Nonrenewable Energy

Chapter 15

Core Case Study: How Long Will Supplies of Conventional Oil Last?

- Oil: energy supplier
- How much is left? When will we run out?
- Three options
  - Look for more
  - Reduce oil use and waste
  - Use other energy sources
- No easy solutions

Thunder Horse Offshore Floating Oil Production Platform in the Gulf of Mexico

15-1 What Major Sources of Energy Do We Use?

- ***Concept 15-1A*** *About three-quarters of the world's commercial energy comes from nonrenewable fossil fuels and the rest comes from nonrenewable nuclear fuel and renewable sources.*

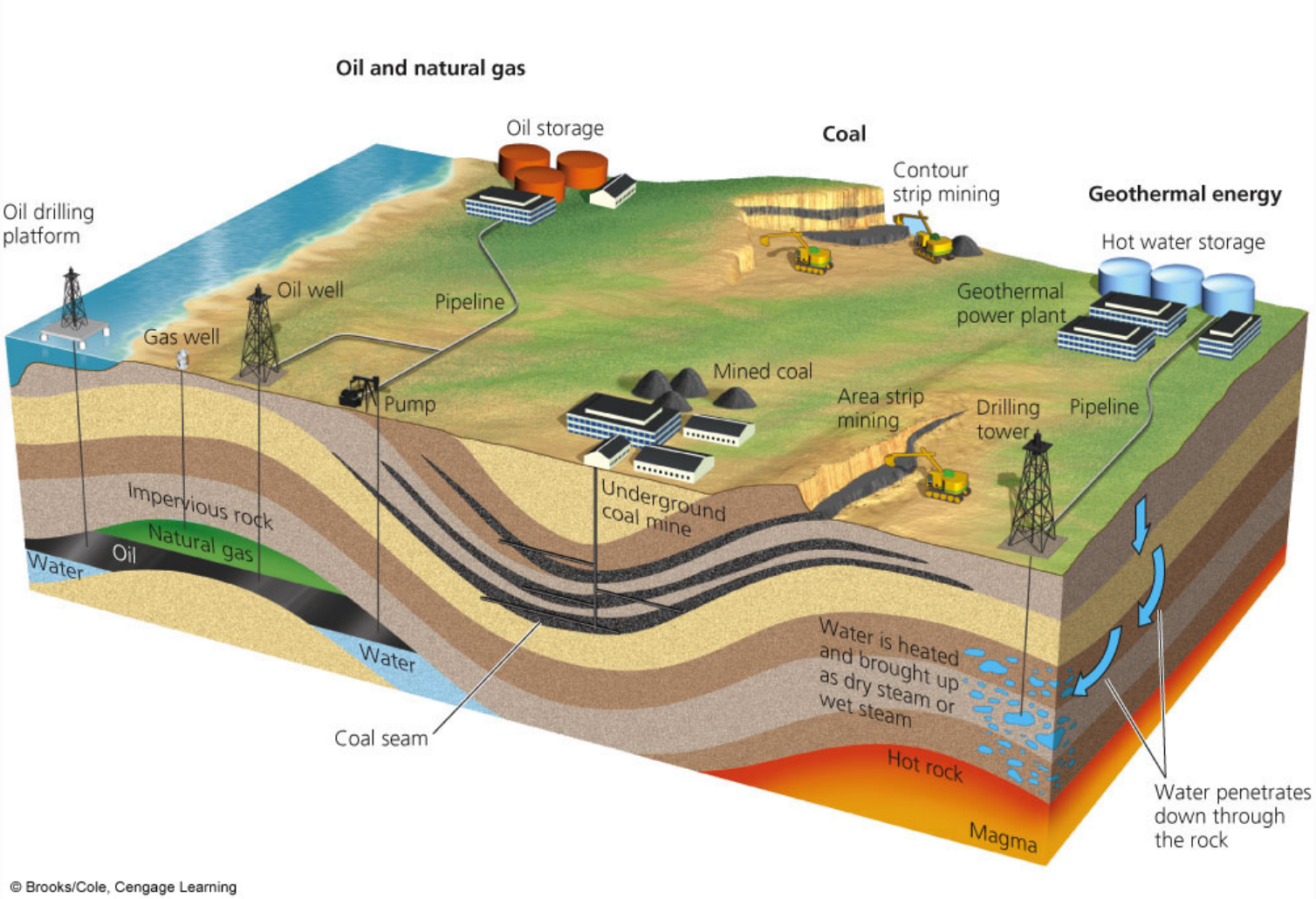
- ***Concept 15-1B*** *Net energy is the amount of high-quality usable energy available from a resource after the amount of energy needed to make it available is subtracted.*

