Renewables

Hydroelectric

Farwestern Photo by Gregg M. Erickson 2009

Grand Coulee Dam on the Columbia River in the state of Washington completed in 1942, currently with a 7 GW capacity.

Hydroelectric

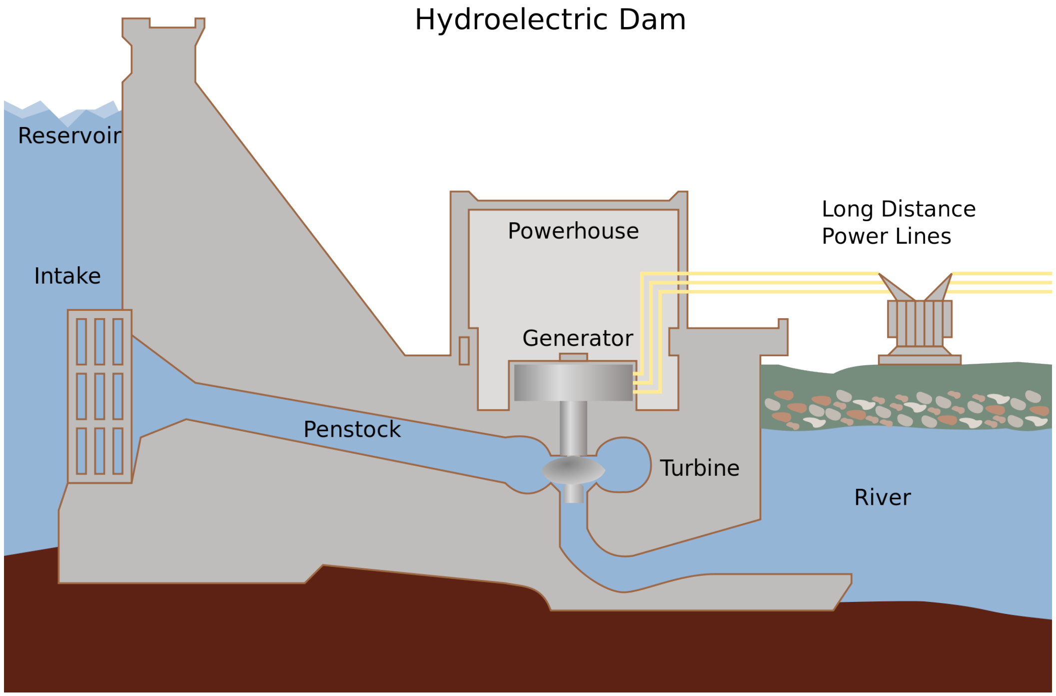


Image by Tomia/CC BY-SA 3.0 2006

Figure 8.2 Schematic of a hydroelectric power plant

Public Domain Photo by Wikisanchez 2010

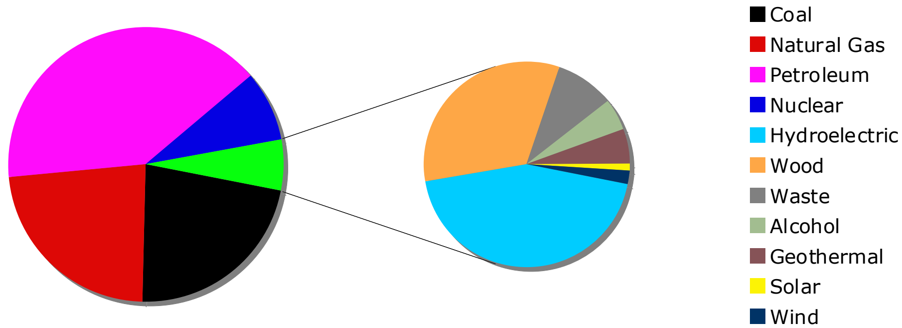
Figure 8.3 – Hydroelectric turbines at the Los Nihuiles Power Station in Argentina

Renewable Fuels

- Fuels from waste
- Biofuels
  - corn ethanol
  - algae-based biodiesel
- Wind
- Geothermal
- Solar
  - solar thermal
  - photovoltaics
  - fuels from the sun

Major Renewable Energy Sources

85% of our energy comes from fossil fuels



Energy Sources

Solar: 0.06%
Wind: 0.14%

Biofuels

Combustion:

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

Photosynthesis:

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

Biofuels

Transportation takes energy

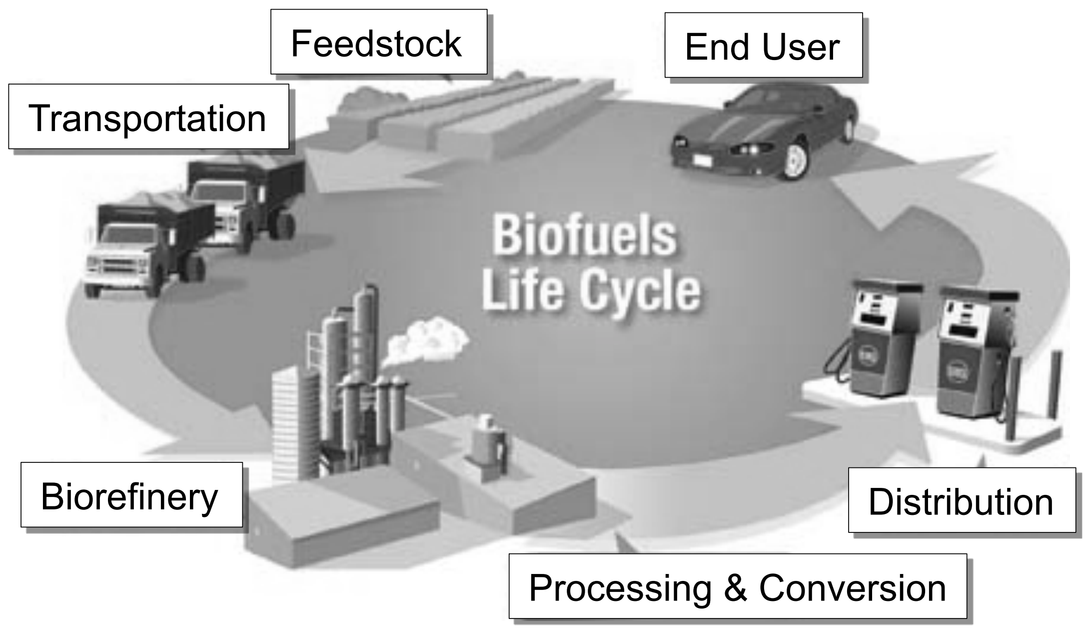
- liquid fuel distribution system exists already
- engines run on liquid fuels already
- renewable resource (solar via plants)
- combustion still results in carbon dioxide emissions
- corn ethanol
  - we eat corn
- cellulosic ethanol
  - nutrients removed from soil
  - fertilizer bad for ground water
- algae-based biodiesel
  - the algae has to live

Biomass ⟹ Ethanol (fuel) / chemicals

Fermentation, cellulosic digestion, Fischer-Tropsch

Seeds ⟹ Fatty acids (fuel) / chemicals

Algae ⟹ Fatty acids (fuel) / chemicals



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

Ethanol

- Sources
  - ethylene + steam
  - **fermentation**
- Fuel relative to gasoline
  - cleaner burning (less CO released)
  - more O atoms → less energy released upon combustion
- Issues
  - energy balance
  - CO_2 emissions
  - food balance

The federal government has got a role to play to encourage new industries that will help this nation diversify away from oil. And so we're strongly committed to corn-based ethanol produced in America. Yet there -- you just got to recognize there are limits to how much corn can be used for ethanol. **After all, we got to eat some. And the animals have got to eat.**

