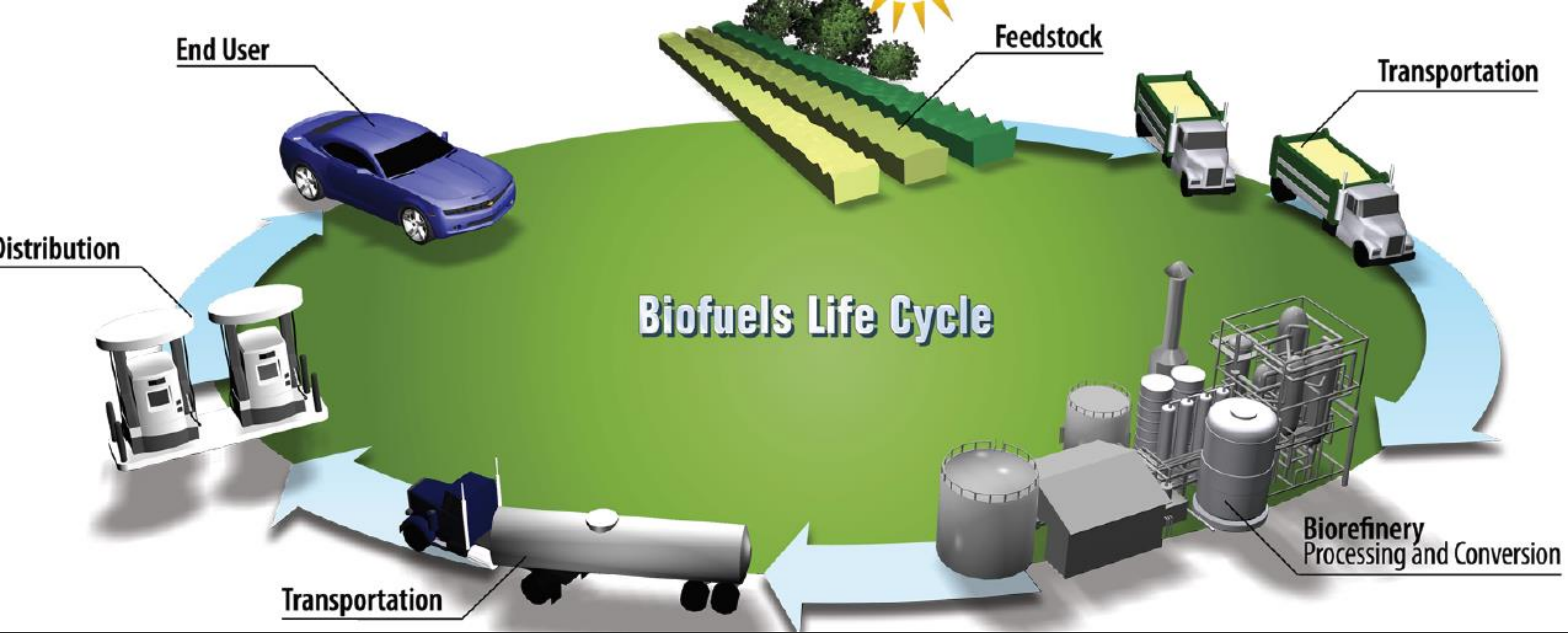


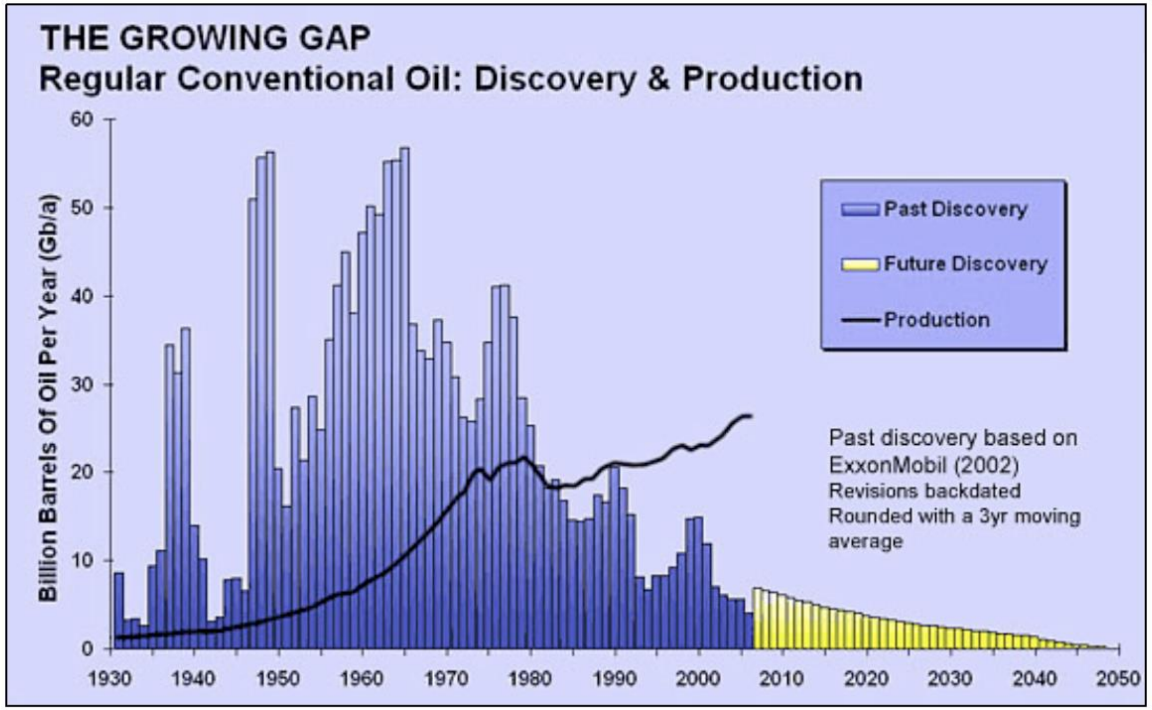
Woods to wheels

Ravikrishnan Elangovan,

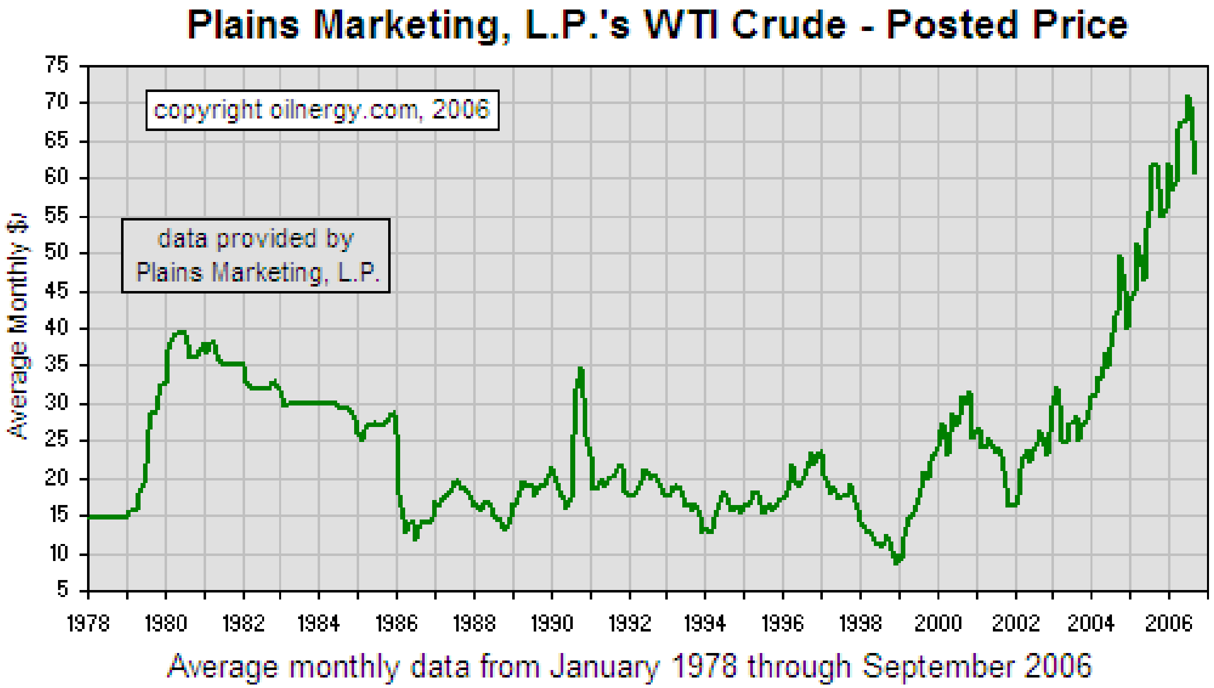
Department of Biochemical Engg and Biotechnology

Indian Institute of Technology - Delhi

Diminishing fossil fuels



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



Bio-ethanol

Gasoline

100%

Ethanol

67%

Biodiesel

86%

World Ethanol Production by Country, 2005	
Country	Production
	Million Litres
United States	16,214
Brazil	16,067
China	3,800
India	1,700
France	910
Russia	750
South Africa	390
Spain	376
Germany	350
Thailand	300
United Kingdom	290
Ukraine	245
Canada	230
Poland	220
Indonesia	170
Saudi Arabia	170
