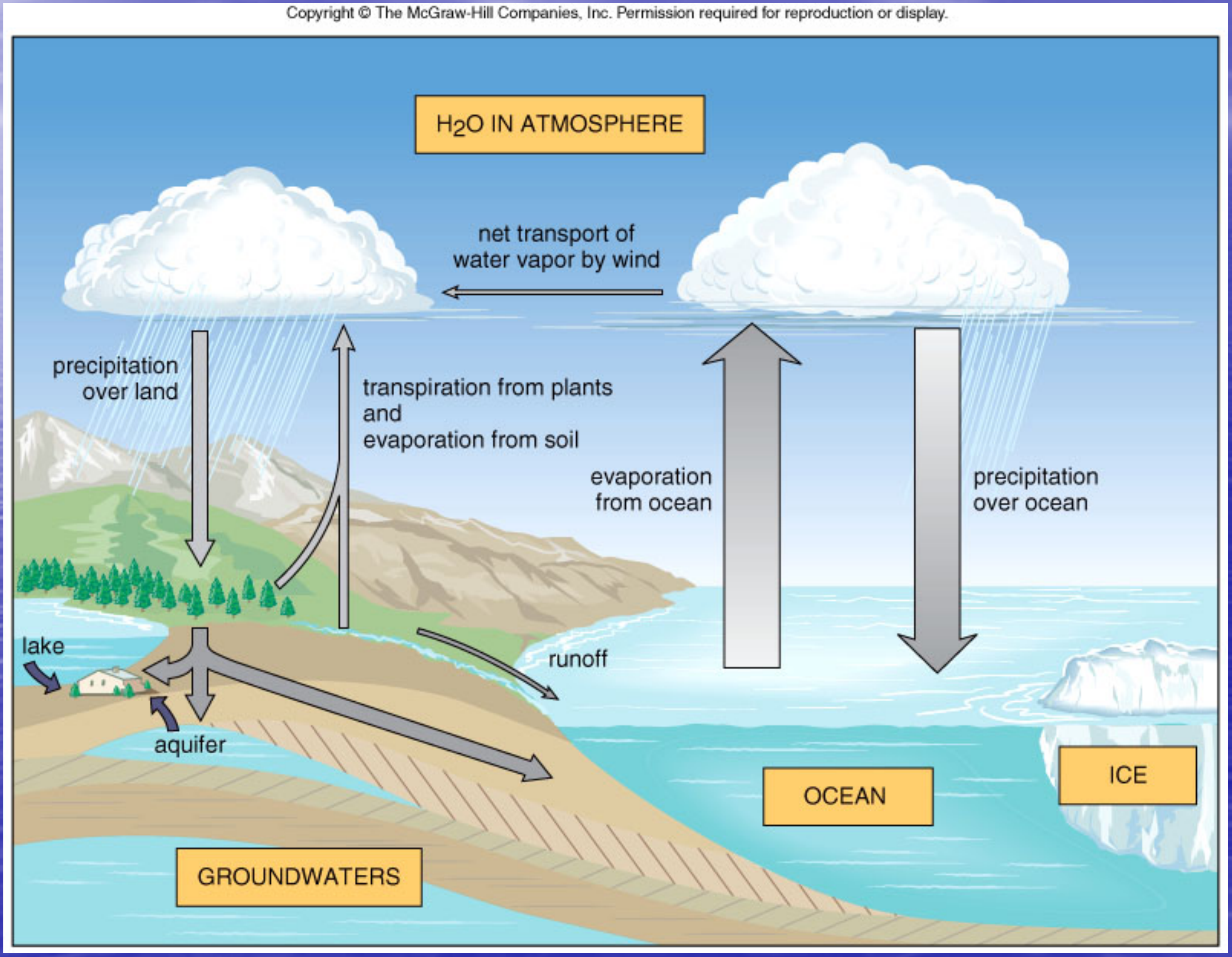
Section 2.1

The Role of Water in Cycles of Matter

Water in the Biosphere

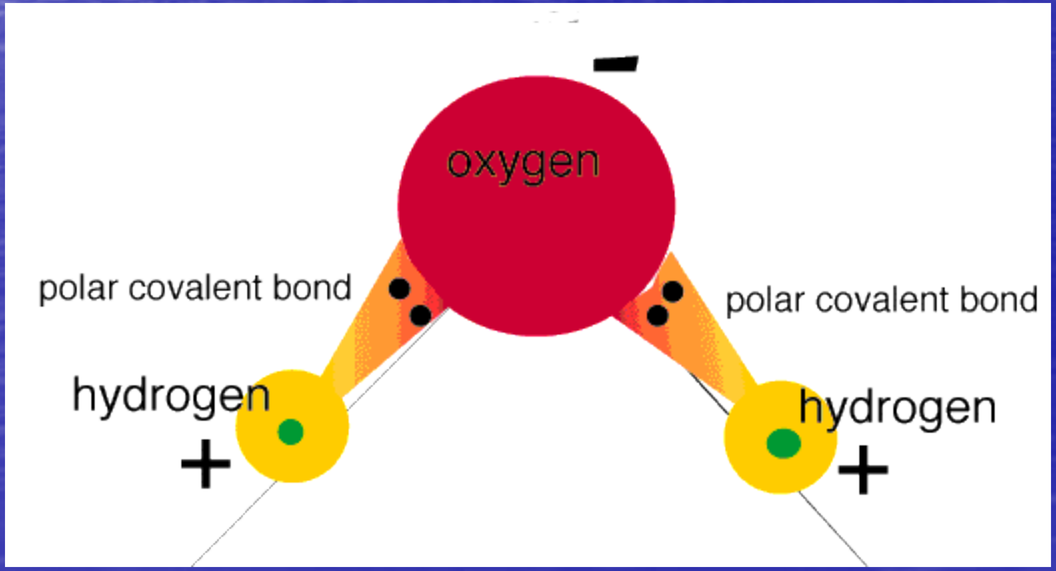
- Because Earth is a closed system, matter must cycle within it
- The water that we see in surface water sources may have come from snow and ice, from oceans, or it may have been a product of cellular respiration
- Water in our atmosphere acts as a greenhouse gas, trapping heat and warming the Earth
- The transfer of heat throughout our biosphere is also mostly due to water's ability to absorb large amounts of heat energy

The Hydrologic Cycle



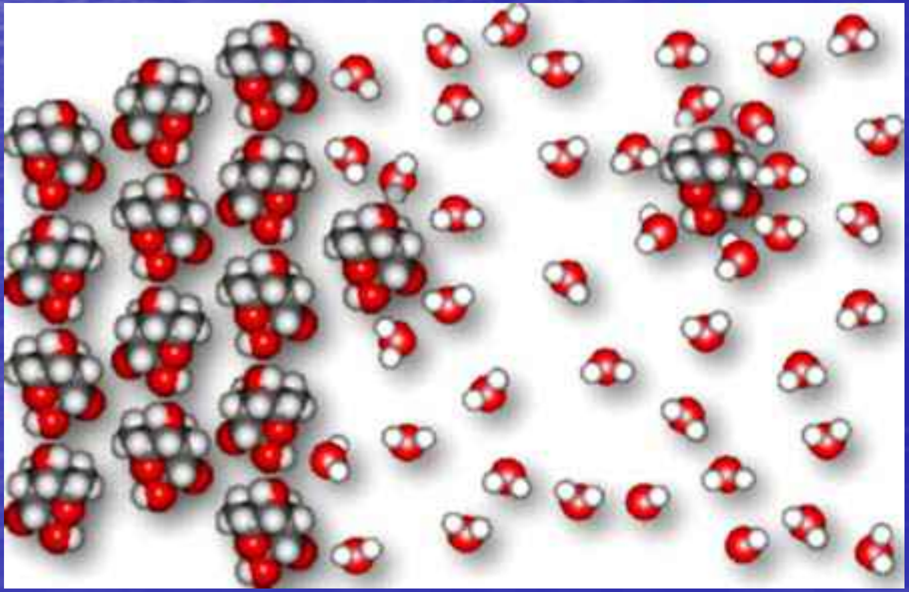
The Universal Solvent

- Water is a polar molecule
- When an ionic compound is placed in water, it dissociates (pulls apart the ions and makes it dissolve)