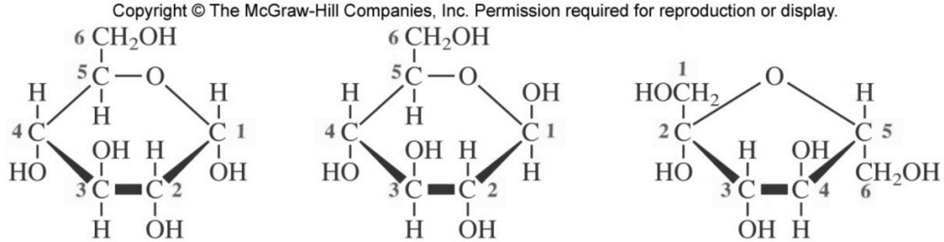
Pres. G. W. Bush
2006 energy policy speech

http://en.wikisource.org/wiki/U.S._Energy_Policy_Discussion

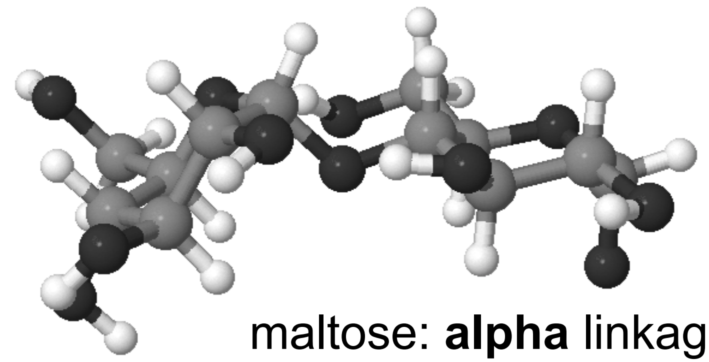
Carbohydrates: a Review

- Carbohydrates (Chapter 11.3)
  - contains C, H, O
  - H:O ratio = 2:1 (just like water)
  - C, H, O atoms arranged in rings

jmol (rotatable) pictures:

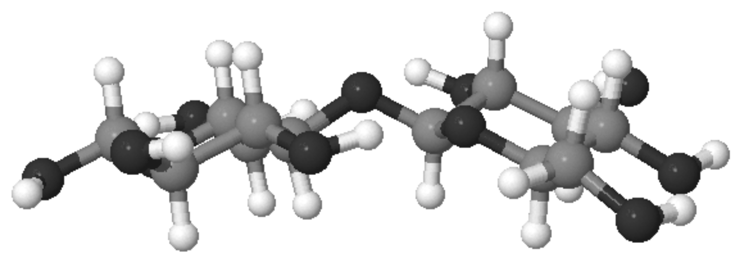


α-glucose, a monosaccharide — β-glucose, a monosaccharide — β-fructose, a monosaccharide



maltose: **alpha** linkage of 2 glucose units

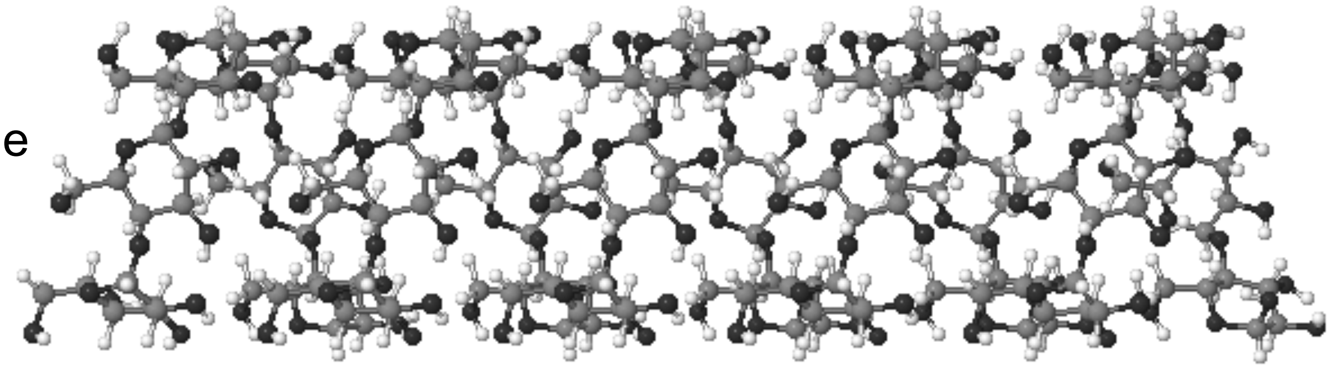
- Polysaccharides are formed from the condensation of 1000s of glucose units
- Alpha (α) linkage: humans can digest these polymers (aka starches)
- Beta (β) linkage: we can't digest these sugars (e.g. cellulose)—cows get bacteria to do it for them…



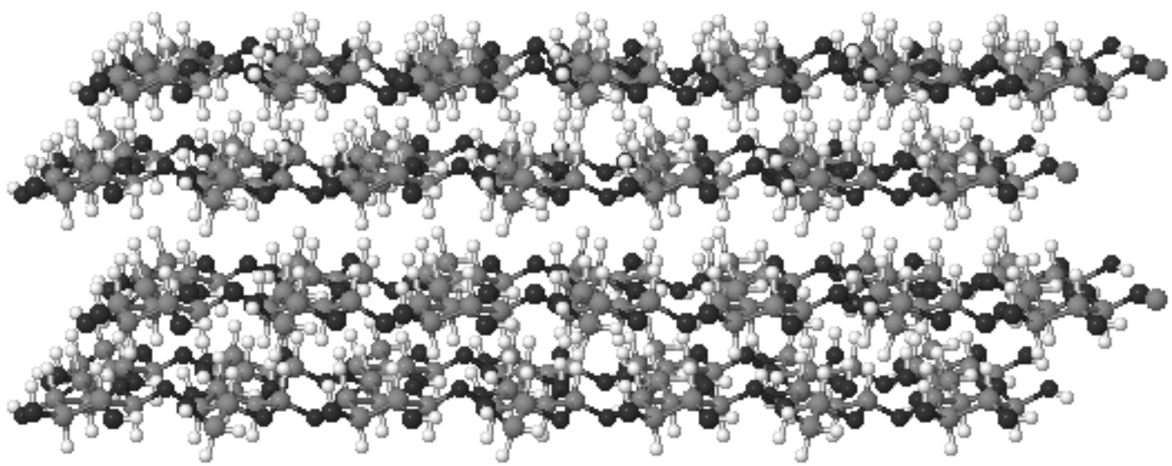
cellubiose: **beta** linkage of 2 glucose units

Structural Effects of α vs β Linkages in Polysaccharides

amylose (starch):
soluble in water,
digestible by people



cellulose (a fiber):
not soluble in water,
not digestible by
people, main
component in plant
cell walls,
approximately 1/3
of all plant matter



