ENVIRONMENT

THE SCIENCE BEHIND THE STORIES

Jay Withgott • Scott Brennan

Ch 20

Conventional Energy Alternatives

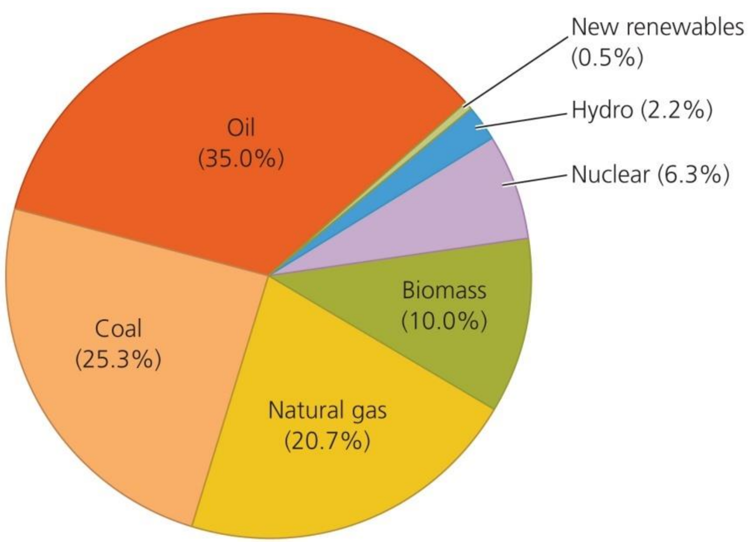
Part 2: Environmental Issues and the Search for Solutions

PowerPoint® Slides prepared by
Jay Withgott and Heidi Marcum

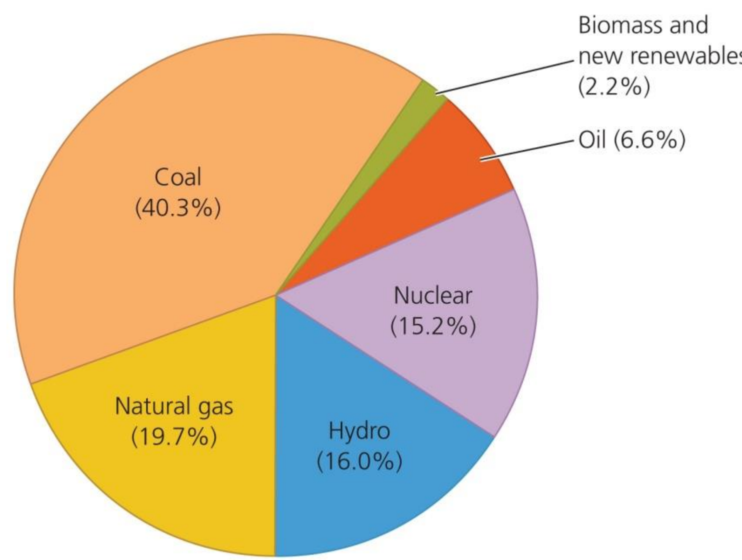
Third Edition

Alternatives to Fossil Fuels

- 80% of our energy comes from oil, coal, and natural gas
  - These three fuels also power two-thirds of the world's electricity generation
- Given fossil fuel's substantial drawbacks, many people believe we need to shift to using less easily depleted and environmentally gentler fuels



(a) World energy production, by source



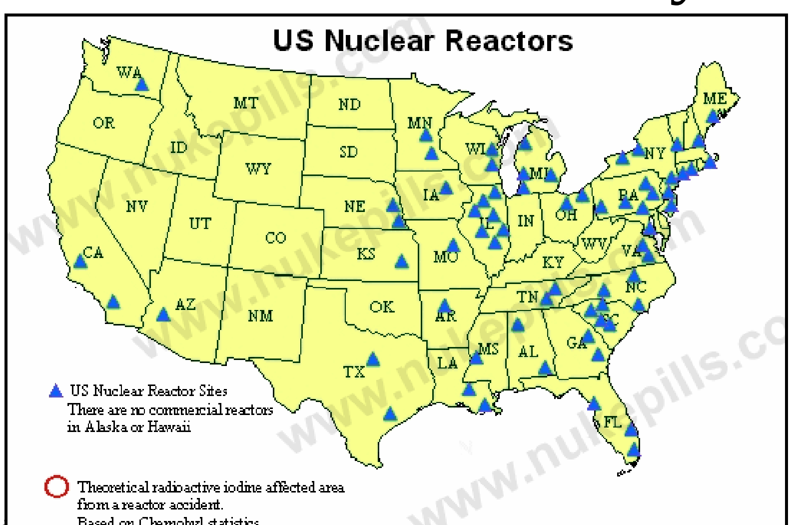
(b) World electricity generation, by source

Conventional alternatives

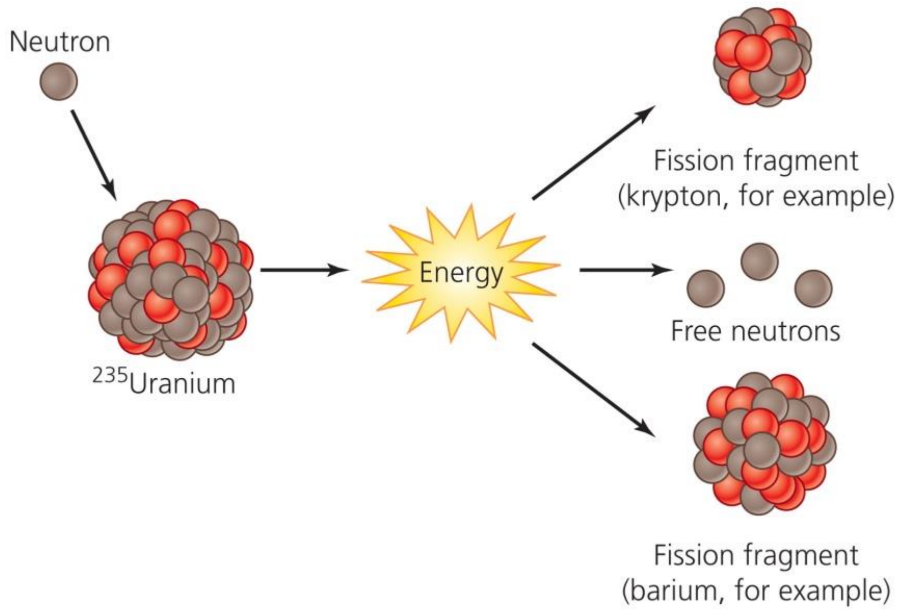
- Three alternative energy sources are currently the most developed and most widely used: nuclear energy, hydroelectric power, and energy from biomass
- These are all “conventional alternatives” to fossil fuels
  - They exert less environmental impact
  - Each has benefits and drawbacks
  - These are best viewed as intermediates along a continuum of renewability
- Fuel-wood and other biomass sources provide 10% of the world’s energy, nuclear power provides 6.3%, and hydropower provides 2.2%
- Nuclear energy and hydropower each account for nearly one-sixth of the world’s electricity generation

