Biomass and Biofuels

PHYS 4400, Principles and Varieties of Solar Energy

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What is bioenergy?

- Photosynthesis: the primary energy input to the carbon cycle
- Bioenergy -- stored in biological material – plant-based, animal-based, etc.
- Examples: wood, food, animal waste, bio-ethanol, algal fuel, switchgrass, etc.
- "Renewable energy source based on the carbon cycle" - *http://en.wikipedia.org/wiki/Bioenergy*
- "Short term carbon cycle"

Biomass refers to the mass of living and once-living things which exist uniquely on Earth, within the biosphere.

The biosphere refers to the system of life on Earth, which is a highly complex and far-reaching system. The system inputs are limited essentially to inbound radiant energy from the Sun, and to Earth's existing heat content. Outputs include outgoing radiant energy associated with the atmosphere and Earth's surface acting as a blackbody.

Photosynthesis (typical efficiency)

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

100% sunlight → non-bioavailable photons waste is 47%, leaving

53% (in the 400–700 nm range) → 30% of photons are lost due to incomplete absorption, leaving

37% (absorbed photon energy) → 24% is lost due to wavelength-mismatch degradation to 700 nm energy, leaving

28.2% (sunlight energy collected by chlorophyll) → 32% efficient conversion of ATP and NADPH to d-glucose, leaving

9% (collected as sugar) → 35–40% of sugar is recycled/consumed by the leaf in dark and photo-respiration, leaving

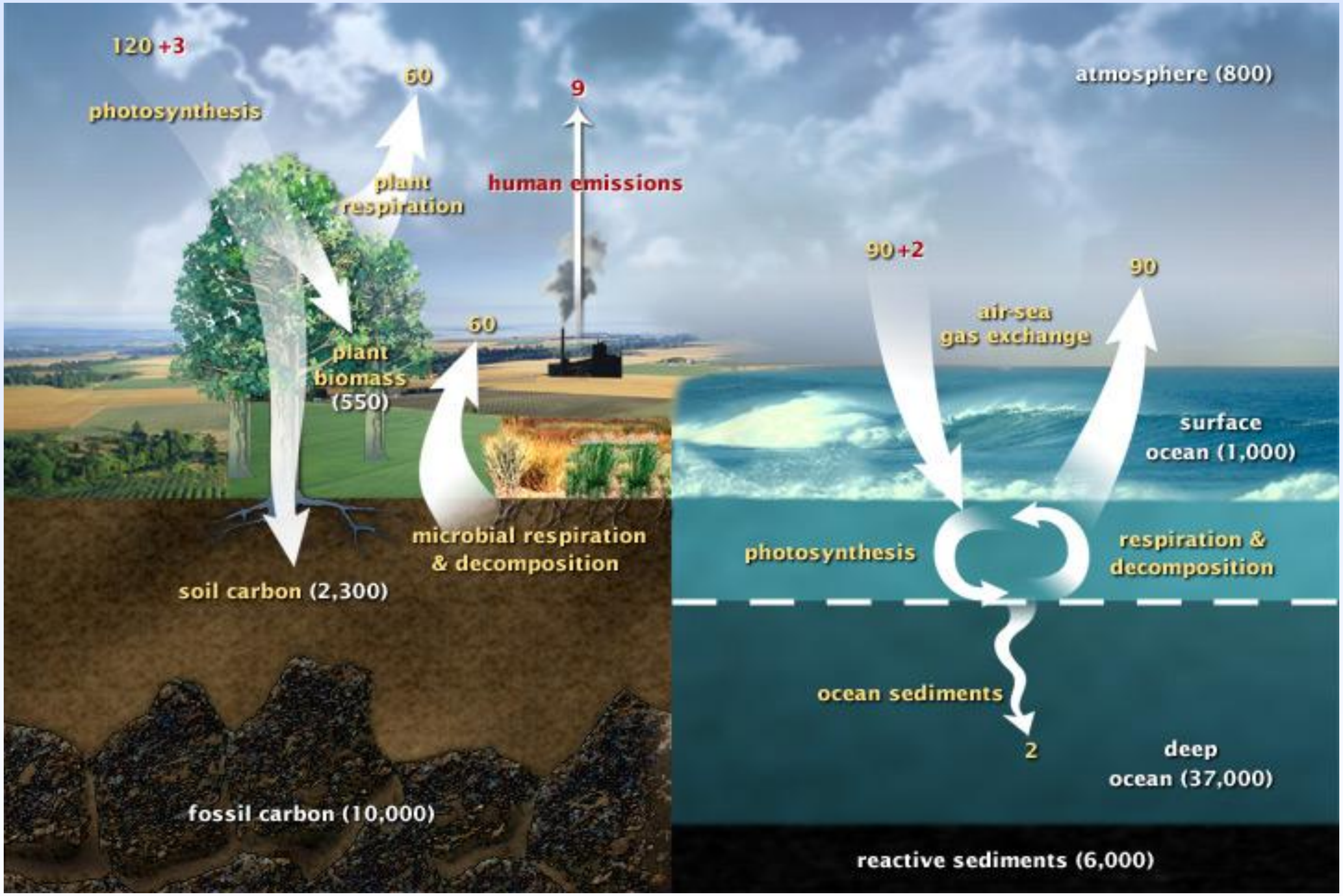
5.4% net leaf efficiency.

