Technology, Research and Development for the Bioeconomy

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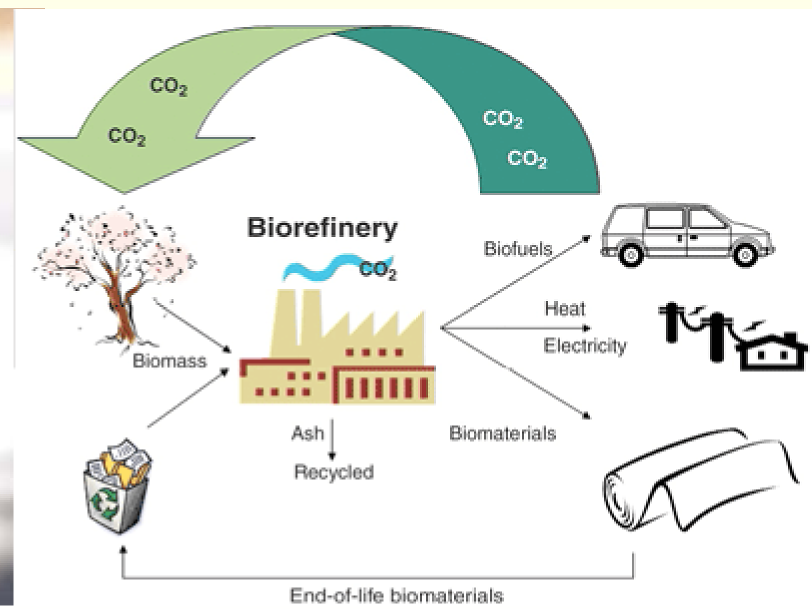
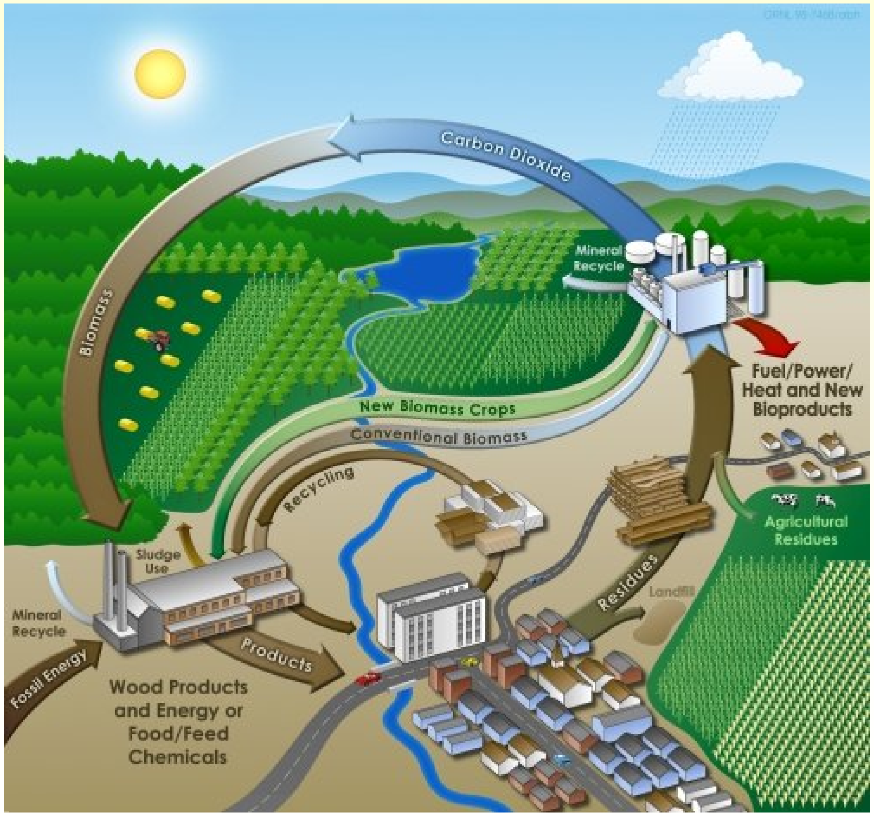
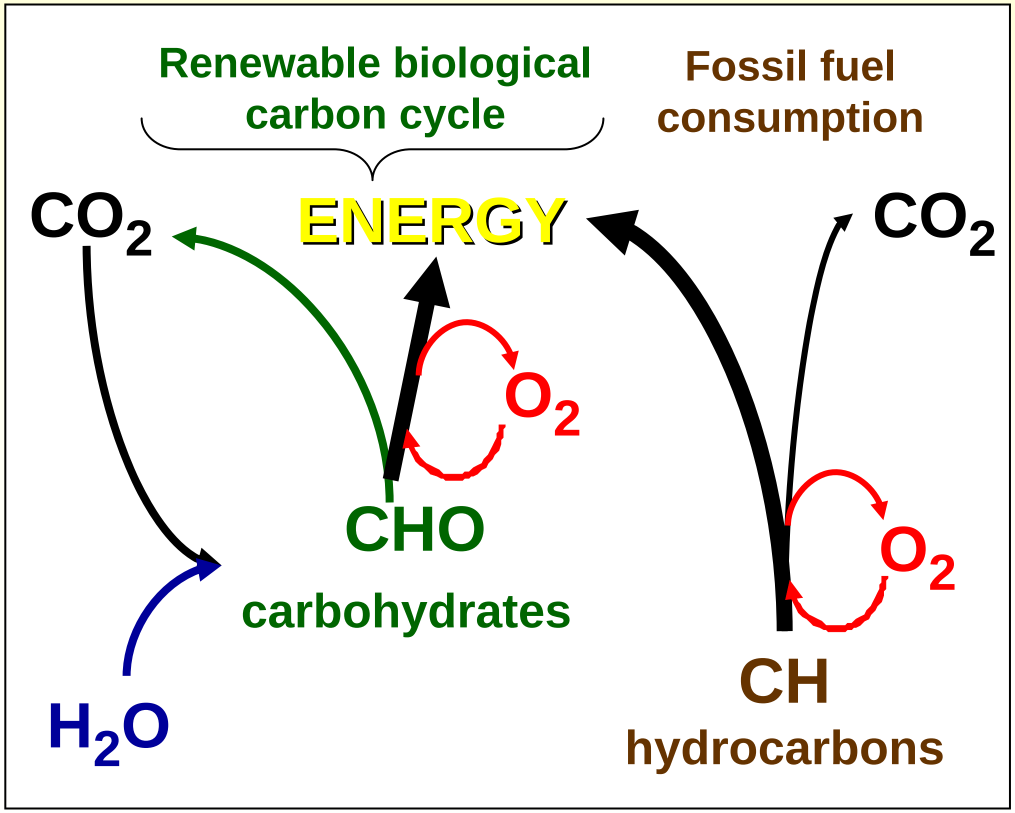


What is the Bioeconomy?

