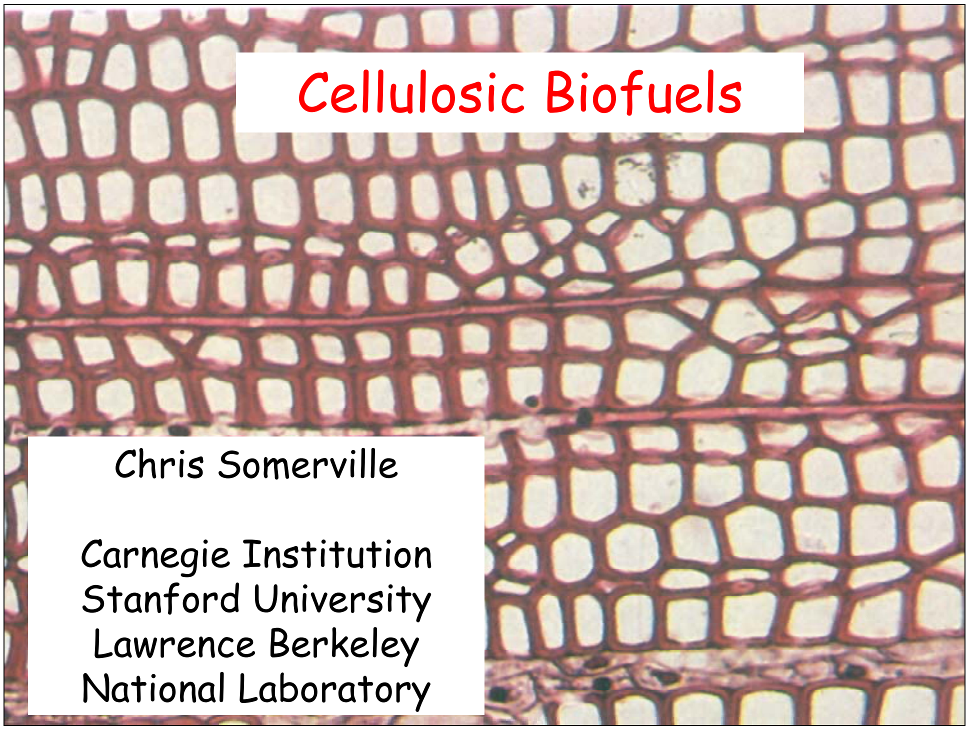
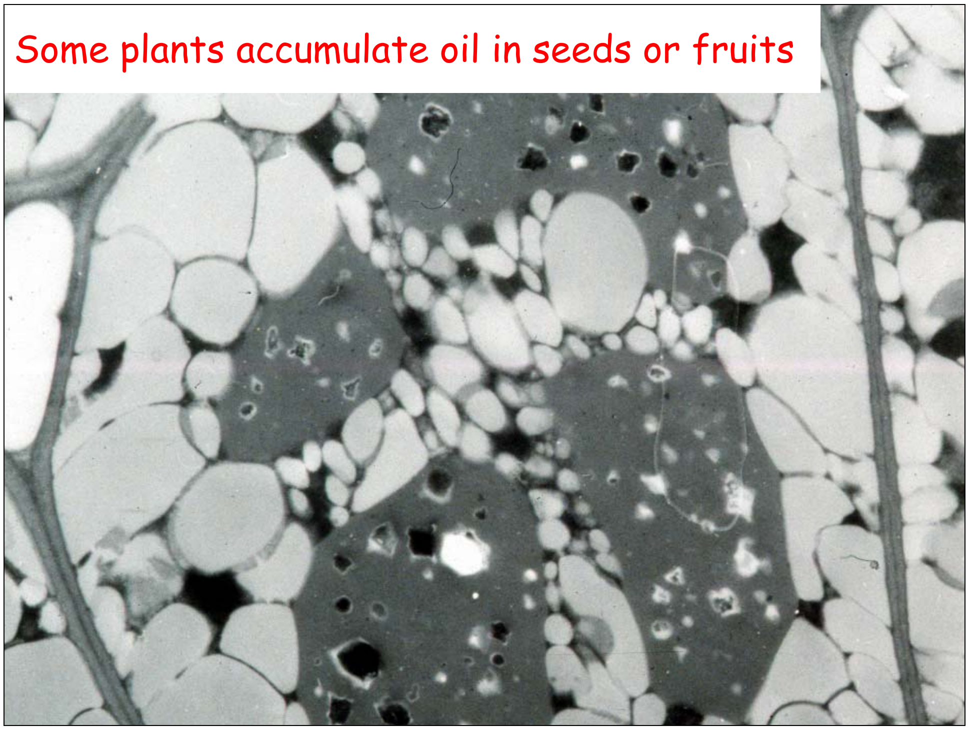
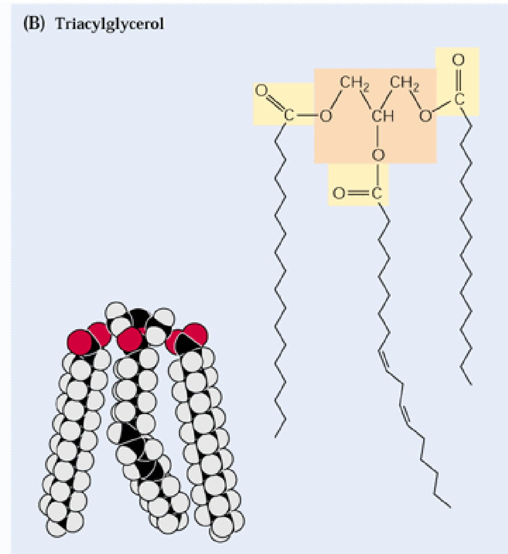