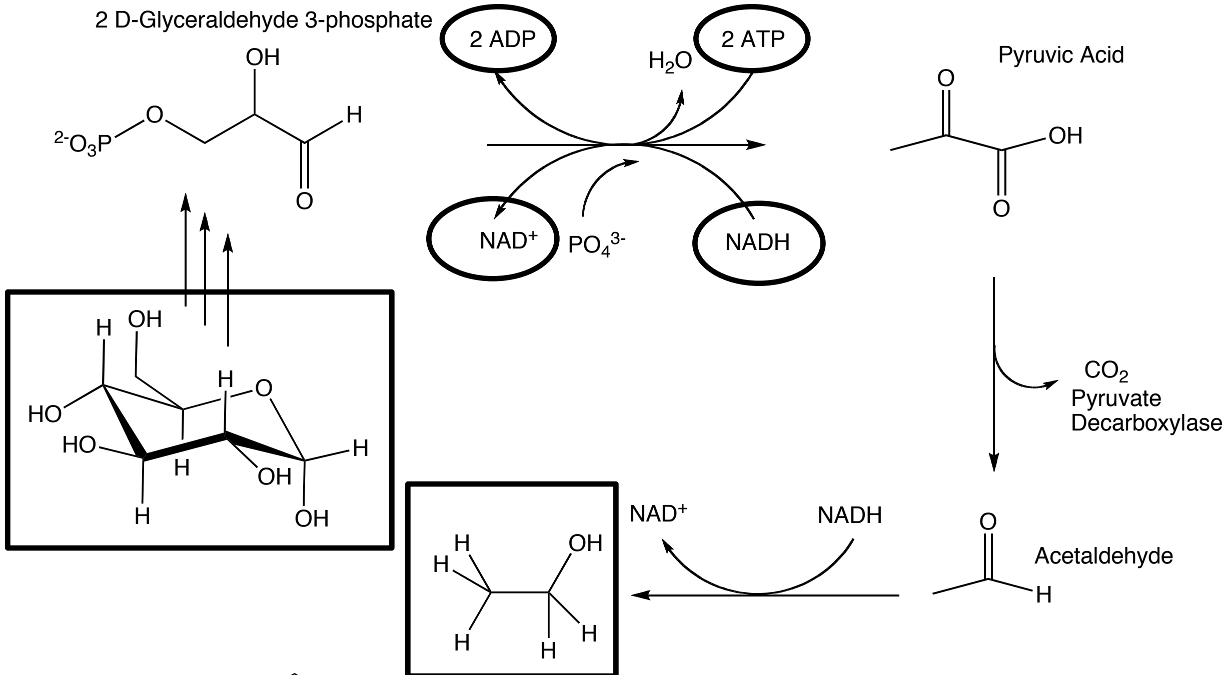
Glucose Fermentation to Ethanol

Net reaction:

$$\boxed{C_6H_{12}O_6} \rightarrow 2\,\boxed{C_2H_6O} + 2CO_2$$

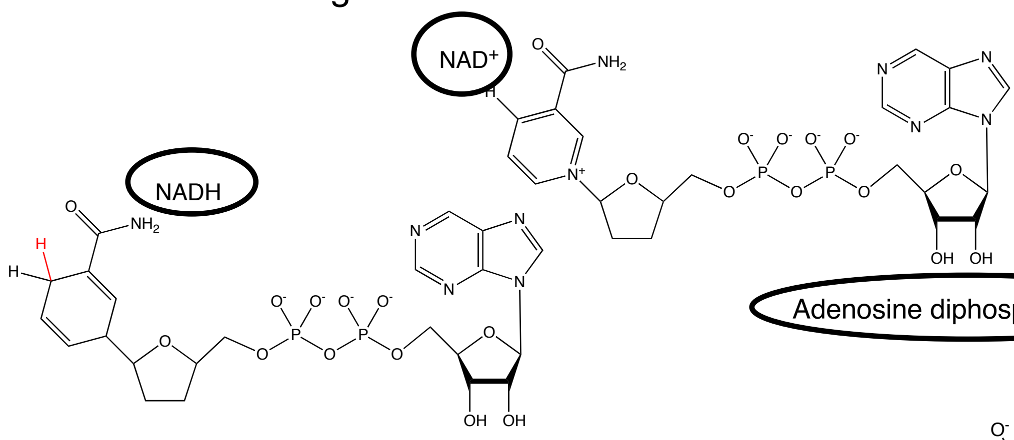
ΔE = -92 kJ/mol: exothermic

Actual pathway (right) is much more complicated…

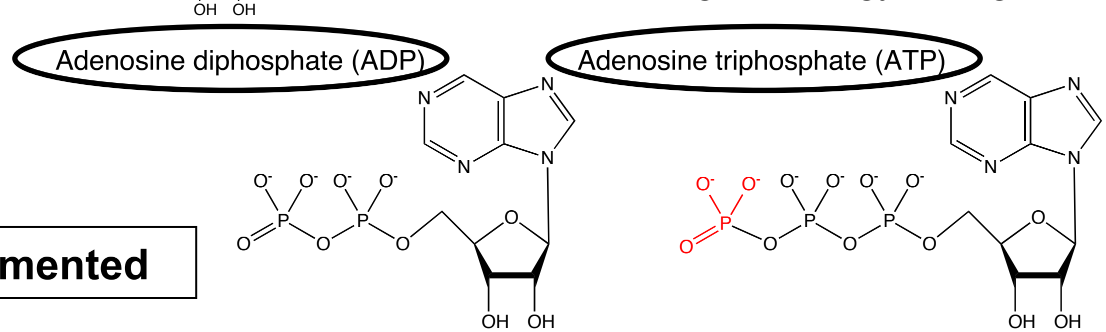


As a fuel, sugars have an energy content of 16 kJ/g

Ethanol has an energy content of 30 kJ/g

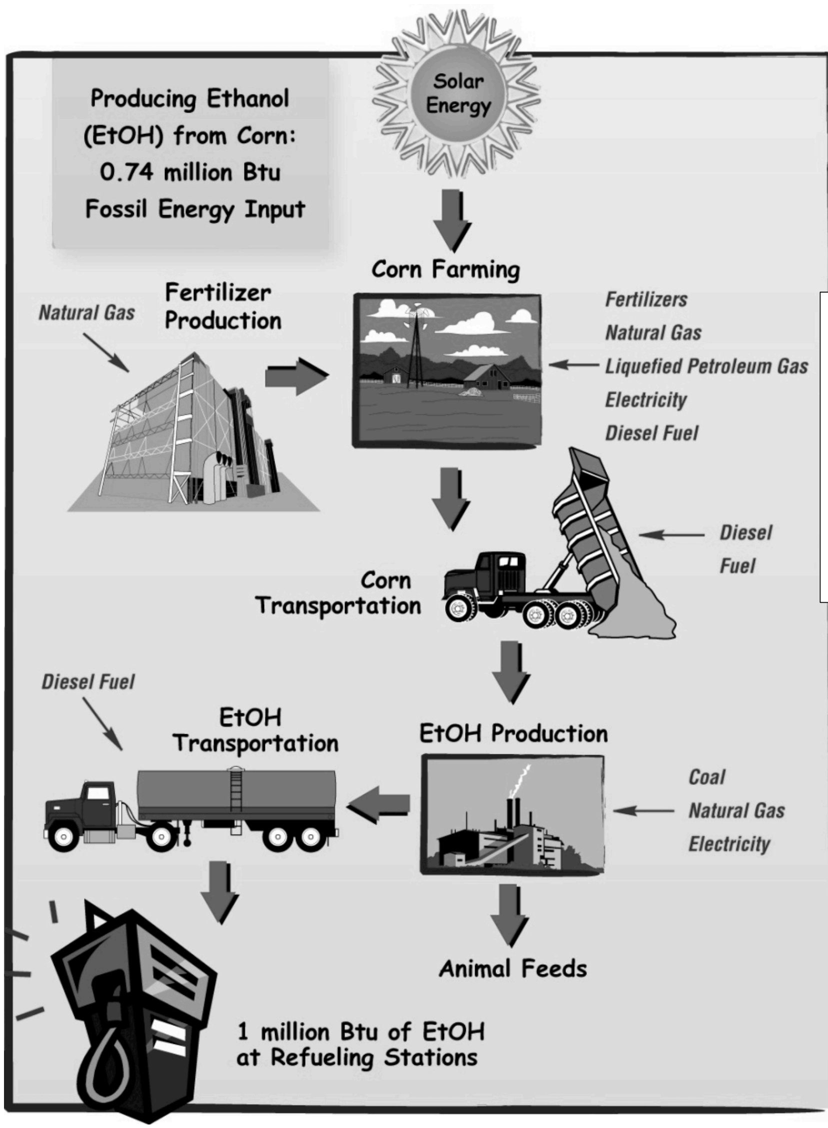


ADP→ATP = biological energy storage

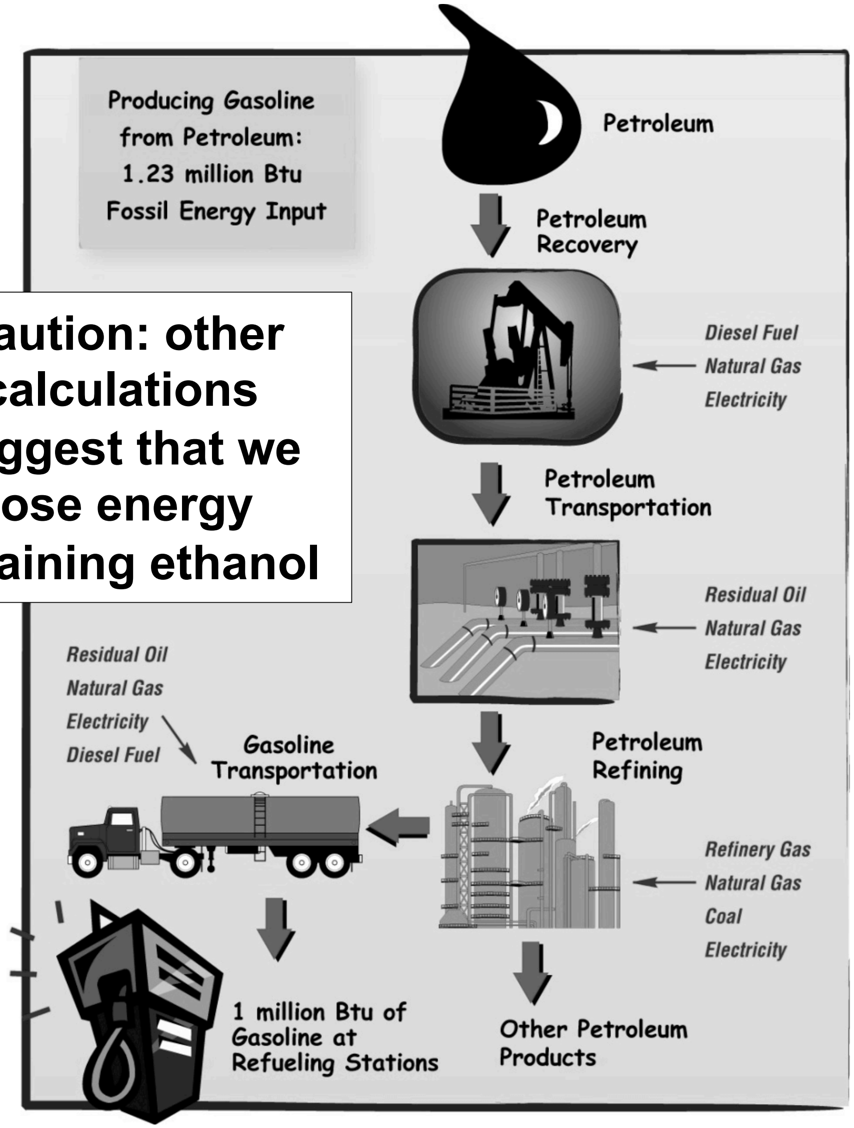


sugars w/ α-linkages can be fermented

Energy Balance: Comparing Ethanol to Gasoline



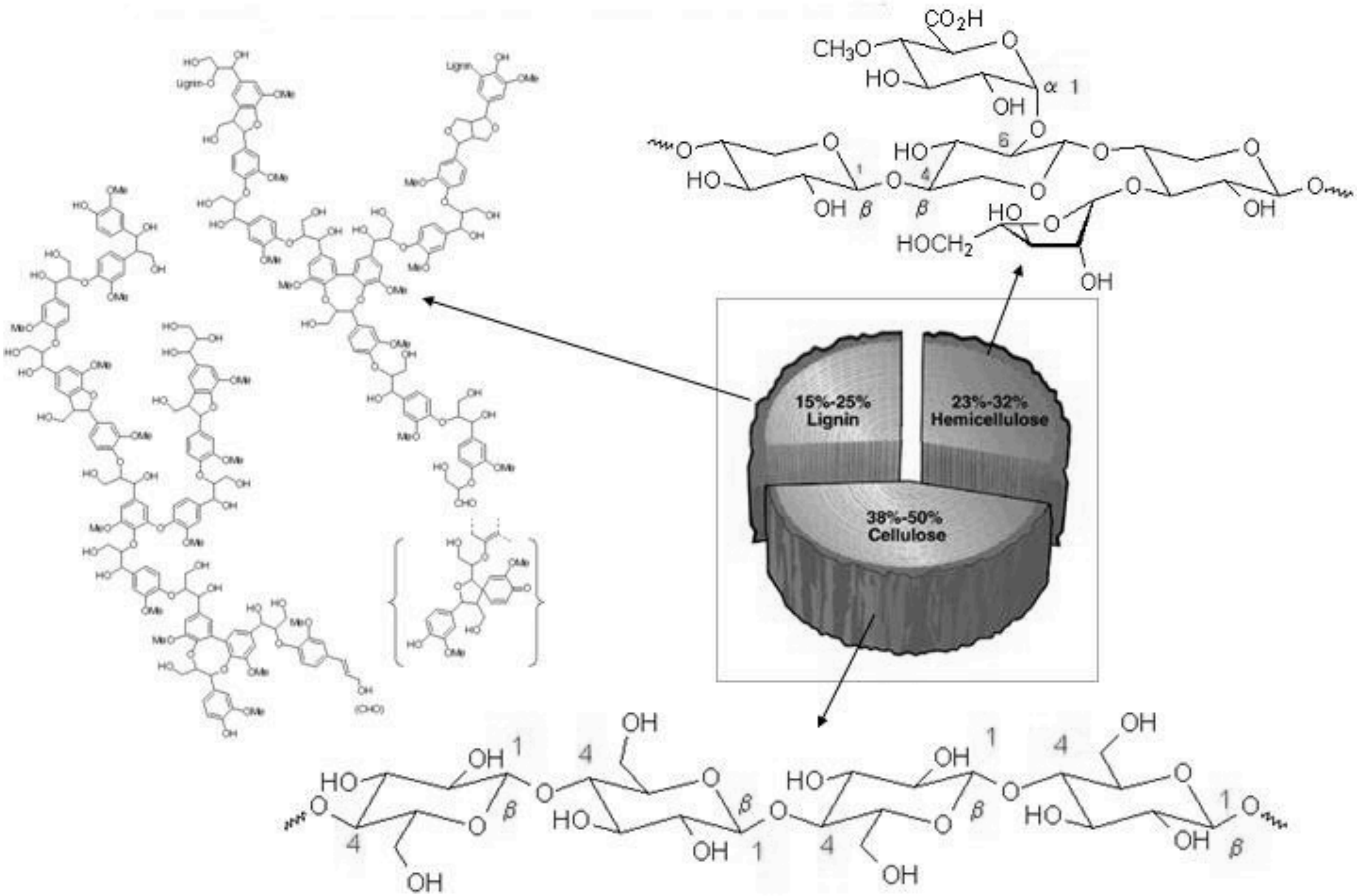
Caution: other calculations suggest that we lose energy obtaining ethanol



Michael Wang, Center for Transportation Research, Energy Systems Division, Argonne National Laboratory; NGCA Renewable Fuels Forum, The National Press Club, August 23, 2005

