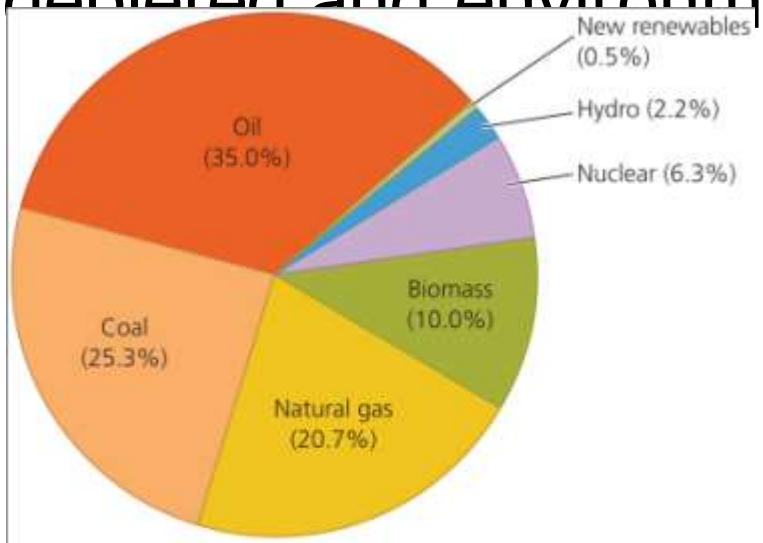
Nuclear Power

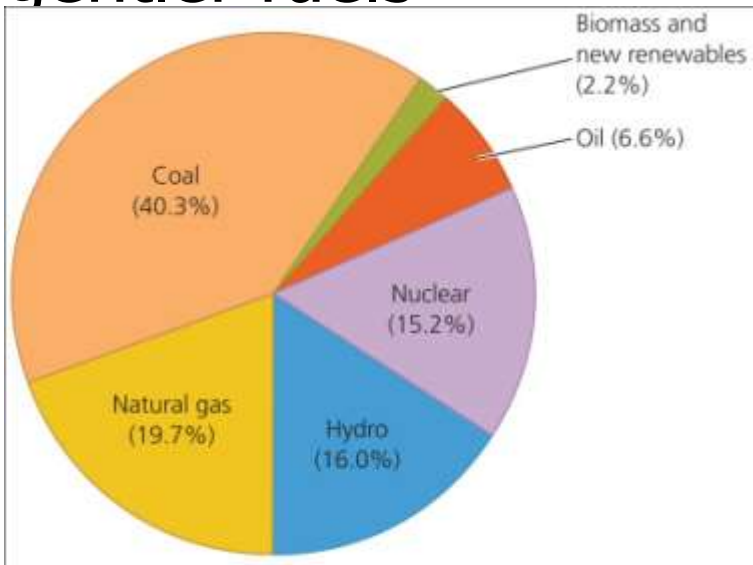
A Non-renewable Alternative to Fossil Fuels

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



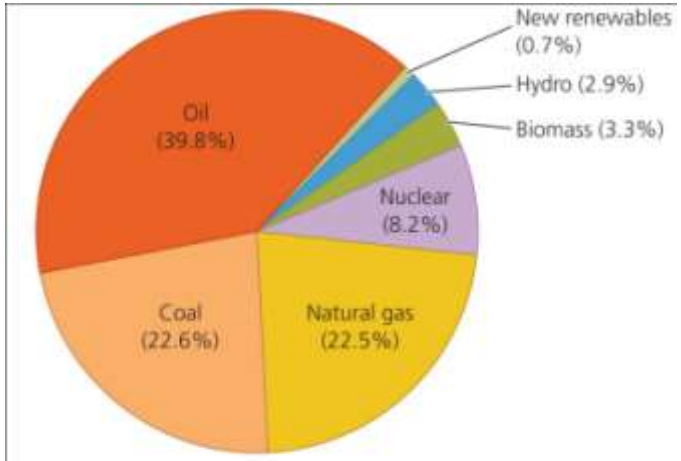
(a) World energy production, by source



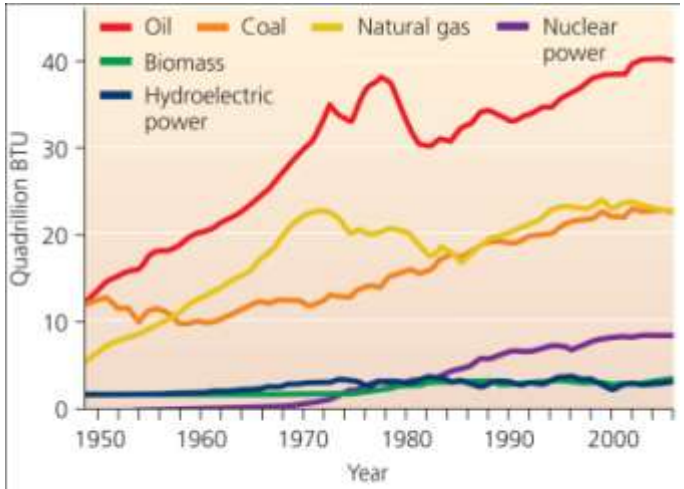
(b) World electricity generation, by source

The U.S. relies on fossil fuels

- The U.S. relies more on fossil fuels and nuclear power than other countries
  - Conventional alternatives play minor, yet substantial roles, in energy use
  - The use of conventional alternatives has been growing more slowly than fossil fuels



(a) U.S. energy consumption, by source



(b) U.S. energy consumption, 1949–2006

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

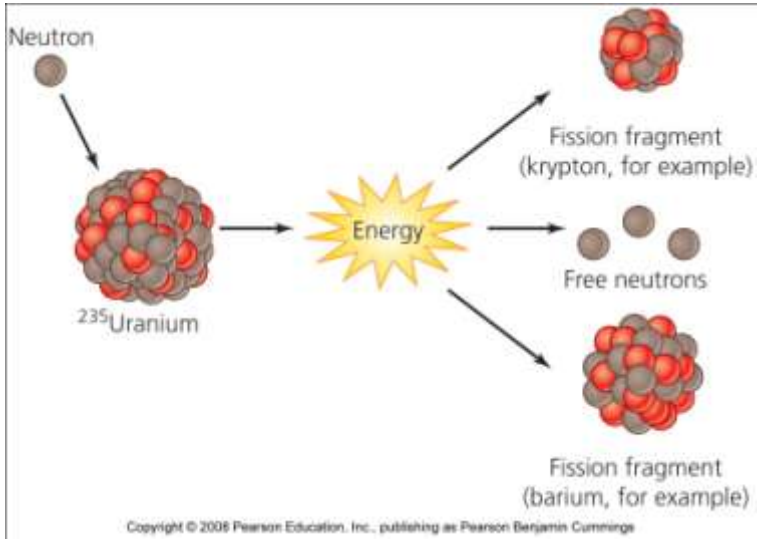
Conventional alternatives provide energy

- Fuelwood 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

What is nuclear energy?

- Potential energy: energy stored in chemical bonds.