Argentina	165
Italy	150
Australia	125
Japan	113
Other Countries	2,139
World	**44,875**

Source: F. O. Licht, "Ethanol: World Production, by Country," table, **World Ethanol and Biofuels Report**, vol. 4, no. 17 (9 May 2006), p. 395, and the Earth Policy Institute.

Why Biofuels?

Biofuels, including cellulosic ethanol, are one of a small handful of petroleum alternatives that can provide:

- (inter) national security advantages
- large greenhouse gas reductions
- economic advantages (lower cost fuels than petroleum fuels)

Currently cellulosic ethanol is gaining major traction

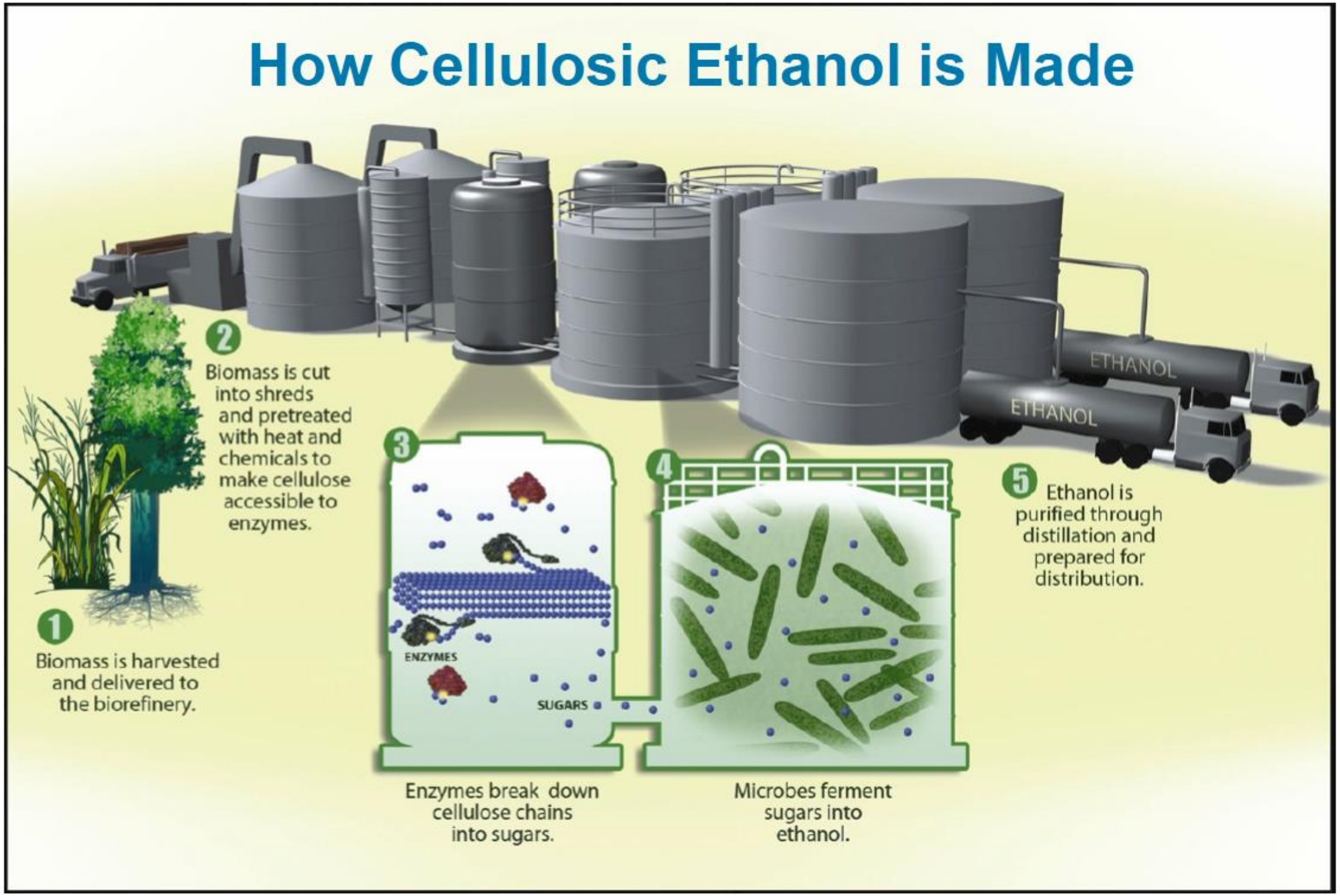
- From agricultural and forestry residues
- From “energy crops”