Cellulosic Biofuels
Chris Somerville
Carnegie Institution
Stanford University
Lawrence Berkeley
National Laboratory

Types of biofuels

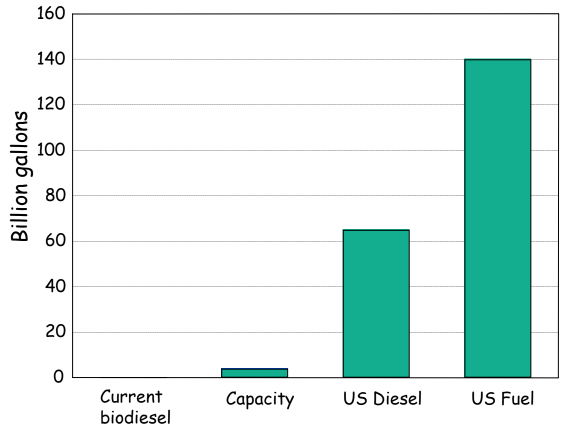
- Solid, burned directly
- Diesel
- Sugar to ethanol
- Cellulose to ethanol


Some plants accumulate oil in seeds or fruits

Plant oils are mostly triacylglycerol



Limited potential of biodiesel



65 biodiesel companies in operation
50 in construction 2006

Total us animal and plant fat production 31.7 billion pounds

7.75 pounds lipid per gallon

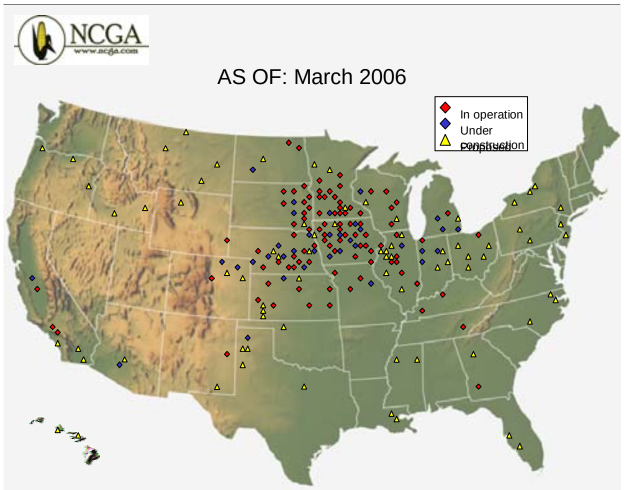
Numbers from congressional research service 2006 report on bioenergy

Oil palm is highly productive
(Best yields ~ 10 tonnes/HA)

