Lecture Eight: Energy Flow
And Biogeochemical Cycles

We now know what a **FOOD WEB** is, and what **TROPHIC LEVELS** are. The Food Web reflects the flow of **ENERGY** and **NUTRIENTS** through ecosystems.

**ENERGY** (E) is defined in physics as the capacity to do work.

- **Kinetic Energy** - the energy of movement (example: )
- **Potential Energy** - stored energy (example: )

Energy is measured in units called **Joules** (J). One J = about 1/4 calorie; and one **calorie** is the amount of energy needed to raise the temperature of 1 gram of water by 1° C (Celsius).

**FIRST LAW OF THERMODYNAMICS**: Energy cannot be created or destroyed; it can only change in form.

**SECOND LAW OF THERMODYNAMICS**: All systems in the universe tend to go from a state of order to a state of chaos (**ENTROPY**). Entropy is energy that is unavailable to do work.

**Energy Transduction in Biological Systems**

The **Sun** provides all the earth's energy in the form of **LIGHT**. Energy **transduction** is the process of changing energy from one form to another.

**Autotroph** - *auto* = "self"; *troph* – "feeding") an organism that captures energy and stores it in the chemical bonds of organic molecules that it manufactures from inorganic molecules. (a.k.a. - producers)

**Heterotroph** - *(hetero = "other"; *troph* – "feeding")* an organism that eats other organisms to obtain energy. (a.k.a. - consumer)

**Storing Energy: Photosynthesis**
The most common means by which autotrophs make organic molecules (sugar) is **PHOTOSYNTHESIS**. (Autotrophs that capture light energy are called **PHOTOAUTOTROPHS**, though there are other kinds of autotrophs)

Overall, the chemical reaction of photosynthesis is as follows:

\[
6\text{CO}_2 + 12\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}
\]

...which means that it takes
* six molecules of carbon dioxide plus
* 12 molecules of water
* light energy (to be stored as chemical energy)
in the presence of light and the proper enzymes in the cell, to make
* **one molecule of glucose**
* 6 molecules of oxygen
* 6 molecules of water
The sugar (glucose) is the storage form for energy in plants, and it’s often converted into long chains for long-term storage as CARBOHYDRATE. The oxygen and water are side products that are not used by the plant in this reaction.

**WHY STORE SUGAR AND CARBOHYDRATES?** What does the plant do with them, once it has them? (1) manufactures its own body and (2) stores energy to do work.

**Releasing Energy: Cellular Respiration**
In fact, any living organism burns organic molecules to release the stored energy and use it to drive its own chemical reactions. The process living organisms use to release the energy stored in sugar is called **CELLULAR RESPIRATION**, and its chemical equation is exactly the opposite of photosynthesis:

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O} \rightarrow 6\text{CO}_2 + 12\text{H}_2\text{O} + \text{ENERGY}
\]

...which means that
- one molecule of glucose in the presence of
- six molecules of oxygen and
- six molecules of water

can be "burned" to release stored energy as well as the "waste" products of
- 6 molecules of carbon dioxide and
- 12 molecules of water

**The Nature of Light and Photons**
How do plants capture light? First, a little bit about light itself…

1. Light, like other forms of electromagnetic radiation, is composed of subunits. A subunit of electromagnetic radiation is called a **QUANTUM** (plural - quanta)
2. The special name for a quantum that we can *see* (i.e., a unit of visible light) is a **PHOTON**.
3. Light is odd among physical phenomena! It has properties of both a particle (it bounces off solid matter, and its path can be bent if it travels through liquid) and a wave (it travels through space in a wave form, like so: )
4. Not all photons are the same! Although all photons travel at the speed of light (299,792,458 meters per second!), individual photons making up the light around us may be travelling at different wavelengths or at different frequencies. (See drawing on the board!)
5. Photons of different wavelengths interact with matter in different ways. For example, photons can range in wavelength from about 380 nm to about 580 nm, and a photon will be perceived by your brain as a certain COLOR depending on its wavelength when it hits your eye’s retina.
6. The shorter the wavelength, the higher the frequency, and the higher the energy!
7. The highest energy photons are in the violet region; the lowest energy ones are in the red region, with the visible spectrum running like so:

<table>
<thead>
<tr>
<th>(short wavelength)</th>
<th>(long wavelength)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ultraviolet) violet</td>
<td>red (infrared)</td>
</tr>
<tr>
<td>360nm</td>
<td>560</td>
</tr>
<tr>
<td>390</td>
<td>520</td>
</tr>
<tr>
<td>400</td>
<td>480</td>
</tr>
<tr>
<td>460</td>
<td>400</td>
</tr>
<tr>
<td>480</td>
<td>390</td>
</tr>
</tbody>
</table>
8. Photons interact with matter in one of three ways. A photon striking matter (liquid, gas or solid) can be
   a. **transmitted** (meaning it passes through the matter)
   b. **reflected** (meaning it bounces off the matter and changes direction)
   c. **absorbed** (its energy is converted into the energy of the molecule it hits)

Only absorbed photons have biological activity, because only those are giving up their energy to the matter which has absorbed them.

**PLANTS** absorb photons only in a specific region of the spectrum. They have special pigments (a "pigment" is any substance that absorbs light) called **CHLOROPHYLLS** and **CAROTENOIDs** which absorb light, capturing its energy to be packaged as sugars.

Plants use photons in the violet → blue region and in the red region for photosynthesis. Only violet, blue and red photons are absorbed by chlorophylls. All other wavelengths are reflected, which is why plants look GREEN. They are reflecting away the green light, and not using it to make sugar!

The chlorophylls are located in special plant organelles called **CHLOROPLASTS** (see the picture!). It is inside the chloroplasts that photosynthesis takes place.

**Primary Productivity: A Measure of an Ecosystem's Energy Capture**

Energy Flow begins with **PRIMARY PRODUCTIVITY**, the amount of light energy converted to chemical energy (organic molecules) by an ecosystem's **autotrophs** over a given period of time.

* **GROSS Primary Productivity (GPP)** - Total primary productivity
* **NET Primary Productivity (NPP)** - Total primary productivity - energy used for respiration

\[ \text{NPP} = \text{GPP} - R \]

The productivity of various ecosystems can be calculated by measuring the biomass of vegetation per unit area per unit of time.

Primary productivity (always expressed as a RATE) can be expressed as **ENERGY** per unit area per unit time (e.g., Joules/m²/year) or as **BIOMASS**, the dry weight of vegetation added to an ecosystem per unit area per unit time (e.g., grams per square meter per year).

**STANDING CROP BIOMASS** is the dry weight of vegetation in an ecosystem at any given "snapshot moment" in time. It is not the same as primary productivity: it's not a rate! The efficiency with which trophic levels convert energy from the previous trophic levels varies greatly with ecosystem, and usually range between 5% - 20% (What does this mean in terms of how much is LOST at each trophic level?), as reflected by the **STANDING CROP BIOMASS** of each level.

Now we get back to that pesky Second Law of Thermodynamics. Energy transfers between trophic levels are NOT 100% efficient. About 90% of the energy of one trophic level is **LOST AS ENTROPY** when it is eaten by the next trophic level! (This varies among ecosystems, with some being more efficient or less efficient).
In other words…
It takes 1,000,000J of sunlight for a plant to store 10,000J worth of biomass.

   If grasshoppers (primary consumers) eat those 10,000J of plant biomass, they will convert it into only 1000J of grasshopper biomass.

   If field mice eat 1000J of grasshopper biomass, they will convert it into only 100J of field mouse biomass.

   If foxes eat 100J of field mouse biomass, they will be able to convert only 10J into fox biomass.

   …and so on! It's this type of PYRAMID OF PRODUCTIVITY that shows us why environmentalists urge us to "eat low on the food chain." The higher you go in trophic levels, the more energy is spent at lower levels.

To make 1 kg of human biomass, it takes 10kg of grain.

   But if you eat beef, it takes 10kg of beef to make 1 kg of human, and 100kg of grain to make that 10kg of beef! So if you skip the cow step, you can feed more people!

The FOOD WEB of an ecosystem reflect its energy transfers, with producers, consumers and decomposers all contributing to the flow of energy and nutrients through the system.
A generalized cycle...

...can be superimposed on Biogeochemical Cycles for other substances

- The Water Cycle
- The Carbon Cycle
- The Nitrogen Cycle
- The Phosphorus Cycle
- ...and any other element.

Your activities any day have profound effects on these cycles, and on ENERGY cycling in the biosphere. To test how much impact you have on our biosphere, take the following test of your Ecological Footprint at

http://www.earthday.net/Footprint/index.asp.

Go forth and spread the word.