Lecture Presentation

CHAPTER 3

Basic Needs of Living Things

Lectures by:
Heidi Marcum, Baylor University

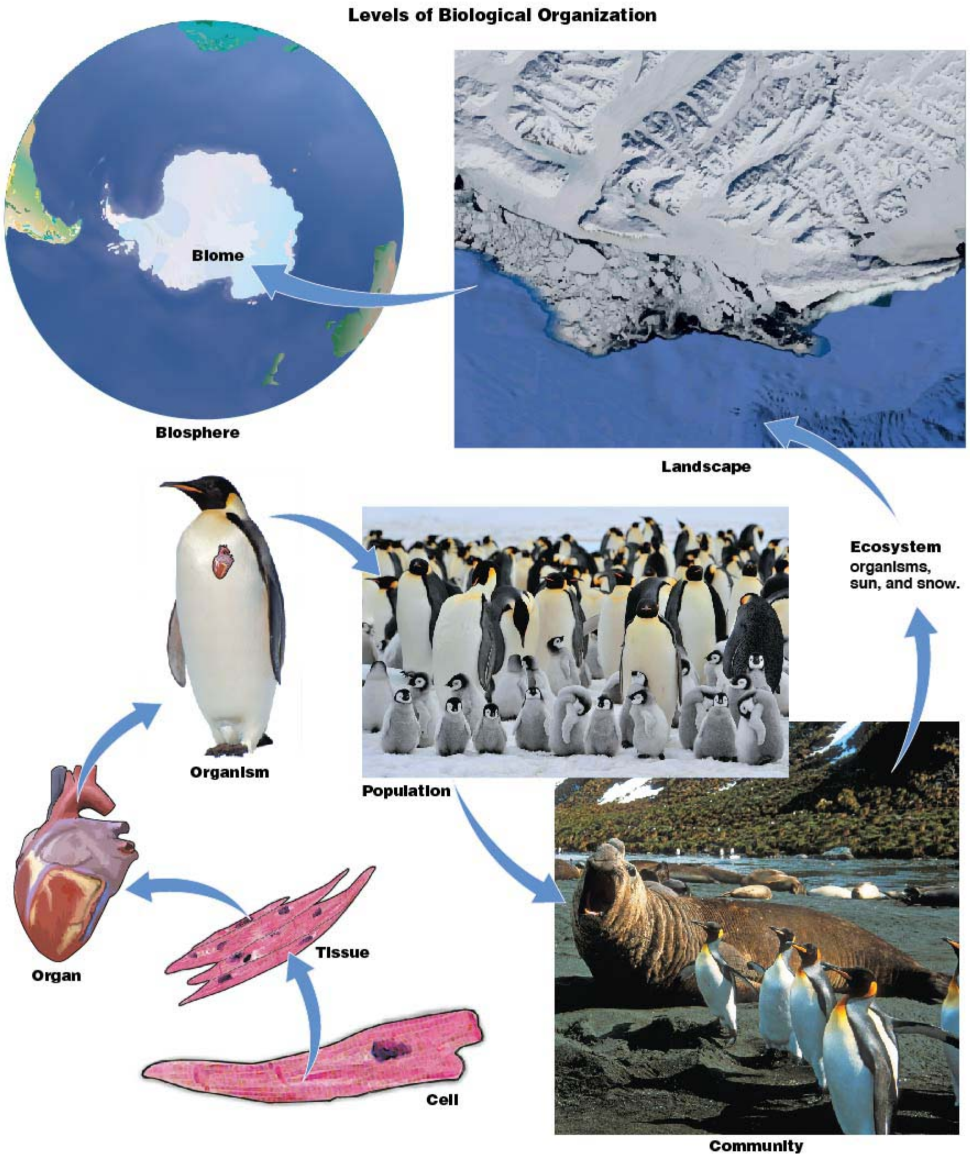
Basic needs of living things

- Emperor penguins are the largest penguins
  - Males incubate the eggs in frigid conditions
  - Females feed in the ocean, then raise the chicks
- Penguins have adaptations to the frigid cold
  - Heavy bones, blubber, dense feathers
  - Constant body temperature, even in the cold
- Overfishing and climate change are threatening penguins
  - But, they may be changing their behavior to adapt to environmental change

What is ecology?

- Species live in a variety of environments
  - Determined by their habitat requirements, evolutionary history, interactions with other species
- **Ecology**: the study of all processes influencing:
  - The distribution and abundance of organisms
  - Interactions between living things and the environment
- Ecology is a hierarchy of studies
  - Operating at different scales and asking different questions
  - How do environmental changes affect living things?

The hierarchy of life



Life consists of a hierarchy of complex systems

What is a species?

- **Species**: a group of individuals that share certain characteristics
  - But are distinct from other groups
- Species are grouped into *genera*
  - Which are grouped into *families*, *orders*, *classes*, *phyla*, *kingdoms*, and *domains*
- The official species name is Latin and has two parts
  - The genus name and species descriptive term

It can be hard to define a species

- All members of a species can interbreed and produce fertile offspring
  - Members of different species generally do not breed
- But what about organisms that do not mate to produce offspring?
  - Scientists use other classification methods
- New species arise due to evolution
  - Species classifications are changed to reflect this

Populations and biotic communities

- **Population:** individuals that make up an interbreeding, reproducing group
  - Only those individuals of a species in an area (e.g., gray wolves in Yellowstone National Park)
  - A species would be all inclusive (e.g., all the gray wolves in the world)
- A **biotic community (biota):** the grouping of populations in an area
  - All vegetation, animals, microscopic organisms
  - It is determined by **abiotic** (nonliving chemical and physical) factors (water, climate, salinity, soil)

Species make up a community

- A community is usually named for its plants
  - They are the most obvious members
  - Vegetation indicates environmental conditions
- Species in a community depend on each other
  - The plant community supports and limits animals
- Populations of different species within a biotic community constantly interact
  - With each other and with the abiotic environment

Communities have predictable vegetation

The vegetation defines the type of habitat other species experience

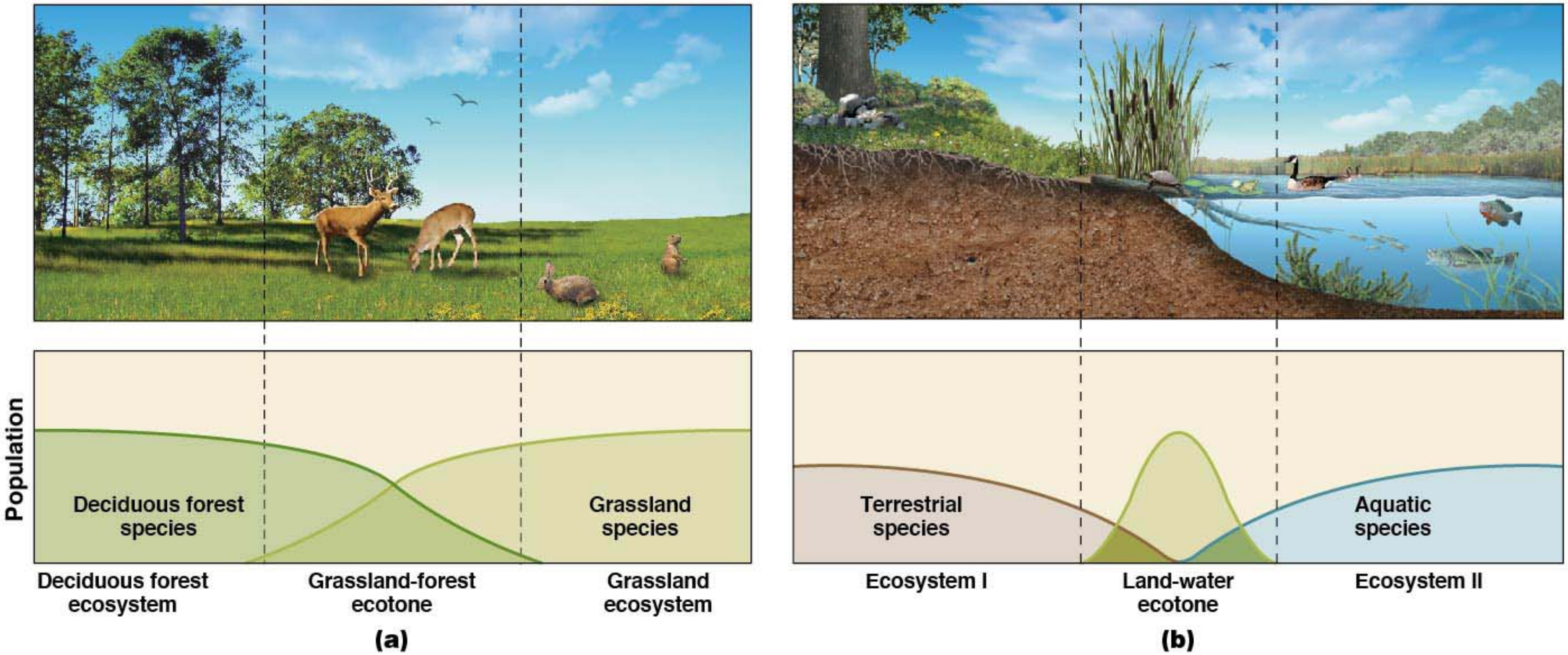
Winter in the forest

In some areas, the vegetation needs a period of freezing for future growth

Ecosystems are made of communities

- **Ecosystem:** an interactive complex of communities and their abiotic environment
  - Forests, grasslands, wetlands, coral reefs, humans
- They lack distinct boundaries and are not isolated
  - Species can occupy multiple ecosystems and move between them
- **Ecotone:** a transitional region between ecosystems
  - Shares species and characteristics of both ecosystems
  - May have more or fewer species than the ecosystems

Ecotones are transitional areas



Ecotones may contain species common to bordering ecosystems, or may create a unique habitat with specialized species