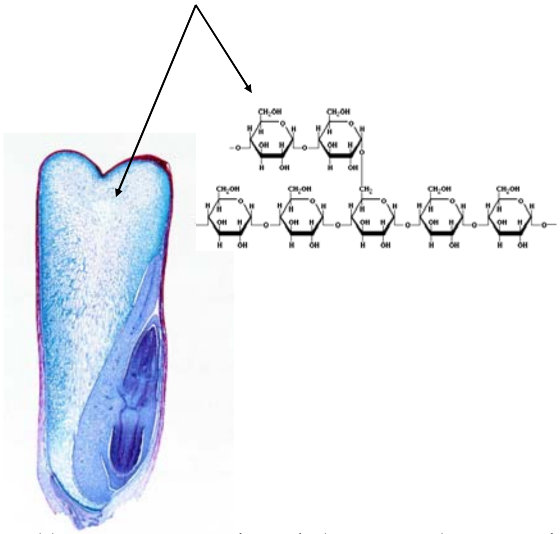
What about algae?

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

US Ethanol Plants

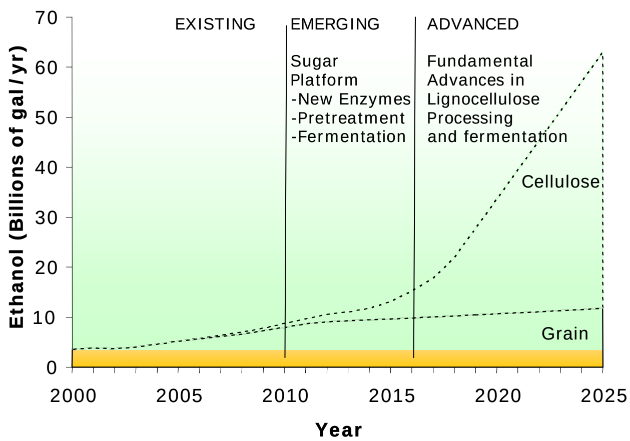


Corn seed is 65% starch



http://www.ucmp.berkeley.edu/monocots/corngrainls.jpg
http://www.scientificpsychic.com/fitness/carbohydrates1.html

A DOE Ethanol Vision



Modified from Richard Bain, NREL

Cindy:

The basis for these projections:

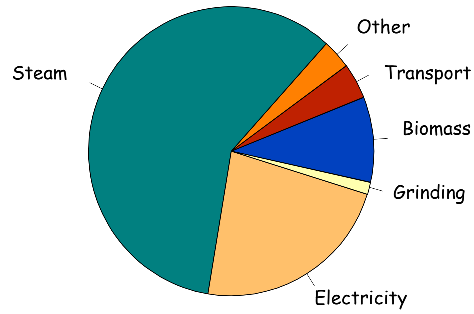
1. The renewable fuel standard demand is based on the US Senate version of the Energy Policy Act of 2002 (S. 517) Section 820, generally referred to as the Renewable Fuel Standard. The House version of the energy bill contains no such provision. Section 820 calls for a ramp up of ethanol use from 2004 to 20012, starting at 2.4 bgy in 04 and reaching 5 bgy in 2012. This corresponds to an increase of 300 to 400 million gal per yr each year.
2. In this analysis, I assume that the bulk of that ethanol will come from corn grain.
3. The analysis further assumes that, by 2005, new technology for utilizing corn fiber or some non starch components in grain will be implemented. These advanced technologies are assumed to add 10% to the yield of the grain ethanol operation.
4. From 2005 to 2012, I assume a linear increase in the adoption of this technology, with one facility starting up in 05, and all facilities adopting the advanced technology by 2012.
5. At the same time, the first stover ethanol plant is assumed to come on line at a capacity of 70 MM gal per year. The number of stover plants doubles each year for the first four years, and then takes on a linear growth rate.
6. In 2015 the first advanced ethanol technology kicks in, with a similar doubling in the number of plants for the first few years, followed by a linear growth of switchgrass and corn stover facilities..
7. In 2025, utilization of switchgrass and stover supplies reaches about half of Marie Walsh's estimates for total biomass supply.