The Universal Solvent

- As well, there is attraction formed between nearby water molecules as a hydrogen bond forms
- This allows water molecules to surround compounds while dissolving them

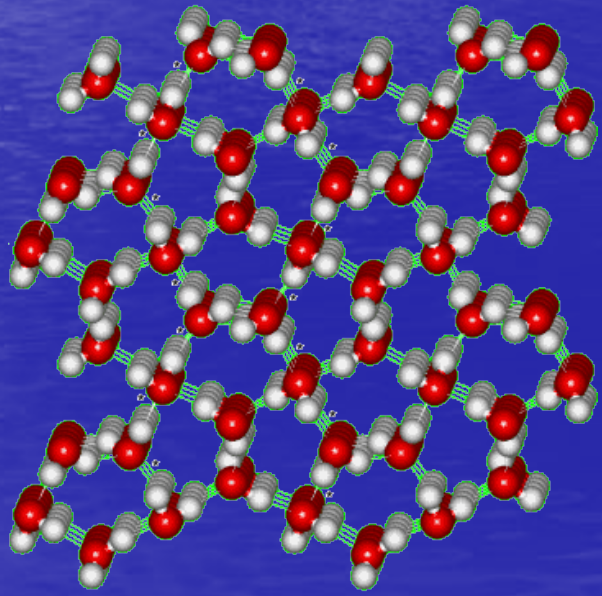


Hydrogen Bonding and Water's Phases

- Because water molecules have relatively strong hydrogen bonds between them, it requires a large amount of energy to break these bonds so that the molecules can move freely
- This means that water will have very high heats of fusion and vaporization
- It also means that water has high melting and boiling points when compared to similar hydrogen compounds

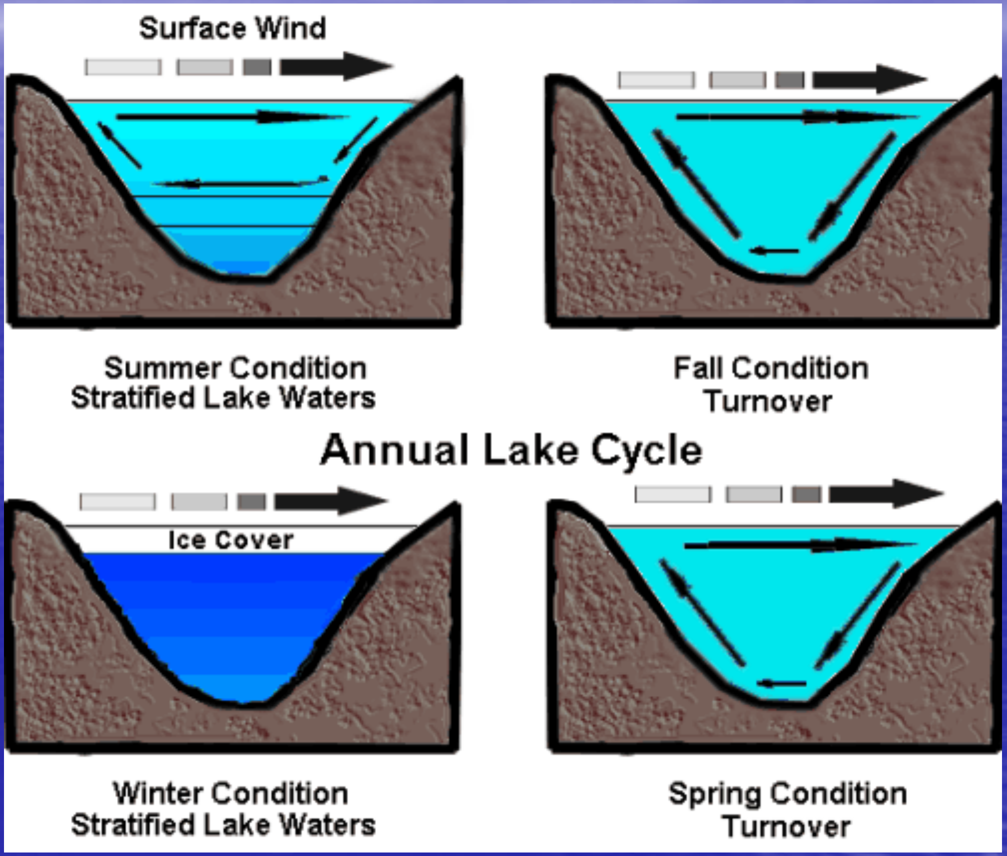
Hydrogen Bonding and Water's Phases

- These hydrogen bonds and the forces of repulsion between the oxygen atoms contributes to the open spacing seen in the crystal structure of ice



Hydrogen Bonding and Water's Phases

- Because ice is less dense than water, lakes always freeze from the top down
- This prevents most lakes and ponds from freezing solid
- As well, it contributes to the cycling of oxygen and nutrients during the spring and fall in bodies of water



Hydrogen Bonding and Water's Phases

- The hydrogen bonds in water produce cohesion between molecules, which gives water its surface tension
- Adhesion also occurs between water molecules and molecules of other substances (such as glass, or xylem!)

Water and Heat

- The hydrogen bonds between water molecules means that water has a high specific heat capacity
- As a result, water stores huge amounts of heat energy
- Large bodies of water near land will moderate terrestrial temperatures because of this
- At the level of the individual organism, the high specific heat capacity of water prevents body temperatures from changing too quickly

Water and Organisms

- Organisms gain water from their environment through eating, drinking, absorption, and cellular respiration
- Organisms lose water through breathing, sweating, and in their waste

Water as a Resource

- When ecosystems lack water, the producers that use it during photosynthesis quickly disappear
- Therefore, droughts in areas can be devastating to ecosystems
- If global temperatures rise, then droughts will become more common in areas such as Alberta, which will greatly affect our economy

Section 2.2

Biogeochemical Cycles

The Necessity of Cycles

- Again, because there is a limited amount of matter in our ecosystem, chemicals must be recycled constantly
- The main biogeochemical cycles are the oxygen, carbon, nitrogen, phosphorus, and sulfur

The Nitrogen Cycle

- Nitrogen is required by organisms to form the amino acids that form proteins and to make up the structure of DNA
- However, the nitrogen gas (N_2) in our atmosphere (78% nitrogen) cannot be used for this purpose
- The nitrogen gas must therefore be converted into another useable form – nitrate (NO_3^-)