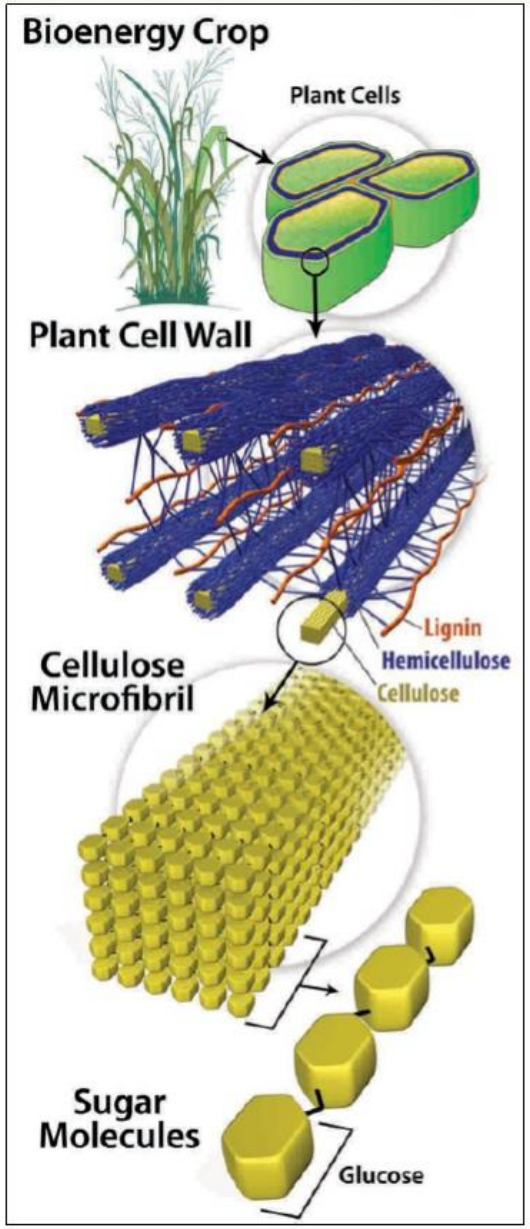
Sugar cane bioethanol

- Brazil produces **3,96 billion gallons** of ethanol from sugar cane
- Production cost **$0.87/gallon, the lowest in the world**
- Fossil fuel energy used to make the fuel (input) compared with energy in the fuel (output) **1:8**
- Green house emission during production and use **56%** less compared with gasoline

Benefits of Cellulosic Ethanol

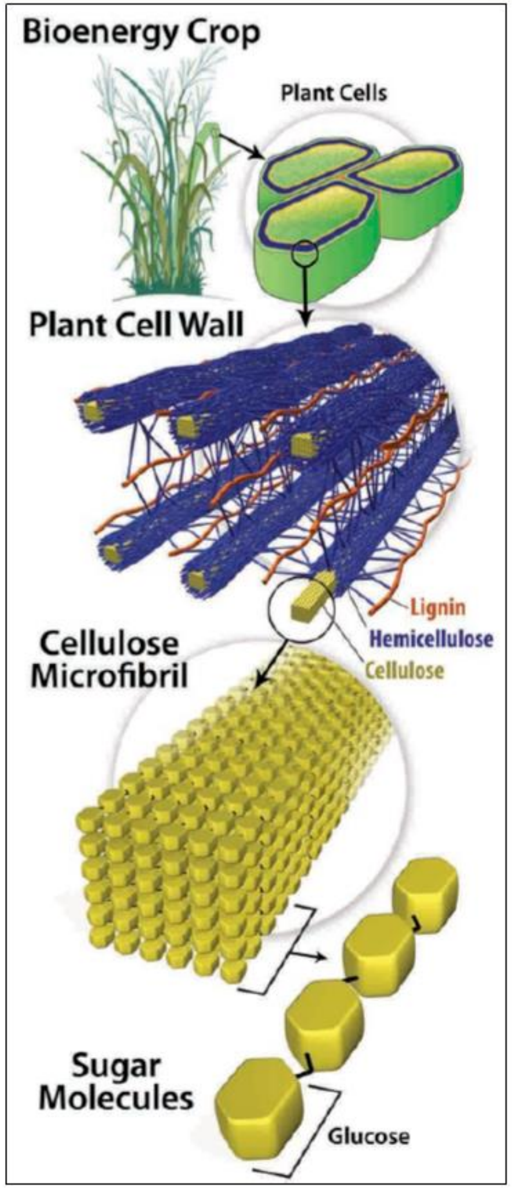
- ✓Access to wider array of potential feedstock, including waste cellulosic materials and dedicated cellulosic crops.
- ✓Greater avoidance of conflicts with land use for food production
- ✓Greater displacement of fossil energy per litre of fuel, due to nearly completely biomass-powered systems.
- ✓Much lower net greenhouse gas emissions than with grain-to-ethanol production powered primarily by fossil energy.


How Cellulosic Ethanol is Made
ETHANOL
ETHANOL
2
Biomass is cut into shreds and pretreated with heat and chemicals to make cellulose accessible to enzymes.
1
Biomass is harvested and delivered to the biorefinery.
3
ENZYMES
SUGARS
Enzymes break down cellulose chains into sugars.
4
Microbes ferment sugars into ethanol.
5
Ethanol is purified through distillation and prepared for distribution.



Cellulosic Biofuels

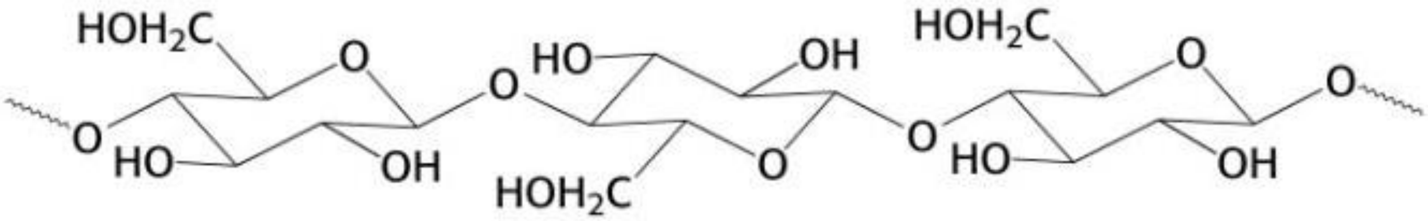
- Cellulose is the most abundant biological material on Earth
- Found in cell walls
- Lack efficient way to break down plant material and convert it into fuel
- Cell wall composition varies