Conversion of energy sector feedstocks from fossil fuels to renewable and sustainable sources of biological carbon





Key Technologies for the Bioeconomy

CO_2 Fixation – photosynthesis

- Plants – cellulose, starch, sugars
- Green algae - lipids

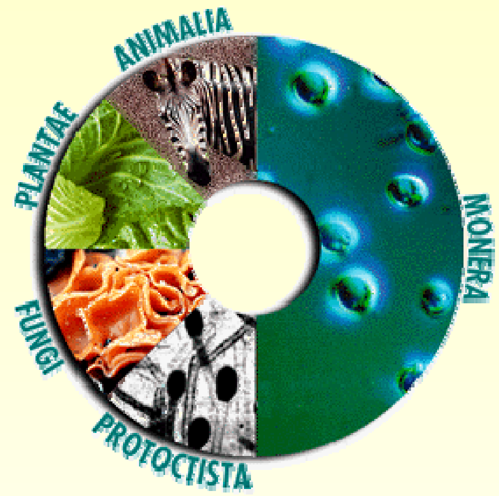
Carbohydrate conversion – removing oxygens

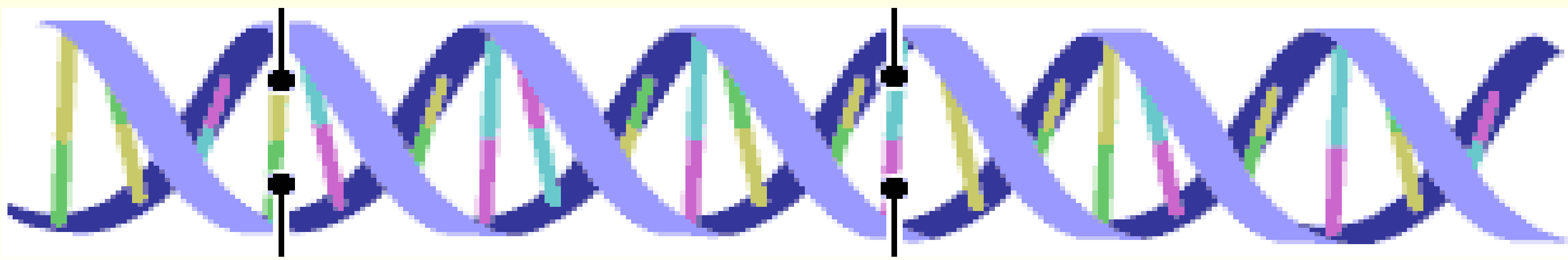
- Biodiesel – biological lipids
- Syngas – carbon monoxide & hydrogen
- Microbial fermentation – ethanol & butanol
- Direct chemical synthesis – alkanes and many others
- Pyrolysis to bio-oil, syngas or biochar

R & D for the Bioeconomy

Greater understanding of biology from cell to ecosystem

Modifying traits by reprogramming DNA via breeding/biotechnology



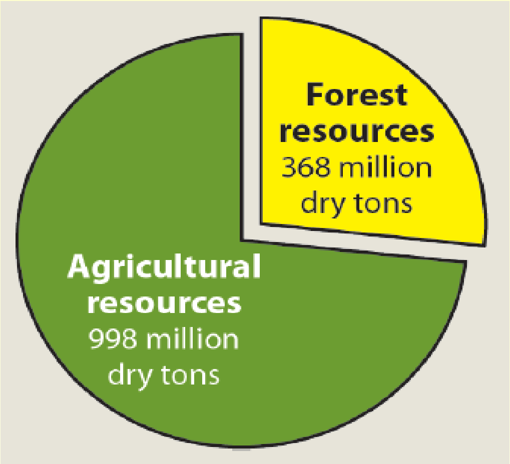


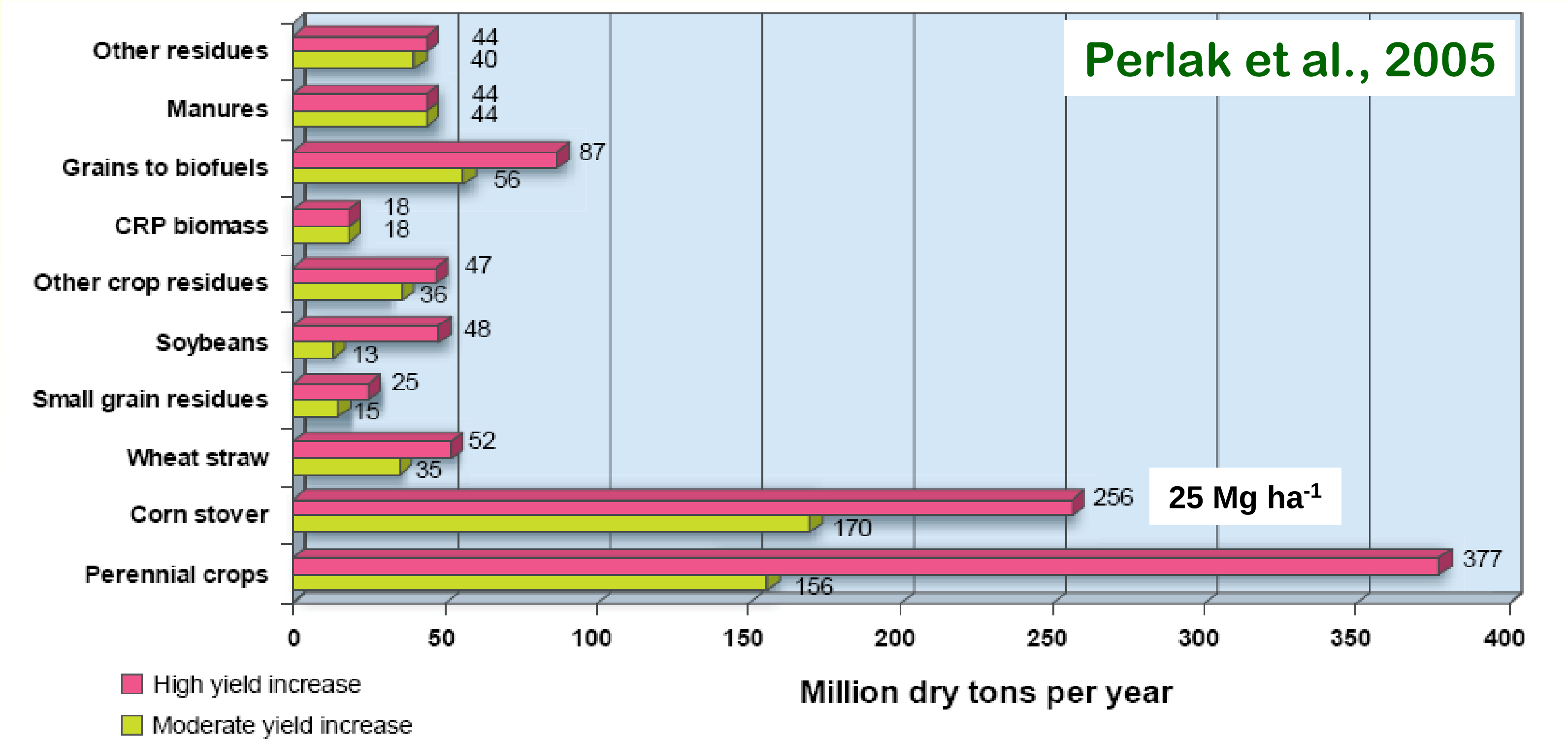
Genome = the entire DNA code for an organism