http://en.wikipedia.org/wiki/Photosynthetic_efficiency

What is the carbon cycle?

“The carbon cycle refers to the flow of carbon between the atmosphere, rocks, oceans and biosphere (all of Earth’s life forms). Each of these is part of a reservoir which contains all the carbon on the planet. The carbon cycle is composed of two reservoirs: a long-term and a short-term. By circulating carbon through these interconnected reservoirs the planet regulates the level of atmospheric carbon dioxide.” -- http://www.motherearthnews.com/understanding-climate-change/the-carbon-cycle.aspx#axzz2Jx1ekX9H

The carbon cycle

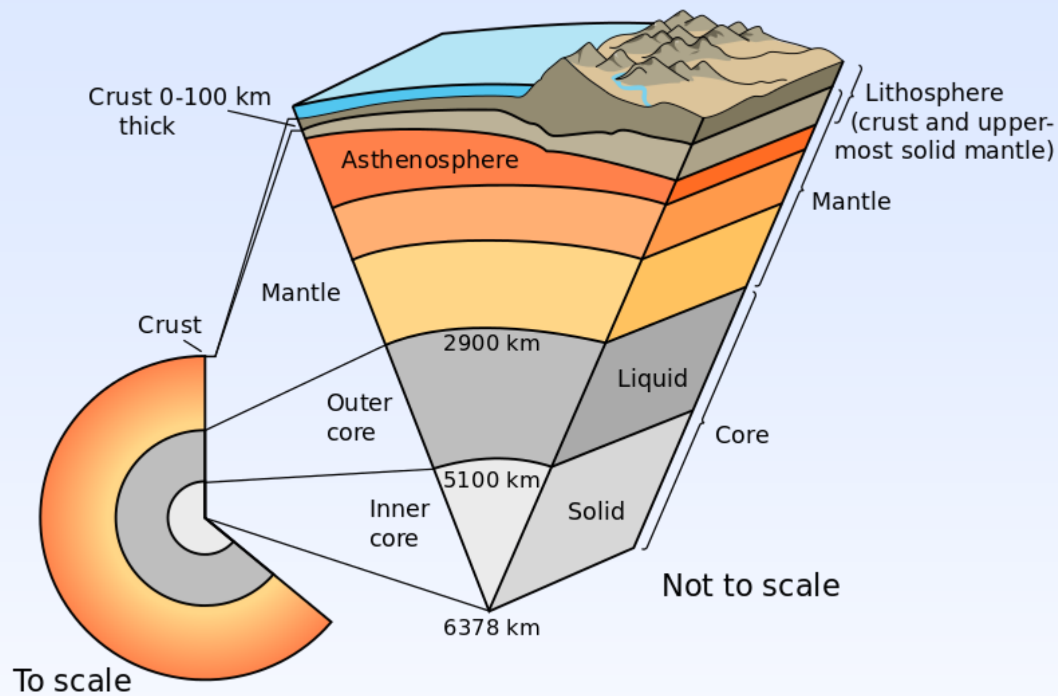


"This diagram of the fast carbon cycle shows the movement of carbon between land, atmosphere, and oceans in billions of tons of carbon per year. Yellow numbers are natural fluxes, red are human contributions in billions of tons of carbon per year. White numbers indicate stored carbon."