Nuclear Power

- Public safety concerns and the costs of addressing them have constrained the development and spread of nuclear power in the United States, Sweden, and many other nations
- The U.S. generates the most electricity from nuclear power, followed by France and Japan
  - 20% of U.S. electricity comes from nuclear sources
- France receives 76% of its electricity from nuclear power

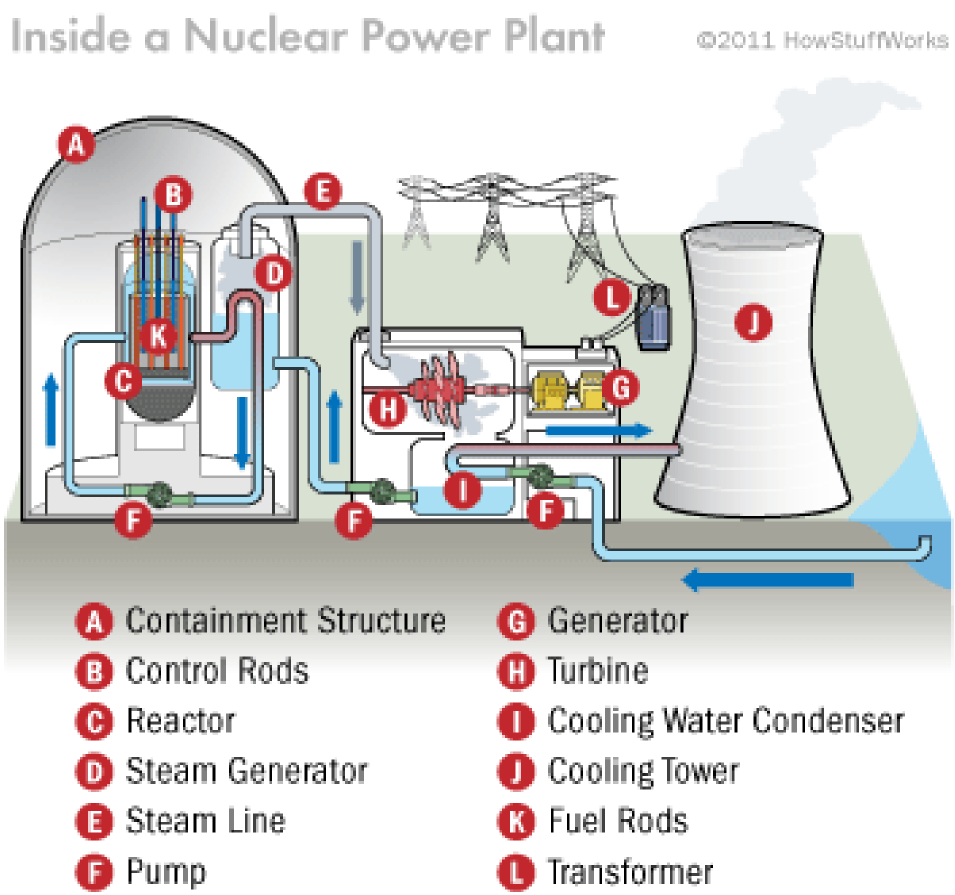


Fission releases nuclear energy



- **Nuclear energy =** the energy that holds together protons and neutrons within the nucleus of an atom
  - The reaction that drives the release of nuclear energy in power plants is **nuclear fission** = the splitting apart of atomic nuclei