Plant Cell Wall Structure

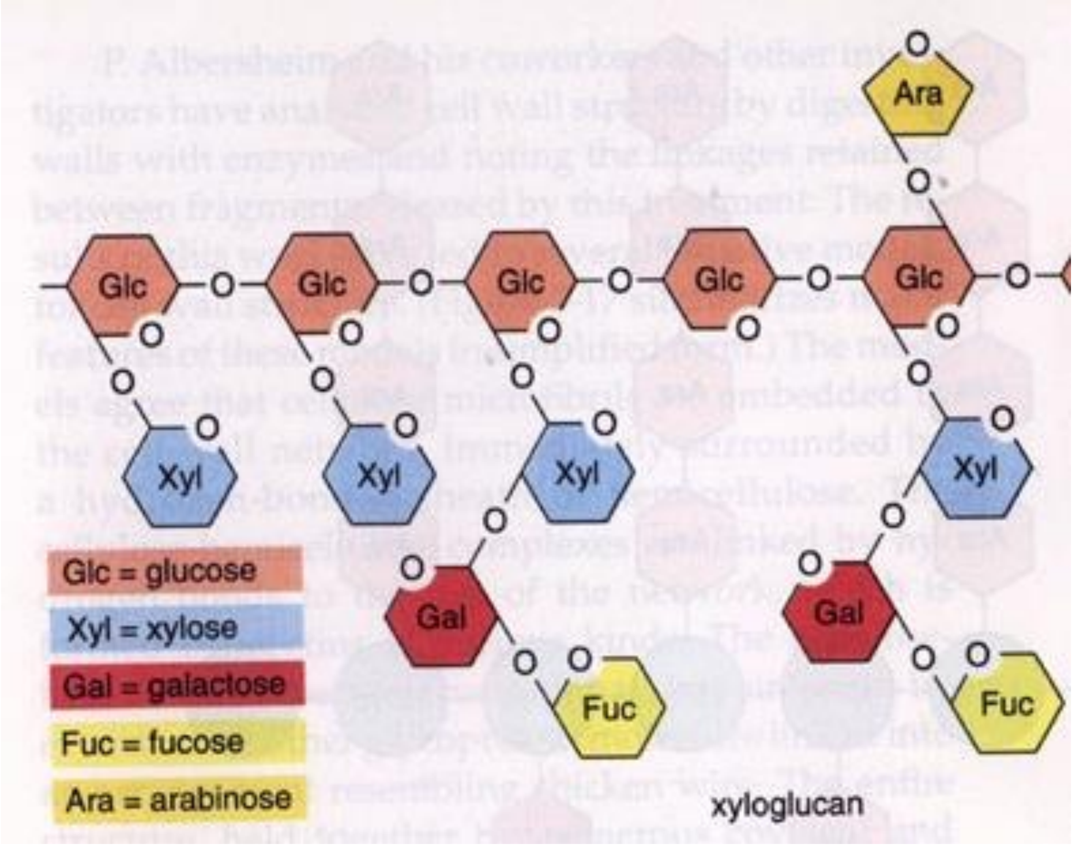
- Cellulose—primary carbohydrate goal for extraction
- Hemicellulose—carbohydrate, harder to convert to fuel
- Lignin—may be burned for heat/electricity, converted into useful chemicals

Cellulose

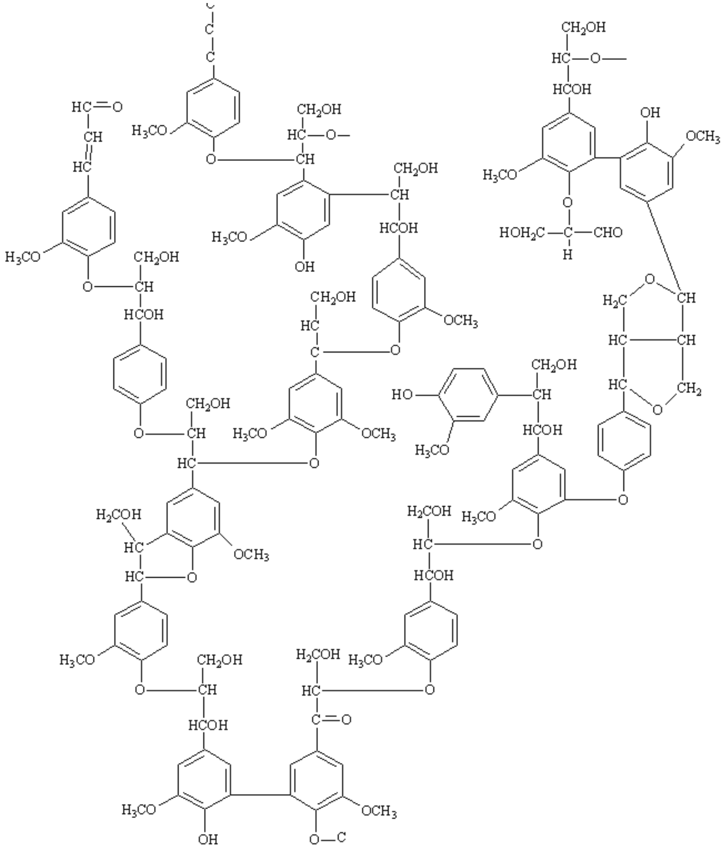


Cellulose
(β-1,4 linkages)

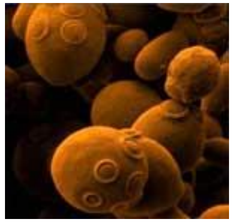
Hemicellulose



Lignin



Bioconversion of biomass to ethanol (pretreatment)



