



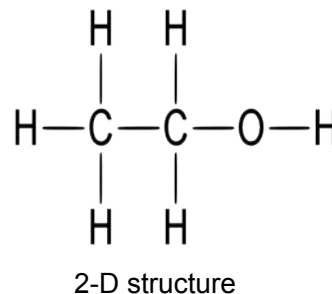
CB2E: Converting Cellulosic Biomass to Ethanol

Supplemental Slides, Figures and
Background information

Introduction and Discussion Questions

What is ethanol?

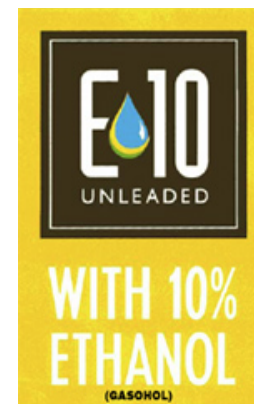
- ✧ Clear liquid
- ✧ Chemical formula: C_2H_6O
- ✧ Burns without smoke
- ✧ Some uses:
 - ✧ Transportation fuel
 - ✧ Alcoholic beverages
 - ✧ Antiseptics
 - ✧ Solvents



3-D structure

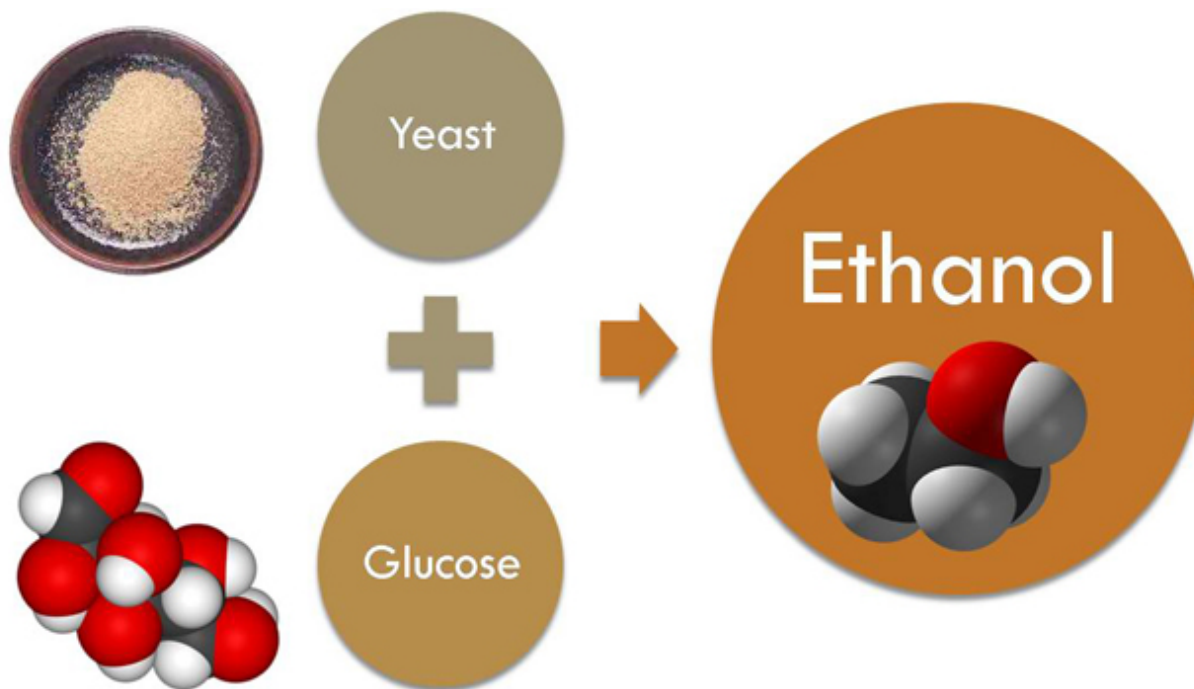


wiseGEEK

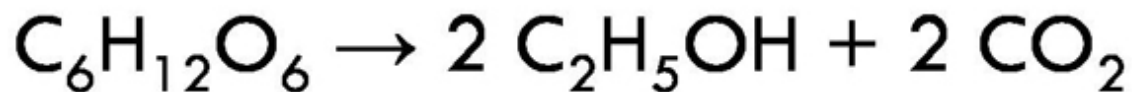


How is ethanol made?

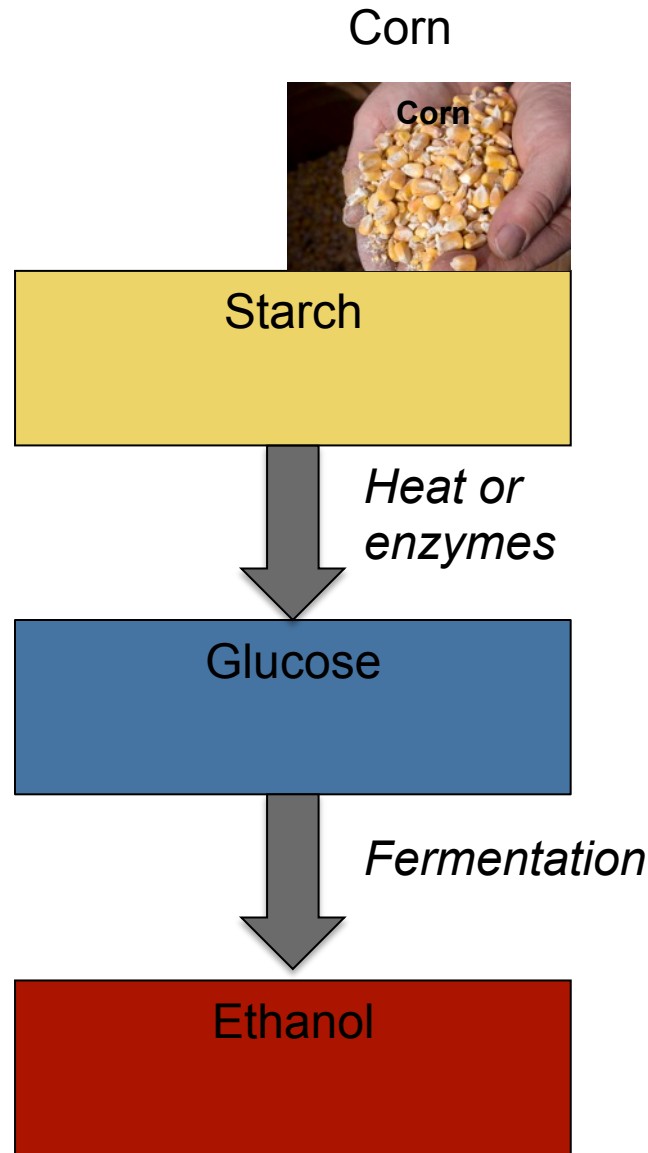
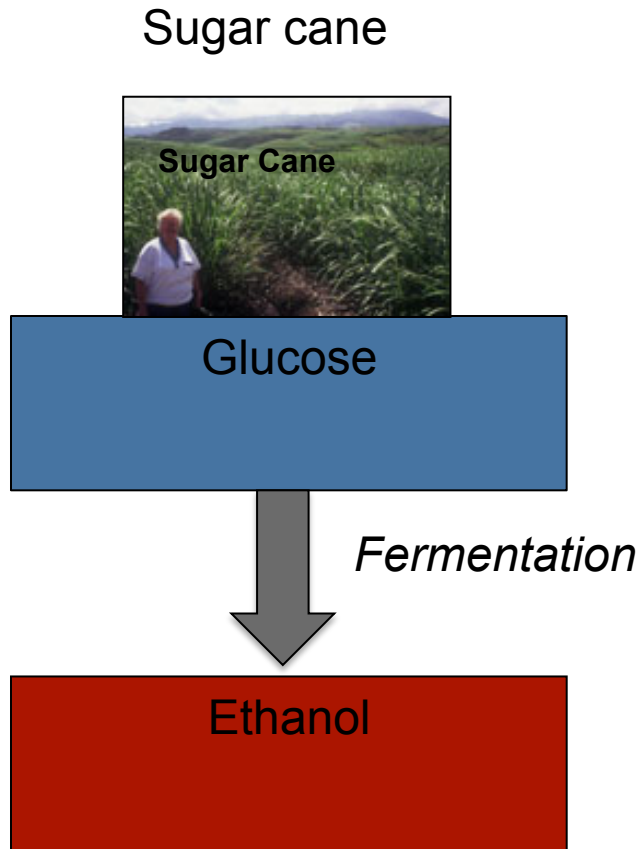
Fermentation of sugars from plants



Sugars (glucose) + yeast → ethanol + carbon dioxide



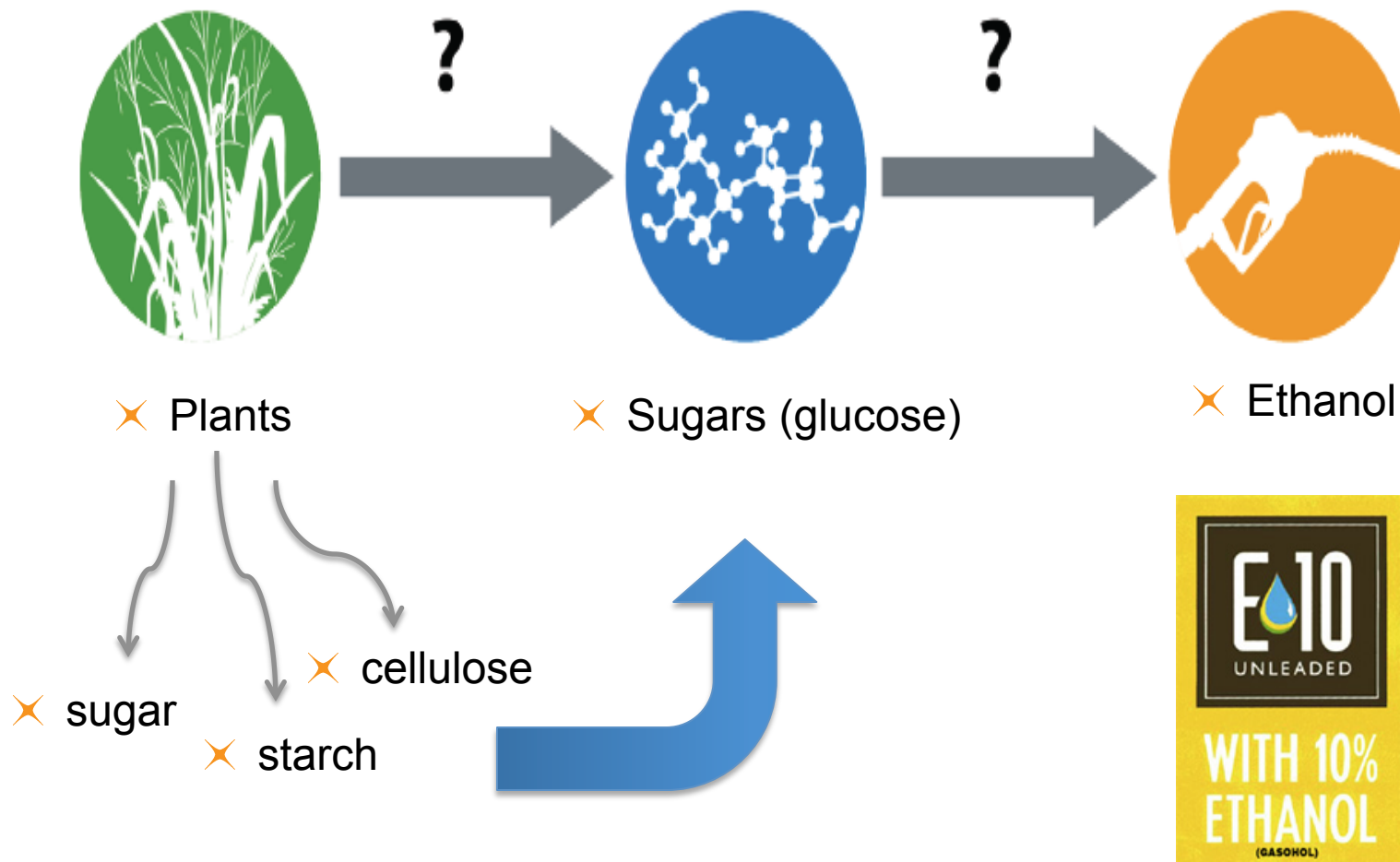
Today's Fuel Ethanol



What can be used to make sugars for fermentation?