Nuclear energy comes from uranium

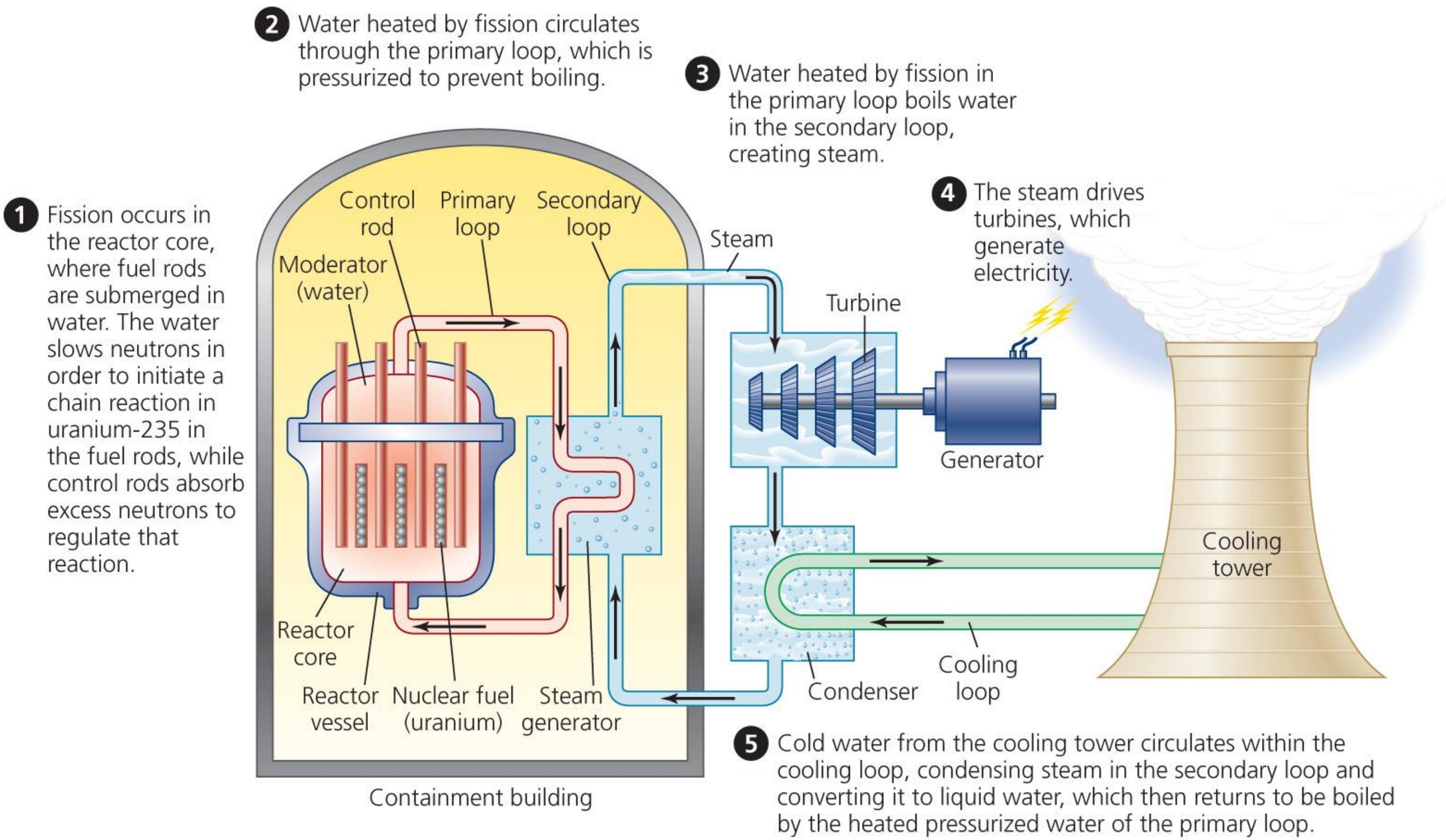


- **Nuclear reactors** = facilities within nuclear power plants
- **Nuclear fuel cycle =** the process when naturally occurring uranium is mined from underground deposits
- **Radioisotopes** = emit subatomic particles and high-energy radiation as they decay into lighter radioisotopes, ultimately becoming stable isotopes
- Most spent fuel is disposed of as radioactive waste

Fission in reactors generates electricity

- For fission to begin in a nuclear reactor, the neutrons bombarding uranium are slowed down with a substance called a **moderator**
- **Control rods** = made of a metallic alloy that absorbs neutrons, and are placed into the reactor among the water-bathed fuel rods
- Containment buildings are constructed to prevent leaks of radioactivity due to accidents or natural catastrophes such as earthquakes
- Not all nations require containment buildings…

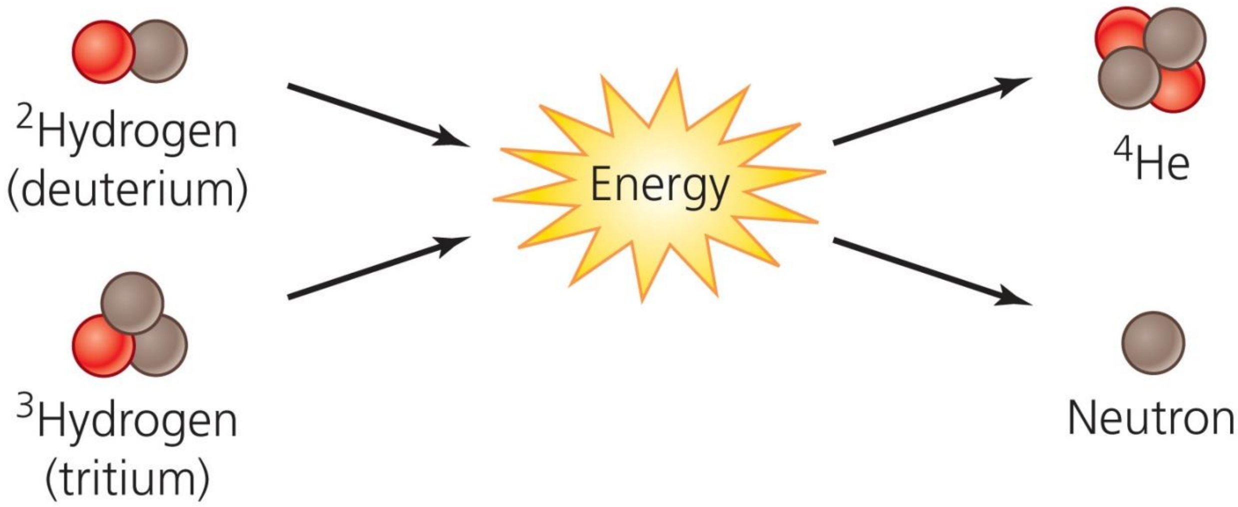
A typical light water reactor



Breeder reactors make better use of fuel

- Breeder reactors make use of U-238, which in conventional fission goes unused as a waste product
- Breeder reactors are more dangerous than conventional reactors because highly reactive liquid sodium is used as a coolant, raising the risk of explosive accidents
- They also are more expensive than conventional reactors
  - Highly reactive sodium, instead of water, is used as a coolant, raising the risk of explosive accidents
- All but a handful of the world's breeder reactors have now been shut down

Fusion remains a dream



- **Nuclear fusion =** the process that drives our Sun's vast output of energy
  - The force behind hydrogen (thermonuclear) bombs
  - Involves forcing together the small nuclei of lightweight elements under extremely high temperature and pressure
  - If we could control fusion, we could produce vast amounts of energy from water

Nuclear power delivers energy cleanly

- Like fossil fuels, nuclear energy is a nonrenewable resource.
  - Huge environmental and social costs are associated with the extraction, processing, use, and disposal of nuclear fuel.
- BUT Nuclear power helps us avoid emitting 600 million metric tons of carbon each year
  - Equivalent to 7% of global greenhouse gas emissions
- Nuclear power plants are safer for workers than coal-fired plants
- Drawbacks of nuclear power:
  - Nuclear waste is radioactive
  - If an accident occurs at a power plant, the consequences can potentially be catastrophic
- Today, the world has 439 operating nuclear plants in 30 nations