Pretreatment

Biomass → Liquid phase → Sugars → Ethanol → Recovery

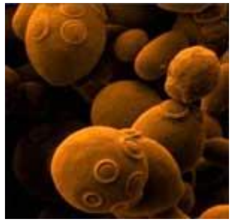
Fermentation

Solid phase: Lignin, Cellulose

Cellulose → Sugars (Hydrolysis) → Ethanol (Fermentation) → Recovery





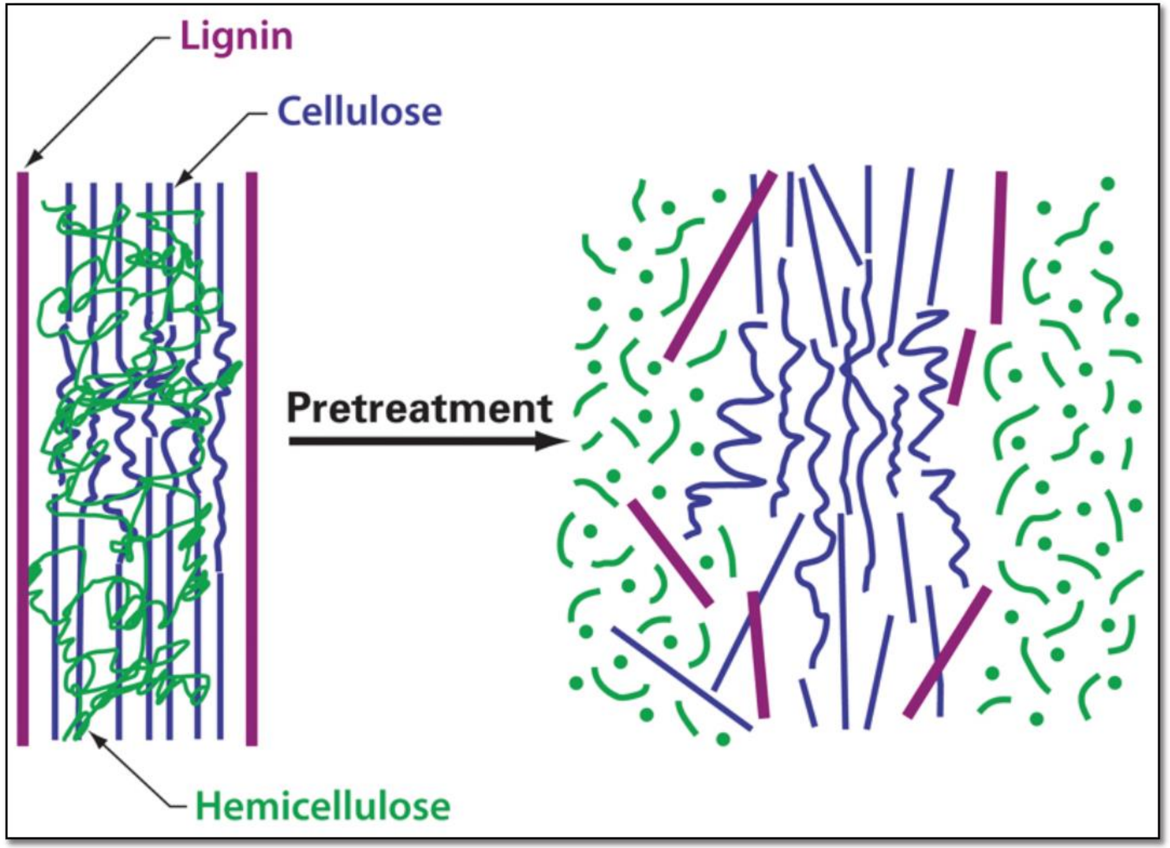


Pretreatment-”disruption”

Helps in separation of main biomass components (cellulose, hemicellulose and lignin)

Increase available surface area

Reduce particle size



Steam explosion

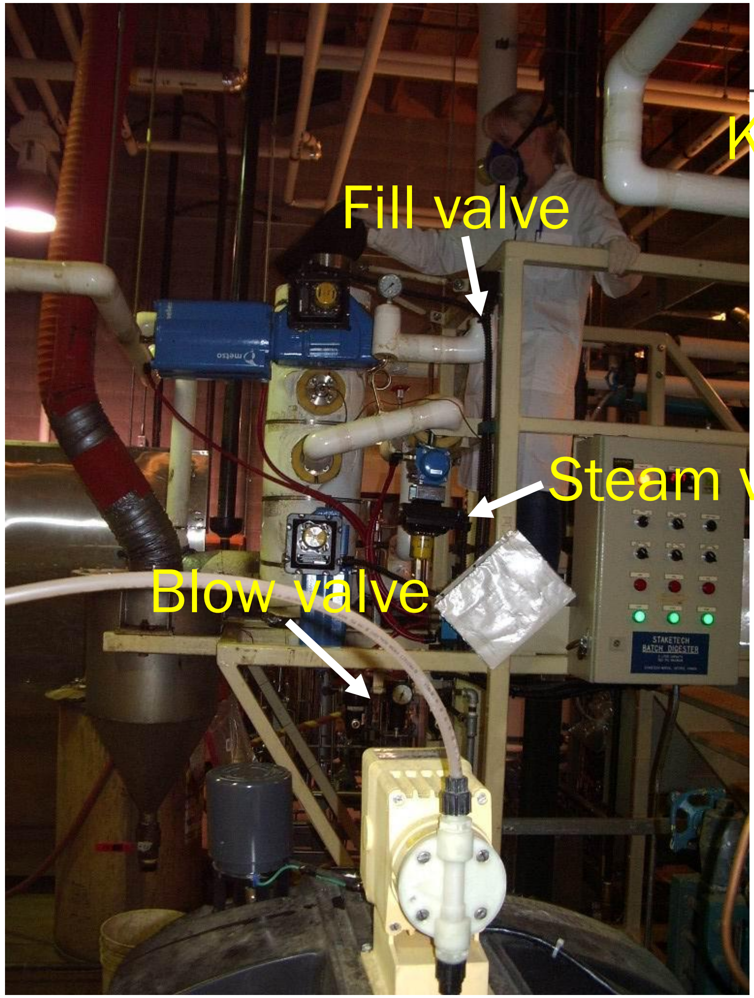
Treatment of biomass with high-pressure steam for a short period of time followed by sudden decompression

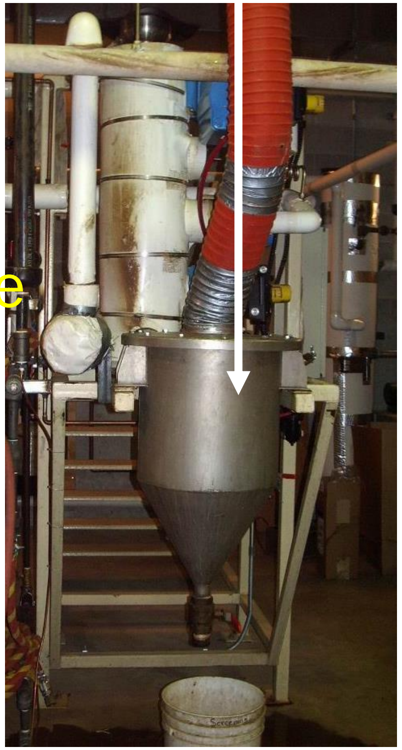
Acid (H_2SO_4, SO_2) impregnation of biomass increases SE efficiency

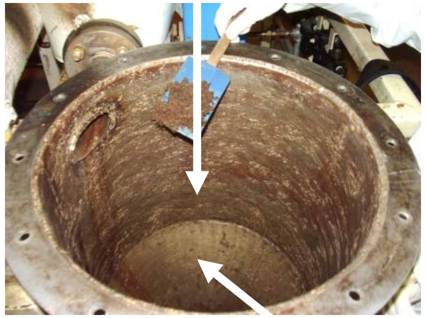
Typical conditions:

