Chapter 4
Biogeochemical Cycles
ENERGY FLOW THROUGH ECOSYSTEMS

Nature’s Building Blocks
- Matter
- Energy
- Laws of Nature
- Earth’s Major Components

Ecosystems
- Ecology and biodiversity
- Organisms
- Components and structure
- Species interactions
- Biomes
- Change
- Human impacts
According to the law of matter, emissions from stacks such as these do not simply disappear but end up somewhere else, often with undesirable consequences (i.e. acid deposition, global warming)
Earth’s Components: Ecosphere

- **Biosphere** (living and dead organisms)
- **Atmosphere** (air)
- **Hydrosphere** (water)

**Crust** (soil and rock)

**Lithosphere** (crust, top of upper mantle)

**Mantle** (approx. 2900 km)
- **Outer core** (approx. 2200 km)
- **Inner core** (approx. 1200 km)

**Atmosphere**
- Vegetation and animals
- Soil
- Rock

**Crust** (approx. 8-40 km)

**Upper mantle**

Figure 3-2
The general structure of the Earth


3-3
Quality of Energy and Energy Transformations

Energy – the capacity to do work

Low Quality – diffused and dispersed, low temperatures (Oceans)

High Quality – easy to use / energy disperses quickly (hot fire or gasoline)

Kinetic Energy – energy derived from an object’s motion or mass

Potential Energy – stored energy that is available for later use

*It is important that we match the quality of the energy supplied to the task at hand
The relevance is for environmental studies and biophysical impacts is that many of the elements that circulate in biogeochemical cycles are required for life

**Macro-Nutrient Scale**

- Carbon - slow circulation in Trees, fast in Atmosphere
- Nitrogen – most plants/animals cannot use from atmosphere
- Phosphorous – Does not exist in a gaseous state
- Oxygen – Intimately linked with the carbon cycle
  - Hydrogen and sulphur
Law of Entropy – when energy is transformed from one form into another, there is always a decrease in the quality of useable energy

- Energy cannot be recycled, it flows through systems in a constantly degrading manner

- The more energy that is transformed, the more it is dispersed into the atmosphere as entropy increases

- Coal Fired Generating Facility converts 35% of coal’s energy into electricity
- Only 10% of chemical energy in gas is converted into mechanical energy
‘In geological terms we have released the energy input of millions of years in the blink of an eye – the last 250 years. Many problems are a result of this increase in entropy.

- Dearden and Mitchell
Biogeochemical Cycles: Reservoirs & Pathways
Carbon Cycle

Atmosphere

Hydrosphere

Lithosphere

Biosphere
Carbon Cycle: Reservoirs

Atmosphere
1x
(= $7.3 \times 10^{17}$ grams carbon)

Biosphere
3x

Hydrosphere
55x

Lithosphere
35,000x
**Carbon Cycle**

**Human Impacts**
- Burning fossil fuels: Increased combustion, increased respiration
- Deforestation: Decrease photosynthesis, increase respiration

**Net Effect:** Increase in Carbon in Atmosphere

**Atmosphere**
- Greenhouse gases

**Biosphere**
- Forests, plants, algae
  - Photosynthesis: Carbon removal
  - Respiration: Carbon release

**Hydrosphere**
- Water bodies

**Lithosphere**
- Rocks, soil, minerals

**Diagram Notes**
- Red arrows indicate pathways of carbon flow.
Figure 4.7 - The Carbon Cycle
Atmospheric Carbon Dioxide
Impact

Global Land Air Temperature [Annual]
10 year moving averages

Year

Degrees Celsius:

8.2
8.4
8.6
8.8
9.0
9.2
9.4

1880 1900 1920 1940 1960 1980 2000

10 yr mov avg
University of Calgary climate change researchers say they are close to figuring out how to commercialize the capture of carbon dioxide directly from the air with a simple system that could be set up anywhere in the world.

If they can make it work, it would allow greenhouse gas to be removed from ambient air and reduce the effect of emissions from transportation sources such as cars and airplanes.

"That's the excitement about it. It's a tool for dealing with diffuse CO2 emissions from transportation that account for roughly half of emissions," physicist and climate change scientist David Keith said Tuesday in a phone interview from his Calgary office.

That's important given how conventional systems for capturing CO2 work. Most involve installing "scrubbing" equipment at, for example, a coal-fired power plant to capture carbon dioxide produced during the burning of coal. But a system that can take CO2 out of ambient air is attractive because cars and airplanes aren't equipped with such scrubbers.
Some Major Cycles of Matter

- Water Cycle
- Rock Cycle
- Chemical Cycles
  - Carbon
  - Nitrogen
  - Phosphorus
  - Sulfur
Nitrogen Cycle

- Represents one of the most important nutrient cycles found in terrestrial ecosystems
- Used by living organisms to produce a number of complex organic molecules (amino acids, proteins)
- As a gas (N2) the store of nitrogen in the atmosphere plays an important role for life (about 1 million x larger than in living organisms)
- Also exists in organic matter in soil and oceans
Nitrogen Cycle

