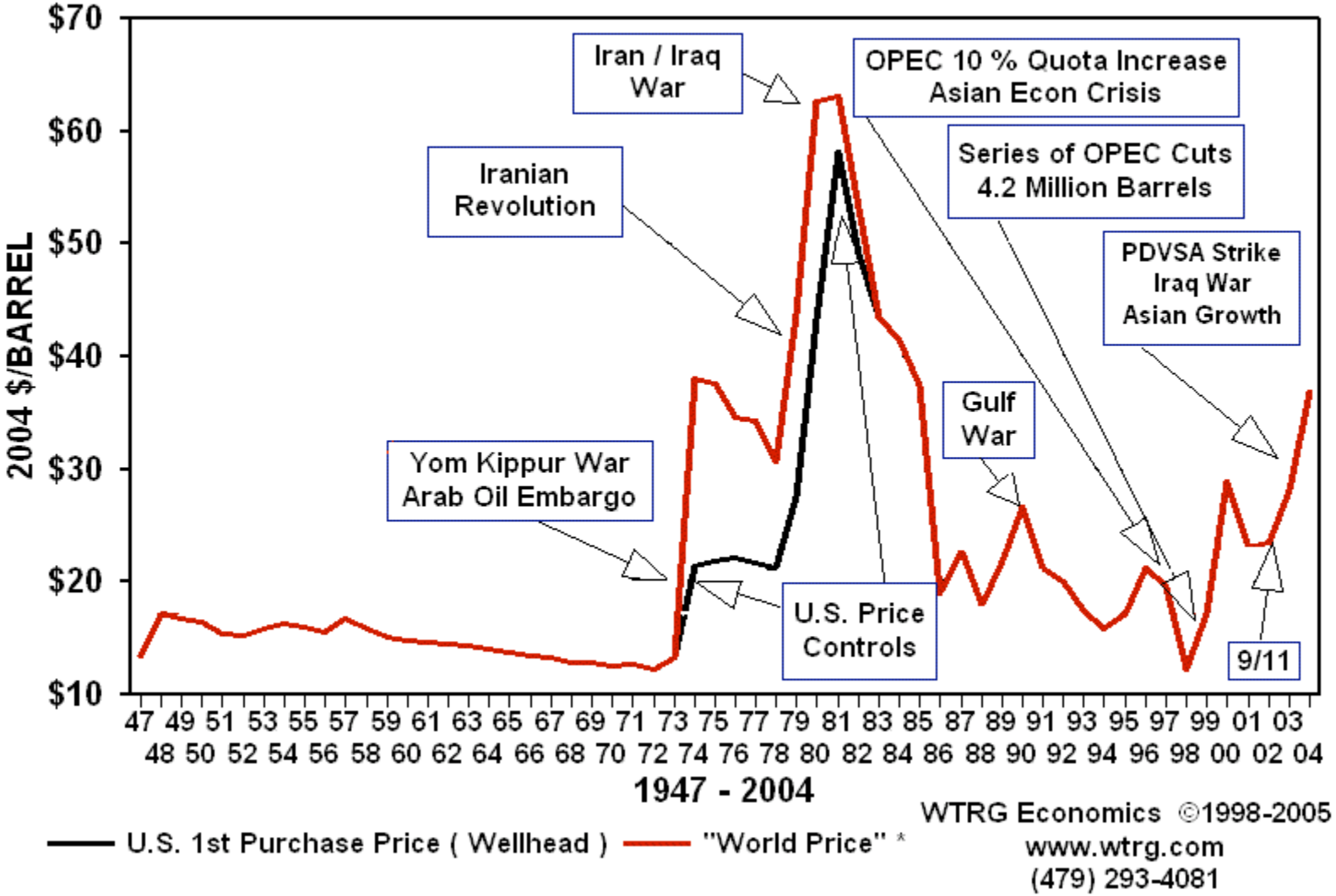
http://genomicsgtl.energy.gov/biofuels/index.shtml

