Growing Bioenergy and Bioproducts

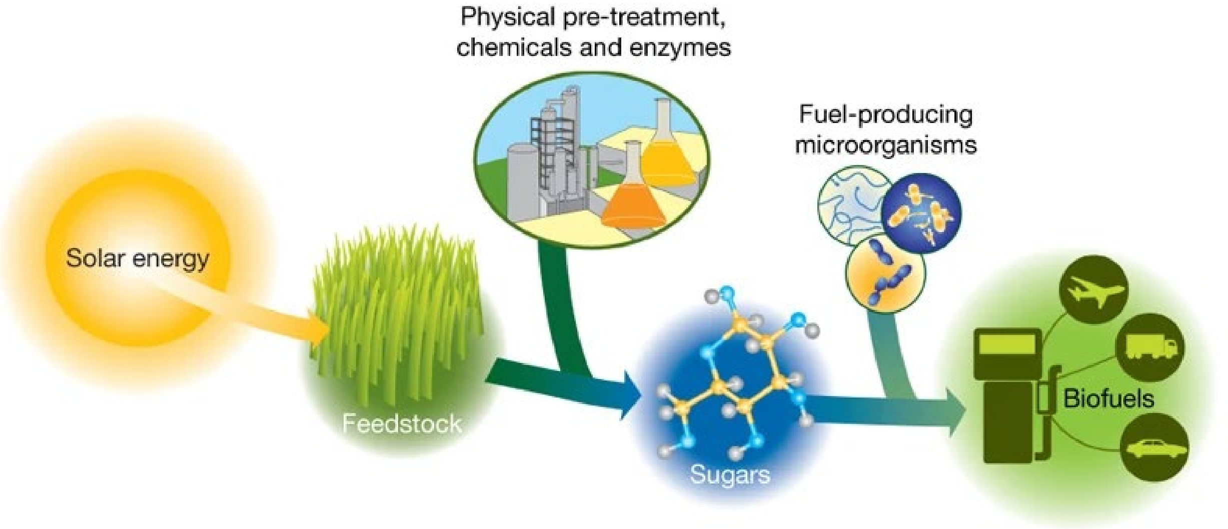
Prof. Steve Moose

Professor of Crop Sciences, UIUC

Professor Steve Moose is director of the Corn Functional Genomics Lab. He received his B.S. in Biology from Case Western Reserve University and went on to earn his Ph.D. in Genetics and Crop Sciences from North Carolina State University. Prior to coming to Illinois, he led a project whose aim was to increase the nutritional quality of corn for Dekalb Genetics Corporation. He has published over 35 papers in journals such as Plant Physiology and Genetics.

Moose's research has focused on genomics and breeding within the Saccharinae tribe of grasses, which includes sugarcane, Miscanthus, and sorghum.

His group constructed a complete genetic map for Miscanthus sinensis which exposed the mechanisms of low-temperature tolerance in Miscanthus. As part of the CABBI program, Prof. Moose uses his expertise in functional genomics to improve the sustainable production of high-value biomass from bioenergy grasses such as sorghum, Miscanthus, and sugarcane.



Growing Bioenergy & Bioproducts

Stephen Moose, University of Illinois

College of Agricultural, Consumer and Environmental Sciences
Crop Sciences

Energy Biosciences Institute

arpa·e

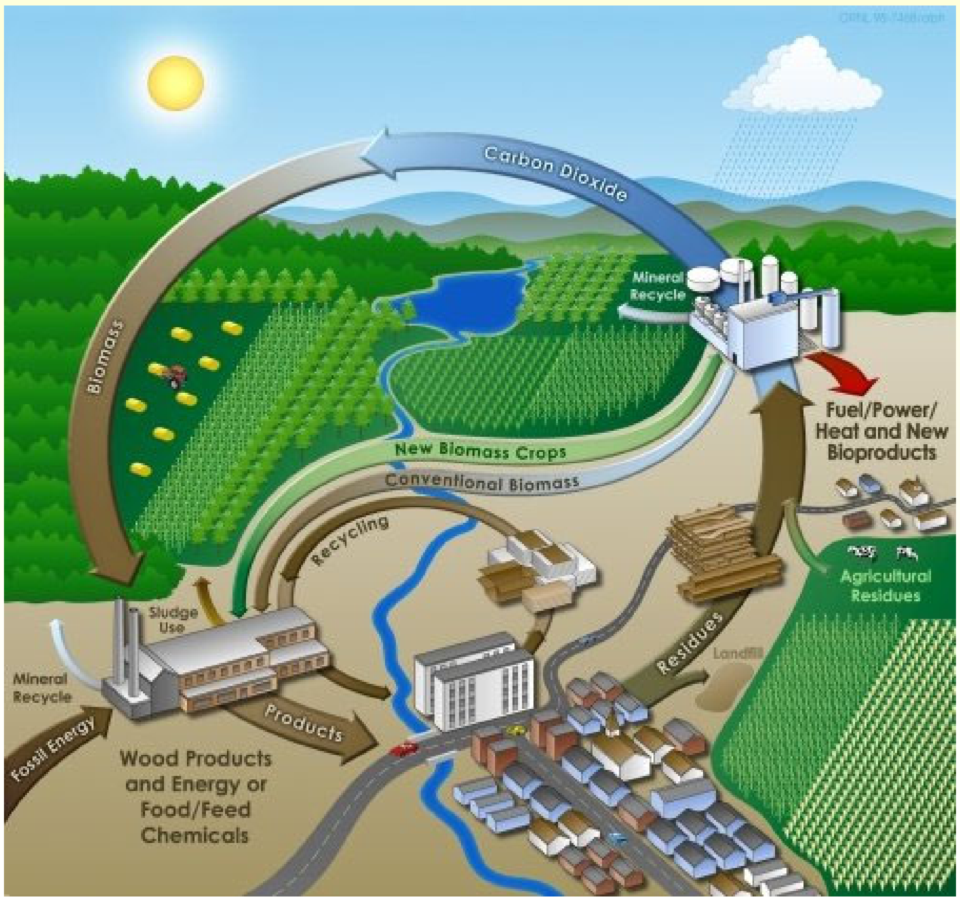
CABBI
Center for Advanced Bioenergy and Bioproducts Innovation

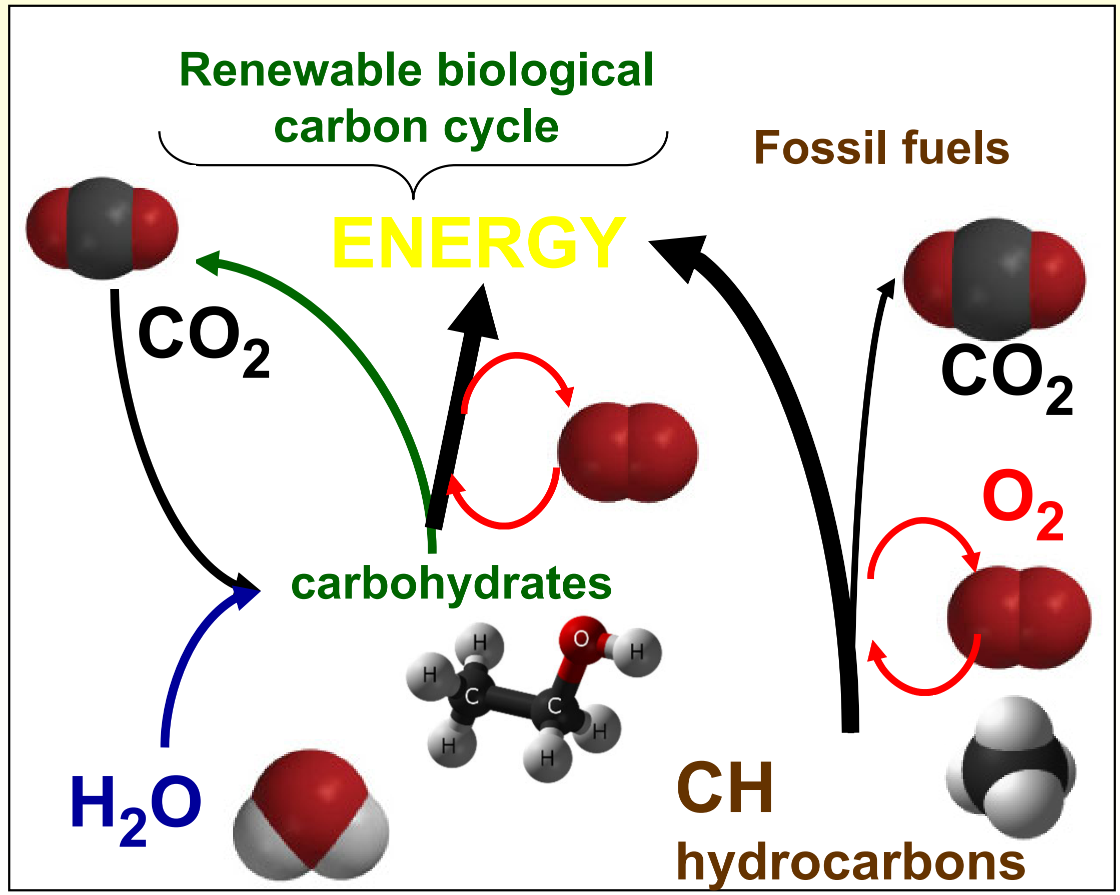
IGB

Growing "industrial carbon"

All fossil energy derives from plants.