Genomics = the study of genes and their function

R & D for the Bioeconomy – increasing agricultural biomass

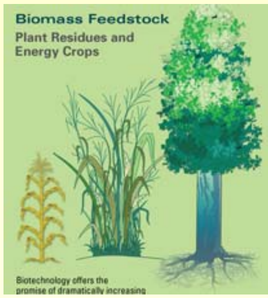
- **DOE "billion ton vision" requires nearly a ~5X increase in harvested biomass.**
- **Must be achieved via sustainable, carbon positive systems**



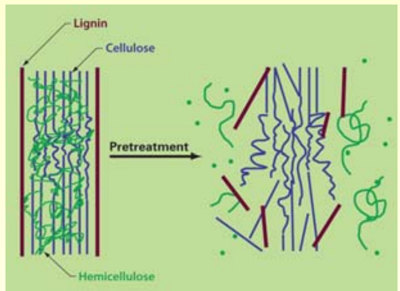


R & D for the Bioeconomy - optimize carbohydrate conversion efficiency…

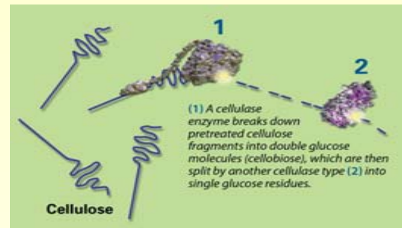
Theoretical yield of EtOH from sucrose is 163 gallons per ton.