- ✧ Sugar
 - ✧ Extract sugars directly from plants – very easy
- ✧ Starch
 - ✧ Break the starch down into sugar (glucose) –pretty easy (you can do this with your saliva)
- ✧ Cellulose
 - ✧ Break the cellulose down into sugar (glucose) – hard (you can't do this, but many organisms can)

What can be used to make sugars for fermentation?



Ethanol Compared to Gasoline – Pros and Cons

Ethanol Pros

- ✧ Renewable – made from plants!
- ✧ Reduction in CO₂ emissions (why?)
- ✧ Cleaner burning
- ✧ Domestically produced
- ✧ Cheaper (usually)

Ethanol Cons

- ✧ Food vs. Fuel (making ethanol from corn)
- ✧ Difficult to make from other sources (cellulose)
- ✧ Gallon of ethanol has 2/3 energy of gallon of gasoline
- ✧ Sufficient land to produce enough fuel?

Concerns with Corn Ethanol

- ✧ Annual crop
 - Dependent on chemical inputs
 - Soil erosion, water quality problems
 - Little below ground carbon storage
- ✧ Food versus fuel
- ✧ Impacts on biodiversity



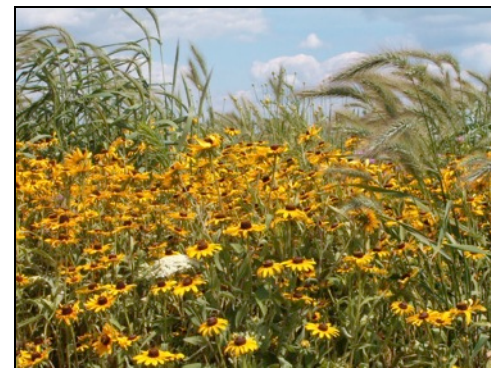
What is cellulosic biomass?

What is Cellulosic Biomass?

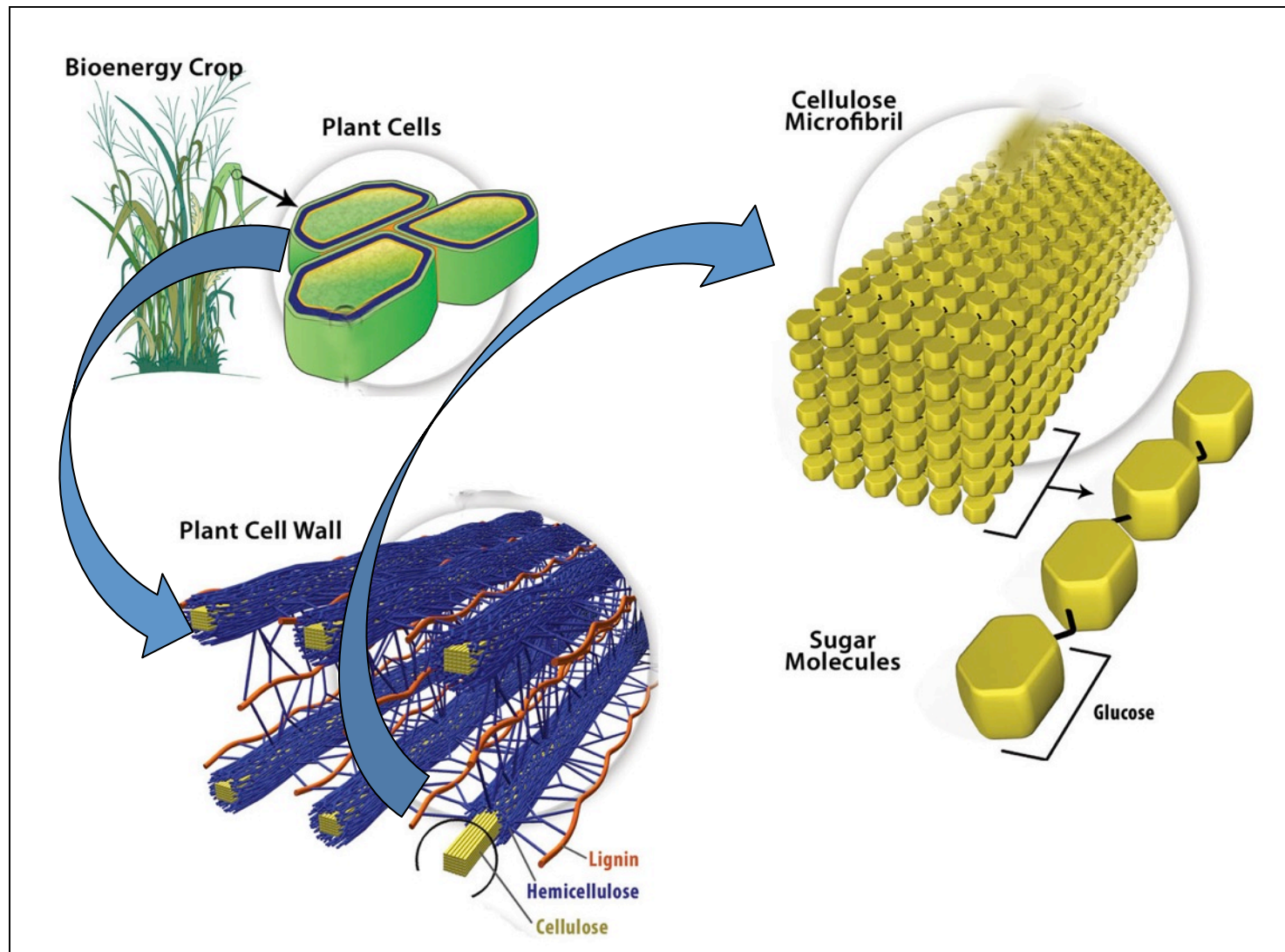


Sources of cellulose

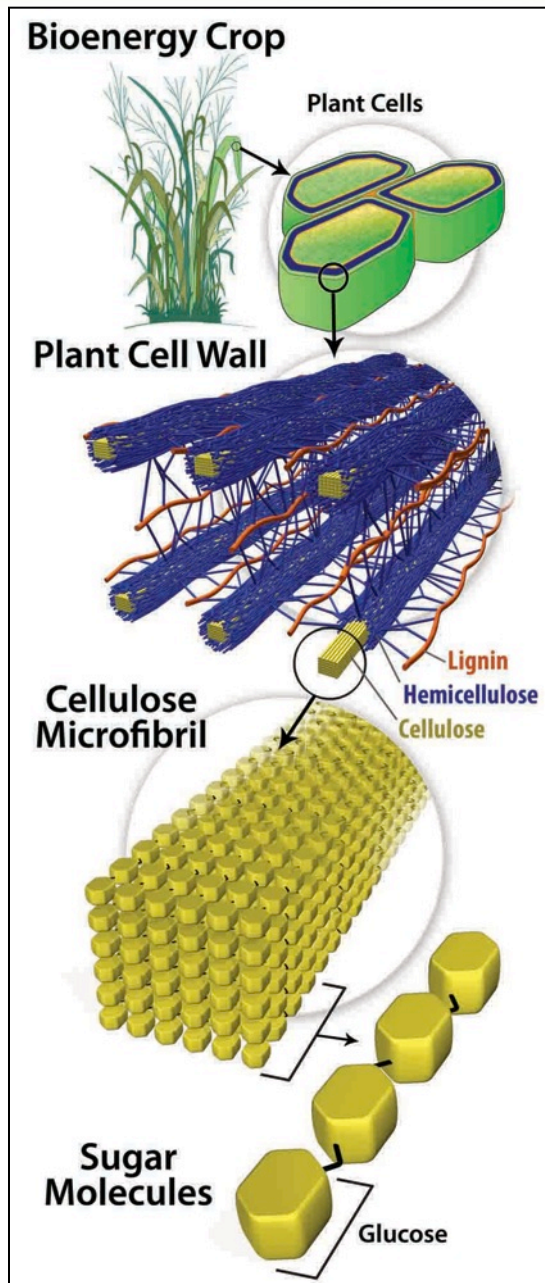
- ✧ Corn stalks, leaves, and husks (stover)
- ✧ Grasses grown as crops
- ✧ Prairie grasses
- ✧ Sawdust and woodchips
- ✧ Yard waste
- ✧ Any plant!



What is Cellulose?



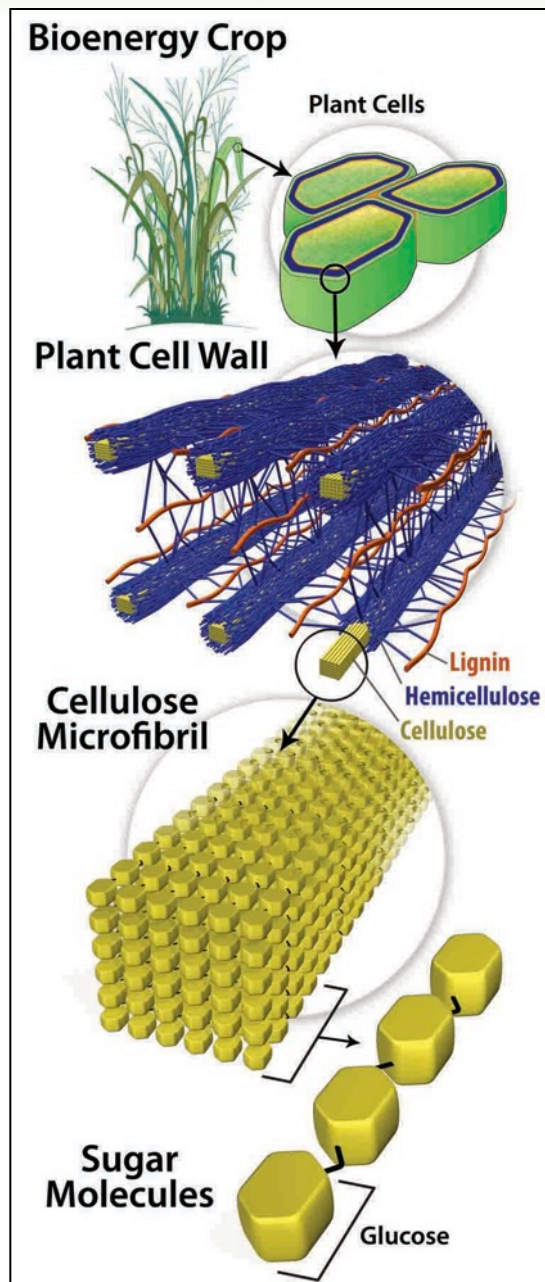
Plant Cell Wall Structure



- ✧ Cellulose—primary carbohydrate goal for extraction
- ✧ Hemicellulose—carbohydrate, harder to convert to fuel
- ✧ Lignin—may be burned for heat/electricity, converted into useful chemicals

