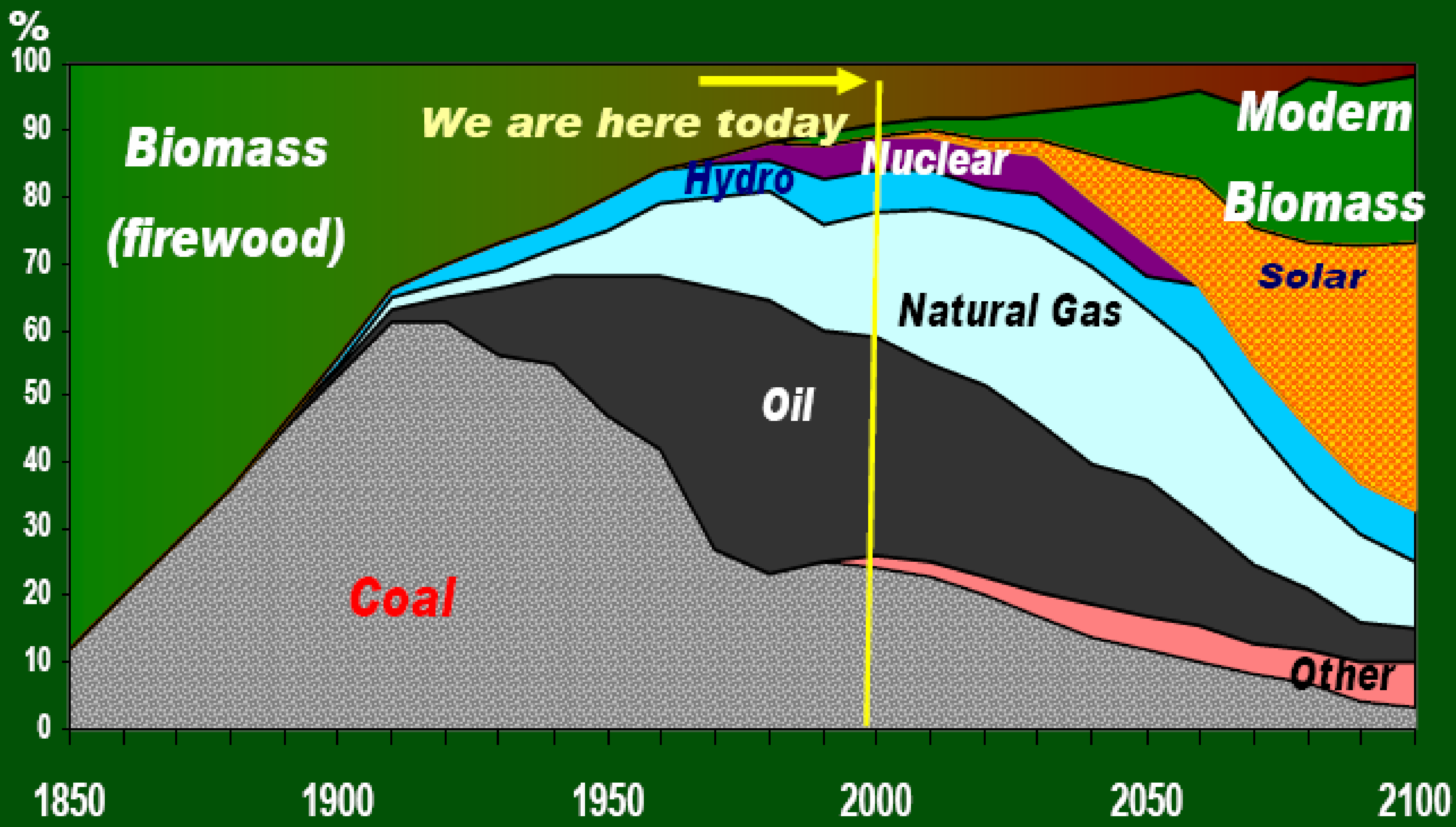
Technologies and Challenges of Competitive Cellulosic Ethanol Production

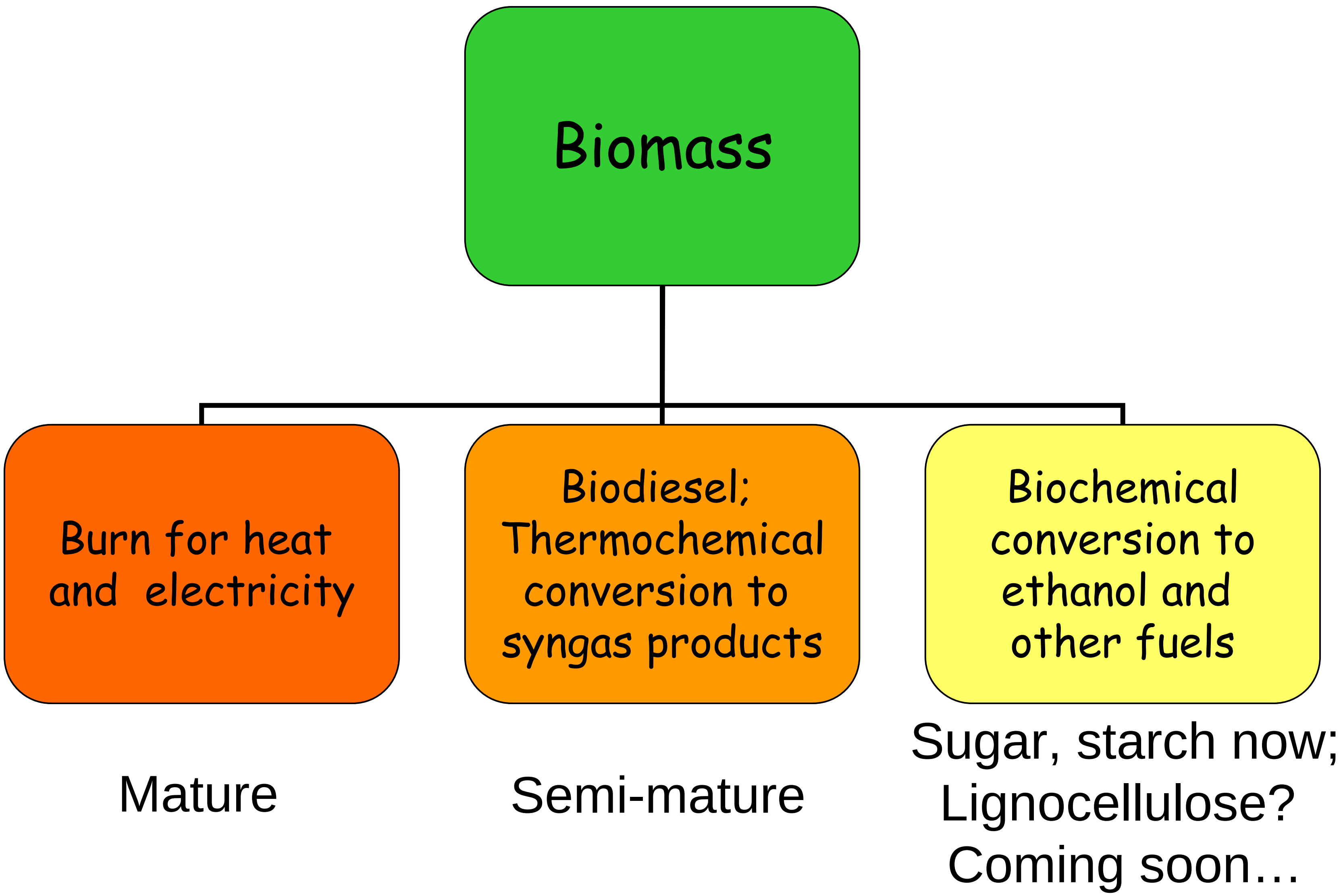
Tom Richard
Penn State University
www.bioenergy.psu.edu