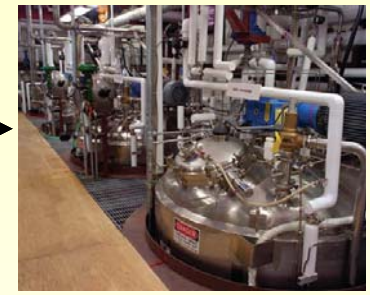
Biomass Feedstock



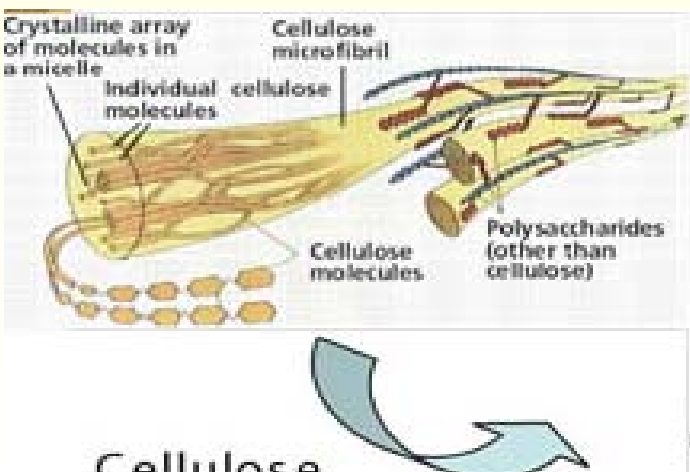
PreTreatment



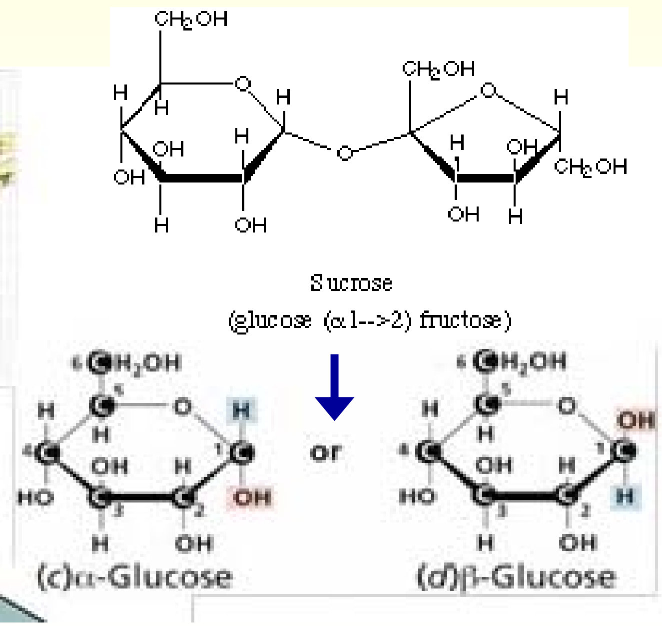
Hydrolysis/ Deconstruction



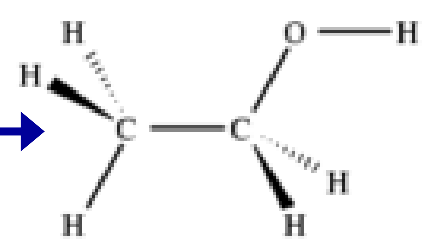
Fermentation



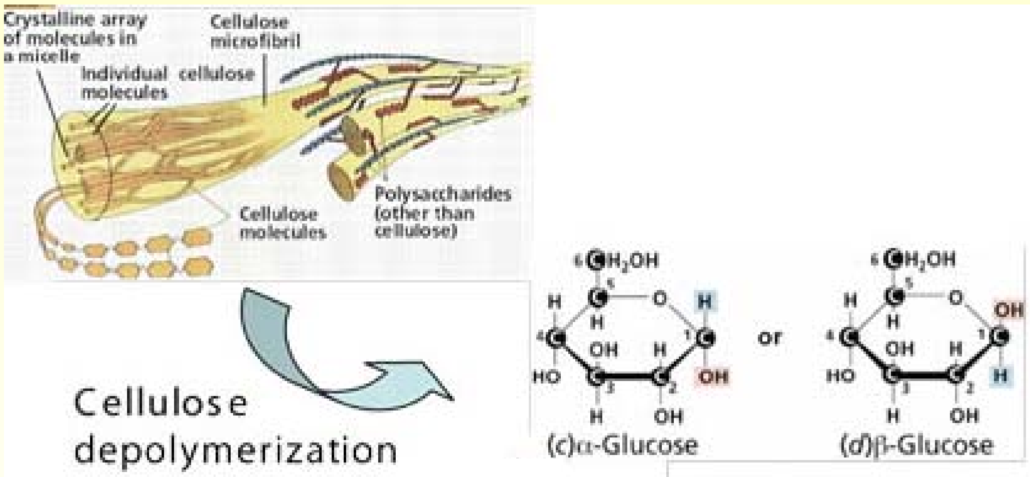
Cellulose depolymerization



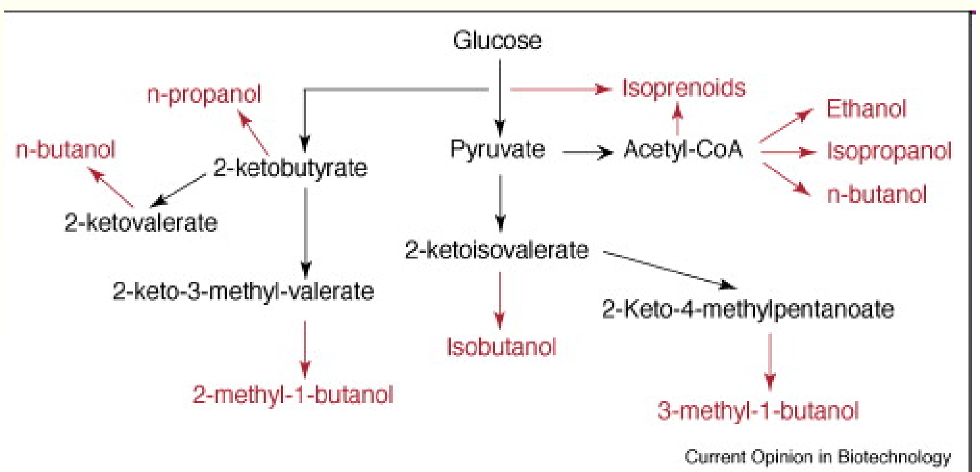
ethanol



R & D for the Bioeconomy – increase yields of desirable end-products through metabolic engineering of microbes



- Rumen flora
- Termite intestinal bacteria
- Plant fungal/bacterial pathogens



- Yeasts - ethanol
- *Clostridia* - butanol
- *E. coli* – model system
- Thermophilic bacteria

R & D for the Bioeconomy – direct chemical conversion of sugars to hydrocarbons

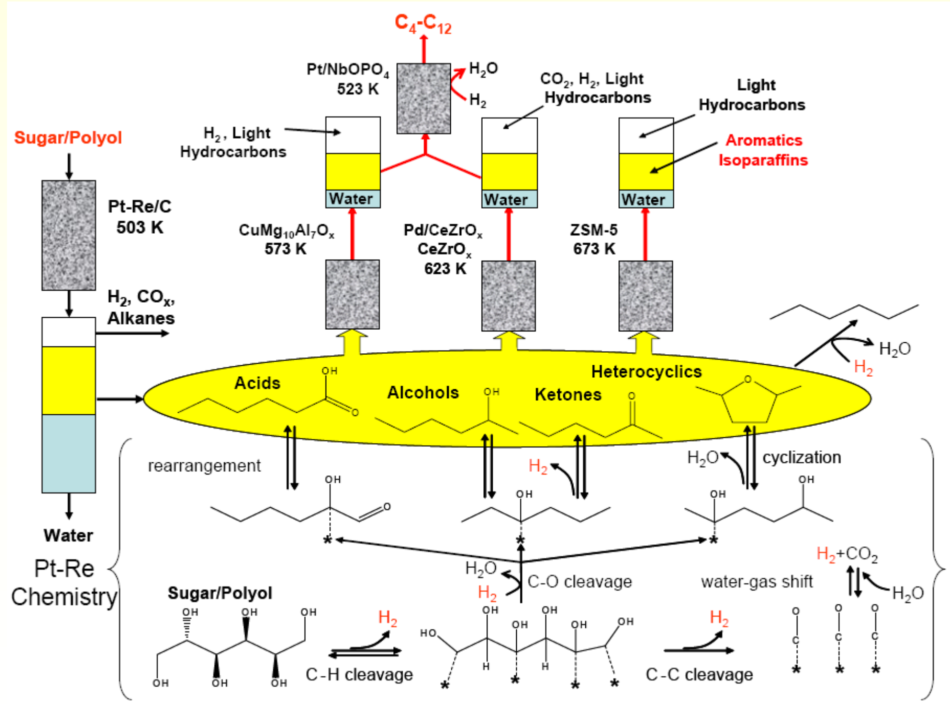
- **Identify preferred substrates**
- **Optimize reaction rates**
- **Increase end-product purity**
- **Separation**

Sciencexpress Report

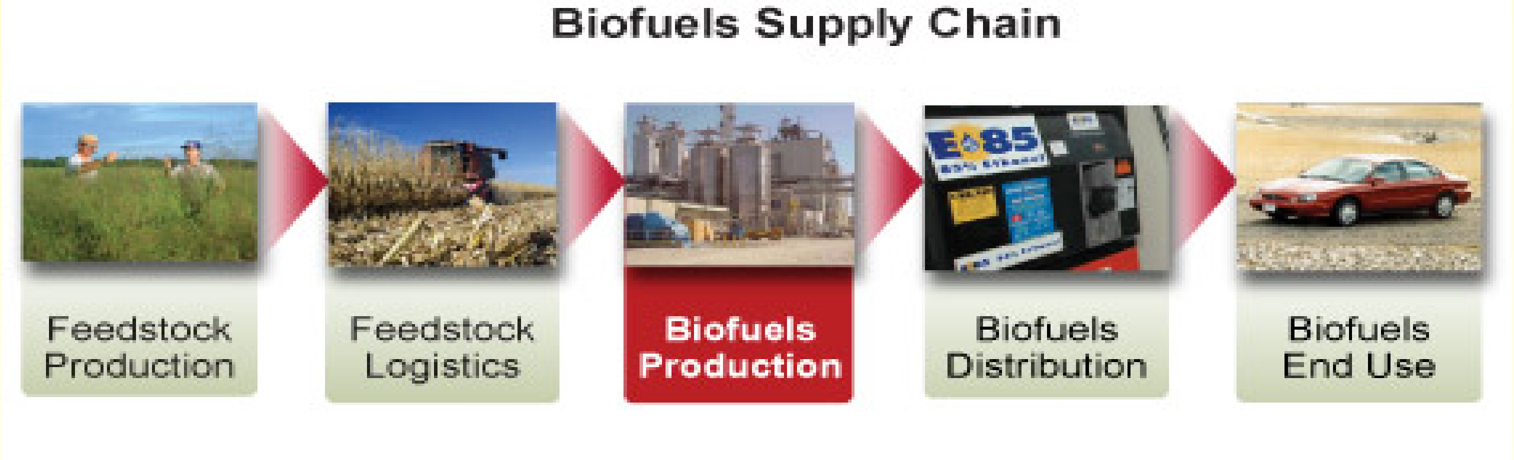
Catalytic Conversion of Biomass to Monofunctional Hydrocarbons and Targeted Liquid-Fuel Classes

Edward L. Kunkes, Dante A. Simonetti, Ryan M. West, Juan Carlos Serrano-Ruiz, Christian A. Gärtner, James A. Dumesic*

Department of Chemical and Biological Engineering, University of Wisconsin-Madison, Madison, WI 53706, USA.