Fission releases nuclear energy

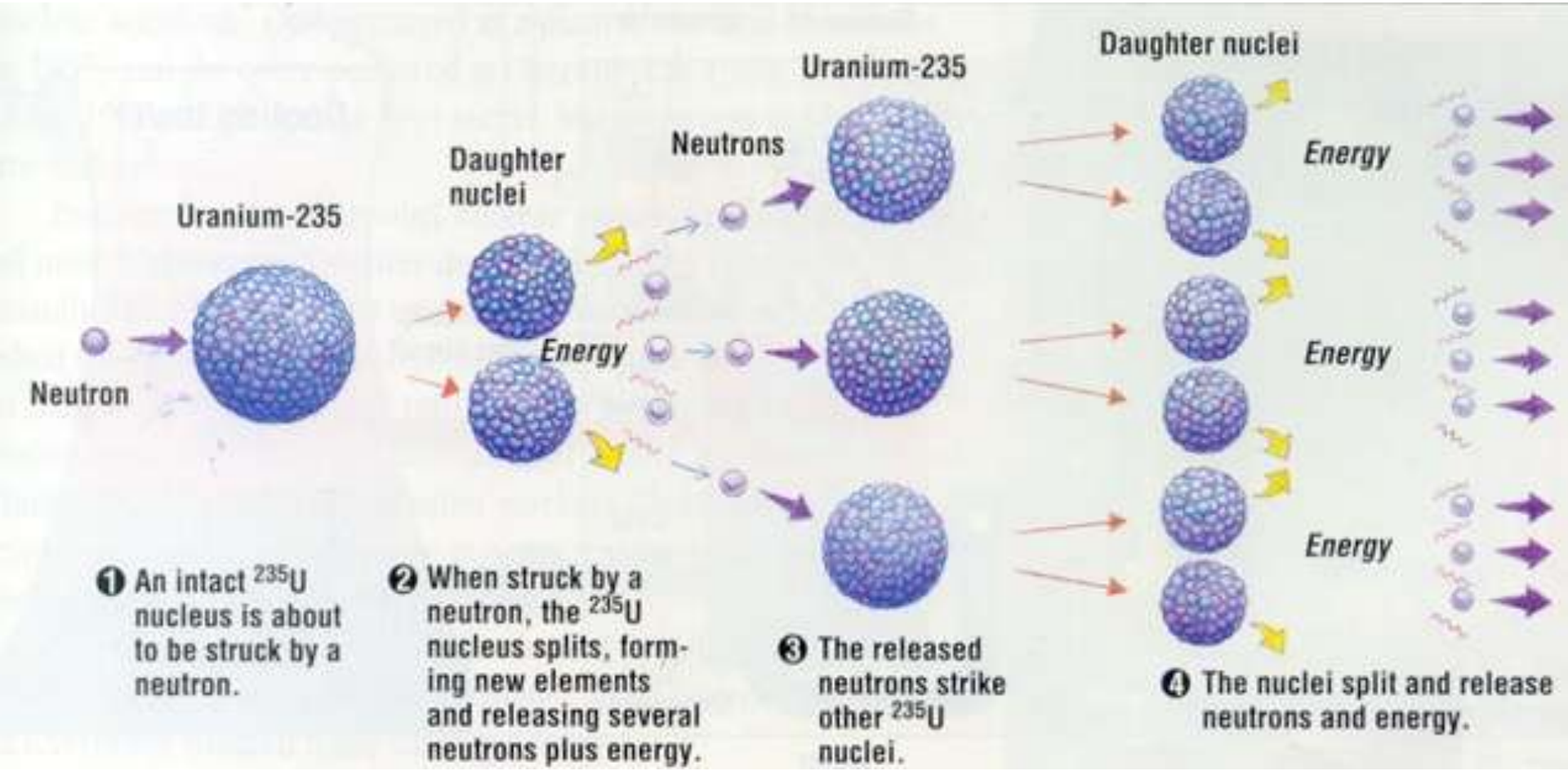


- **Nuclear energy =** the energy that holds together protons and neutrons within the nucleus of an atom
  - The reaction that drives the release of nuclear energy in power plants is **nuclear fission** = the splitting apart of atomic nuclei

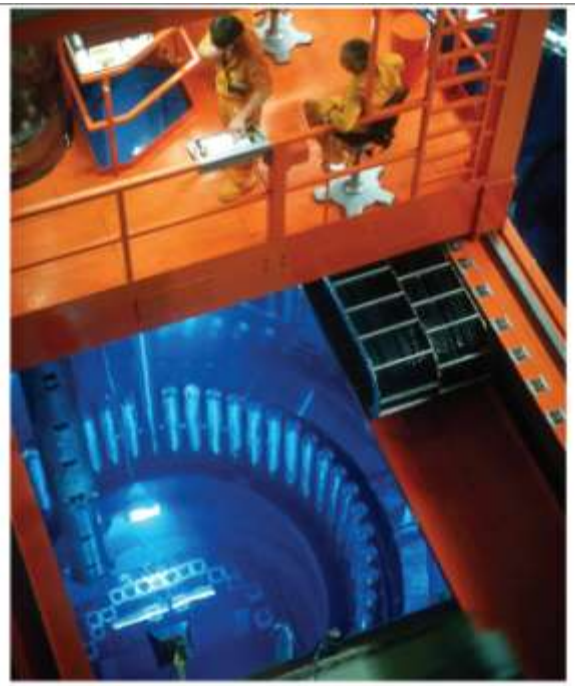
Fission in reactors generates electricity

- 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

How is Nuclear Fission Energy produced?



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

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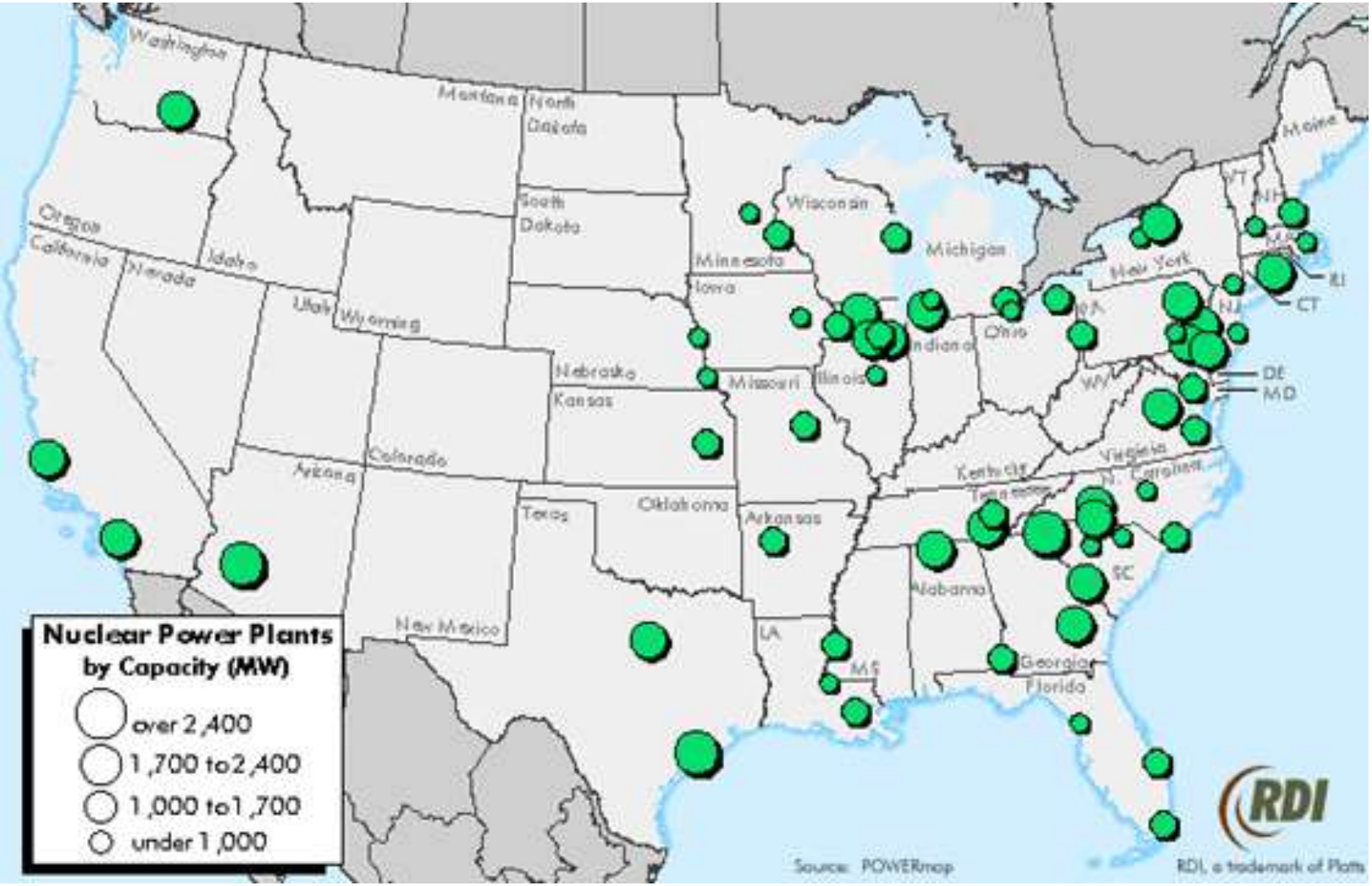
- When isotopes of uranium and plutonium undergo controlled nuclear fission, the resulting heat produces steam that spins turbines to generate electricity.
  - The uranium oxide consists of about 97% nonfissionable uranium-238 and 3% fissionable uranium-235.
  - The concentration of uranium-235 is increased through an enrichment process.

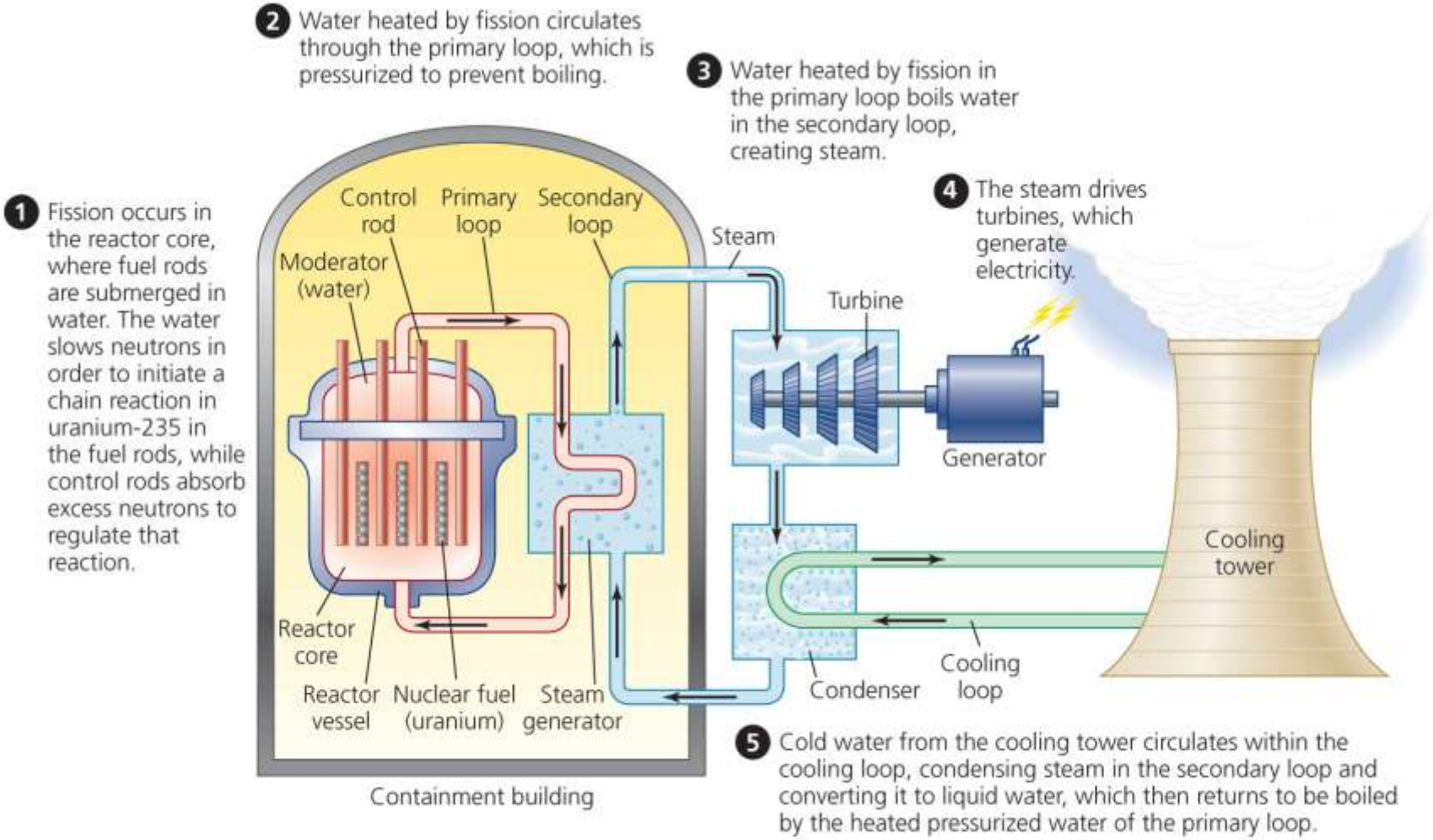
How much energy is produced?

- Nuclear power is an extremely rich energy source.
- One gram of Uranium-235 delivers as much energy as 3.5 metric tons of coal!!!
- One in every 5 houses in the U.S. is supplied with nuclear energy.

Where are Nuclear Power Plants located?



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 have now been shut down

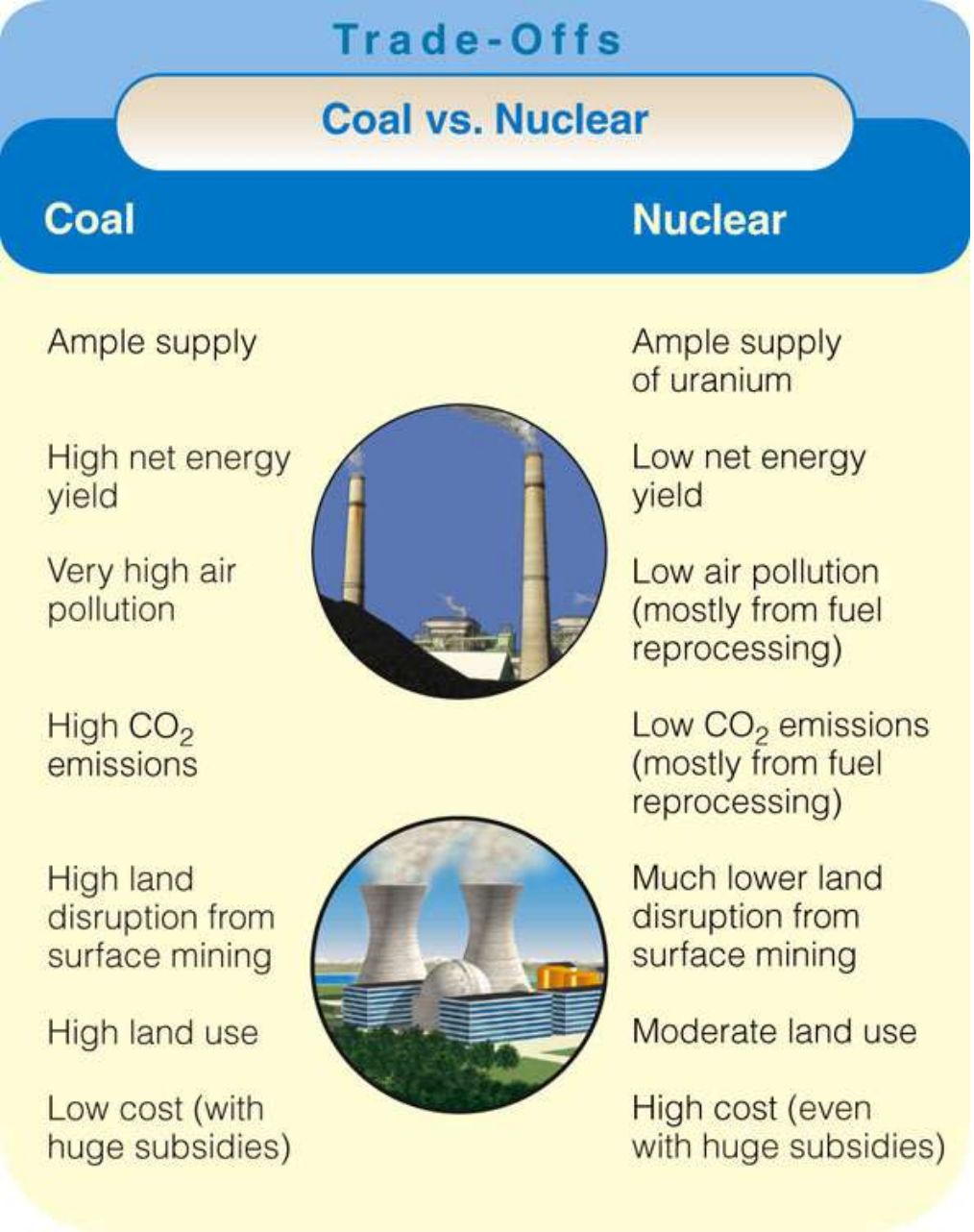
Nuclear power delivers energy cleanly

- Nuclear power helps us avoid emitting 600 million metric tons of carbon each year
  - Equivalent to 8% 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 436 operating nuclear plants in 30 nations

Coal versus nuclear power

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 ENERGY



- A 1,000 megawatt nuclear plant is refueled once a year, whereas a coal plant requires 80 rail cars a day.

Figure 16-20

Why don’t we have more nuclear power plants?

- We, as the general public, do not fully understand the concept of nuclear fission.
- We are afraid of major accidents because of the history
- http://abcnews.go.com/search?searchtext=chernobyl&r=video

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
  - 20% of U.S. electricity comes from nuclear sources
- France receives 78%+ of its electricity from nuclear power

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.

Meltdown at Three Mile Island

- **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

Case Study: The Chernobyl Nuclear Power Plant Accident

- The world's worst nuclear power plant accident occurred in 1986 in Ukraine.
- The disaster was caused by poor reactor design and human error.
- By 2005, 56 people had died from radiation released.
  - 4,000 more are expected from thyroid cancer and leukemia.

Chernobyl was the worst accident yet

- The 1986 explosion at the Chernobyl plant in Ukraine caused 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 many became sick or developed cancer

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

The Chernobyl accident

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

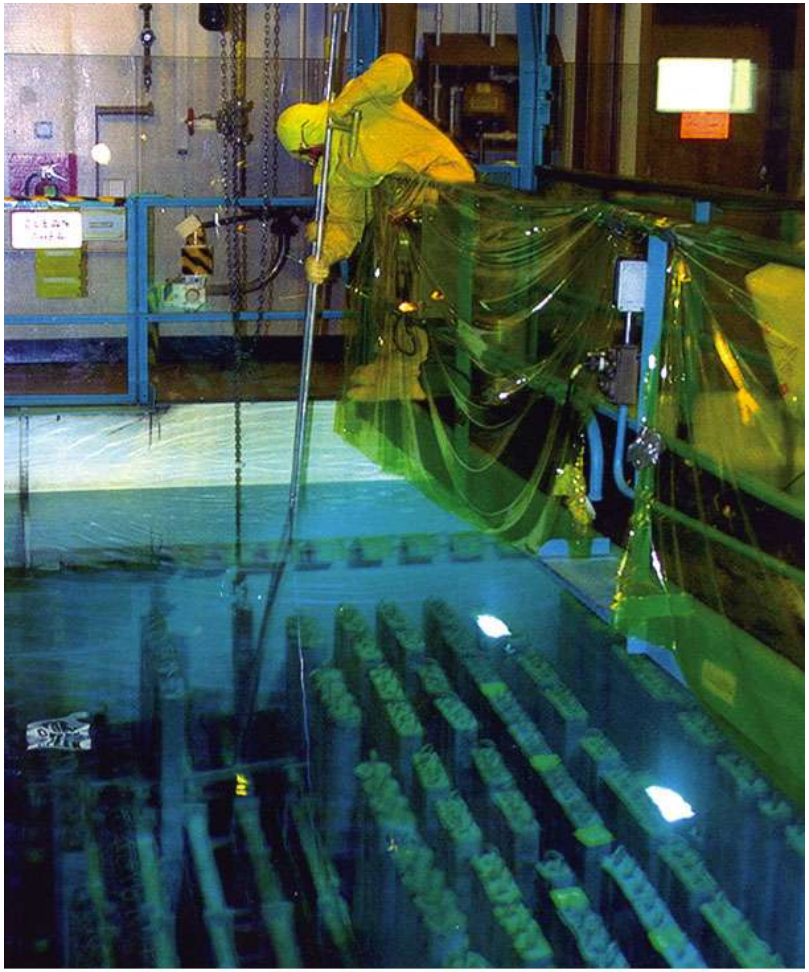
(a) The Chernobyl sarcophagus

(b) Technicians measuring radiation

Smaller-scale accidents have occurred

- Although western reactors are far safer than Chernobyl, smaller accidents have occurred
  - A 1999 accident in Japan killed two workers and exposed 400 others to leaked radiation
- As plants around the world age, they require more maintenance and are less safe
  - Recent terrorist attacks raised fears that similar attacks could be carried out against nuclear plants
  - Or stolen radioactive material could be used in attacks
- The U.S. government's "megatons to megawatts" program has been buying up radioactive material and using it in power plants

NUCLEAR ENERGY



- After three or four years in a reactor, spent fuel rods are removed and stored in a deep pool of water contained in a steel-lined concrete container.