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

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

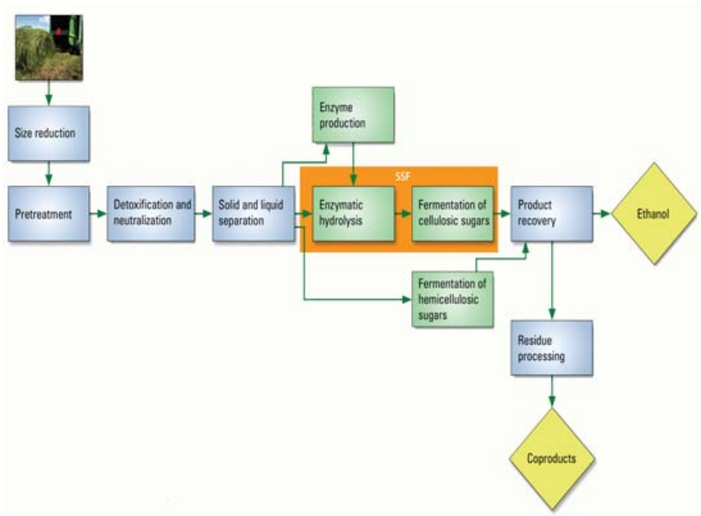
The challenge is efficient conversion



Energy consumption

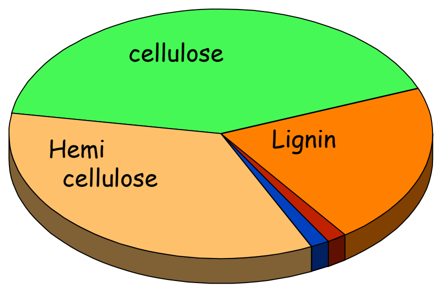
*Pimentel & Patzek
Nat Res Res 14,65 (2005)