The Beginning of a New Era

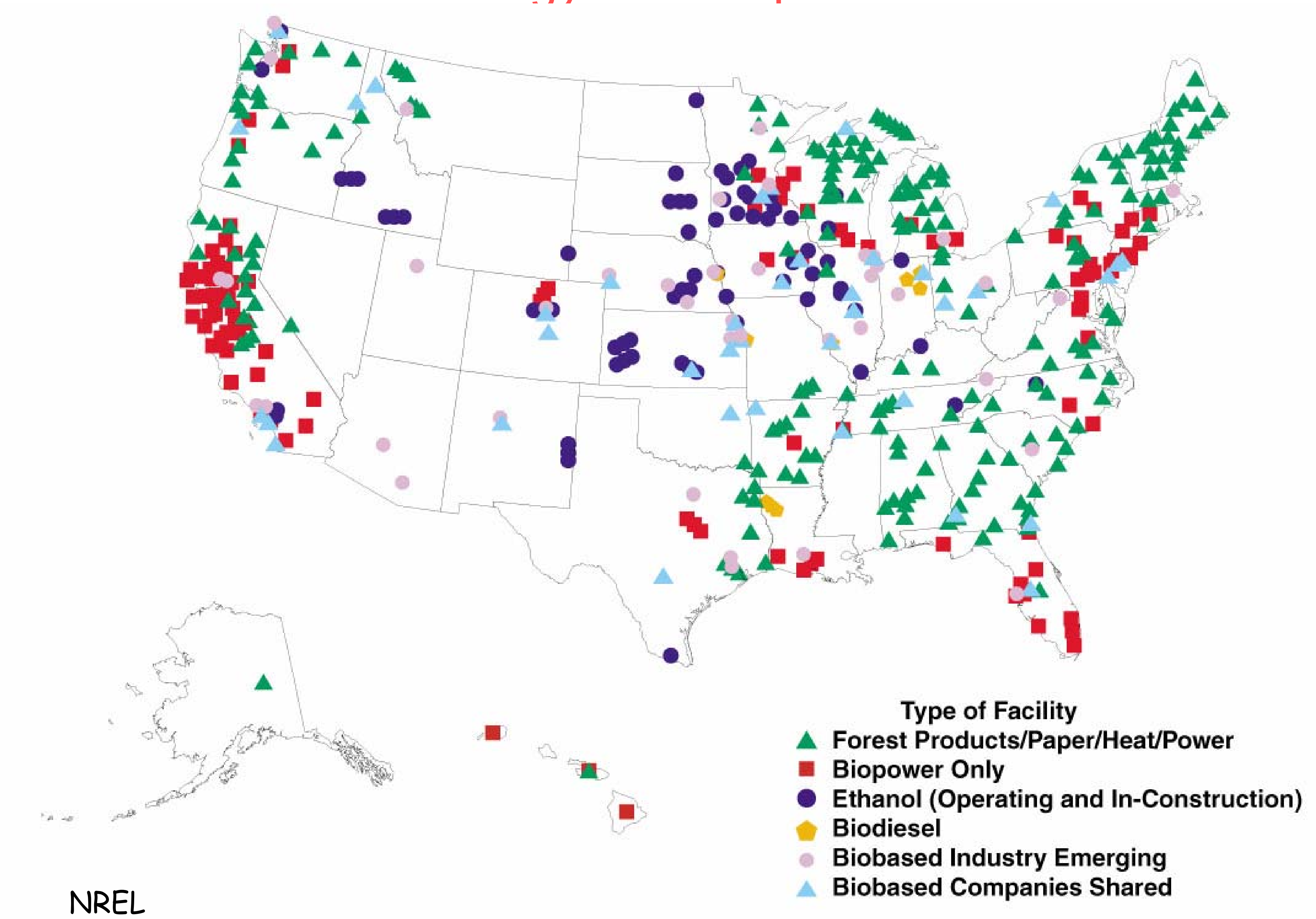


Source: Nakícenovic, Grübler and McDonald, 1998
World Energy Council

Biomass Energy Alternatives

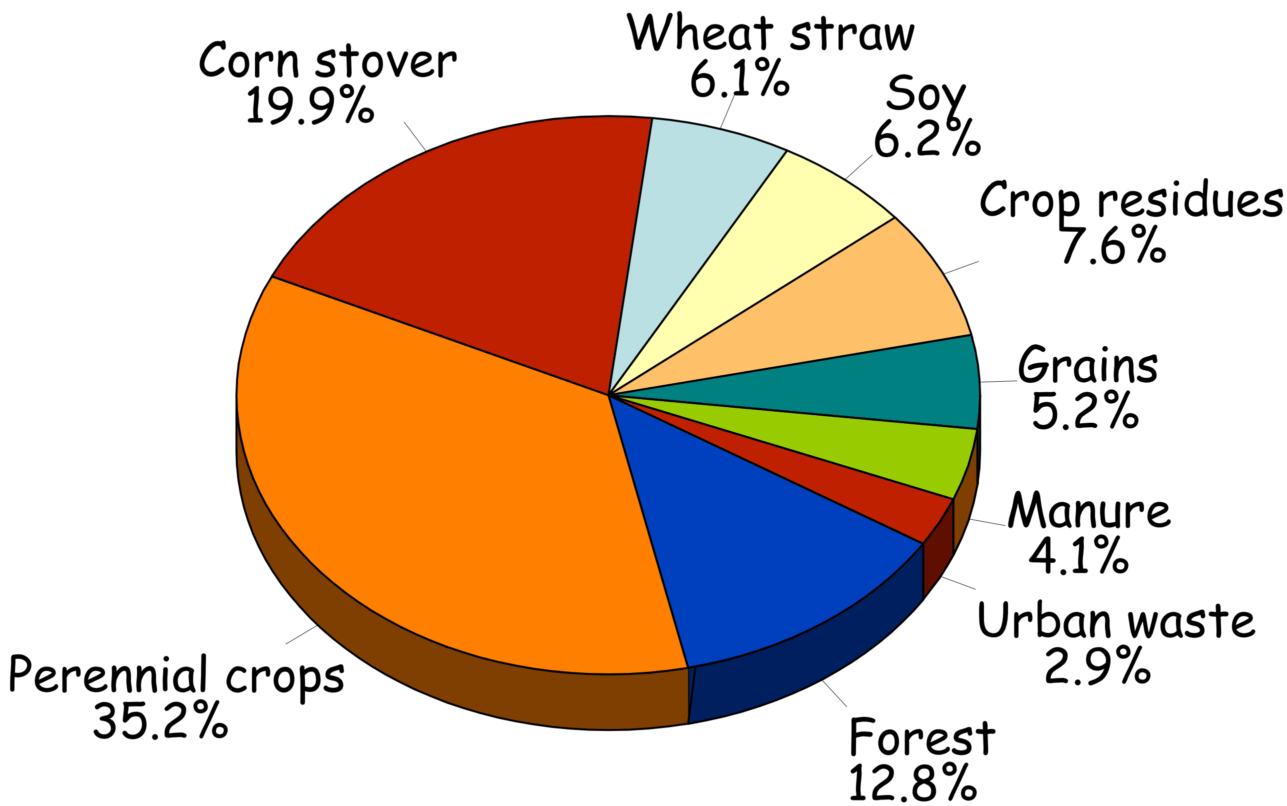


Current Bioenergy and Bioproduct Facilities

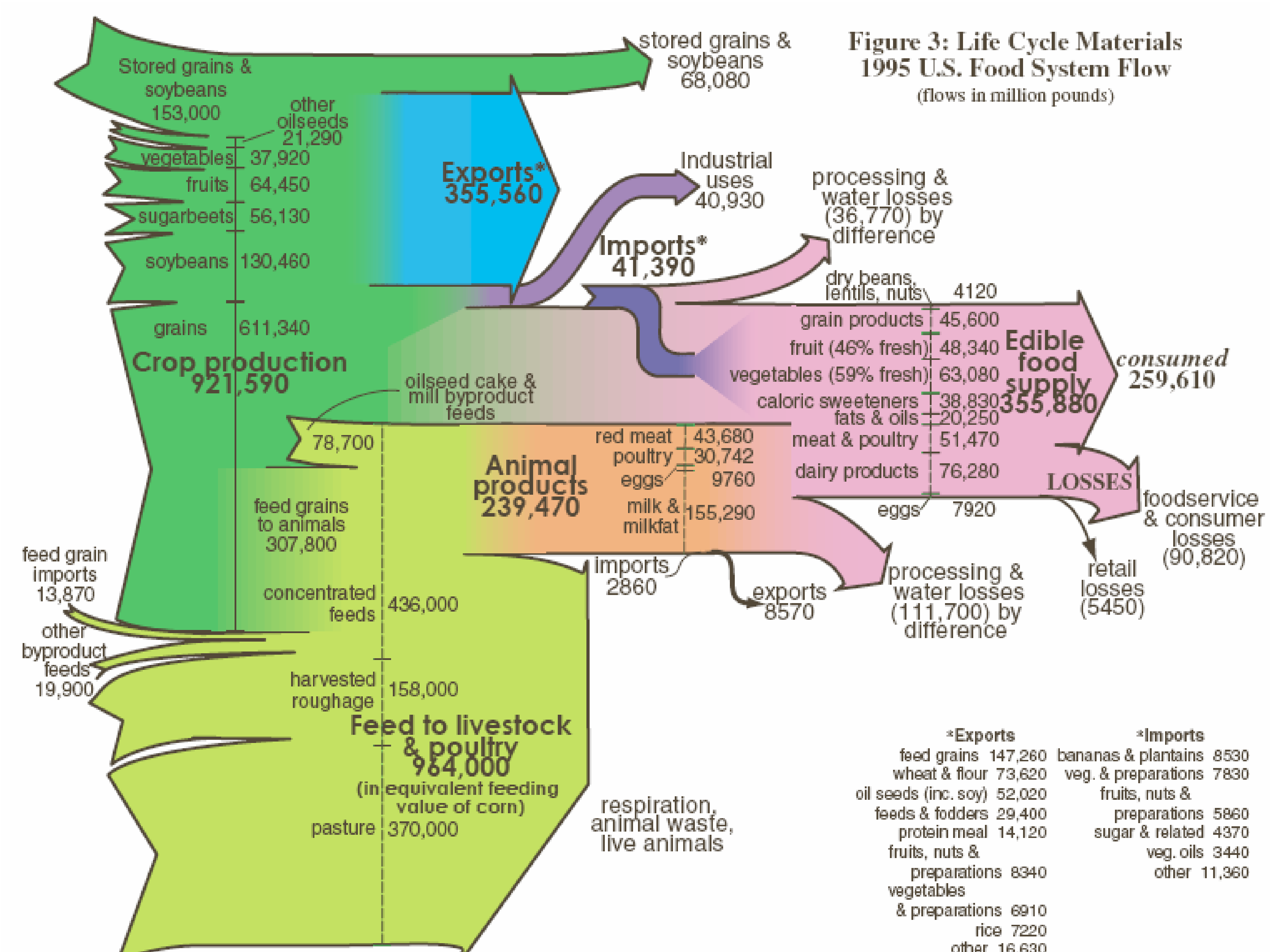


NREL

US Biomass inventory = 1.3 billion tons

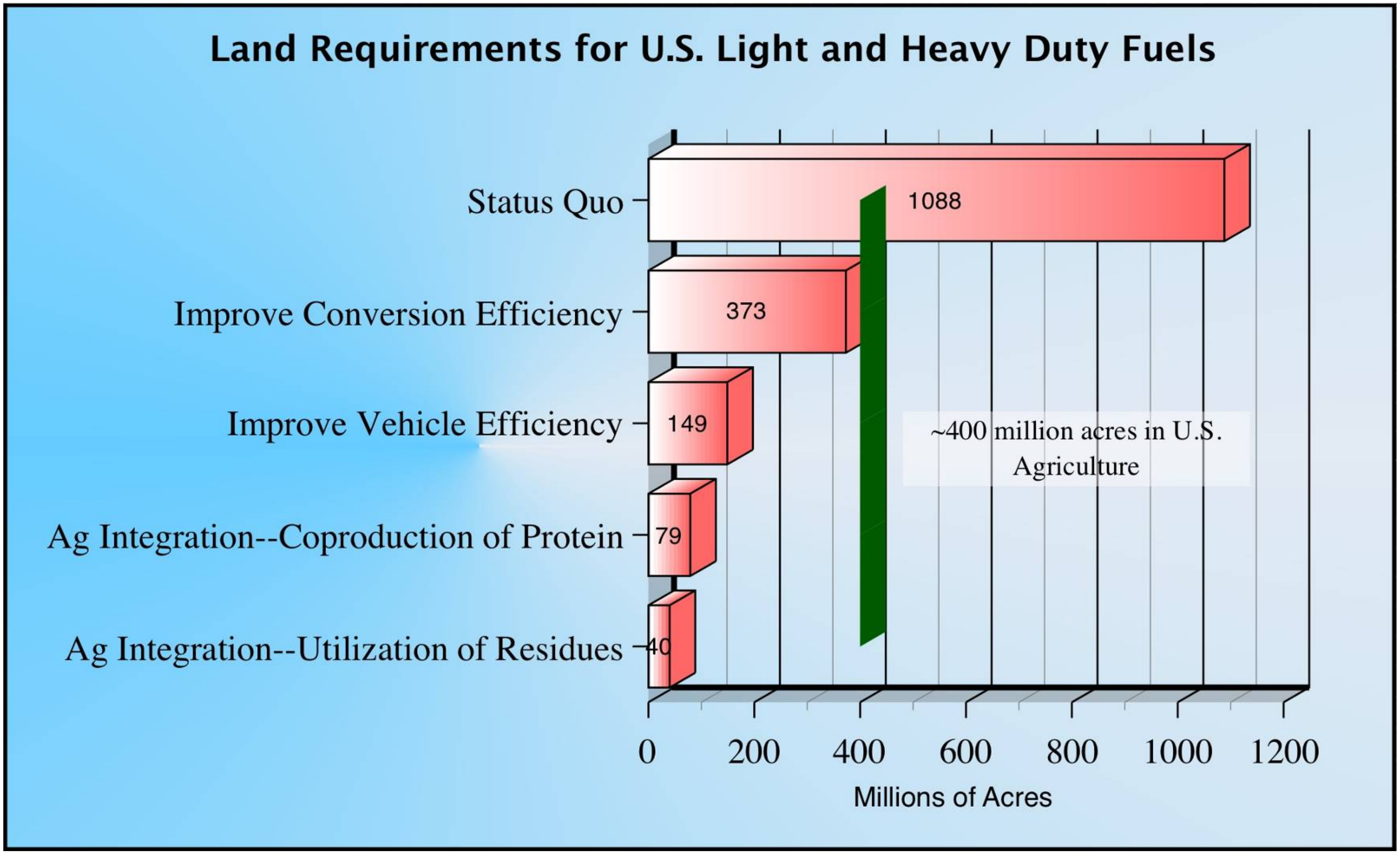


From: Billion ton Vision, DOE & USDA 2005 (projections to 2030)