HISTORY OF US FEDERAL GOVERNMENT R & D

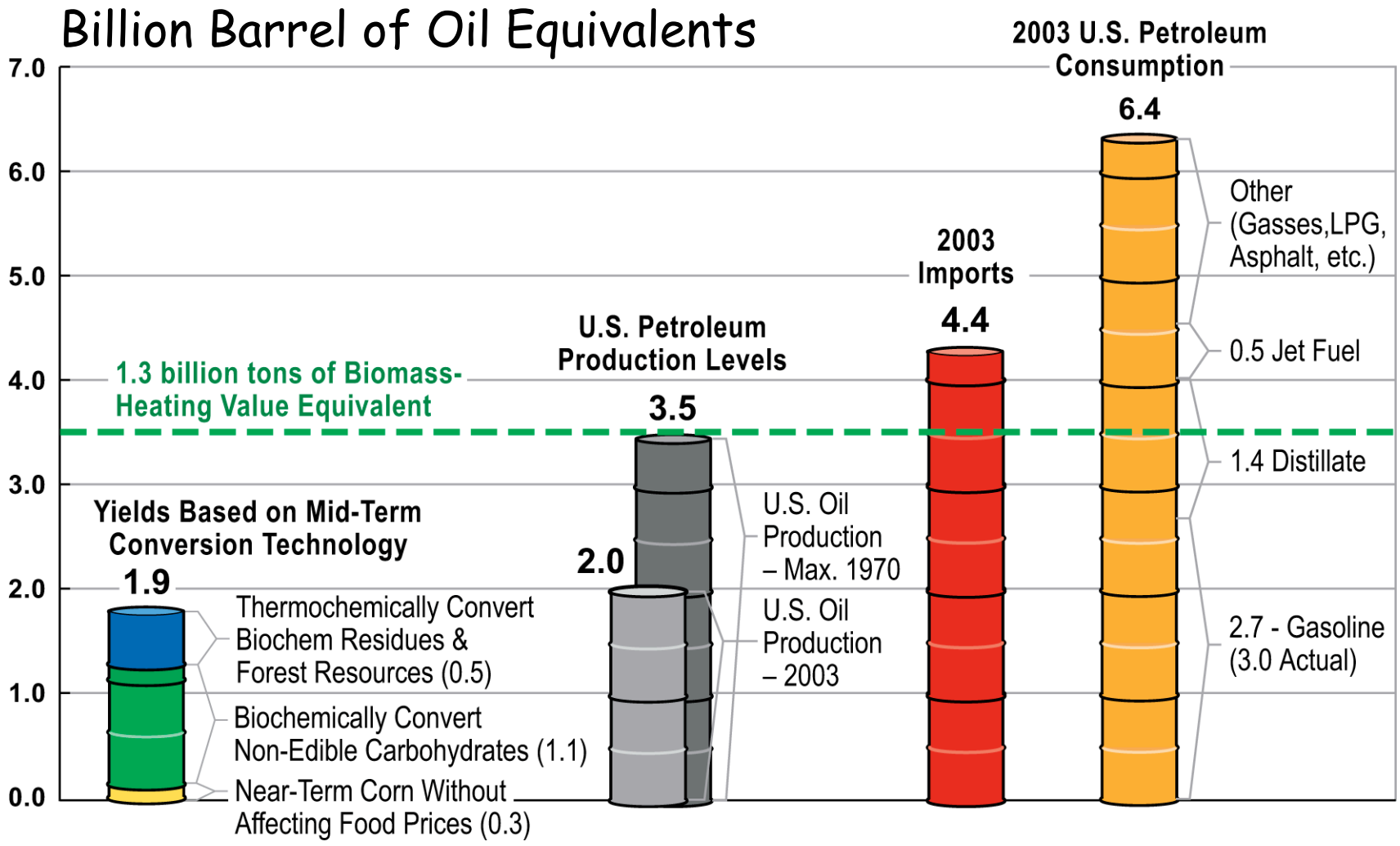


M. Hoeffert

Risks: Historical Price of Oil



The 1.3 Billion Ton Biomass Scenario



Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf