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This instructional resource forms part of FLATE's outreach efforts to facilitate a connection between students and teachers throughout the State of Florida. We trust that these activities and materials will add value to your teaching and/or presentations.

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Introduction to Alternative and Renewable Energy

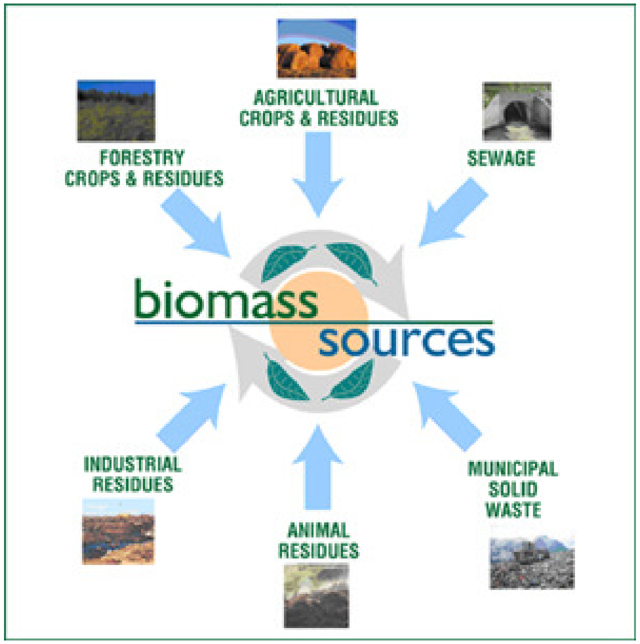
EST1830

3. Energy Production

3.1 Renewable Energy Technologies

3.1.3 Biomass Energy

Biomass



http://dailyenergy.net/search/Biomass

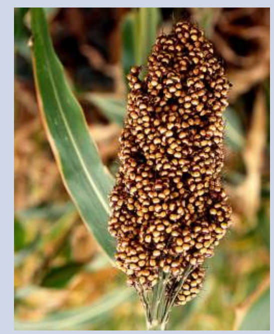
- Definition: All living plant matter as well as organic wastes derived from plants, humans, marine life, and animals.
- Examples: Trees, grasses, animal dung, sewage, garbage, wood construction residues, and other components of municipal solid waste.

Tester, et al., *Sustainable Energy: Choosing Among Options, 2005,* The MIT Press

Biomass: Three Major End Products

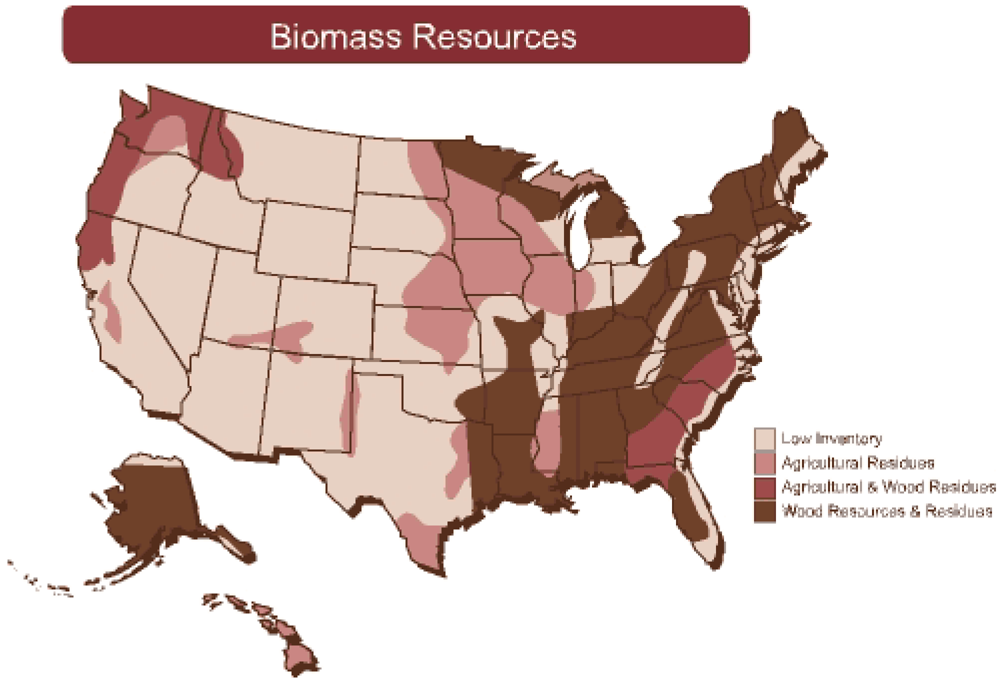
Department of Energy Categories

1. **Biopower:** Generation of electricity utilizing biomass as feedstock
2. **Biofuels**
   – Syngas
   – Ethanol
   – Biodiesel
3. **Biobased Products**: plastics, chemicals

Biomass Plant Terms: Definition	Example
Bagasse: the fibrous residue remaining after sugarcane or sorghum stalks are crushed to extract their juice.	
Miscanthus (elephant grass): a genus of about 15 species of perennial grasses native to subtropical and tropical regions of Africa and southern Asia	 
Sorghum: a genus of numerous species of grasses, one of which is raised for grain and many of which are used as fodder plants either cultivated or as part of pasture. The plants are cultivated in warmer climates worldwide. Species are native to tropical and subtropical regions of all continents in addition to the South West Pacific and Australasia.	 
Corn Stover: consists of the leaves and stalks of corn, sorghum or soybean plants that are left in a field after harvest.	

Biomass Plant Terms: Definition	Example
Switchgrass: is a perennial warm season bunchgrass native to North America, where it occurs naturally from 55°N latitude in Canada southwards into the United States and Mexico. Switchgrass is one of the dominant species of the central North American tallgrass prairie and can be found in remnant prairies, in native grass pastures, and naturalized along roadsides.	
Sugarcane: species of tall perennial grasses of the genus *Saccharum*. Native to warm temperate to tropical regions of Asia, they have stout, jointed, fibrous stalks that are rich in sugar, and measure two to six meters (six to nineteen feet) tall.	 
Arundo Donax: **Giant Cane**, is a tall perennial cane growing in damp soils, either fresh or moderately saline. *Arundo donax* is native to eastern and southern Asia, and probably also parts of Africa and southern Arabic Peninsula. It has been widely planted and naturalised in the mild temperate, subtropical and tropical regions of both hemispheres especially in the Mediterranean, California, the western Pacific and the Caribbean. It grows to 6 metres (20 ft).	 

Biomass Resources: National

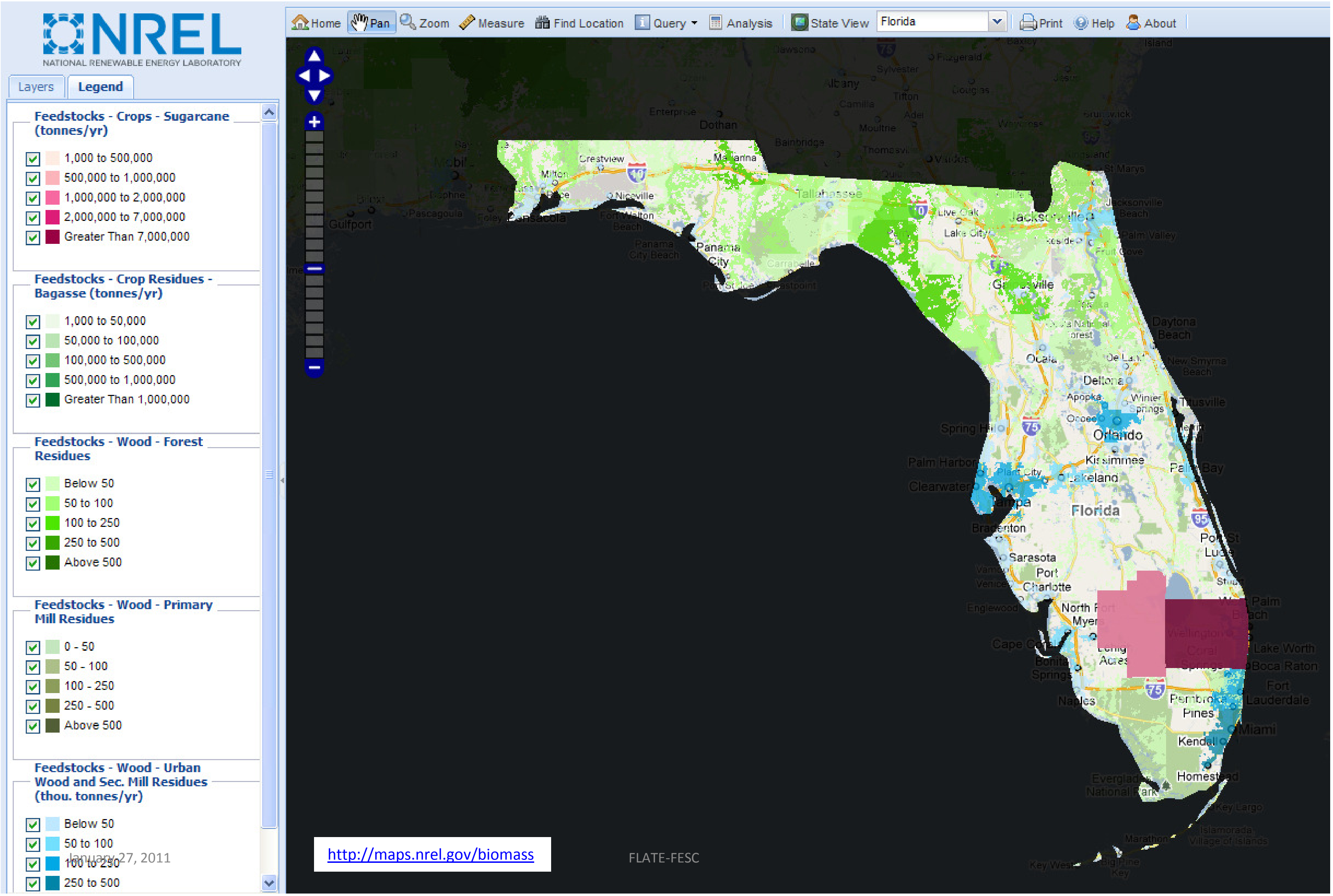


Potential world energy from biomass assuming complete conversion: 7-10 TW

http://mitworld.mit.edu/video/518/

October 2010 Data

Biomass Resources: Florida



http://maps.nrel.gov/biomass

Biomass Resources: Florida

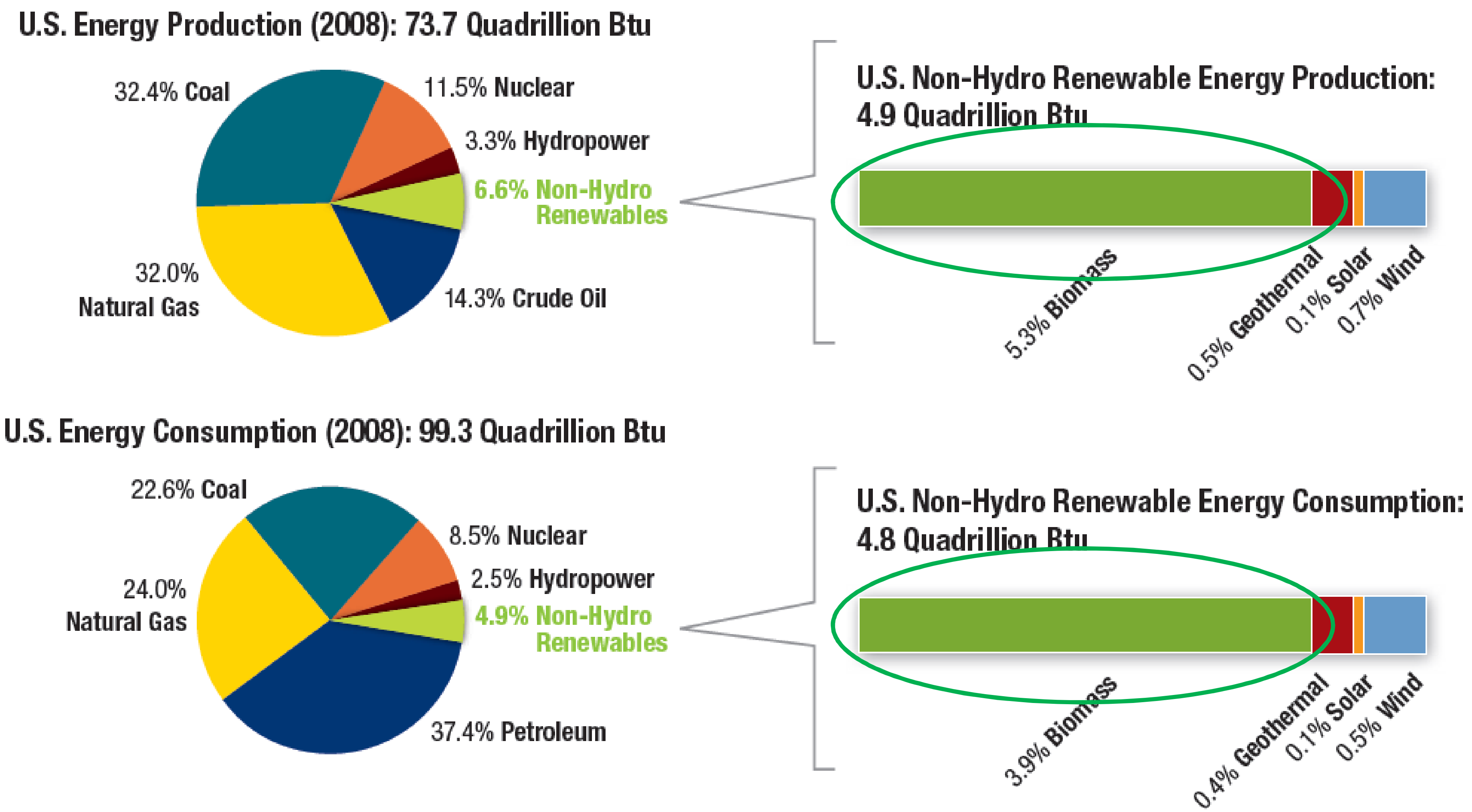
Feedstock	Tons/year	Expected Yield	Theoretical Yield
Bagasse	2,591,680.54	86.00	115.50
Corn Cobs *	2,749.48	84.00	108.90
Corn Stover	18,329.86	87.20	113.00
Forest Residues	2,399,000.00	62.90	81.50
Primary Mill Residues	1,883,475.00	82.20	106.50
Sugarcane	11,803,017.78	21.50	19.50
Urban Wood and Sec Mill Residues	1,795,503.50	82.20	106.50
Total	**20,491,006.68**		

Item	Value
Biodiesel Stations	17
E85 Stations	38
Ethanol Plants	0
Ethanol Plant Capacity (millon gallons/year)	0
Biodiesel Plants	2
Biodiesel Plant Capacity (million gallons/year)	11
Biopower Plants	30
Biopower Plant Capacity (nameplate, MW)	1,240.00

October 2010 Data

http://maps.nrel.gov/biomass

Biomass Trends

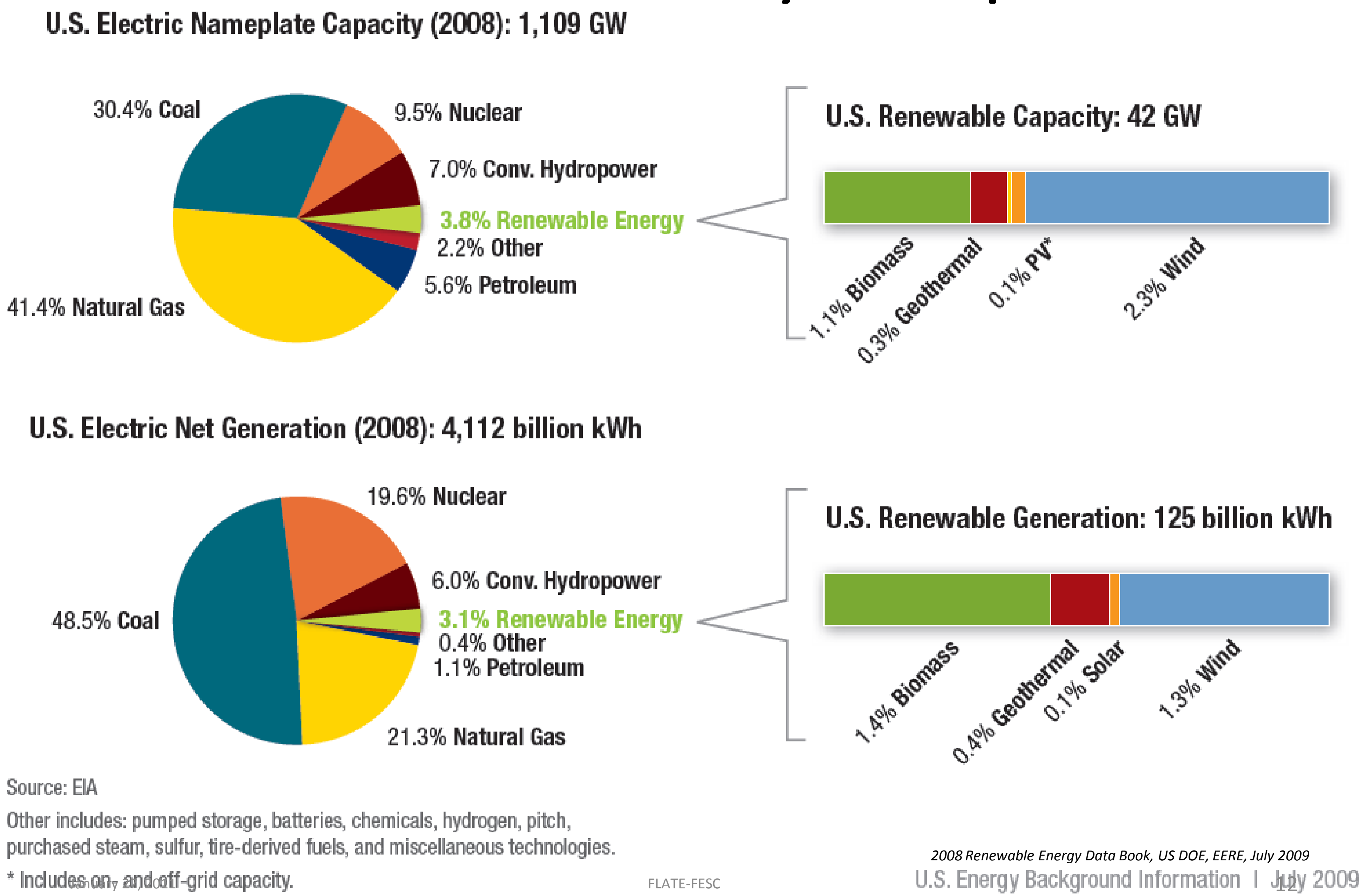


Source: EIA; full references are provided starting on p. 122.

Note: Because hydropower is considered a conventional source of energy, it is accounted for separate from other new renewable sources of energy. Energy consumption is higher than energy production due to oil imports.

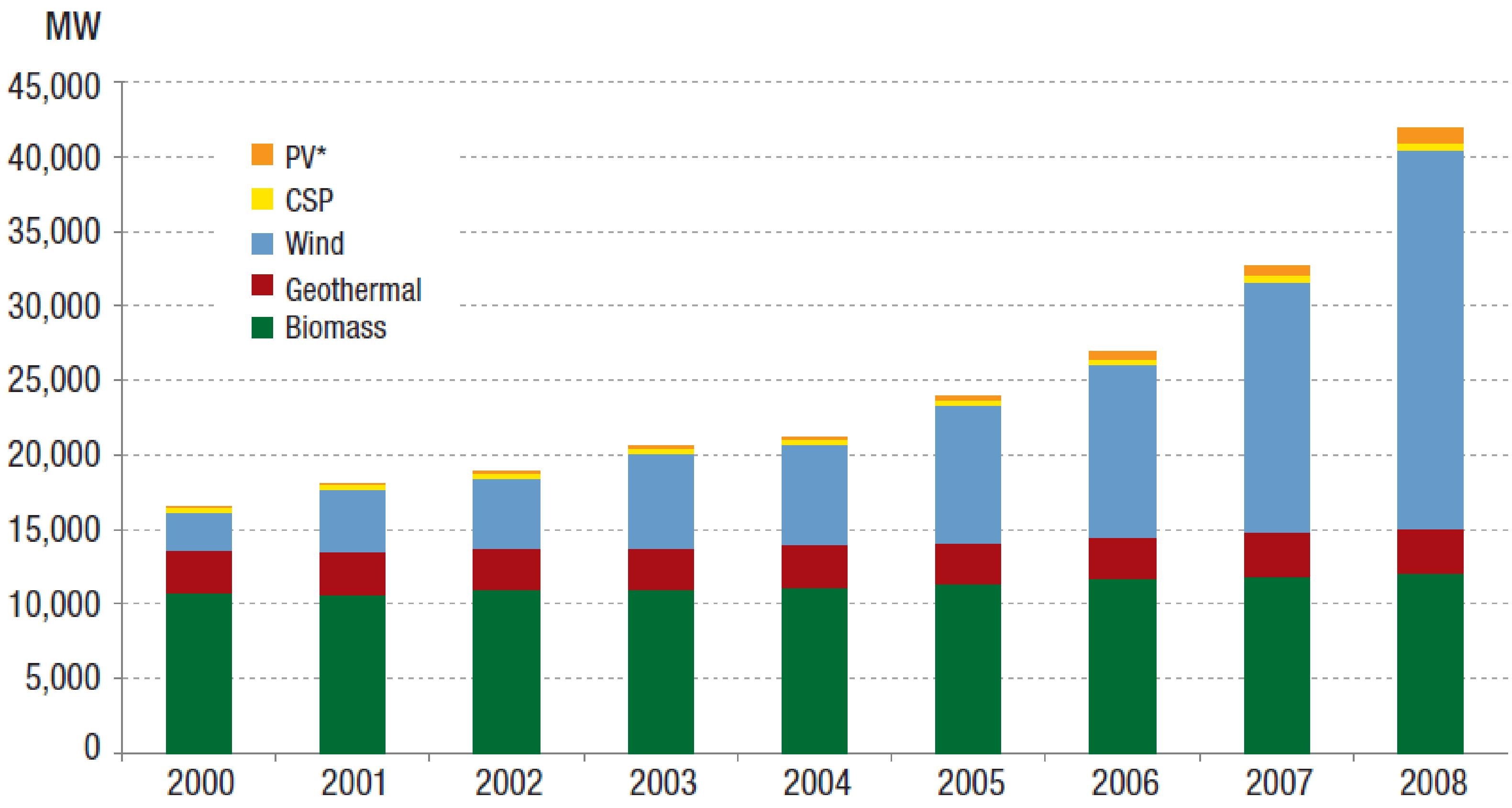
2008 Renewable Energy Data Book, US DOE, EERE, July 2009

Biomass Electricity= Biopower



2008 Renewable Energy Data Book, US DOE, EERE, July 2009

Biomass Trends- Biopower



Sources: EIA, AWEA, IEA PVPS, Navigant, GEA, Larry Sherwood/IREC, Greentech Media
* Includes on- and off-grid capacity.