Growing plants for industrial carbon closes the CO_2 cycle





Key Technologies for the Bioeconomy

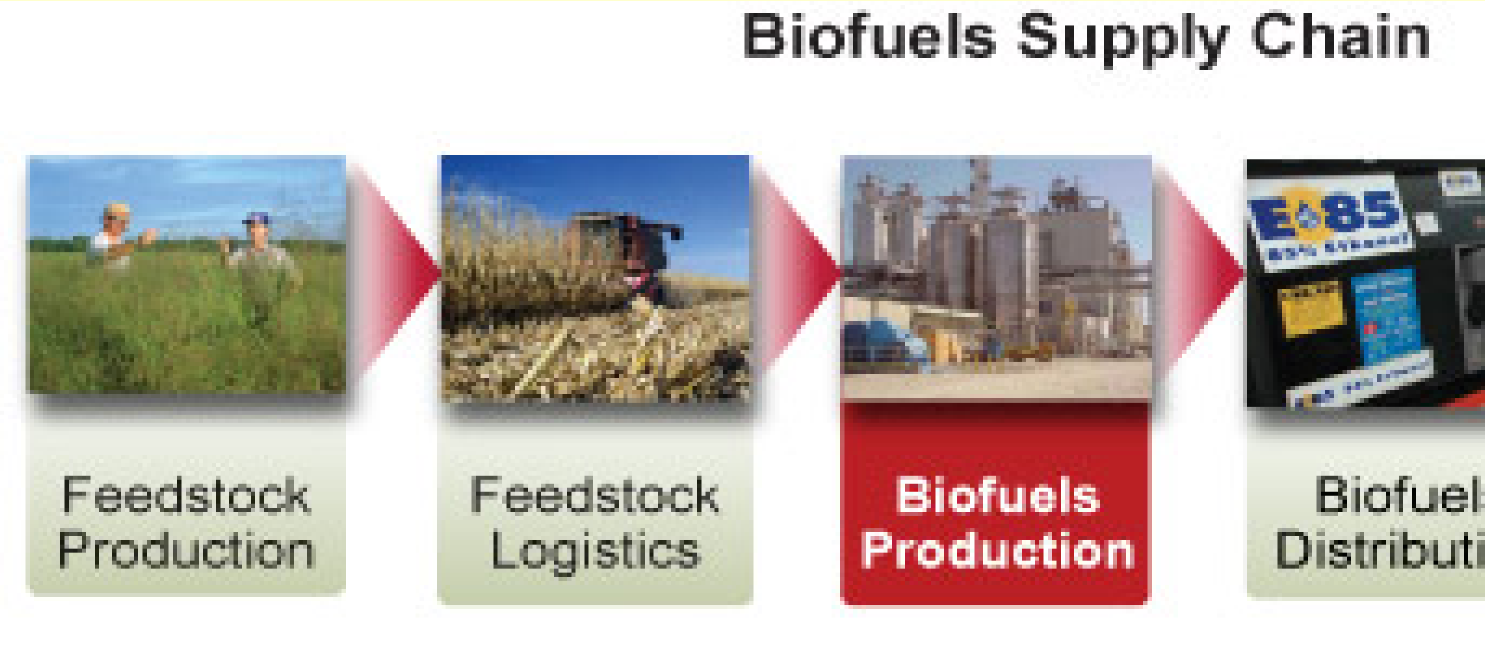
CO_2 Fixation – photosynthesis

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

Carbohydrate conversion – removing oxygens

- Biodiesel – vegetable oil, "drop-in" fuel
- Microbial fermentation – ethanol & butanol
- Biogas/Syngas – exchange with methane & hydrogen
- Direct chemical synthesis – alkanes and many others
- Pyrolysis heat+pressure to bio-oil, syngas or biochar
- Combustion – to electricity, releasing CO_2

U.S. Dept. Energy, c. 2009



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

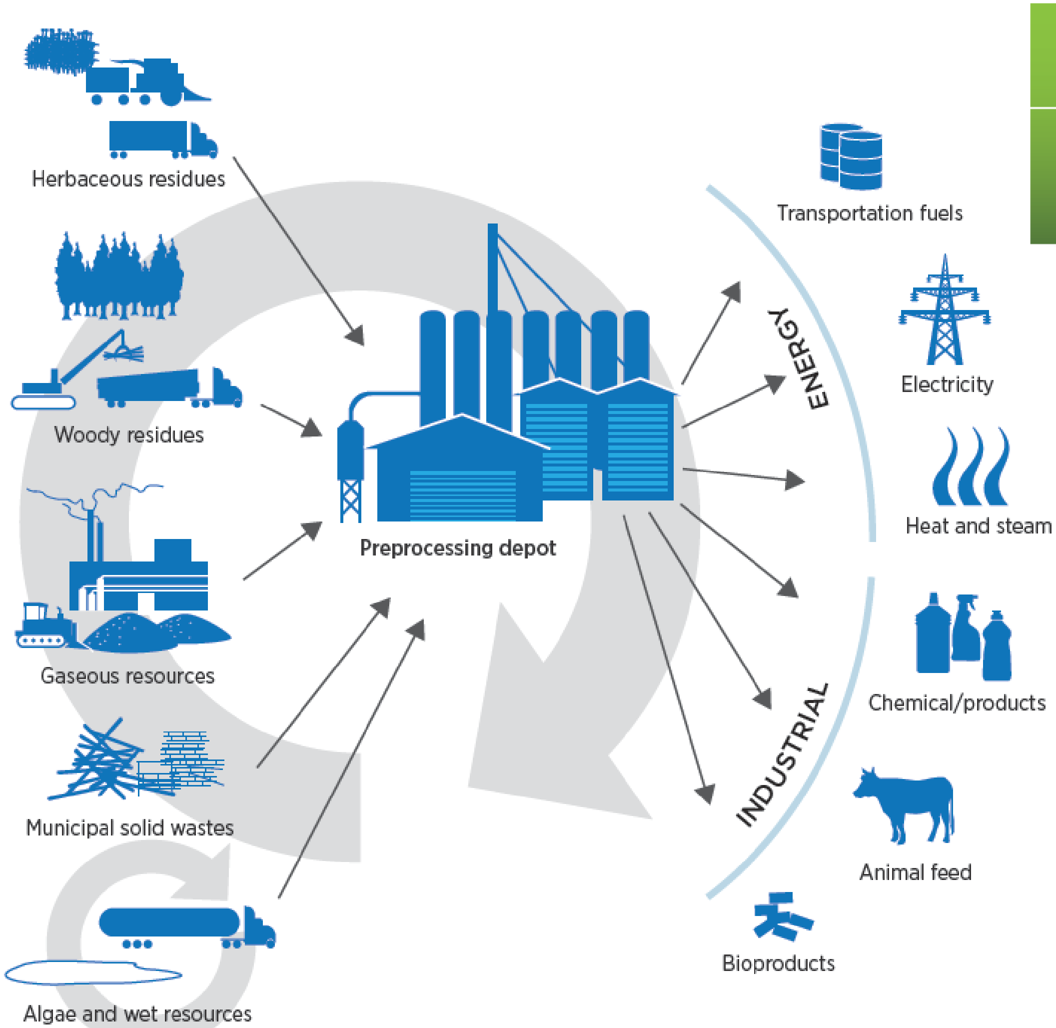
- Energy balance
- Environmental impacts – reducing GHGs
- Scalability
- Economic factors and societal impacts

Biomass conversion is a complex system…

From the 2016 “Billion Ton Vision”

Grower payment, stumpage price, procurement price	Farmgate price, roadside price	Delivered Cost
Production	**Harvest**	**Delivery and Preprocessing**
Site preparation, planting, cultivation, maintenance, profit to landowner	Cut and bale, rake and bale; fell, forward, and chip into van	Load, transport, unload
In the field or forest, dispersed	Baled or chipped into van roadside	Comminuted to <¼ inches (conventional) or pelleted (advanced)

Figure 6.2 | Proposed future feedstock supply system for transforming raw biomass into stable, tradeable commodities suitable for long-distance transport and handling in existing infrastructure



