

Modeling the Carbon Cycle

Model the carbon cycle –the principal reservoirs and flow rates–using rice (or other small objects).

Materials:

About 10 Pounds (4.5 Kg) Rice (black rice if possible)
Scale or balance
Carbon Reservoir Images (Attached)
Containers for the rice

Preparation (can be done by students, if time allows):

Count 500 grains of rice, and find the mass of this amount. In my sample, 500 grains of rice had a mass of 9 g. To build the carbon reservoirs accurately, assuming each grain of rice is one giga ton of carbon (Gt C) or one Peta gram of carbon (Pg C). These units, Gt C and Pg C, are the fundamental units of measurement of Carbon at planetary cycling scales. One gigaton is equal to one billion tons of carbon (or one Peta gram - 10^{15} g). Use the amounts below (in bold) to create each of the five principal carbon reservoirs, measuring rice into appropriately sized containers. Label the containers with the Carbon Reservoir Images.

Principal carbon reservoirs

Rock	65, 500, 000 Gt C
Atmosphere	800 Gt C
Ocean	Total: 44,000 Gt C
Surface Ocean	1000 Gt C
Deep Ocean	37,000 Gt C
Reactive Sediments	6000 Gt C
Terrestrial Biosphere Total:	2850 Gt C
Plant Biomass	550 Gt C
Soil Carbon	2300 Gt C
Fossil Carbon (Fossil Fuels)	10,000 Gt C

To Do and Notice:

1. Discuss the principal carbon reservoirs: can students name them?
2. Divide class into five groups: one for each reservoir. If time allows, have students research the amount of carbon in their group's reservoir, as well as the form(s) of carbon in the reservoir.

Rock: 65, 500, 000 Gt C mostly solid carbonate as in limestone, CaCO_3

Rocks are by far the largest reservoir of carbon on earth, but changes in the flow of carbon to and from this reservoir are extremely slow, and they have no real impact on changes in the global carbon cycle at human timescales (10's to 1000's of years).

Atmosphere: 800 Gt C carbon gases such as CO_2 , (carbon dioxide), CH_4 , (methane), and CO (carbon monoxide)

Ocean: 44,000 Gt C dissolved carbon dioxide (CO₂), bicarbonate (HCO₃), and carbonate (CO₃)
 The relative abundance of these three carbon compounds is controlled by the pH of the water. CO₂ dissolves in seawater, creating carbonic acid, which releases H ions. H ions combine with carbonate in seawater to form bicarbonate, which doesn't escape the ocean easily.
<http://earthobservatory.nasa.gov/Features/OceanCarbon>

Terrestrial Biosphere Total: 2850 Gt C organic plant material and soils

Fossil Carbon (Fossil Fuels): 10,000 Gt C solid coal, liquid hydrocarbon petroleum, and gas hydrocarbon methane, resulting from photosynthesis hundreds of millions of years ago and subsequent burial

3. How does C flow from one reservoir to another?

The natural flux between the terrestrial biosphere and the atmosphere is about 120 Gt C per year. In the terrestrial biosphere, photosynthesis removes about 120 Gt C from the atmosphere; decomposition of biological material and respiration from plants and soil microbes return 120 Gt C to the atmosphere. Having each of these two groups count out 120 grains of rice and exchange them, discussing how the carbon flows from one reservoir to another.

4. Carbon cycles between the oceans and atmosphere at a rate of 90 Gt C per year. Most of this exchange occurs by diffusion at the ocean/atmosphere. Have each of these two groups count out 90 grains of rice and exchange them, discussing how the carbon flows from one reservoir to another.