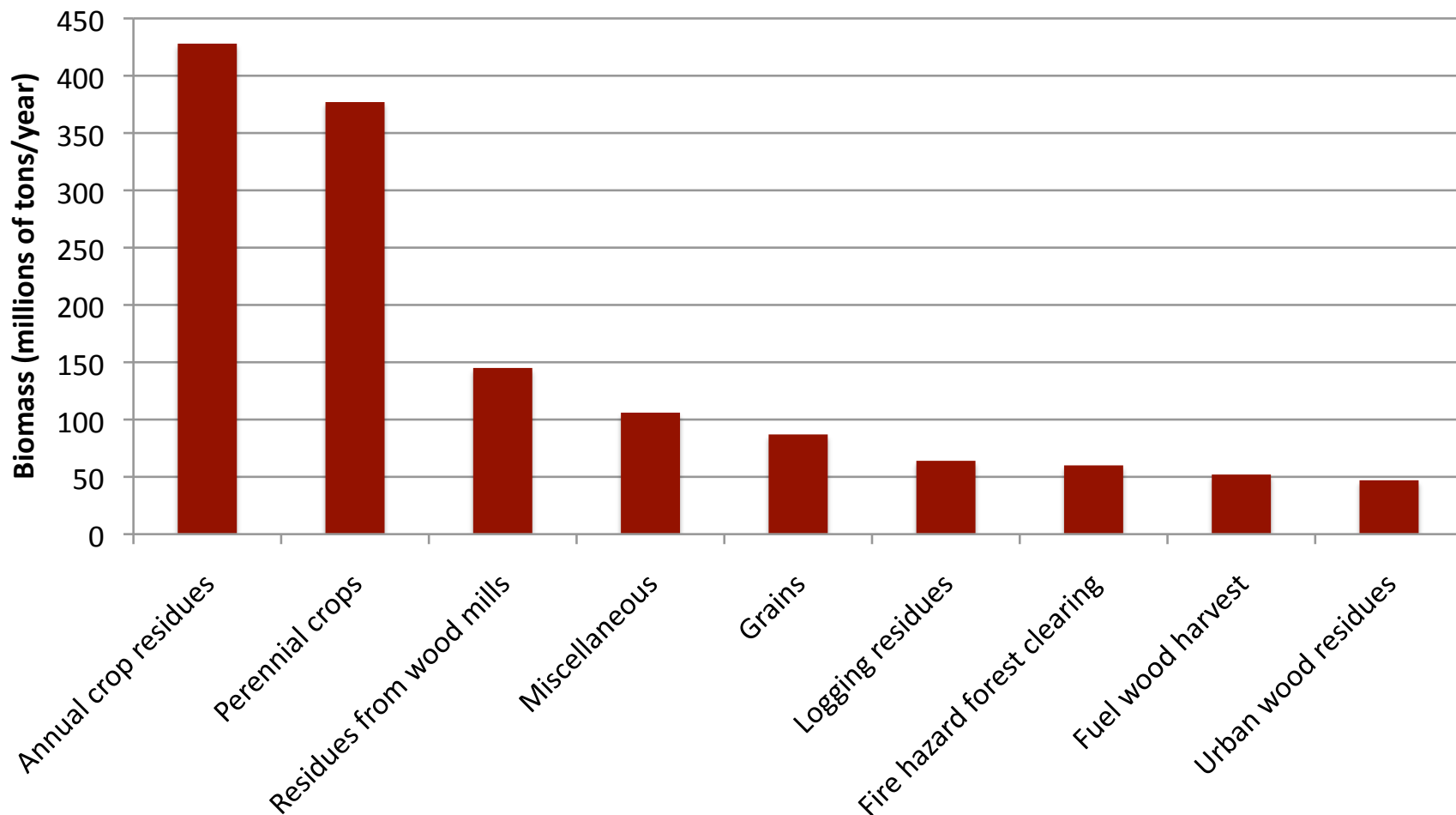
Cellulosic Biofuels

- ✧ Cellulose is the most abundant biological material on Earth
- ✧ Found in cell walls
- ✧ Lack efficient way to break down plant material and convert it into fuel
- ✧ Cell wall composition varies

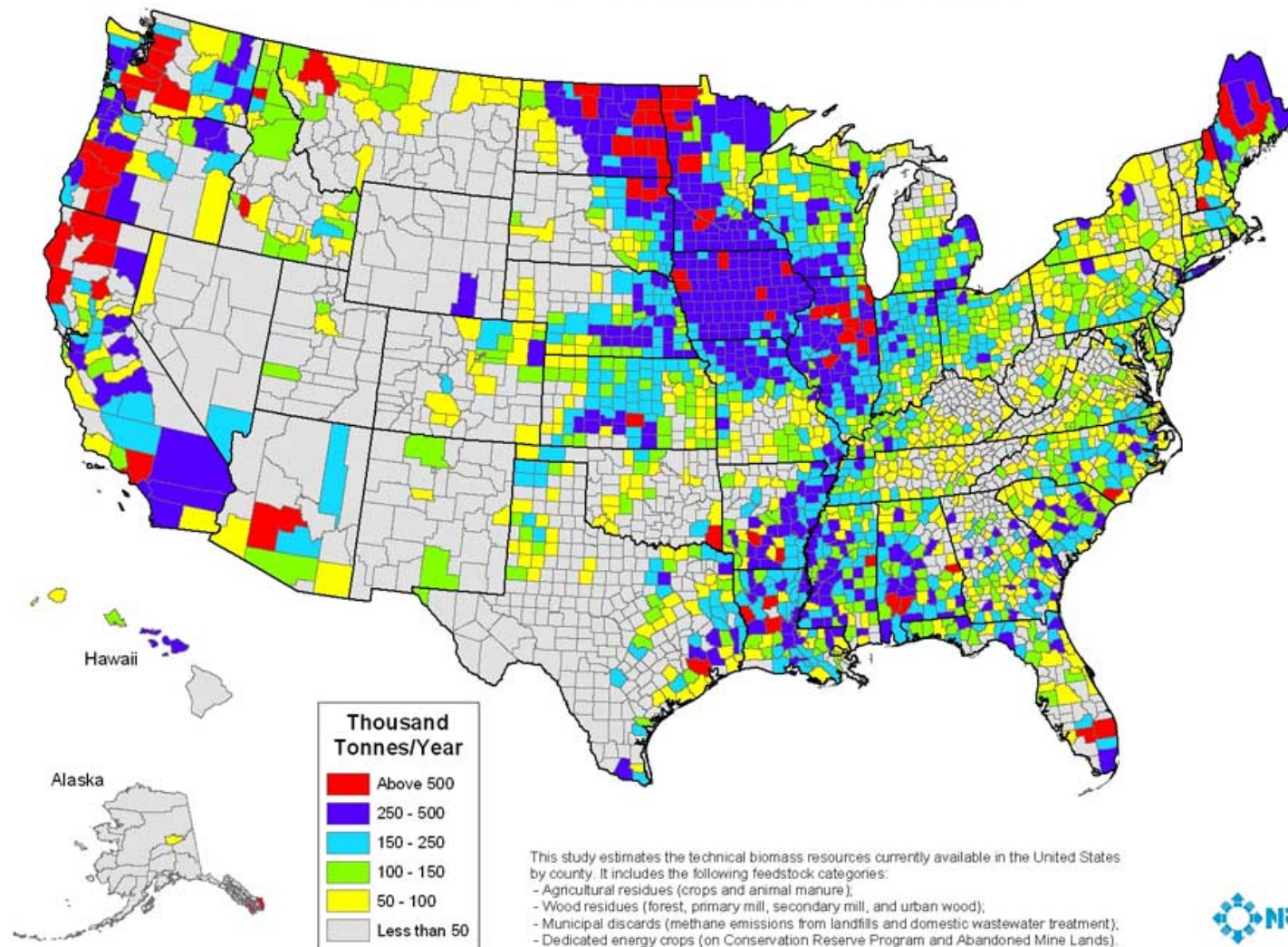


Biomass Feedstocks Available for Billion Ton/Year Harvest in the U.S.

R.D. Perlack, et al, 2005, Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply (DOE/GO-102005-2135). Oak Ridge, TN: US DOE