- Temperature: 170-250^{o}C, 338-482 F
- Time: 10sec-10min

Steam gun



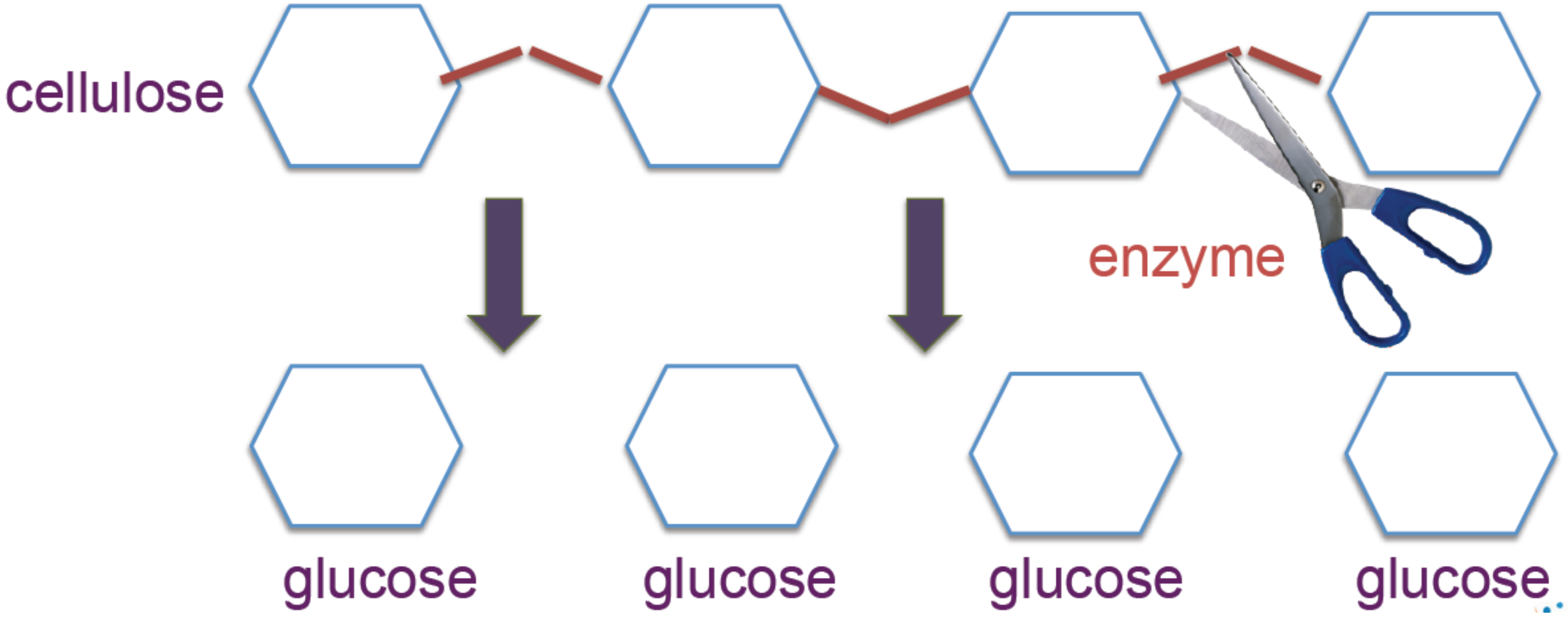




Pretreated corn stover

Enzyme Digestion (Hydrolysis)

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

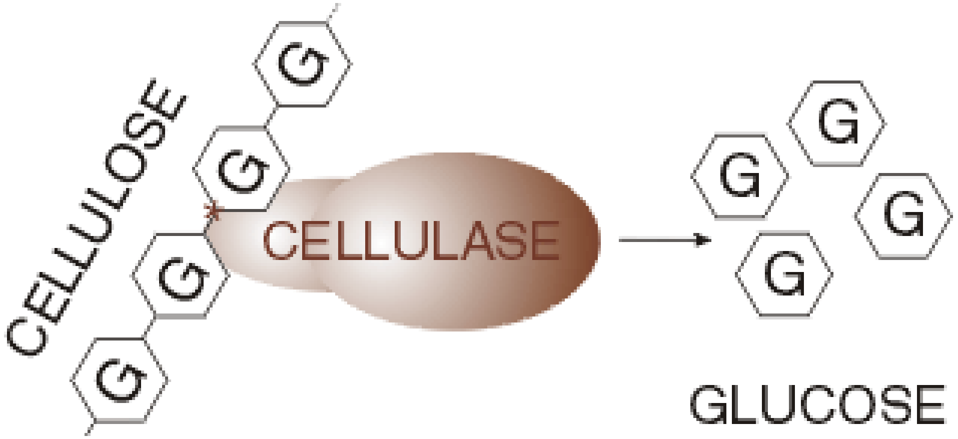


What are cellulases?

Produced by many strains of bacteria and fungi

Catalyzes the depolymerization of cellulose chains

- Endoglucanases
- Exoglucanases
- β-glucosidases



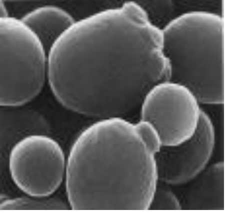
Fermentation

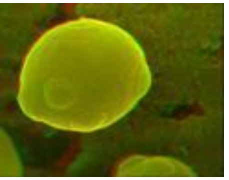
Defined as:

Cellular metabolism under anaerobic conditions (absence of oxygen) for the production of energy and metabolic intermediates

Many organisms can "ferment" (i.e., grow anaerobically)

Not all produce ethanol as an end-product of fermentation





Strain selection

Choice of microorganism for ethanol production has traditionally been a Yeast

Yeast:

- Single cell microorganism
- Fungi
- Facultative anaerobe

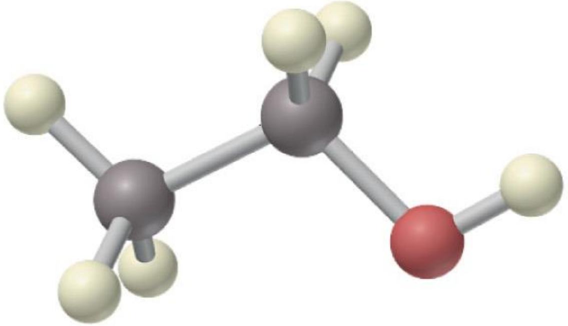
Most common industrial fermenter is *Saccharomyces cerevisiae* (baker's or brewer's yeast)