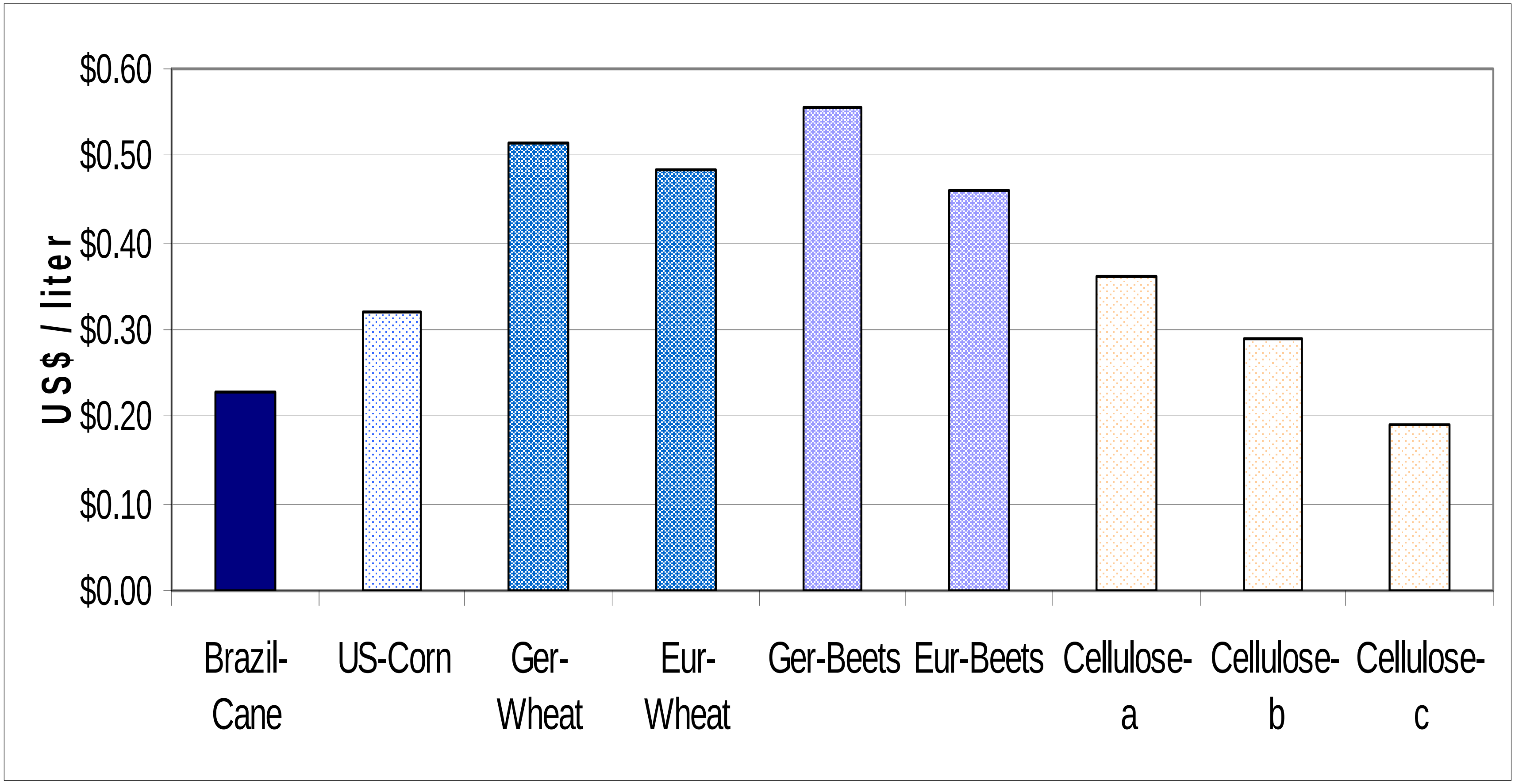
Heller and Keoleian, U. Michigan, 2000

What else can we do?



Sheehan 2004

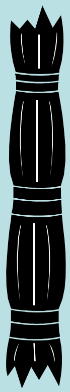
Comparative production costs



Source: Compiled by Brewer from data in IEA, 2004

Ethanol Production Today

BRAZIL



sugarcane

(sucrose) → extract → Sugars → ferment → **ethanol**

USA

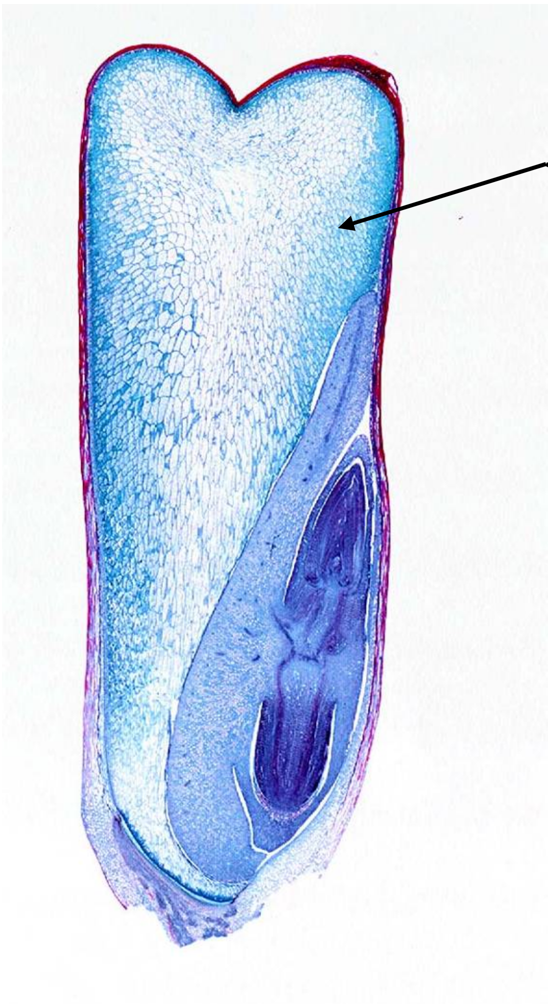
(starch) → Hydrolyze (enzymes) → Sugars → ferment → **ethanol**

Brazil and the US are the leaders in ethanol fuel production

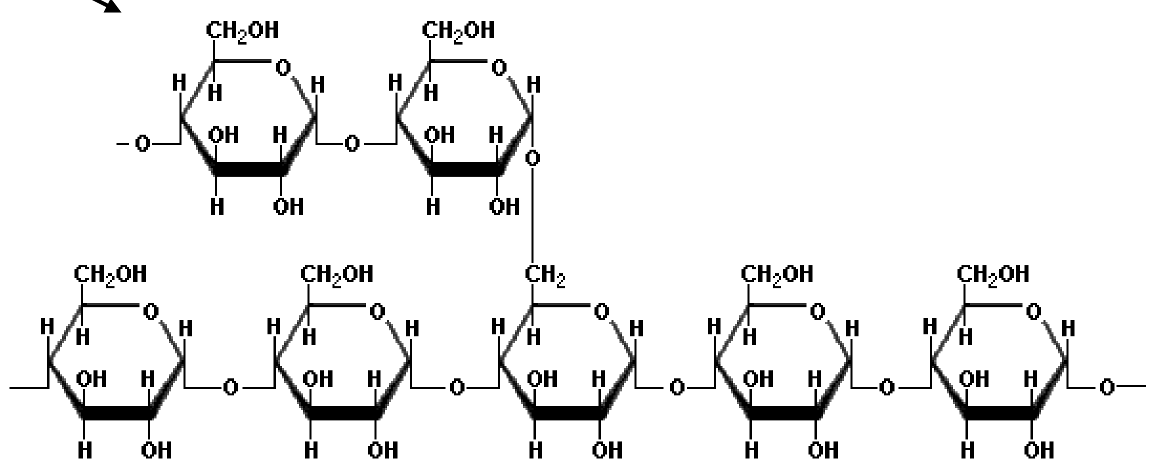
They use the "easy way" to make ethanol.

Cosgrove, 2006

Chemical structure of starch



STARCH

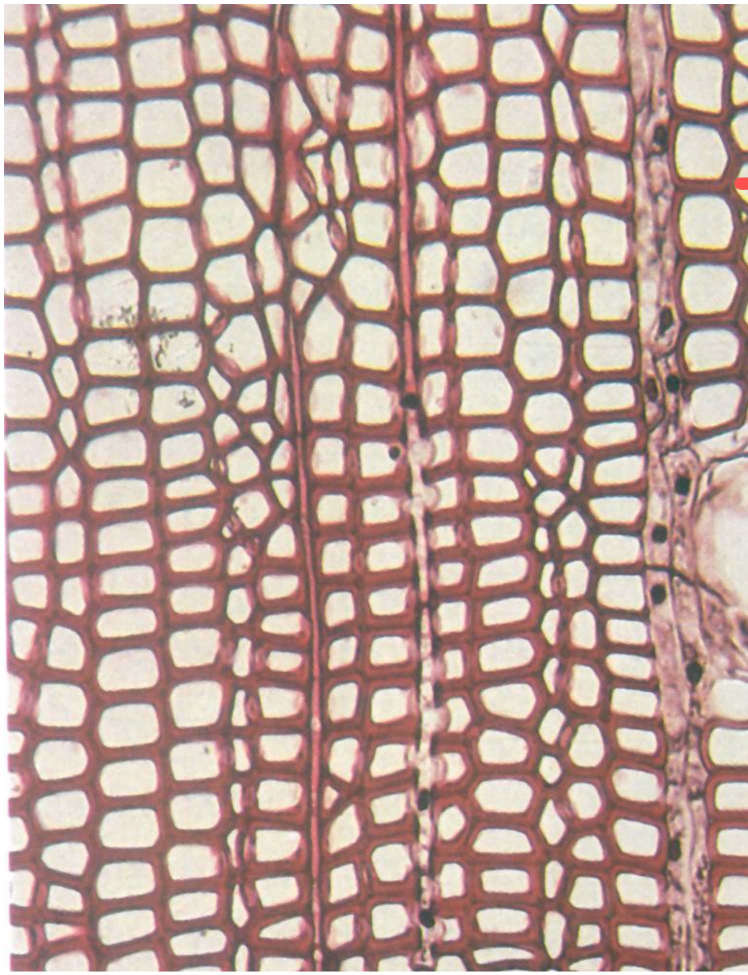


http://www.ucmp.berkeley.edu/monocots/corngrainls.jpg

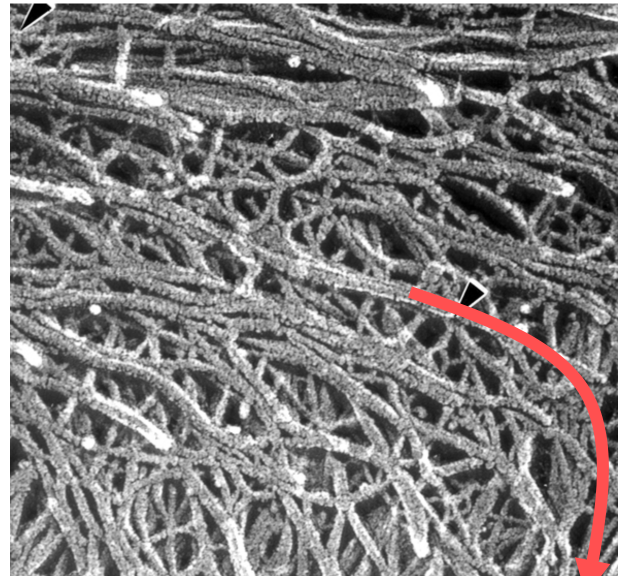
http://www.scientificpsychic.com/fitness/carbohydrates1.html