Fossil Fuels Supply Most of Our Commercial Energy

- Solar energy
- Indirect solar energy
  - Wind
  - Hydropower
  - Biomass

- Commercial energy
  - Nonrenewable energy resources, e.g. fossil fuels
  - Renewable energy resources

Natural Capital: Important Nonrenewable Energy Resources



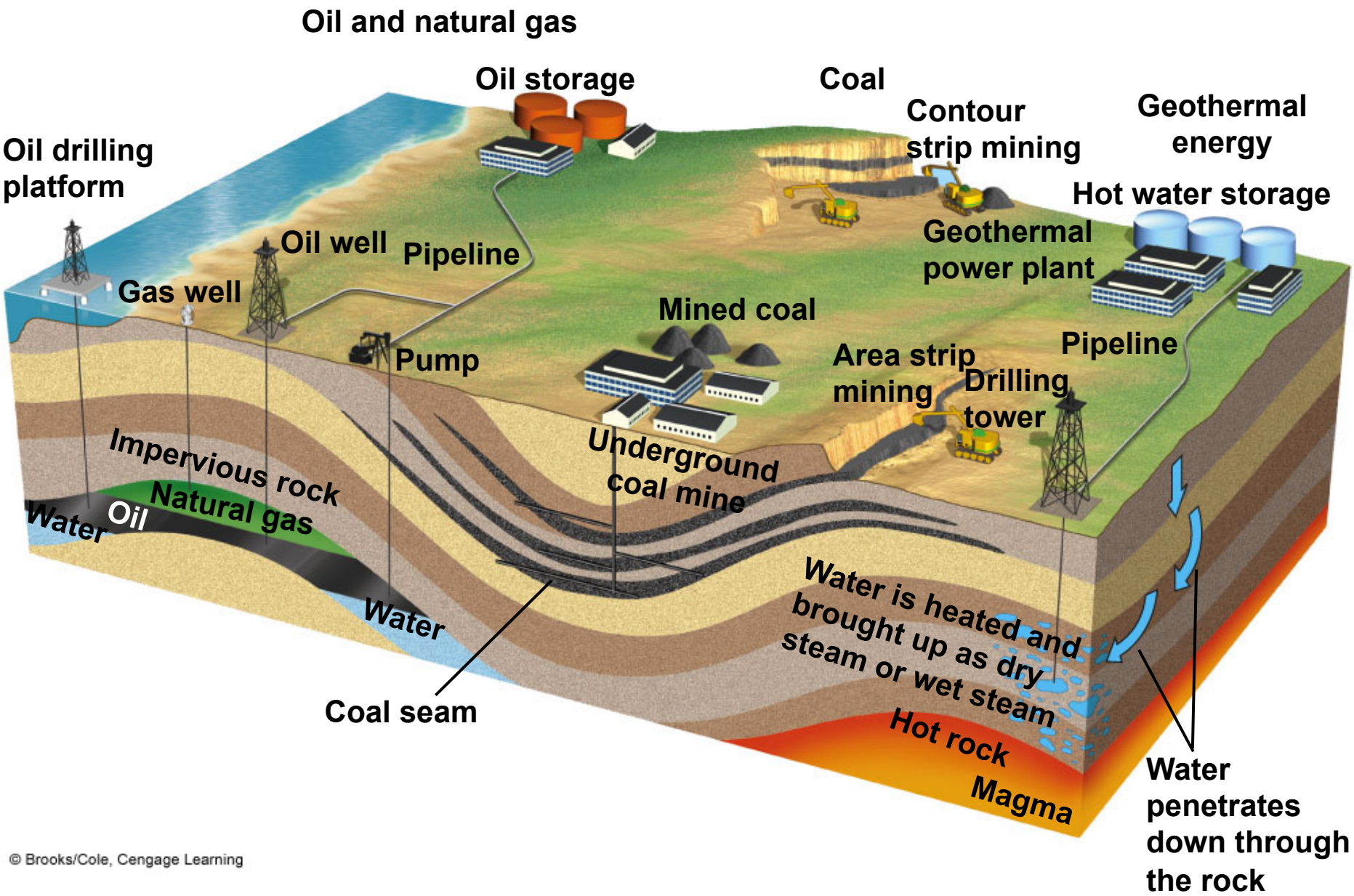
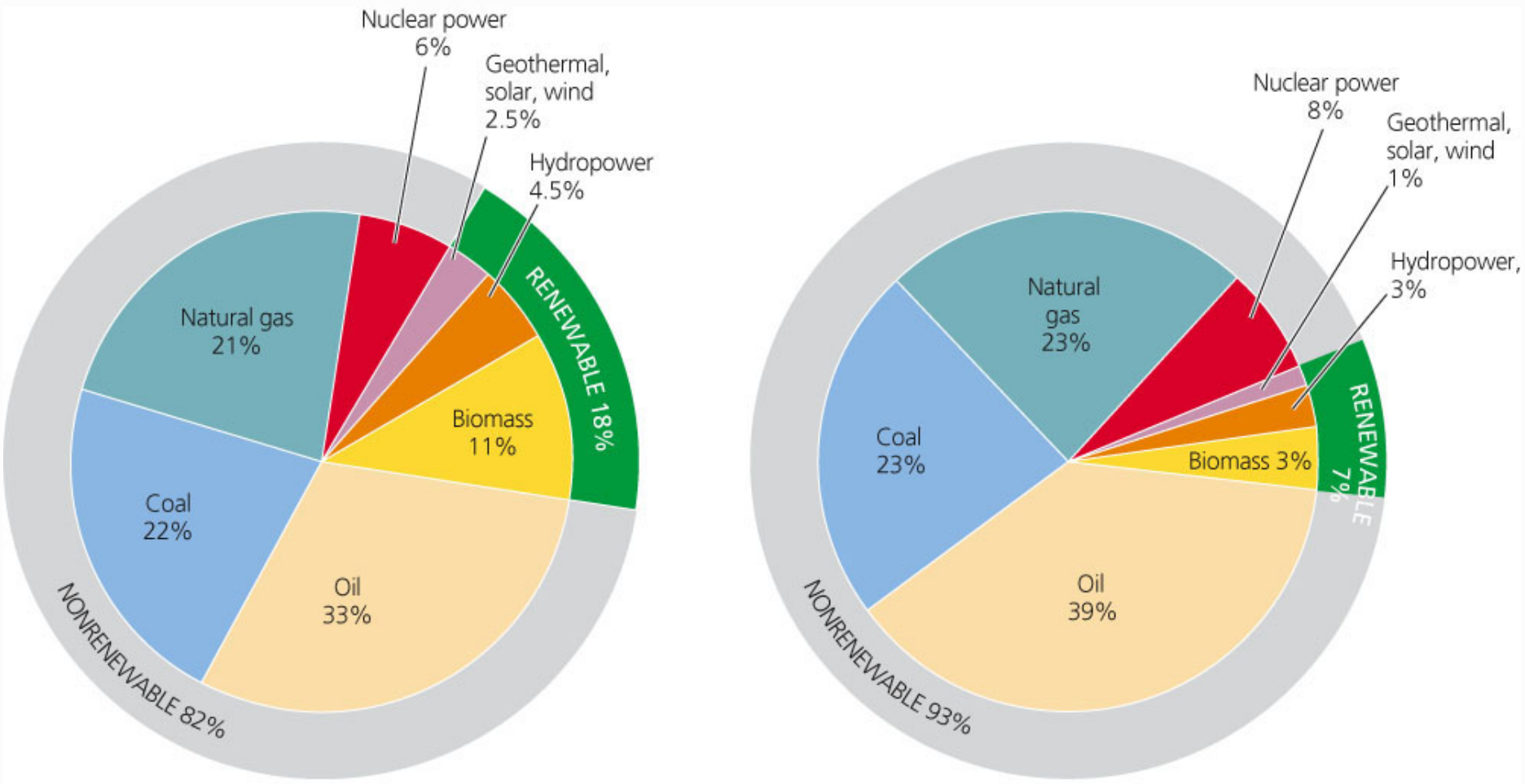
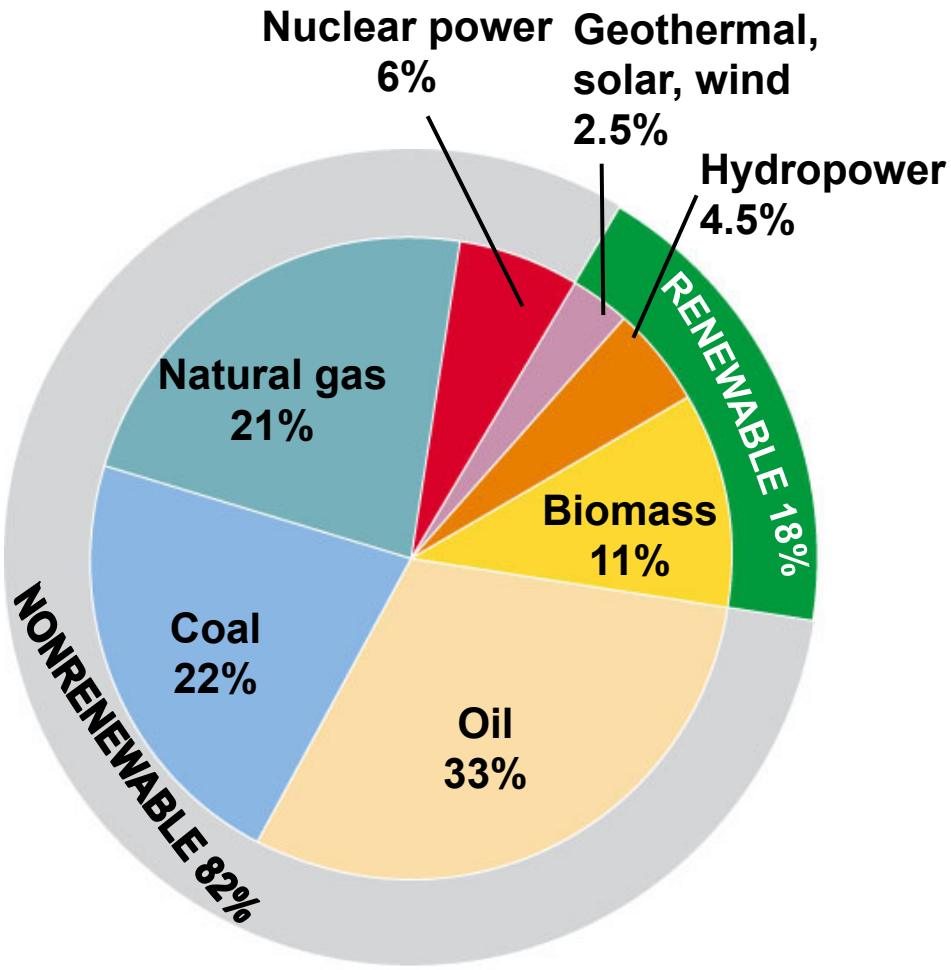