Steps in cellulosic ethanol production

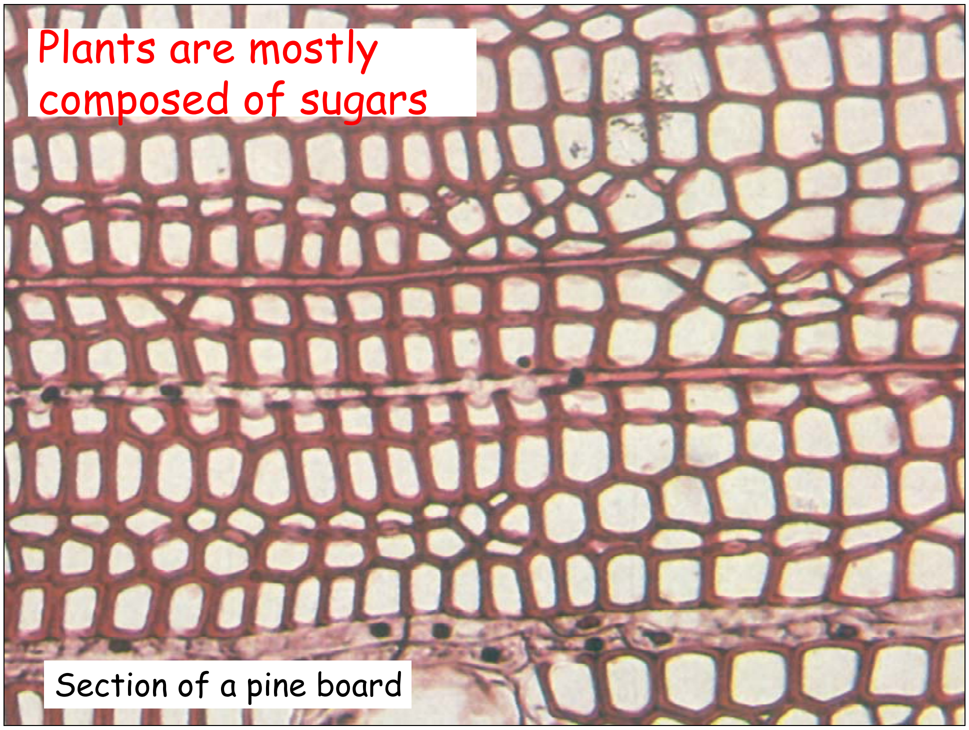


From: Breaking the Biological Barriers to Cellulosic Ethanol

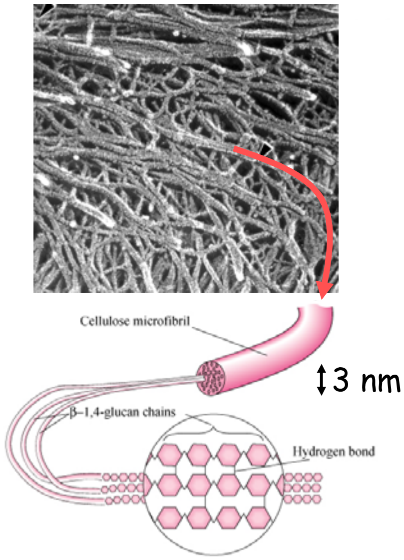
Three major components of biomass



Typical grass composition

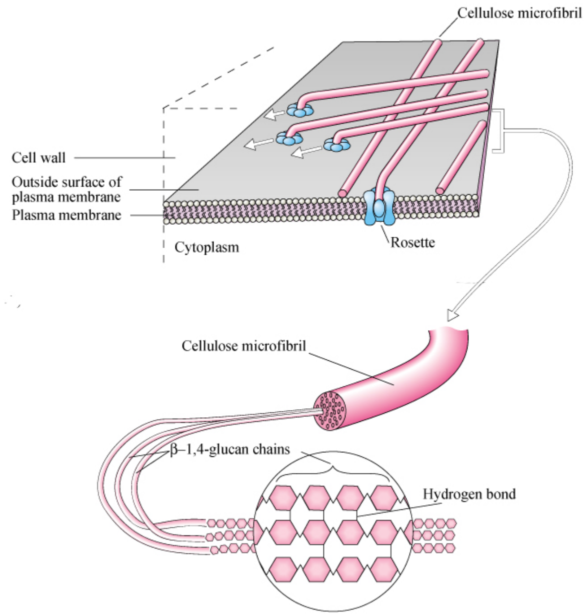

Plants are mostly composed of sugars
Section of a pine board

Plants are mostly composed of sugars

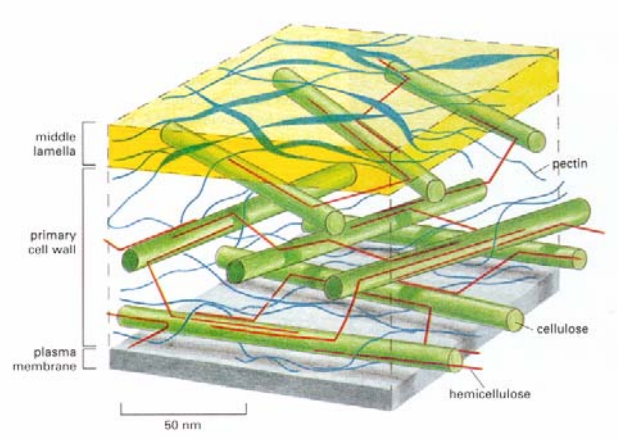


Polymerized glucose

Cellulose is synthesized at the plasma membrane