Landscapes and biomes are on a larger scale

- **Landscape:** a cluster of interacting ecosystems
  - **Macrosystems ecology:** studies broad questions across many ecosystems
- **Biome:** a large area with the same climate and vegetation
  - Can be predicted by rainfall and temperature
  - There are no sharp boundaries between biomes
- Aquatic biomes are determined by depth, salinity, and permanence of water
- **Biosphere:** the huge system of all living things

Tools used to study landscape features

Geographic Information Systems (GIS) and remote sensing (images from satellites) are used to study landscape features

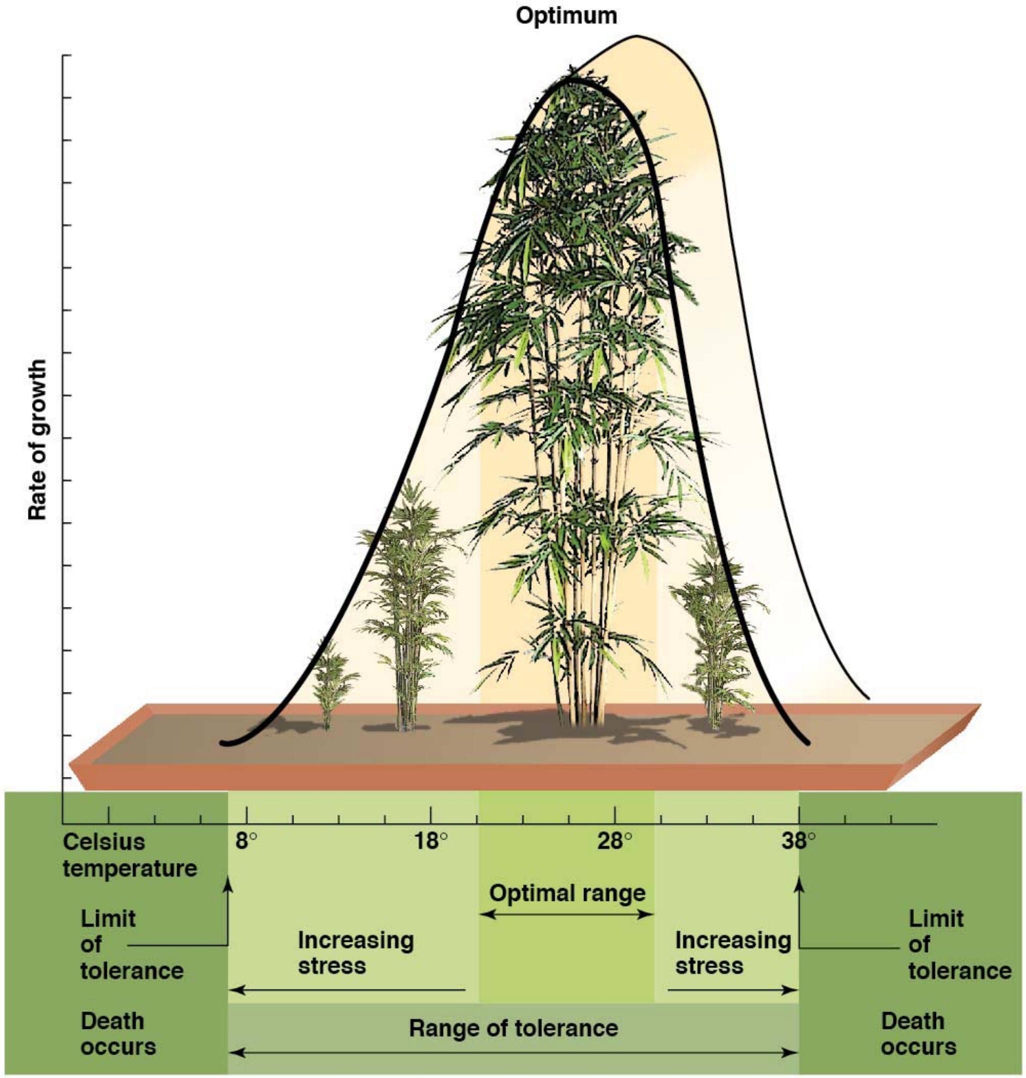
Environmental factors affect organisms

- Physical, chemical, and biological factors (biotic or abiotic) affecting organism survival
- **Condition:** a factor that varies in space and time
  - But, is not used up (temperature, wind, pH, salinity)
- **Resource:** a factor consumed by organisms
  - Water, nutrients, light, oxygen, food, space
- A factor can be both a condition and resource
  - Plants use water as a resource, but ocean water is a condition for many fish, algae, and penguins
- Factors determine if a species occupies an area

Species live within environmental limits

- For every factor there is an *optimal range*
  - A level where organisms grow or survive best
  - Organisms do less well at higher or lower levels
  - They do not survive at extremes
- **Range of tolerance:** the entire span allowing any growth at all
- **Limits of tolerance:** the high and low ends of the range of tolerance
- **Zones of stress:** between the optimal range and high or low limit of tolerance

A survival curve



For every factor influencing growth, reproduction, and survival, there is an optimum level

A fundamental biological principle

- *Every species has an optimum range, zones of stress, and limits of tolerance for every abiotic factor*
  - These characteristics vary among species
  - Some species have a broad range of tolerance
  - Other species have a narrower range
- The range of tolerance for a factor affects an organism's growth, health, survival, reproduction
- The population density of a species is greatest where all conditions are optimal

The law of limiting factors

- **Limiting factor:** any factor that limits growth
  - It may be a problem of *too much* or *too little*
  - It can change over time
- **Law of limiting factors:** any factor outside the optimal range will:
  - Cause stress and limit growth, reproduction, and survival of a population
- **Synergistic effects (synergisms):** factors that interact to cause a greater effect than expected
  - Pollution may increase vulnerability to disease

Habitat vs. niche

- **Habitat:** place where a species is adapted to live
  - It is defined by the plant community and physical environment
  - *Microhabitat*: puddles, rocks, holes in tree trunks
- **Ecological niche:** the sum of all conditions and resources under which a species can live
  - What the animal eats, where it feeds and lives, how it responds to abiotic factors
- Species coexist in a habitat
  - But have separate niches
  - Reducing competition by using different resources

A damselfly’s niche

A damselfly’s niche contains the specific habitat and food needed for its survival and reproduction

Matter is made up of atoms

- Organisms take in matter and energy from the environment to grow and function
- **Matter:** anything that occupies space and has mass
  - All solids, liquids, and gases
  - All living and nonliving things
  - Is composed of atoms
- **Atoms:** the building blocks of all matter
- **Element:** a substance that cannot be broken down into simpler substances

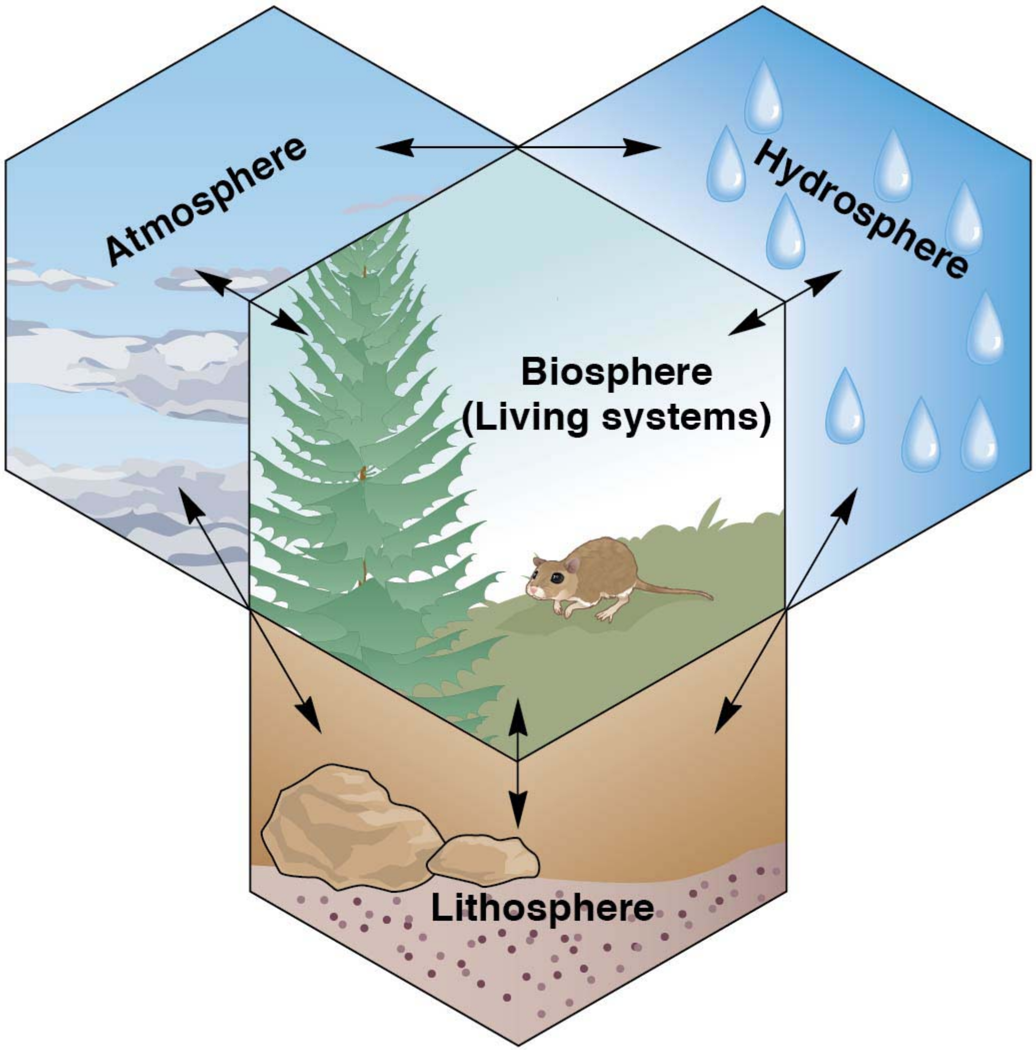
Atoms have even smaller parts

- Atoms are made of protons, neutrons, and electrons
- Chemical reactions rearrange atoms to form different kinds of matter
- **Law of Conservation of Matter:** atoms can be rearranged, but do not change
  - They are not created or destroyed
- Nuclear reactions split atoms
  - This is very rare and is not a chemical reaction