R & D for the Bioeconomy



For any potential carbon fixation and conversion process, also need to consider:

- **Energy balance**
- **Environmental impacts – reducing GHGs**
- **Scalability**
- **Economic factors and societal impacts**

R & D for the Bioeconomy

Broad interdisciplinary scope of research has led to the establishment of interdisciplinary research institutes:

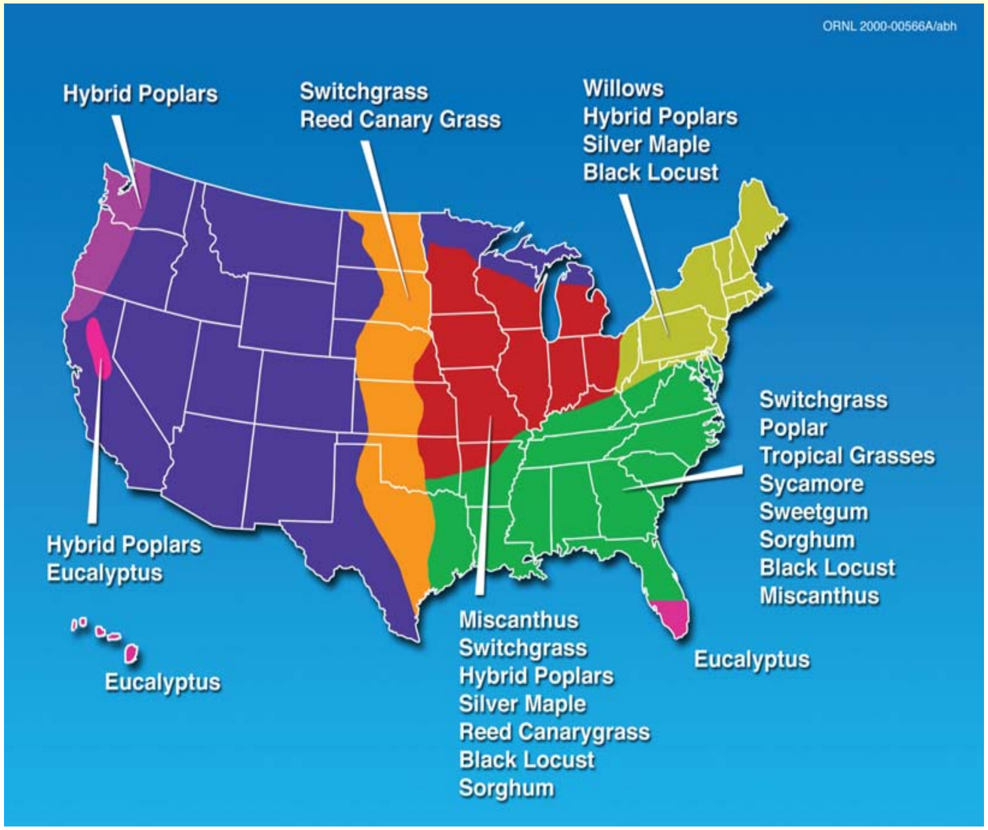
Other Important Players:

- Major grain/chemical processors – ADM, Dow, DuPont
- Major crop and forestry biotechnology firms – Monsanto, Pioneer
- Enabling technology startups
- Government – DOE, USDA
- Universities
- University-industry partnerships

Bioenergy Feedstocks – Many Choices and Options

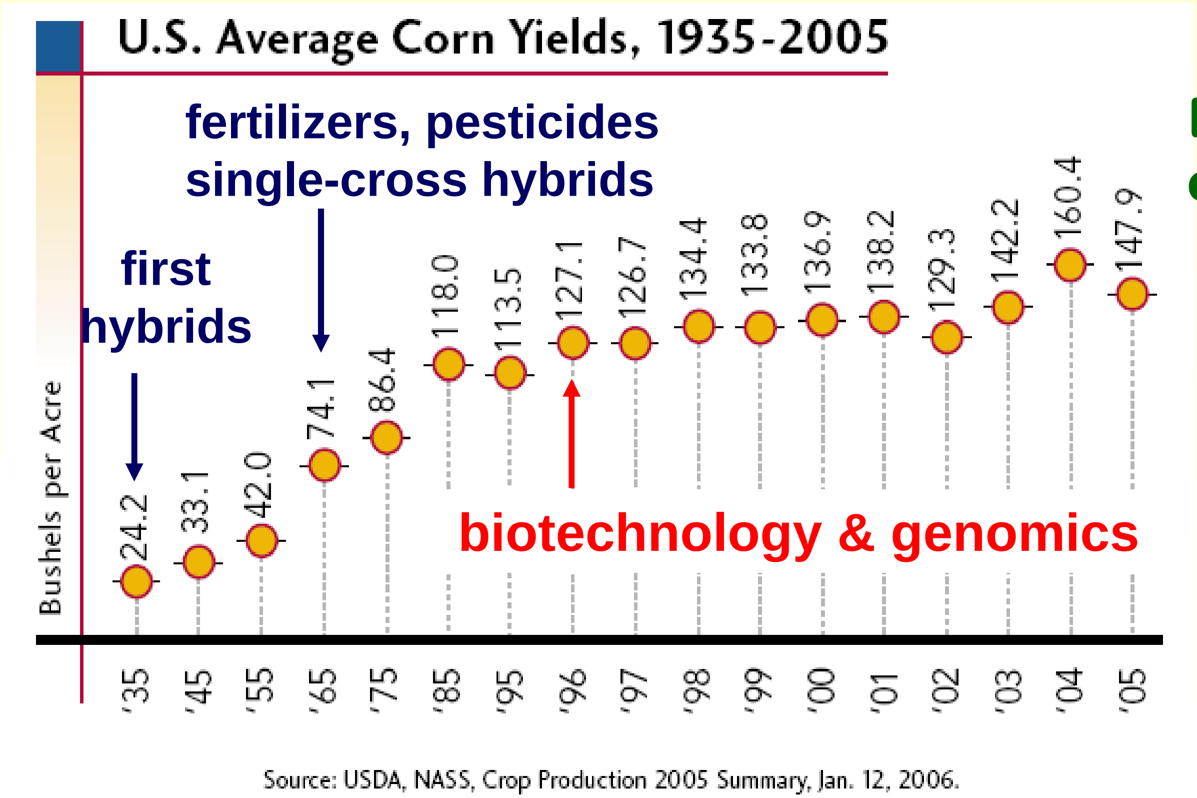
Adaptation for high biomass yields in the target production environment is a major driver for selection of feedstock crops.

Observed Annual Yields of U.S. Biomass Crops (Mg/ha/yr)	
Alfalfa Soybean	2 – 8 5 – 10
Softwoods (e.g., poplar)	5 - 15
Switchgrass	5 - 20
Maize *Sorghum* *Saccharum* *Miscanthus x giganteus*	15 – 30 15 – 30 25 – 50 25 - 50



Increasing biomass yields 5X!!