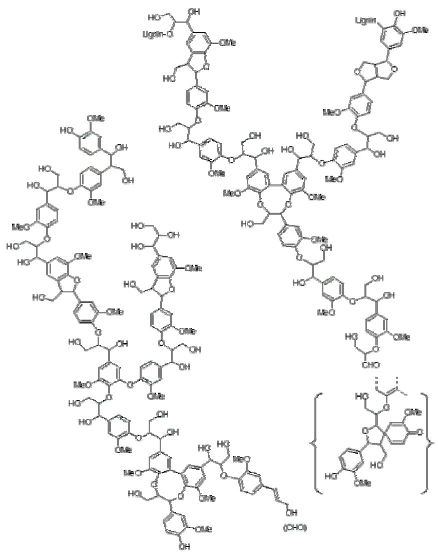


Model of the cellulose/hemicellulose and pectic cell wall networks

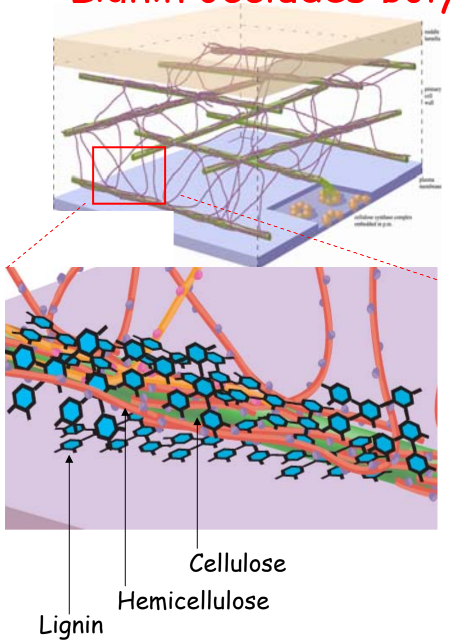


McCann & Roberts (1991) *The Cytoskeletal Basis of Plant Growth and Form*, p. 126

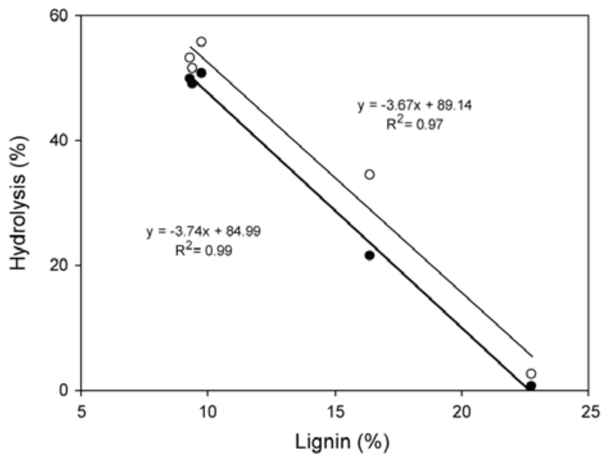
Structure of lignin



Lignin occludes polysaccharides

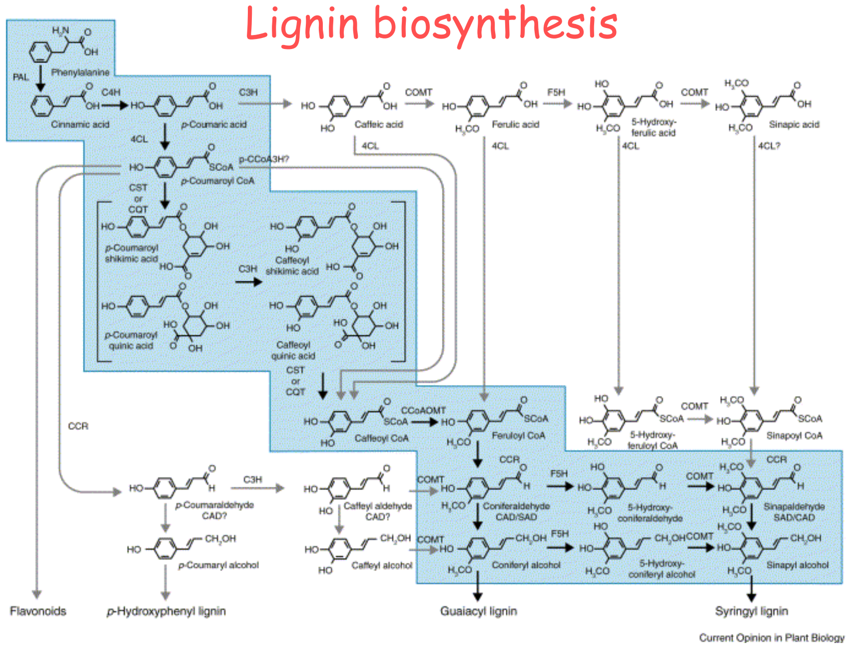


Effect of lignin content on enzymatic recovery of sugars from Miscanthus



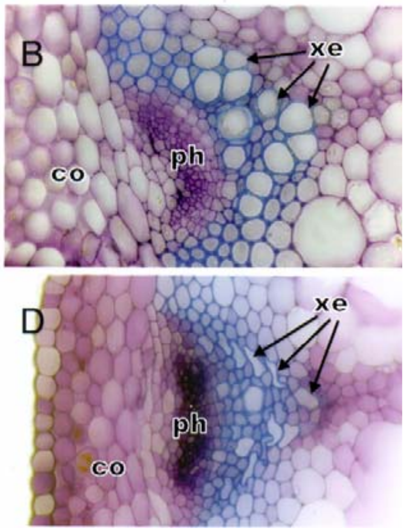
D Vrije et al (2002) Int J Hydrogen Energy 27,1381