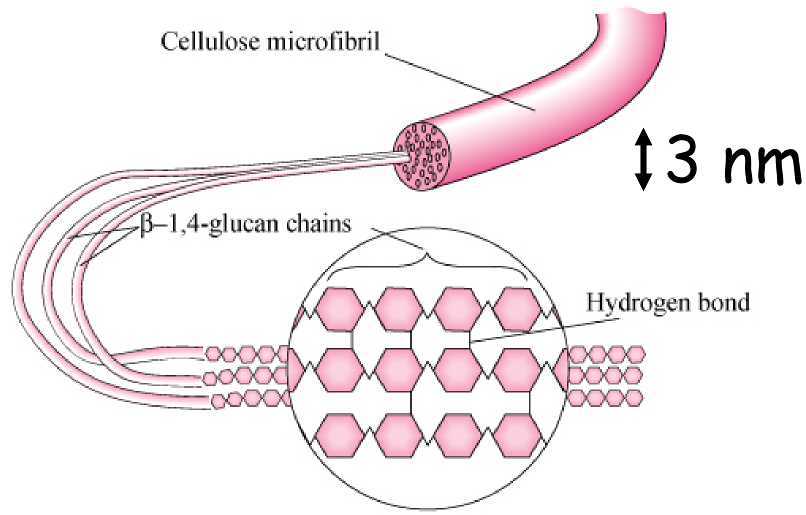
The rest of the plant is mostly sugar too!

Section of a pine board



Somerville, 2006





Polymerized glucose

Cell walls → fuel

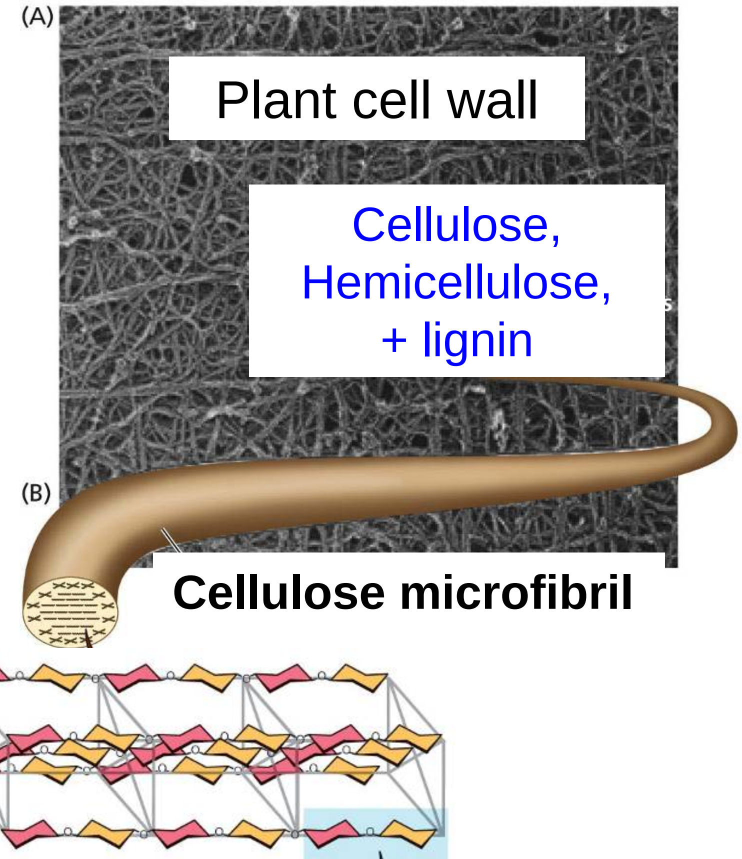
Slow & expensive step

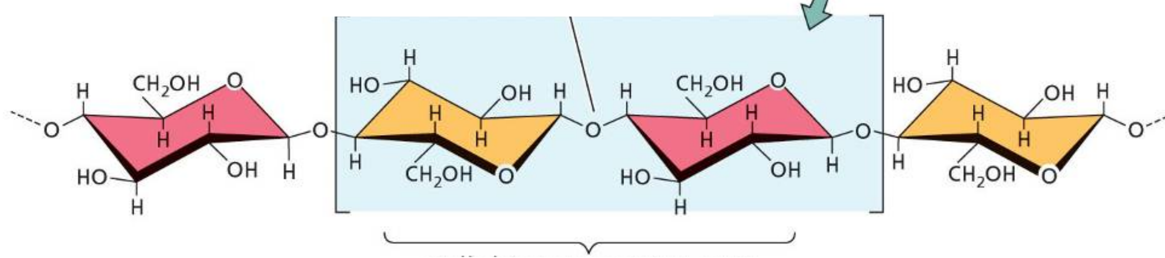
"*recalcitrance*"