Atmosphere

Hydrosphere

Lithosphere

Biosphere

Nitrogen fixation:
• bacteria
• lightning

Denitification: bacteria

Absorption

Waste & Decomposition

Erosion
Nitrogen-Fixing Bacteria in Root Nodules
Nitrogen in atmosphere ($N_2$) flows into plants through assimilation. Plants release nitrates ($NO_3^-$) and nitrites ($NO_2^-$) back into the soil. Nitrates and nitrites are converted into ammonium ($NH_4^+$) by nitrifying bacteria. Nitrogen-fixing soil bacteria fix nitrogen directly into ammonium. Plants also receive nitrogen through nitrogen-fixing bacteria in root nodules of legumes. Decomposers (aerobic and anaerobic bacteria and fungi) convert ammonium into nitrites and back again.
Nitrogen Cycle

Human Impacts

Net Effect: Increase in Nitrogen in water & soil

Nitrogen fixation:
- industrial (fertilizer)
- combustion

Increased Erosion

Hydrosphere

Atmosphere

Biosphere

Lithosphere
Conclusions

Agricultural and industrial nitrogen (N) inputs to the environment currently exceed inputs from natural N fixation (Galloway 2003).

As a consequence of anthropogenic inputs, the global nitrogen cycle has been significantly altered over the past century.

Global atmospheric nitrous oxide (N$_2$O) concentrations have increased from a pre-industrial value of ~270 ppb to ~319 ppb in 2005 (Alley et al. 2007).
Some Major Cycles of Matter

- Water Cycle
- Rock Cycle
- Chemical Cycles
  - Carbon
  - Nitrogen
  - Phosphorous
  - Sulfur
Phosphorous Cycle

**Atmosphere**
- Waste & Decomposition
- Weathering & Erosion
- Absorption

**Lithosphere**
- Weathering & Erosion
- Sedimentation
- Absorption

**Hydrosphere**
- Absorption

**Biosphere**
- Absorption

Never enters the atmosphere
**Phosphorous Cycle**

**Human Impacts**

- Mining, use (fertilizer, detergent, etc.)
- Increased runoff

**Net Effect:**
- Increase in phosphorous in water & "algal blooms";
- Depletion in soils

**Hydrosphere**
- More Phos. for organisms

**Biosphere:**

**Lithosphere**

Mining, use (fertilizer, detergent, etc.)
& increased runoff
Impact: Eutrophication

- Sunlight
  - Phosphorus in surface runoff
    - Phosphorus fertilizes small floating aquatic plants
      - Light penetration is reduced
        - Reduced submerged aquatic vegetation (SAV)
          - Plants die off. When they decompose, the water becomes depleted in oxygen
            - Some animals die because of lack of oxygen
Impact: Red Tide
Eutrophication

Eutrophication results from the disruption in the phosphorous cycle

• process of damaging a lake ecosystem through excessive input of nutrients such as phosphorous

Among the Great Lakes, Lake Erie once suffered from major eutrophication

- 1972 Great Lakes Water Quality agreement between Canada/US
  - controlling discharges of phosphorous in the lake

Lake Superior has the least eutrophication problems (large, deep and relatively lower levels of industrialisation)
Lake of Fire!!
ELA Location
Lake 227 (1975) – Initial Loading

Lake 227 - Today
Sulfur Cycle

Animal and Plant Residue

Organic Sulfur Compounds

Mineralization
Immobilization

Sulfides and Elemental Sulfur

Sulfates ($SO_4^{2-}$)

Oxidation
Reduction
Leaching

Soil Minerals

Dissolution

SO$_2$ Sulfur Dioxide
Industrial Emissions

Fertilizer (Pesticides)

Clay

Acid Rain

H$_2$S Hydrogen Sulfide

Volatilization
Sulfur Cycle

Atmosphere

Hydrosphere

Lithosphere

Biosphere

Volcanoes & Weathering

Absorption

Precipitation

“Evaporation”

Weathering

Bacteria Release

Absorption

Waste & Decomposition

Sedimentation

Deep Sea Vents

Bacteria Absorption
Sulfur Cycle

Hydrosphere

Atmosphere

Biosphere

Lithosphere

Human Impacts

Net Effect: Increase in atmosphere (health effects) and acid rain

Burning Fossil Fuels
Acid Deposition

any precipitation (rain, snow, fog, mist) that is more acidic than normal high because of the nature or the pH scale

Logarithmically, a decrease in value from pH 6 to pH 5 means that the solution has become ten times more acidic

If the number drops to pH 4 from pH 6, then the solution is 100 times more more acidic

• The largest sources of increased acidity in lakes and other surface waters are through smelting of sulphur rich metal ores and the burning of fossil fuels
• presence of sulphuric acid (H2SO4) and nitric acid (HNO3)
• most common acids that are discharged by industrial emissions
• roughly about two thirds of these emissions are sulphuric acid
• about one third are acid
The forest and soils of this landscape were killed and eroded through action of air pollution from smelters downwind in nearby Mt Lyell copper mines. Ironically this landscape is featured as a tourist attraction. Formerly temperate forest.