Carbon pools

Carbon pools in the major reservoirs on earth.[2]

Pool	Quantity (gigatons)
Atmosphere	720
Oceans (total)	38,400
Total inorganic	*37,400*
Total organic	1,000
Surface layer	670
Deep layer	36,730
Lithosphere	
Sedimentary carbonates	> 60,000,000
Kerogens	15,000,000
Terrestrial biosphere (total)	2,000
Living biomass	600 - 1,000
Dead biomass	1,200
Aquatic biosphere	1 - 2
Fossil fuels (total)	4,130
Coal	3,510
Oil	230
Gas	140
Other (peat)	250



Atmospheric carbon cycle

Earth's atmosphere: a large reservoir of carbon, in the forms of CO_2, methane, and other carbon-containing gases.

The atmosphere holds ~720 x 10^9 tons of carbon, and plays a significant role in the global carbon cycle.

Human activity has resulted in a 2-fold increase in the atmosphere's CO_2 concentration over the past ~200 years.

Terrestrial carbon cycle

Forests store ~86% of Earth's above-ground carbon, and 73% of the planet's soil carbon. Animals eating plants convert and store some of the carbon.

Bacteria and other heterotrophs also ingest and store carbon from decaying plants (and animals).

The food chain embodies carbon transfer processes between organisms, and ultimately heterotroph respiration emits carbon into the atmosphere.

http://thebutterflydiaries.files.wordpress.com/2009/10/clavaire_droite2.jpg

Typically, ~50% of the dry weight of a living organism is carbon. Carbon is key to all cell growth.

600 to 1,000 gigatons of carbon (mainly wood) is stored in living biomass.

~1,200 gigatons of carbon stored as dead biomass.

Aerobic respiration emits CO_2 into the atmosphere.

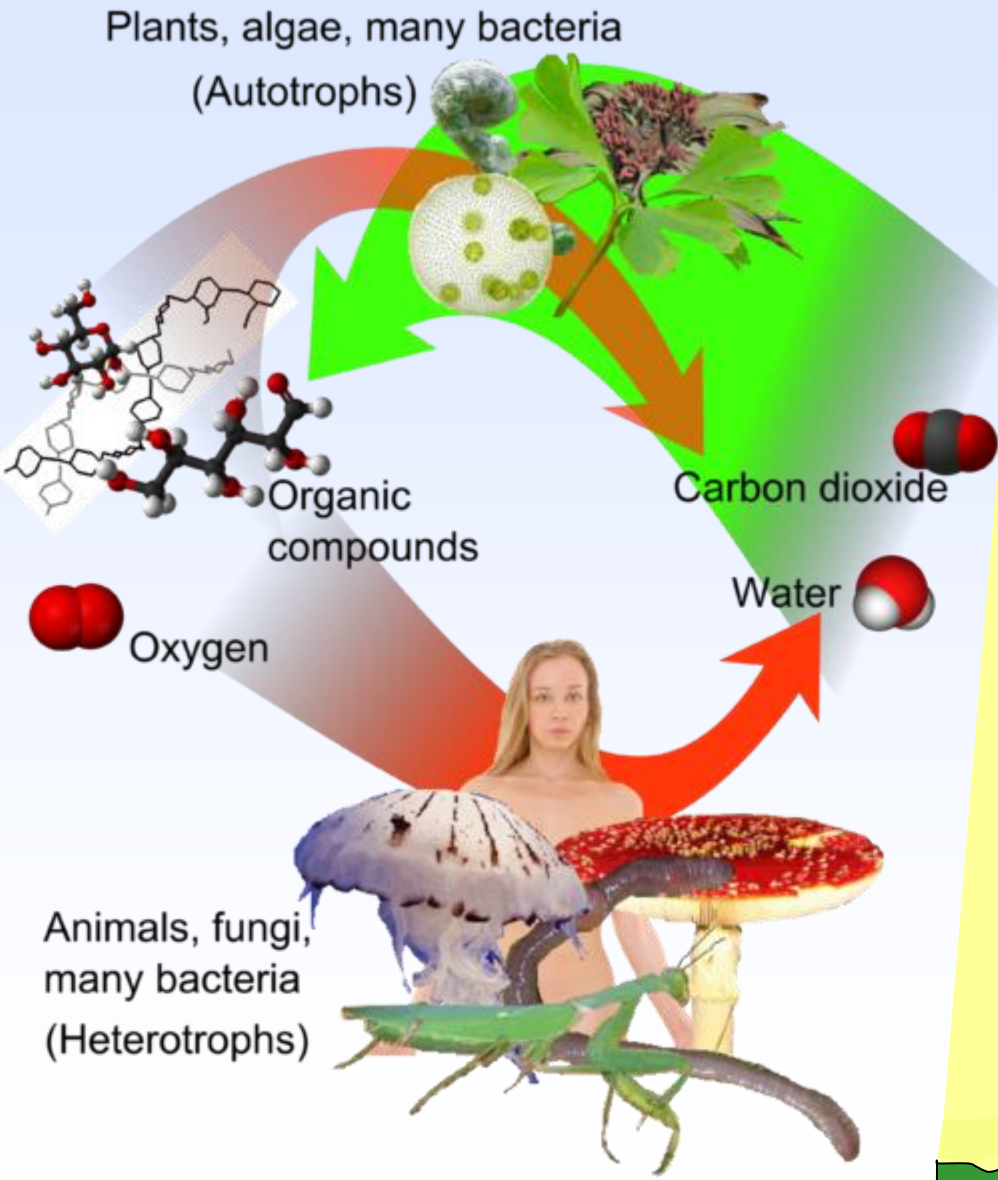
http://en.wikipedia.org/wiki/Terrestrial_biological_carbon_cycle