Fermentation

$$C_6H_{12}O_6 \xrightarrow{\text{Yeast}} 2\,CO_2 + 2\,CH_3CH_2OH$$

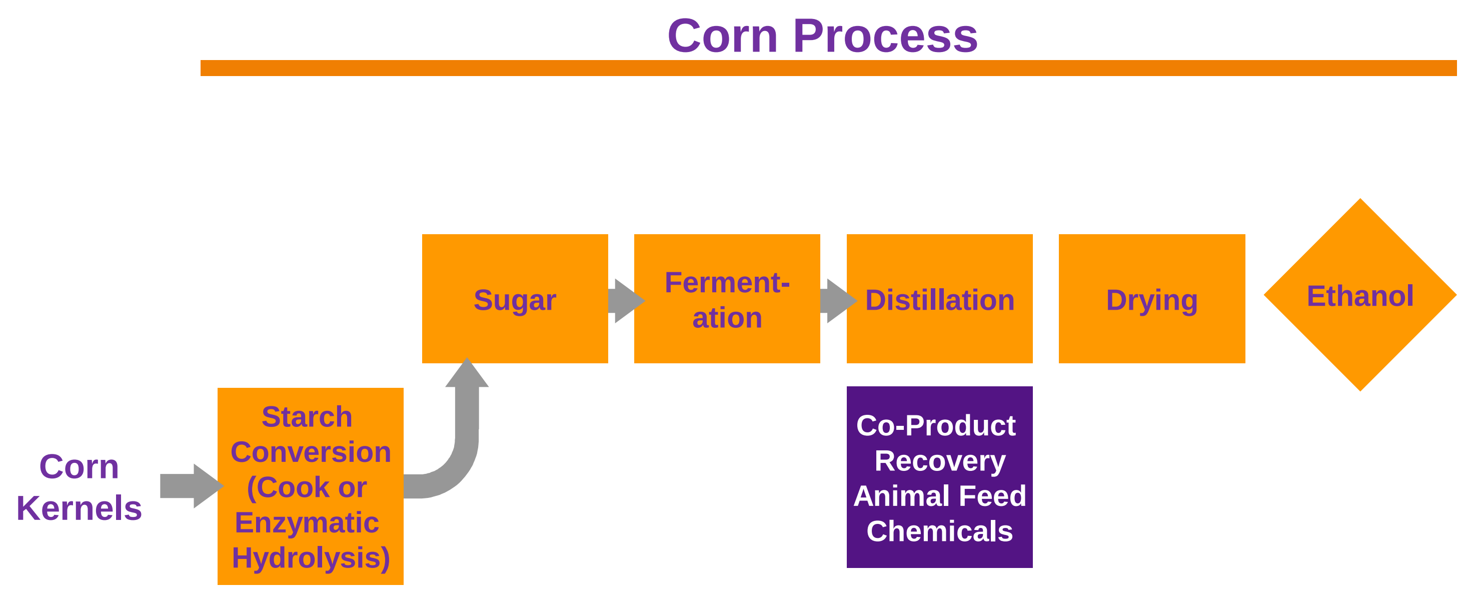
Glucose — Ethanol



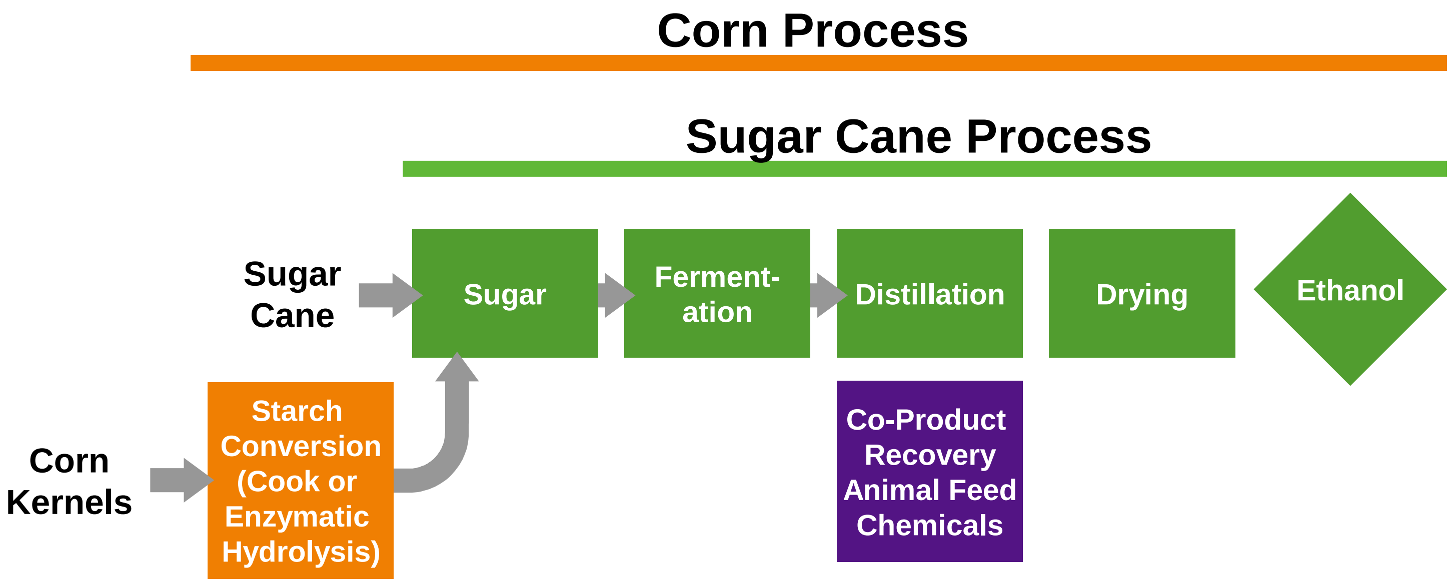
Conversion factor 0.51

1g/L of glucose: 0.51g/L ethanol (maximum)