ARGONNE NATIONAL LABORATORY

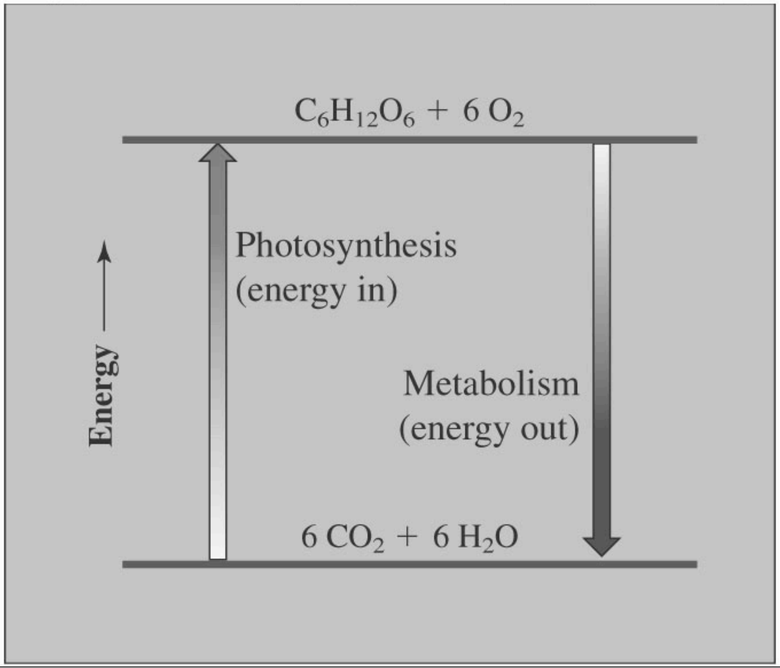
Biomass Carbohydrates: Not Just Sugars

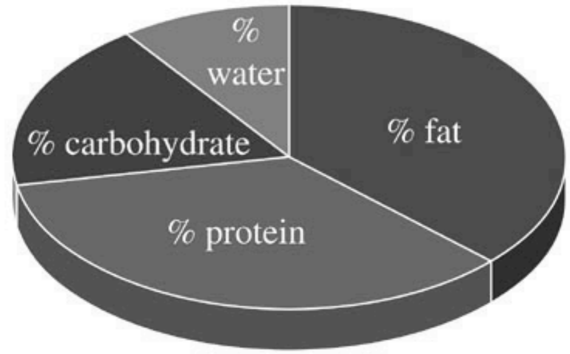


Graphic from the B.S. thesis of Renee Whippee, UMaine, 2006

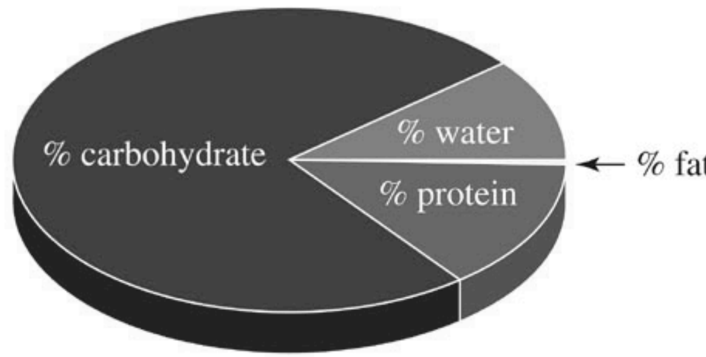
http://chemistry.umeche.maine.edu/Fort/Cole-Fort.html

Energy Content (Ch. 11)





Soybeans



Wheat

Table 11.5 Average Energy Content of Macronutrients

Fats	9 Cal/g	38 kJ/g
Carbohydrates	4 Cal/g	17 kJ/g
Proteins	4 Cal/g	

9 Cal/g → 4080 Calories/lb → 3500 Calories/lb

Fatty Acids, Fats and Oils (Ch. 11.2)

fatty acid: long chain hydrocarbon w/ even # of C atoms, plus a carboxylic acid end group

triglyceride:
chemical combination of three fatty acids with glycerol; releases 3 equivalents of water

fat: triglyceride that is solid at room temperature

oil: triglyceride that is liquid at room temperature

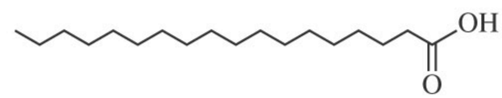
more double bonds → lower triglyercide melting points