2008 Renewable Energy Data Book, US DOE, EERE, July 2009

Renewable Electricity in the U.S. I July 2009

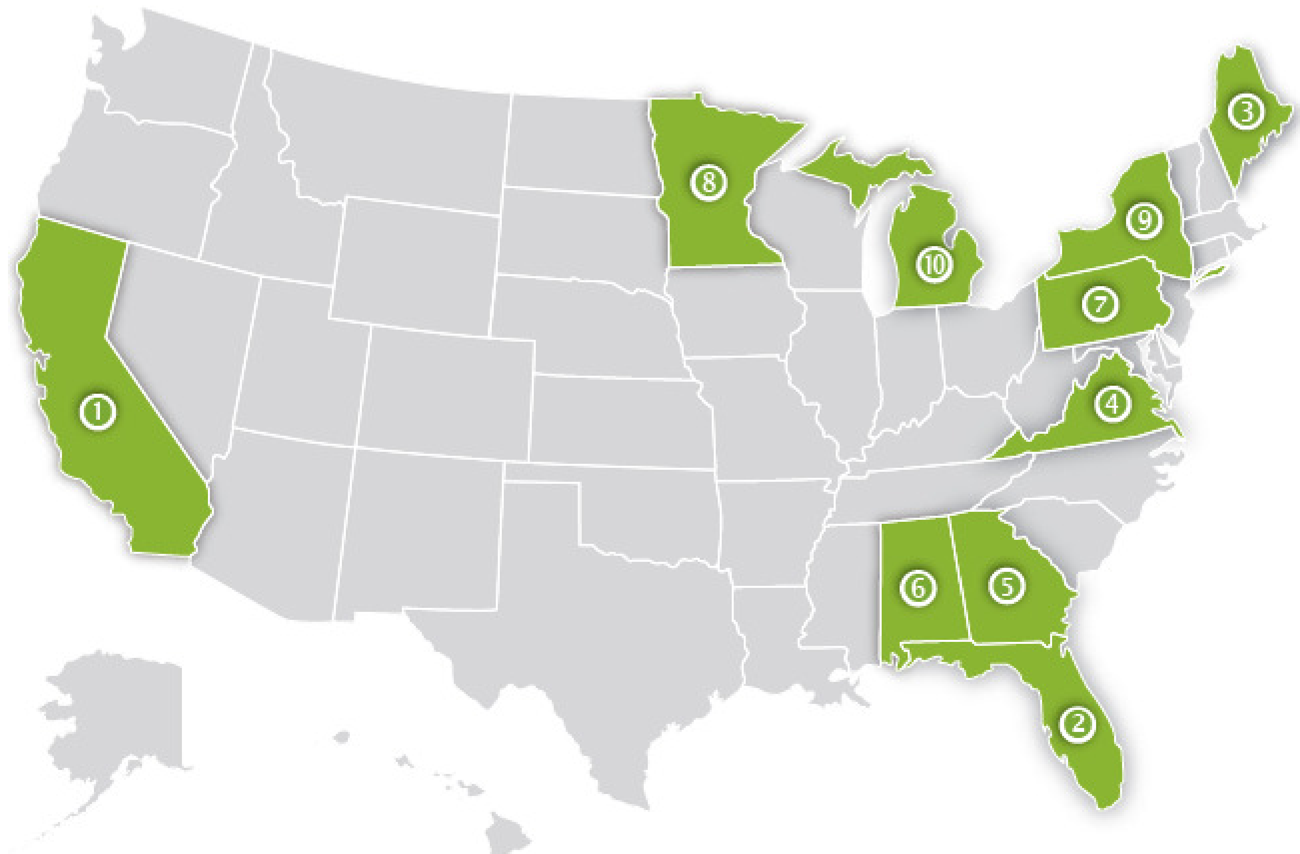
Biomass Trends- Biopower

- Biopower generation has remained steady during the past seven years, and currently accounts for **45% of all renewable energy generated in the United States** (excluding hydropower).

- Biomass electricity primarily comes from wood and agricultural residues that are burned as a fuel for cogeneration in the industrial sector (such as in the pulp and paper industry).

2008 Renewable Energy Data Book, US DOE, EERE, July 2009

States Leading Biopower Energy Development (2008)

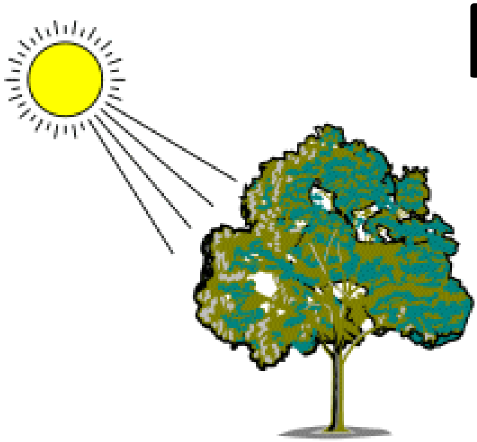


Total Installed Capacity (2008, MW)	
❶ California	1,217
❷ Florida	1,158
❸ Maine	768
❹ Virginia	760
❺ Georgia	712
❻ Alabama	622
❼ Pennsylvania	565
❽ Minnesota	445
❾ New York	439
❿ Michigan	430

2008 Renewable Energy Data Book, US DOE, EERE, July 2009

Biomass

Technical Background



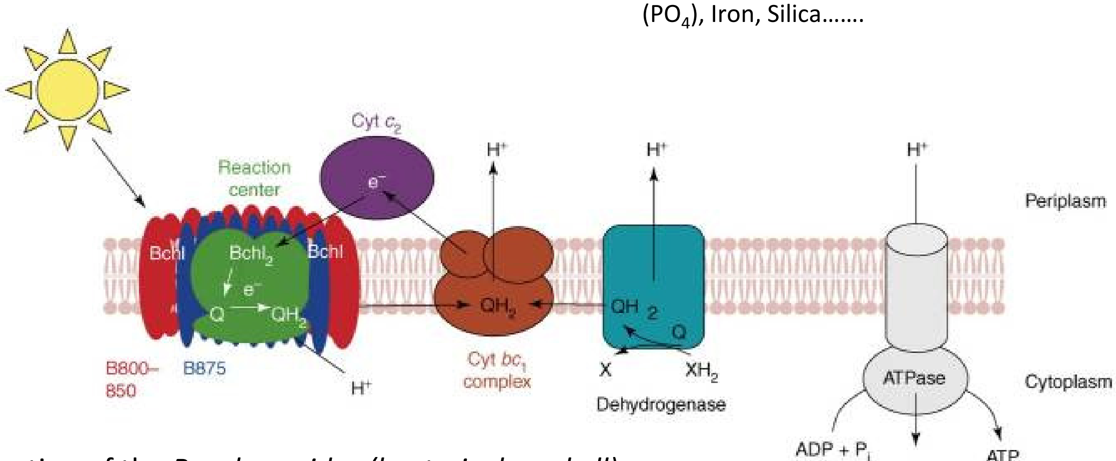
Photosynthesis

- Biomass energy is a form of solar energy
- Solar energy is captured via photosynthesis as carbon dioxide is incorporated as fixed carbon during the growth stage of all biomass
- Average solar incidence is about 4000 $W/m^2/day$

MIT OpenCourseWare, 3.564J Sustainable Energy, Spring 2005, http://ocw.mit.edu
http://www.eia.doe.gov/kids/energy.cfm?page=biomass_home-basics

$$6\ CO_2 + 6\ H_2O + \text{Nutrients} \rightarrow C_6H_{12}O_6 + 6O_2$$

Carbon Dioxide | Water | Nitrate (NO_3), Phosphate (PO_4), Iron, Silica……. | Glucose (sugar)

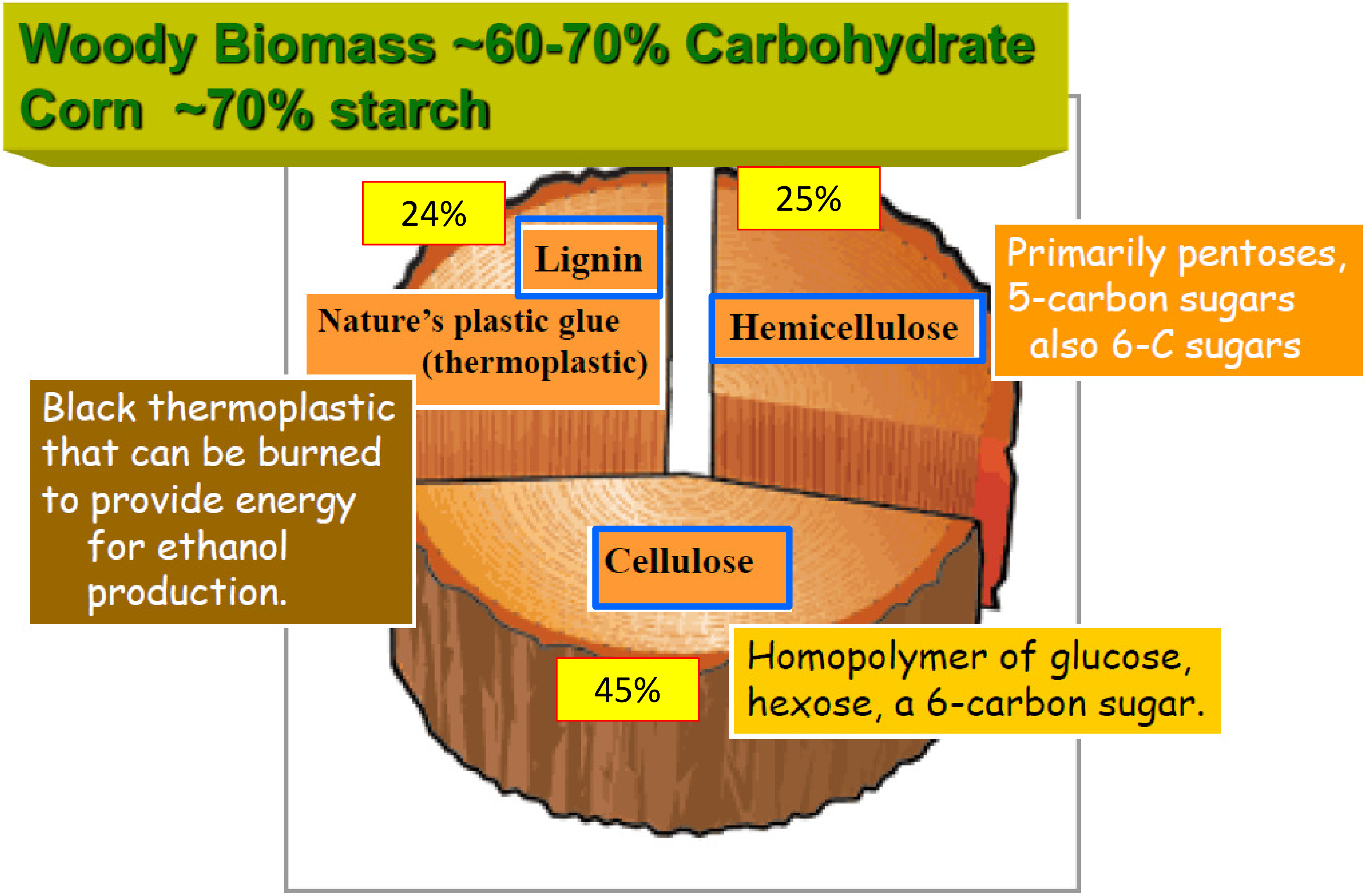


Cross-section of the *R. sphaeroides (bacterioclorophyll)*

Photosynthesis is about 10.5% efficient in solar energy conversion

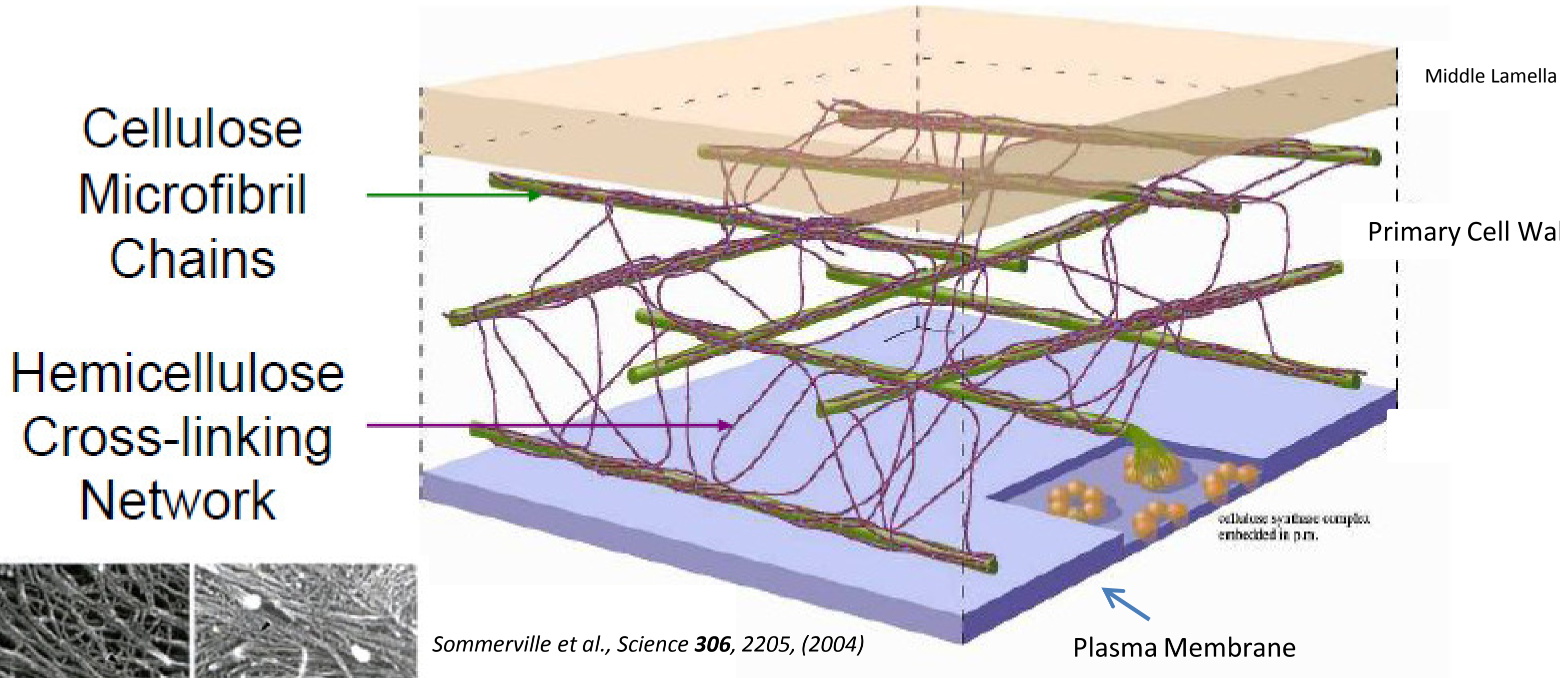
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2765710/?tool=pmcentrez