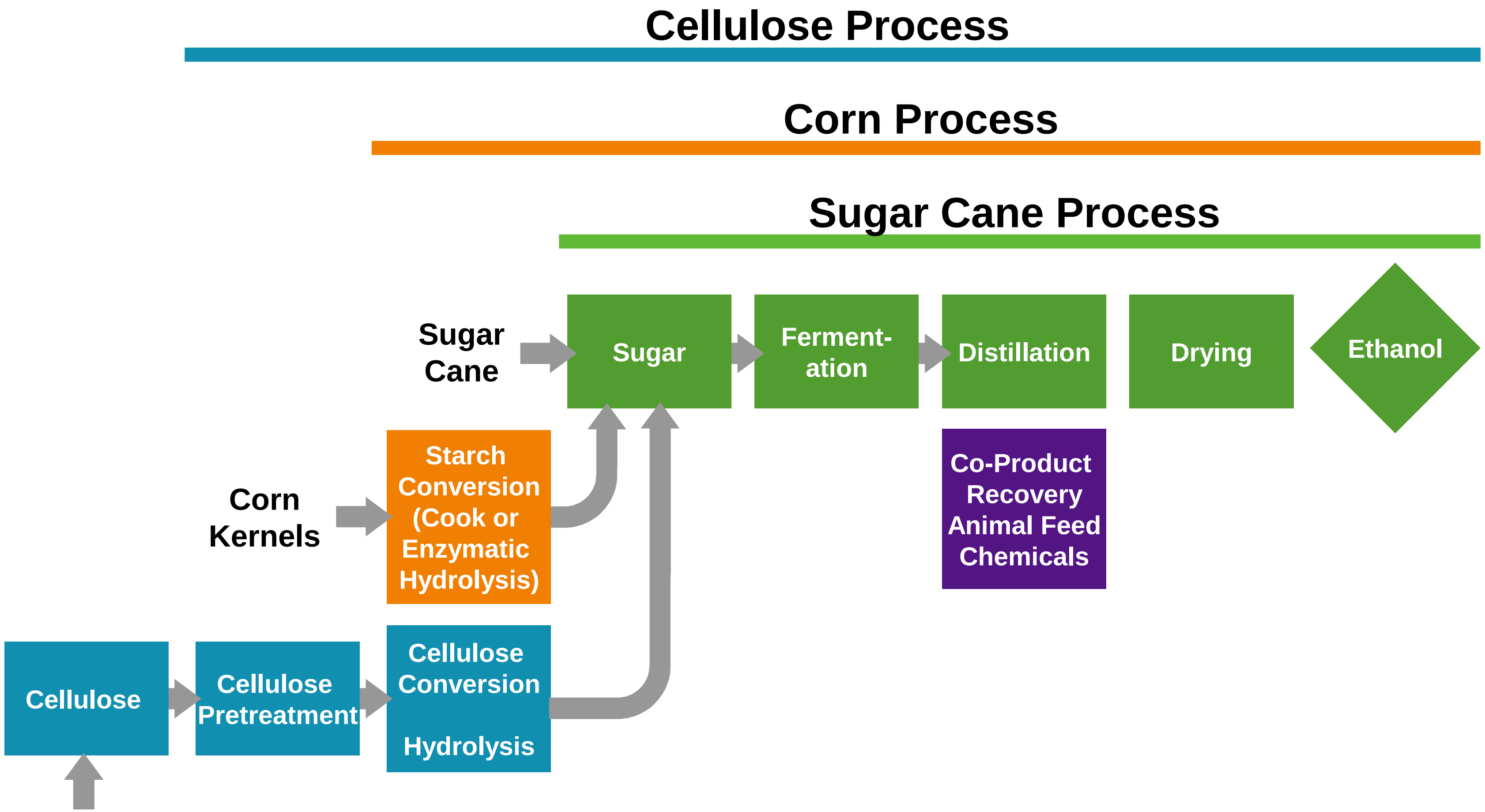
Ethanol Production Flowchart



Ethanol Production Flowchart

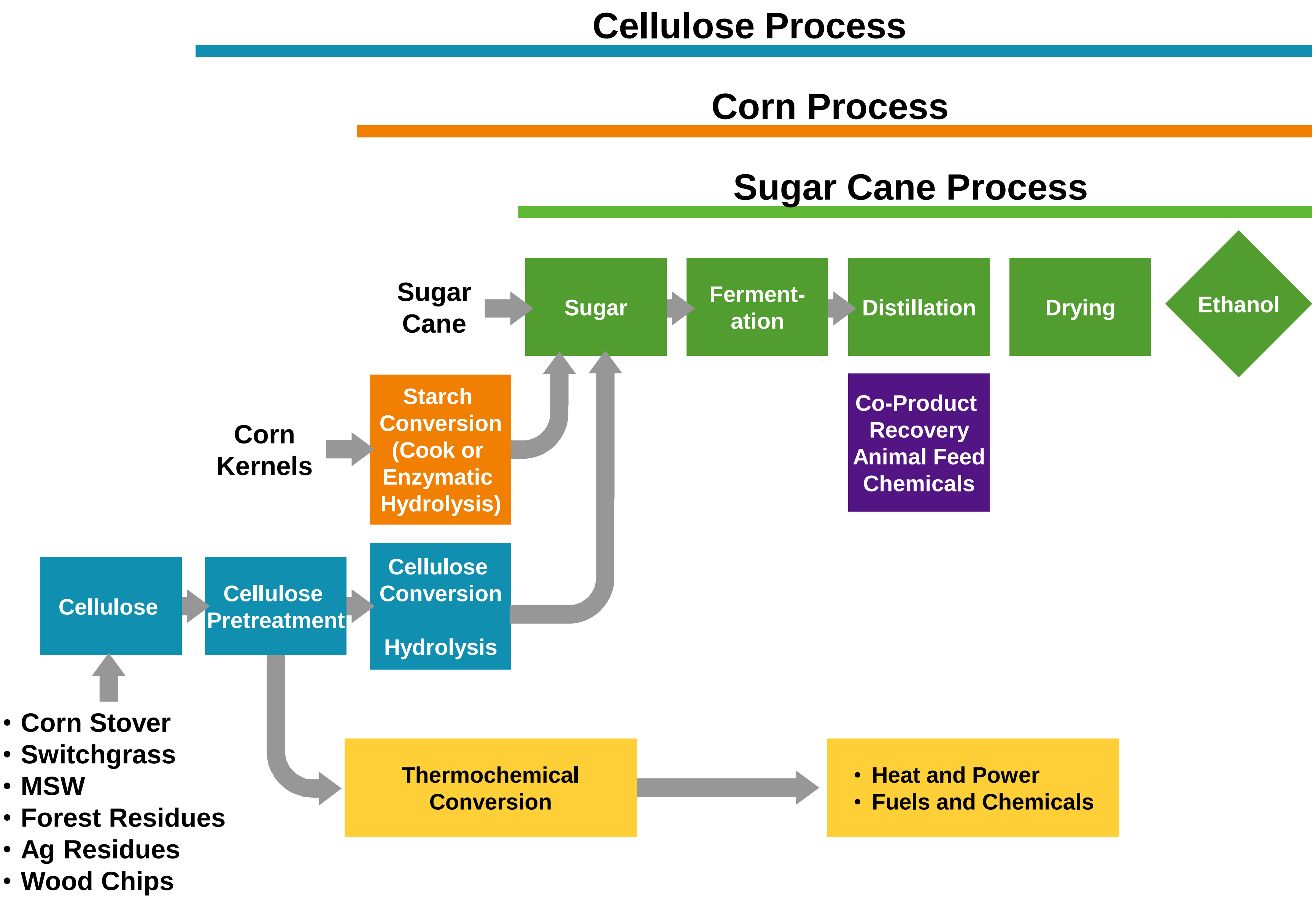


Ethanol Production Flowchart



- Crop residues: corn stover, rice straw, wheat straw, etc.
- Forestry residues/slash
- Energy crops: switchgrass, poplar, *Miscanthus,* many others
- Municipal & construction wastes, etc

Ethanol Production Flowchart



RE·
FORM·
ENERGY

Capturing Local Benefits from Biofuels

Some issues for farmers/local interests

- If farmers merely supply biomass, they will not benefit much from the biofuels revolution
- Investment required for cellulosic ethanol biorefinery is huge ~ $250 million and up—difficult for farmers to participate

Some issues for biofuel firms/larger society

- Supply chain issues are enormous—need 5,000 ton/day from ~1,000 farmers: chemicals/fuels industries have zero experience with such large agricultural systems
- Cellulosic biomass is bulky, difficult to transport
- Need to resolve "food vs. fuel" problem: actually "animal feed and fuel opportunity"

Is there a common solution?

- Regional Biomass Processing Center– concept worthy of study
- Pretreat biomass for biorefinery & ruminant (cattle) feeding
- Much lower capital requirements—accessible to rural interests
- Develop additional products over time—animal feed protein, enzymes, nutraceuticals, biobased composites, etc