Biomass Resources Available in the United States

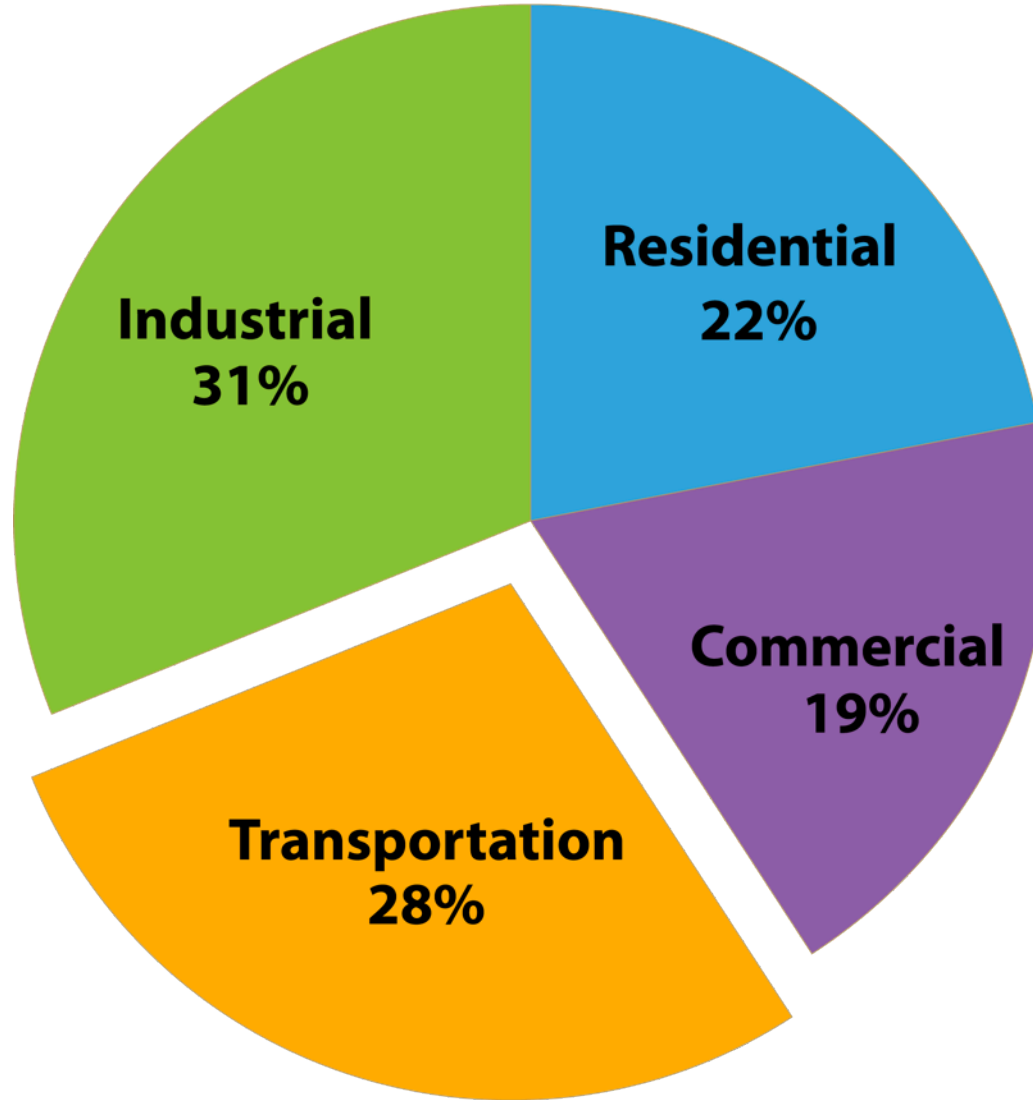


September 2005

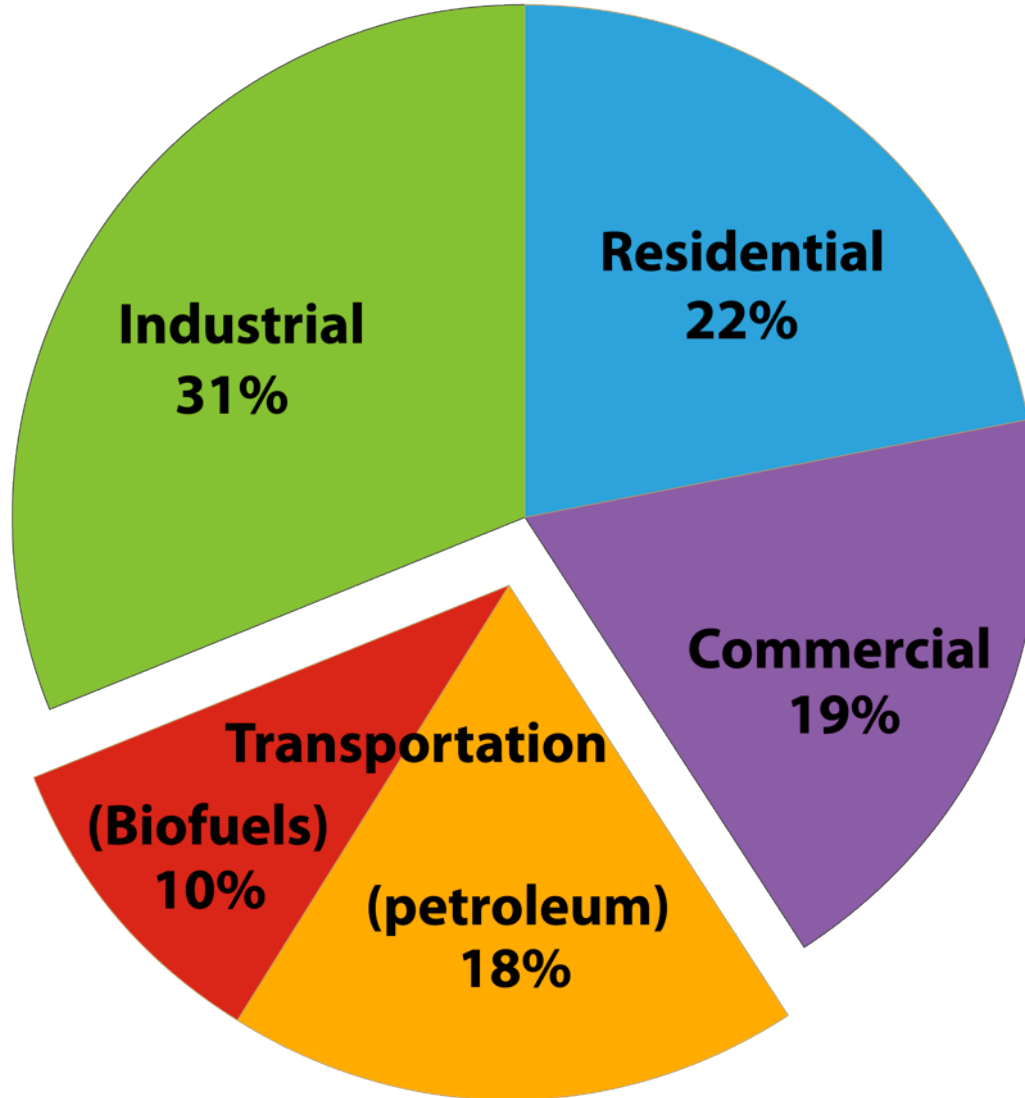
Background Information and Graphs

Energy Use and Potential for Biofuels

U.S. Energy Consumption, 2008

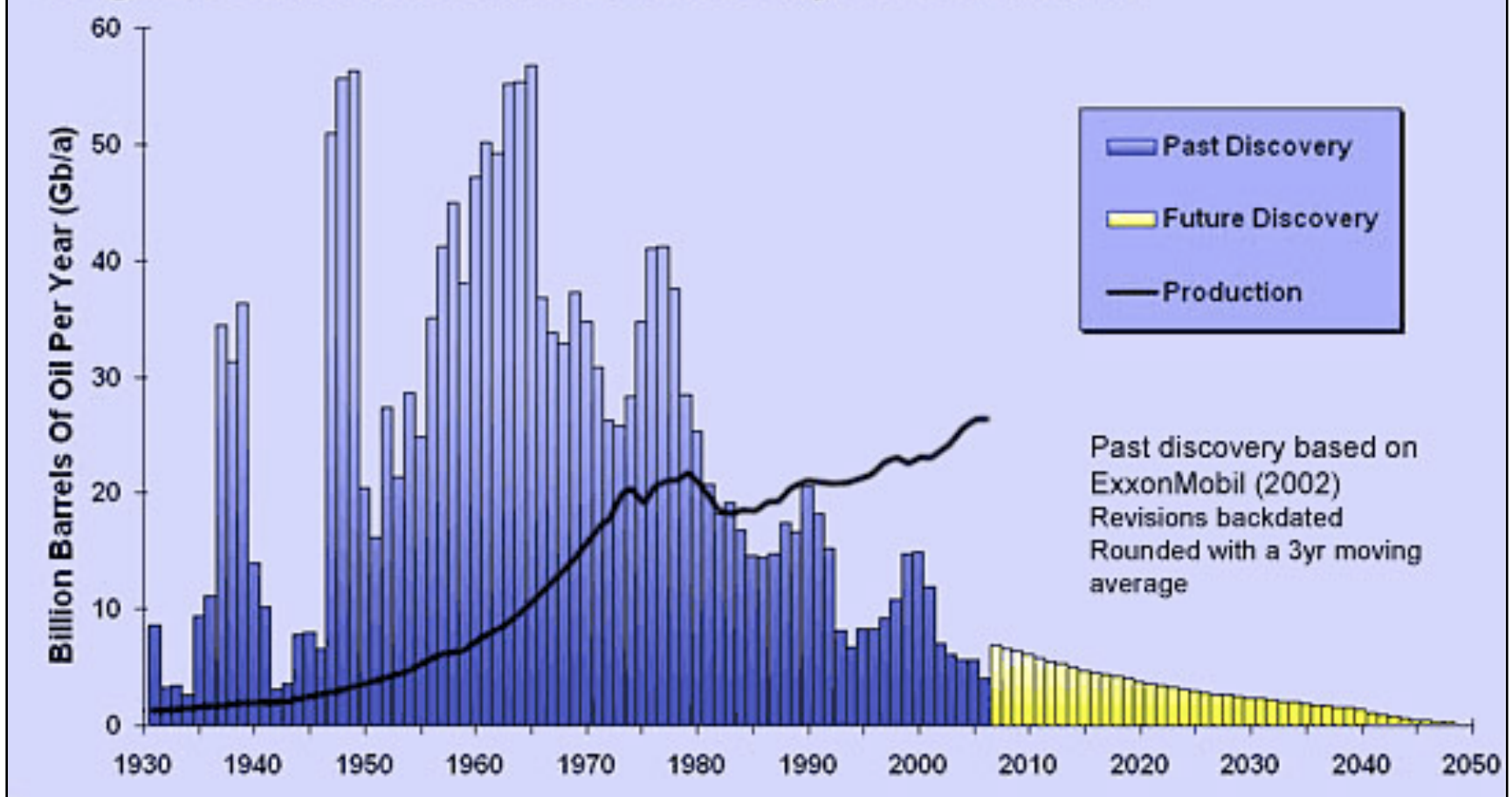


U.S. Energy Consumption, Biofuels Potential



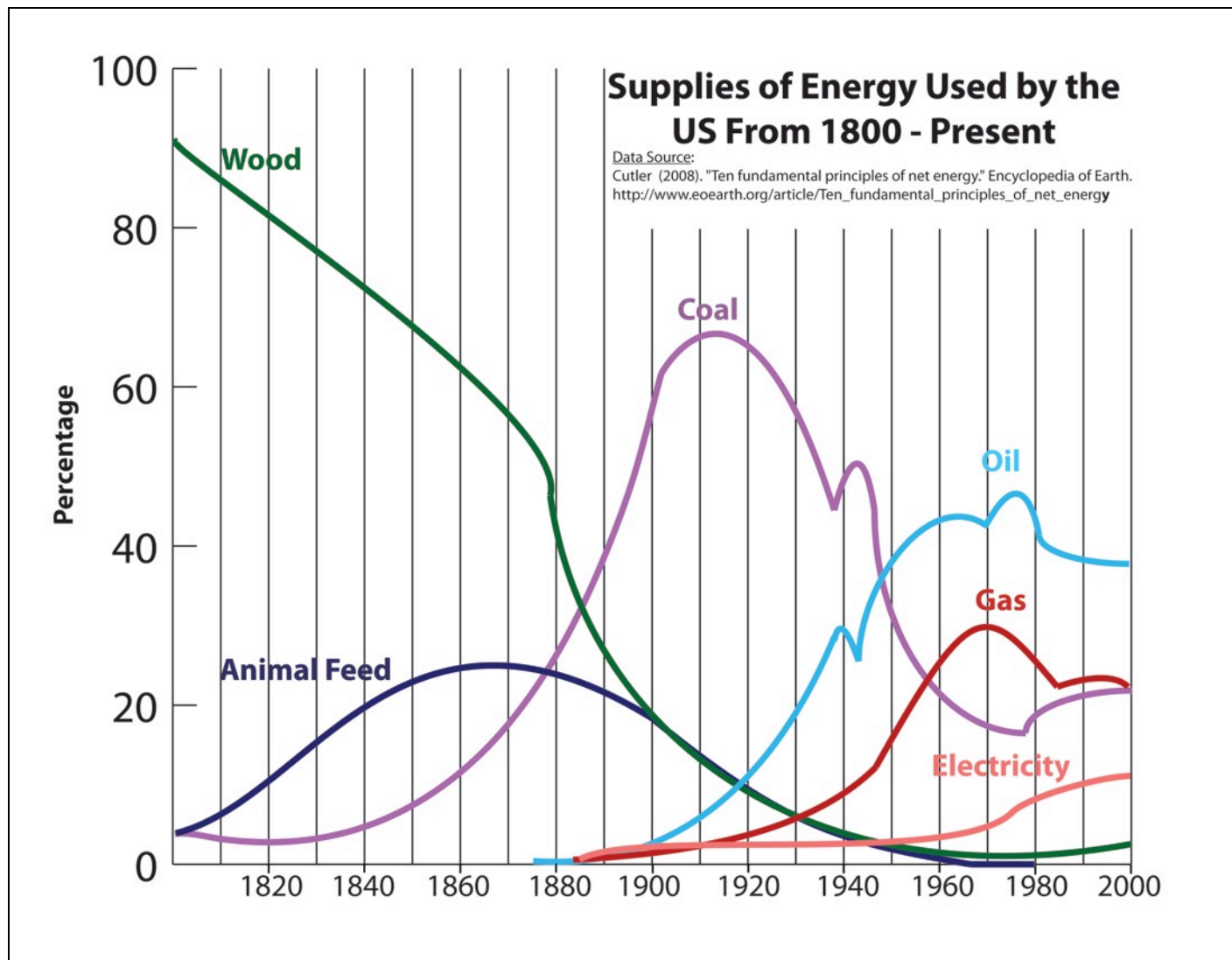
THE GROWING GAP

Regular Conventional Oil: Discovery & Production



C. Cleveland and R. Kaufmann, Fundamental principles of energy, 2008, Encyclopedia of Earth

U.S. Energy Sources: Historical



Energy Densities by Volume

Cleveland, C. J. and R. Kaufmann, 2008, Fundamental Principles of Energy, Encyclopedia of Earth
http://www.eoearth.org/article/Fundamental_principles_of_energy