Composition of Lignocellulosic Biomass



Lonnie Ingram, 2010 FESC Summit, http://www.floridaenergy.ufl.edu/?page_id=3657

Plant Cell Wall Structure



*Sommerville et al., Science **306**, 2205, (2004)*

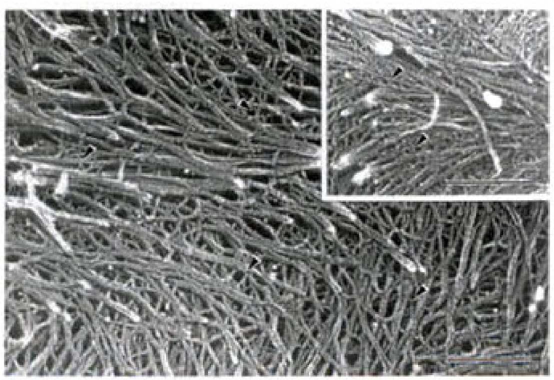
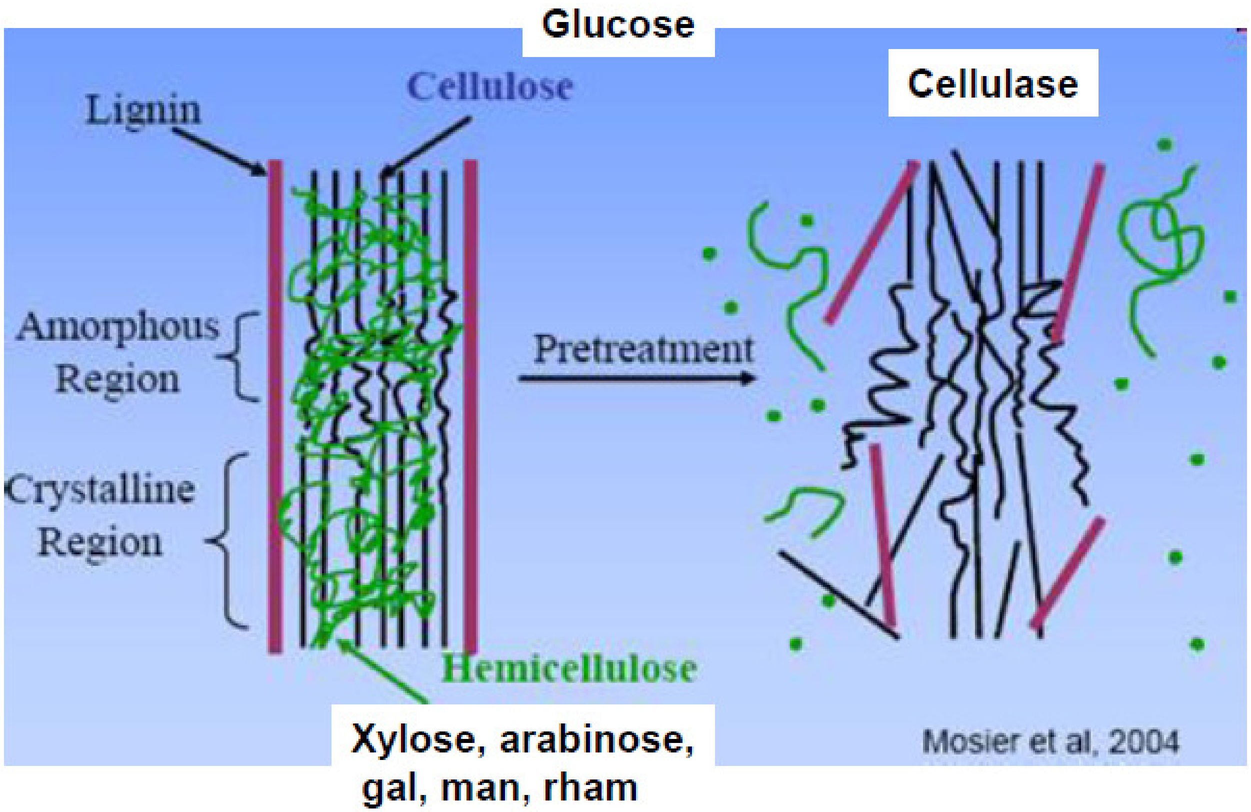


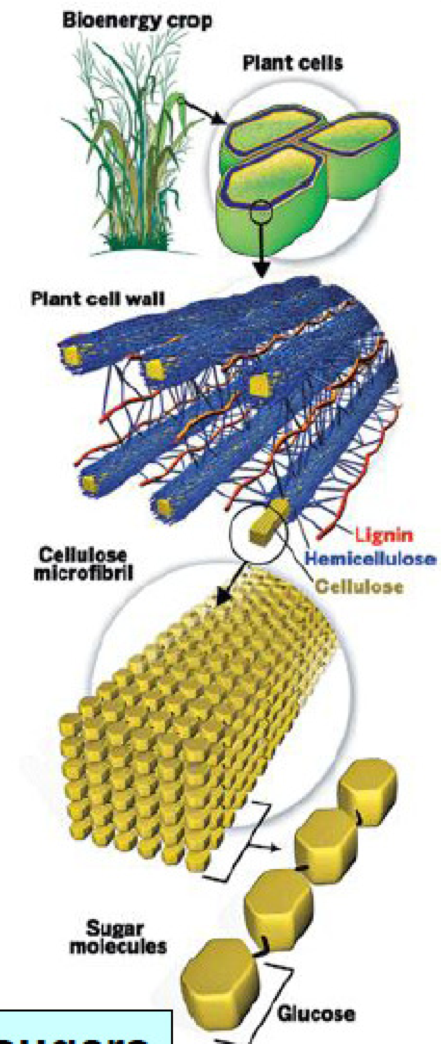
Fig. 1. Electron micrograph of outer cell walls of EDTA-extracted epidermal cells of pea (*Pisum sativum*) plants. Cellulose microfibrils and their cross-links are indicated by arrowheads. The inset shows the walls before extraction. Scale bars, 200 nm. [Image from (*16*)]

- Macrostructure is polymorphous
  - Crystalline regions
  - Amorphous regions
- Heterogeneous
  - Cellulose, hemicellulose, lignin

Breakdown of Biomass

Acid or Base pretreatment is essential for deconstruction of lignocellose.





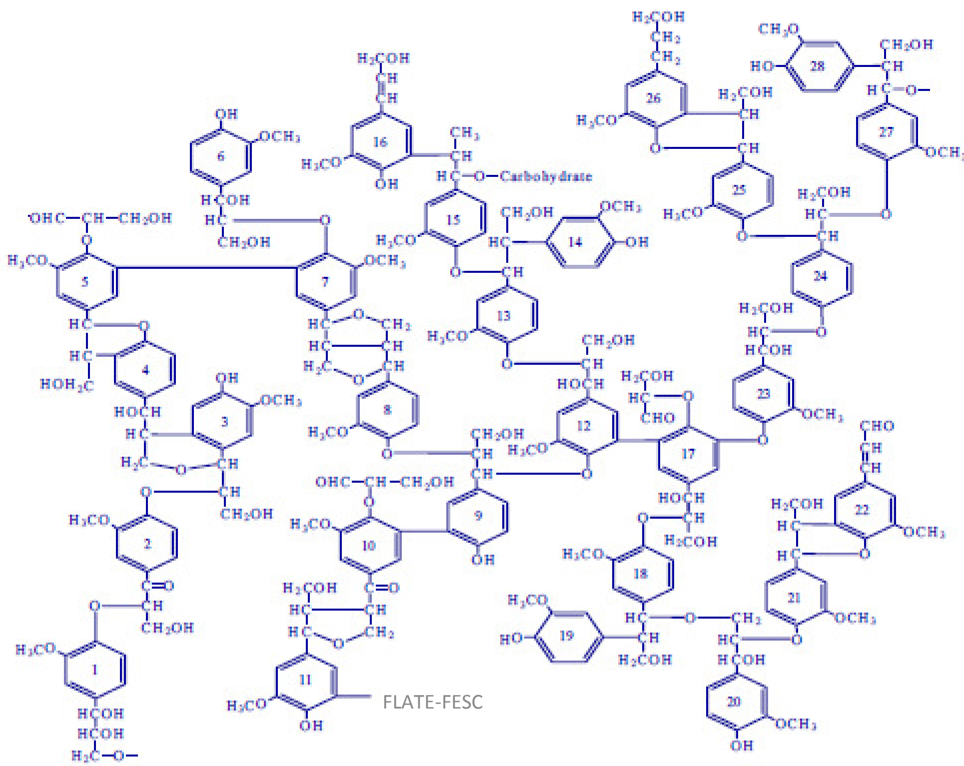
Lonnie Ingram, 2010 FESC Summit, http://www.floridaenergy.ufl.edu/?page_id=3657

1. Dilute acid pretreatment → syrup of hemicellulose sugars
2. Enzymes to convert cellulose → glucose syrup

Lignin

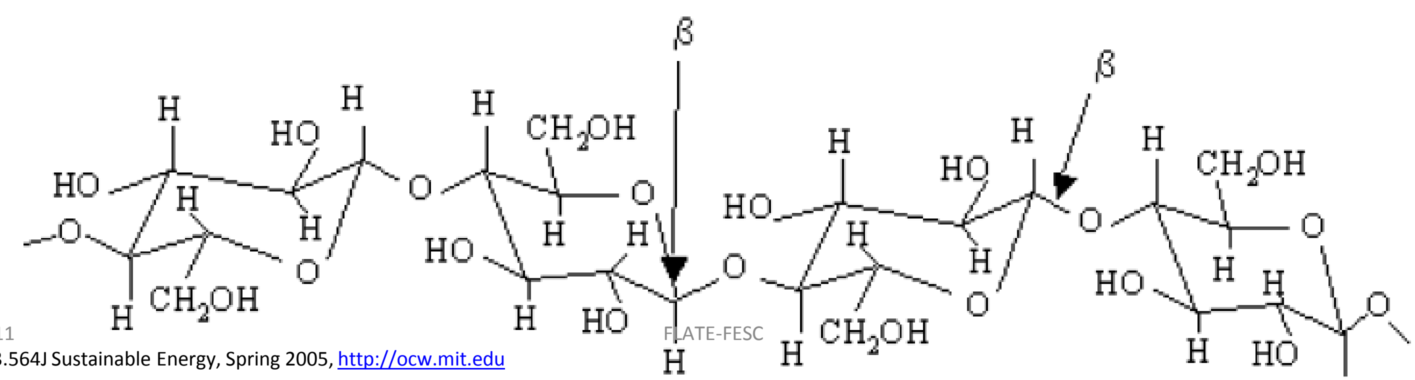
- The major noncarbohydrate, polyphenolic structural constituent of wood and other plant material that encrusts the cell walls and cements the cells together
- A highly polymeric substance, with a complex, cross-linked, highly aromatic structure of molecular weight about 10,000 derived principally from coniferyl alcohol ($C10H12O3$) by extensive condensation polymerization
- Higher heating value: HHV=9111 Btu/lb