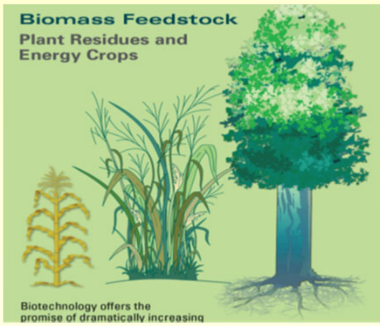
(Image courtesy of Idaho National Laboratory)

(Photo courtesy of Maynard Herron, AGCO)

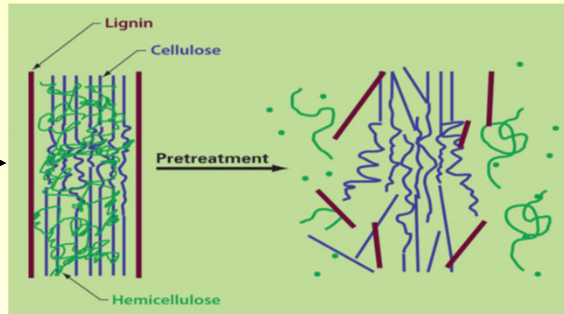
(Photos courtesy of Al Womac, University of Tennessee)

Biomass conversion via microbial fermentation

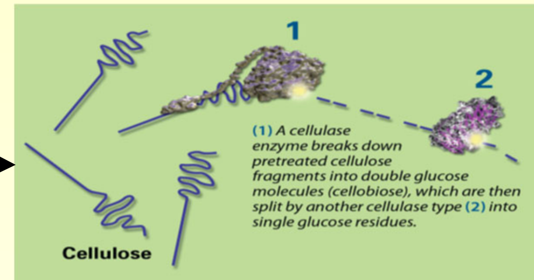
Theoretical yield = 617L (163 gal) ethanol from 907kg (ton) sucrose.



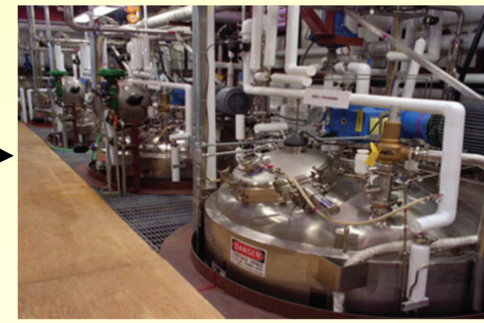
Biomass Feedstock



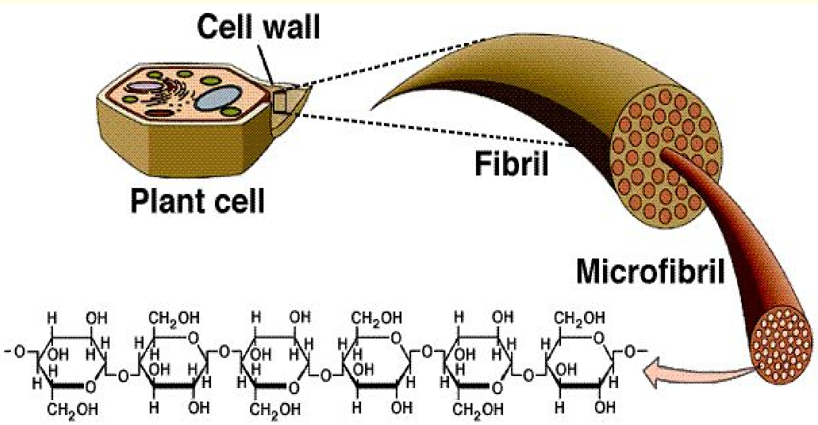
PreTreatment



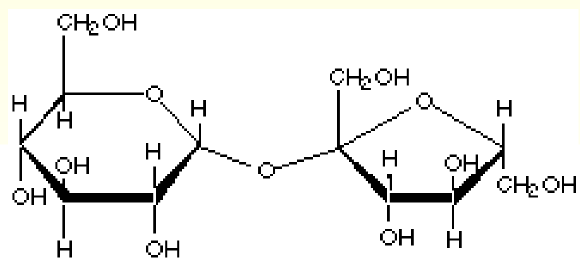
Hydrolysis/ Deconstruction



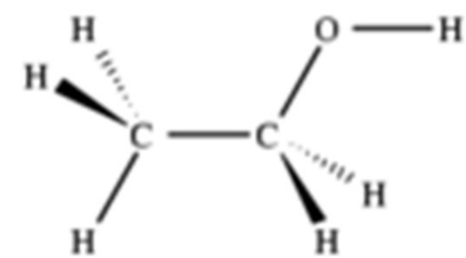
Fermentation



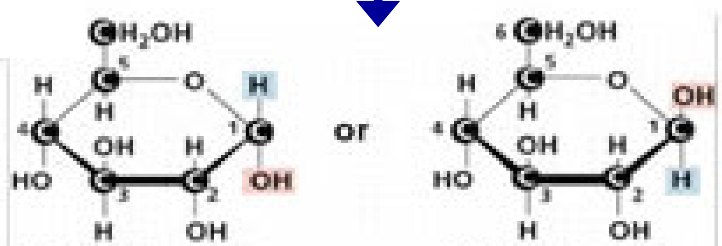
Cellulose



Sucrose
(glucose (α1-->2) fructose)



Cellulose depolymerization

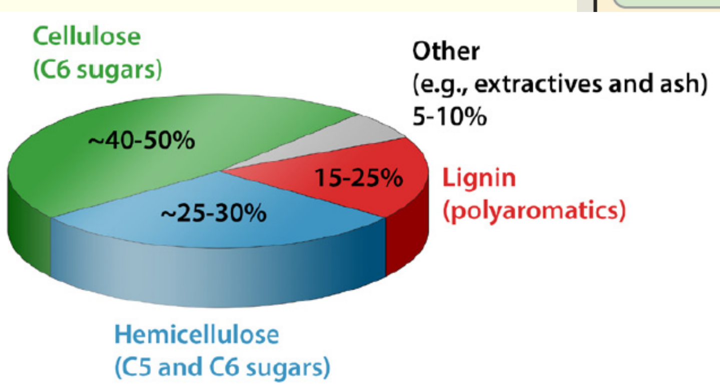


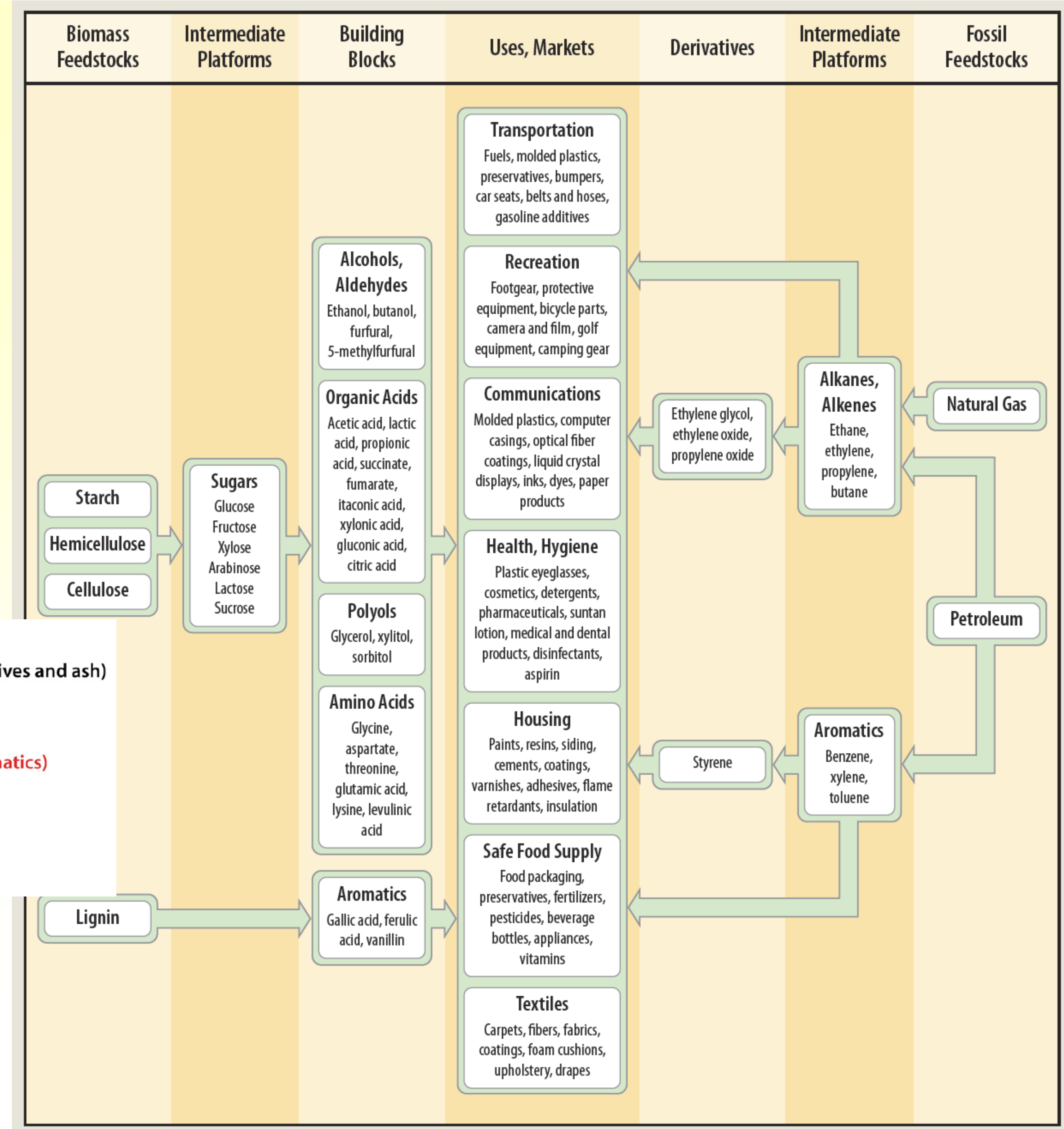
(c) α-Glucose or (d) β-Glucose

ethanol

specialty chemicals

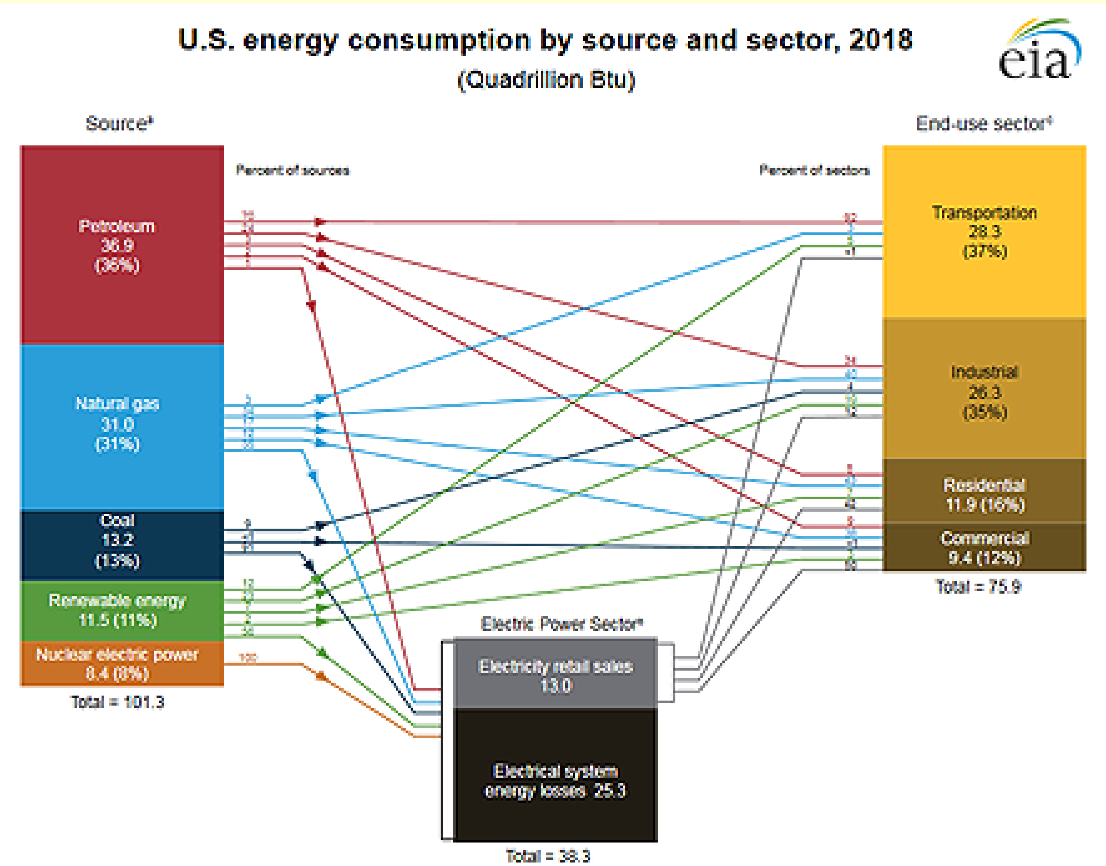
Biomass can be used to produce a variety of high-value specialty chemicals…

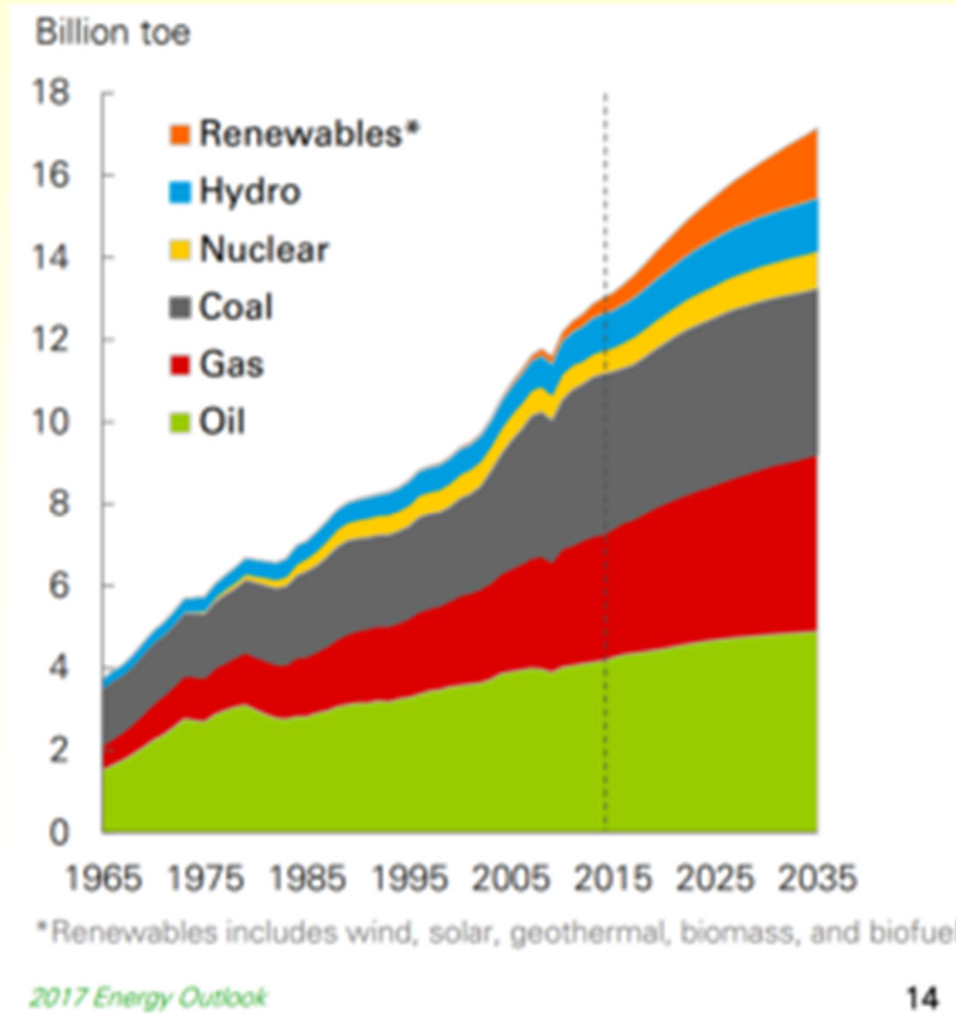




Current and Projected US Biofuel Production

- Renewables are trending upward
- 2nd generation biorefineries are still small capacity
- Electricity demand growing more than transportation fuels





The Bioeconomy requires increasing agricultural biomass

- DOE "billion ton vision" https://bioenergykdf.net/billionton2016/reportinfo
- Must be achieved via sustainable, carbon positive systems

https://bioenergykdf.net/billionton2016/1/2/tableau

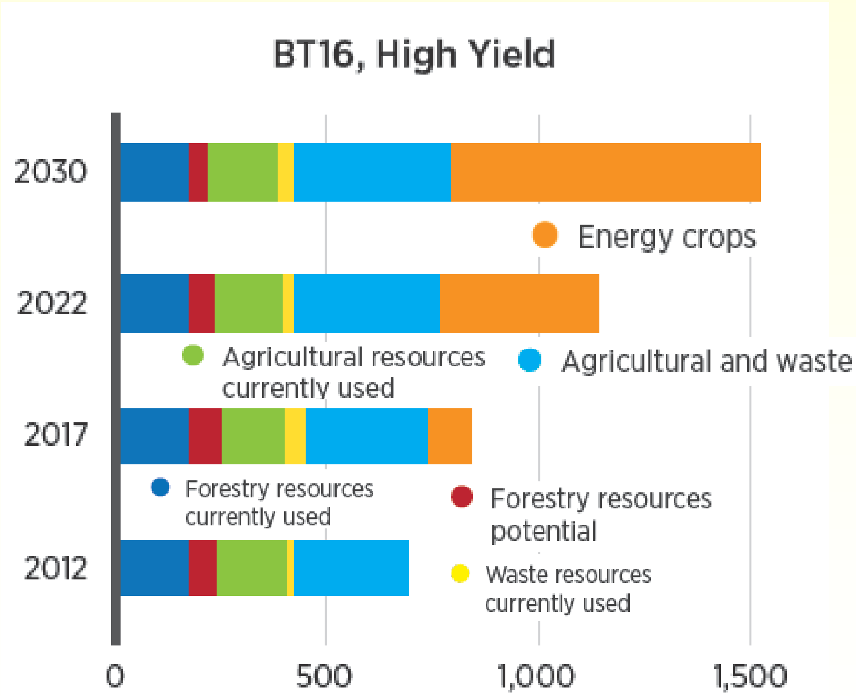
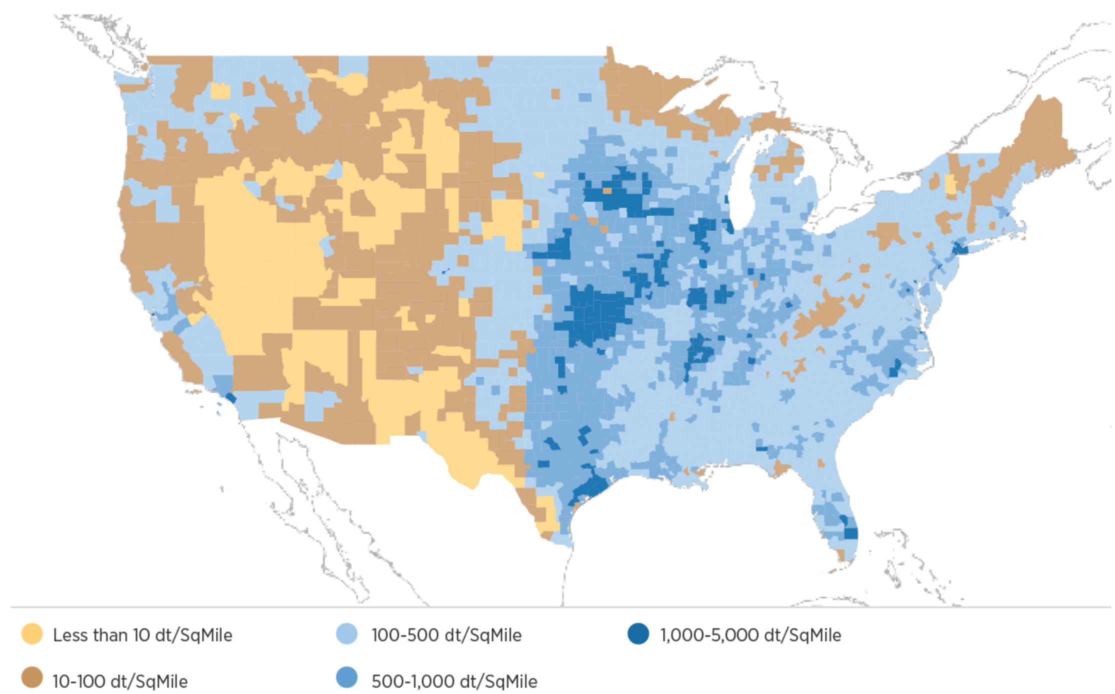
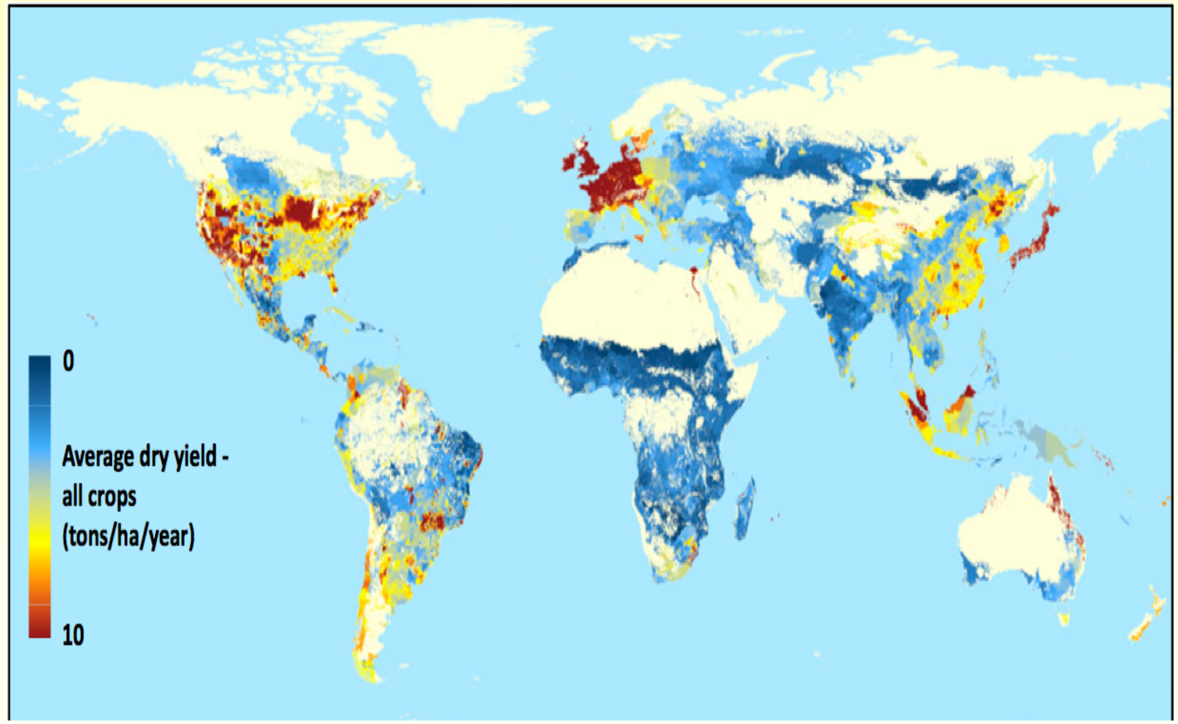


Figure ES.4 | Combined potential supplies from forestry, wastes, and agricultural resources, base case, 2040[10]



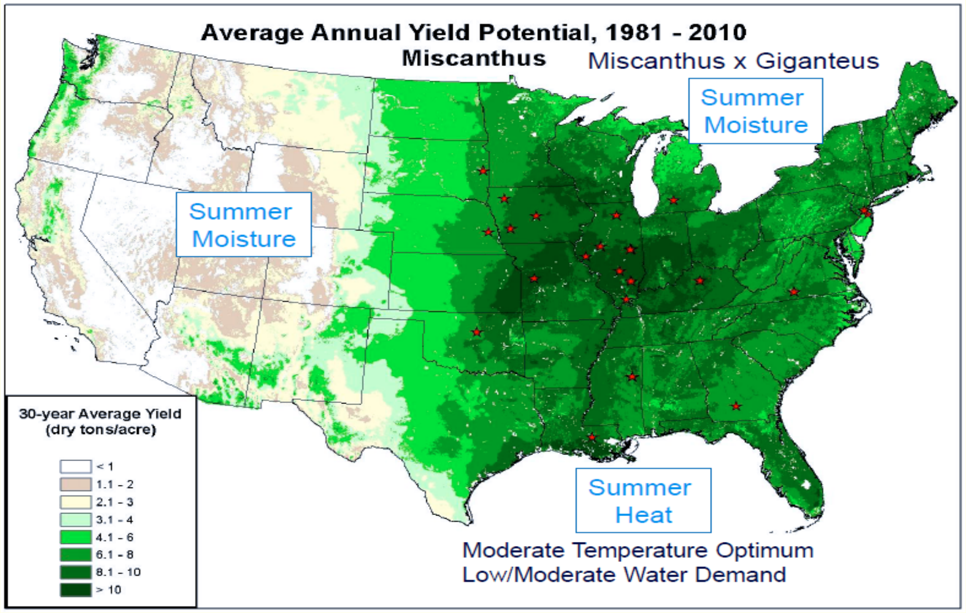
Andropogoneae Grasses are Important Global Food & Energy Crops

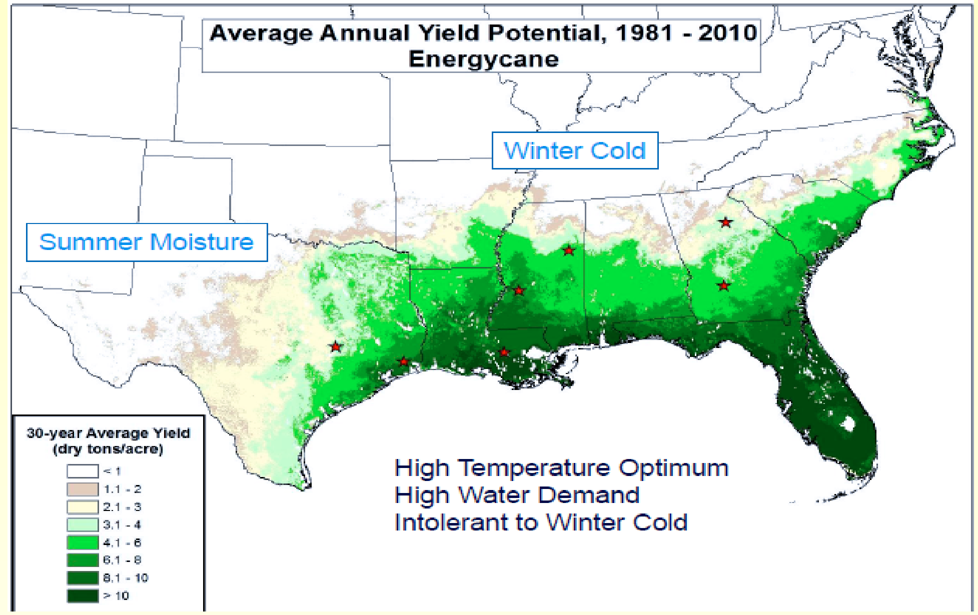


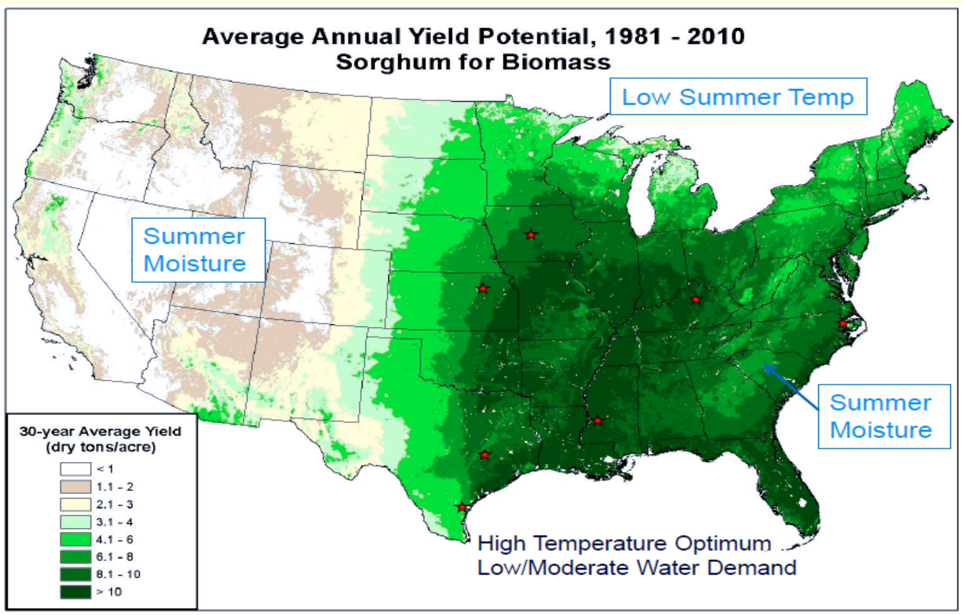
Versatility of carbon forms
- Starch
- Sugar
- Lignocellulose

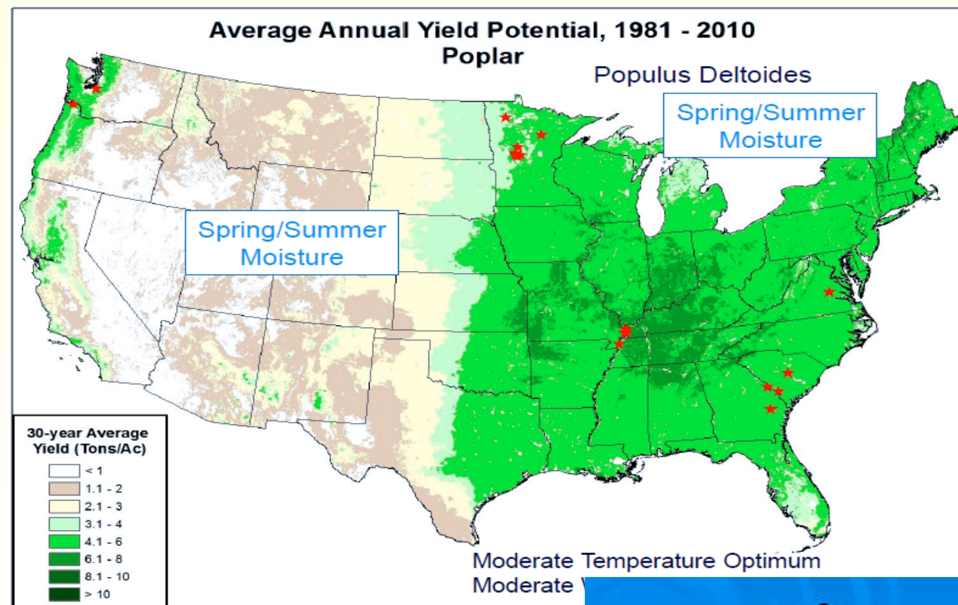
Adaptation
- C4 photosynthesis
- Tropical, temperate
- Perennial, annual
- Tolerance to abiotic stresses

Yield Potential of Bioenergy Crops





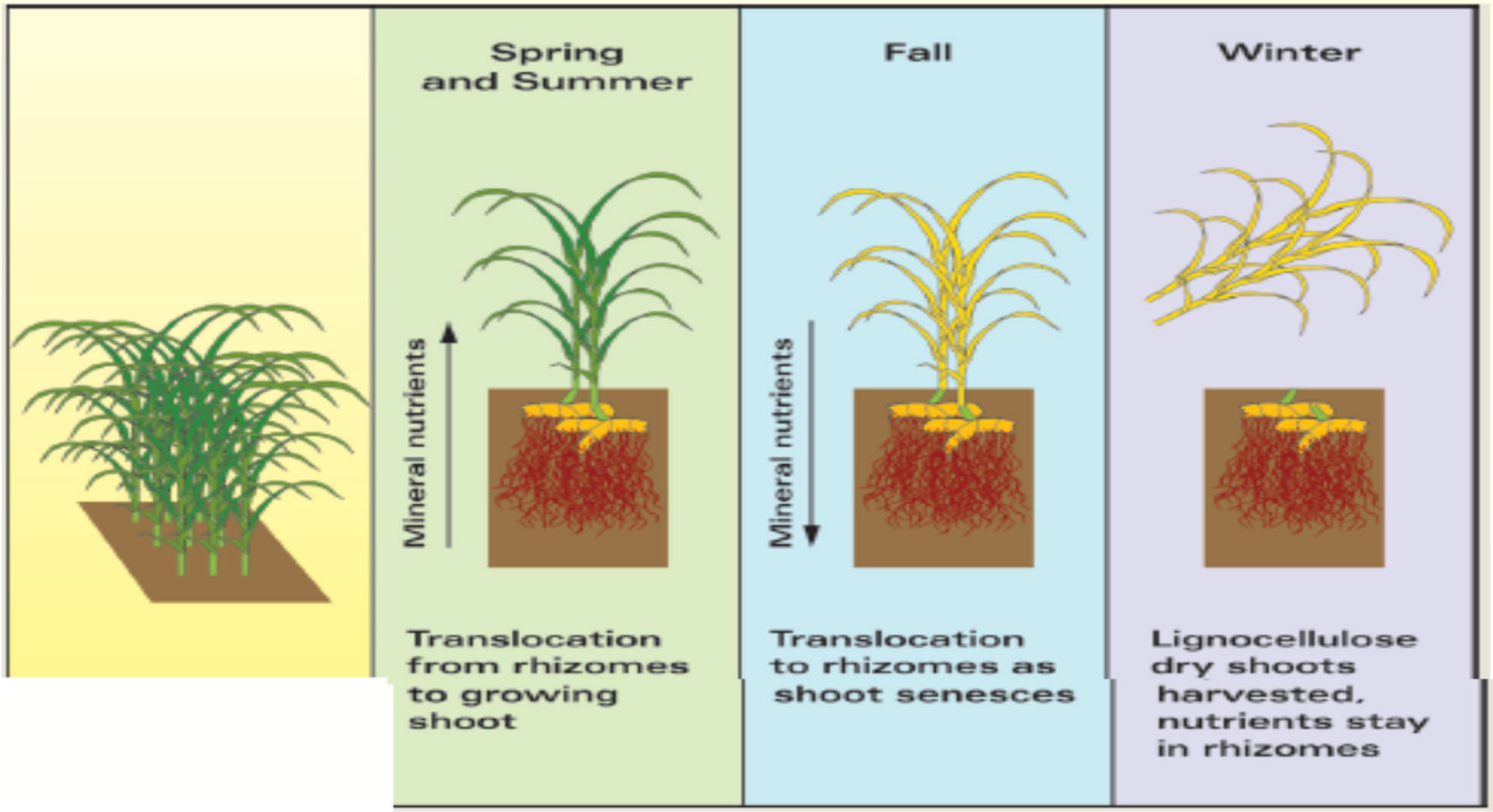




Daly and Halbleib (2014), "Potential Yield Mapping of Dedicated Energy Crops," energy.gov/sites/prod/files/2014/11/f19/ daly_biomass_2014.pdf.

Perennial grasses offer sustainability benefits…

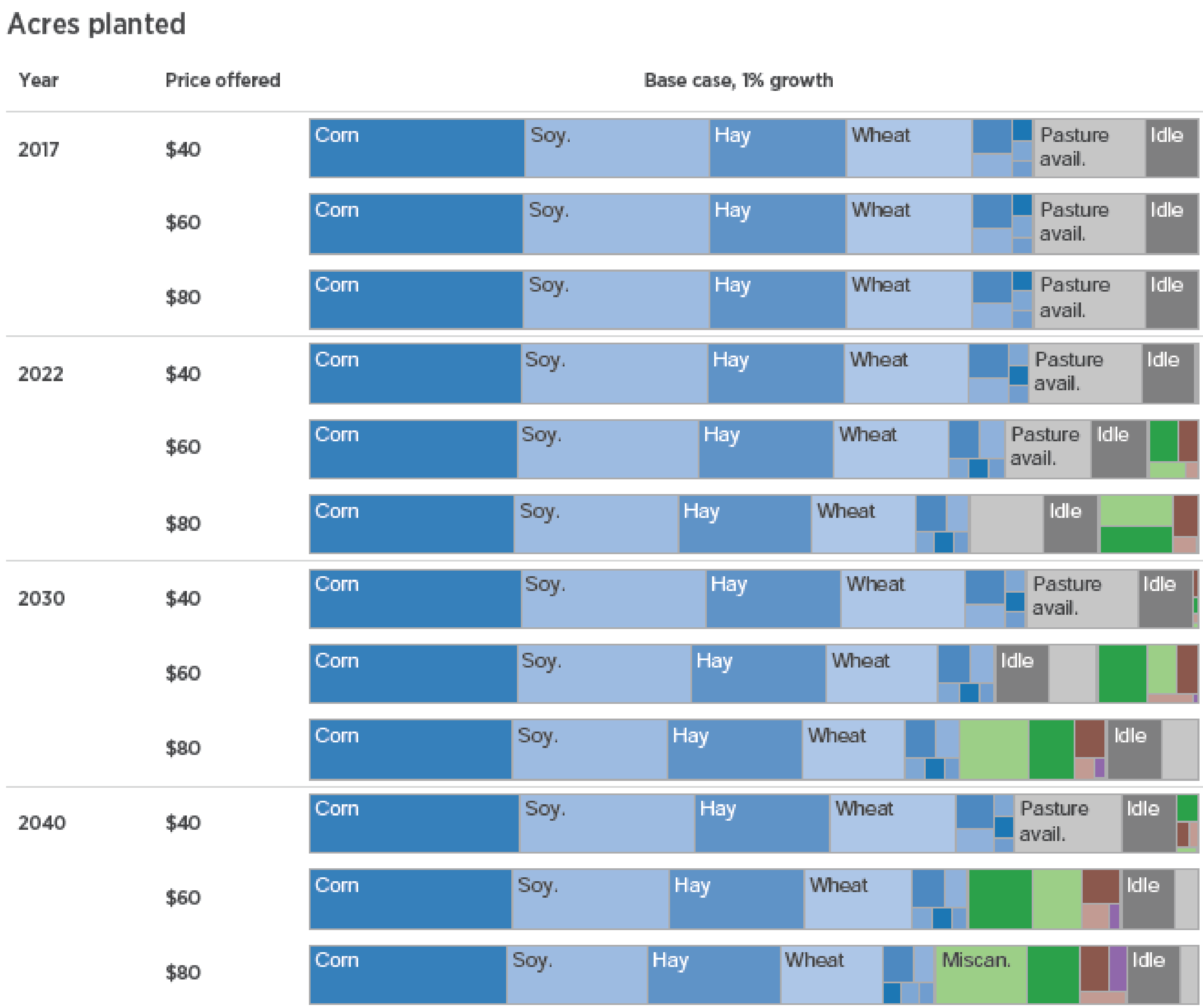
- Lower requirements and removal of nutrients in harvested biomass
- Nutrient recycling to overwintering rhizomes
- Carbon sequestration underground



Overstated concerns of "food versus fuel"

- Models suggest expansion of bioenergy crops will minimally impact food crop acreage
- Reality is we need food AND fuel, versatile systems are most sustainable

Figure 4.9 | Total planted acres by crop type after constraints are met at select prices under base-case assumptions[11]



energies

MDPI

Review

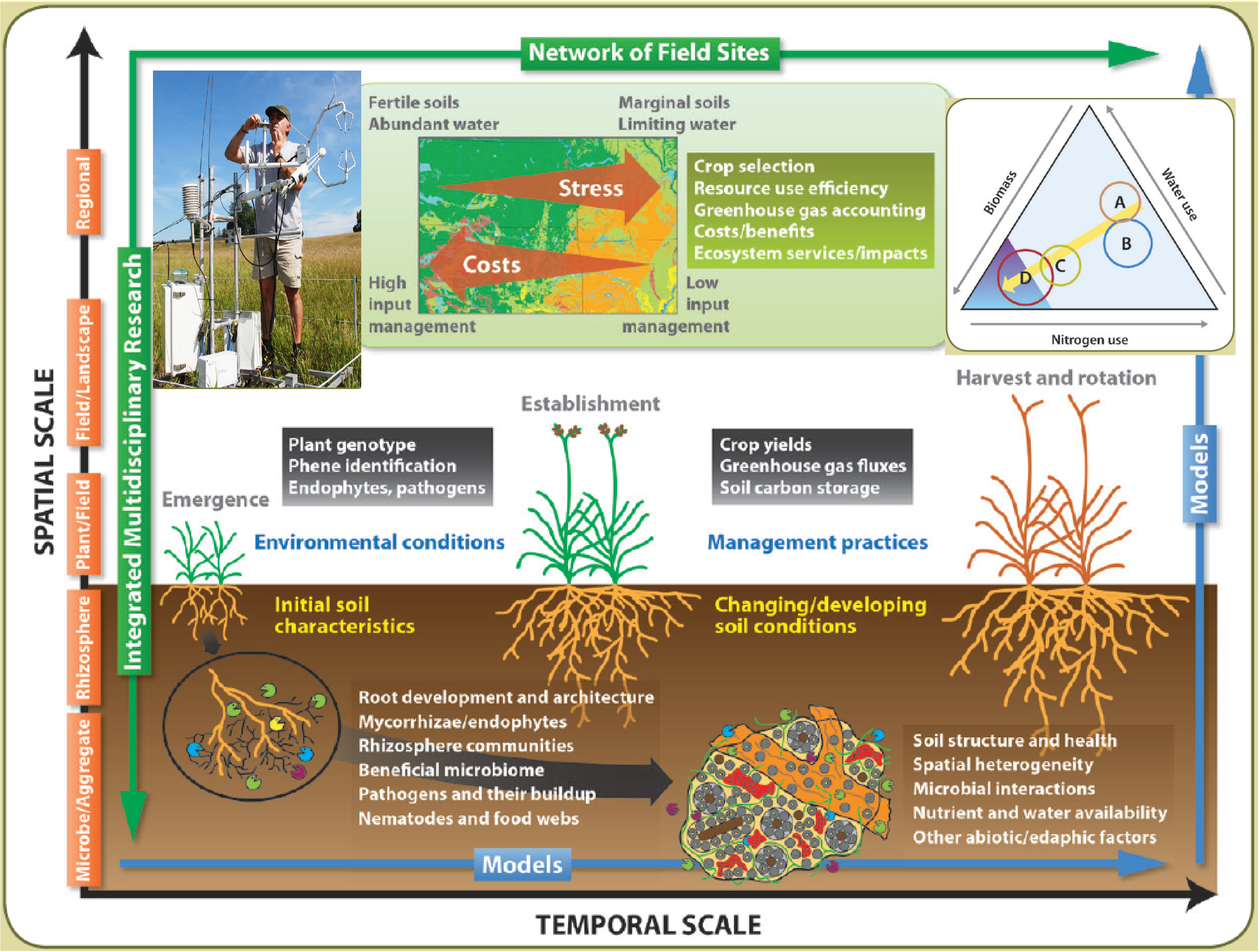
Significance and Challenges of Biomass as a Suitable Feedstock for Bioenergy and Biochemical Production: A Review