Figure 16-17

Spent Rods

- After spent fuel rods are cooled considerably, they are sometimes moved to dry-storage containers made of steel or concrete.

Figure 16-17

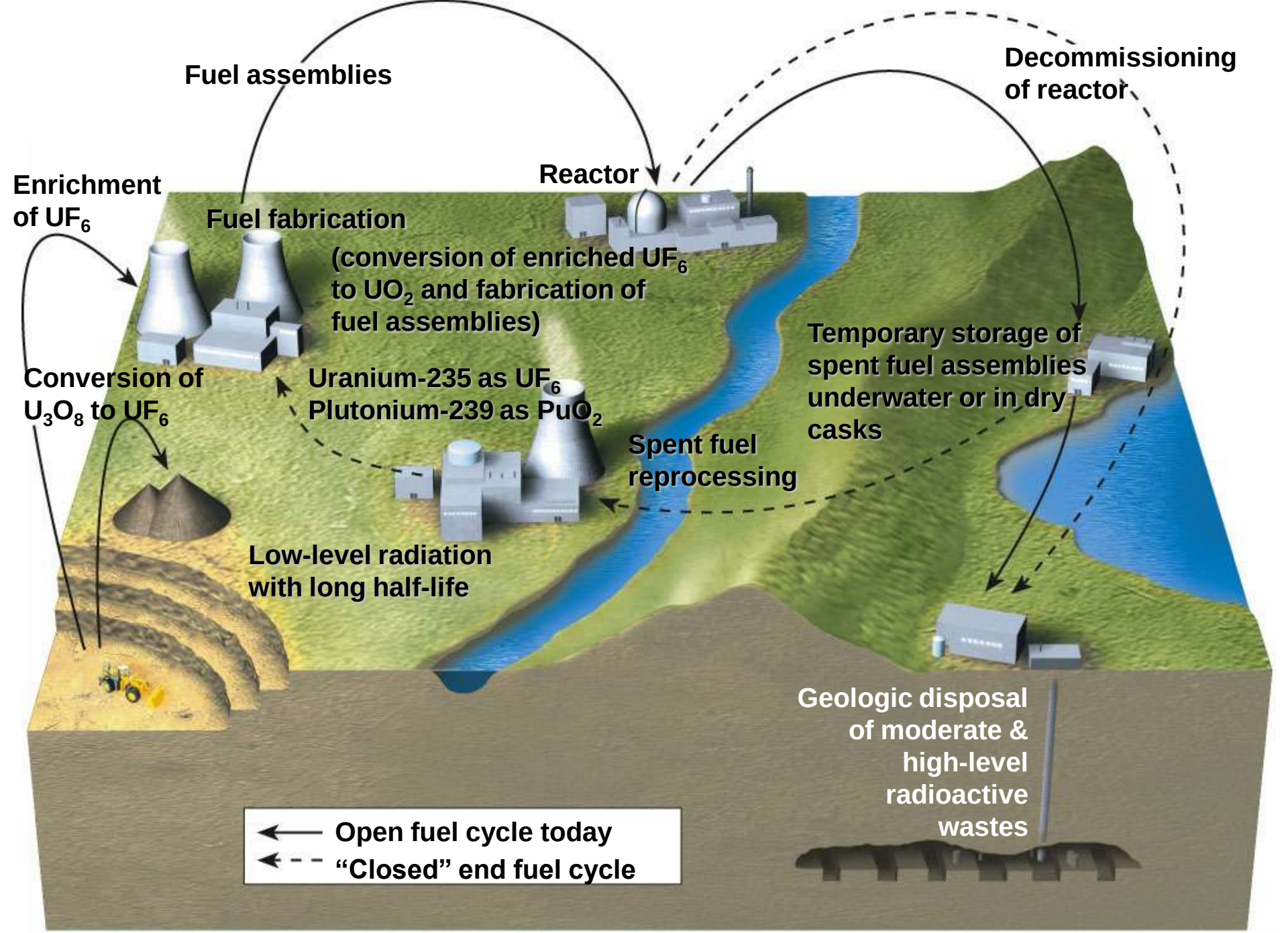


Fig. 16-18, p. 373

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

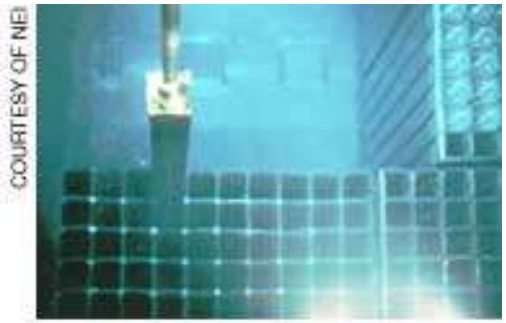
Spent fuel rods must be stored

(b) Dry storage

- Spent fuel rods are sunk in pools of cooling water to minimize radiation leakage
- By 2010, 75% of U.S. plants will 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

Currently, nuclear waste is stored.

- Radioactive waste is temporarily stored on-site, awaiting approval of a national long-term nuclear waste storage facility.
- WE'RE RUNNING OUT OF SPACE!!!



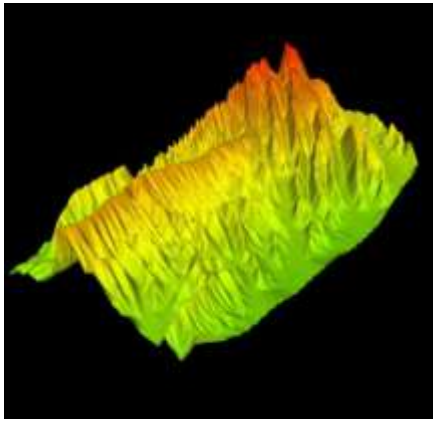
Spent nuclear fuel is stored first in cooling pools near the reactor at power plants.

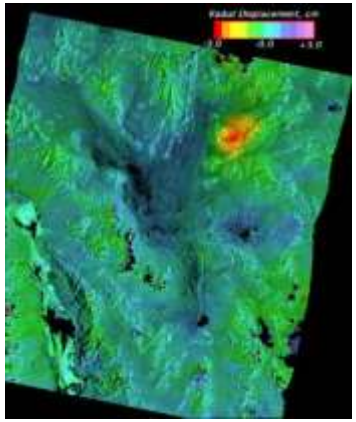
The Decision Has Been Made!

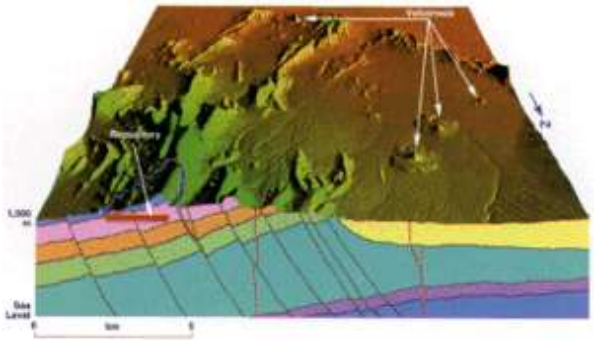
- The Federal Government vetoed Nevada and had decided that Yucca Mountain will serve as the long-term storage facility for all commercially generated nuclear waste in the U.S.