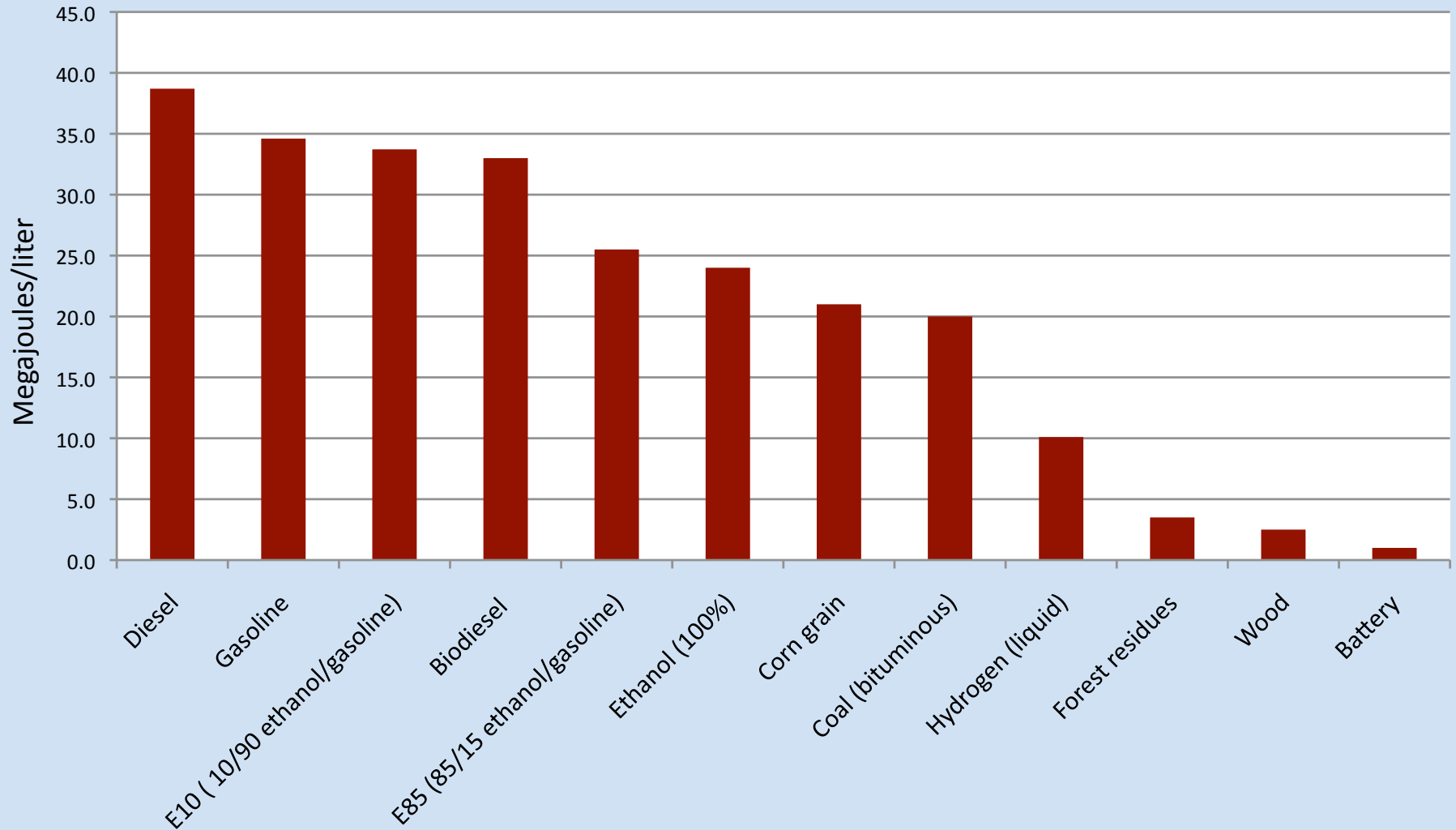
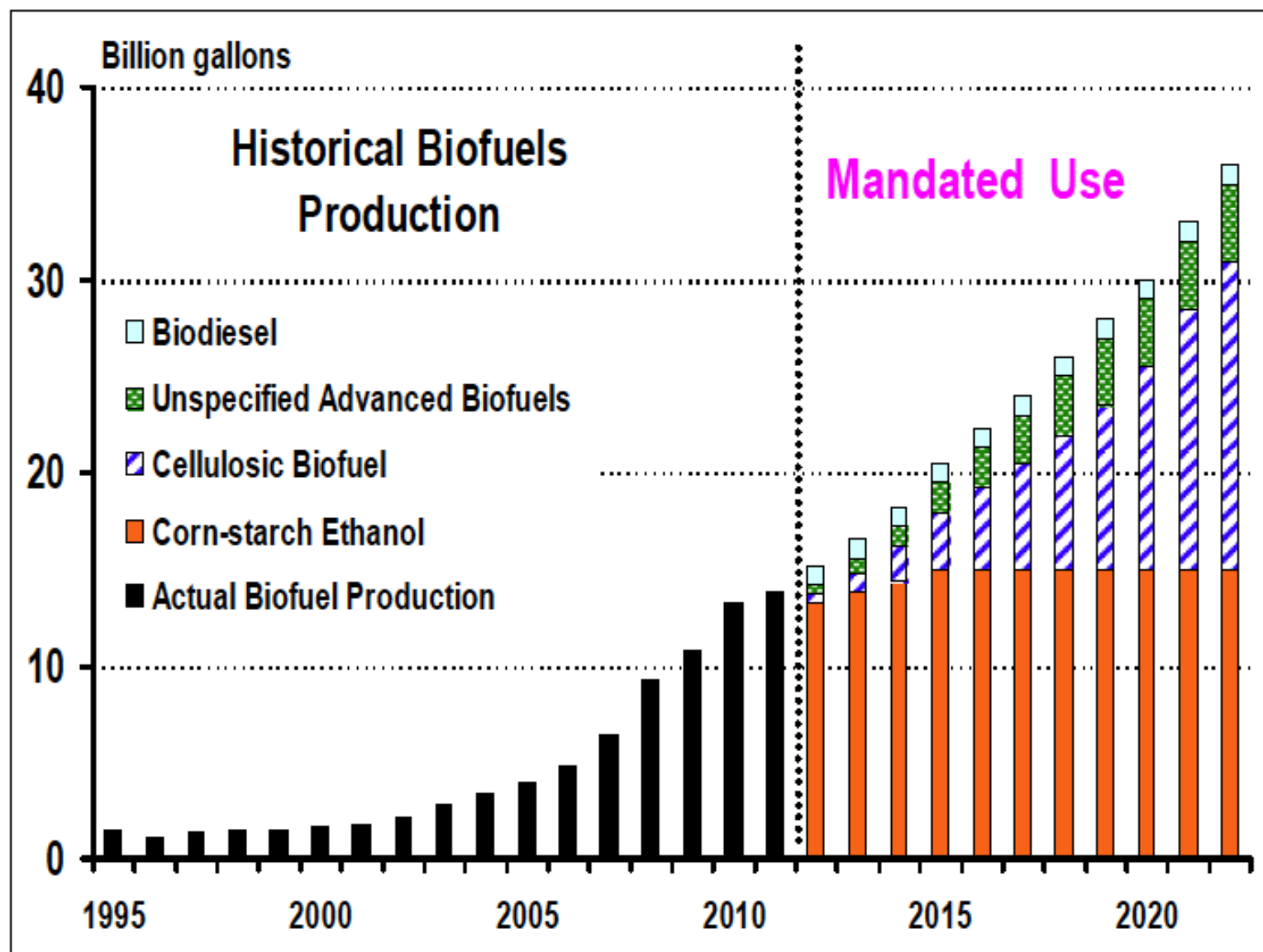


Figure 1. Renewable Fuels Standard (RFS2) vs. U.S. Ethanol Production Since 1995

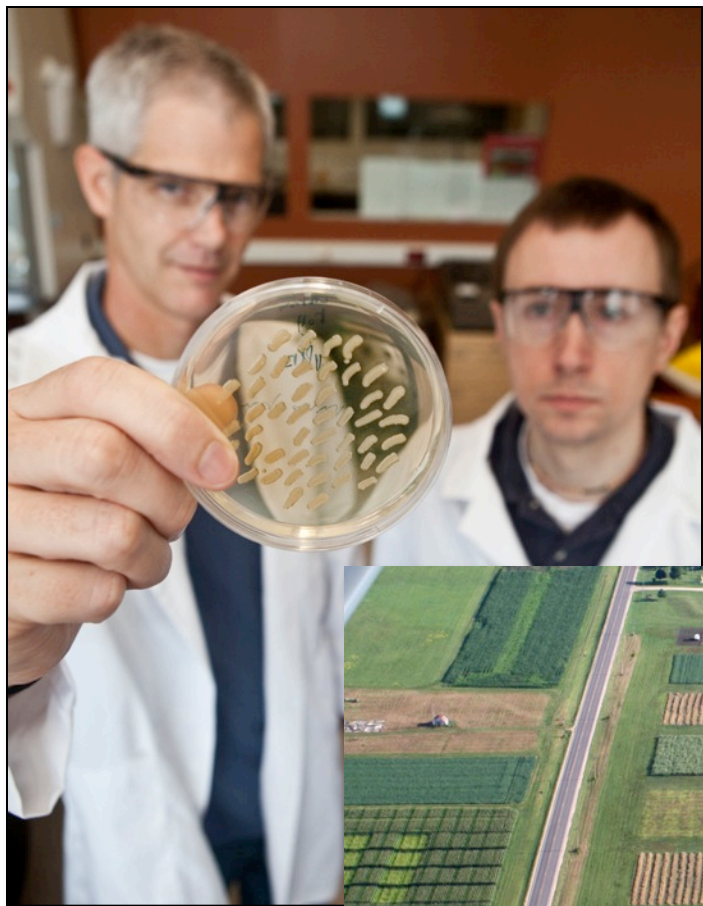


Source: Actual ethanol production data for 1995-2010 is from Renewable Fuels Association; the RFS2 by category is from EISA (P.L. 110-140).

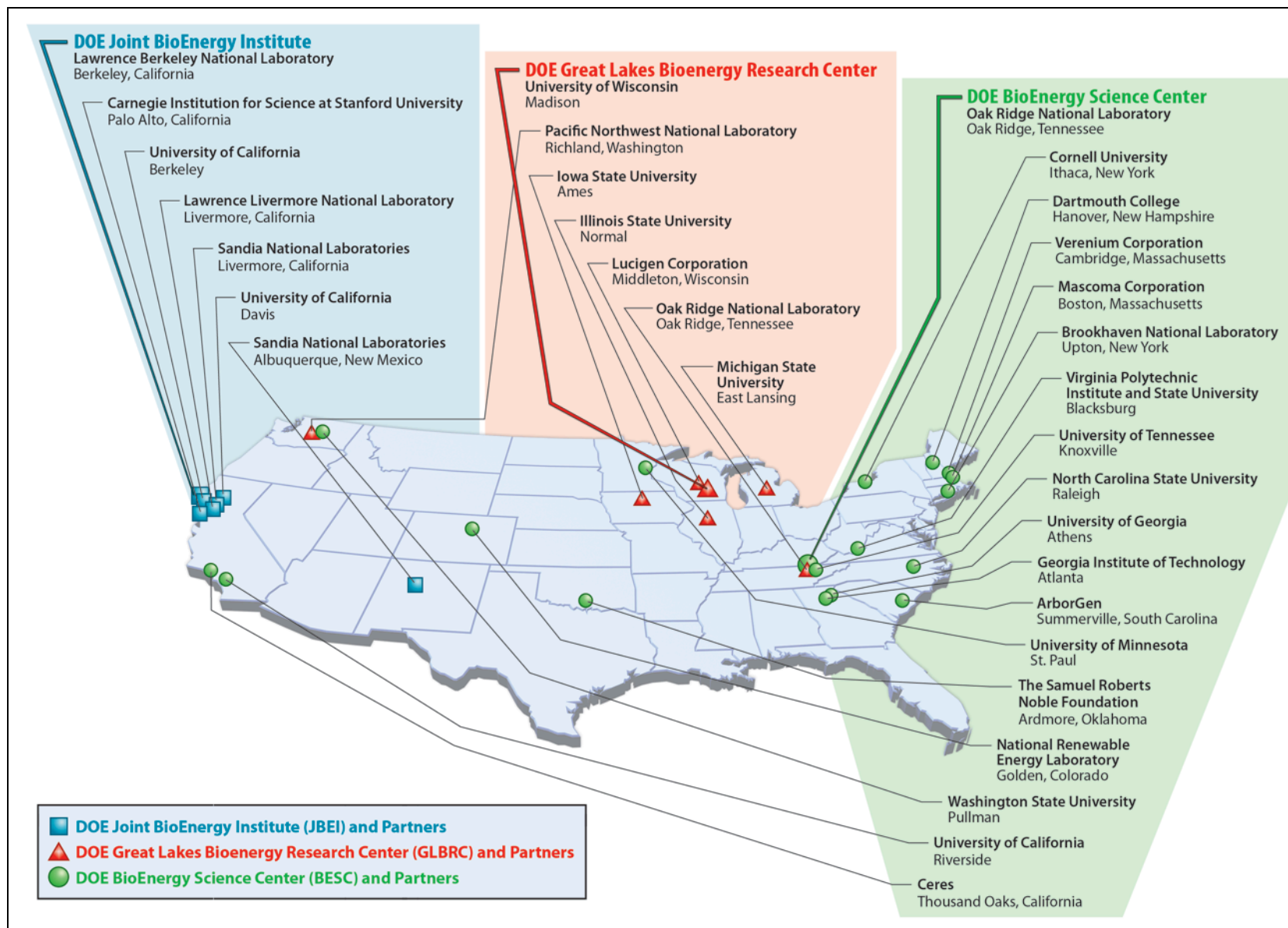
What is the Great Lakes Bioenergy Research Center (GLBRC)?