Richard Ahorsu, Francesc Medina * and Magda Constantí

Listing of EU bioenergy projects circa 2018

Project Name	Biorefinery Feedstock	Coordinating Country	Period	Total Cost €
AgriChemwhey	Byproducts from dairy processing	Ireland	2018–2021	29,949,323
GRACE	Miscanthus or hemp varieties from marginal lands Kraft	Germany	2017–2022	1,500,085,121
SmartLi	Kraftlignins lignosulfonates and bleaching effluent	Finland	2015–2019	240,746,125
BIOSKOH	Lignocellulosic feedstock	Italy	2016–2012	30,122,313,773
BARBARA	Agri and food waste	Spain	2017–2020	2,711,375
AgriMax	Agri and food waste	Spain	2016–2020	1,554,349,456
PULP2VALUE	Sugarbeet pulp	Netherlands	2015–2019	1,142,384,750
GreenSoIRES	Lignocellulosic residues or wastes	Netherlands	2016–2020	1,060,963,701
Dendromass4Europe	Dendromass on marginal land	Germany	2017–2022	2,044,231,8750
SYLEED	Wood residues	France	2017–2020	14,976,590
GreenProtein	Vegetable residues from packed salad processing	Netherlands	2016–2020	554,651,999
PROMINENT	Cereal processing side streams	Finland	2015–2018	14,976,590
FIRST2RUN	Cardoon from marginal lands	Italy	2015–2019	310,389,750
Zelcor	Lignocellulosic residues from ethanol production, lignins dissolved during pulping process, and lignin-like humins formed by sugar conversion	France	2016–2020	671,001,250
STAR4BBI	Lignocellulosic feedstock from forests and agriculture	Netherlands	2016–2019	99,587,750
BIOrescue	Wheat straw and agroindustrial waste	Spain	2016–2219	376,758,750
OPTISOCHEM	Residual wheat straw	France	2017–2021	1,637,681,683
US4GREENCHEM	Lignocellulosic feedstock	Germany	2015–2019	3,803,925
FUNGUSCHAIN	Mushroom (*Agaricus bisporus*) farming residues	Netherlands	2016–2020	814,366,125
POLYBIOSKIN	Food waste	Spain	2017–2020	405,835,938
Valchem	Woody feedstock	Finland	2015–2019	1,850,270,325
LIBBIO	Andes lupin from marginal lands	Iceland	2016–2020	4,923,750
LIGNOFLAG	Straw	Germany	2017–2020	34,696,215

Improving performance of cropping systems…



Improving Biomass to Bioenergy/Bioproducts

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

BESC BioEnergy Science Center

jbei Joint BioEnergy Institute

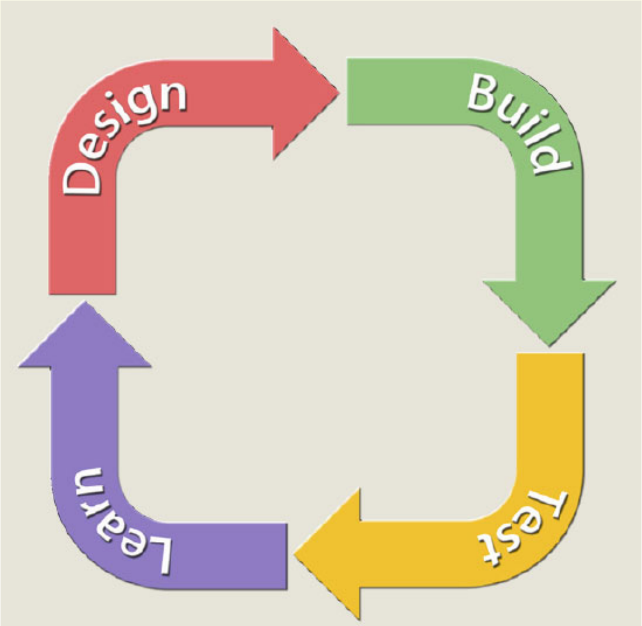
GLBRC Great Lakes Bioenergy Research Center

Energy Biosciences Institute

CABBI Center for Advanced Bioenergy and Bioproducts Innovation

Important Goals:

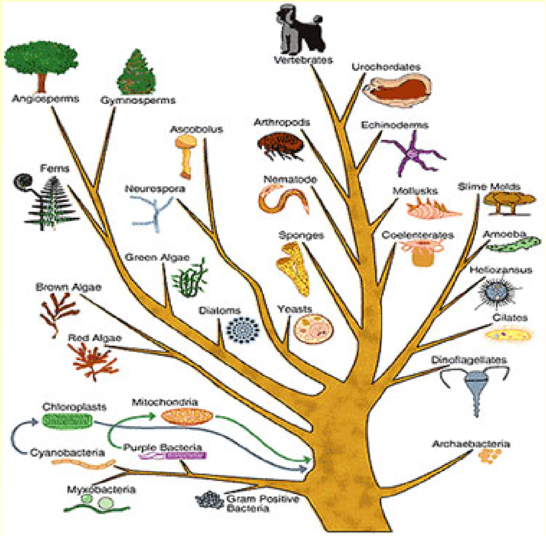
1. Understanding the biological processes most relevant to bioenergy.
2. Genomics and synthetic biology-driven improvement of key traits:
   - Increasing biomass value – oils, sugars, lower lignin, high-value specialty chemicals.
   - Increasing yields and sustainability.
3. Monitoring and enhancing environmental sustainability

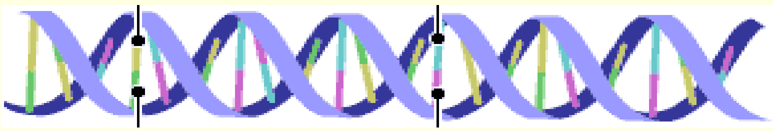


Genome editing of organisms

A research tool to better understand rules of life.

A more precise way to improve upon nature by careful reprogramming of DNA.

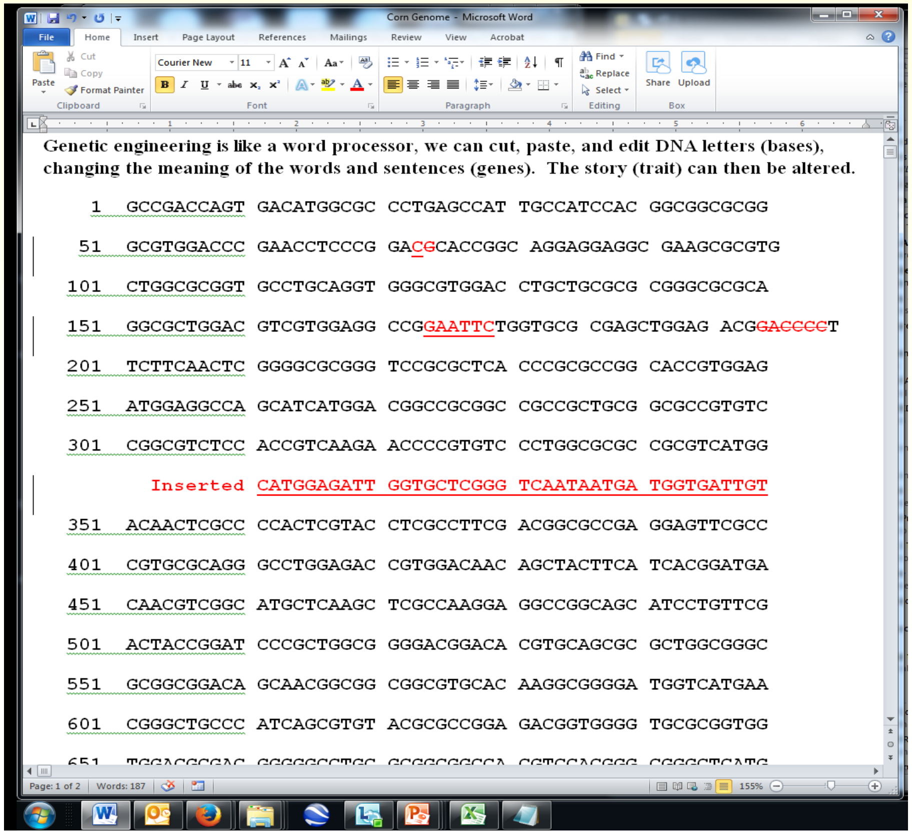




Genome = the entire DNA code for an organism

Genomics = the study of genomes and gene function

CRISPR = a “word processor” for genome DNA “text”



Summary

Biomass to bioenergy/bioproducts holds great promise in development of a robust bioeconomy.

Key steps include growing crops, deconstructing cell walls, microbial fermentation to high-value chemicals.

Past work has established leading crops, now higher biomass value to achieve market pull.

Recent and rapid advances in genomics and synthetic biology are enabling new strategies to increase biomass feedstock yields, enhance composition, and improve environmental sustainability.