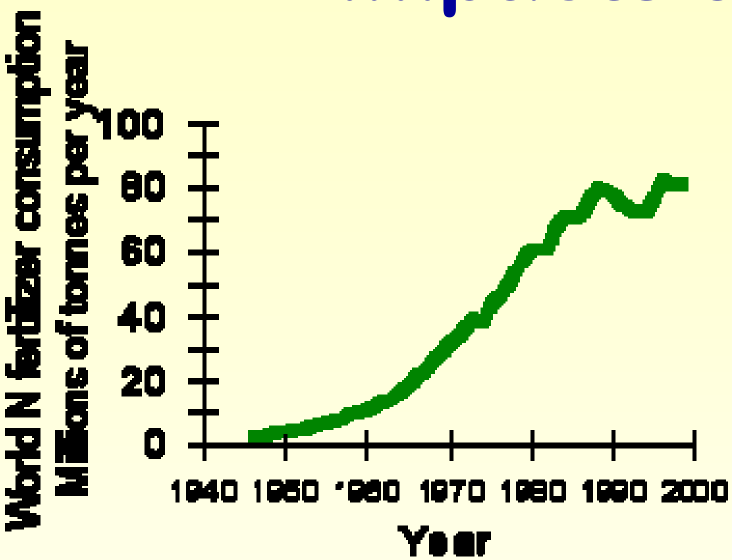
- Corn grain yields increased > 6X during 20th century
- Increases were obtained through improved genetics and crop management practices



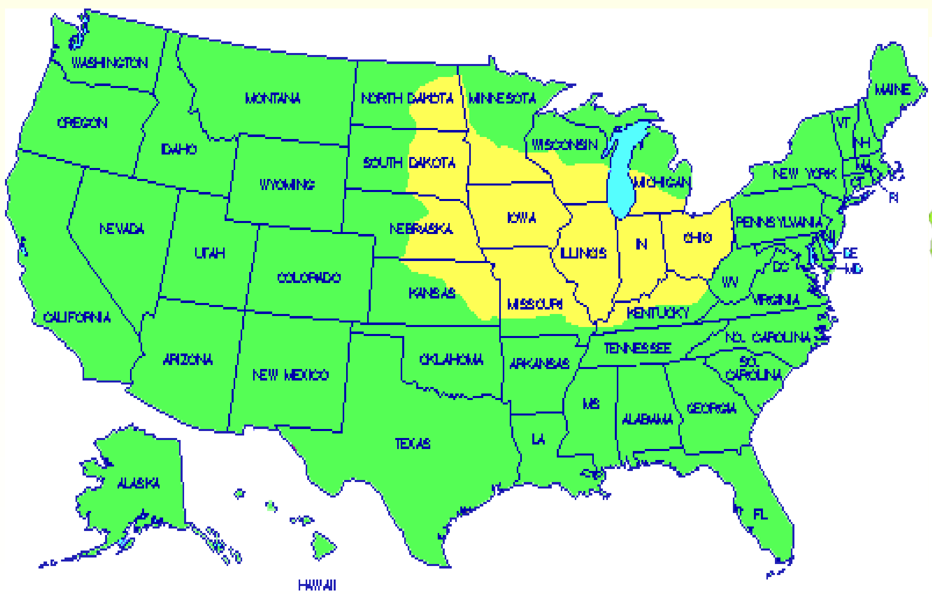
Relative energy use for crop management factors

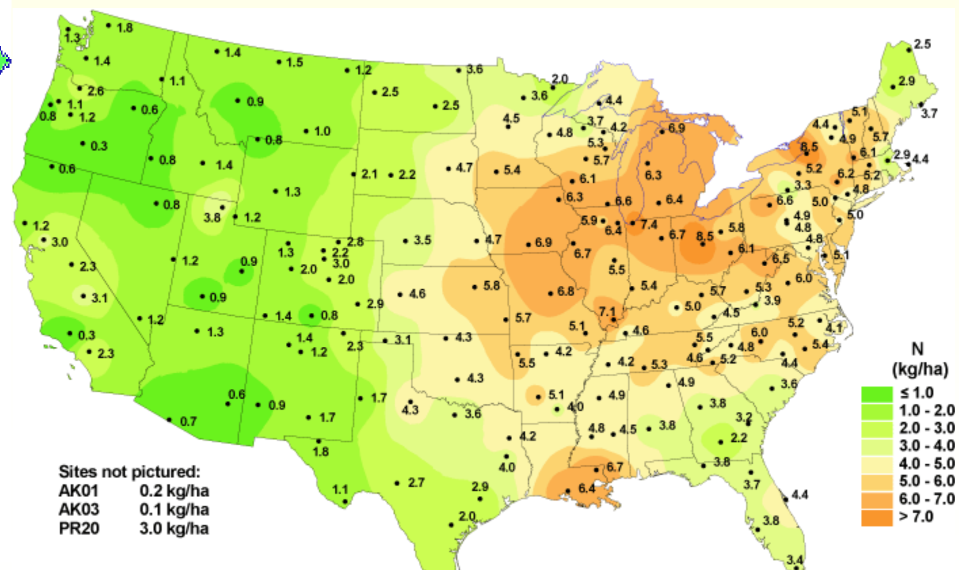
1. Fertilizer (N >> P > K)
2. Tillage
3. Pesticide application
4. Irrigation

Impacts of N Fertilizer Use



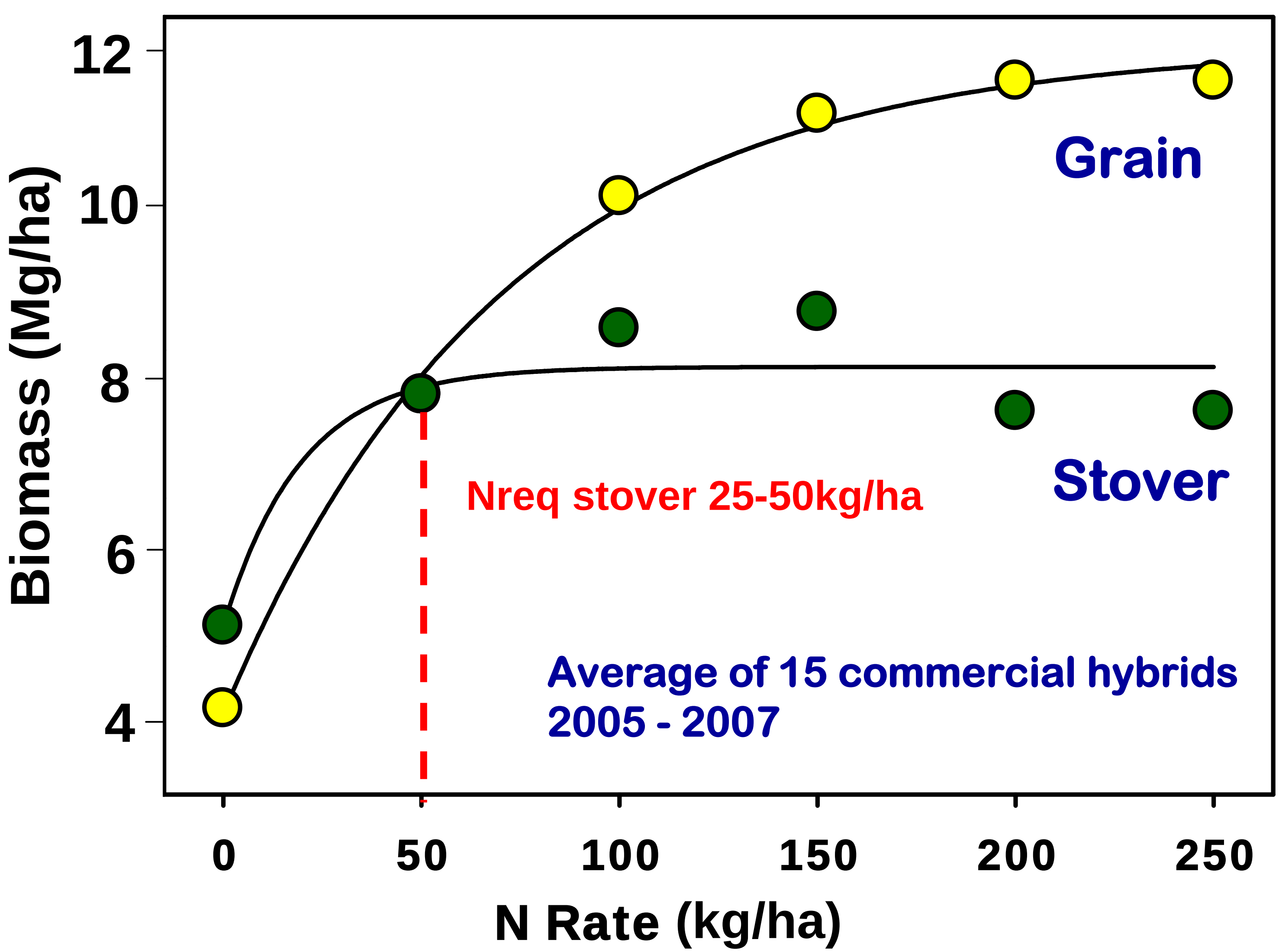
- N fertilizer is energy intensive to produce, transport, and apply.
- N production costs are rising
- Environmental impacts of N cycles