Atoms form molecules and compounds

- **Molecule:** two or more atoms of the same or different kinds that are bonded in a specific way
  - Properties depend on how atoms are bonded
  - Oxygen: O_2
- **Compound:** two or more *different* kinds of atoms
  - Water: H_2O (it is also a molecule)
- The cycle of growth, reproduction, death, and decay is a continuous process
  - Molecules and compounds are used, assembled, and disassembled repeatedly

The environment has four spheres



The biosphere interacts with, and depends on, the three nonliving spheres

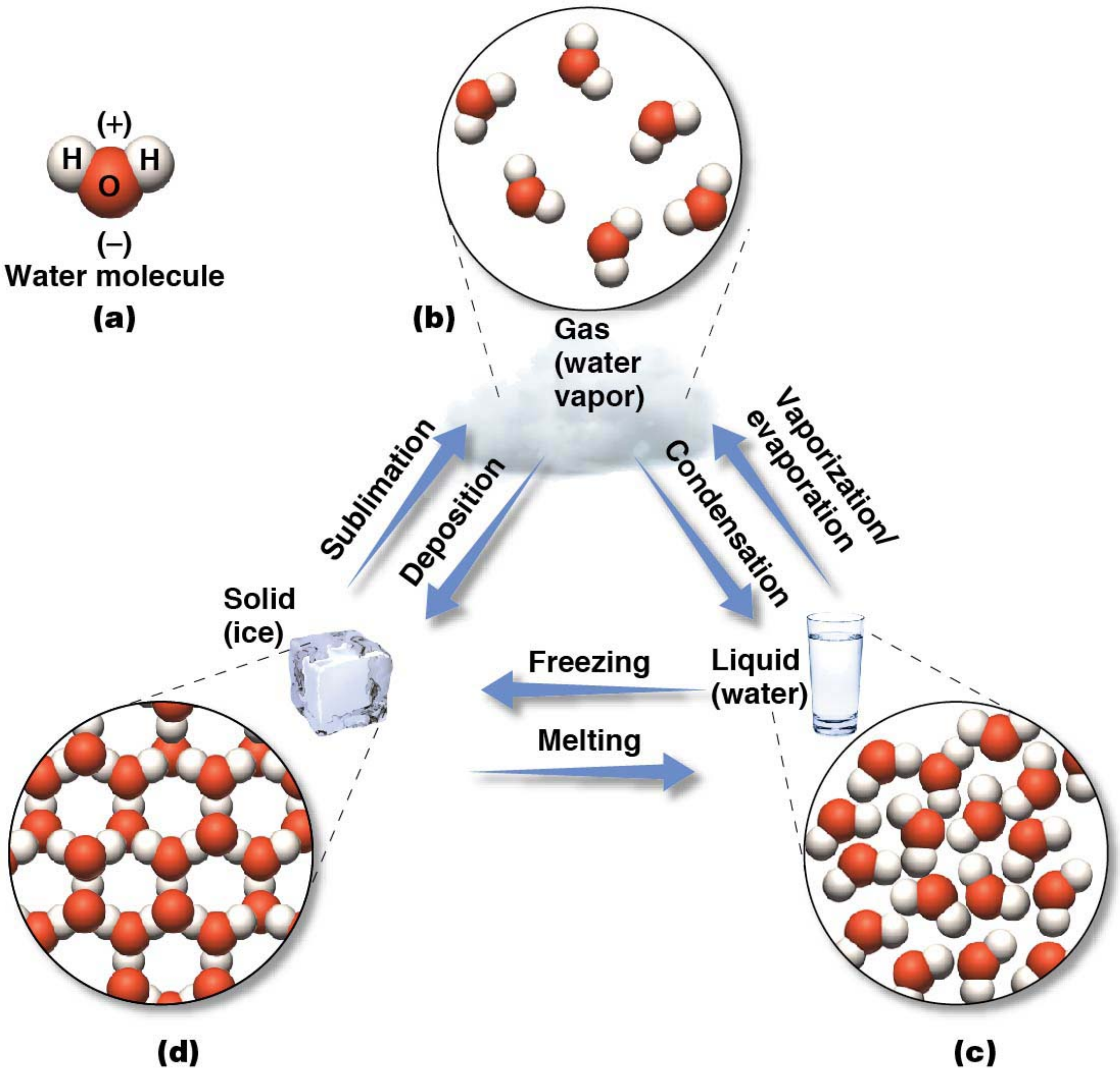
The atmosphere—a mixture of gases

- **Atmosphere:** the thin layer of gases separating Earth from outer space
  - Oxygen (O_2), nitrogen (N_2), carbon dioxide (CO_2)
  - Plus water vapor and other trace gases
- Gases are normally stable
  - But may react chemically to form new compounds
- Plants take in carbon dioxide through leaves
- Animals take in oxygen through special organs
  - Lungs, skin, and so on.

The hydrosphere—source of hydrogen

- All the water in oceans, rivers, ice, groundwater
- *Hydrogen bonding*: a weak attraction that joins two hydrogen atoms to an oxygen atom
- Water comes in different forms:
  - Liquid water is important for living things
  - Below freezing, it is a solid crystal (ice or snow)
  - Above freezing but below vaporization, it is a liquid
- Water usually melts and evaporates
  - *Sublimation*: water goes from solid directly into air
- Changing states needs or releases energy

Water and its three states



Water can occur as water vapor, liquid water, or solid ice

The lithosphere—site of all elements

- All elements are found as rock and soil minerals
- **Mineral:** a naturally occurring solid made by geologic processes
  - A hard, crystalline structure of a given chemical composition
- Rocks: small crystals of two or more minerals
  - Soil: particles of many different minerals
- A mineral’s atoms are bonded by an attraction between positive and negative charges

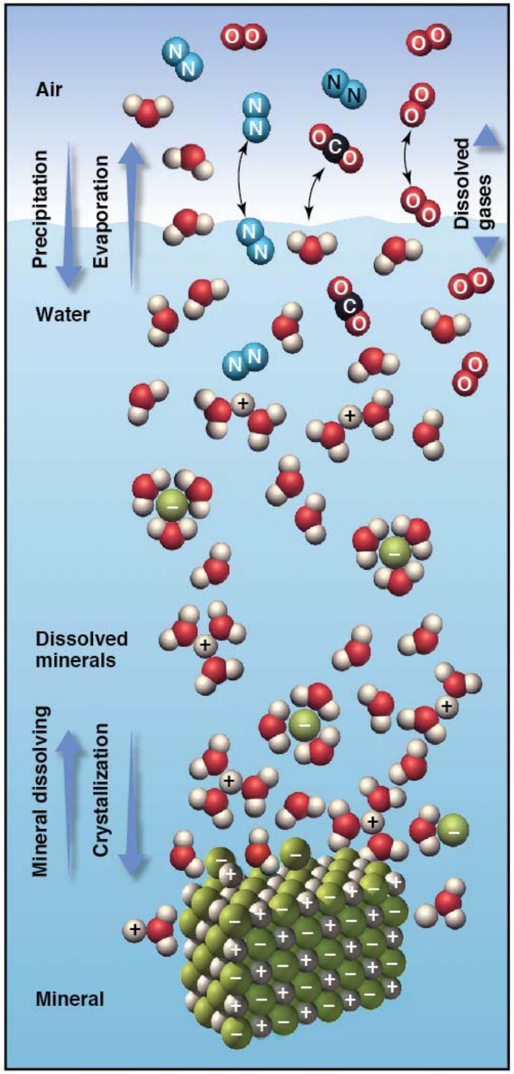
Minerals are made of clusters of atoms

A mineral, such as gypsum, has a predictable pattern of atoms held closely together

Air, water, and minerals interact

- Water is a **solution** containing dissolved gases and minerals
  - Substances can enter or leave water
- Water molecules enter the air through evaporation
  - Water leaves air via condensation or precipitation
  - Air moisture constantly fluctuates
- Wind carries dust or mineral particles
- Living organisms in the biosphere use materials from the other three spheres to build molecules

Interrelationships among the spheres



Minerals, gases, and water can travel among the four spheres

Organic compounds

- An organism is composed of large compounds
  - Proteins, carbohydrates (sugars, starches), lipids (fats), nucleic acids (DNA, RNA)
- These compounds contain six key elements
  - Carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), and sulfur (S)
- **Organic compounds:** chemical compounds making up tissues of living organisms
  - Very large, complex molecules
  - Mainly carbon, hydrogen, and oxygen

Organic vs. inorganic compounds

- **Inorganic compounds:** molecules or compounds lacking carbon–carbon or carbon–hydrogen bonds
  - But, inorganic carbon dioxide contains carbon bond
- But, plastics and other human-made compounds are based on carbon bonding and so are organic
- **Natural organic compounds:** in living organisms
- **Synthetic organic compounds:** human-made
- Elements essential to life (C, H, O, etc.)
  - Are simple molecules in the hydrosphere, lithosphere, and atmosphere
  - Are complex organic compounds in the biosphere