MIT OpenCourseWare, 3.564J Sustainable Energy, Spring 2005, http://ocw.mit.edu



Cellulose

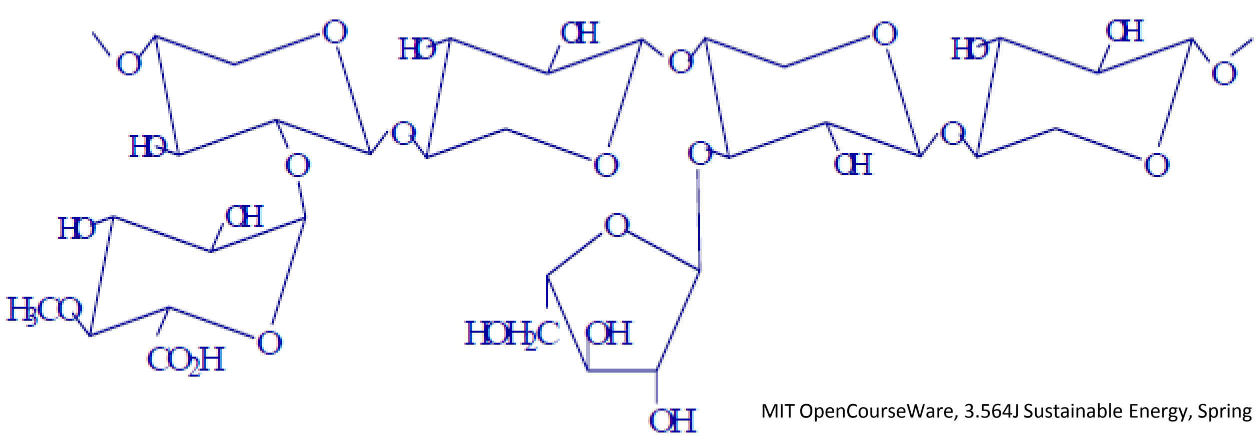
- Composed of long chains of ß-glucose linked together (repeating unit $C_6H_{10}O_4$)
- Principal constituent for the structural framework of wood and other biomass cells
- The ß-linkages form linear chains which are highly stable and resistant to chemical attack because of the high degree of hydrogen bonding that occurs between chains of cellulose, inhibiting the flexing of the molecules that must occur in the hydrolytic breaking of the glycosidic linkages
- Hydrolysis can reduce cellulose to a cellobiose (repeating unit $C_{12}H_{22}O_{11}$) and ultimately to glucose, $C_6H_{12}O_6$
- Higher heating value: HHV = 7500 Btu/lb



MIT OpenCourseWare, 3.564J Sustainable Energy, Spring 2005, http://ocw.mit.edu

Hemicellulose

- Composed of short, highly branched chains of five different sugars
- Contains five-carbon sugars (usually D-xylose and L-arabinose) and six-carbon sugars (D-galactose, D-glucose, and D-mannose) and uronic acid
- Sugars are highly substituted with acetic acid
- Branched nature of hemicellulose renders it amorphous and relatively easy to hydrolyze to its constituent sugars compared to cellulose



MIT OpenCourseWare, 3.564J Sustainable Energy, Spring 2005, http://ocw.mit.edu

Composition

Composition of Selected Ligncellulosic Resouces, % dry weight

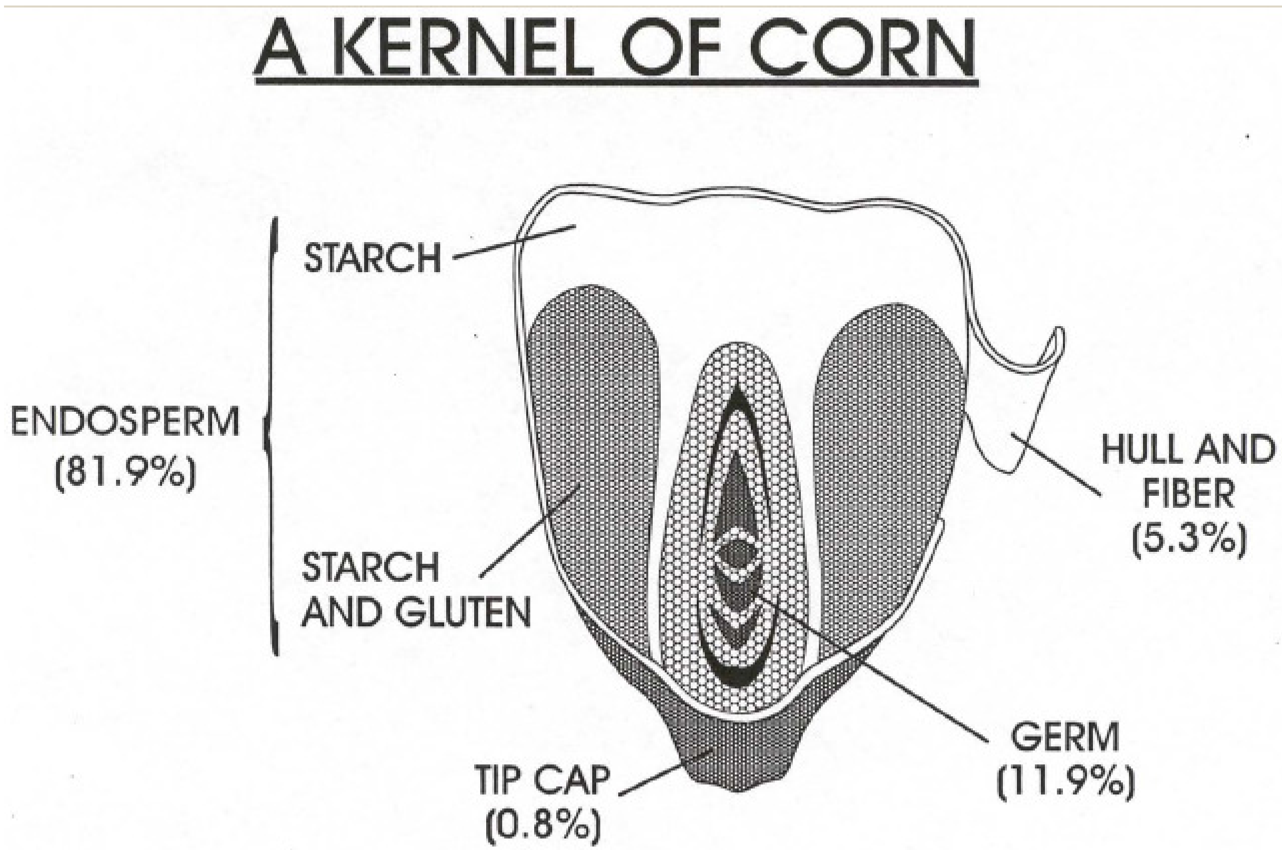
Feedstock	Glucan (cellulose)	Xylan (hemicellulose)	Lignin
Corn stover	37.5	22.4	17.6
Corn fiber	14.28	16.8	8.4
Pine wood	46.4	8.8	29.4
Poplar	49.9	17.4	18.1
Wheat straw	38.2	21.2	23.4
Switch grass	31.0	20.4	17.6
Office paper	68.6	12.4	11.3

Adapted from N. Mosier et al., 2005. Biores Technol. 96:673-686 http://bioenergy.ornl.gov/papers/misc/energy_conv.html

Energy Content

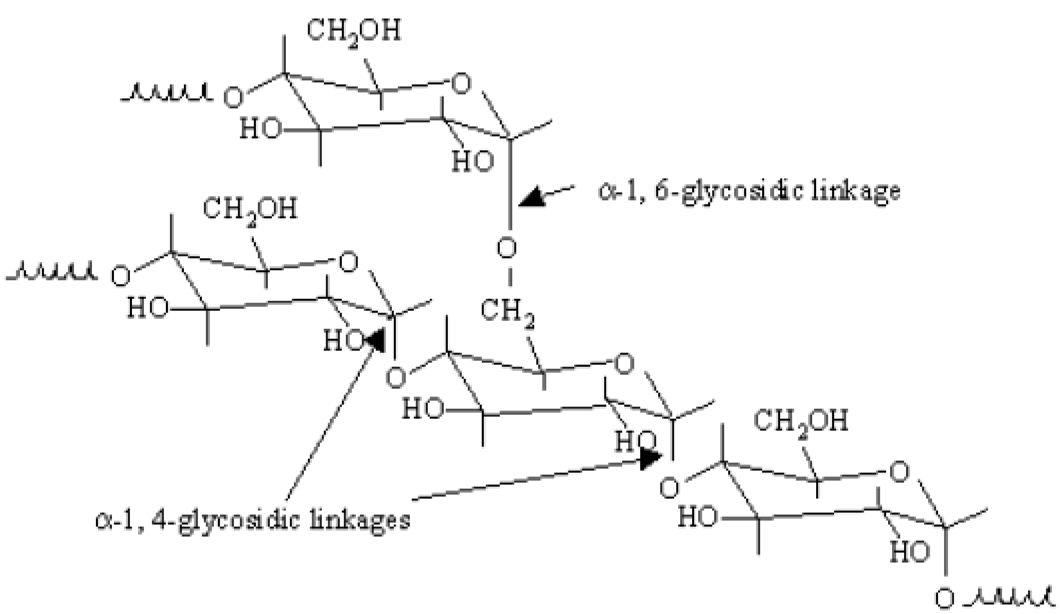
		CHEMICAL CHARACTERISTICS				
		heating value (gross, unless specified; GJ/t)	ash (%)	sulfur (%)	potassium (%)	Ash melting temperature [some ash sintering observed] (C)
Bioenergy Feedstocks	corn stover	17.6	5.6			
	sweet sorghum	15.4	5.5			
	sugarcane bagasse	18.1	3.2-5.5	0.10-0.15	0.73-0.97	
	sugarcane leaves	17.4	7.7			
	hardwood	20.5	0.45	0.009	0.04	[900]
	softwood	19.6	0.3	0.01		
	hybrid poplar	19.0	0.5-1.5	0.03	0.3	1350
	bamboo	18.5-19.4	0.8-2.5	0.03-0.05	0.15-0.50	
	switchgrass	18.3	4.5-5.8	0.12		1016
	miscanthus	17.1-19.4	1.5-4.5	0.1	0.37-1.12	1090 [600]
	Arundo donax	17.1	5-6	0.07		
Liquid Biofuels	bioethanol	28		<0.01		N/A
	biodiesel	40	<0.02	<0.05	<0.0001	N/A
Fossil Fuels	Coal (low rank; lignite/sub-bituminous)	15-19	5-20	1.0-3.0	0.02-0.3	~1300
	Coal (high rank; bituminous/anthracite)	27-30	1-10	0.5-1.5	0.06-0.15	~1300
	Oil (typical distillate)	42-45	0.5-1.5	0.2-1.2		N/A

Corn


A KERNEL OF CORN
STARCH
ENDOSPERM
(81.9%)
STARCH
AND GLUTEN
HULL AND
FIBER
(5.3%)
TIP CAP
(0.8%)
GERM
(11.9%)

Starch

- Composed of long chains of α-glucose molecules linked together (repeating unit $C_{12}H_{16}O_5$)
- Linkages occur in chains of α-1,4 linkages with branches formed as a result of α-1,6 linkages
- Widely distributed and stored in all grains and tubers
- Due to α linkages in starch, this polymer is highly amorphous, and more readily broken down by enzyme systems into glucose
- Gross heat of combustion: Q_v(gross)=7560 Btu/lb