sugars ← enzyme digestion ← chemical pretreatments

Fermentation

ethanol

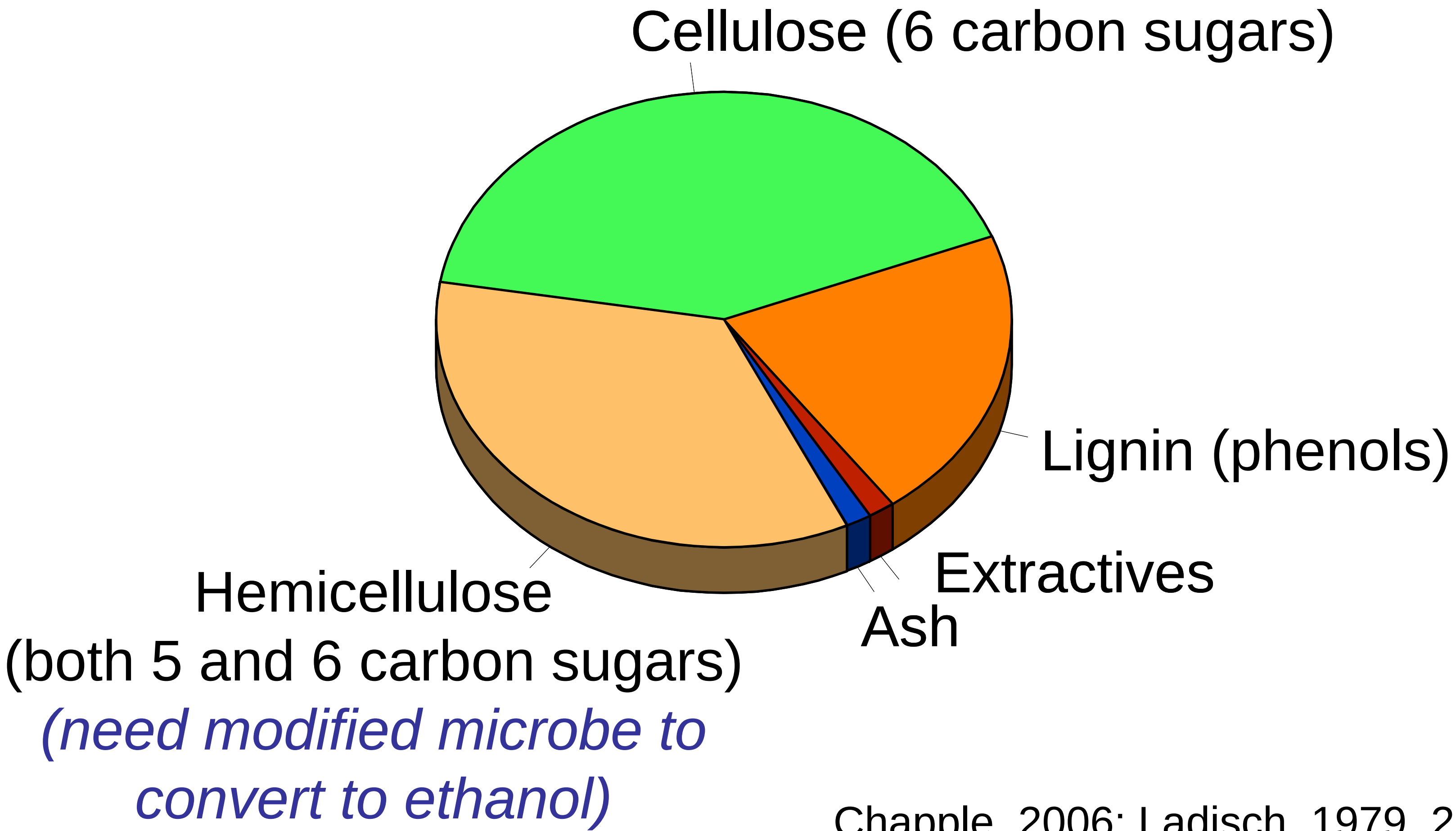




Parallel strands of glucose polymers

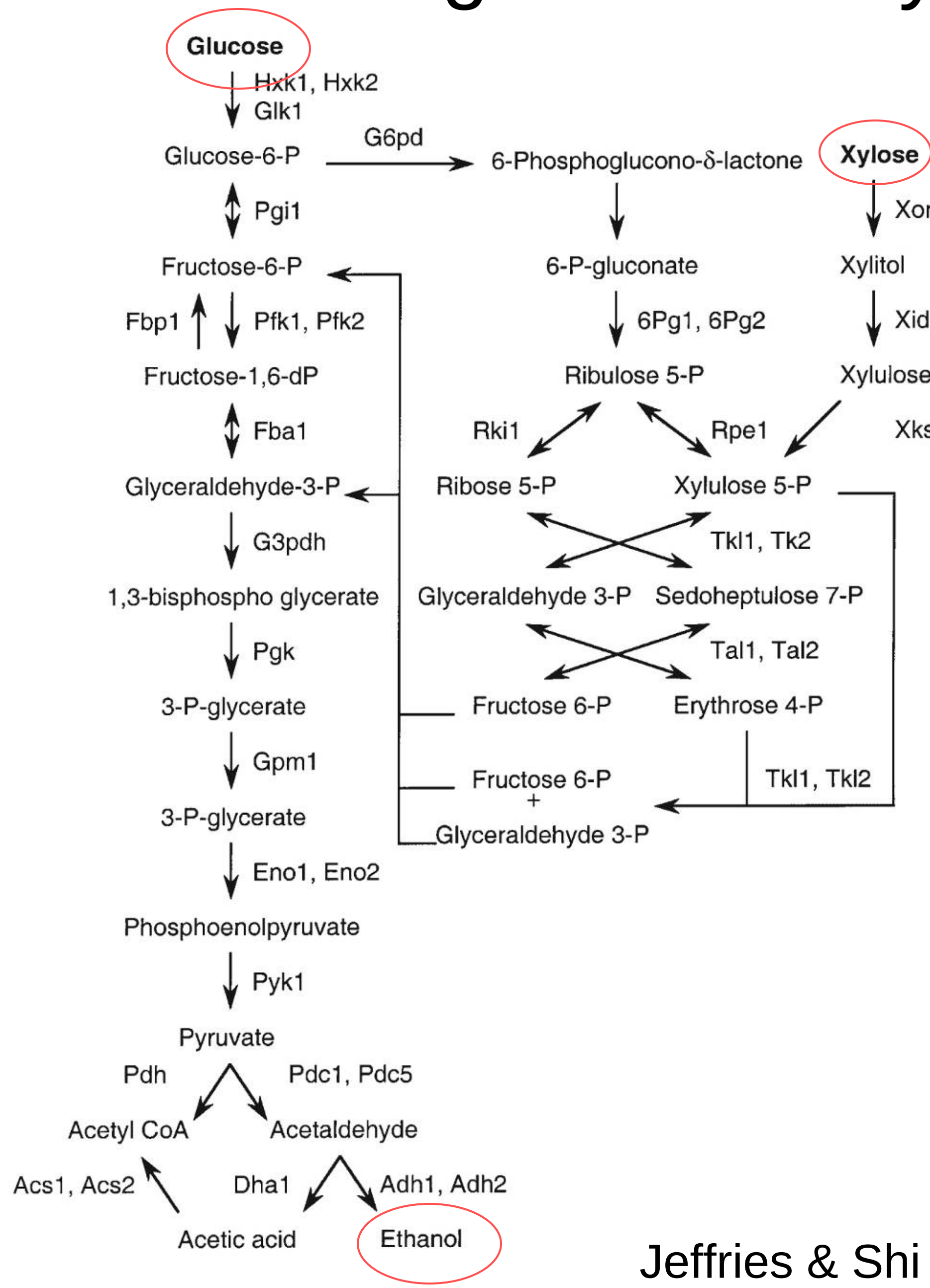
Cosgrove, 2006

Components of plant cell walls



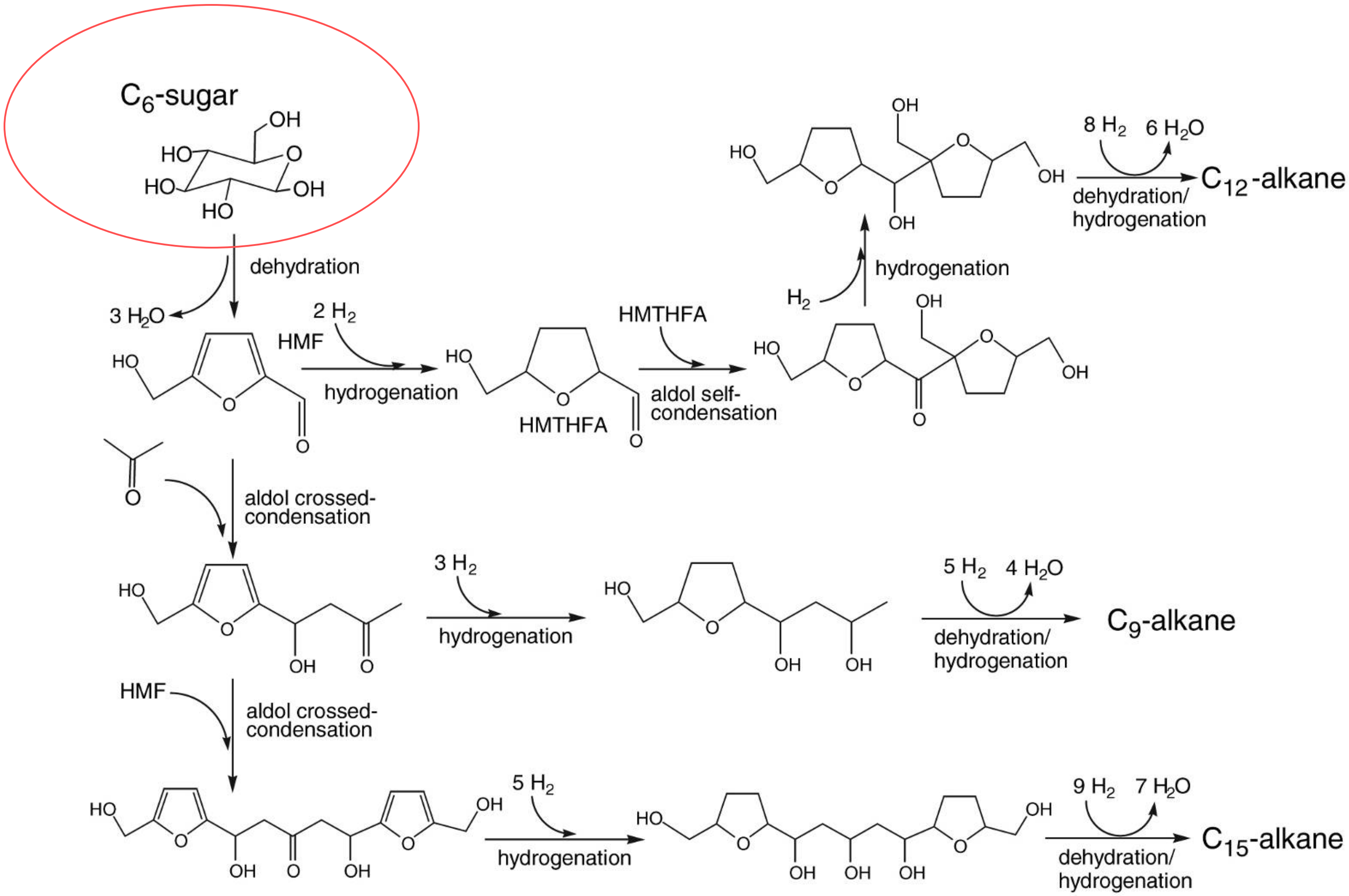
Chapple, 2006; Ladisch, 1979, 2006

Ethanol from glucose or xylose



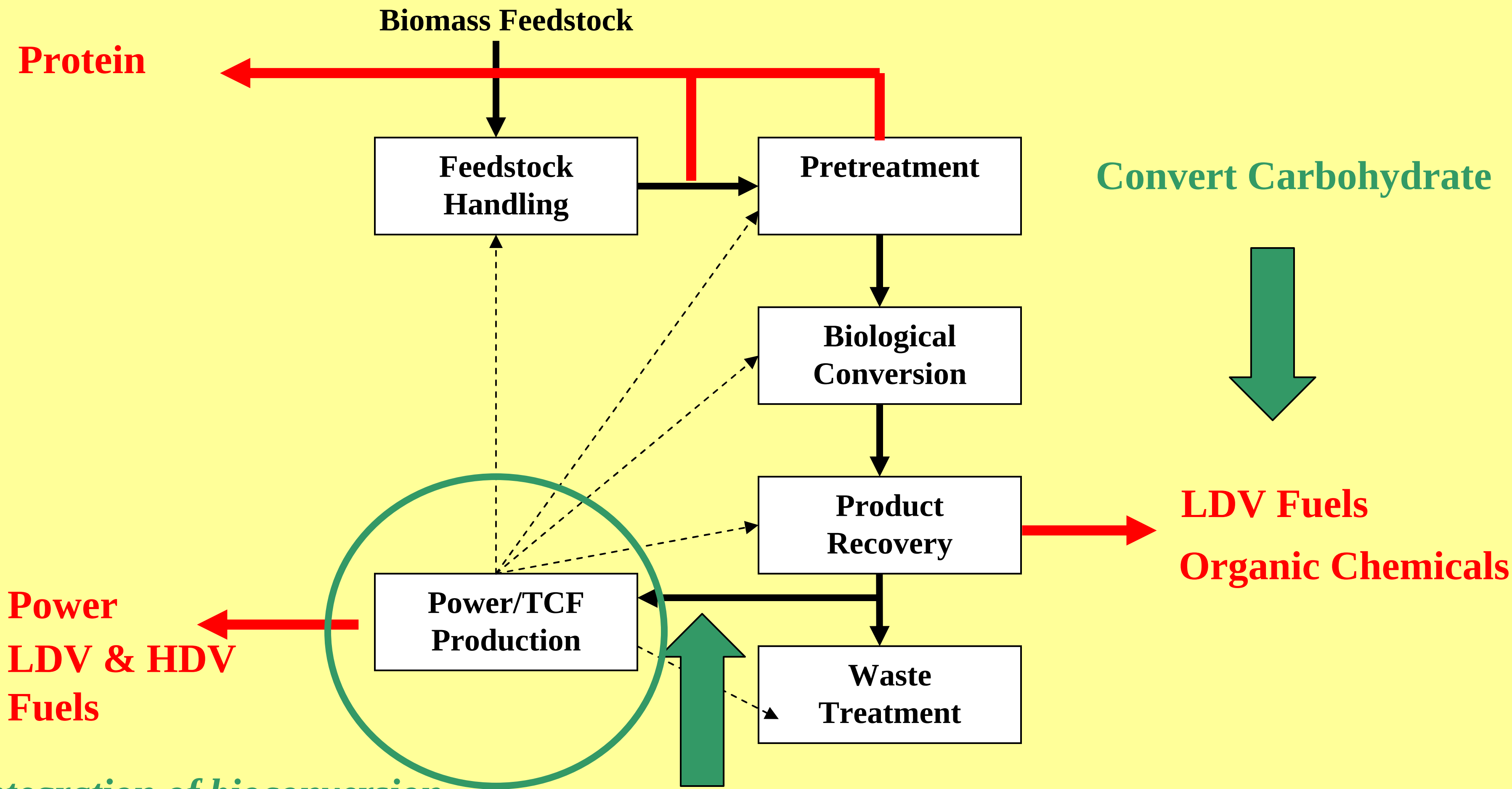