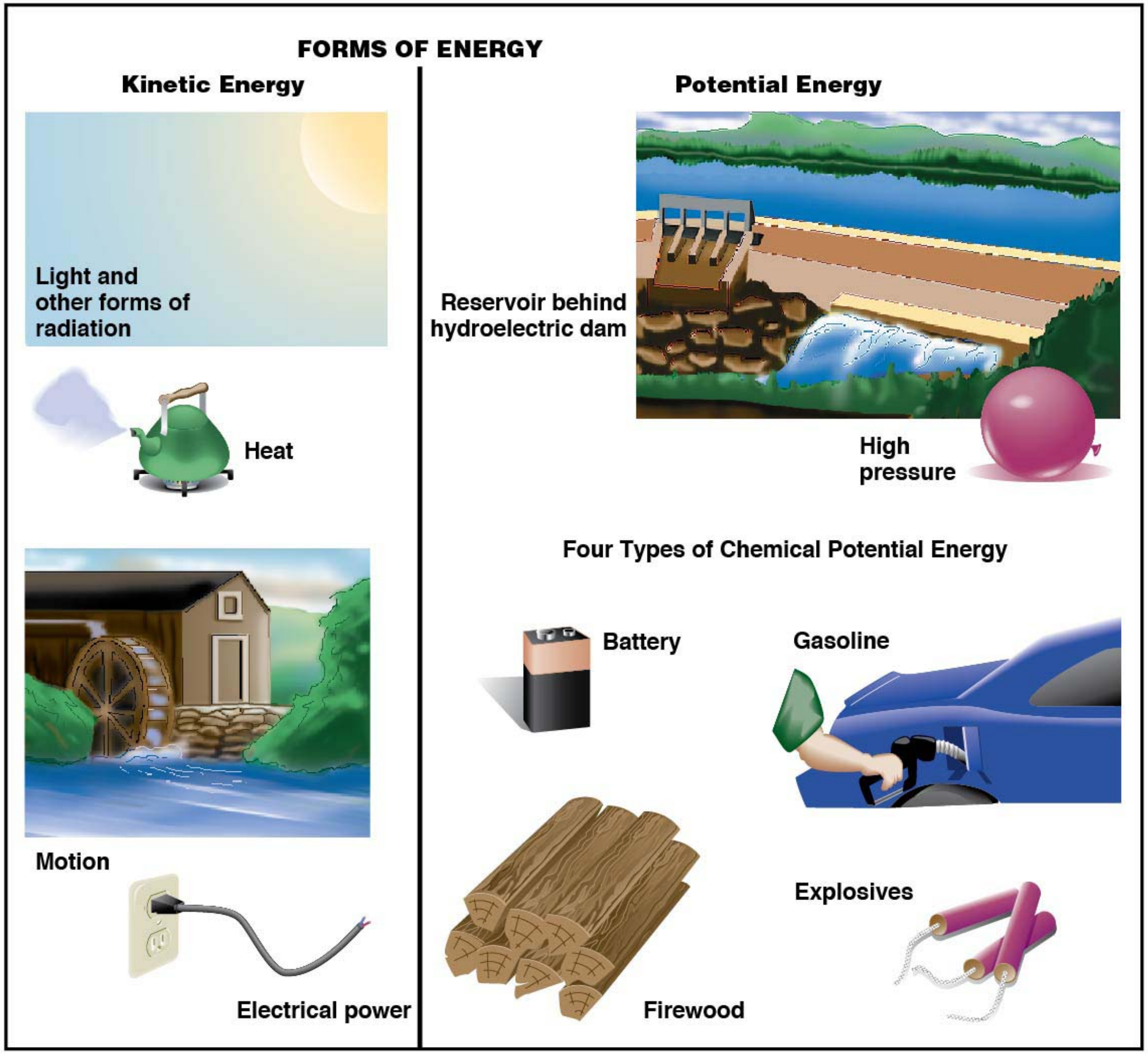
Energy affects matter

- Common forms of energy: light, heat, movement, electricity
  - Do not have mass or occupy space
- Energy changes the *position* or *state* of matter
  - An explosion releases energy that causes matter to move
  - Heating water causes it to boil and change state
- Energy: *the ability to move matter*
  - Changing a substance's state involves movement of atoms or molecules

What are the different types of energy?

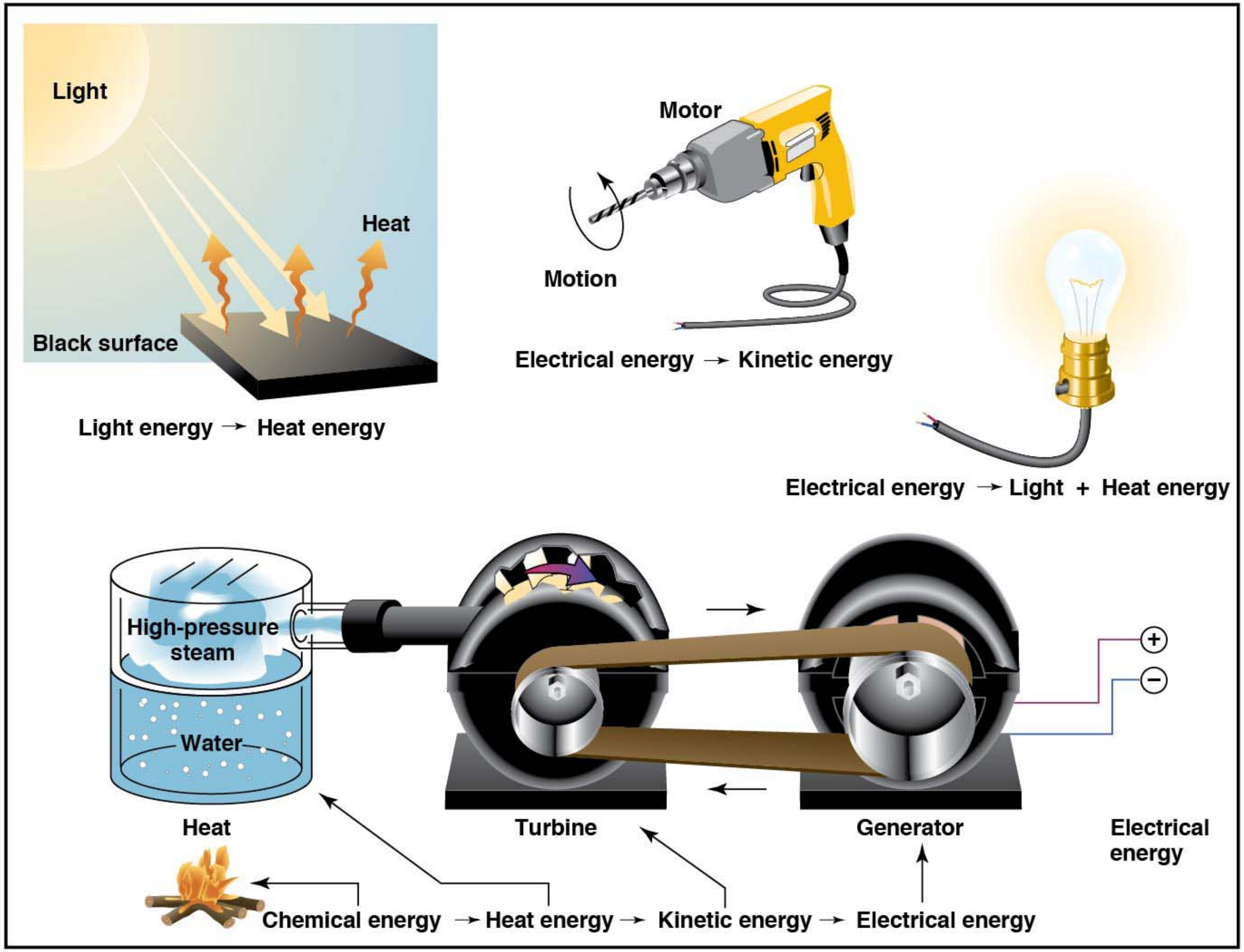
- **Kinetic energy:** energy in action or motion
  - Light, heat, physical motion, electrical current
- **Potential energy:** energy in storage
  - Gasoline, stretched rubber band
- **Chemical energy:** potential energy contained in chemicals and fuels
- Energy can be changed from one form to another
  - Potential to kinetic energy
  - Kinetic to potential energy (e.g., charging a battery, photosynthesis in plants)

Forms of energy



Energy does not have mass or occupy space, but can act on matter

Energy can be transformed



Each time energy is transformed, some is lost as heat

How is energy measured?

- Energy is not measured by weight or volume
- **Calorie:** the amount of heat required to raise the temperature of 1 gram of water 1 degree Celsius
  - 1 kilocalorie (“Calorie”) = 1,000 calories
- *Temperature*: measures the molecular motion in a substance
  - Caused by kinetic energy
- Movement of matter requires energy absorption or release
  - Change in matter and energy cannot be separated