$CH_3(CH_2)_{16}COOH$

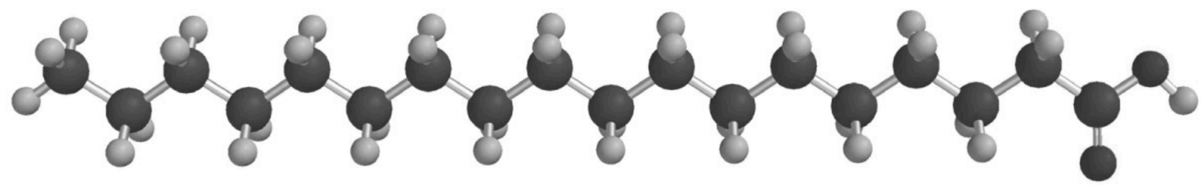
Condensed structural formula

$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2{-}C(=O)OH$

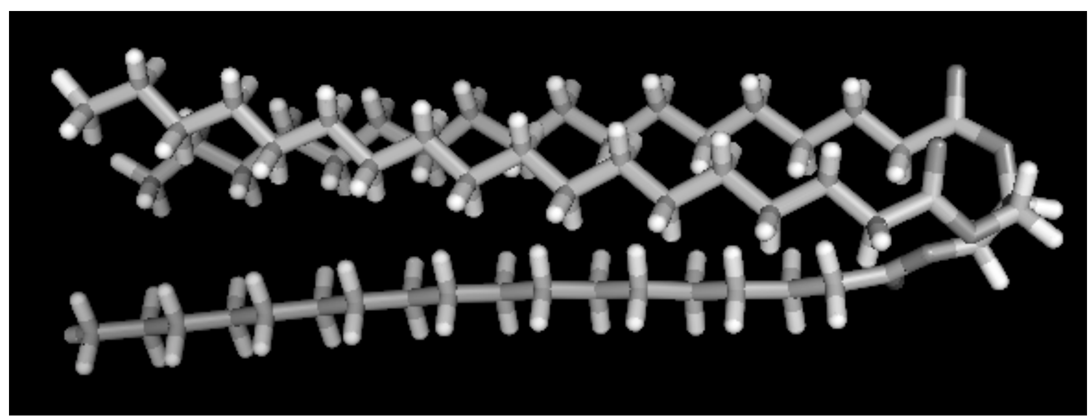
Semi-expanded structural formula



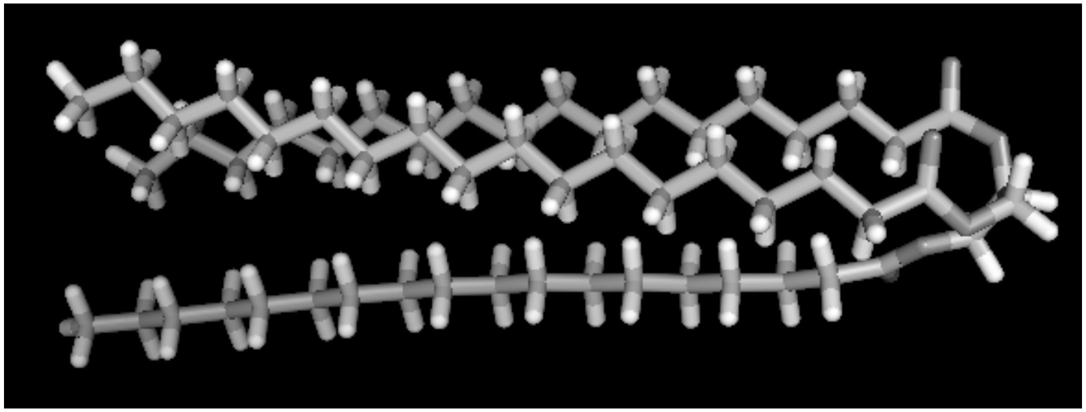
Line-angle drawing



Ball-and-stick model



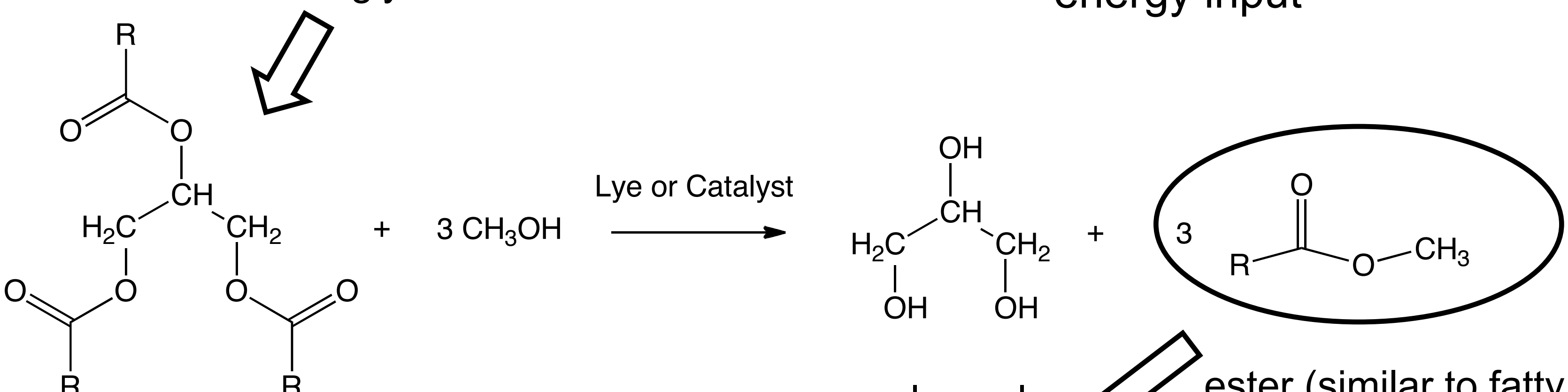
Biodiesel from Fats



Triglyercides react with alcohols to produce glycerol and three equivalents of ester via **transesterification**

This process requires energy input

triglyceride from stearic acid



glycerol

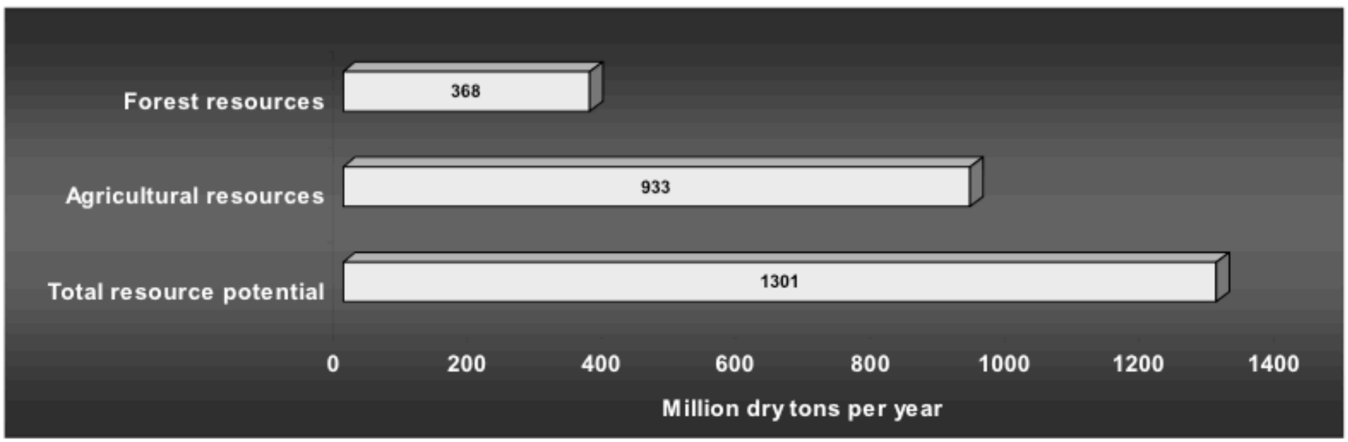
ester (similar to fatty acid, except with methyl group instead of H atom)

Biodiesel: defined in the USA as a mono-alkyl ester

DOE Billion Ton Study (2005)

Are there sufficient resources to meet 30% of the country's petroleum requirements?

- Yes, land resources of the U.S. can sustainably supply more than 1.3 billion dry tons annually and still continue to meet food, feed, and export demands
- Realizing this potential will require R&D, policy change, stakeholder involvement
- Required changes are not unreasonable given current trends



Annual energy available if this study were implemented:

$$1.3x10^{9}\,\text{ton} \times \frac{900\text{kg}}{\text{ton}} \times \frac{1000\text{g}}{\text{kg}} \times \frac{1.4x10^{4}\,\text{J}}{\text{g}} = 1.6x10^{19}\,\text{J} = \boxed{16\ \text{EJ}}$$

glucose: 14 kJ/g

Energy Summary

World Reserves	
Coal	20,200 EJ
Natural Gas	7,170 EJ
Oil	10,200 EJ
US use:	
Coal	20.8 EJ
Natural Gas	26.3 EJ
Oil	37.2 EJ
Nuclear	8.7 EJ
Biofuels	16.7 EJ

Wind

Moving air (like in a steam turbine)

Air moves:

- from high pressure to low pressure
- from high temperature to low temperature
- because the planet is spinning

Photo by Quistnix at nl.wikipedia 2009
Figure 8.6 – A windmill in the Netherlands used to drain wetlands

Figure 8.7 – Farm windmill used for pumping water

Wind Power

- Positives
  - wind is free
  - no (carbon dioxide) emissions from operation
- Negatives
  - not in my backyard…or in my ocean view…
  - wind doesn't blow all the time
  - transmission losses
  - energy storage
  - environmental/ecological effects (e.g. bird migration)
  - it takes energy and resources to make windmills

Energy Balance for Wind

Lifecycle energy cost of making, using and dismantling a 4.5 MW Windmill:

	Energy (GJ)
Construction	52,759
Operational phase	5,242
Transport	15,631
Decommissioning	
transport	1,240
energy	4,230
recycling	-8,950
Total	70,152

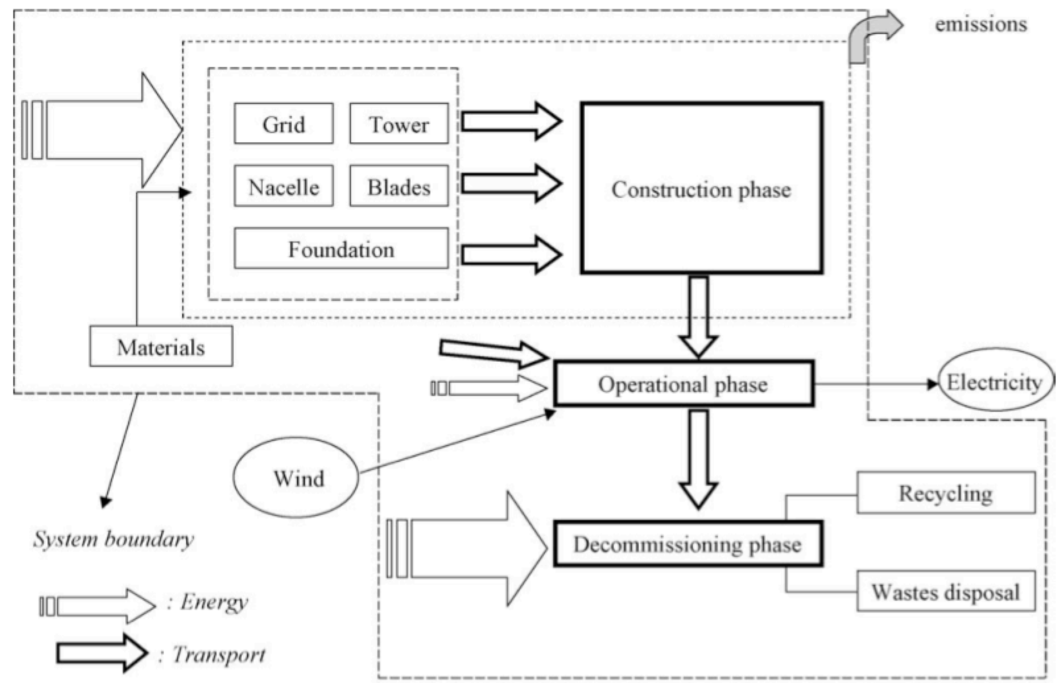


Fig. 1. Life cycle boundary of the 4.5 MW wind turbine.