Lignin biosynthesis



Humphreys and Chapple, Curr Opin Plant Biol 5,224

Lignin-deficient mutants have weak tissues

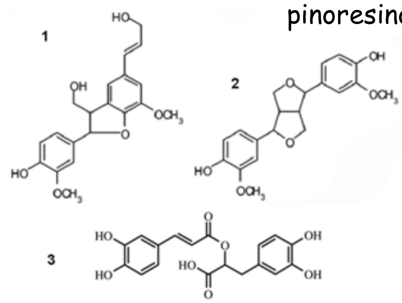


Turner and Somerville Plant Cell 9,689

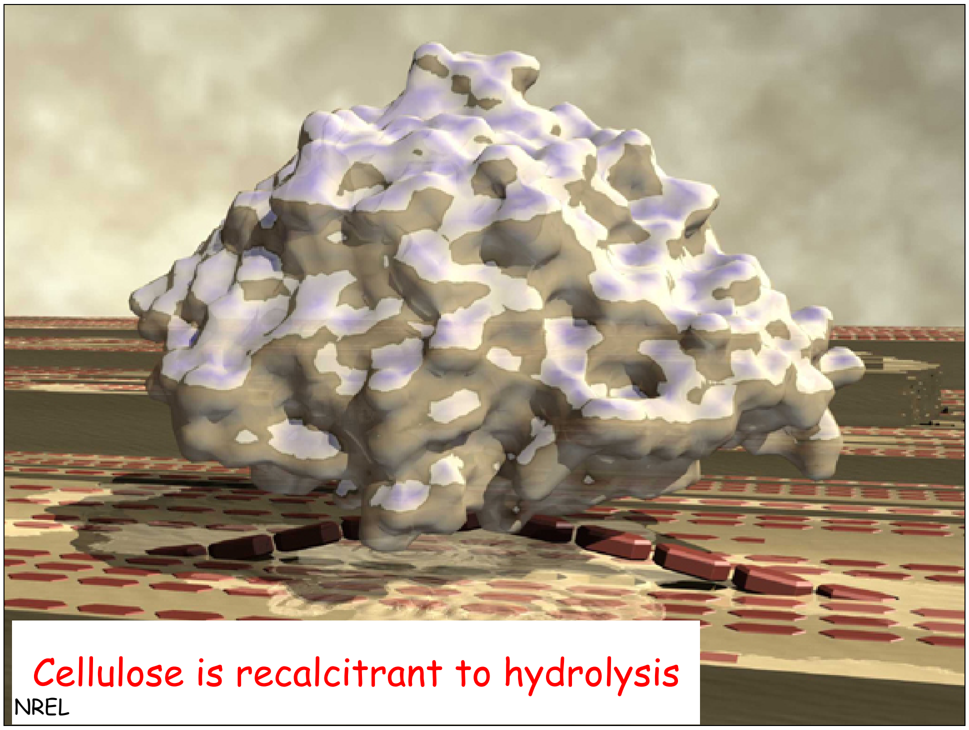
A cleavable lignin precursor would fundamentally alter preprocessing

dehydrodiconiferyl alcohol

pinoresinol



rosmarinic acid


Cellulose is recalcitrant to hydrolysis
NREL

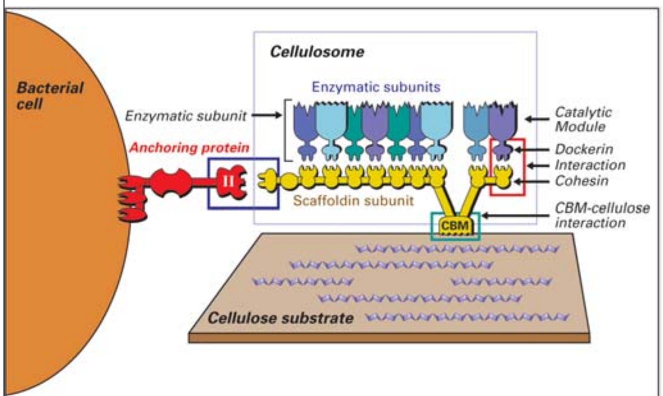
Possible routes to improved catalysts

- Explore the enzyme systems used by termites (and ruminants) for digesting lignocellulosic material
- Compost heaps and forest floors are poorly explored