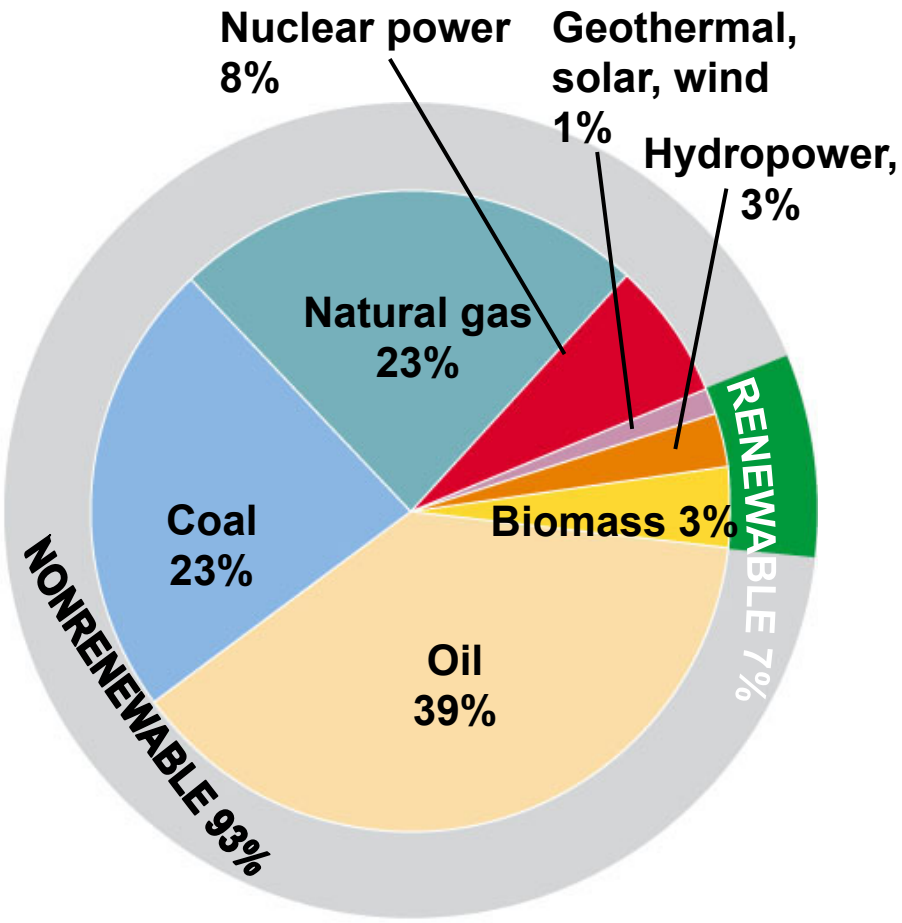
Fig. 15-2, p. 372

Commercial Energy Use by Source for the World and the United States





World



United States

Fig. 15-3, p. 373

Case Study: A Brief History of Human Energy Use

- Muscle power: early humans
- Discovery of fire
- Agriculture
- Use of wind and flowing water
- Machines powered by wood, then coal
- Internal combustion engine
- Nuclear energy
- Energy crisis