Scientists have studied Yucca Mountain

- DOE has spent over $4 billion testing and tunneling Yucca mountain over 20 years.
- 200 pits, 450 boreholes, 6.8 miles of tunnels, 75,000 feet of core samples, 18,000 other geological samples, heated 7 million cubic feet of rock, tested 13,000 metals for corrosive resistance.







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

Waste storage at Yucca Mountain, Nevada

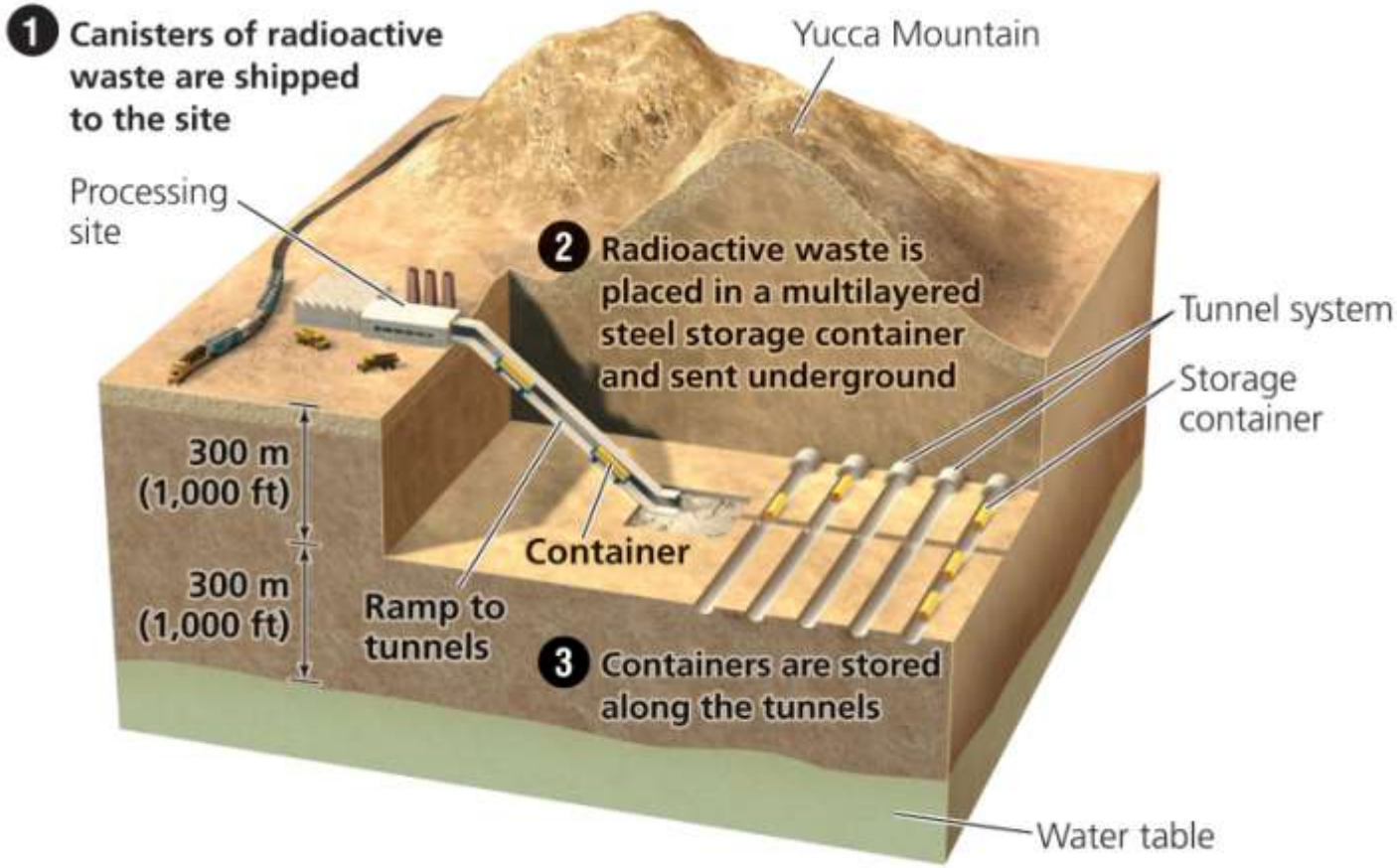
- Nuclear waste managers want to send all waste to a central repository that can be heavily guarded
  - Yucca Mountain, Nevada, was recommended by the president and approved by Congress
  - It's waiting approval from the Nuclear Regulatory Commission to become the site that receives waste from nuclear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

(b) Scientific testing

What is Yucca Mountain?

- Site that has been declared "scientifically sound" and technically suitable" to geologically isolate nuclear waste for at least 10,000 years.
- Located 100 miles from Las Vegas
- Accept over 77,000 metric tons of nuclear waste before another site is built.
- Transportation of nuclear waste to Yucca Mountain will take 24 years to complete.

Yucca Mountain, Nevada



(c) Proposed design

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

Cons Concerning Transportation of Nuclear Waste

- "Mobile Chernobyls" to carry 154 million pounds of radioactive waste through America's heardland.
- Every year starting around 2010, 175 train and truck convoys filled with nuclear waste would pass through counties where more than a third of all Americans live.
- If an accident occurred en route, the nuclear fallout could kill thousands.
- Traveling convoys may become terrorists target.
- Current mishap rates for trains and trucks suggest there would be nearly 100 rail accidents and one or two truck accidents over the 24 years the Yucca Mountain would be accepting waste. (No harmful radiation is LIKELY to leak in those accidents…)
- About 6.5 million pounds of waste would be hauled 1 million miles by train and 100,000 miles by truck each year for 24 years.
- Waste will travel through 45 states!
- Some politicians are in favor of Yucca Mountain only because it will get their nuclear waste out of their back yard.


EY
AVE TO
TRAVEL
THRU YOUR
BACKYARD
TO DUMP IT
IN MINE!!