Heterotrophs and autotrophs

"A heterotroph is an organism that cannot fix carbon and uses organic carbon for growth.

This contrasts with autotrophs, which use energy from sunlight (photoautotrophs) or inorganic compounds (lithoautotrophs) to produce organic compounds such as carbohydrates, fats, and proteins from inorganic carbon dioxide.

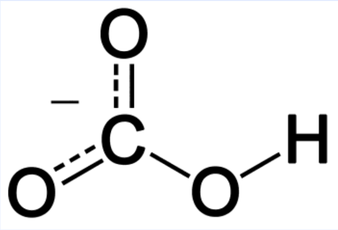
These reduced carbon compounds can be used as an energy source by the autotroph and provide the energy in food consumed by heterotrophs."



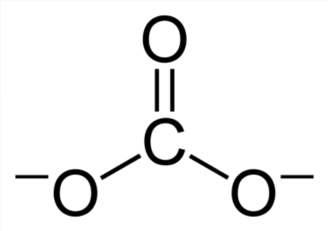
Oceanic carbon cycle

Oceans contain ~ 36 x 10^{12} tons of carbon – mainly (90%) in the form of the bicarbonate ion, and the rest as carbonate ions.

Bicarbonate ion: HCO_3^-



Carbonate: ion: CO_3^{2-}



E.g., calcium carbonate
(also called calcite), which derives from mollusk and other shells, and also from coral skeletons.

Ocean acidification

Liquids absorb gases, according to the solubility of the specific gas molecules in the liquid, and according to the partial pressure of the gas molecules in contact with the liquid.

Henry's law: the amount (i.e. mole fraction) of a slightly soluble gas dissolved in a liquid is proportional to the partial pressure of the gas. The most common form of the equation for Henry's law in the air pollution control field is: $y^* = Hx$, where y^* is the mole fraction of gas phase in equilibrium with liquid, H is Henry's Law constant, and x is the mole fraction of the gas within the liquid phase.

Units for H are (mole fraction in gas/mole fraction in liquid). Sometimes Henry's law constant is also expressed in units of atm/mole fraction, 1/mole fraction, or m^3 atm/gm mole.

Ocean acidification (cont.)

Our oceans have absorbed ~35% of the anthropogenic CO_2 from the atmosphere, increasing their acidity (lowering the pH).

Dissolved CO_2 reacts in the water to form carbonic acid, and then to form bicarbonate ions along with the hydronium ion (increasing the ocean's acidity).

"*Between 1751 and 1994 surface ocean pH is estimated to have decreased from approximately 8.25 to 8.14,*[4] *representing an increase of almost 30% in* H^+ *ion concentration in the world's oceans.*" Note: more acidic → decreasing pH, and less acidic (more basic) → increasing pH.

Increased acidity affects sea life, and decreases the carbonate ion concentration which in turn inhibits calcification in coral and some plankton – these organisms become prone to dissolution, which disrupts the food chain and the health of the ocean ecosystem.