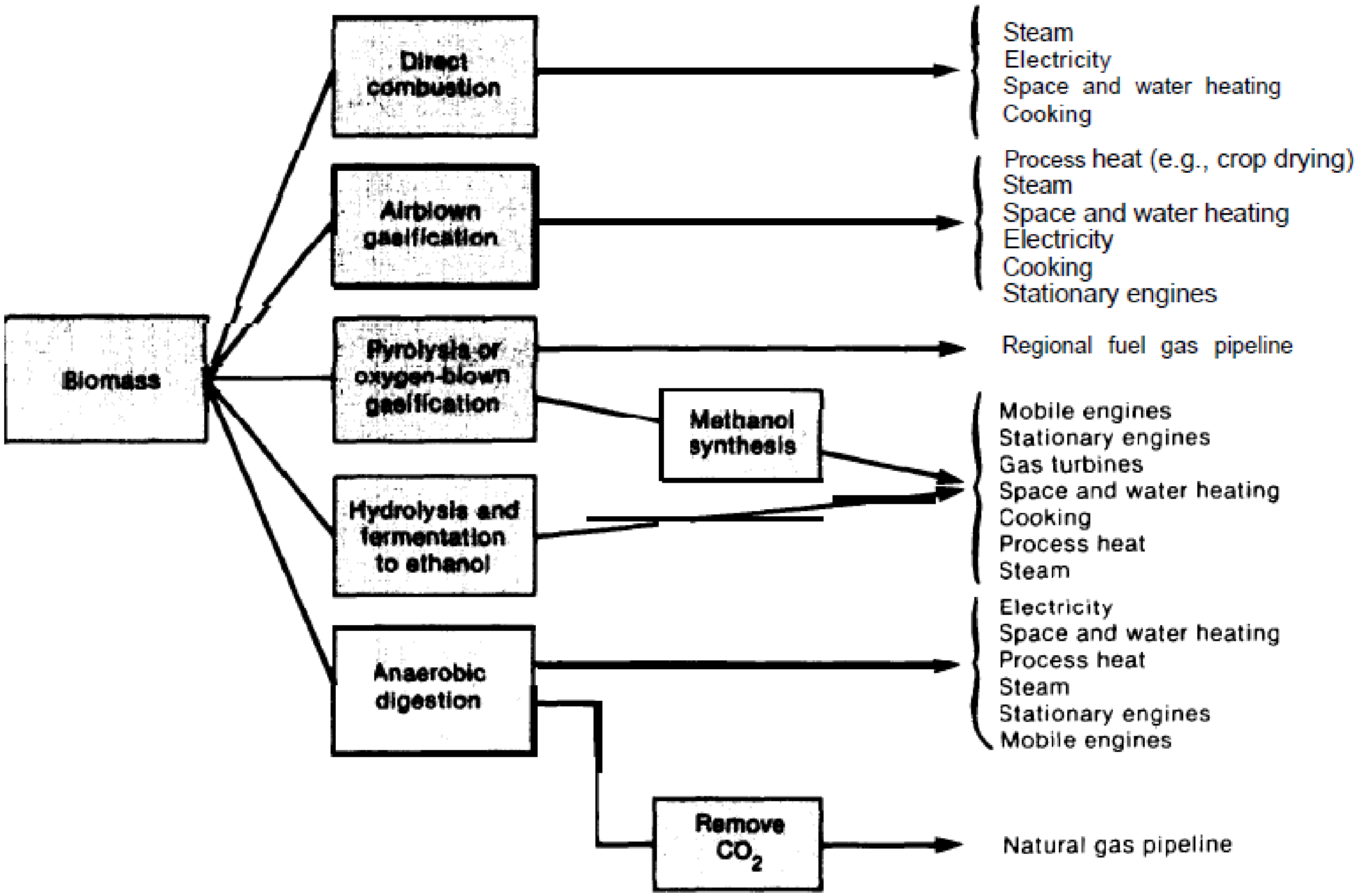


MIT OpenCourseWare, 3.564J Sustainable Energy, Spring 2005, http://ocw.mit.edu

Biomass Processes

1. Biopower
2. Biofuels
3. Biomass Chemical Products

Biomass Processing



Office of Technology Assessment, Energy From Biological Processes, July 1980

http://www.princeton.edu/~ota/ns20/year_f.html

1. Biopower

Biomass Electricity = Biopower

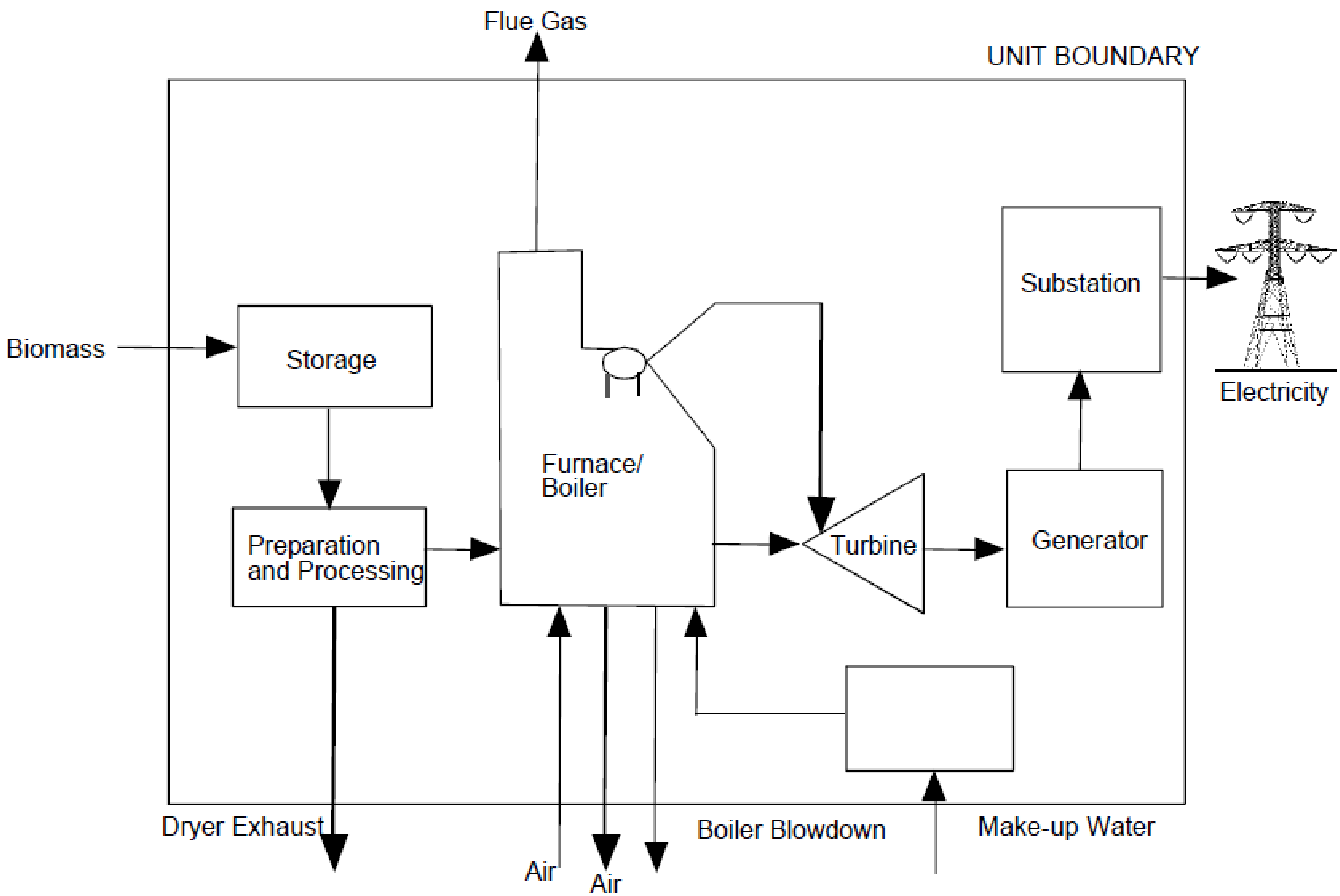
Most electricity generated using biomass today is by direct combustion using conventional boilers.

These boilers burn primarily waste wood products generated by the agriculture and wood-processing industries. When burned, the wood waste produces steam, which is used to spin a turbine. The spinning turbine activates a generator that produces electricity. This could be in a co-generation system.

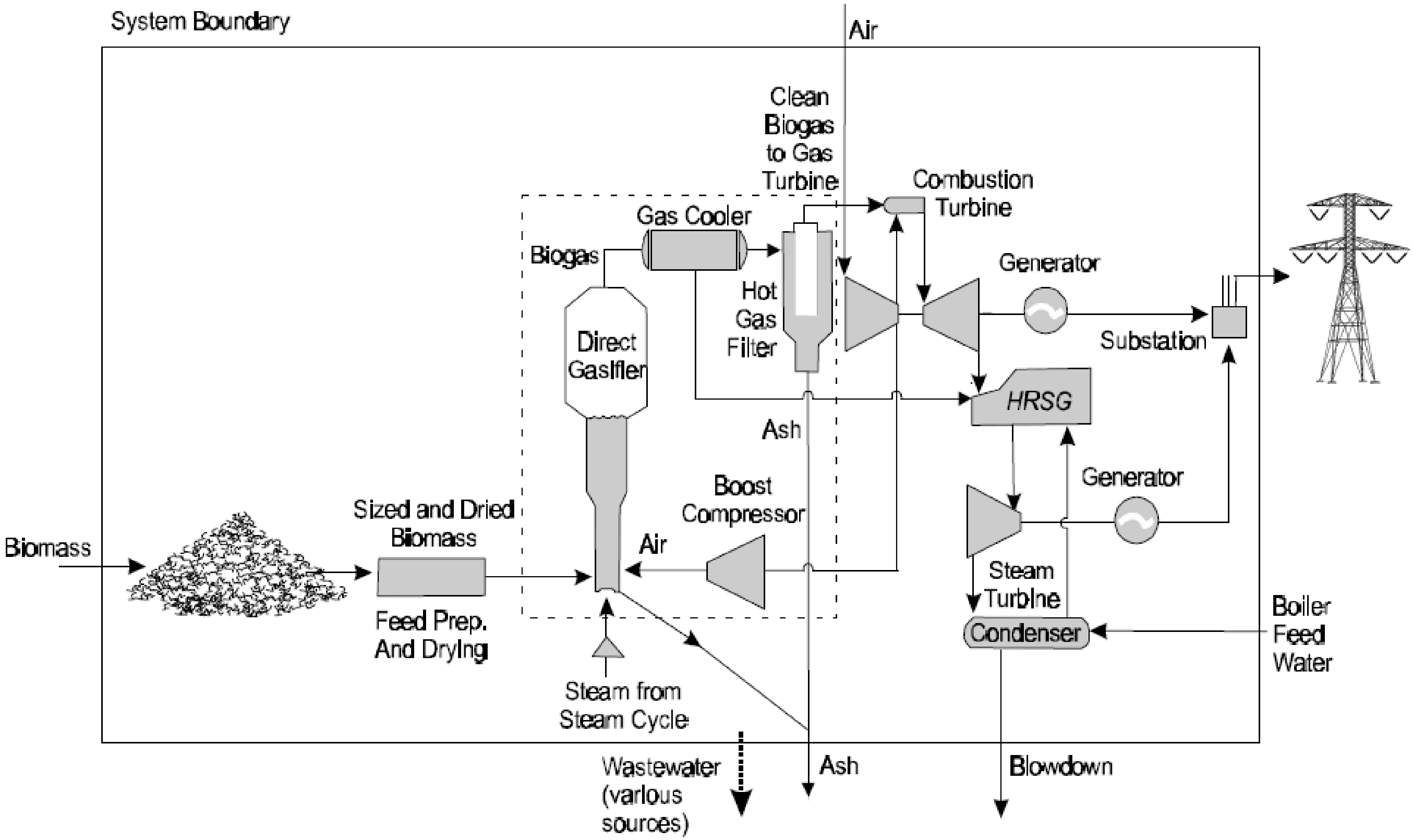
Biomass can also be gasified prior to combustion. Gases generally burn cleaner and more efficiently than solids, which allows removal of toxic materials. Gasification also makes it possible to use biomass in combined-cycle gas turbines, such as used in the latest natural gas power plants. Using gasification, these natural gas power plants can achieve much higher efficiencies. Small modular biomass gasification systems are well suited for providing isolated communities with electricity

In addition, the decay of biomass in landfills produces gas (primarily methane) naturally, which can be harvested and burned in a boiler to produce steam for generating electricity.