Jeffries & Shi Adv. Bioch Eng 65,118

Conversion of sugar to alkanes



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

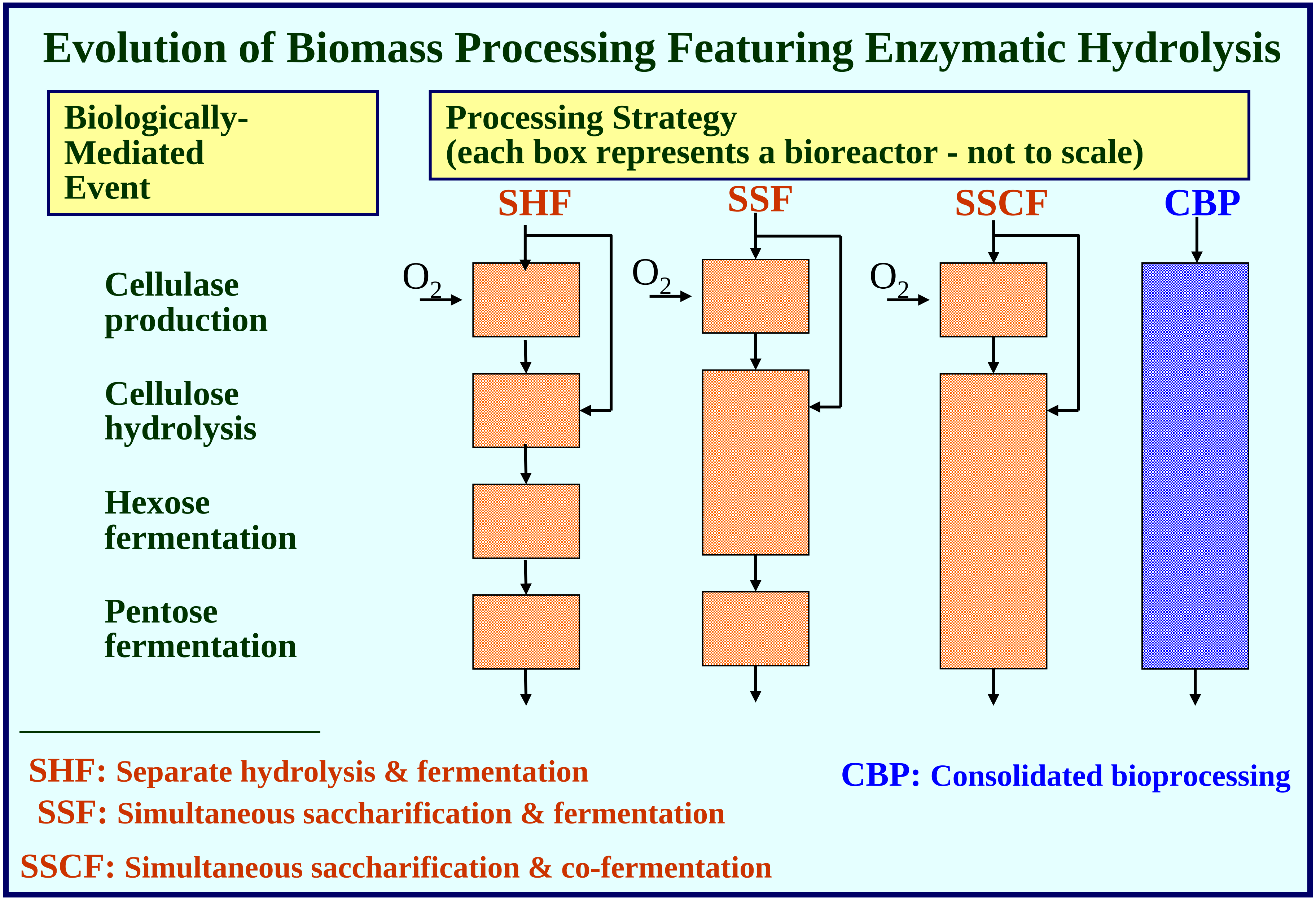
Bioconversion Platform



Integration of bioconversion and thermochemical platforms

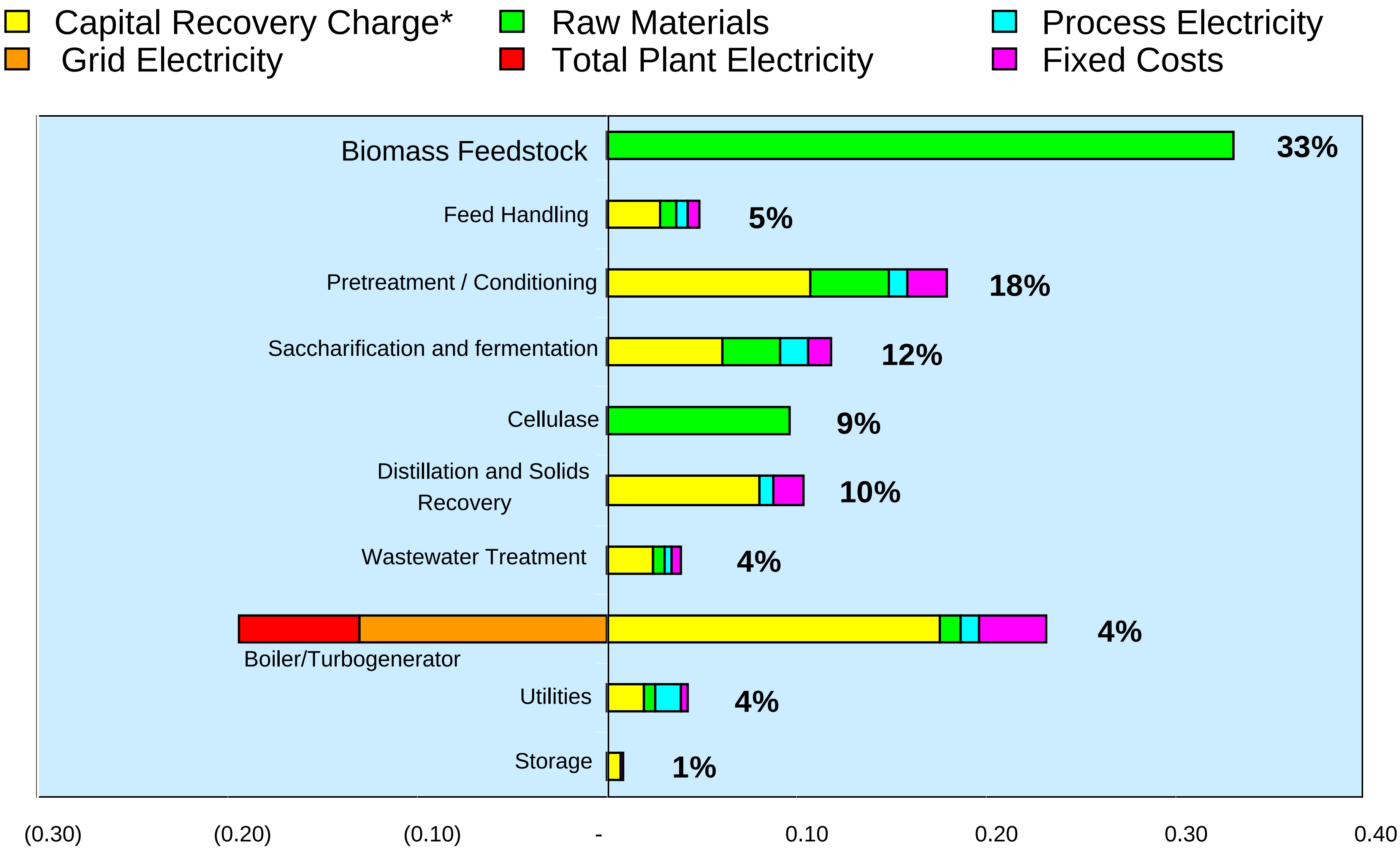
Lignin-Rich Residue
(*More energy dense than original feedstock*)