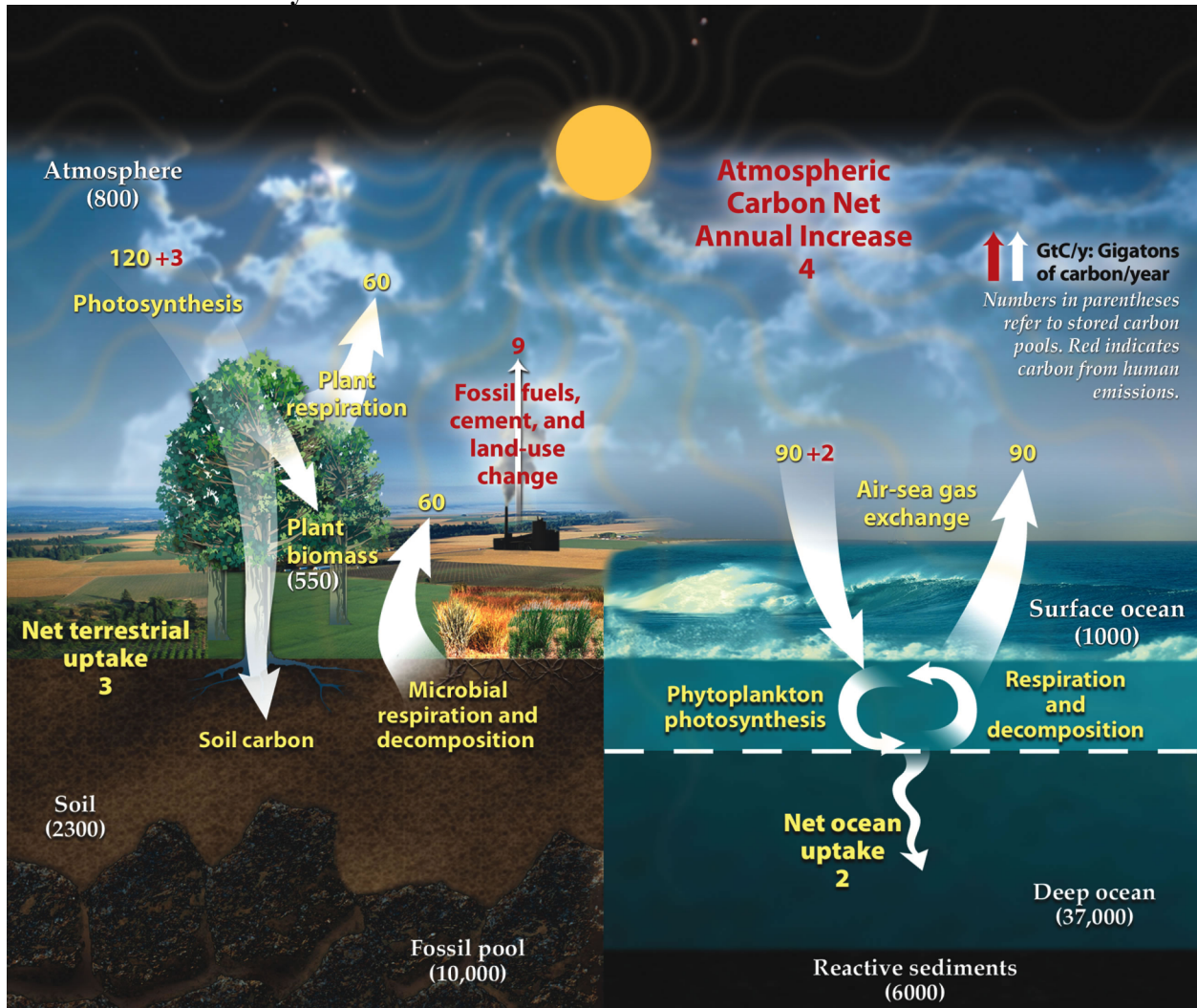
5. Notice that up until now the carbon cycle is in balance, and no reservoir has a net gain or loss. Discuss human use of fossil fuels, the burning of which releases carbon dioxide into the atmosphere. Have the fossil fuel group count out nine grains of rice to give to the atmosphere group.

6. The Earth system is absorbing some of this added carbon: have the atmosphere group count out 3 grains of rice to give to the terrestrial biosphere, and count out two grains of rice to give to the ocean reservoir. Notice a net gain in the atmosphere of four Gt C per year. See "Average Annual Fluxes" below.

Average Annual Fluxes for the period 2000-2008: (Modified from LeQuéré et al., 2009)

Atmospheric increase	=	Emissions from fossil fuels	+	Net emissions from changes in land use	-	Oceanic uptake	-	Residual carbon sink
4.1(±0.04)	=	7.7 (±0.4)	+	1.5 (±0.7)	-	2.3 (±0.4)	-	2.8 (±0.9)

The “Fast” Carbon Cycle:



https://public.ornl.gov/site/gallery/originals/BioComponents_Carbon.jpg

Values in parentheses are estimates of the main carbon reservoirs in gigatons (Gt) as reported in Houghton (2007), excluding rock carbon.

Cycles:

Between the terrestrial biosphere and the atmosphere 120 Gt C is exchanged per year (IPCC, 2007). In the terrestrial biosphere, photosynthesis removes about 120 GT of carbon from the atmosphere; decomposition of biological material and respiration from plants and soil microbes return 120 Gt C to the atmosphere. (IPCC, 2007)

Between the oceans and atmosphere is about 90 Gt C is exchanged per year (IPCC, 2007). In the oceans, the marine biosphere does not take up CO₂ directly from the atmosphere. Each

year the oceans absorb and release about 90 Gt C largely via diffusion across the air-ocean interface. The physical processes controlling the sinking of CO₂ into colder, deeper waters (where CO₂ is more soluble) and the mixing of ocean water at intermediate depths are known collectively as the “solubility pump”. Phytoplankton photosynthesis converts CO₂ into organic carbon that is largely returned to ocean water as CO₂ via microbial respiration and decomposition. The “biological pump” refers to the small fraction of organic carbon that forms into degradation-resistant clumps and sinks to the ocean floor. Together the solubility and biological pumps control the amount of carbon transported to ocean depths and the exchange of CO₂ between ocean and atmosphere.