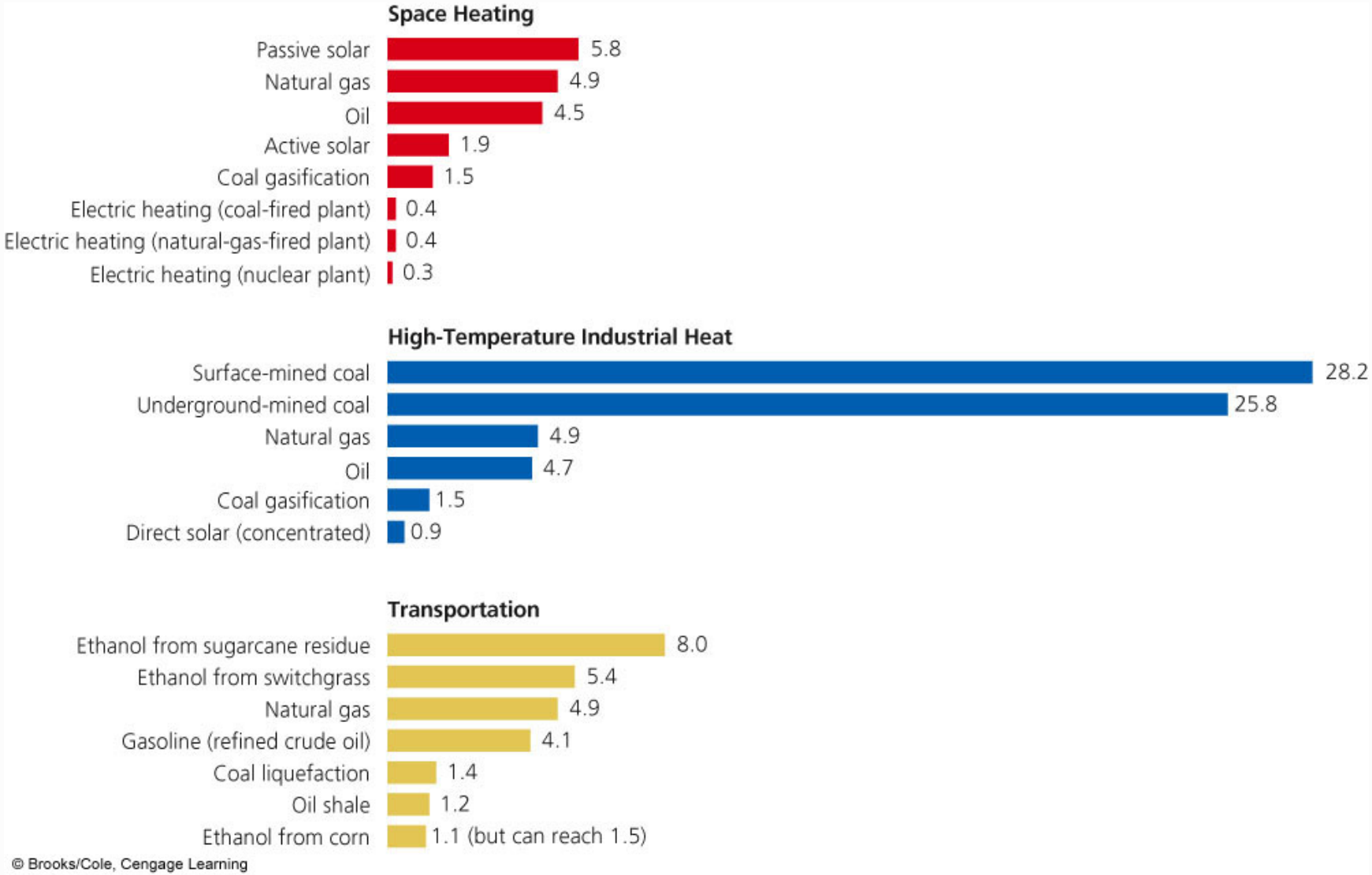
How Should We Evaluate Energy Resources?

- Supplies
- Environmental impact
- How much useful energy is provided?

Science Focus: Net Energy Is the Only Energy That Really Counts

- It takes energy to get energy
- Second Law of Thermodynamics
- **Net energy** expressed as **net energy ratio**
- Conventional oil: high net energy ratio
- Electricity produced by the **nuclear power fuel cycle**: low net energy ratio