The Mission of GLBRC

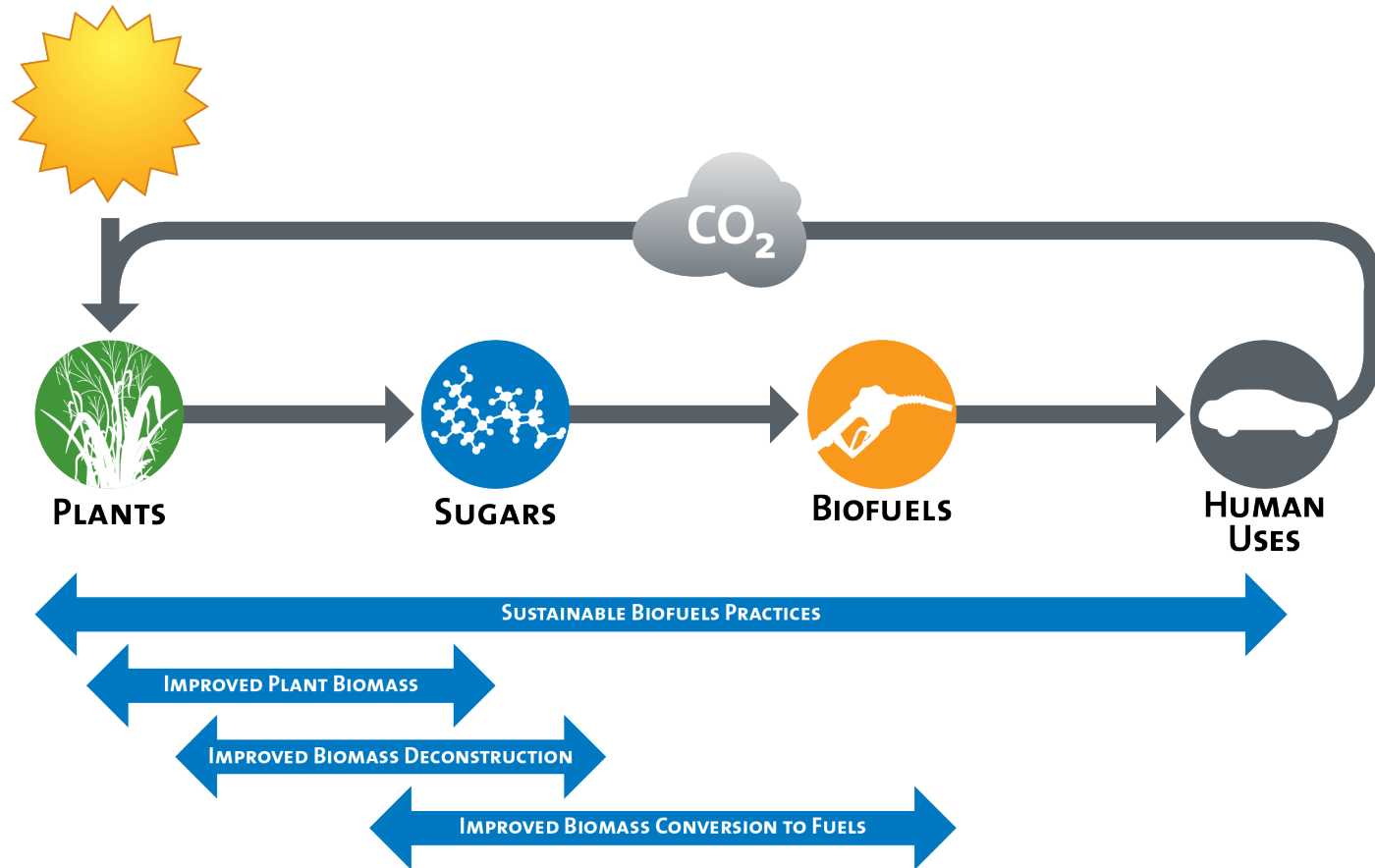
To perform the basic research that generates technology to convert cellulosic biomass to sustainable biofuels.



GLBRC: 1 of 3 DOE Bioenergy Research Centers



GLBRC Research Roadmap



Four discovery science areas provide knowledge to sustainably convert cellulosic biomass into liquid transportation fuels

GLBRC: Who We Are

~400 scientists, staff & students across sites

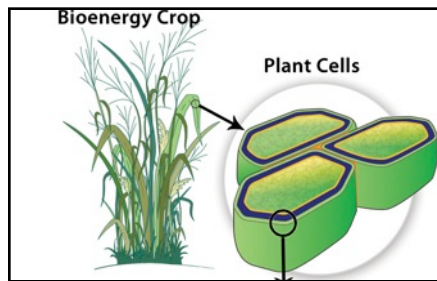
- ✧ 70 Faculty (17%)
- ✧ 29 Senior scientists (7%)
- ✧ 66 Post-doctoral scientists (16%)
- ✧ 52 Ph.D. Students (13%)
- ✧ 55 Technicians (14%)
- ✧ 85 Undergraduates (23%)
- ✧ 42 Support staff in Operations, IIT, E&O (10%)
- ✧ ~ 60 Research Projects



Process for Making Cellulosic Ethanol

Overview

Moving Beyond Corn Ethanol



cellulosic material



*Tomorrow's technology
(GLBRC)*

Plant biomass



? Pretreat (grind, heat, chemicals, pressure)

"Loosened" cell wall material
(cellulose hemicellulose, lignin)



? Enzymes (cellulases, etc) or microbes

Mixed sugars, etc.
(glucose, arabinose, xylose, phenolics, etc.)



? Fermentation (microbes) or catalysts

Ethanol (next generation fuel)

Today's technology

Corn
(kernels)

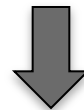


Starch



Heat and/or enzymes

Glucose



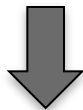
Fermentation (microbes)

Ethanol

Sugar
Cane



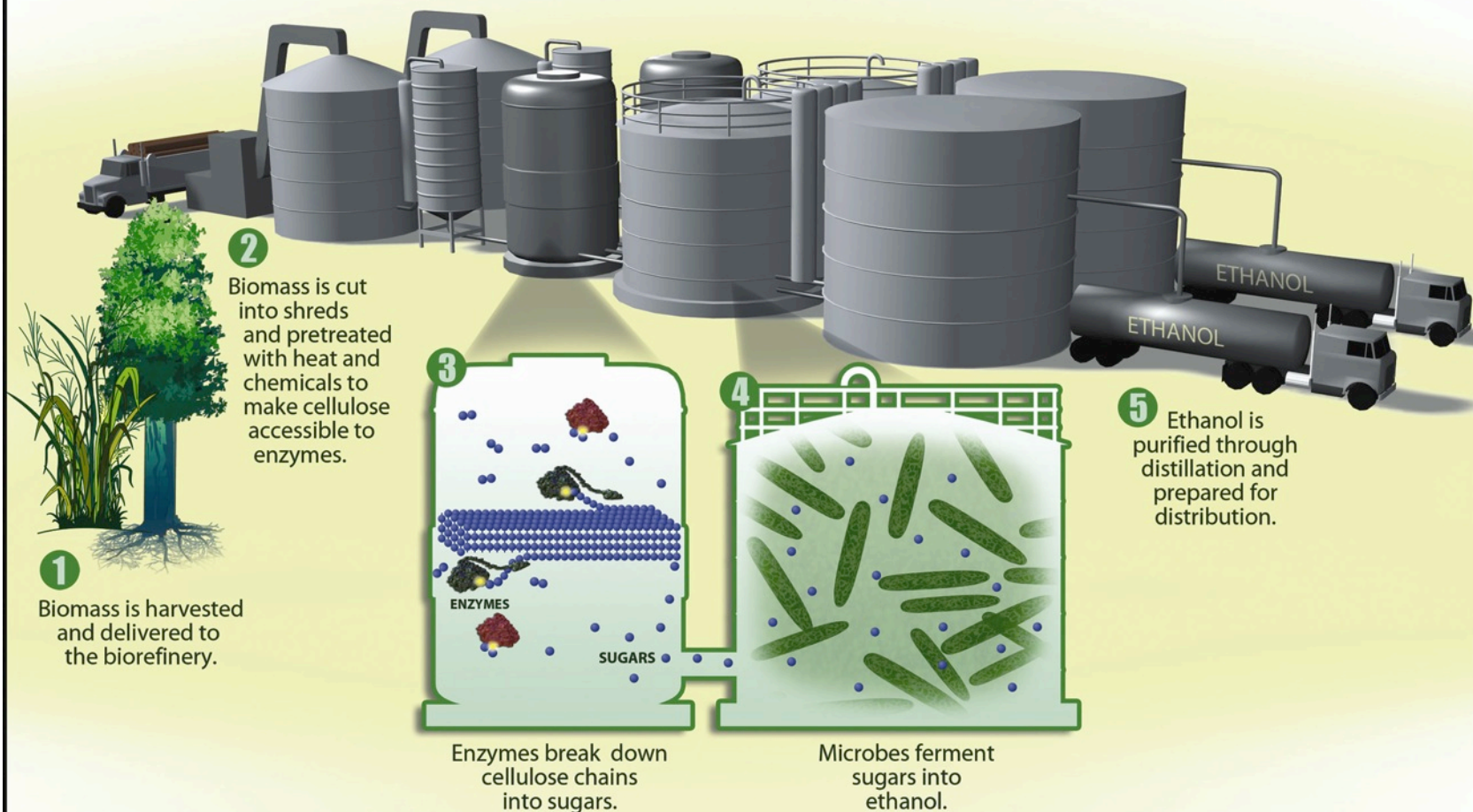
Glucose

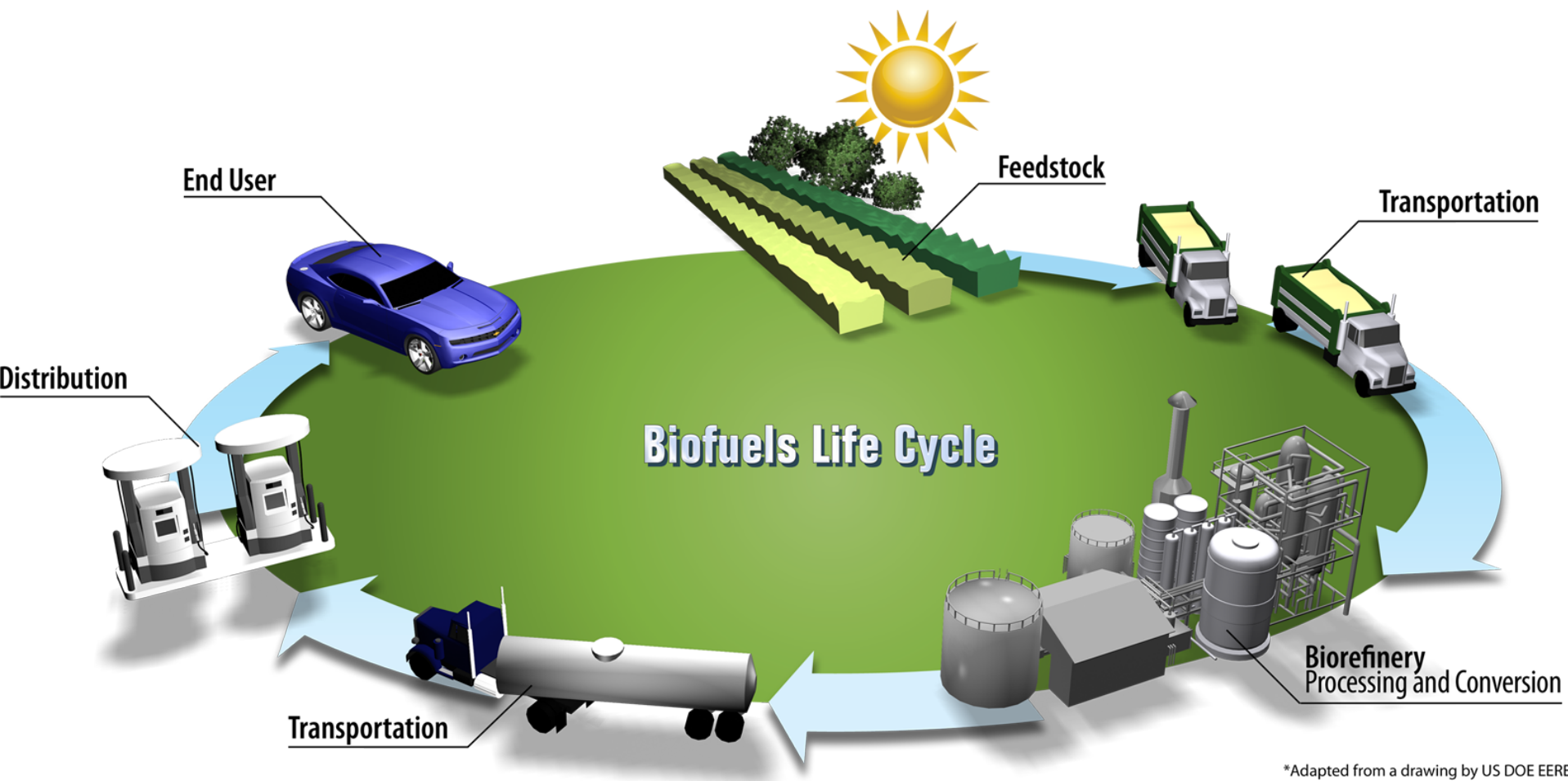


Fermentation (microbes)