Coal versus nuclear power Nuclear

Environmental Impacts of Coal-fired and Nuclear Power

Type of Impact	Coal	Nuclear
Land and ecosystem disturbance from mining	Extensive, on surface or underground	Less extensive
Greenhouse gas emissions	Considerable emissions	None from plant operation; much less than coal over the entire life cycle
Other air pollutants	Sulfur dioxide, nitrogen oxides, particulate matter, and other pollutants	No pollutant emissions
Radioactive emissions	No appreciable emissions	No appreciable emissions during normal operation; possibility of emissions during severe accident
Occupational health among workers	More known health problems and fatalities	Fewer known health problems and fatalities
Health impacts on nearby residents	Air pollution impairs health	No appreciable known health impacts under normal operation
Effects of accident or sabotage	No widespread effects	Potentially catastrophic widespread effects
Solid waste	More generated	Less generated
Radioactive waste	None	Radioactive waste generated
Fuel supplies remaining	Should last several hundred more years	Uncertain; supplies could last longer or shorter than coal supplies

Nuclear power poses small risks

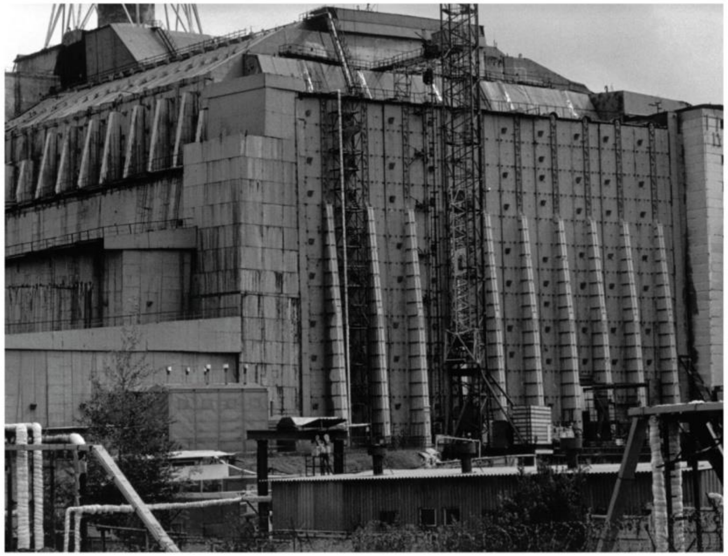
- Nuclear power poses the possibility of catastrophic accidents
  - Spawning public anxiety over nuclear power
- **Three Mile Island** was the most serious accident in the U.S. (1979)
- **Meltdown** = coolant water drained from the reactor vessel, temperatures rose inside the reactor core, and metal surrounding the uranium fuel rods began to melt, releasing radiation
  - Three Mile Island is regarded as a near-miss: the emergency could have been far worse
- The event raised safety concerns for U.S. citizens and policymakers

Chernobyl was the worst accident yet

- The 1986 explosion at the Chernobyl plant in Ukraine caused one of the most severe nuclear power plant accident the world has ever seen
  - For 10 days, radiation escaped from the plant while crews tried to put out the fire
  - The Soviet Union evacuated more than 100,000 residents
  - The landscape around the plant for 19 miles remains contaminated
  - The accident killed 31 people directly and over 200,000 became sick or developed cancer

The Chernobyl accident

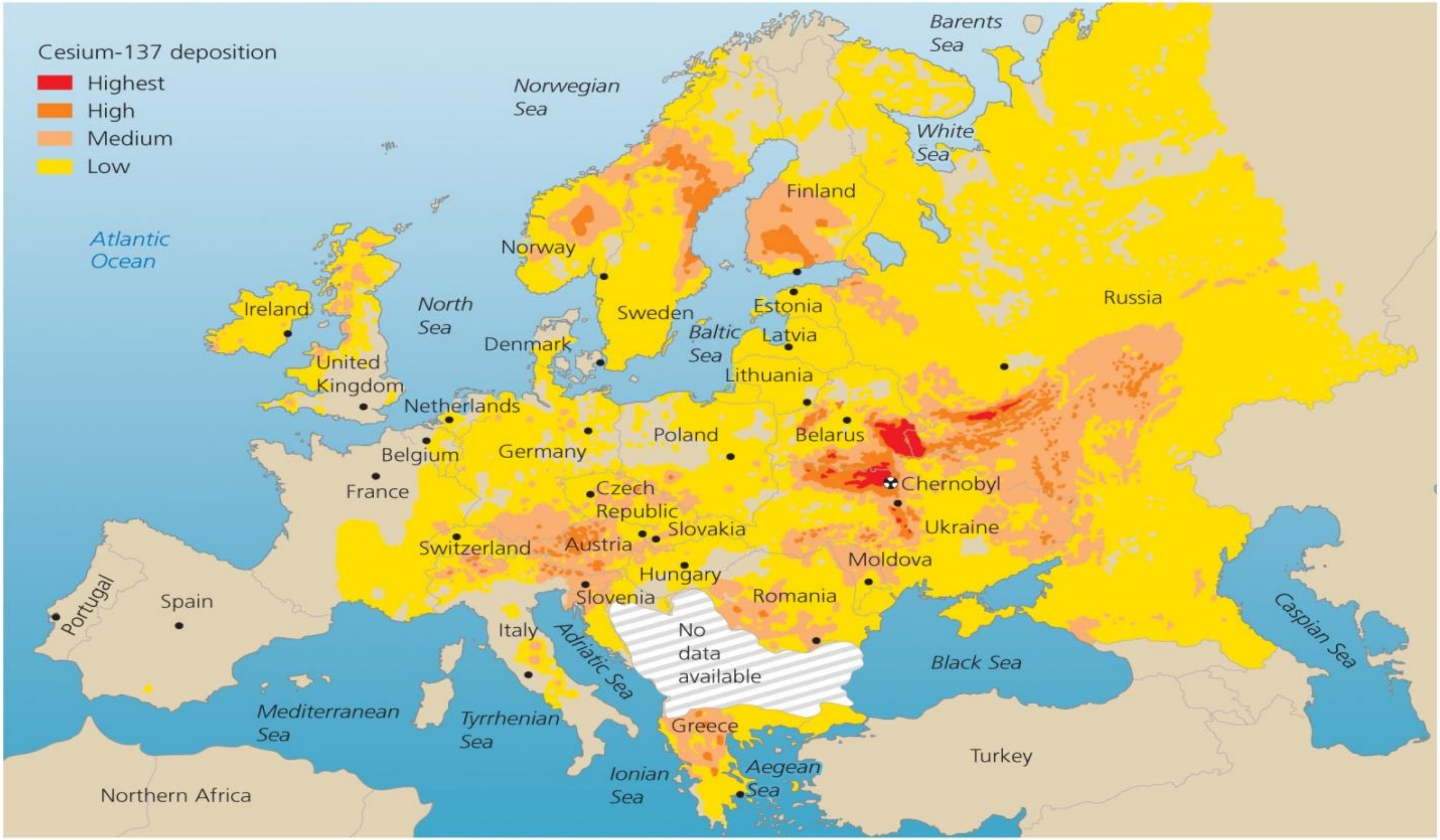
The destroyed reactor was encased in a massive concrete sarcophagus to contain further leakage