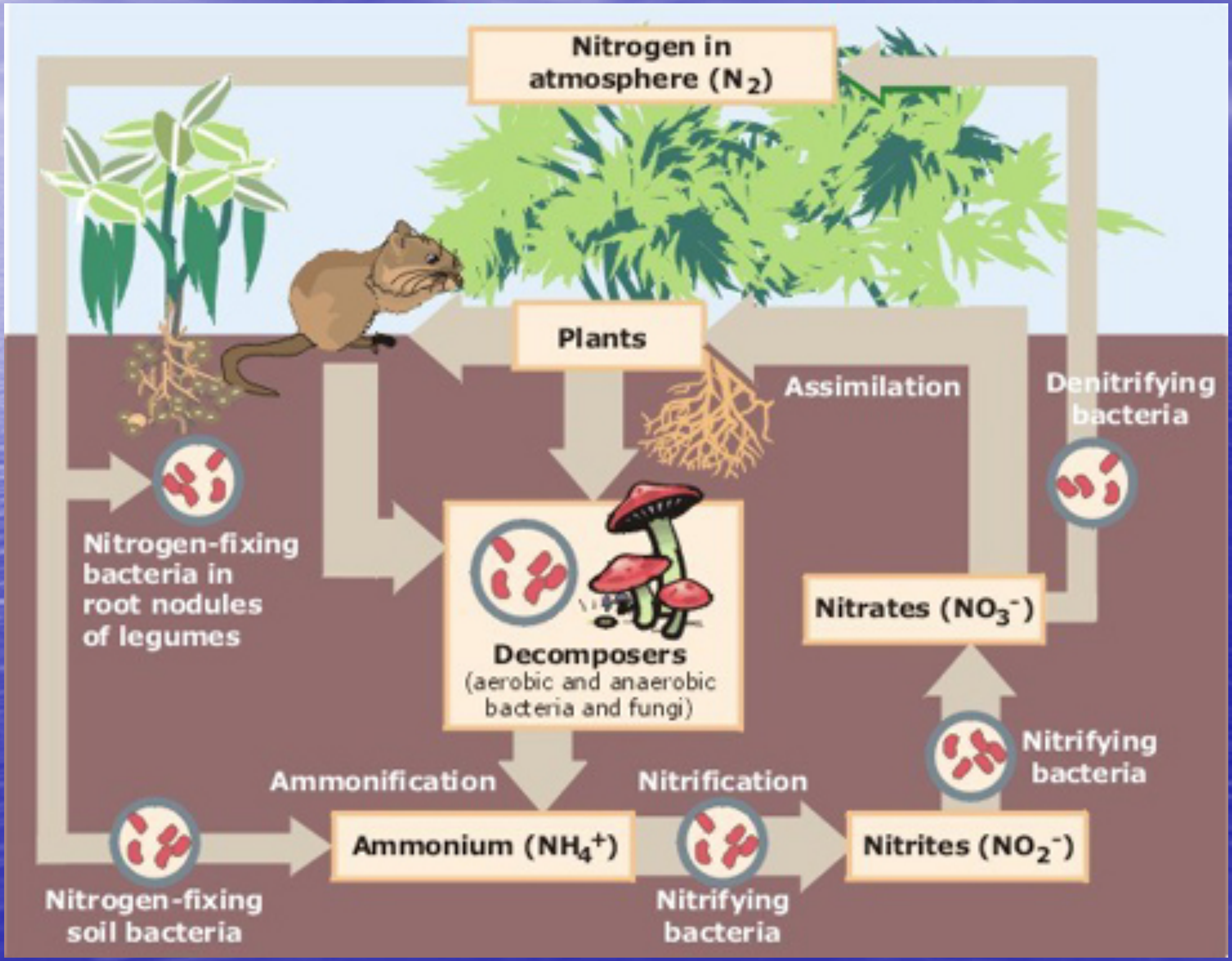
Processes in the Nitrogen Cycle

- Nitrogen fixation is the conversion of atmospheric nitrogen into ammonium (NH_4^+)
  - This is carried out by nitrogen-fixing bacteria found in nodules attached to the roots of legumes
- Ammonification also produces ammonium as bacteria break down urine and dead organic matter

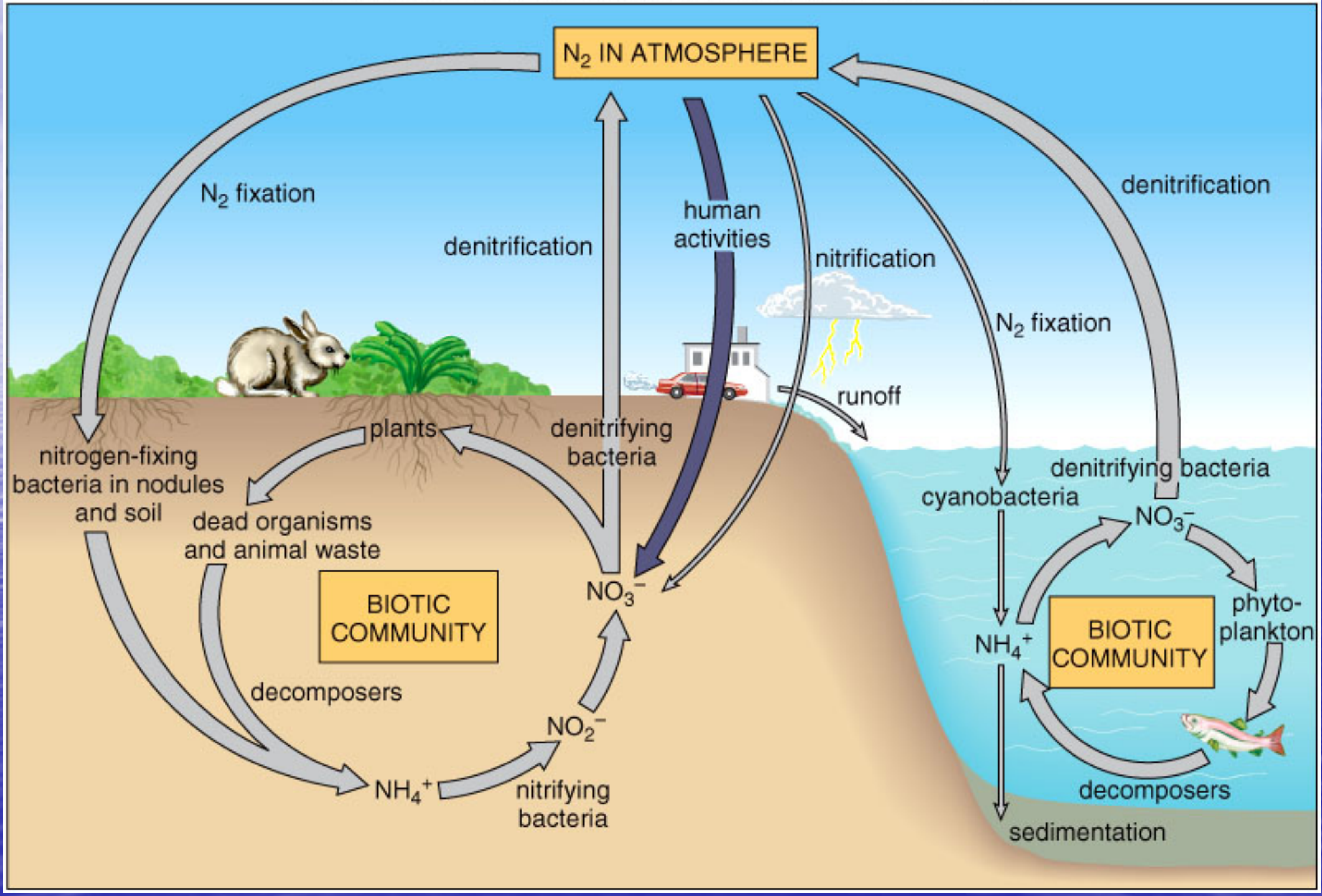
Processes in the Nitrogen Cycle

- Nitrification – production of nitrates (NO_3^-) which plants use
    - Nitrogen gas converted to nitrate in atmosphere by lighting, meteor trails, cosmic radiation
    - Ammonium in soil converted to nitrate by nitrifying bacteria
- Denitrification – denitrifying bacteria complete the cycle by breaking down nitrogen compounds and releasing nitrogen gas back into the atmosphere
    - Denitrification typically occurs in anaerobic environments (why do we aerate our lawns?)