Possible routes to improved catalysts

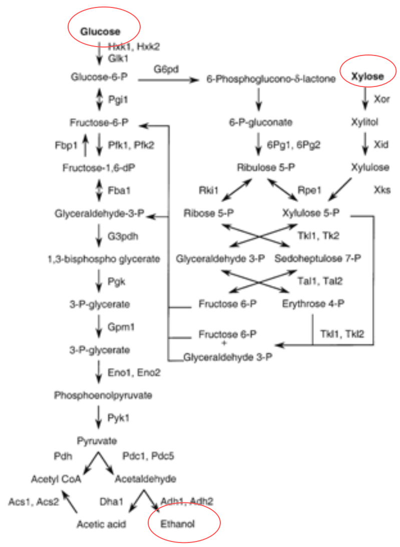
- In vitro protein engineering of promising enzymes
- Develop synthetic organic catalysts (for polysaccharides and lignin)

Some cellulytic enzymes are components of a "molecular machine"



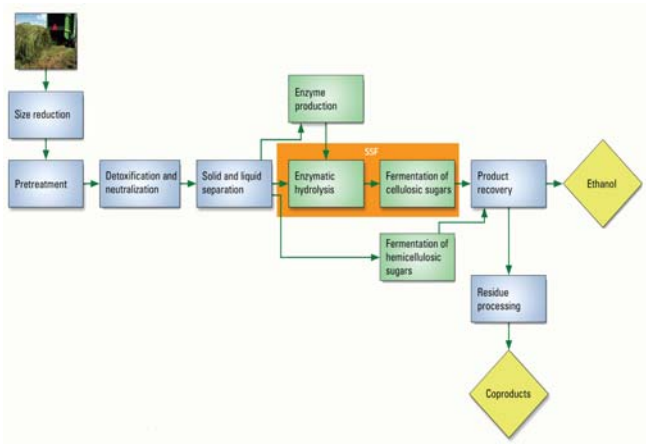
From: Breaking the Biological Barriers to Cellulosic Ethanol

Fermentation of all sugars is essential



Jeffries & Shi Adv Bioch Eng 65,118

Steps in cellulosic ethanol production

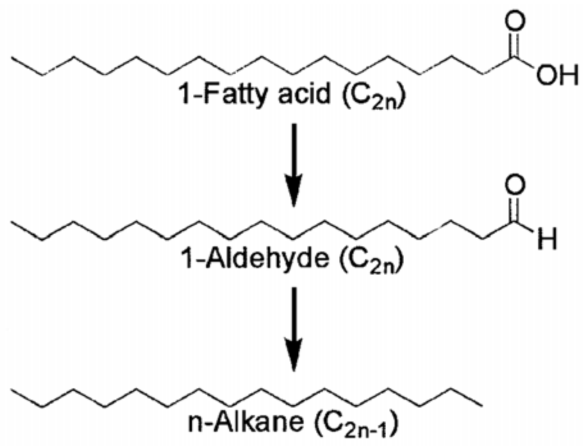


From: Breaking the Biological Barriers to Cellulosic Ethanol

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

Many organisms make alkanes



Summary of priorities

- Modify plant composition to minimize energy required for depolymerization
- Identify or create more active catalysts for conversion of biomass to sugars

Summary of priorities

- Develop industrial microorganisms that ferment all sugars
- Develop new types of microorganisms that produce and secrete hydrophobic compounds

Questions

- How challenging are the technical problems?
- What is the timeframe for development of cost-competitive cellulosic fuels?
- Why not other technologies such as solar, wind, photovoltaics?
- Are there risks?