Yearly energy produced by a 4.5 MW Windmill:

Fraction of windy hours

Efficiency of turbine

$$4.5\text{ MW} \times .30 \times 0.99 \times 24 \times 365 = 11.7\text{GWh}$$

$$11.7\text{GWh} \times \frac{1.0\text{x}10^6\text{kW}}{1\text{GW}} \times \frac{3.6\text{x}10^6\text{ J}}{1\text{kWh}} = 4.21\text{x}10^{13}\text{J} = 42{,}100\text{GJ}$$

$4.2\text{x}10^{-5}$ EJ

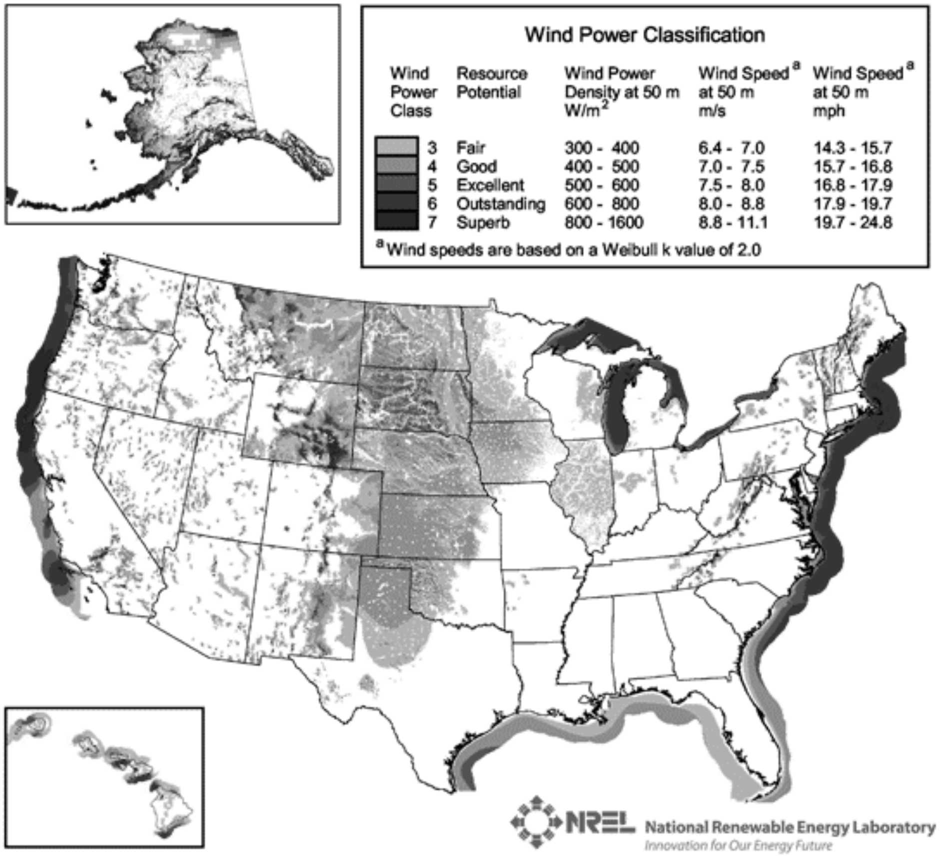
Without recycling it takes 1.9 years to break even

Brice Tremeac & Francis Meunier *Renewable and Sustainable Energy Reviews* **2009**,*13*,2104–2110

Wind Power in US

TABLE 8.2 – TOP 10 CAPACITY US WIND FARMS		
PROJECT	**CAPACITY (MW)**	**STATE**
Alta Wind Energy Center	1020	California
Shepherds Flat Wind Farm	845	Oregon
Roscoe Wind Farm	781	Texas
Horse Hollow Wind Energy Center	736	Texas
Tehachapi Pass Wind Farm	705	California
Capricorn Ridge Wind Farm	662	Texas
San Gorgonio Pass Wind Farm	619	California
Fowler Ridge Wind Far	600	Indiana
Sweetwater Wind Farm	585	Texas
Altamont Pass Wind Farm	576	California

Wind Potential



North Dakota:

$$1.21\text{x}10^{12}\text{kWh} \times \frac{3.6\text{x}10^{6}\text{ J}}{1\text{kWh}} = 4.4\text{x}10^{18}\text{ J} = 4.4\text{EJ}$$

TABLE 8.3 – TOP 20 STATES FOR WIND ENERGY POTENTIAL

SOURCE: AN ASSESSMENT OF THE AVAILABLE WINDY LAND AREA AND WIND ENERGY POTENTIAL IN THE CONTIGUOUS UNITED STATES, PACIFIC NORTHWEST LABORATORY, AUGUST 1991. PNL-7789

STATE	B kWh/YR	STATE	B kWh/Yr
1. North Dakota	1,210	11. Colorado	481
2. Texas	1,190	12. New Mexico	435
3. Kansas	1,070	13. Idaho	73
4. South Dakota	1,030	14. Michigan	65
5. Montana	1,020	15. New York	62
6. Nebraska	868	16. Illinois	61
7. Wyoming	747	17. California	59
8. Oklahoma	725	18. Wisconsin	58
9. Minnesota	657	19. Maine	56
10. Iowa	551	20. Missouri	52

Windmills range from ~100 kilowatts (kW) to 3.5 megawatts (MW)

Top 12 have potential for $10\text{x}10^{12}$ kWh

$$10 \times 10^{12}\text{kWh} \times \frac{3.6 \times 10^{6}\text{ J}}{1\text{ kWh}} = 36 \times 10^{18}\text{ J} = \boxed{36\text{ EJ}}$$