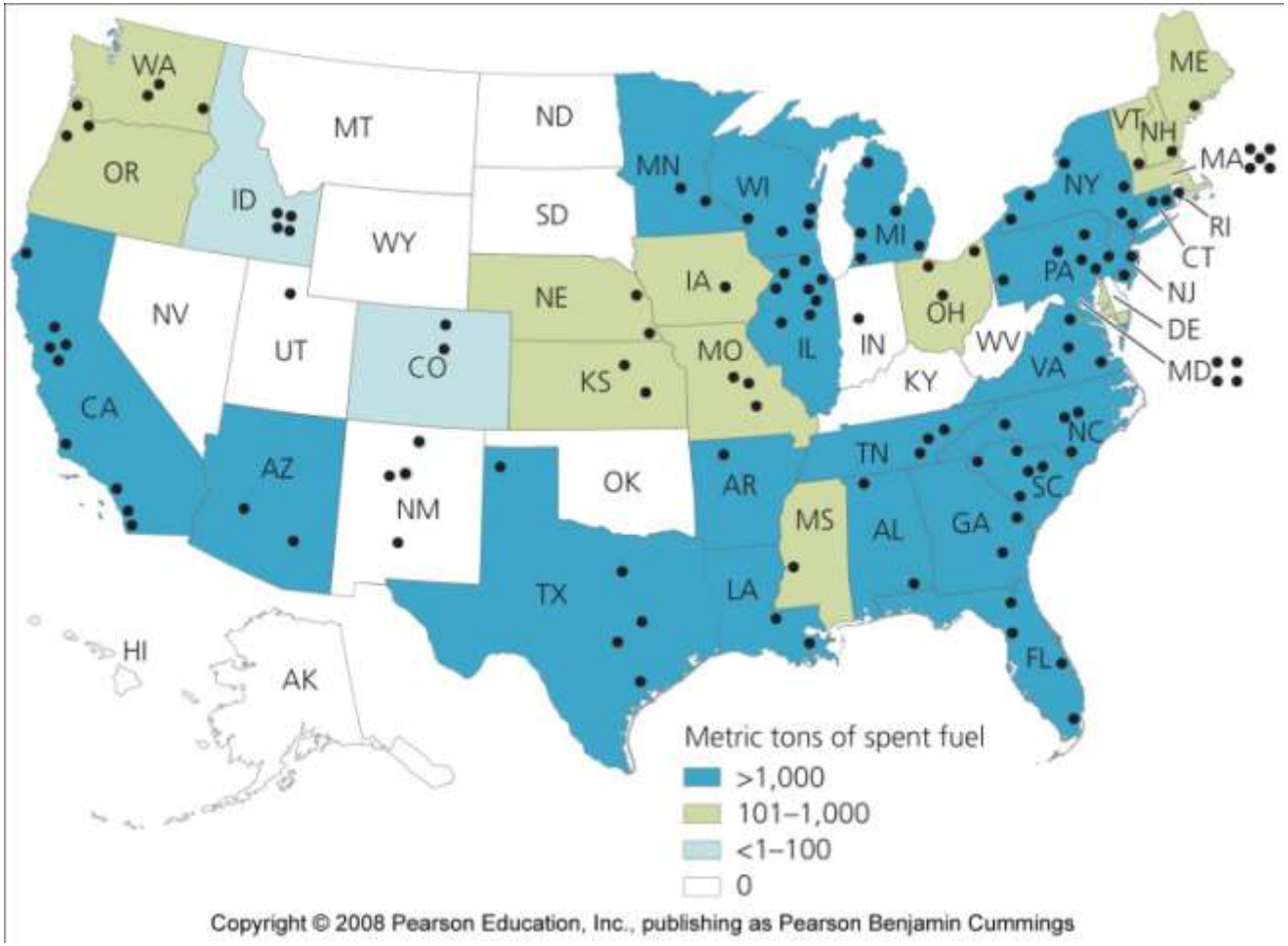

NEVADA IS NOT A WASTELAND
CITIZEN ALERT


13
Mobile
Chernobyl
Express

U.S. power plants store tons of waste

- U.S. power plants store 56,000 metric tons of high-level radioactive waste, as well as much more low-level radioactive waste
- Waste is held at 125 sites in over 39 states
  - Most of these sites are vulnerable to terrorist attacks
- Over 161 million U.S. citizens live within 75 miles of temporarily stored waste

Storage of high-level radioactive waste



What Happened to Nuclear Power?

- After more than 50 years of development and enormous government subsidies, nuclear power has not lived up to its promise because:
  - Multi billion-dollar construction costs.
  - Higher operation costs and more malfunctions than expected.
  - Poor management.
  - Public concerns about safety and stricter government safety regulations.

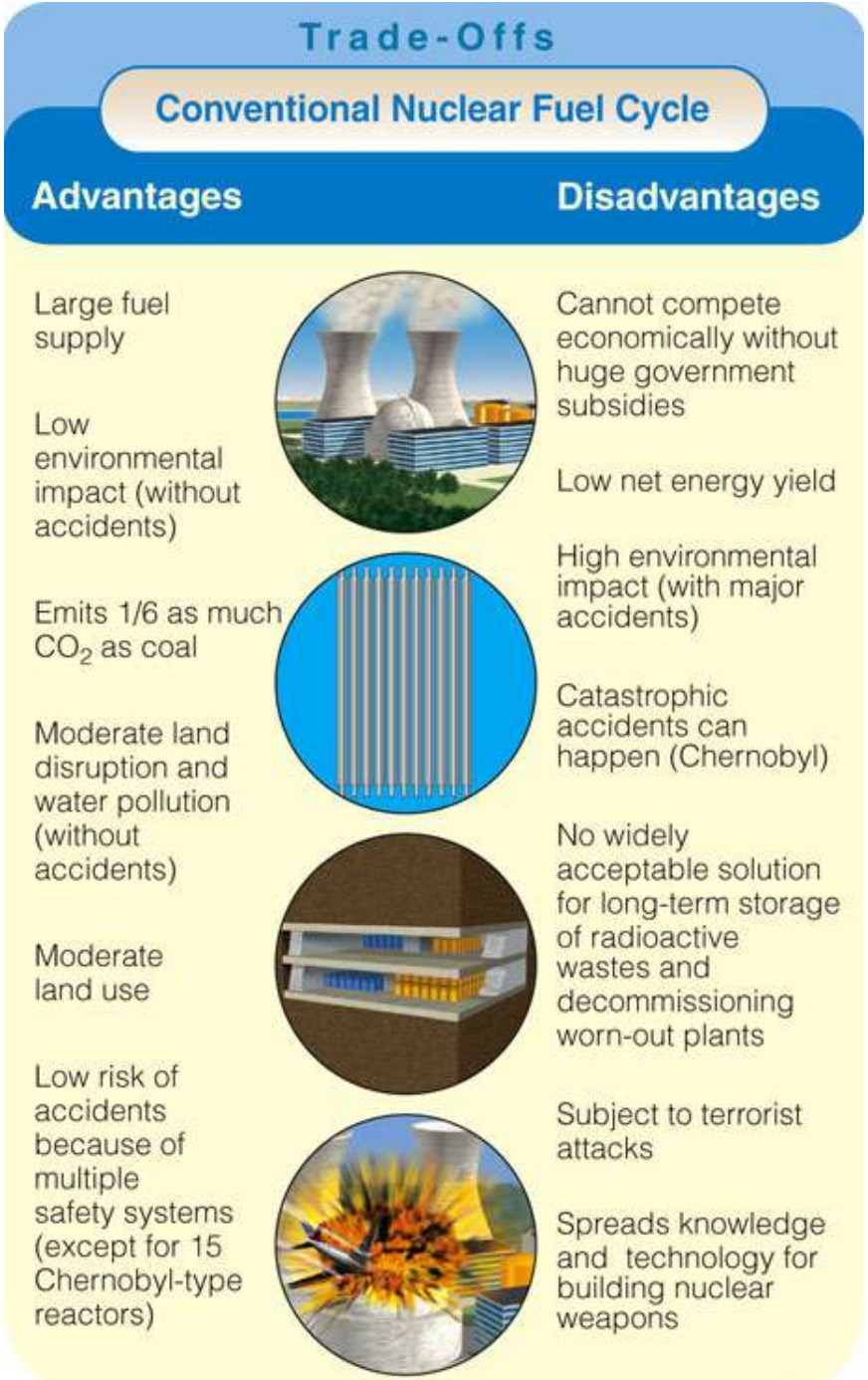
Dilemmas have slowed nuclear power's growth

- 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

The future of U.S. nuclear energy

- The U.S. nuclear industry has stopped building plants
  - Expanding nuclear capacity would decrease reliance on fossil fuels
  - Engineers are planning ways to make nuclear power plants safer and less expensive

NUCLEAR ENERGY



- In 1995, the World Bank said nuclear power is too costly and risky.
- In 2006, it was found that several U.S. reactors were leaking radioactive tritium into groundwater.