Nitrogen Cycle



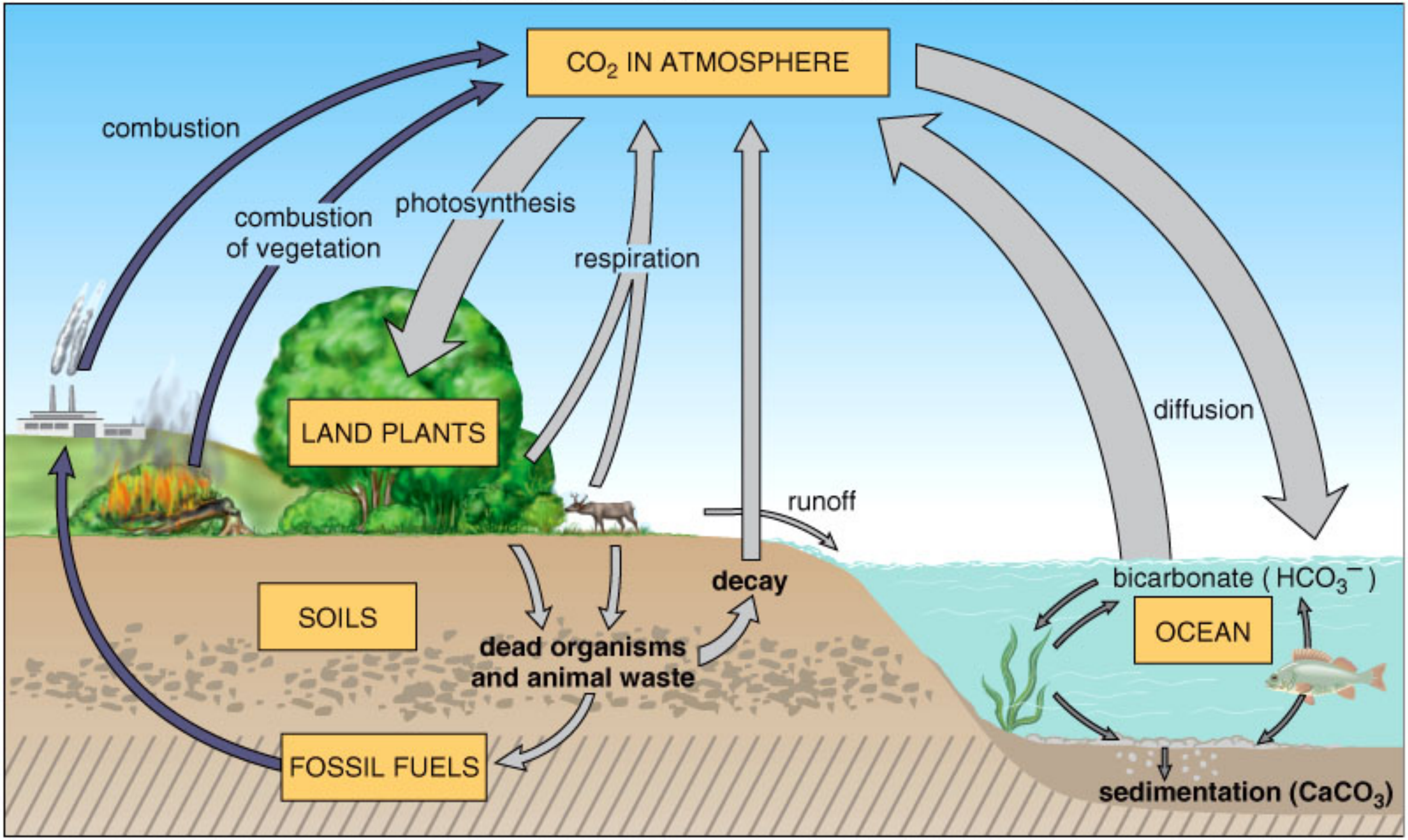
The Nitrogen Cycle



The Carbon Cycle

- Carbon is the key element in all organic compounds. In the carbon cycle, carbon starts in the form of CO_2 in the atmosphere.
- Carbon dioxide is used by plants in photosynthesis, converted to glucose, and moved up the food chain as they are eaten by animals.
- Atmospheric carbon is the returned by many different processes (ie: cellular respiration, combustion, volcanic eruption, etc)

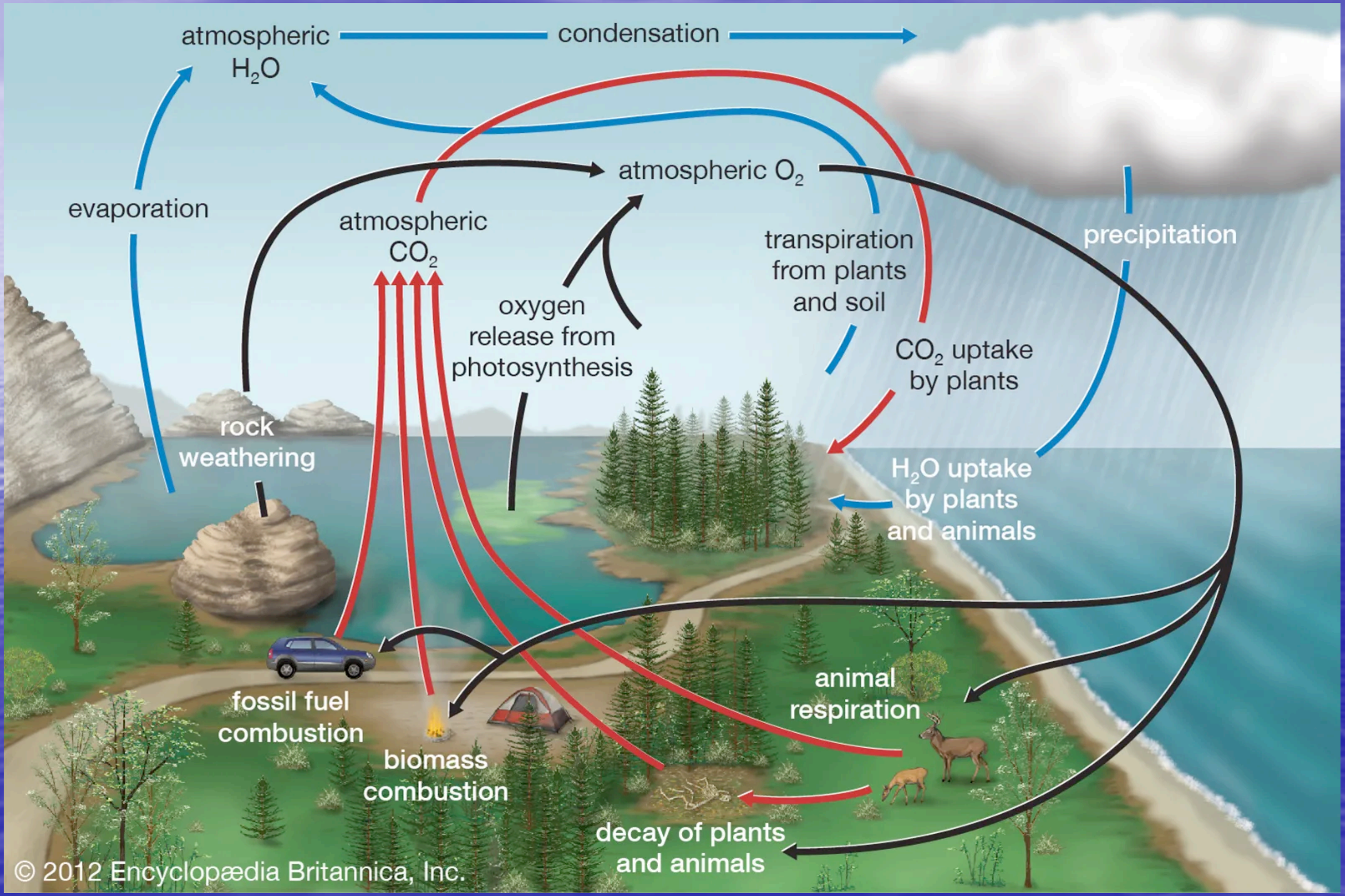
The Carbon Cycle



The Carbon and Oxygen Cycle

- Carbon and oxygen are closely related in our ecosystem
- As a result, they can often be illustrated in the same cycle

Carbon-Oxygen Cycle



Slow vs. Rapid Cycling of Carbon

- Organisms are involved in the rapid cycling of carbon through photosynthesis and cellular respiration
- However, some carbon gets trapped in deep oceans and sedimentary rock layers when organisms die and become part of earth's crust/fossils/fossil fuels. This carbon only gets released after millions of years of weathering or human excavation and subsequent burning