Direct Combustion Biopower



Air-blown Gassification based Biopower



Biomass gasification combined cycle (BGCC) system schematic.

http://www1.eere.energy.gov/biomass/

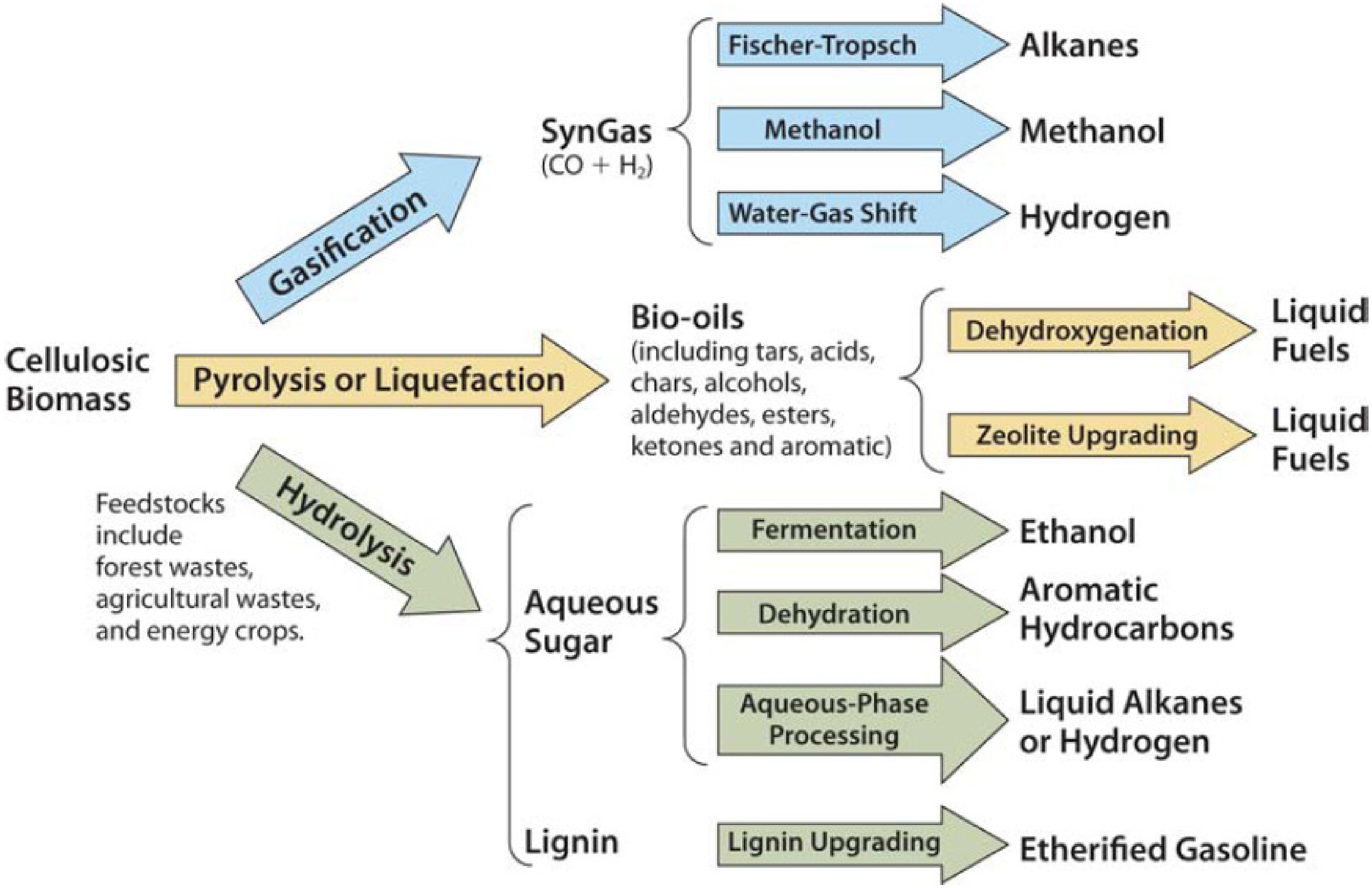
2. Biofuels

Syngas

Ethanol

Biodiesel

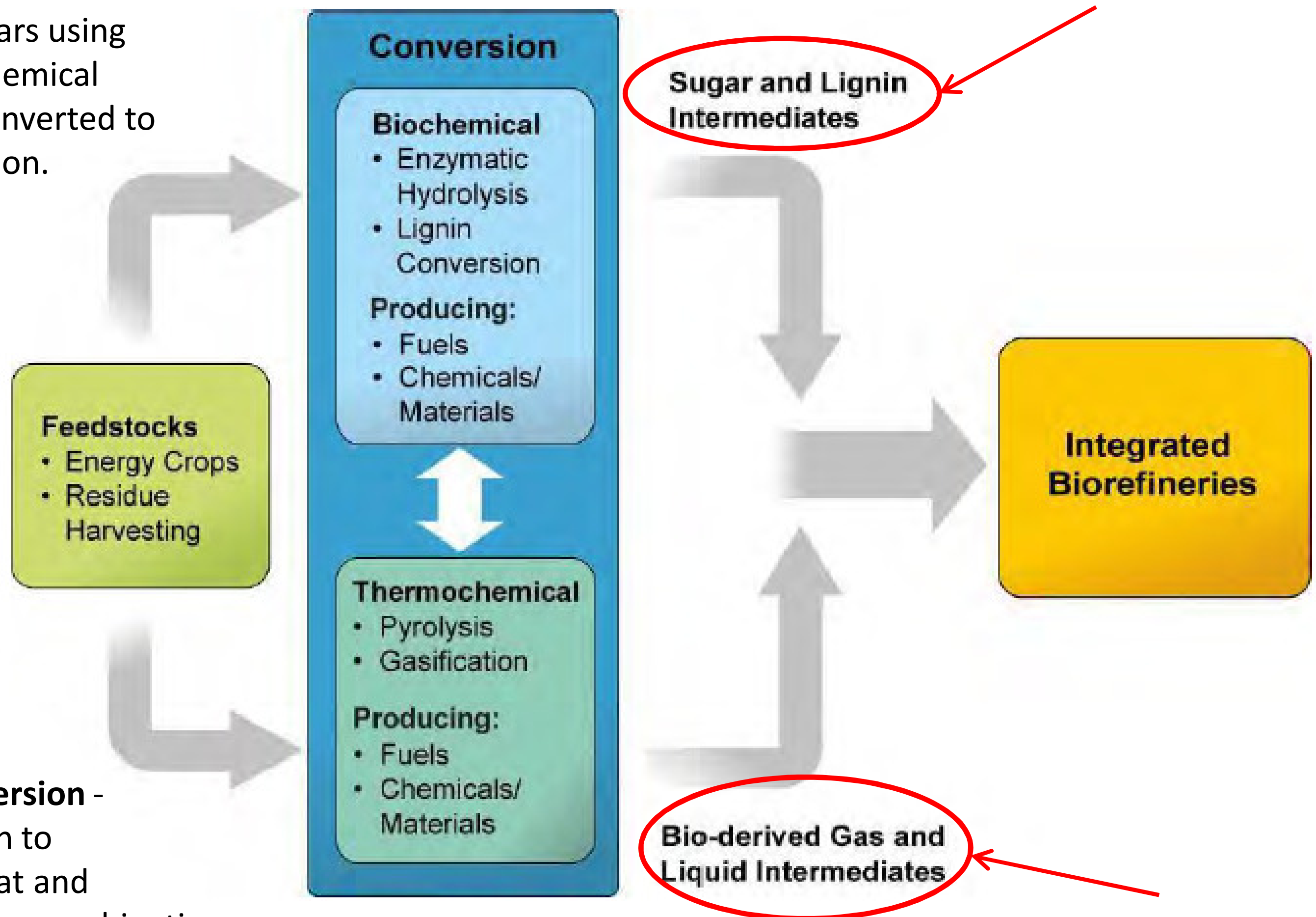
Various Routes to Biofuels



Science for Energy Technology: Strengthening the Link between Basic Research and Industry, DOE, August 2008, http://www.er.doe.gov/bes/reports/abstracts.html

Conversion Processes

Biochemical Conversion - Biomass is broken down to sugars using either enzymatic or chemical processes and then converted to ethanol via fermentation.



Thermochemical Conversion - Biomass is broken down to intermediates using heat and upgraded to fuels using a combination of heat and pressure in the presence of catalysts.

Figure 3-11: Conversion Routes for Biomass to Biofuels

http://www1.eere.energy.gov/biomass/

Biochemical Conversion

Lignocellulose (mainly lignin, cellulose and hemicellulose), is the primary component of plant residues, woody materials and grasses.

The cell walls or these plant matters are comprised of long chains of sugars (carbohydrates), which can be converted to biofuels.

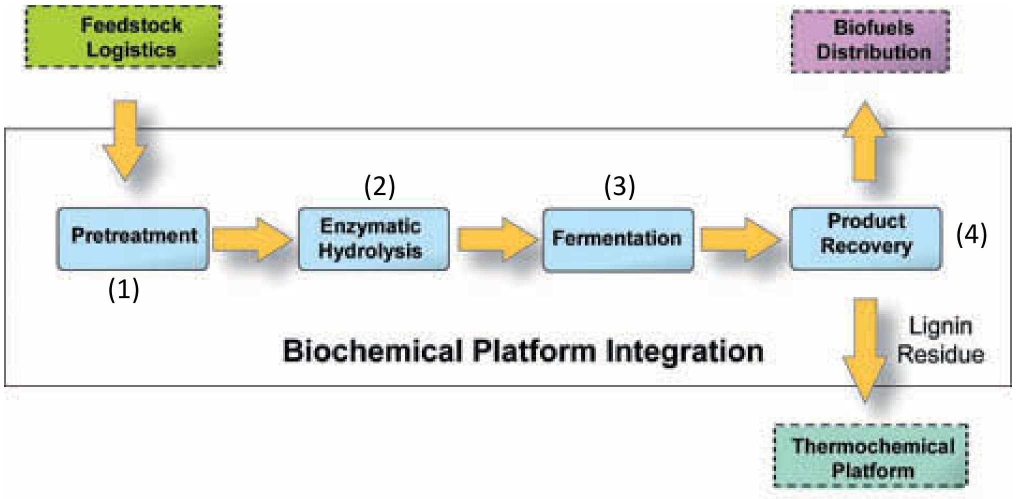
Biochemical conversion breaks down the cell wall through the introduction of enzymes or acid in order to extract the sugars which are then converted to biofuels using **microorganisms**.

Due to the complex structure of the **cell wall** it is more difficult to break down into sugars, making this material more expensive to convert to biofuels.

Current R&D focuses on high-yield feedstocks, more efficient enzymes, and more robust microorganisms to advance biochemical conversion processes

http://www1.eere.energy.gov/biomass/biochemical_conversion.html

Biochemical Conversion



(1) Pretreatment (also known as Prehydrolysis)

Biomass undergoes a thermochemical process, where heat and either water, an acid or a base are used to break down the cellulosic biomass into soluble sugars and make the cellulose more accessible for the hydrolysis step.

(2) Hydrolysis/Saccharification

The pretreated material is saccharified (separating the carbohydrates) and the sugar is released. Enzymes or acid are used in this process to beak down any remaining solid cellulose to simple sugars. This process takes several days after which the mixture of sugars and any solids or un-reacted cellulose is transferred to a fermenter.

(3) Fermentation

Fermenting organisms are added to the mixture to ferment the sugars to alcohol and carbon dioxide.