Figure 16-19

NUCLEAR ENERGY

- Terrorists could attack nuclear power plants, especially poorly protected pools and casks that store spent nuclear fuel rods.
- Terrorists could wrap explosives around small amounts of radioactive materials that are fairly easy to get, detonate such bombs, and contaminate large areas for decades.

NUCLEAR ENERGY

- When a nuclear reactor reaches the end of its useful life, its highly radioactive materials must be kept from reaching the environment for thousands of years.
- At least 228 large commercial reactors worldwide (20 in the U.S.) are scheduled for retirement by 2012.
  - Many reactors are applying to extent their 40-year license to 60 years.
  - Aging reactors are subject to embrittlement and corrosion.

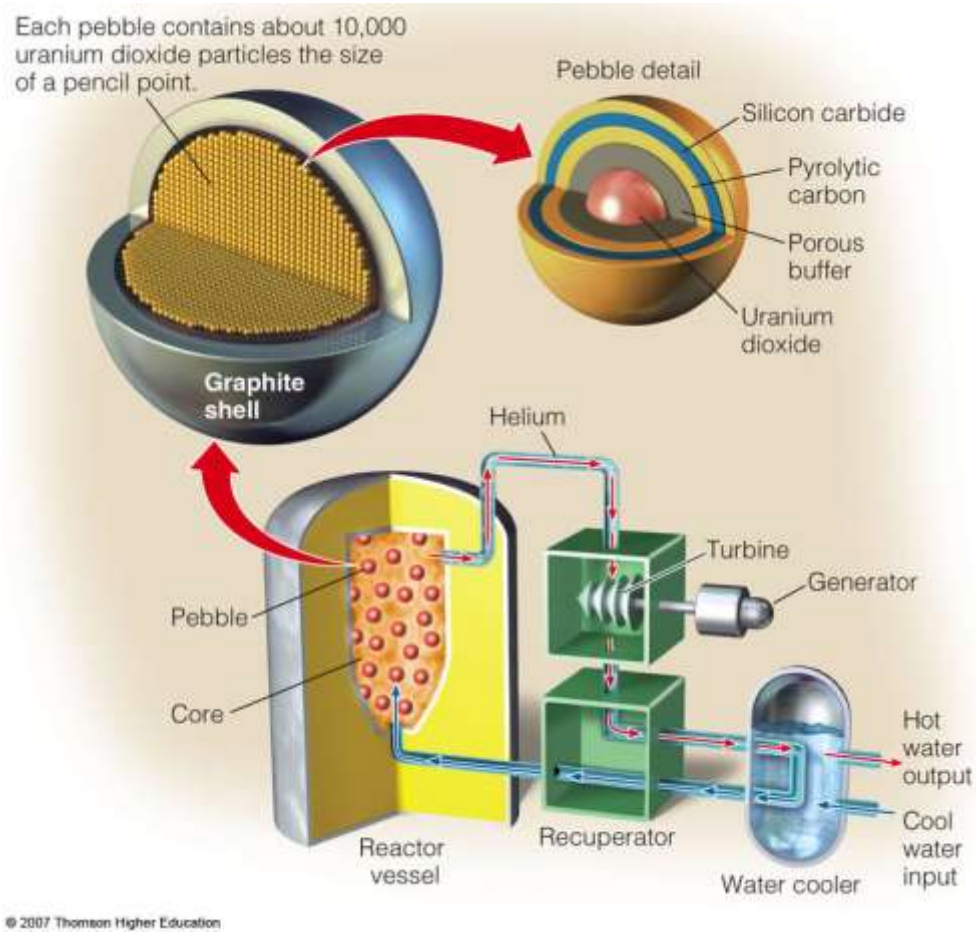
NUCLEAR ENERGY

- Building more nuclear power plants will not lessen dependence on imported oil and will not reduce CO_2 emissions as much as other alternatives.
  - The nuclear fuel cycle contributes to CO_2 emissions.
  - Wind turbines, solar cells, geothermal energy, and hydrogen contributes much less to CO_2 emissions.

NUCLEAR ENERGY

- Scientists disagree about the best methods for long-term storage of high-level radioactive waste:
  - Bury it deep underground.
  - Shoot it into space.
  - Bury it in the Antarctic ice sheet.
  - Bury it in the deep-ocean floor that is geologically stable.
  - Change it into harmless or less harmful isotopes.

New and Safer Reactors



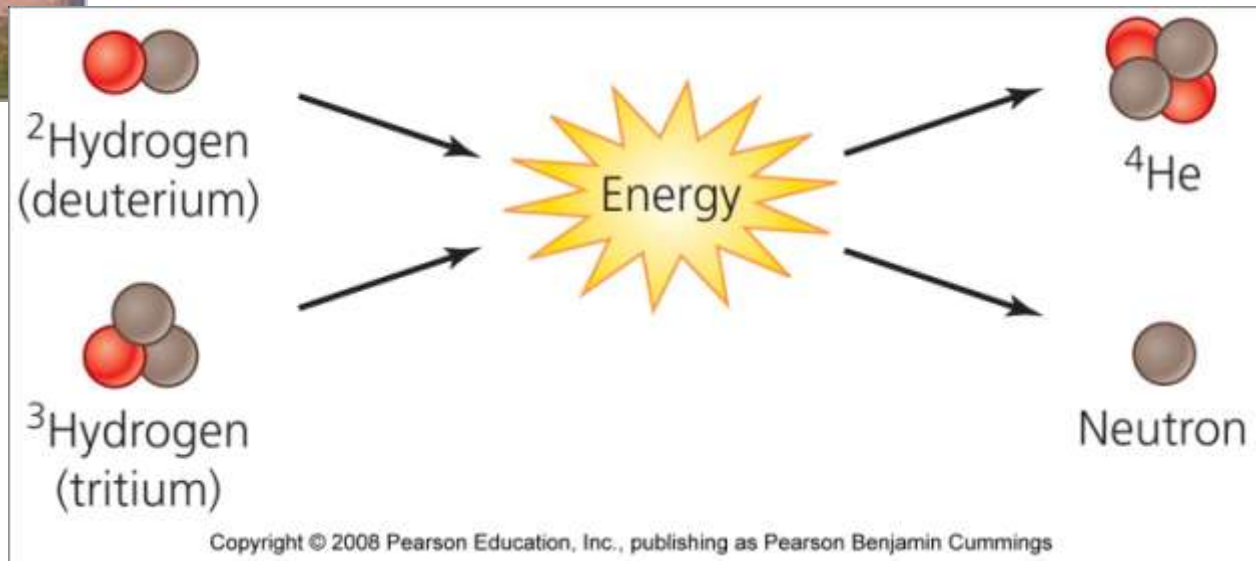
- Pebble bed modular reactor (PBMR) are smaller reactors that minimize the chances of runaway chain reactions.

Figure 16-21

New and Safer Reactors

- Some oppose the pebble reactor due to :
  - A crack in the reactor could release radioactivity.
  - The design has been rejected by UK and Germany for safety reasons.
  - Lack of containment shell would make it easier for terrorists to blow it up or steal radioactive material.
  - Creates higher amount of nuclear waste and increases waste storage expenses.

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