(a) The Chernobyl sarcophagus

(b) Technicians measuring radiation

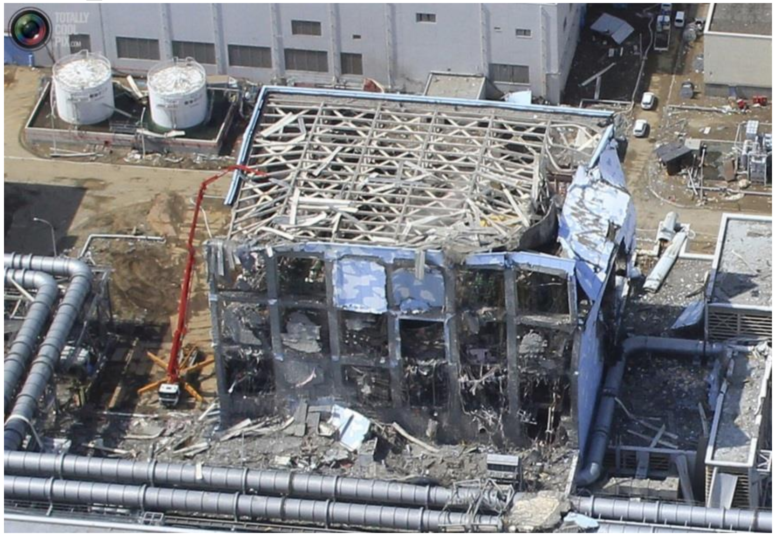
Atmospheric currents carried radioactive fallout from Chernobyl across much of the Northern Hemisphere



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings

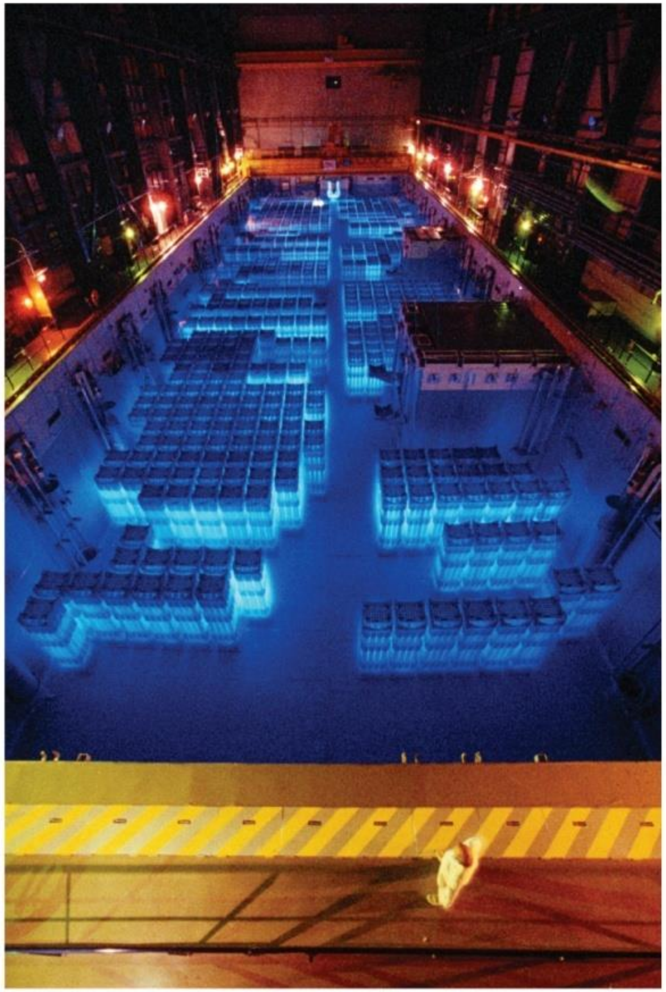
Most recent nuclear disaster

- Following a major earthquake in Japan, a tsunami disabled the power supply and cooling of three Fukushima Daiichi reactors, causing a nuclear accident on 11 March 2011.
- All three cores largely melted in the first three days.
- Apart from cooling, the basic ongoing task was to prevent release of radioactive materials, particularly in contaminated water leaked from the three units.
- Over 100,000 people had to be evacuated from their homes



Waste disposal remains a problem

- The long half-lives of uranium, plutonium, and other radioisotopes will cause them to continue emitting radiation for thousands of years
- Radioactive waste must be placed in unusually stable and secure locations where radioactivity will not harm future generations
- Nuclear waste from power generation is being held in temporary storage at nuclear power plants across the U.S. and the world



(a) Wet storage

Spent fuel rods must be stored

(b) Dry storage

- Spent fuel rods are sunk in pools of cooling water to minimize radiation leakage
- 75% of U.S. plants have no room left for this type of storage
  - They are now expanding their storage capacity by storing waste in thick casks of steel, lead, and concrete