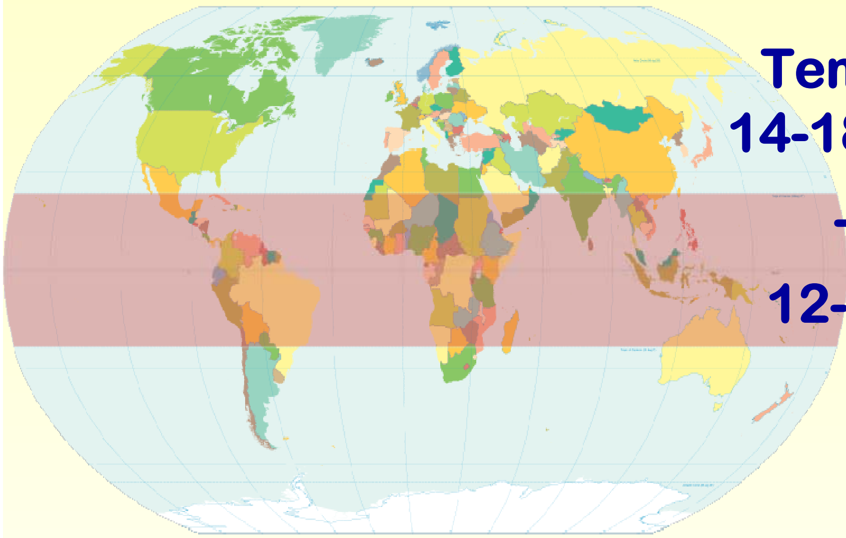


National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

N Requirement to Maximize Maize Stover Biomass is Significantly Less Than Grain

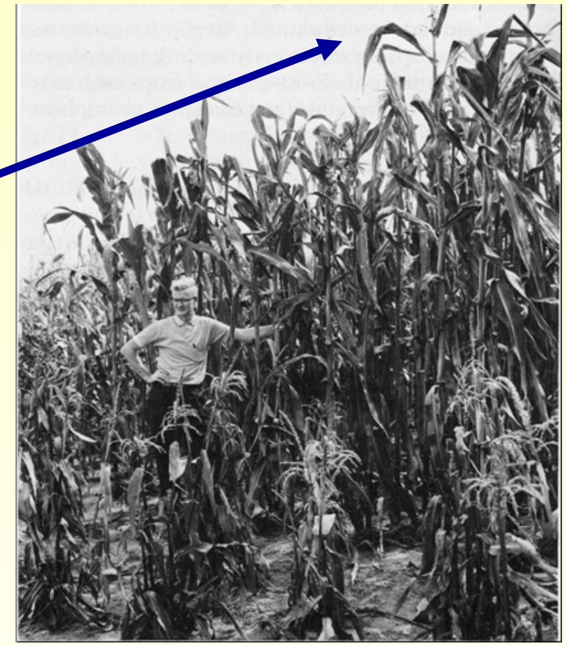


Temperate x Tropical Hybrids Produce Greater Biomass



Temperate
14-18 hr days

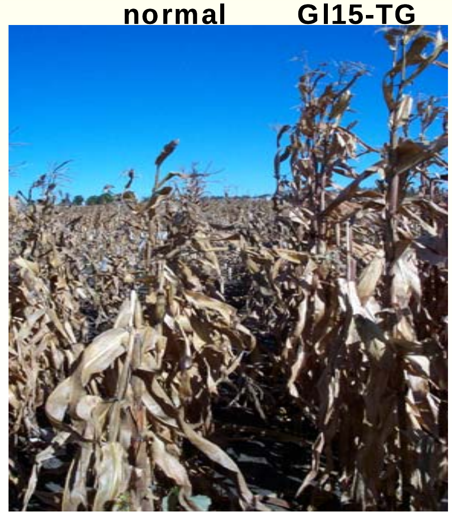
Tropical
12-14 hr days



A new biotechnology strategy to increase total corn biomass.

Make stronger a gene that suppresses flowering triggered by daylength, leading to delayed flowering and higher biomass.