Ethanol

How Cellulosic Ethanol is Made

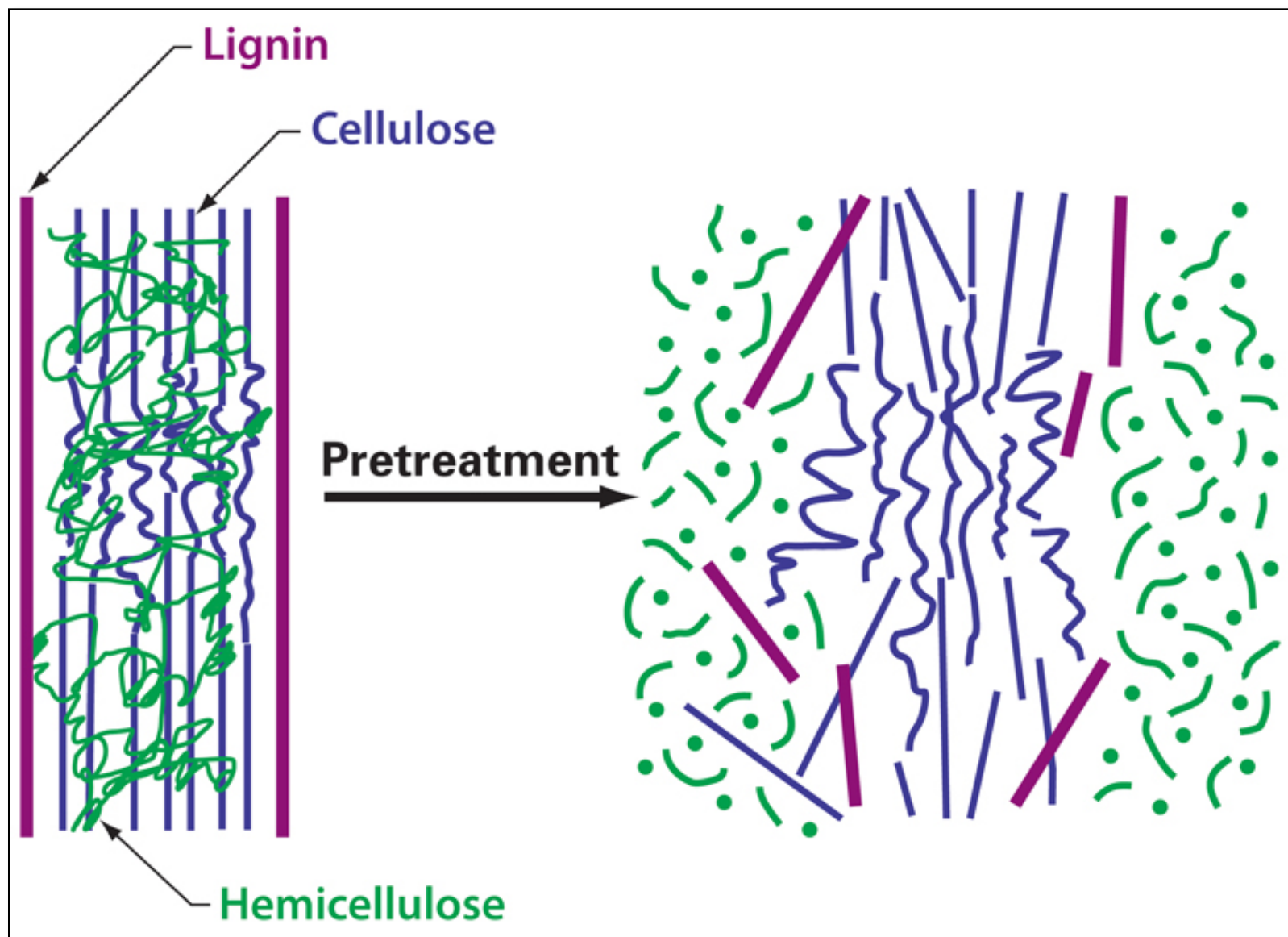




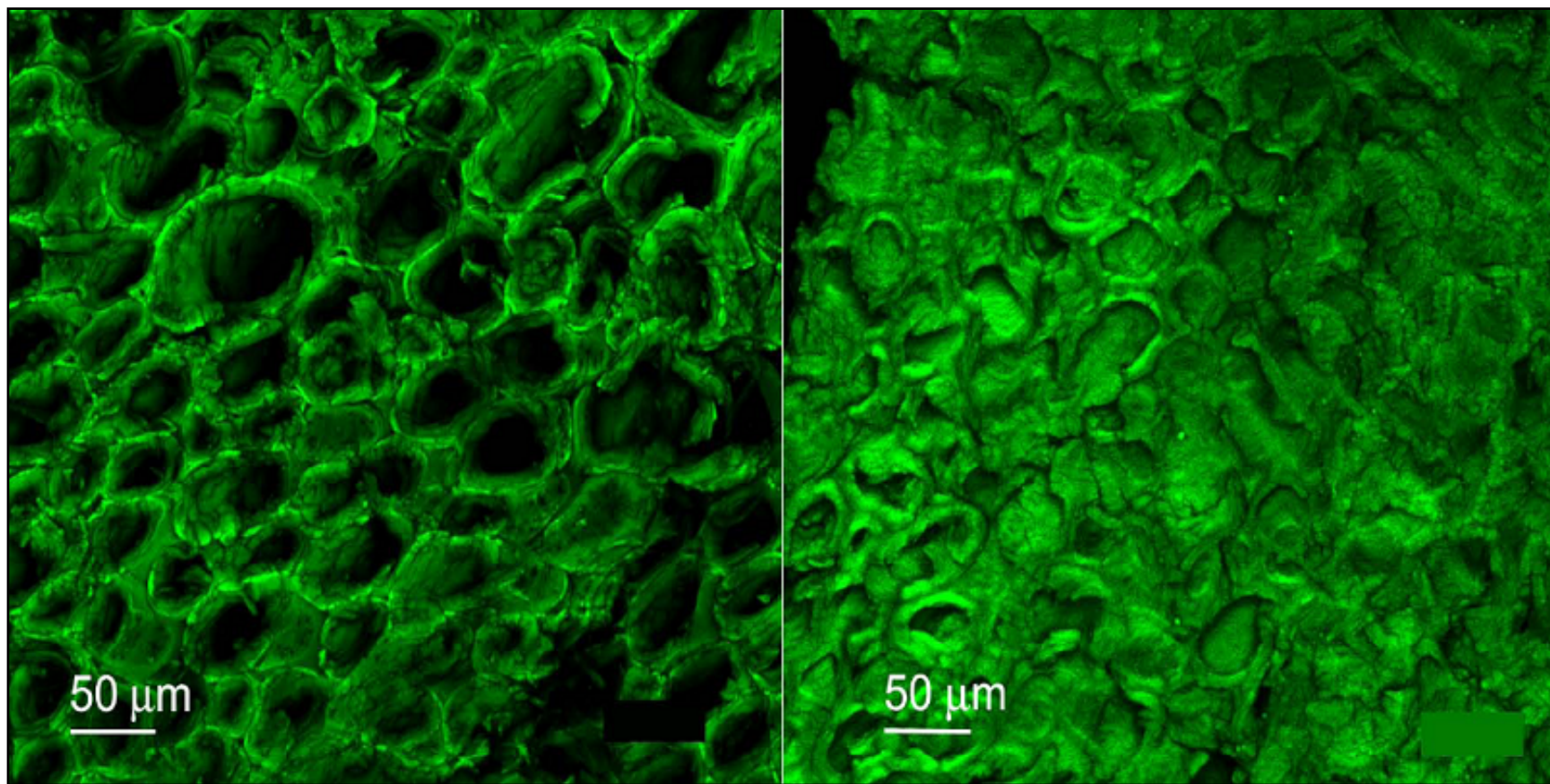
*Adapted from a drawing by US DOE EERE

Step 1: Pretreatment

Goal: use heat, grinding to break down plant cell walls to release cellulose fibers



Effect of Pretreatment of *Corn Cob Granule Sclereid Cells*

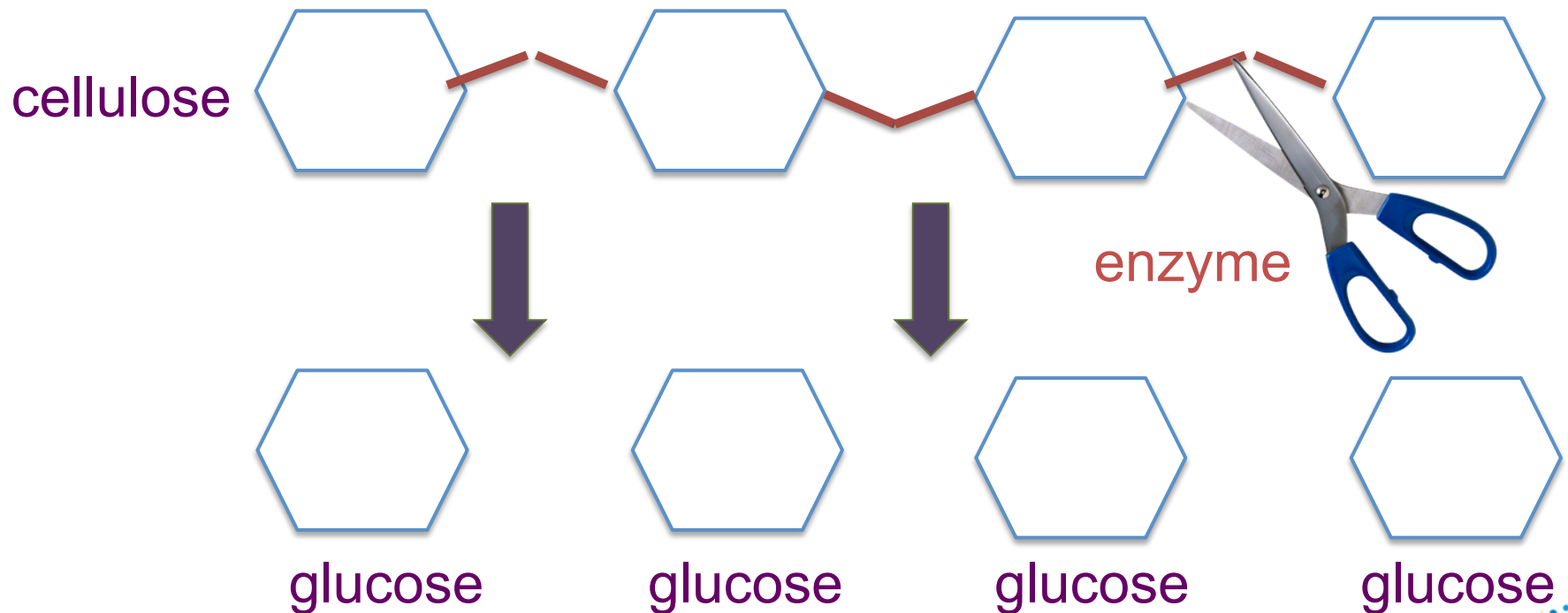


Step 2: Enzyme Digestion (Hydrolysis)