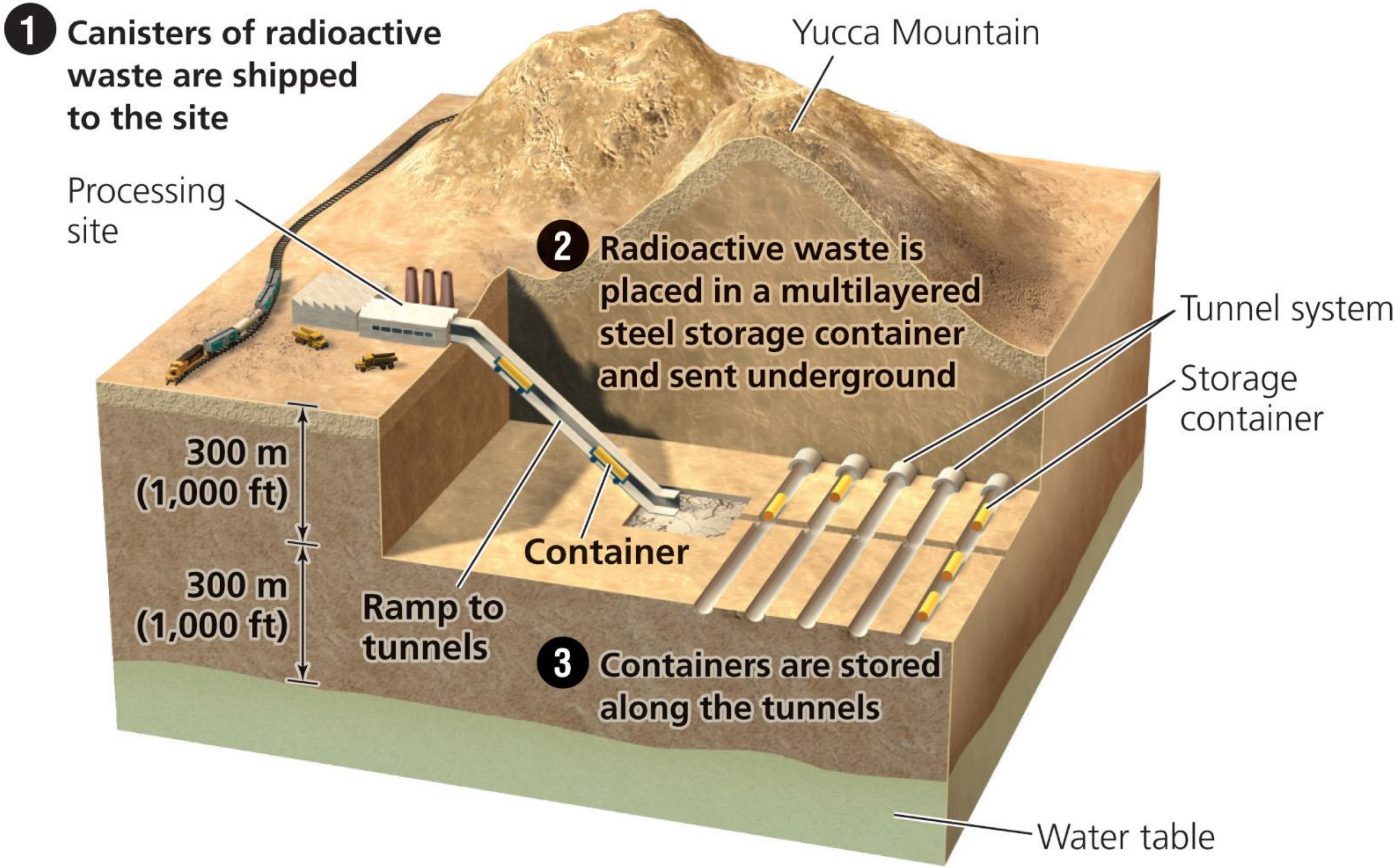
Waste storage at Yucca Mountain, Nevada

- Nuclear waste managers want to send all waste to a central repository that can be heavily guarded
  - Yucca Mountain, Nevada, was recommended by the president and approved by Congress
  - It's waiting approval from the Nuclear Regulatory Commission to become the site that receives waste from nuclear reactors and military installations. Should be ready by 2017.
  - Keeps meeting roadblocks in Congress that stall the approval process.

(a) Yucca Mountain

(b) Scientific testing

Yucca Mountain, Nevada



(c) Proposed design

Scientists and policymakers chose Yucca Mountain

- It is 14 miles to the nearest year-round residences
- It has stable geology, with minimal risk of earthquakes that could damage the tunnels and release radioactivity
- Its dry climate should minimize water infiltration, reducing chances of groundwater contamination
- The water table is deep underground, making groundwater contamination less likely
- The pool of groundwater does not connect with groundwater elsewhere, so any contamination would be contained
- The location on federal land can be protected from sabotage

Concerns with Yucca Mountain as a site

- Some argue that earthquakes and volcanic activity could destabilize the site's geology
- They also fear that fissures in the mountain's rock could allow rainwater to seep into the caverns
- Nuclear waste will need to be transported to Yucca Mountain from the 120-some current storage areas and from current and future nuclear plants and military installations
  - Shipments by rail and truck across thousands of public highways through all the states in the union cause a high risk of accident or sabotage

Dilemmas have slowed nuclear power's growth

- It is enormously expensive to build, maintain, operate, and ensure the safety of nuclear facilities
  - Shutting down (decommissioning) plants can be more expensive than construction
- Electricity is more expensive than from coal and other sources
- Nuclear power plants in Western Europe will be retired by 2030
  - Asian nations are increasing nuclear capacity; 15 to 26 plants are under construction

Biomass energy

- Biomass energy has great potential for addressing our energy challenges
- **Biomass** = organic material that makes up living organisms
- People harness biomass energy from many types of plant matter
  - Wood from trees, charcoal from burned wood, and matter from agricultural crops, as well as combustible animal waste products

Biomass sources are widely used

- More than 1 billion people use wood from trees as their principal energy source
- In developing nations, families gather fuelwood for heating, cooking, and lighting
- Fuelwood and other biomass sources constitute 80% of all renewable energy used worldwide
- Biomass is only renewable when it is not overharvested
  - With rapid deforestation, soil erosion, and forest failures to regrow, biomass is not replenished

New biomass strategies

- Biomass sources include a variety of materials
- **Biopower** = produced when biomass sources are burned in power plants, generating heat and electricity
- **Biofuels** = biomass sources converted into fuels to power automobiles