Laser and Lynd 2007



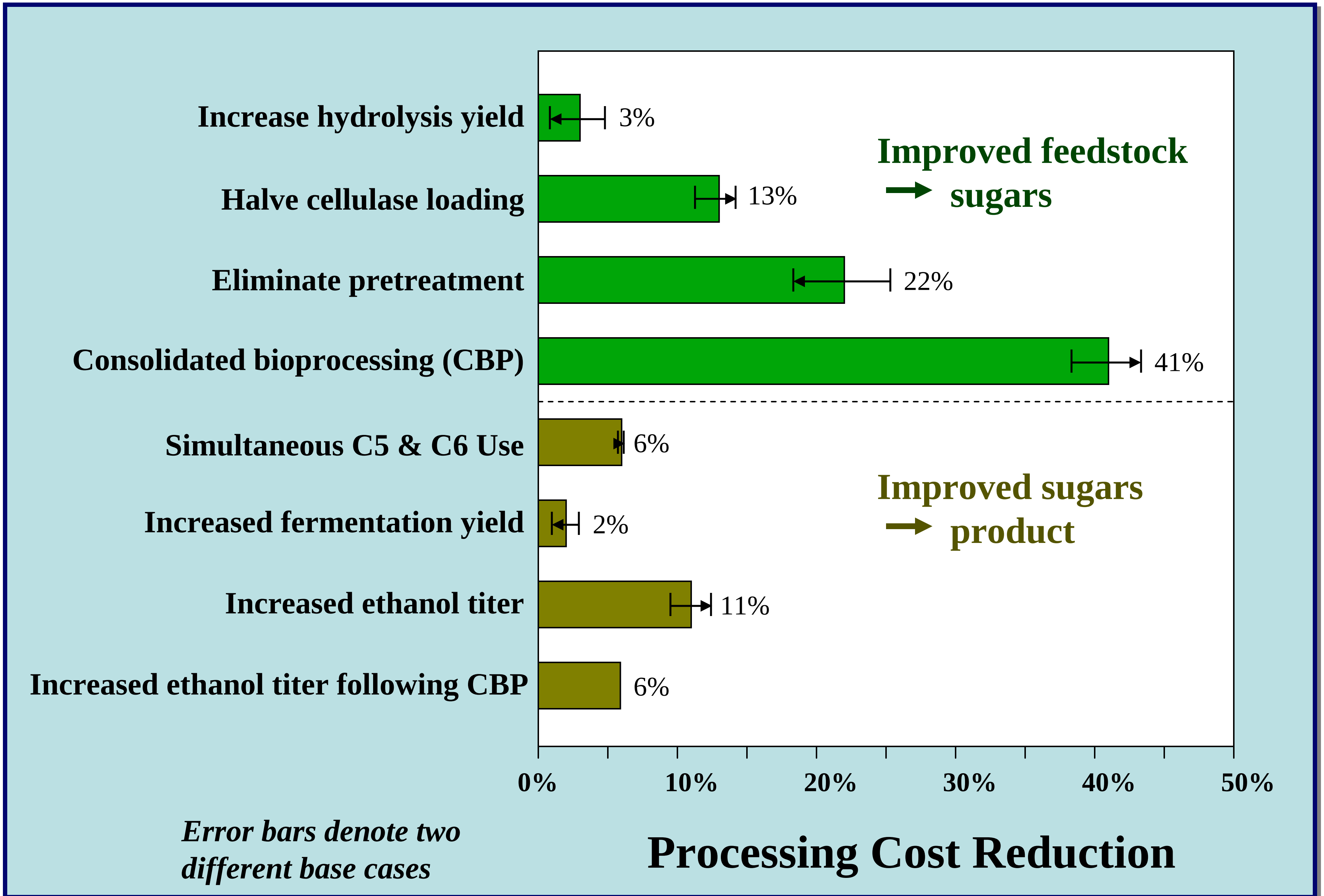
Laser and Lynd, 2007

Relative cost factors of cellulosic ethanol



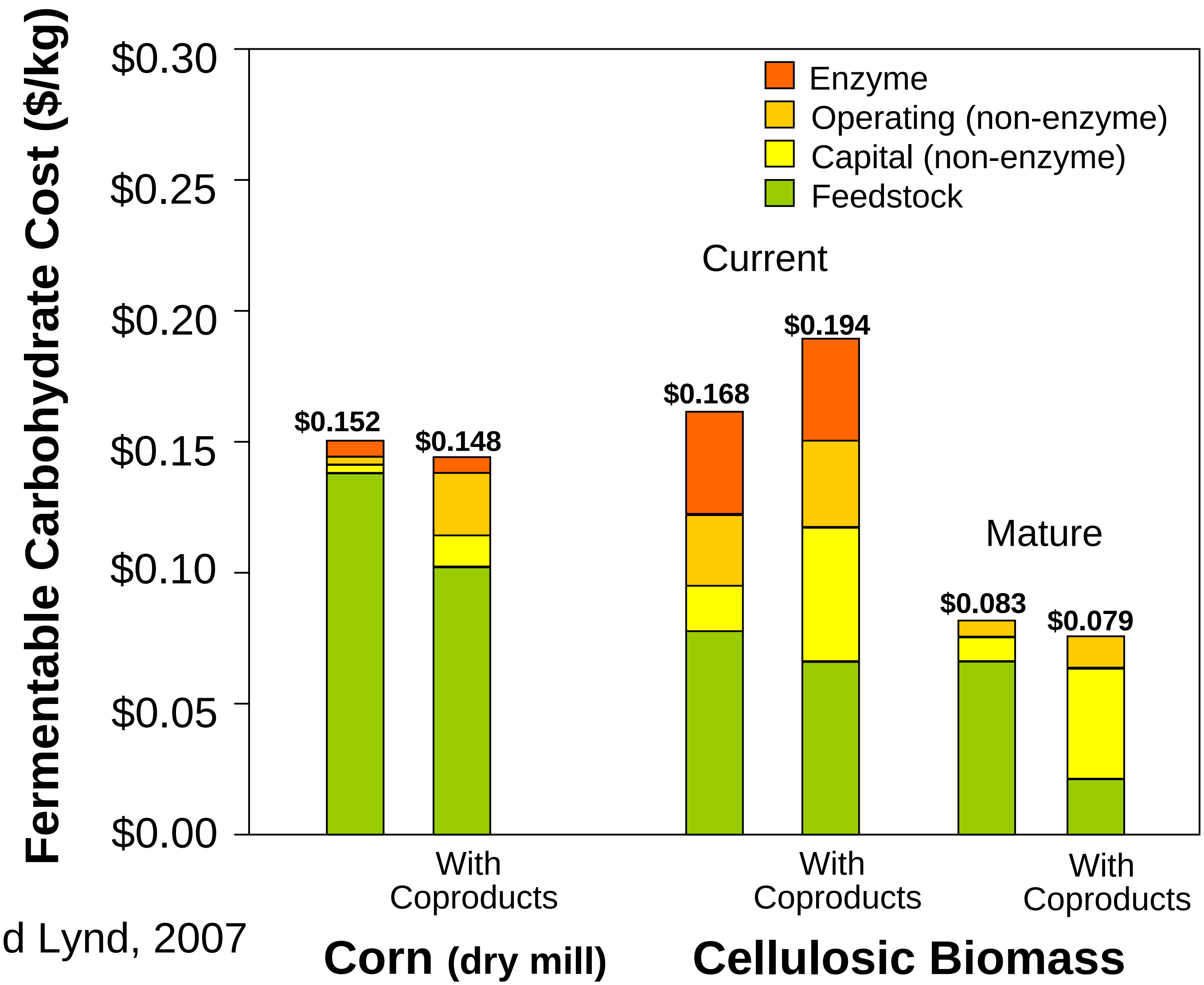
NREL Analysis

Economic Impact of Various R&D-Driven Improvements



Laser and Lynd, 2007

Economic Drivers: Biological Processing of Lignocellulose



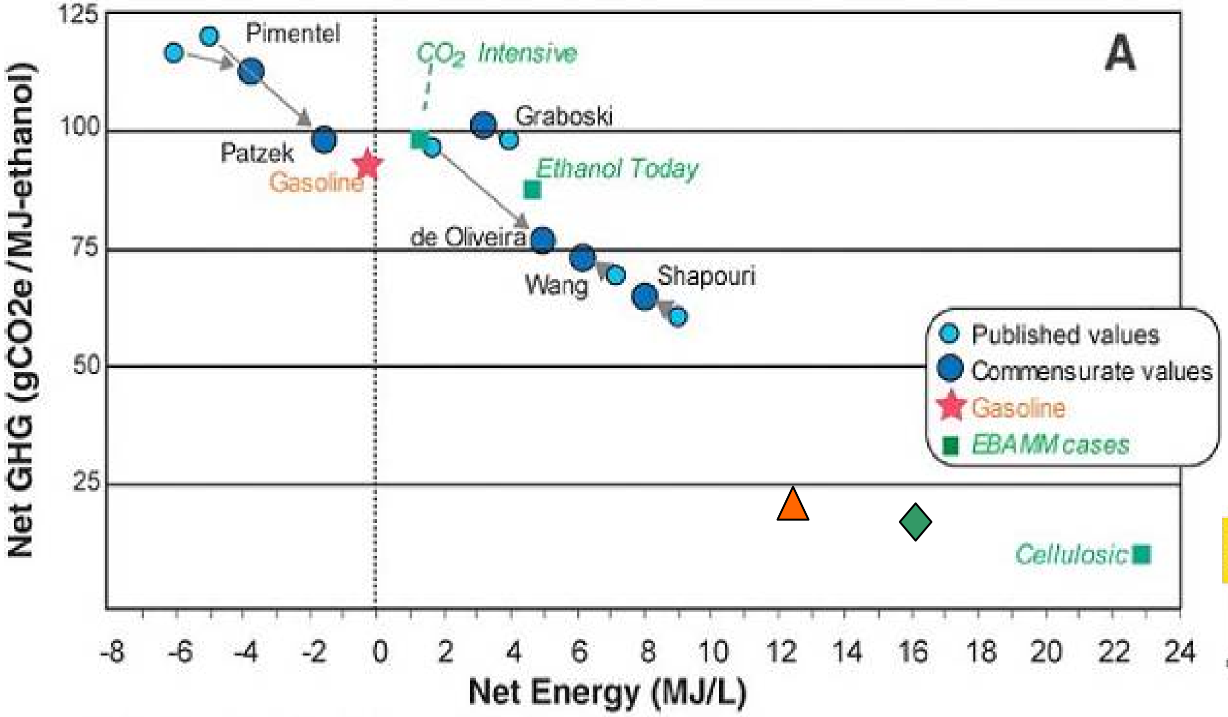
Laser and Lynd, 2007

For current technology, the lower purchase price of cellulosic biomass is entirely cancelled by the cost of hydrolysis

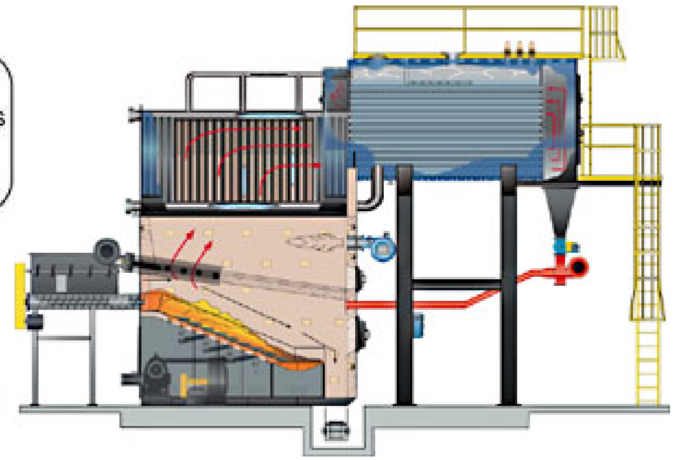
Biorefinery By-Product Utilization

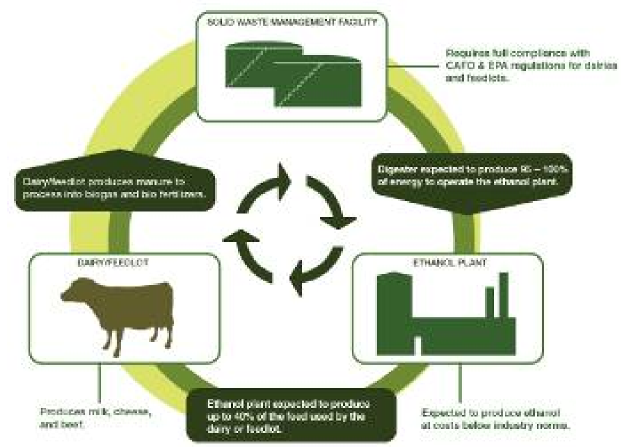
- Lignin
  - Burn to power the plant & export electricity
  - Platform for specialty chemicals?
- Wastewater
  - Conventional treatment? Energy recovery?
- Still Bottoms
  - Value as animal feed?
  - Fire boiler to supplement heating demand

Net energy and net greenhouse gases for gasoline, six studies, and three cases



A. E. Farrell et al., Science 311, 506 -508 (2006)

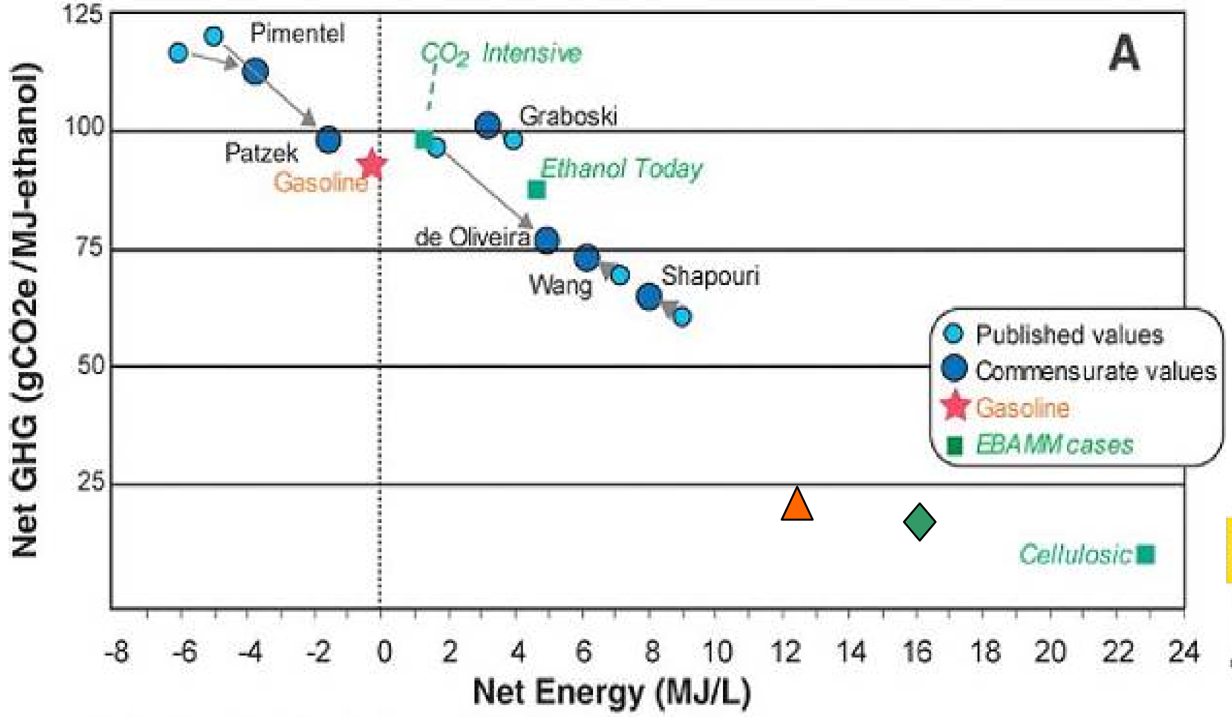




- △ **Ethanol dry-mill with process heat produced by firing stover in a solid-fuel boiler. Net Energy = 12.2 MJ/L**
- ◇ **Ethanol dry-mill with process heat produced by Anaerobic Digestion of manure and thin stillage. No drying of WDG or evaporation of thin stillage. Net Energy = 16 MJ/L**

Rob Anex, Iowa State Univ.