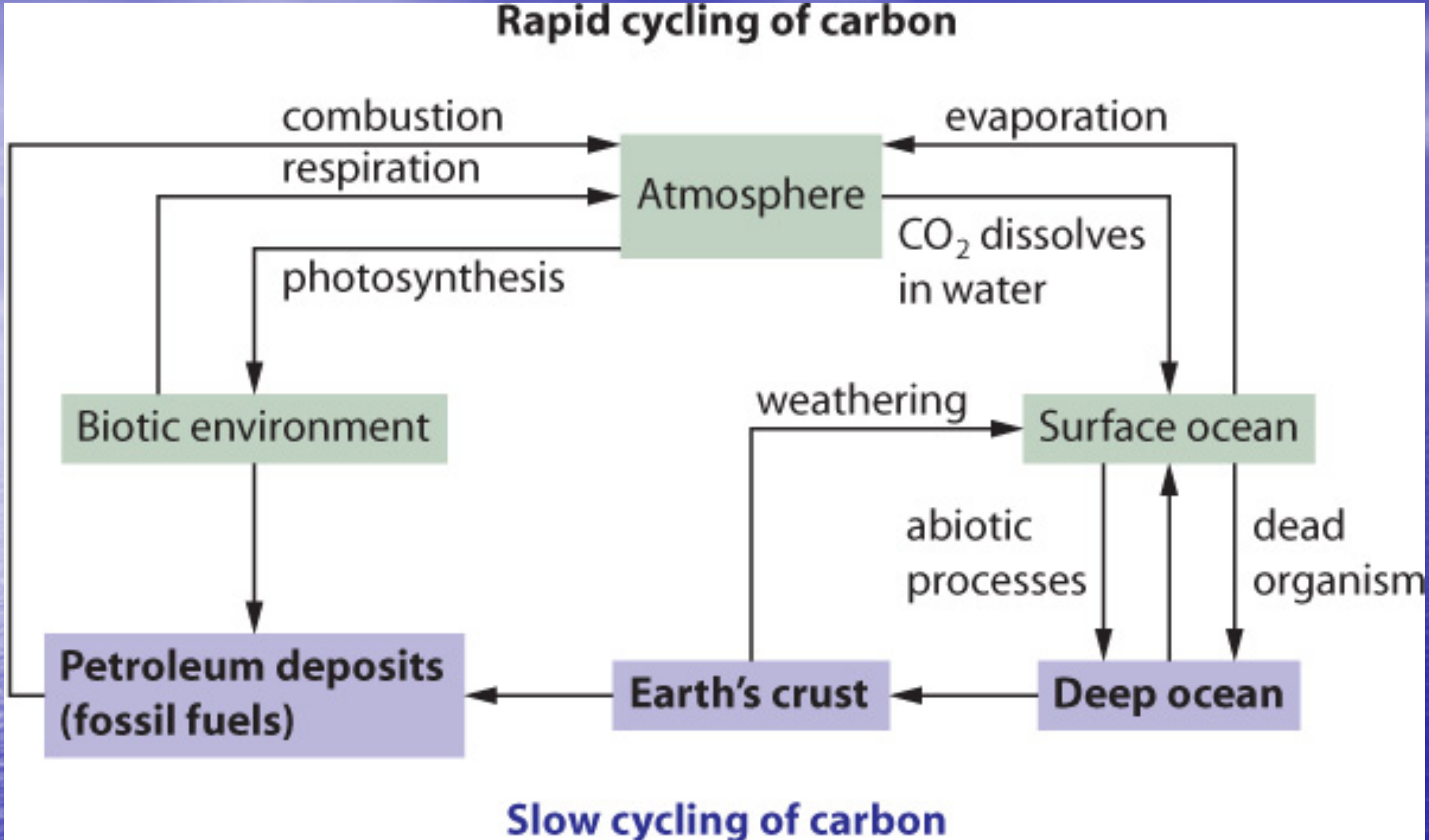


Figure 2.12 The rapid cycling of carbon is shown in green, and the slow cycling of carbon is shown in purple.

The Carbon Cycle

- Reservoirs of carbon (aka carbon sinks)
  - Dead organisms – fossil fuels
  - Forests
  - Methane captured in permafrost (ancient swamps)
  - Oceans / large bodies of water   Ocean Acidification
- Human activities
  - More carbon dioxide is being deposited in atmosphere than is being removed   TEDx Tetris
    - Due to deforestation and burning of fossil fuels
    - Canada's forests are now a carbon source not carbon sink
  - Methane escaping natural gas wells
    - methane (CH_4) is 23x better at being a GHG than CO_2

Carbon Cycle and Climate Change

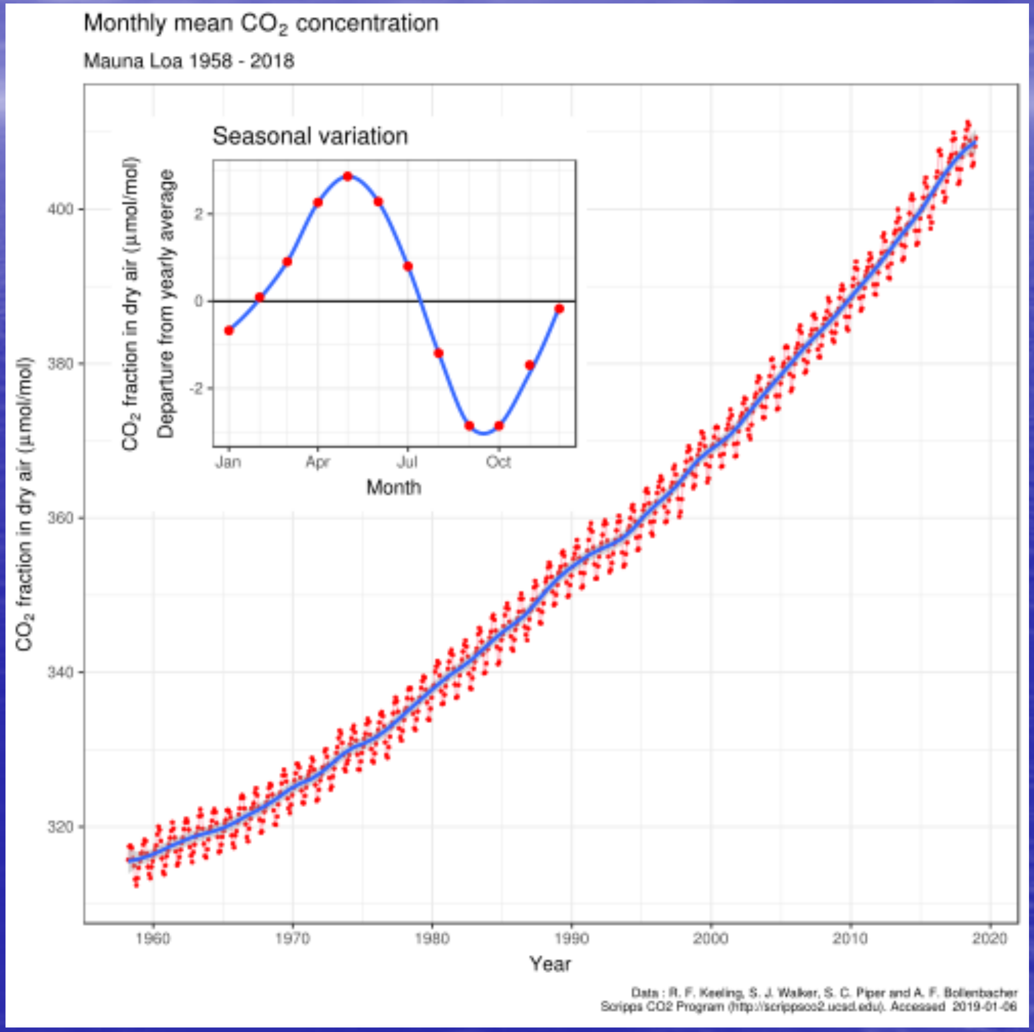
- The roots of the greenhouse effect concept lie in the 19th century, when French mathematician Joseph Fourier calculated in 1824 that the Earth would be much colder if it had no atmosphere.
- In 1896, Swedish scientist Svante Arrhenius was the first to link a rise in carbon dioxide gas from burning fossil fuels with a warming effect.
- Nearly a century later, American climate scientist James E. Hansen testified to Congress that "The greenhouse effect has been detected and is changing our climate now."
- Increased carbon dioxide in atmosphere contributes to global warming