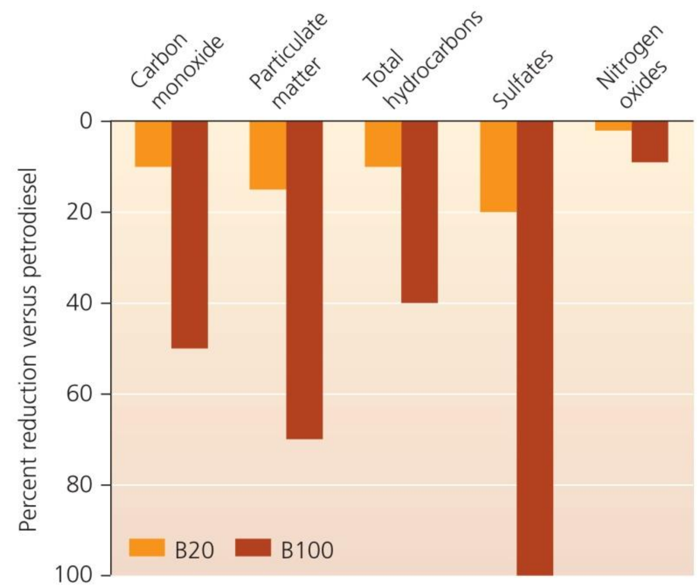
Biofuels can power automobiles

- Ethanol = produces as a biofuel by fermenting carbohydrate-rich crops
  - Ethanol is widely added to U.S. gasoline to reduce emissions
  - Any vehicle will run well on a 10% ethanol mix
- **Flexible fuel vehicles** = run on 85% ethanol
  - But, very few gas stations offer this fuel

(a) Corn grown for ethanol

Biodiesel is produced from vegetable oil

- U.S. biodiesel producers use soybean oil
  - Animal fats, used grease, and cooking oil can also be used
  - Vehicles can run on 100% biodiesel, but the engine needs to be modified
  - Biodiesel cuts down on emissions; its fuel economy is almost as good and costs slightly more than gasoline



Biopower generates electricity

- Many sources of biomass can be used
  - Waste products of existing industries or processes
  - Woody debris from logging operations and sawmills
  - Crops can be specifically grown, such as fast-growing willow trees or bamboo
  - **Co-firing** combines biomass with coal
  - Bacterial breakdown of waste to produce methane

Biomass energy brings benefits

- It is essentially carbon-neutral, releasing no net carbon into the atmosphere
  - Only if biomass sources are not overharvested
  - Capturing landfill gases reduces methane emissions
- Economic benefits include
  - Supporting rural communities
  - Reducing dependence of fossil fuel imports
  - Improved energy efficiency
  - Reduces air pollutants such as sulfur dioxide
  - Helps move industries toward sustainability

Drawbacks of biomass energy

- Health hazards from indoor air pollution
- Rapid harvesting can lead to deforestation
- Growing crops exerts tremendous impacts on ecosystems
  - Fertilizers and pesticides
  - Land is converted to agriculture
- Biofuel is competing with food production
- Substantial inputs of energy are required