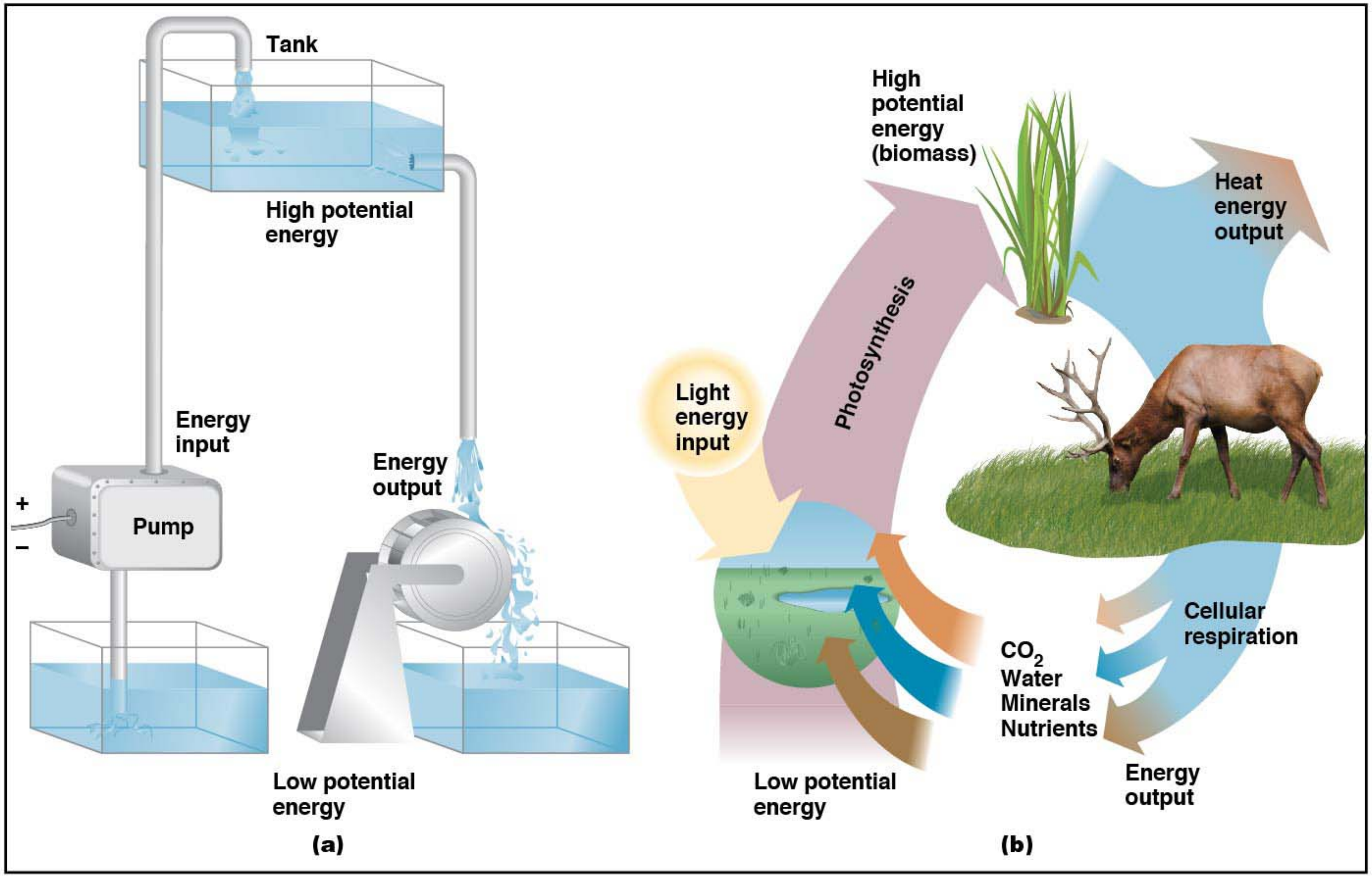
The two Laws of Thermodynamics

- **First Law of Thermodynamics (Law of Conservation of Energy)**
  - *Energy is neither created nor destroyed, but it may be converted from one form to another*
- **Second Law of Thermodynamics:** some usable energy is lost in any energy conversion
- **Entropy:** measures a system's degree of disorder
  - Everything goes to entropy unless energy is put in
  - Increasing disorder releases heat from the system
- To increase potential energy, energy must come from somewhere else

Systems go spontaneously toward increasing entropy

When energy is transformed, the energy lost as heat is less concentrated and less useful

Storage and release of potential energy



Energy put into a system increases potential energy—but energy leaves the system spontaneously

Energy changes in organisms

- Breaking molecular bonds releases energy to do work
- **Oxidation:** a chemical reaction that loses electrons
  - Usually accomplished by the addition of oxygen (which causes *burning*)
- Inorganic compounds have low potential energy
  - So they are nonflammable
- Production of organic material from inorganic material represents a gain in potential energy
  - Breakdown of organic material *releases* energy

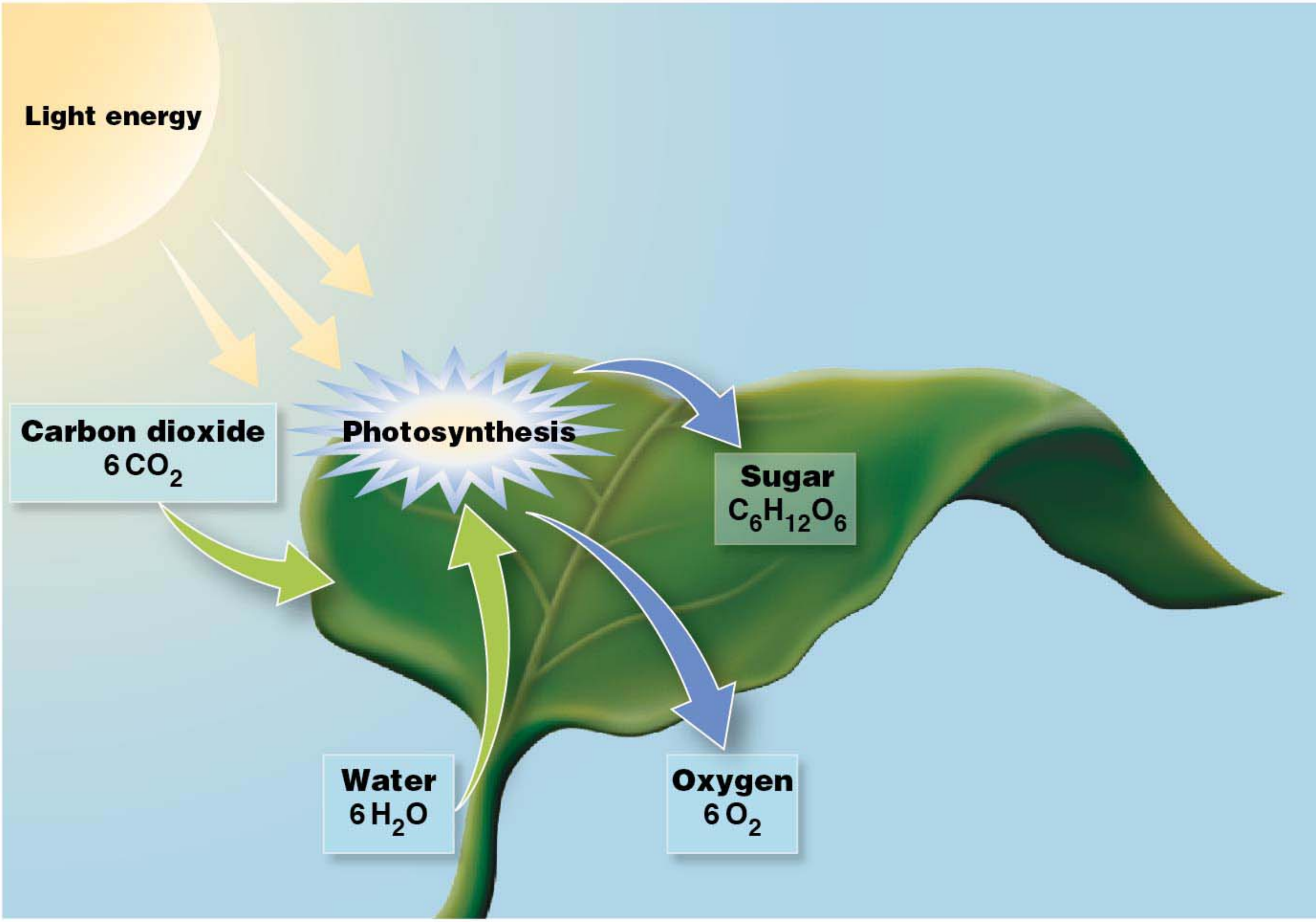
Producers make organic molecules

- **Producers** (plants and algae): convert *low-potential-energy raw materials* (CO_2, H_2O, N, P)
  - *To high-potential-energy organic molecules*
- Chlorophyll in plants absorbs kinetic light energy
  - Which powers the production of organic molecules
- Green plants use the process of photosynthesis to turn carbon dioxide, water, and light energy into:
  - Sugar (glucose—contains stored chemical energy)
  - Oxygen is released as a by-product

$$6\ CO_2 + 12\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

Low potential energy *High potential energy*

Producers as chemical factories



Producers use light energy to make glucose from carbon dioxide and water

What happens within a plant?

- Chlorophyll in plant cells absorbs kinetic energy of light, using it to remove H atoms from water
  - H atoms combine with the C atoms from CO_2 to form a glucose molecule, and release O_2 gas
- Glucose: can make all other organic molecules
  - Provides energy to run cell activities (e.g., growth)
  - Is stored (as starch in potatoes and grains; as oil in seeds) for future use
- Each stage of these reactions uses **enzymes**
  - Proteins that promote the synthesis or breaking of chemical bonds