CO2 and Climate Mt Kilaeua
Volcanos and Climate
Climate Change in a nutshell
CO2

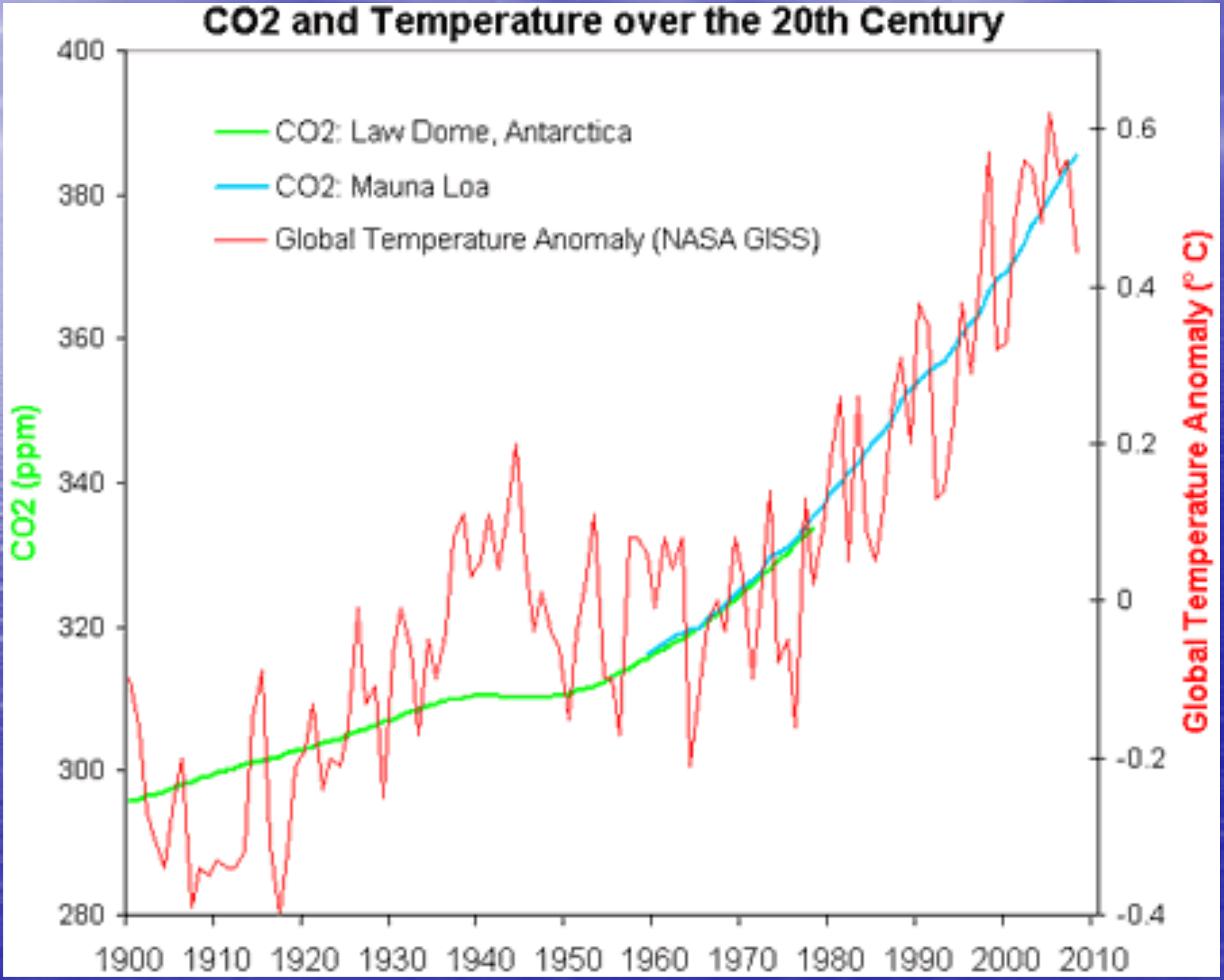
Greenhouse gasses
Greenhouse effect
Climate vs Weather
Possible solutions

Carbon Cycle and Climate Change

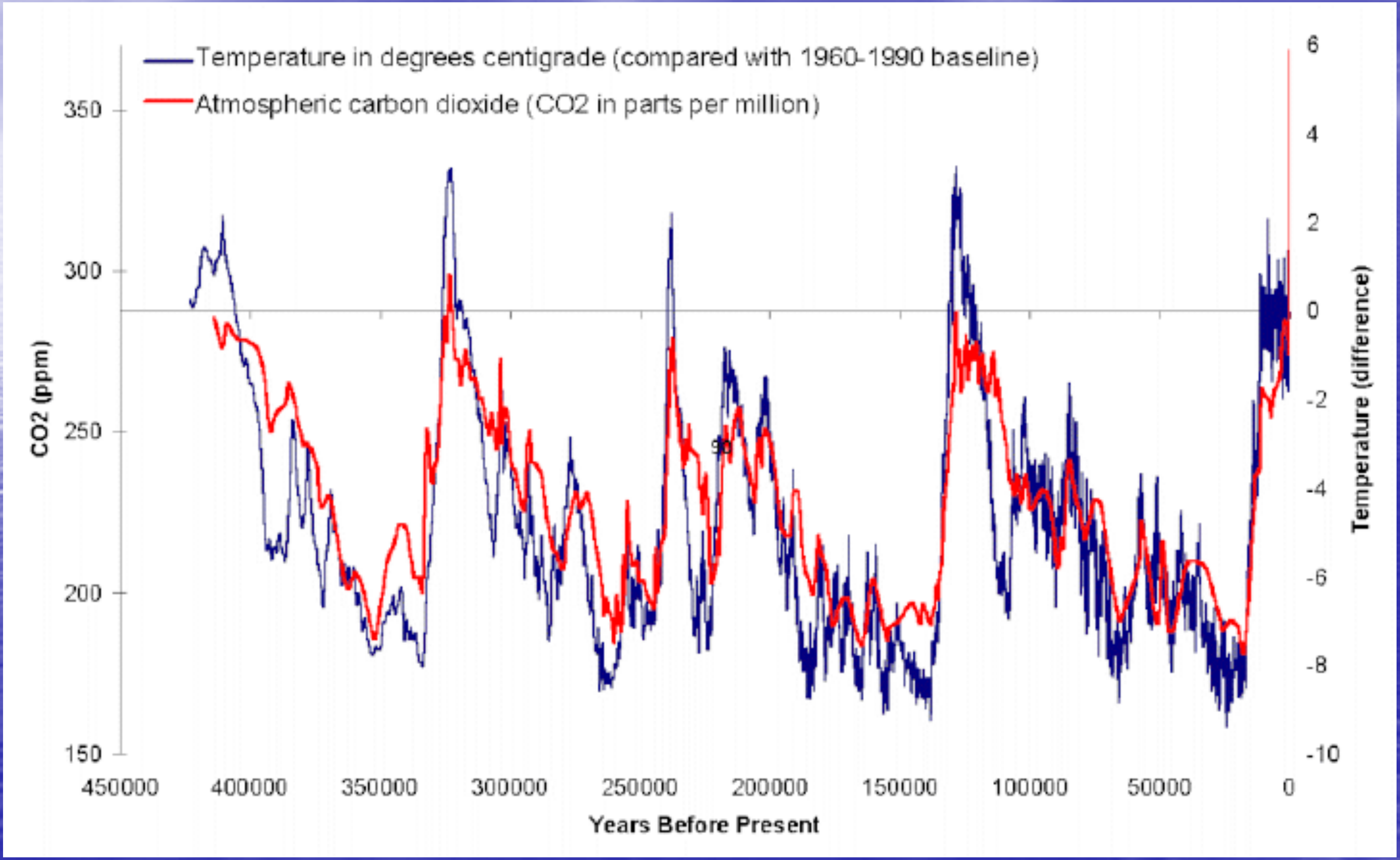
- The **Keeling Curve** is
  a graph of the accumulation of carbon dioxide in the Earth's atmosphere based on continuous measurements taken at the Mauna Loa Observatory on the island of Hawaii from 1958 to the present day.
- Named for Charles David Keeling
- it's steadily risen year after year. In 2016, when Scripps announced that the curve had broken 400 ppm, Keeling's
- Charles' son Ralph, reported Sunday May 11, 2019 reading hit a record-breaking 415.26 parts per million