Net Energy Ratios for Various Energy Systems over Their Estimated Lifetimes



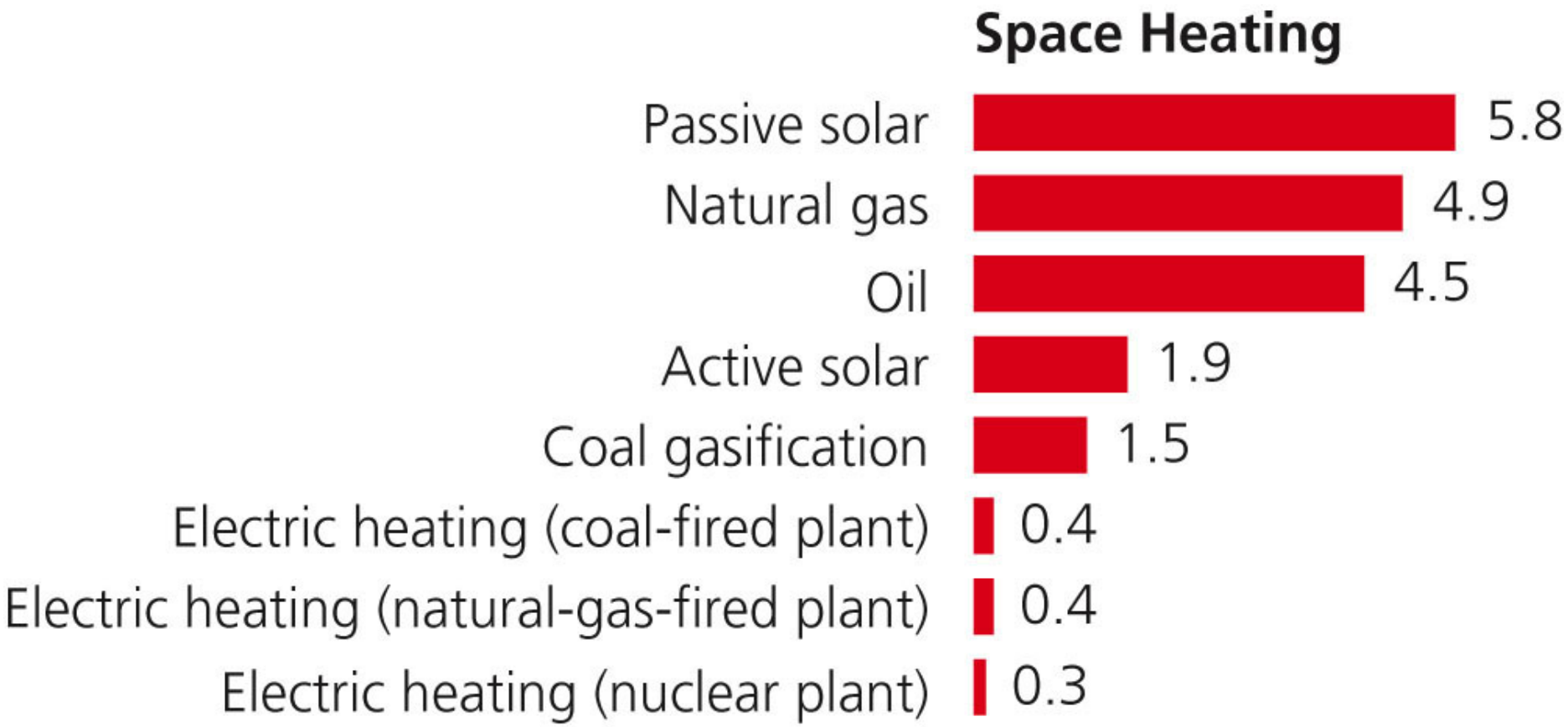


Fig. 15-A (1), p. 374