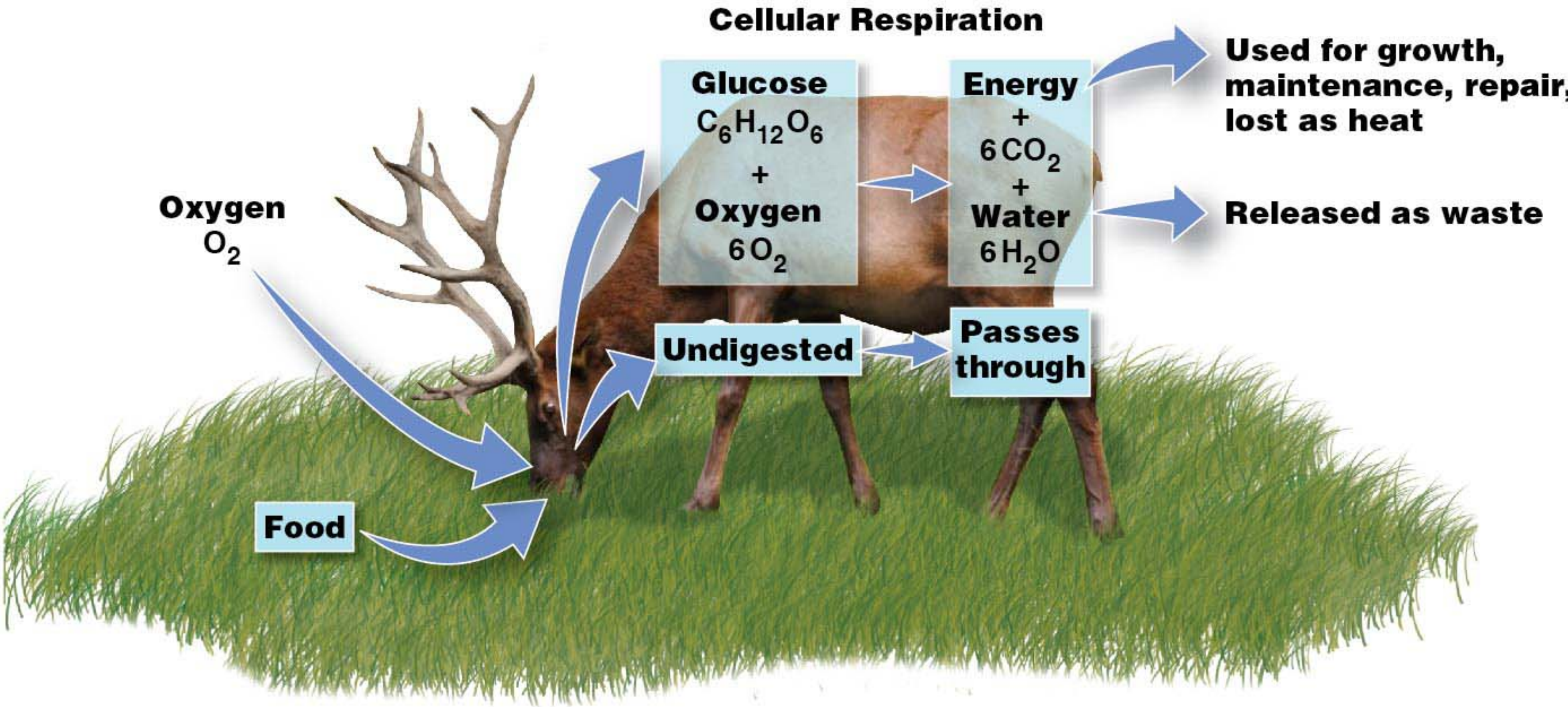
Cellular respiration

- **Cellular respiration:** breaks organic molecules
  - Releasing potential energy for the cell to use
  - Involves the breakdown of glucose
  - Is the reverse of photosynthesis
- Respiration consumes oxygen
  - Oxygen is taken in through lungs and gills
  - Many aquatic plants are oxygen limited

$$C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$$

High potential energy *Low potential energy*

Consumers get their food from others



The energy in the chemical bonds of food is released through cellular respiration (the reverse of photosynthesis)

PLAY Animation: Photosynthesis

Cellular respiration is not 100% efficient

- According to the Second Law of Thermodynamics
  - Cellular respiration is only 40–60% efficient
  - Energy is also released as waste (body) heat
- Consuming more calories than your body needs
  - Converts calories to fat and results in weight gain
- Stored energy can also be released from food without oxygen
  - Anaerobic respiration (fermentation) is less efficient than oxidation
  - Occurs in organisms living in oxygen-limited areas

Energy flow is a one-way street

- Most solar energy entering Earth is absorbed
  - Heats the atmosphere, oceans, and land
  - 2–5% is passed through plants to consumers
- All energy eventually escapes as heat
  - Entropy is increased and all energy is degraded
  - Energy is eventually re-radiated into space
- *Energy flows in a one-way direction through ecosystems*
  - It is resupplied by sunlight

The cycling of matter in ecosystems

- Since atoms cannot be created or destroyed (Law of Conservation of Matter):
  - Recycling is the only way to maintain a dynamic system
- Four key elements are heavily affected by humans
  - Carbon, phosphorus, nitrogen, sulfur
- *These nutrients are recycled and continually reused through **biogeochemical cycles***
  - Some processes occur rapidly (photosynthesis, respiration)
  - Some processes take hundreds of millions of years (coal formation)

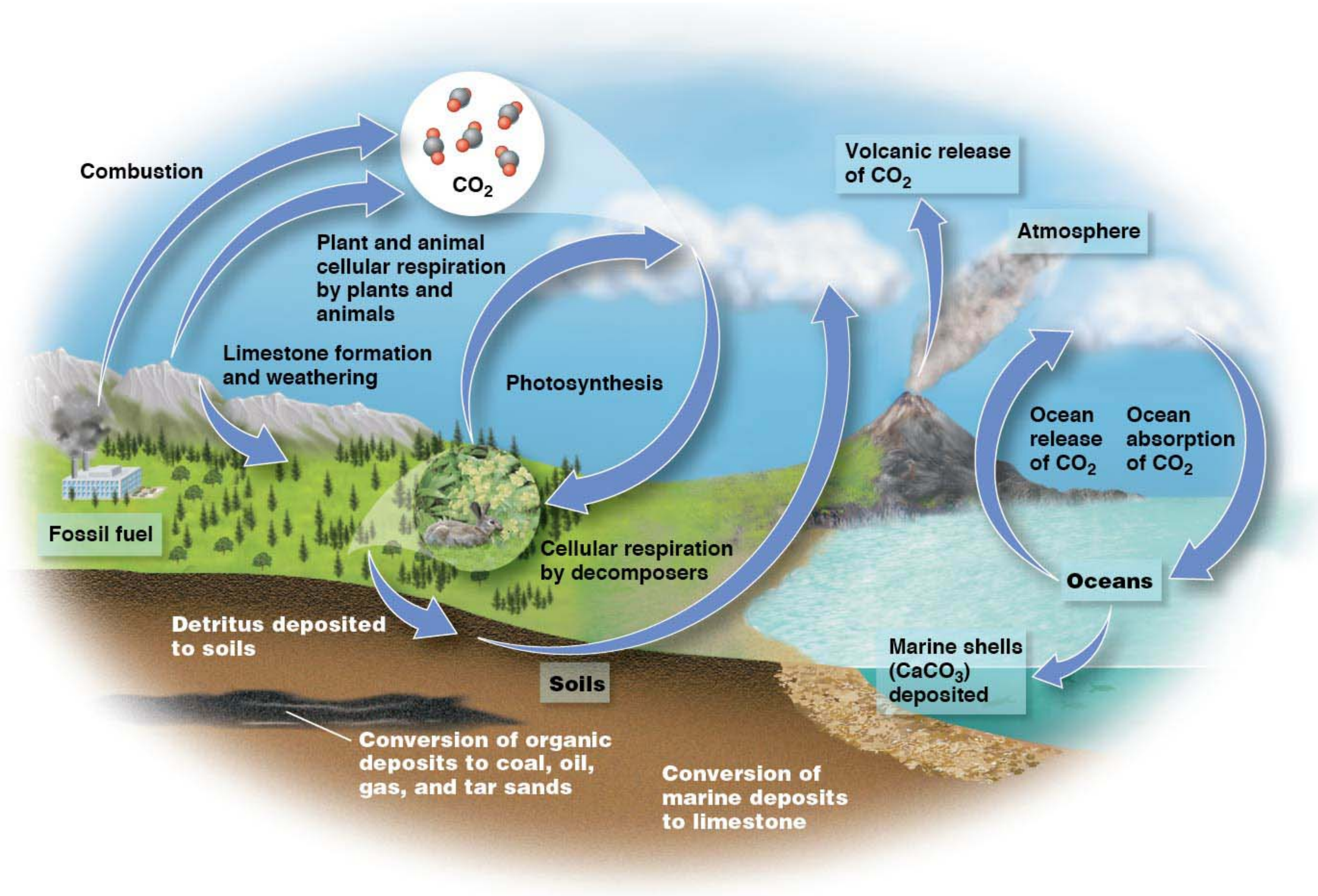
The carbon cycle

- Starts with the reservoir of carbon dioxide in air
  - Through photosynthesis, CO_2 atoms become organic molecules in organisms
- Plants and animals respire carbon into the air
  - Or carbon is deposited in soil (a large reservoir) as **detritis** (dead organisms)
- Photosynthesis in oceans moves CO_2 from seawater into organisms
  - Respiration returns inorganic carbon to seawater

Other ways to transfer carbon

- Diffusion exchange between the air and oceans
- Combustion of fossil fuels releases CO_2 into the air
- Fossilization of dead plants and animals into coal
  - Moves CO_2 from the atmosphere to underground
  - Burning coal and oil releases CO_2 into the air
- Limestone keeps carbon out of circulation
  - Weathering of exposed limestone releases carbon
- A carbon atom cycles through the system about every five or six years

The global carbon cycle



Boxes show pools of carbon, and the arrows show the movement of carbon between pools