(4) Product Recovery

This process involves distilling the fermented mixture to separate the ethanol from the water and any residual solids. The remaining solids are primarily composed of lignin, which can be burned for heat and power or thermochemically (using heat) converted to synthesis gas or pyrolysis oil intermediates for upgrading to fuels.

http://www1.eere.energy.gov/biomass/biochemical_conversion.html

Enzyme Hidrolysis

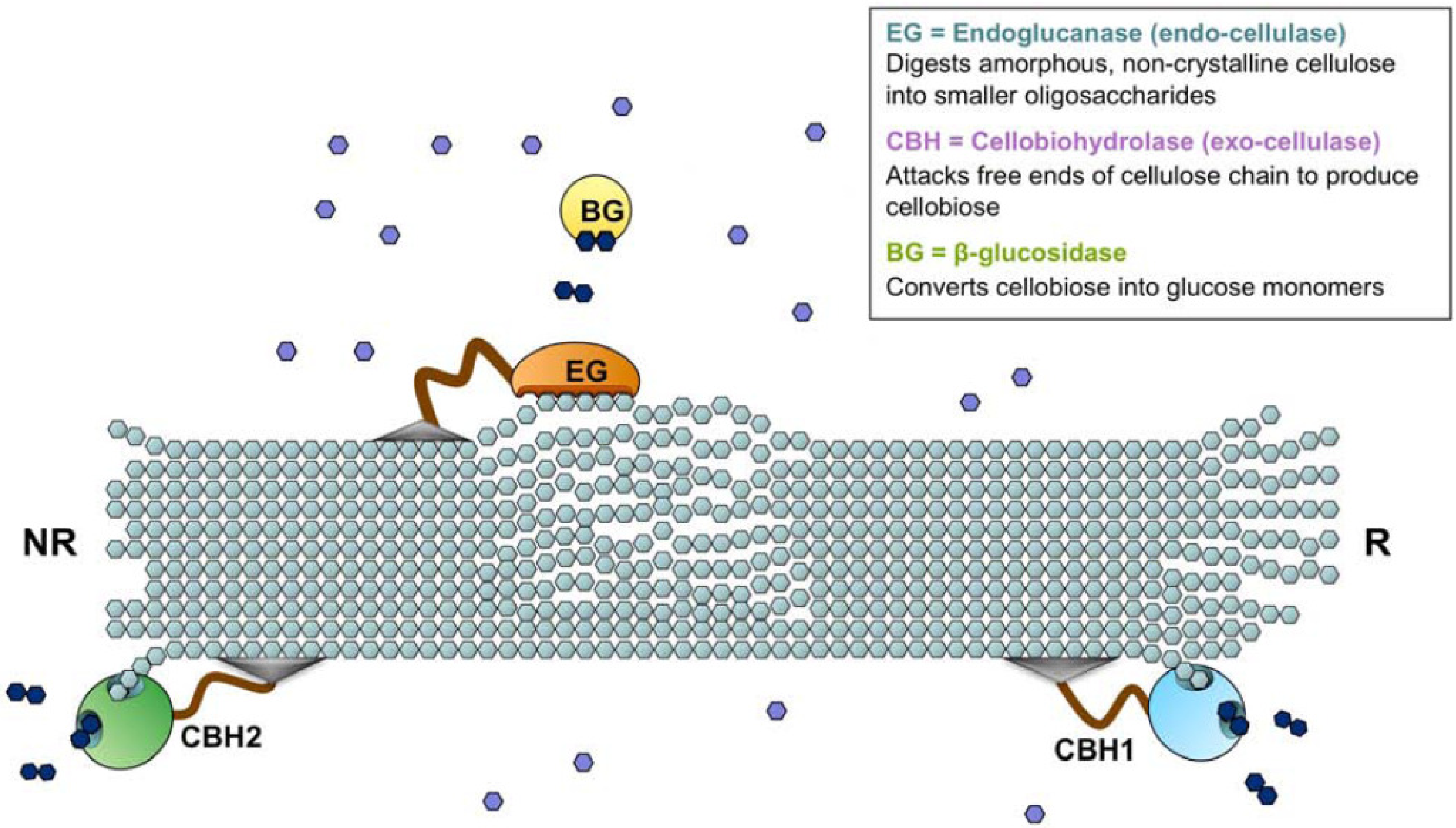
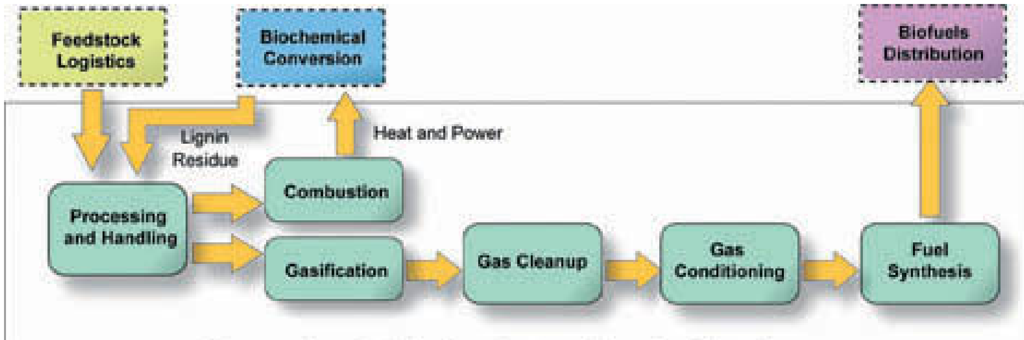


Figure 9-3 Schematic of enzyme actions on cellulose surface and in solution. Source: J. Stege, Verenium Corp. (Copyright Verenium Corporation, 2010)

Science for Energy Technology: Strengthening the Link between Basic Research and Industry, DOE, August 2008, http://www.er.doe.gov/bes/reports/abstracts.html

Thermochemical Conversion

Gasification



Thermochemical Platform Integration - Gasification

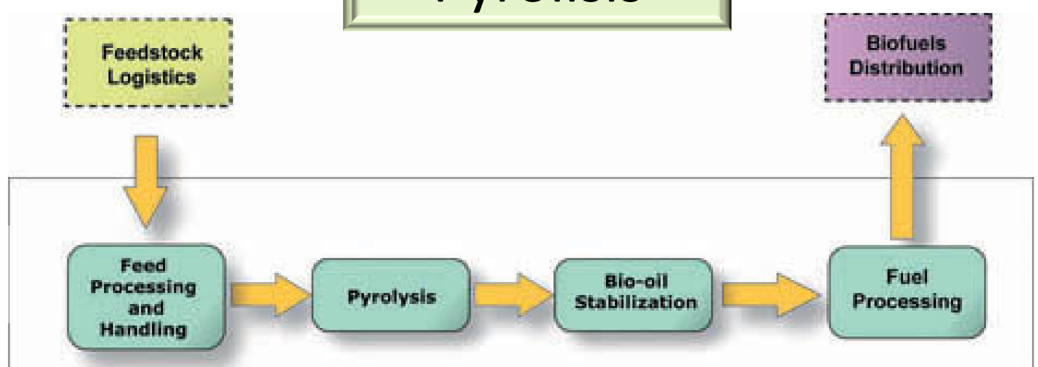
Gasification

In gasification conversion, lignocellulosic feedstocks such as wood and forest products are broken down to synthesis gas, primarily carbon monoxide and hydrogen, using heat. The feedstock is then partially oxidized, or reformed with a gasifying agent (air, oxygen, or steam), which produces synthesis gas (syngas).

Pyrolisis

Pyrolysis

In pyrolysis processing, biomass feedstocks are broken down using heat in the absence of oxygen, producing a bio-oil that can be further refined to a hydrocarbon product. The decomposition occurs at lower temperatures than gasification processes, and produces liquid oil instead of a synthesis gas.

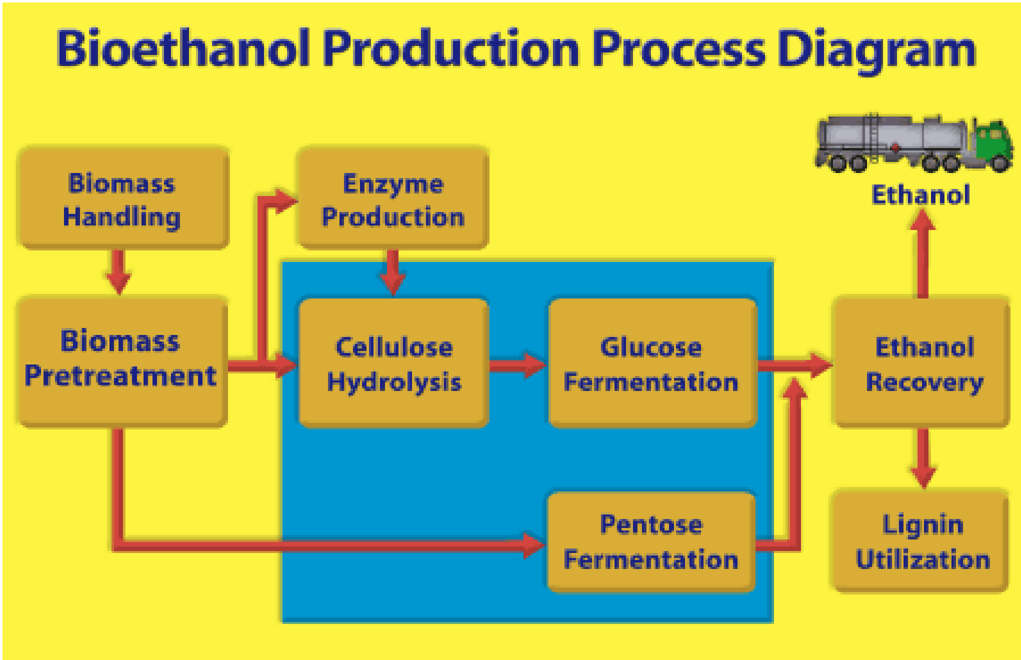


Thermal Platform Integration - Pyrolysis

Biofuels

- **Syngas (Synthetic Gas)**
  - A gas mixture of primarily carbon monoxide and hydrogen resulting from gasification.
  - The name comes from their use as intermediates in creating synthetic natural gas (SNG) and for producing ammonia or methanol
  - Can be used for combustion in gas turbine engines to produce electricity or as fuel for distributed generation equipment.
- **Bioethanol**
  - An alcohol made by fermenting the sugar components of biomass.
  - Ethanol can be used as a fuel for cars in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions.
- **Biodiesel**
  - A mixture of fatty acid alkyl esters made from vegetable oils, animal fats or recycled greases.
  - Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a petroleum diesel additive to reduce levels of particulates, carbon monoxide, hydrocarbons and air toxics from diesel-powered vehicles.

Bioethanol



$$C_6H_{12}O_6 \longrightarrow 2\ CH_3CH_2OH + 2\ CO_2$$

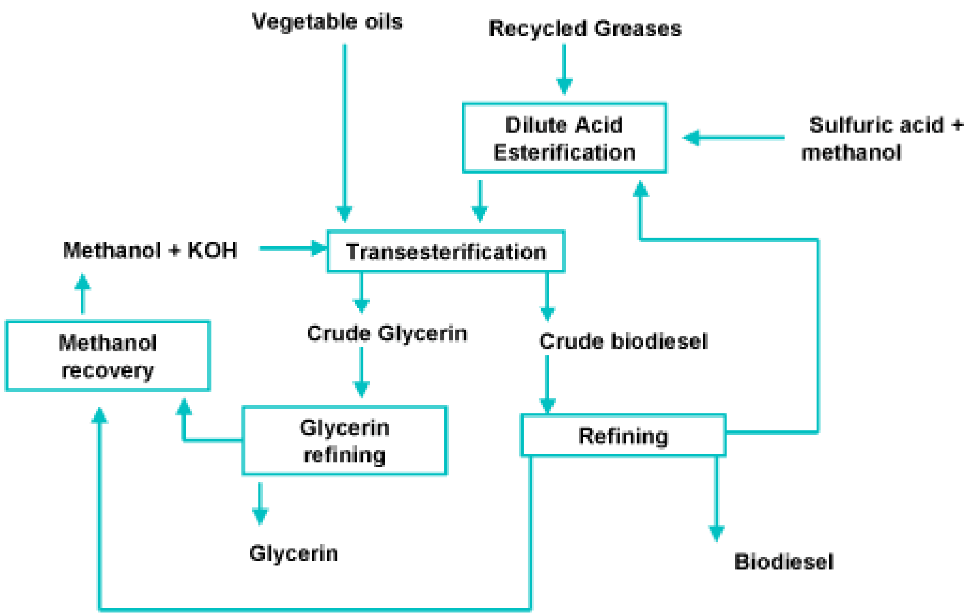
Glucose (sugar) Ethanol

http://www1.eere.energy.gov/biomass/abcs_biofuels.html

Oil Yields of Some Seeds

Crop	Oil Yield Gallons/acre
Corn	18
Cotton	35
Soybean	48
Mustard seed	61
Sunflower	102
Rapeseed/Canola	127
Jatropha	202
Oil palm	635

Biodiesel Processes



- Can utilize oil producing crops, or
- Waste oil
  - Restaurants