Net energy and net greenhouse gases for gasoline, six studies, and three cases



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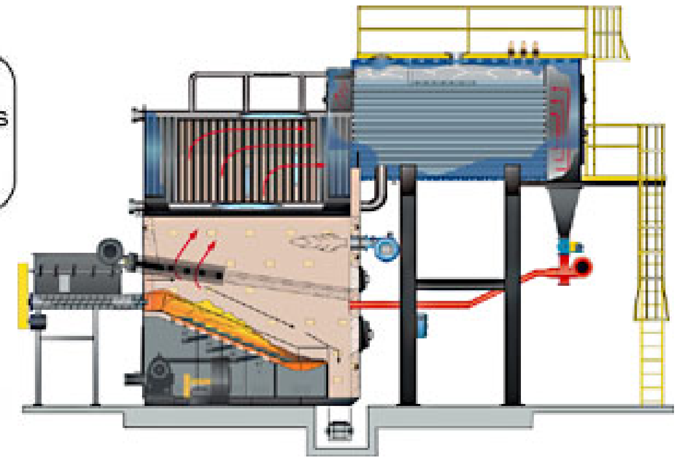

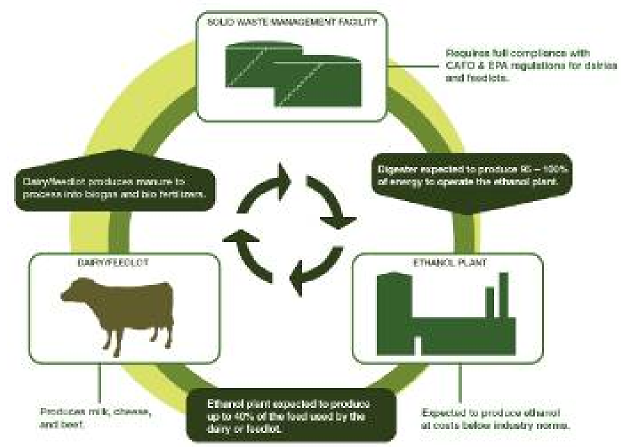

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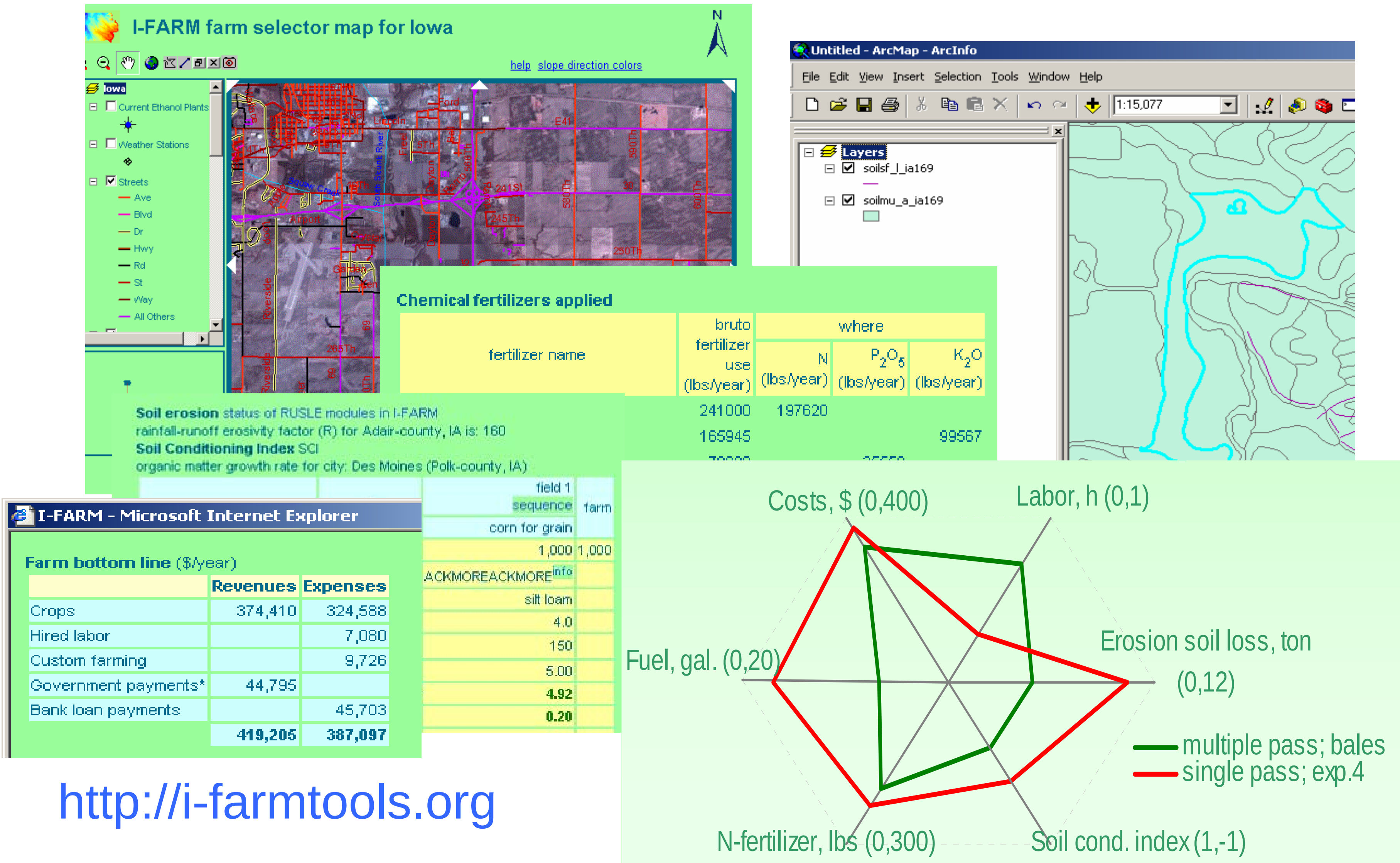
I-FARM Decision Support Tool



http://i-farmtools.org

The Journey Ahead

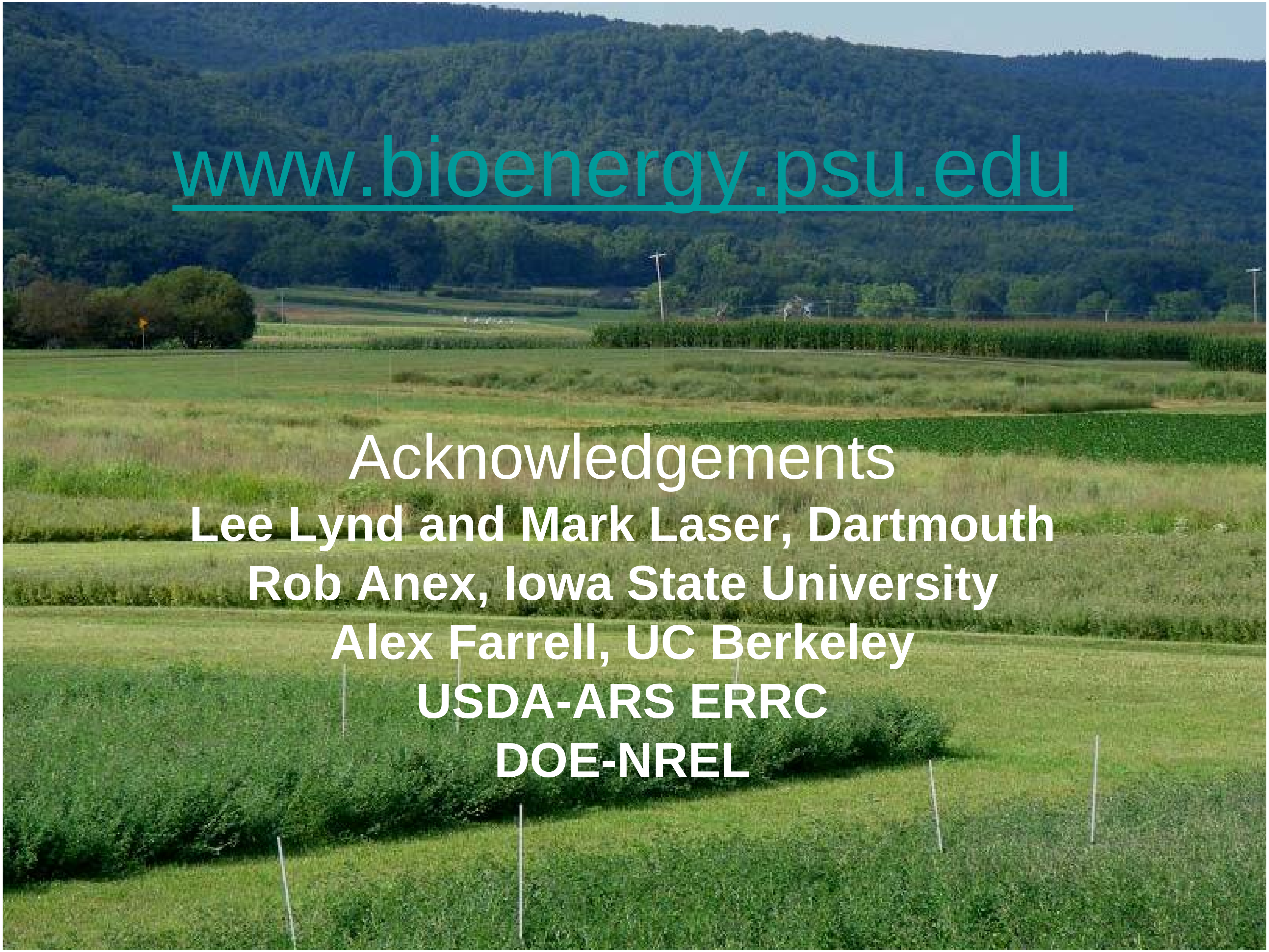
- Cellulosic conversion technologies mature
- Feedstock demand grows
- The landscape transforms…

But HOW?

A sustainable bioenergy system

requires

a sustainable agricultural system…



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USDA-ARS ERRC

DOE-NREL