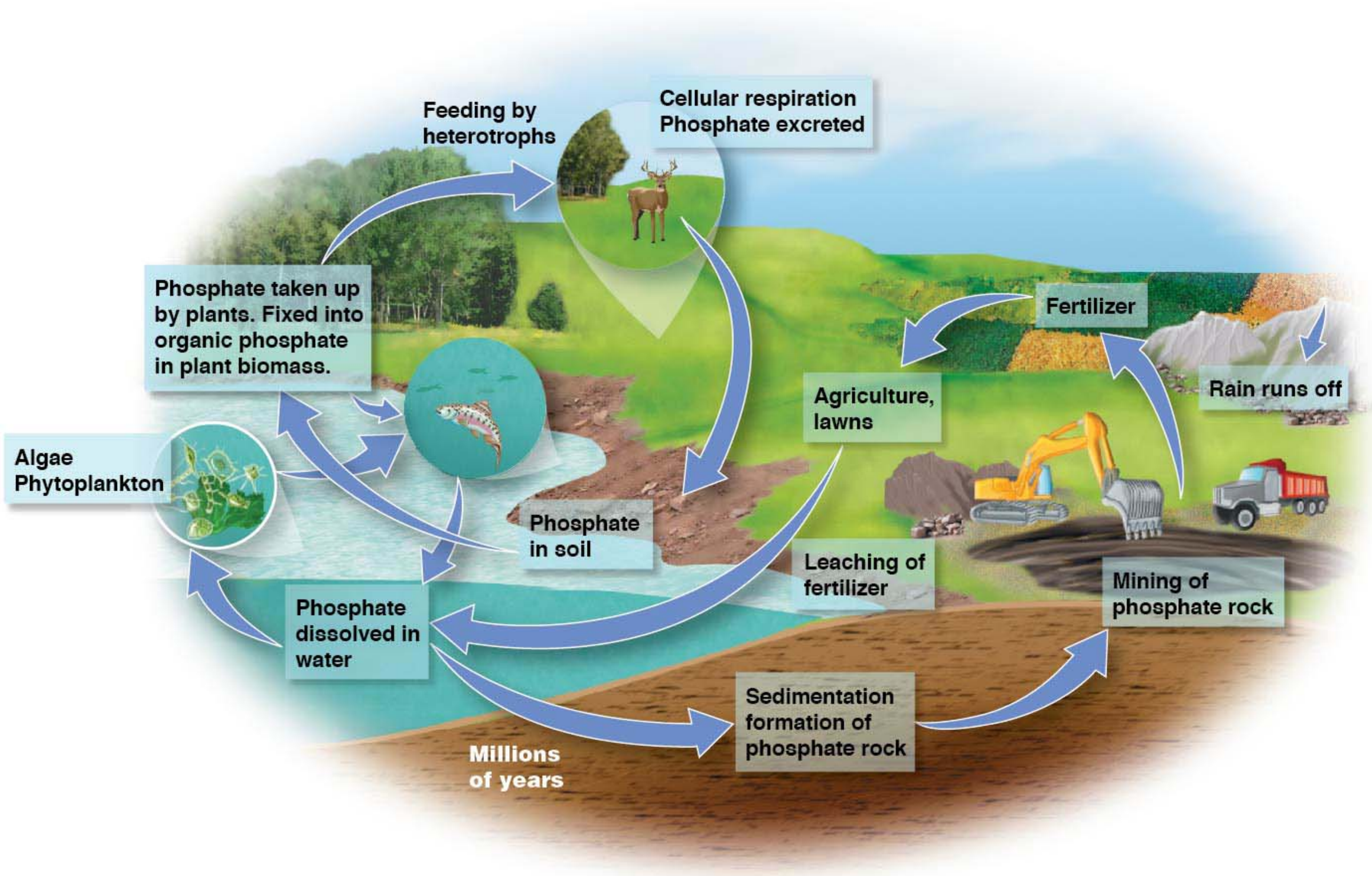
Human impacts on the carbon cycle

- Human intrusion into the cycle is significant
- We are diverting or removing 40% of the photosynthetic productivity of land plants
- Burning fossil fuels has increased atmospheric CO_2 by 35% over preindustrial levels
- Deforestation and soil degradation release significant amounts of CO_2 into the atmosphere
  - Recent reforestation and changed agricultural practices have improved this somewhat

The phosphorus cycle

- Mineral elements originate in rock and soil minerals
  - A shortage of phosphorus is a limiting factor
  - Excessive phosphorus can stimulate algal growth
- As rock breaks down, phosphate is released
- **Organic phosphate:** incorporated into organic compounds by plants from soil or water
  - Cycles through the food chain
  - Broken down by cellular respiration or decomposers
- Enters into chemical reactions with other substances (iron, aluminum, calcium)

The global phosphorus cycle



This cycle is not connected to the atmosphere, which limits biosphere recycling

Human impacts on the phosphorus cycle

- Phosphorus is mined and made into fertilizers, animal feeds, detergents, etc.
  - The most serious intrusion comes from fertilizers
- When added to soil, it can stimulate production
- Human applications have tripled the amount reaching the oceans, accelerating the cycle
  - Phosphorus can't be returned to the soil
- Excess phosphorus in water causes severe pollution (eutrophication)
  - Can cause overgrowth of algae, and kill fish

The nitrogen cycle

- Nitrogen is in high demand by aquatic and land plants
- Is a unique cycle
  - Bacteria in soils, water, and sediments perform many steps of the cycle
- Air is the main reservoir of nitrogen (gas: N_2)
  - **Nonreactive nitrogen:** most organisms cannot use it
- **Reactive nitrogen (Nr):** forms of nitrogen that can be used by organisms in chemical reactions
  - The supply of Nr in most ecosystems is quite limited

Land plants take up nitrogen

- Land plants ("non-N-fixing producers") take up Nr as ammonium (NO_4^+) or nitrate (NO_3^-) ions
  - They incorporate them into proteins and nucleic acids
  - The nitrogen moves through the food chain to decomposers, releasing nitrogen wastes (NO_4^+)
- Soil bacteria (*nitrifying bacteria*) oxidizes ammonium to nitrate to obtain energy
  - Nitrate is available for plant uptake
- Bacteria and cyanobacteria can use nonreactive N through biological **nitrogen fixation**

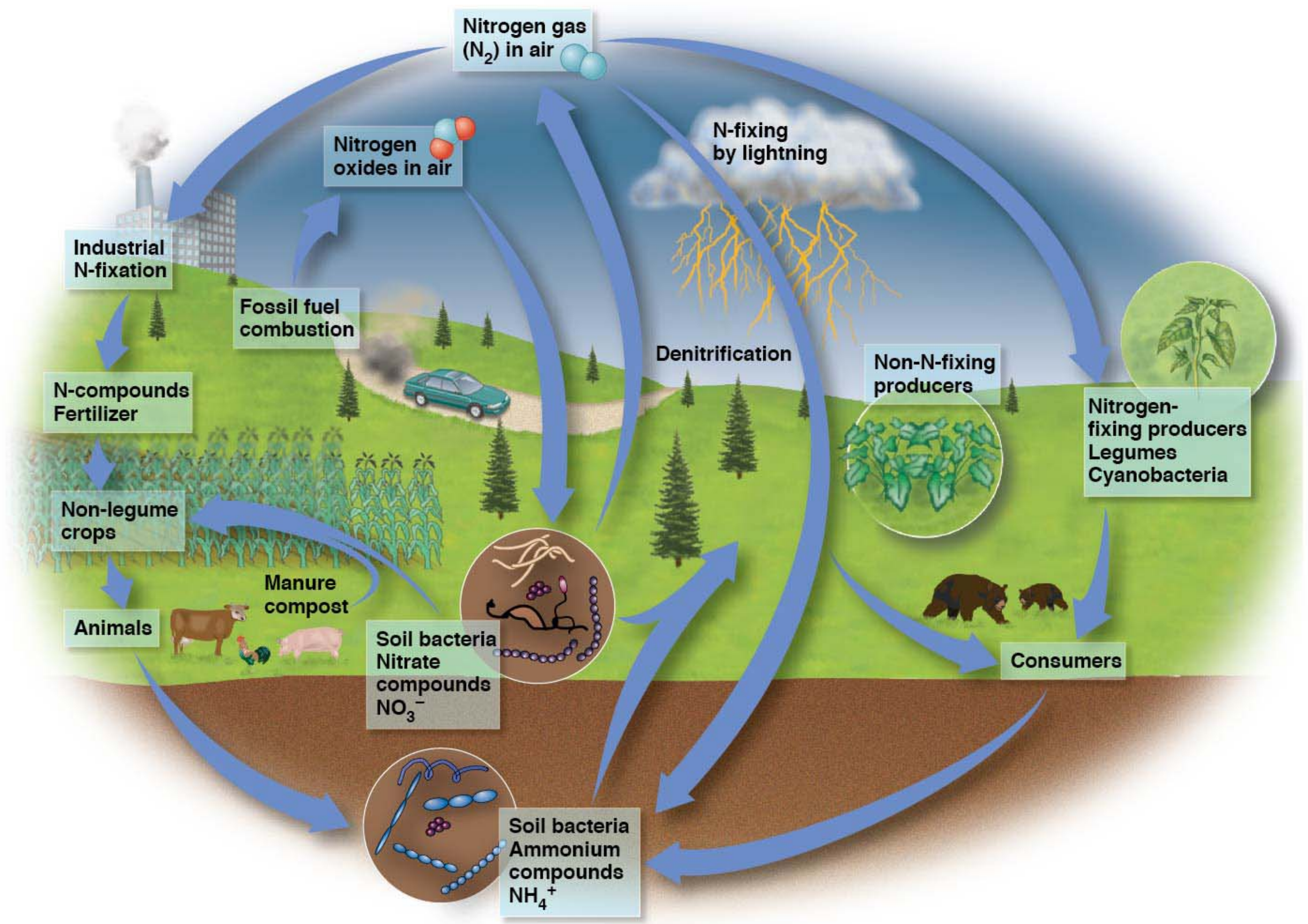
There are several methods of nitrogen fixation

- Nitrogen-fixing microbes live in legume root nodules
  - The legume provides the bacteria a home and food
  - The legume receives a source of nitrogen in return
  - Nitrogen enters the food web from the legumes
- Three other processes “fix” nitrogen
  - *Atmospheric nitrogen fixation*: lightning
  - *Industrial fixation*: in fertilizer manufacturing
  - *Combustion of fossil fuels*: oxidizes nitrogen
- Industrial fixation and fossil fuels
  - Release nitrogen oxides, which are converted to nitric acid (acid precipitation)

Denitrification returns N to the air

- A microbial process in oxygen-poor soils and sediments
  - Microbes use nitrate as a substitute for oxygen
- Nitrogen is reduced (it gains electrons) to nitrogen gas
  - Released into the atmosphere
- Also occurs in sewage treatment systems to remove N from wastewater

The global nitrogen cycle



Like phosphorus, nitrogen is often a limiting factor. Its cycle involves different groups of bacteria.