CO_2 vs Temp: Last Century



Keeling Curve vs Global Temperatures



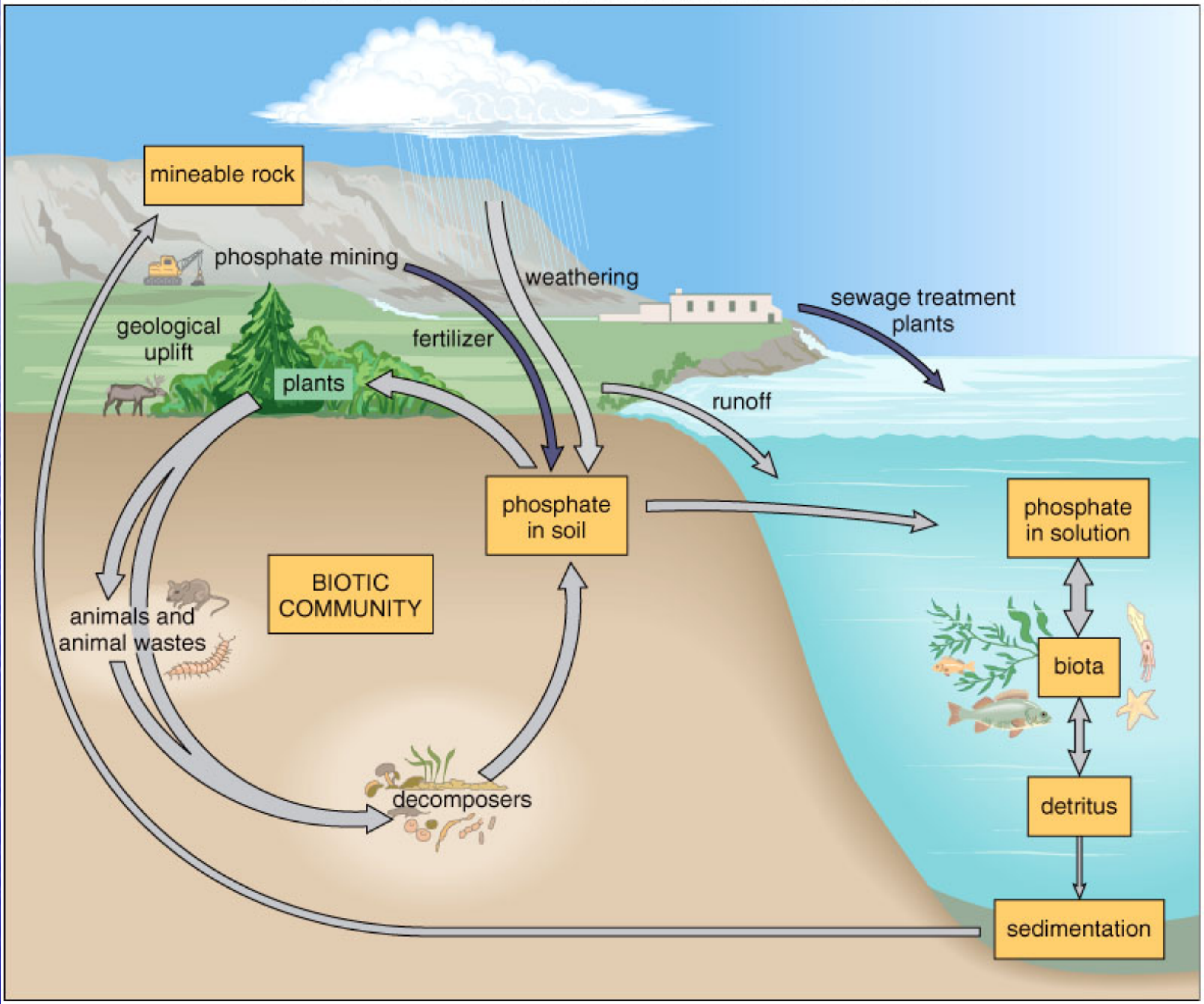
Global Warming

- How can we know the global temperatures from so long ago?
- Paleoclimatology Ice cores
- Bill Nye explains

The Phosphorus Cycle

- Phosphorus (in the form of phosphate, PO_4^{3-}) is required for cellular materials such as DNA, phospholipids, and ATP
- Phosphorus does not cycle in the atmosphere, but is found in soil and water
- Large amounts of phosphorus (PO_4^{3-}) are stored in rocks and released during erosion
  - Picked up by producers and cycles through consumers and finally decomposers

Phosphorus Cycle



Phosphorus Cycle: Human Impact

- Because most of the world's phosphorus is locked in rocks and sediments, the release of phosphates, and thus growth of plants, is limited
- However, excess phosphates can be added to ecosystems due to phosphate mining, overuse of fertilizers on farm fields, & detergent runoff in landfills
- Can cause uncontrolled growth of algae and plant life, or accelerated eutrophication. As algae die off, decomposers consume high levels of oxygen in the water – results in massive marine life deaths

The Phosphorous Cycle

- Environmental phosphorous is recycled in two ways:

  1. Long-term cycle involving rocks of the Earth's crust
  2. Short-term cycle involving living organisms

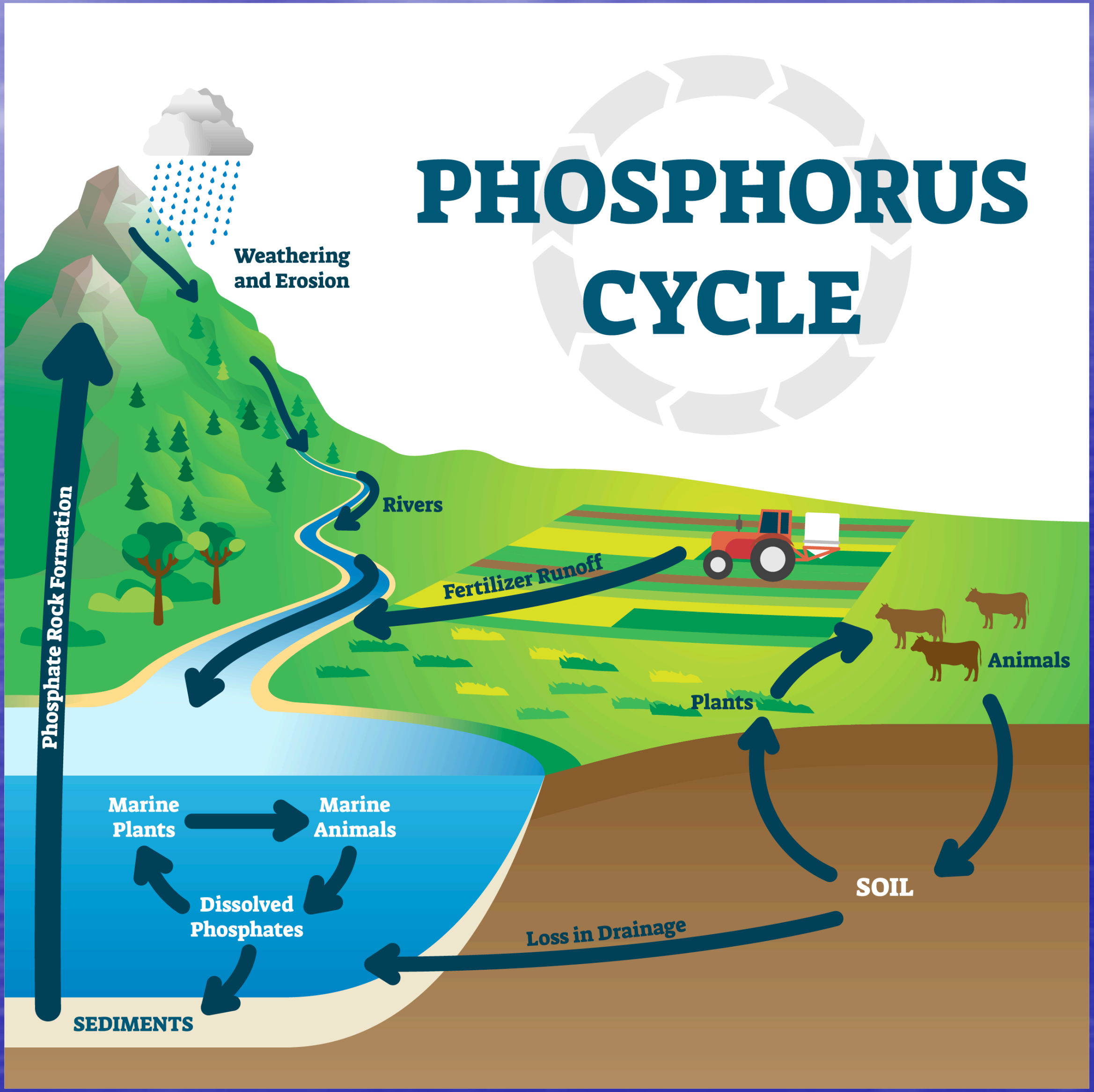
The Phosphorous Cycle

- Long-Term Cycle:
  - overall process can take millions of years
  - The soluble phosphates in the continental rock dissolve over time in water and leach into the rivers and, eventually, the oceans.
  - Through millennia of geological uplift (earthquakes, erosion, etc), the dissolved phosphate is thrust upward and once again becomes part of the land surface.