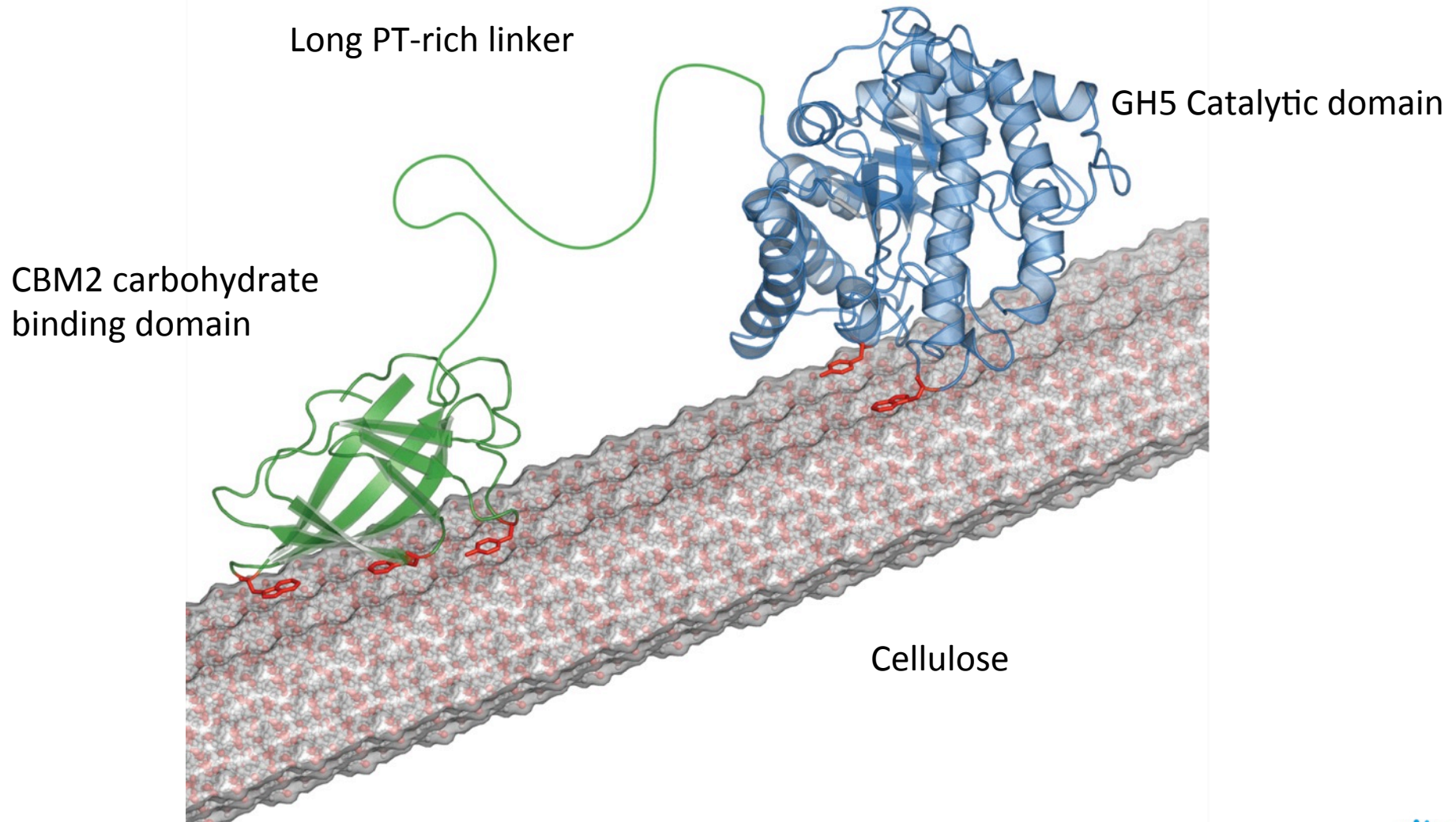
Goal: use cellulase enzymes to break down cellulose fibers into glucose molecules (sugar)

Enzyme Digestion (Hydrolysis)

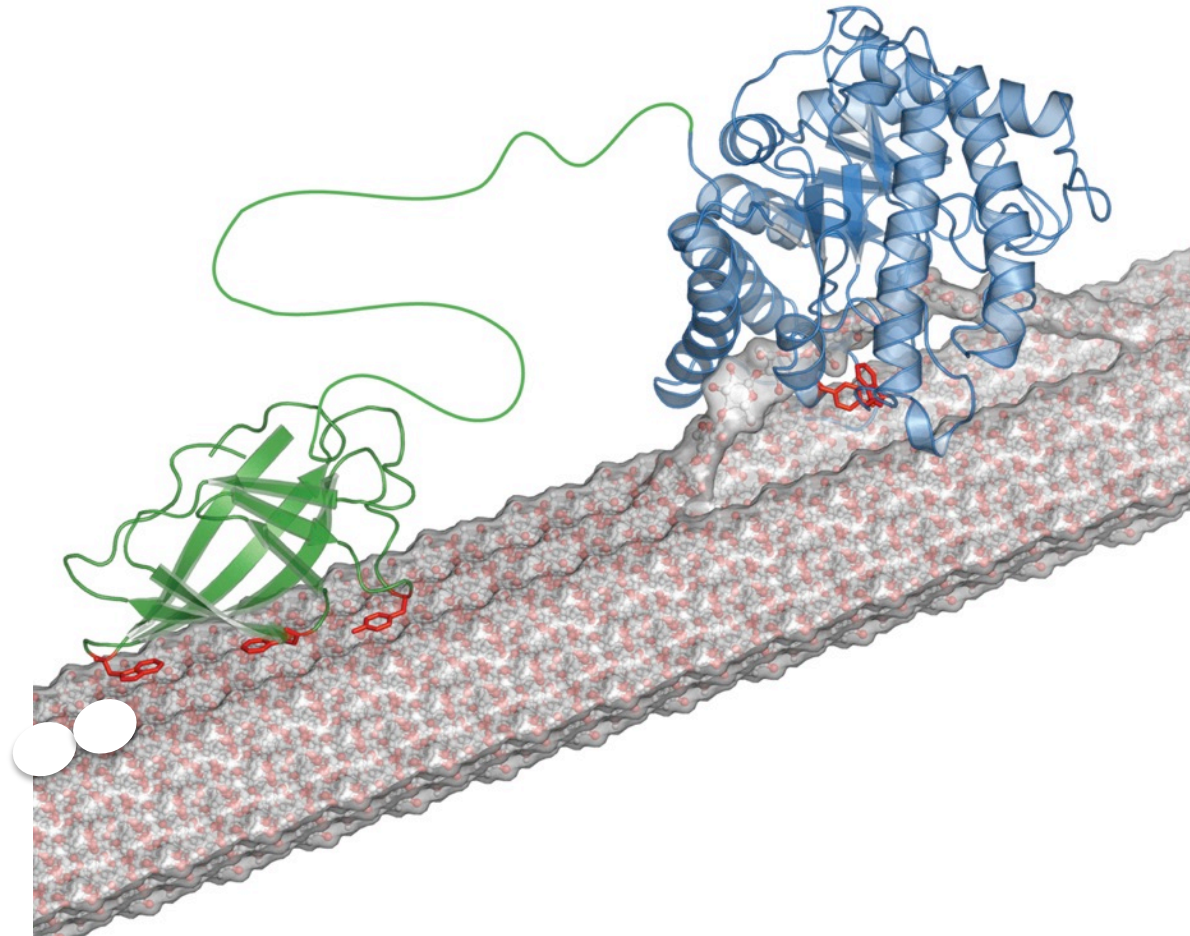
- ✧ Cellulose must be broken into individual glucose molecules using enzymes before fermentation can occur.



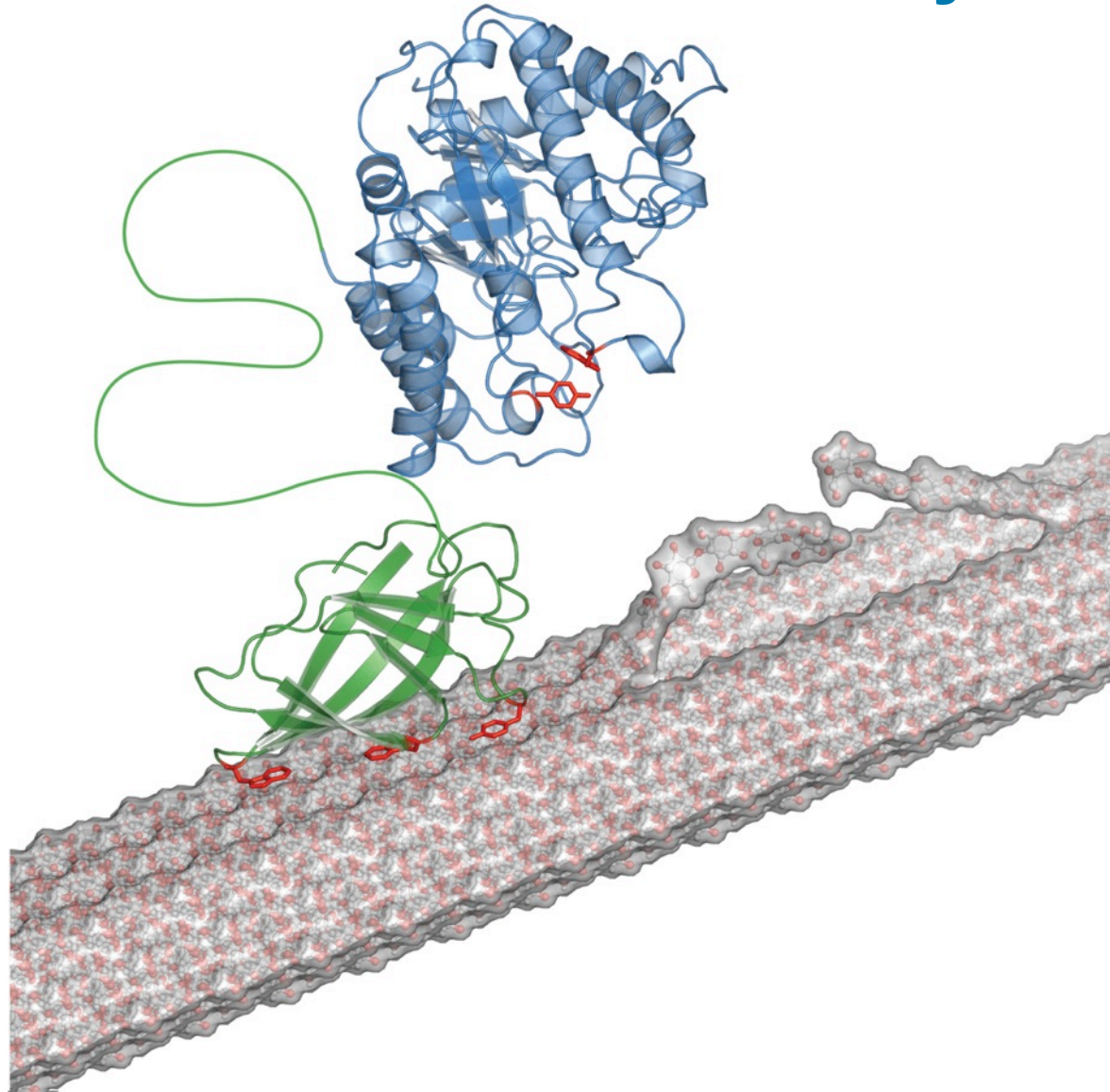
Endocellulase in Action!



Catalytic Domain Pulling up Cellulose Strand



Hydrolysis and Release of Catalytic Subunit

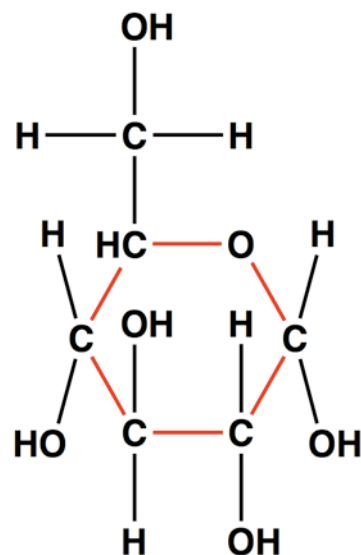


Step 3: Fermentation

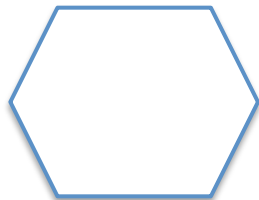
Goal: use yeast to consume glucose
and produce ethanol (fuel)

Standard fermentation:

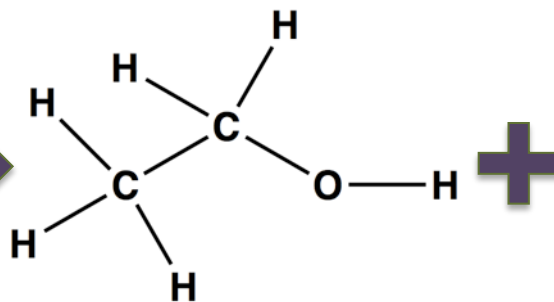
- enzymes in yeast convert glucose into ethanol and carbon dioxide when there is no oxygen.



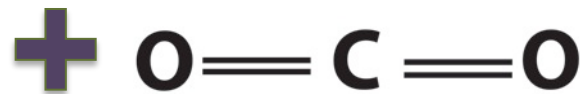
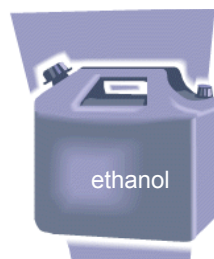
glucose



yeast



2 ethanol



2 carbon dioxide