Human impacts on the nitrogen cycle

- Humans significantly affect the nitrogen cycle
- Many crops are legumes and draw N from the air
  - Peas, beans, soybeans, alfalfa
  - Increases the rate of nitrogen fixation on land
- Nonleguminous crops are heavily fertilized with nitrogen from industrial fixation
  - Corn, wheat, potatoes
- Burning fossil fuels fixes nitrogen from the air
- *We are more than doubling the rate of nitrogen moving from air to land*

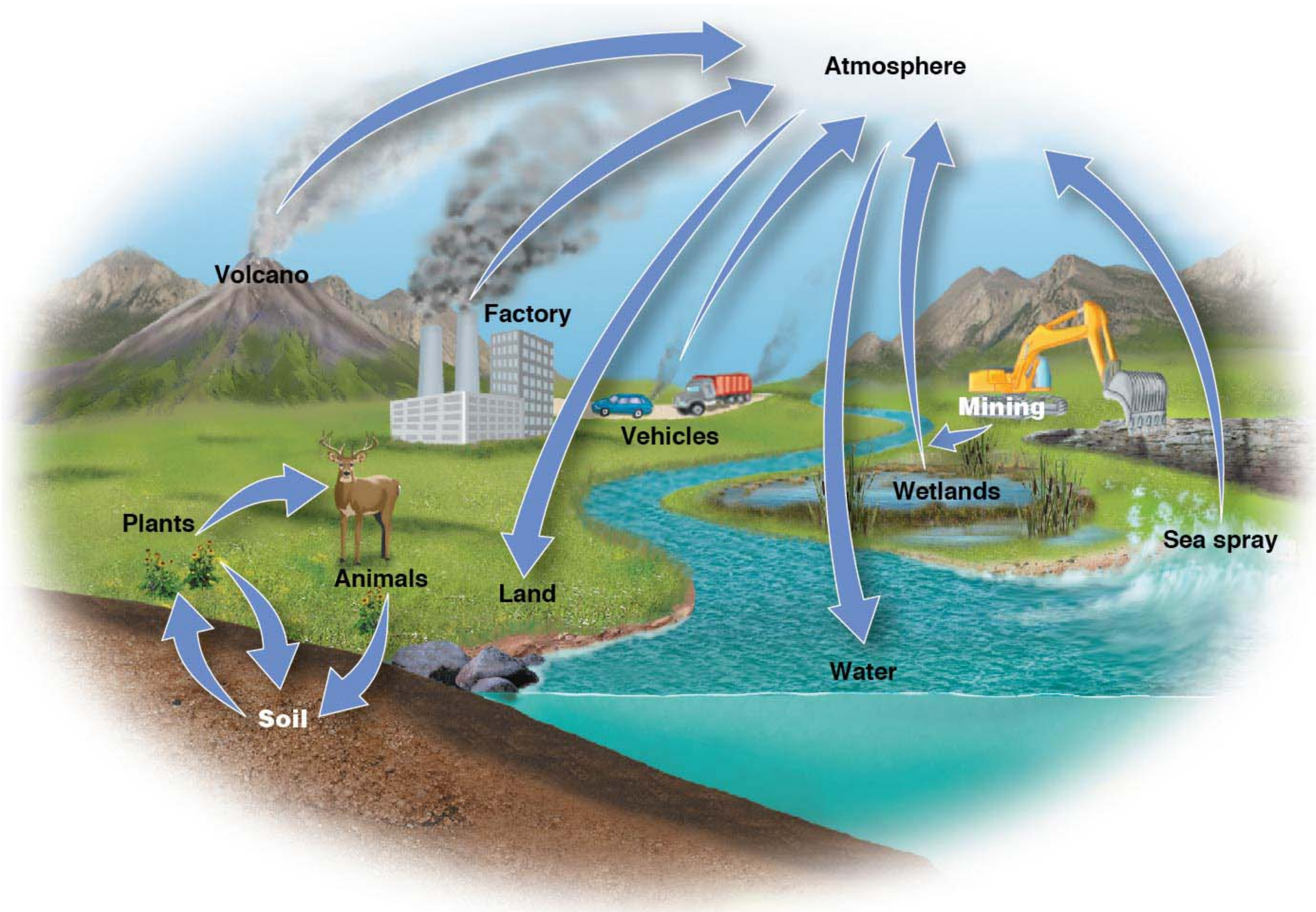
Serious consequences of fertilization

- Nitric acid has destroyed lakes, ponds, and forests
- Nitric (and sulfuric) acid damages lakes and forests
- Atmospheric nitrogen adds to ozone pollution, climate change, and stratospheric ozone depletion
- In many areas, organisms cannot use excess N
  - It is released into the soil
  - Washed into water, it leads to eutrophication of estuaries and coastal ocean areas
- **Nitrogen cascade:** the ecological effects and problems as Nr moves through the environment

The sulfur cycle

- Sulfur is a part of proteins, hormones, vitamins
- It is often linked with oxygen (e.g., sulfate—SO_4)
- Most sulfur is in rocks, minerals, ocean sediments
- Sulfur enters the air or soil by:
  - Weathering of rocks, volcanic activity, fossil fuel burning, processing of metals
- Plants and microbes take up soil sulfate
- In air, sulfur dioxide (SO_2) forms acid rain
- Sulfur enters water bodies from air or rock weathering and can be a serious pollutant

The global sulfur cycle



Sulfur spends little time in the atmosphere

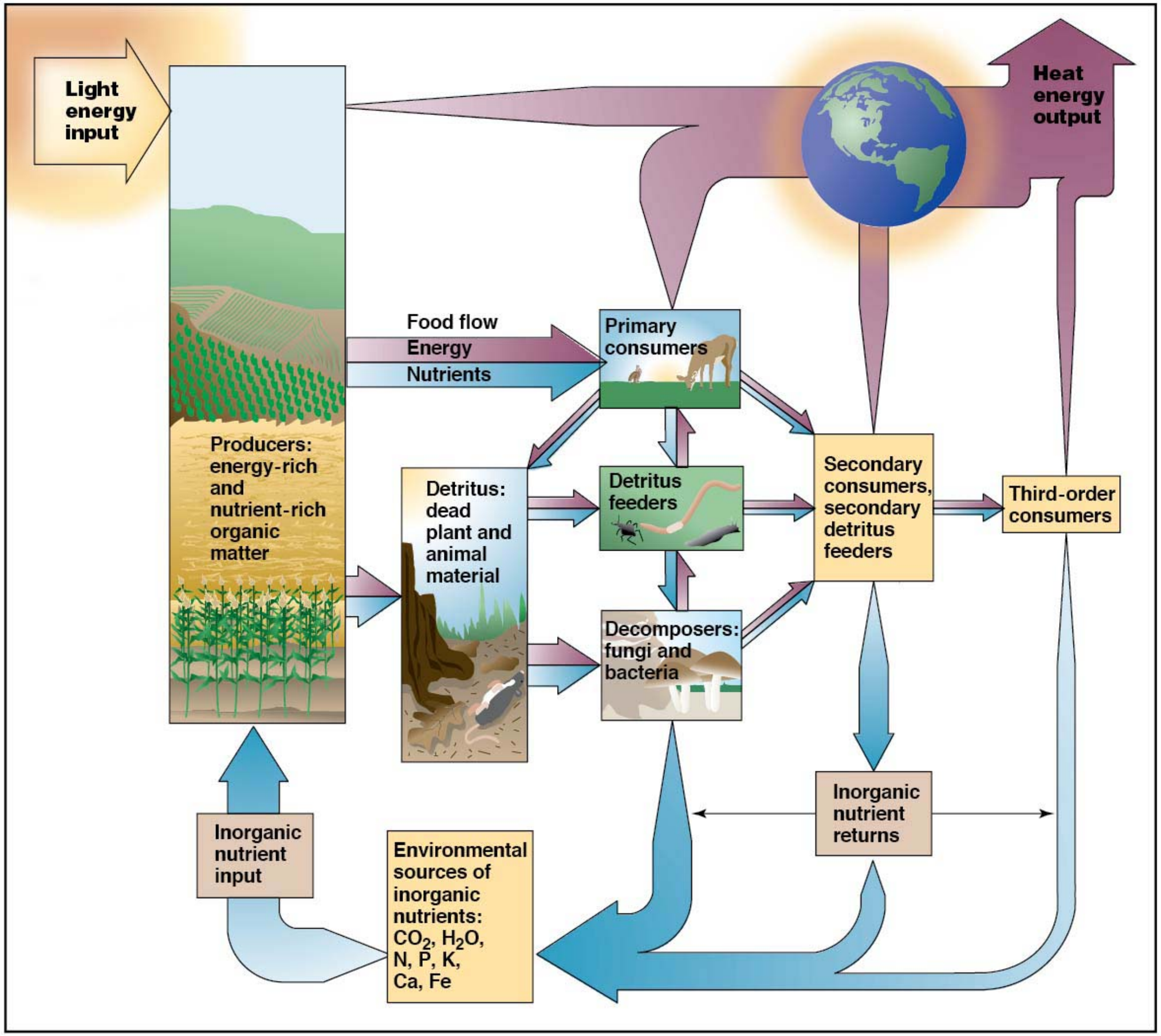
Human impacts on the sulfur cycle

- Acid rain and water pollution are major effects
  - Sulfur is not usually added to soil (as fertilizer)
  - Sulfur in the Everglades is 60 times higher than normal
- Sulfur aerosols (small particles or drops) temporarily cool the atmosphere
  - But cause other problems when they fall to Earth

Comparing the cycles

- Carbon is mainly found in the atmosphere
  - Directly taken in by plants
  - It is rarely a limiting factor in plant growth
- Nitrogen and phosphorus are limiting factors
- Humans have sped up all four cycles
  - Acid rain, greenhouse gases, eutrophication
- Other cycles exist for other elements (e.g., water)
  - All go on simultaneously
  - All come together in tissues of living things

Nutrient cycles and energy flow



Nutrients and energy move through ecosystems