normal GI15-TG



B73 x H99

B73 x H99: GI15-TG

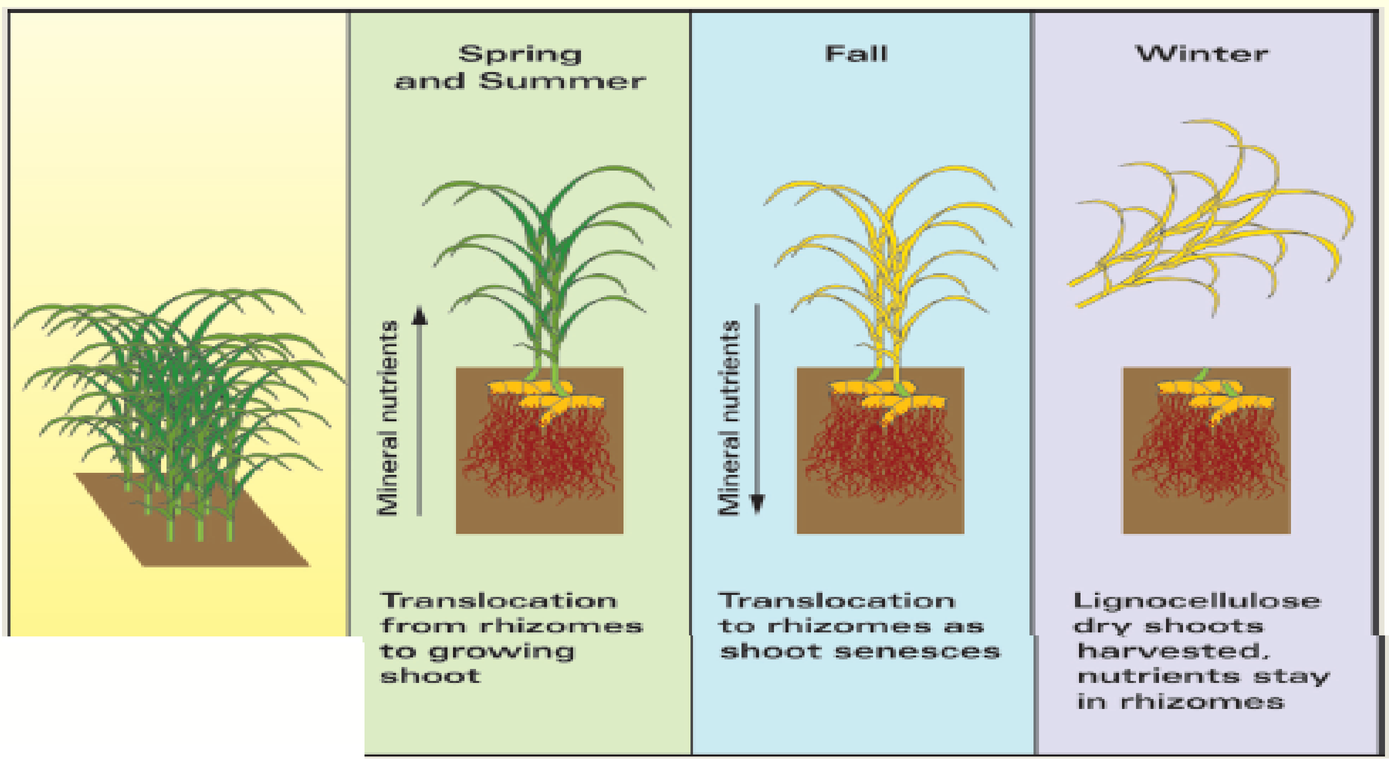
"Sugarcorn" – Maize as a Temperate Sugarcane?

Hybrid	Stover biomass (Mg ha^{-1})	% gluc equiv.	Sugar Yield (Mg ha^{-1})
Early commercial	5.2	16	0.5
Late commercial	6.6	22	0.7
Tropical hybrid 1	15.4	40	3.1
Tropical hybrid 2	18.7	35	3.3
Tropical hybrid 3	20.2	30	3.0
early GI15-TG hybrid	15.0	38	2.8
late GI15-TG hybrid	15.9	33	2.6

- Hybrids grown without supplemental N, stalk juice pressed in Sept. 2007
- Sugar yields comparable to US sugar beet (3-4 Mg ha^{-1}) and approach US sugarcane (4-5 Mg ha^{-1}).
- Sugar from pressed maize stalks is primarily sucrose.
- After dilution ~2X, maize stalk sap can be used directly for efficient fermentation to butanol by *Clostridium* solventogenic bacteria.

Perennial grasses require less N inputs…

- 25-50 kg N/ha requirement, typically not applied in establishment year.
- Increased N in leaf, then stems.
- N remobilization and storage in rhizomes after flowering greatly reduces amount of harvested N.



Energy Biosciences Institute

EBI Overview

Institutions & Leadership:

- UC-Berkeley – Chris Somerville
- University of Illinois – Steve Long
- Lawrence Berkeley National Laboratory
- BP – Paul Willems

Programs (14) and Projects (16):

- Feedstock Development (Genomics, Genetics, Agronomy, Engineering Systems, Pest/Pathogen Interactions, Ecosystem Interactions)
- Biomass Depolymerization (Imaging, Enzyme Design, PreTreatments, Chemical Conversion)
- Biofuels Production (Bacteria and Yeast engineering)
- Fossil Fuels Bioprocessing (extraction, conversion)
- Environmental, Social and Economic Dimensions (Law, Policy, Life-Cycle Analysis)

Feedstock Genomics Program

Participants:

Steve Moose, Matt Hudson, Ray Ming at Univ. Illinois

Dan Rokhsar, UC-Berkeley and JGI

6 additional project scientists

The primary goal for the initial phase of the EBI Feedstock Genomics Project is to characterize genes and their function in *Saccharum* and *Miscanthus*

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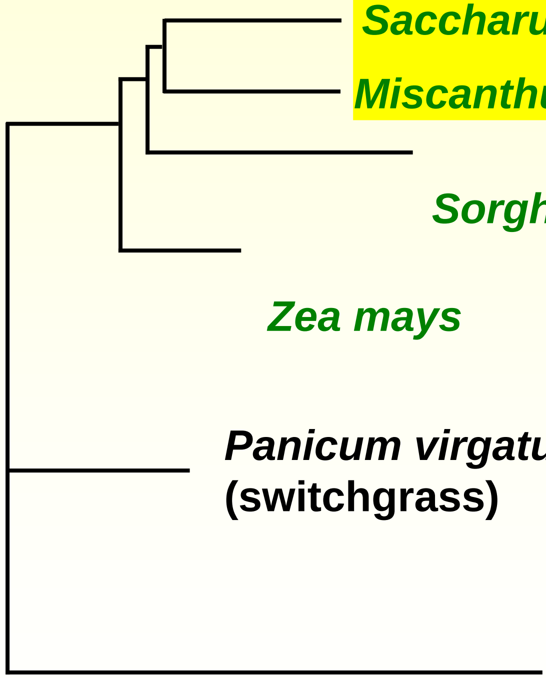
Genomics Resources for *Andropogoneae* Fuelstock Grasses

Very little is known about *Miscanthus* genes, but it is closely related to well-characterized genomes



	Genome	Expression	Genetic Variation
Saccharum officinarum	NO	YES	NO
Miscanthus x giganteus	NO	NO	NO
Sorghum bicolor	YES	NO	YES
Zea mays	YES	YES	YES
Panicum virgatum (switchgrass)	planned	starting	starting
Oryza sativa	YES	YES	YES

Summary

Key Technologies for the Bioeconomy focus on CO_2 fixation to carbohydrates, followed by carbohydrate conversion to portable energy.

R & D efforts span a wide range of disciplines in biology, chemistry, and process development.

Key players in bioeconomy R & D have assembled interdisciplinary linkages aimed at overcoming current limitations.

Genomics and biotechnology will enable rapid advances in developing new feedstocks for sustainable biomass production and efficient conversion to energy sources.

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