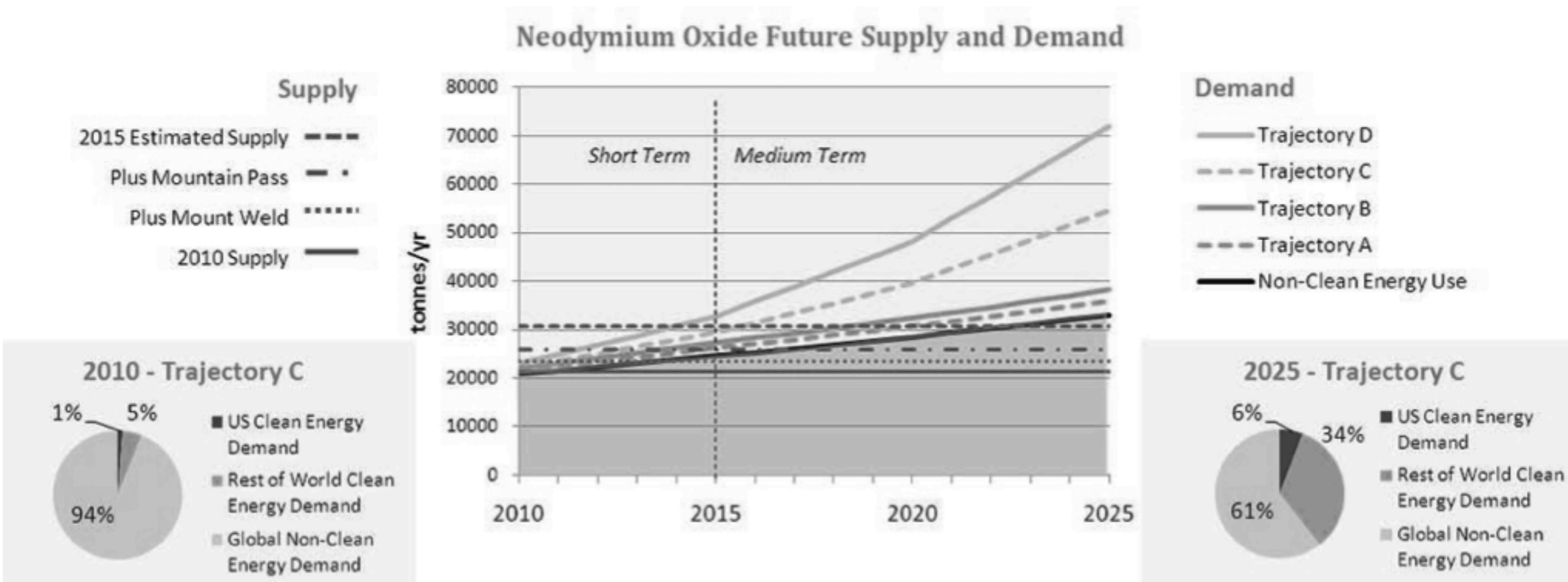
Energy Summary

World Reserves	
Coal	20,200 EJ
Natural Gas	7,170 EJ
Oil	10,200 EJ
US use:	
Coal	20.8 EJ
Natural Gas	26.3 EJ
Oil	37.2 EJ
Nuclear	8.7 EJ
Biofuels	16.7 EJ
Wind	36 EJ

Use and Supply of Rare Earth Elements

$Nd_2Fe_{14}B$: one of the strongest permanent magnets known; used for electric motors and computer hard drives (and electric guitar pickups)

~150 kg Neodymium/MW for windmills
5.8×10^7 kg for 86,000 4.5 MW windmills
2.1×10^7 kg mined/year



http://www.energy.gov/news/documents/criticalmaterialsstrategy.pdf

Geothermal

Geothermal

Public Domain Photo from the US Department of Defense 1982

Figure 8.12 Geothermal power plant in California

Geothermal

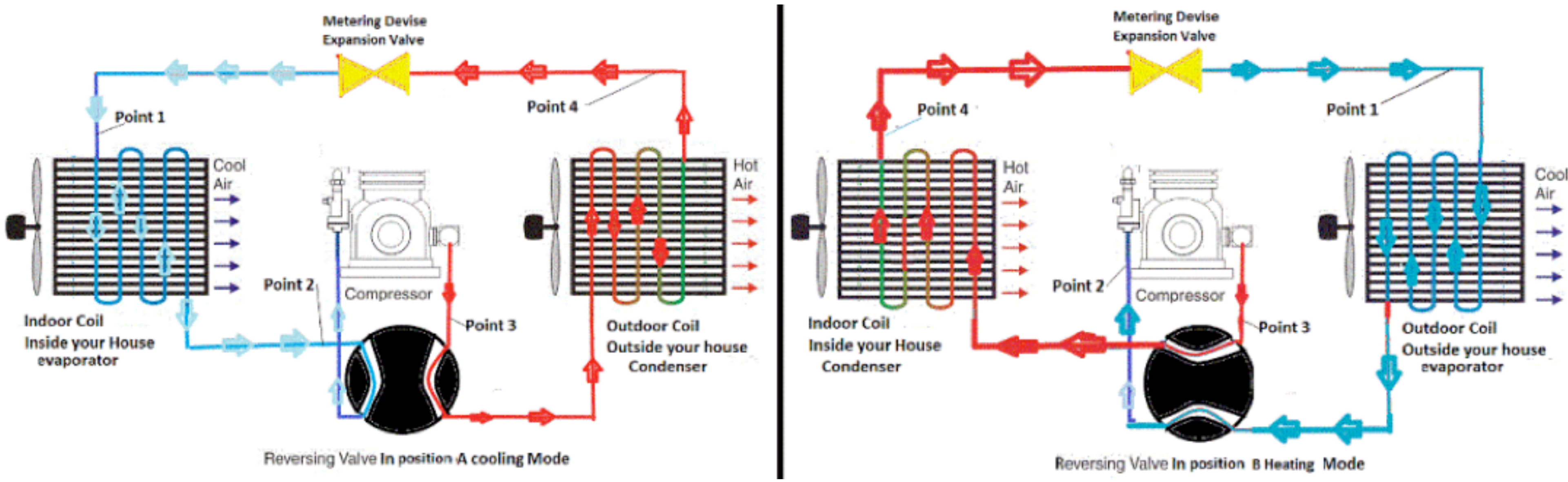


Figure 8.13 – Schematic of a heat pump

Geothermal

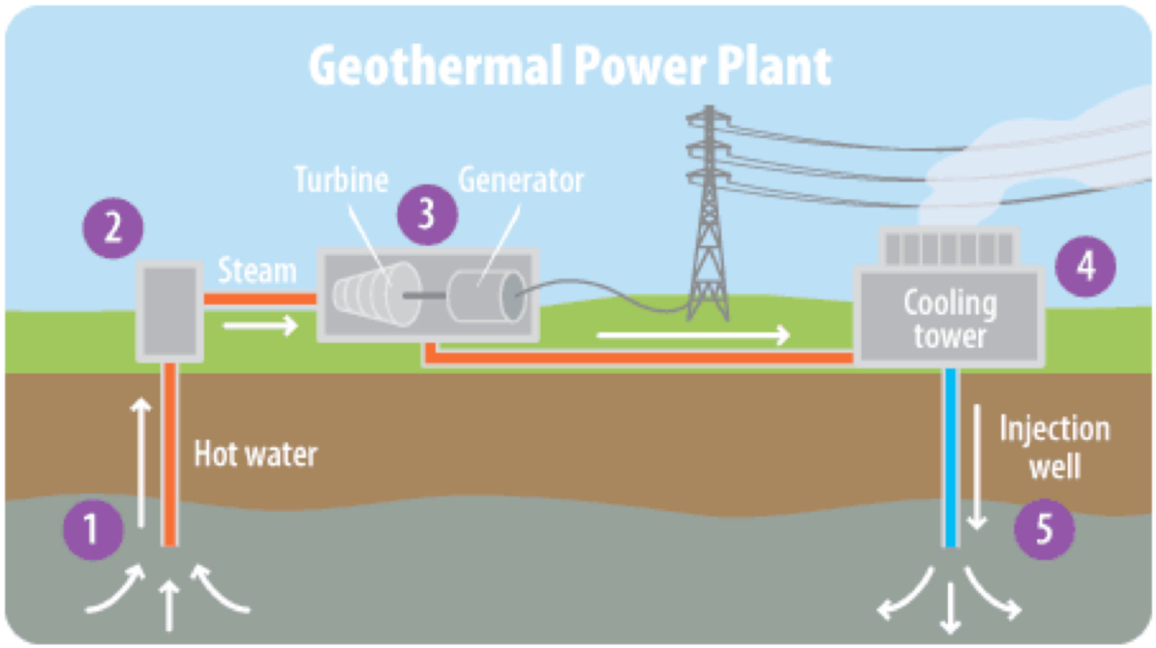


Figure 8.14 Schematic of a geothermal power plant