Human Activities

Human activities (primarily fossil fuel use) emit about 9 Gt C each year. About 4 Gt of this human-contributed carbon remain in the atmosphere; 3 Gt C are taken up by natural terrestrial processes, and another 2 Gt C are removed by the ocean (Canadell et al. 2007).

Source of Graphics: *U.S. Department of Energy Genomic Science Program*

<http://genomicscience.energy.gov>

Global Carbon Reservoir Data

<http://www.esd.ornl.gov/projects/gen/carbon2.html>

<http://www.ess.uci.edu/~reeburgh/fig1.html>

Citations:

IPCC Fourth Assessment Report: Climate Change 2007

http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch7s7-3.html

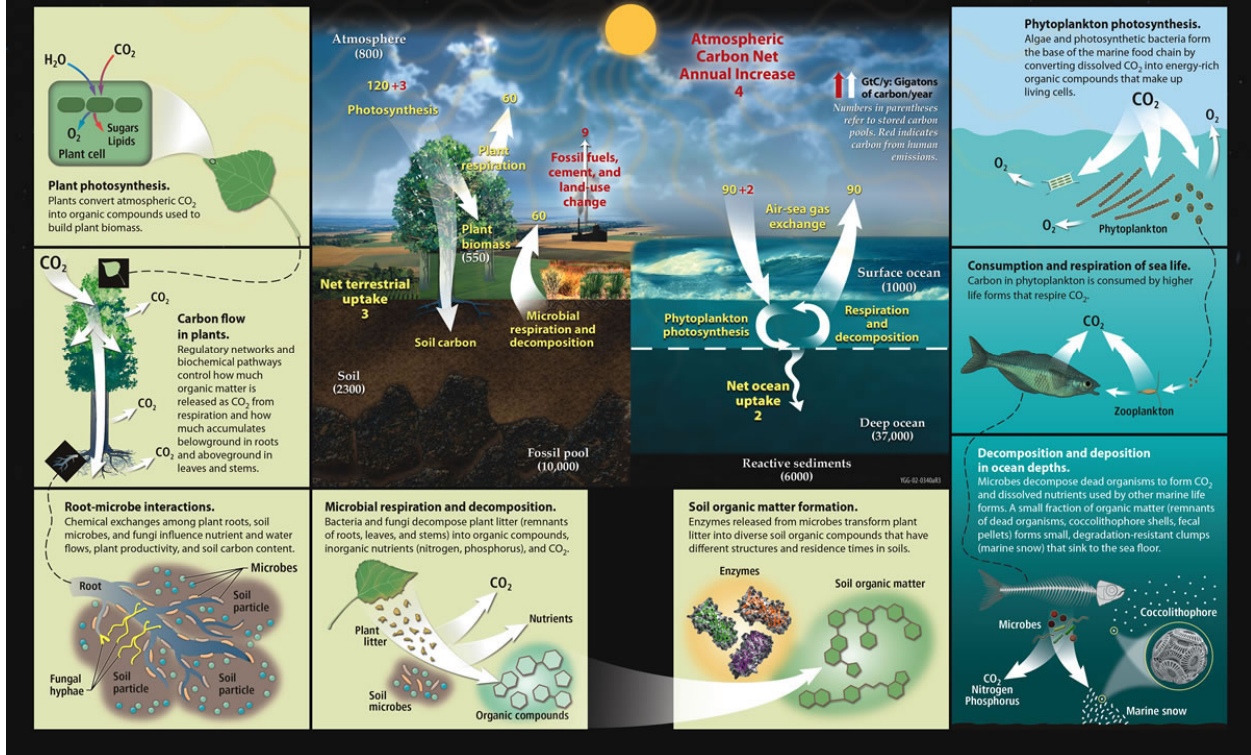
Houghton, R.A. (2007), Balancing the Global Carbon Budget, *Annu. Rev. Earth Planet. Sci.* 35:313 – 47

http://www.unalmed.edu.co/~poboyca/documentos/documentos1/Ecologia_Bosques_tropicales_01_2008/Flavio/Balancing%20the%20carbon%20budget%20HoughtonAnnRevEarthPlanet.07.pdf

Canadell, J. G. et al. (2007), Contributions to accelerating atmospheric CO₂ growth from economic activity, carbon intensity, and efficiency of natural sinks. *PNAS*, Vol. 104, no. 47.

<http://www.pnas.org/content/104/47/18866.full.pdf>

Components of the Global Carbon Cycle



https://public.ornl.gov/site/gallery/originals/Pg002_CCycle08.jpg



Terrestrial Biosphere

Biosfera Terrestre

2850 Gt C



Atmosphere

Atmósfera

800 Gt C



Ocean

El Océano

44,000 Gt C



Rock Piedra 65,500,000 Gt C



Fossil Fuels Combustibles de Fósiles 10,000 Gt C