The Phosphorous Cycle

- Short-Term Cycle:
  - the dissolved phosphates in groundwater can be absorbed by plants and then passed up the food chain when eaten by animals.
  - living organisms use the phosphates to help create energy storage molecules (adenosine triphosphate or ATP)
  - phosphates are then passed back to the ground and re-enter the cycle when these organisms decompose

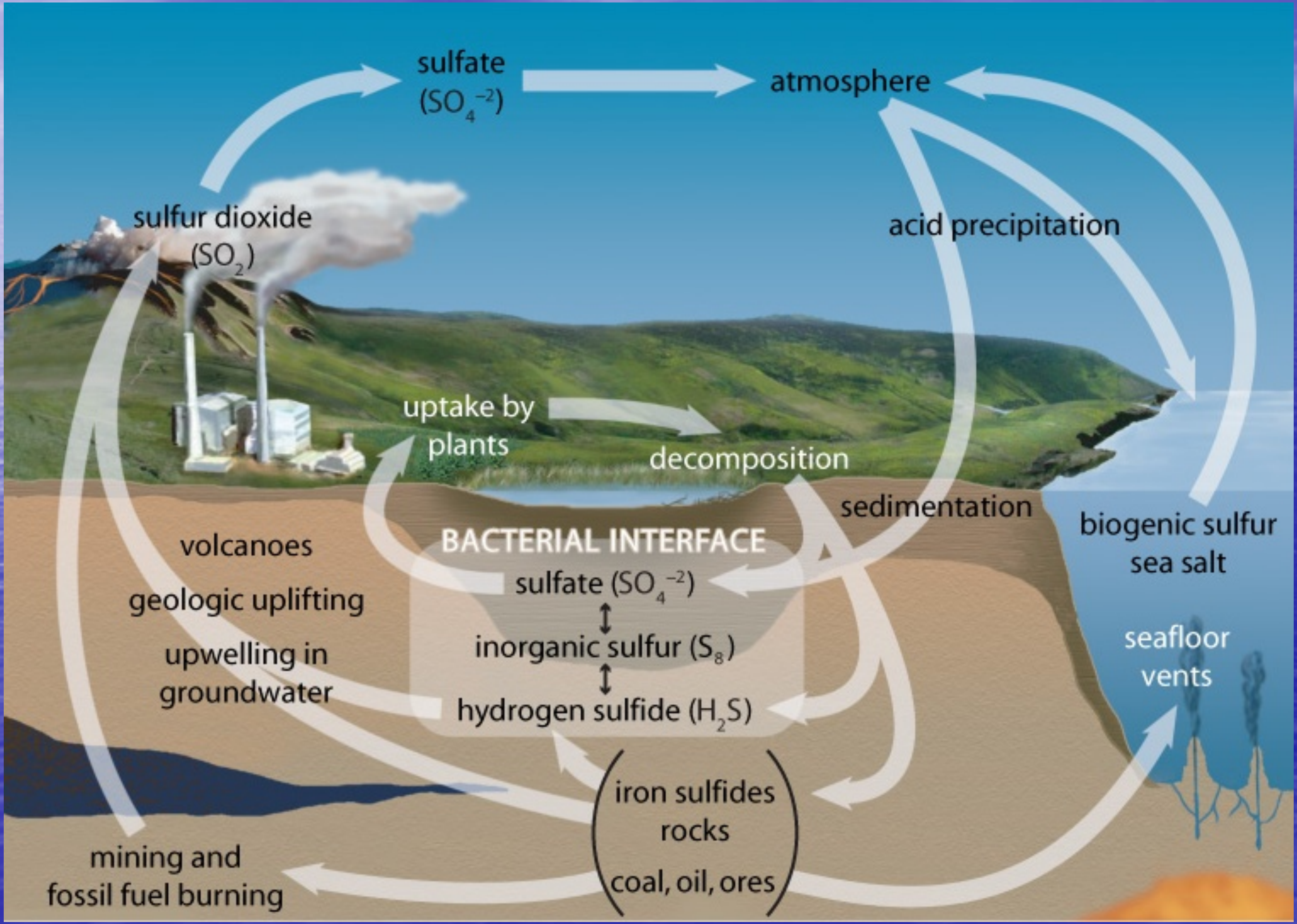
The Phosphorous Cycle



The Sulfur Cycle

- All organisms require sulfur. It is an important part of proteins and vitamins.
- Plants and algae use sulfur in the form of <u>sulfate</u> (SO_4^{2-}) which readily dissolves in water.
- The sulfur is incorporated into their cells and tissues, and moves up the food chain. When organisms die, decomposers quickly return the sulfur to the soil and atmosphere.
- Many bacteria use sulfur compounds in photosynthesis or certain types of cellular respiration
- Bacteria also release sulfur that is in forms that cannot be used by other organisms

Sulfur Cycle



Acid Deposition

- The combustion of fossil fuels that contains sulfur releases sulfur oxides into the atmosphere
- Sulfur dioxide reacts with oxygen and water vapour in the atmosphere to form sulfuric acid and sulfurous acid
- When this acid condenses, it falls as acid precipitation
- The acid can change soil and water pH, making it impossible for organisms to survive

Energy and Matter Transfer

- Remember that energy is involved in each step of these cycles
- As well, water is also a necessary component of these cycles, so the biogeochemical cycles are all linked together through energy and water

2.3 – The Balance of Matter and Energy Exchange

- The amount of sunlight an area receives often determines its productivity
- Productivity rates are often expressed as energy or biomass
- As well, moisture plays a significant role in the productivity of an ecosystem

Balance in the Biosphere

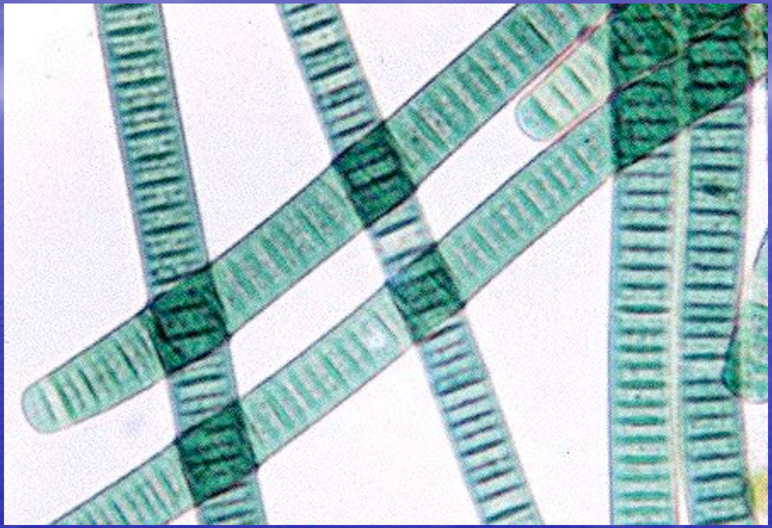
- Inside our own bodies, we maintain homeostasis
- To do this, we must use energy
- In 1979, James Lovelock proposed the Gaia Hypothesis, which is homeostasis on a global level
- In essence, this hypothesis suggests that the Earth is self-regulating

The Gaia Hypothesis and Living Things

- Life itself plays a large role in the balance we see in our biosphere
- The composition of our atmosphere, for instance, would be very different if living things had not modified it through cellular respiration and photosynthesis
- As well, some of the sediments that make up our geological features come from biological sources

The Origin of Life

- Life likely began as single celled bacteria, called cyanobacteria, around 3.5 billion years ago
- Stromatolites are formations of sedimentary rocks that are composed partly of the cellular debris left behind by organisms like cyanobacteria



The Origin of Life

- At some point, cyanobacteria developed the ability to do photosynthesis, converting methane (instead of CO_2) into breathable oxygen (O_2)
- Early stromatolite layers and rock called banded ironstone show that there was large amounts of oxygen trapped in iron oxides
- Later layers indicate that this oxygen was no longer being trapped – it had moved out of the oceans and into the atmosphere

The Origin of Life

- Stromatolites and banded ironstone are NOT fossils. They are sometimes referred to as *trace* fossils, because they are the material evidence left behind that certain life existed.
- As more oxygen was released to the atmosphere, it coincided with a dramatic drop in methane, a greenhouse gas, in the atmosphere.
- This resulted in a runaway cool down effect on Earth, resulting in the first major ice age which covered most of the Earth (called Snowball Earth)
  - also resulted in a probable mass extinction of anaerobic organisms