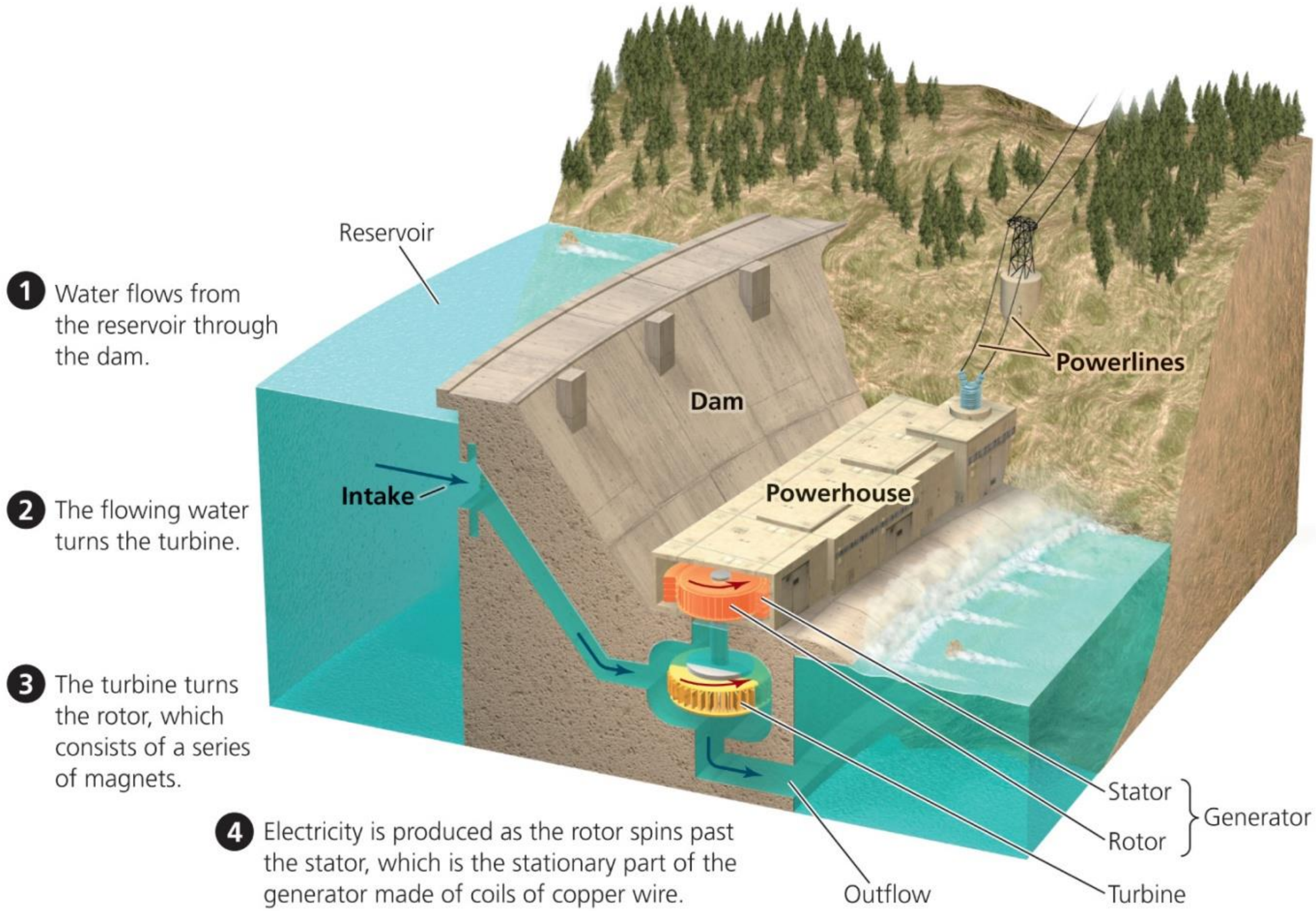
Hydroelectric power

- **Hydroelectric power** = uses the kinetic energy of moving water to turn turbines and generate electricity
- **Storage technique** = impoundments harness energy by storing water in reservoirs behind dams
  - Water passing through the dam turns turbines
- Run-of-river approaches generates energy without greatly disrupting the flow of river water

(a) Ice Harbor Dam, Snake River, Washington

(b) Turbine generator inside McNary Dam, Columbia River

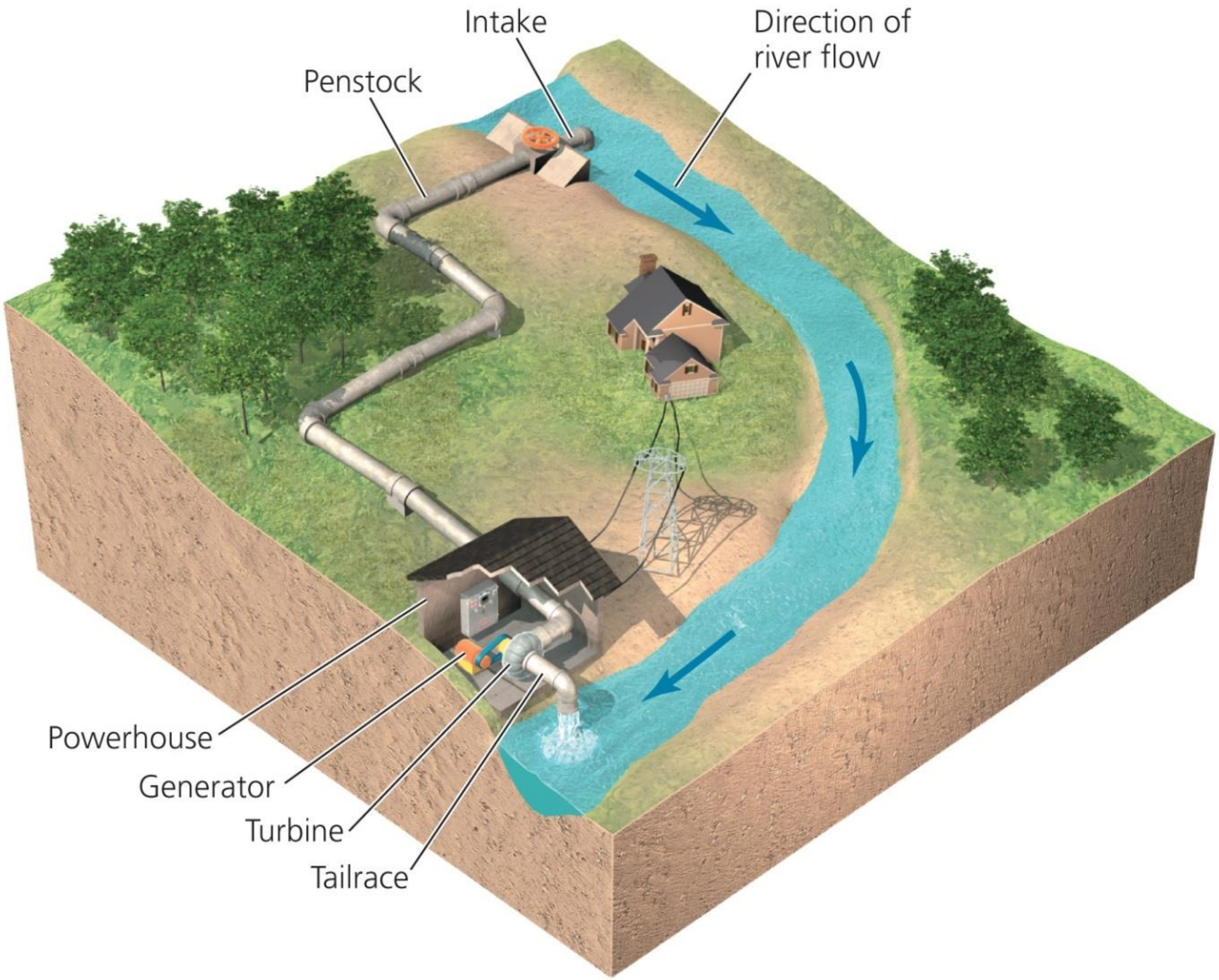
A typical dam



(c) Hydroelectric power

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings

A run-of-river system



Hydroelectric power is widely used

- Hydropower accounts for 2.2% of the world's energy supply
  - And 16% of the world's electricity production
- Nations with large rivers and economic resources have used dams
  - However, many countries have dammed their large rivers. Canada, Brazil, Norway, Austria, and Venezuela get a large amount of their energy from hydropower.
  - People want some rivers left undammed

Hydropower is clean and renewable

- Hydropower has two clear advantages over fossil fuels for producing electricity:
  - It is renewable: as long as precipitation fills rivers we can use water to turn turbines
  - It is clean: no carbon dioxide is emitted
- Hydropower is efficient
  - It has an EROI of 10:1, as high as any modern-day energy source

Hydropower has negative impacts

- Damming rivers destroys habitats
  - Upstream areas are submerged
  - Downstream areas are starved of water
- Natural flooding cycles are disrupted
- Thermal pollution of downstream water
- Periodic flushes of cold reservoir water can kill fish
- Dams block passage of fish, fragmenting the river and reducing biodiversity

Hydropower may not expand much more

- China's Three Gorges Dam is the world's largest dam
- Most of the world's large rivers have already been dammed
- People have grown aware of the ecological impact of dams
- Developing nations will probably increase hydropower if they have rivers