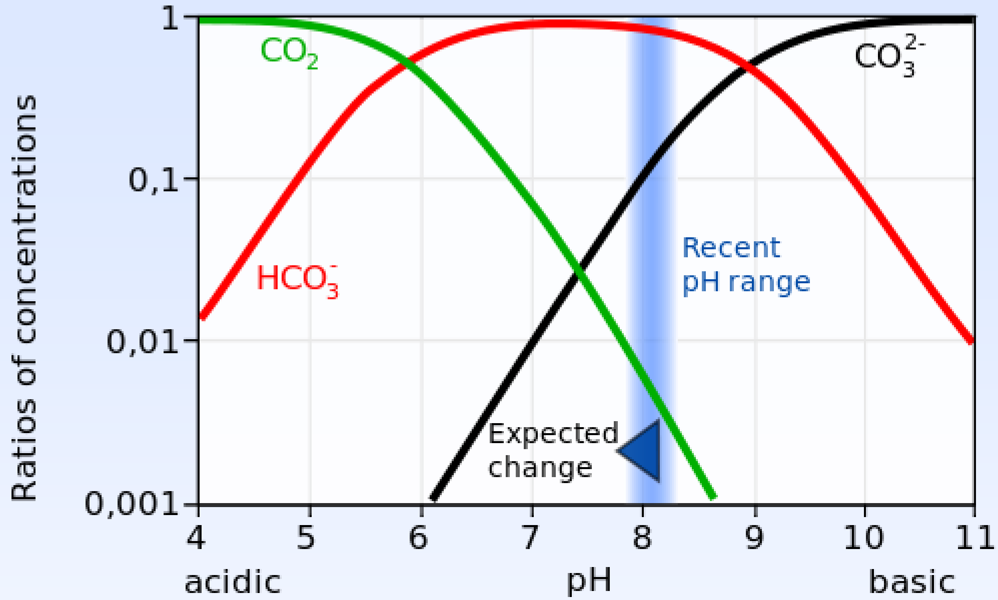
http://en.wikipedia.org/wiki/Ocean_acidification

Determination of pH

It is the presence of hydronium ion relative to hydroxide that determines a solution's pH. Water molecules auto-dissociate into hydronium and hydroxide ions in the following equilibrium: $2\ H_2O \Leftrightarrow OH^- + H_3O^+$.

http://en.wikipedia.org/wiki/Hydronium

Ocean acidification (cont.)



Natural absorption of CO_2 by oceans helps mitigate climatic effects, though it is believed that the decreasing pH will disrupt calcifying organisms -- including coccolithophores, corals, foraminifera, echinoderms, crustaceans and mollusks.

Although normally calcite and aragonite are stable in surface waters, as ocean pH falls, the concentration of carbonate ions required for saturation to occur increases, and when carbonate becomes undersaturated, structures made of calcium carbonate are vulnerable to dissolution. Therefore, even if there is no change in the rate of calcification, the rate of dissolution of calcareous material increases.

http://en.wikipedia.org/wiki/Ocean_acidification

Electricity from biomass

Biomass supplied 3.2 quadrillion BTU of energy out of a total of 98.5 quadrillion BTU in 2000;

Vast majority used in the pulp and paper industries, where residues from production processes are combusted to produce steam and electricity;

The industrial cogeneration sector consumed almost 2.0 quadrillion BTU of biomass in 2000;

Outside the pulp and paper industries, only a small amount of biomass is used to produce electricity. The electricity generation sector (excluding cogenerators) consumed about 0.7 quadrillion BTU of biomass in 2000.

Remaining 0.5 quadrillion BTU of biomass -- wood burned for heat;

To put these numbers in perspective, the electricity generation sector consumed 20.5 quadrillion BTU of coal and 6.5 quadrillion BTU of natural gas in 2000;

11,000 MW capacity in US, or ~1.4% of total electricity generation capacity.

http://www.eia.gov/oiaf/analysispaper/biomass/

Electricity and heat from biomass: combined heat and power, or *cogeneration* plants

Cogeneration station in Metz (France), using waste wood biomass from the surrounding forests as renewable energy source.

Turbine efficiency maximum is ~60%. (http://en.wikipedia.org/wiki/Electricity_generation#Turbines)

Recovery of waste energy (thermal) for space heating.

Electricity from biomass: environmental effects of combustion

Pollution and negatives:

CO_2 and CO generation and release

Particulate pollution – "black carbon"

NO_x

VOC's – volatile organic compounds

Non-harvested biomass sequesters higher levels of carbon than do annually harvested crops.

Mature, intact forests sequester carbon more effectively than cut-over areas.

Favorable aspect(s):

Avoids conversion of fossil fuels. Why does this matter based on pollutants listed above? – Discuss.