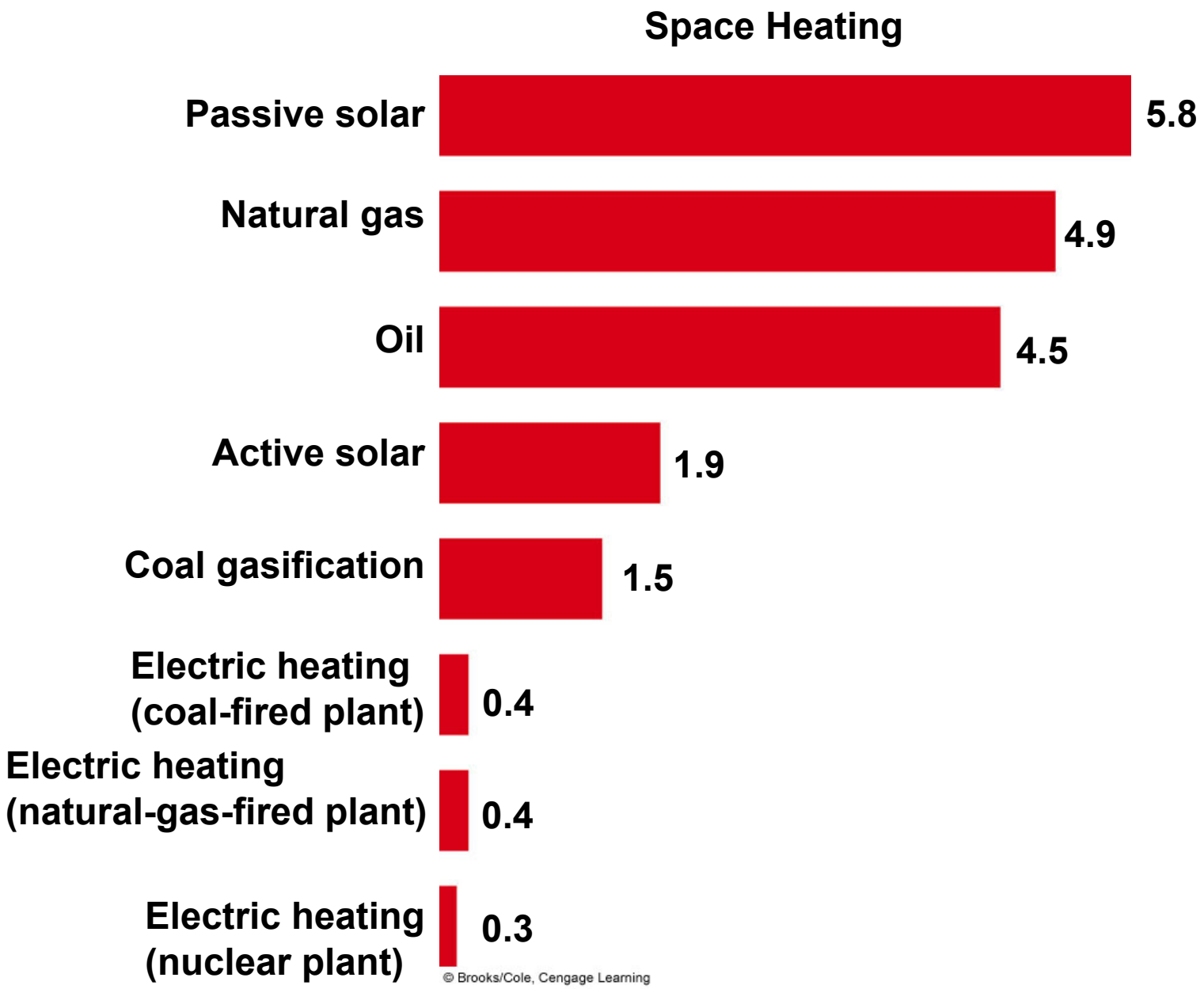
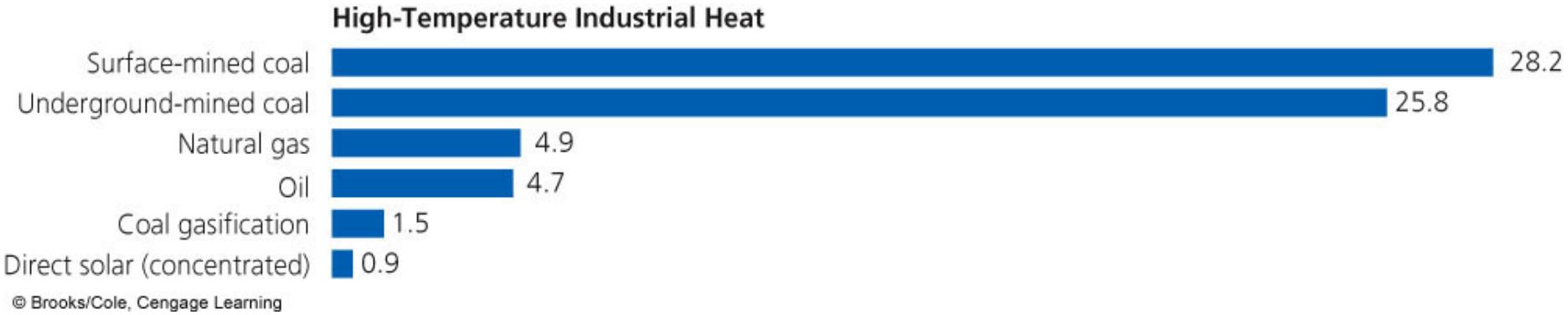


Fig. 15-A (1), p. 374



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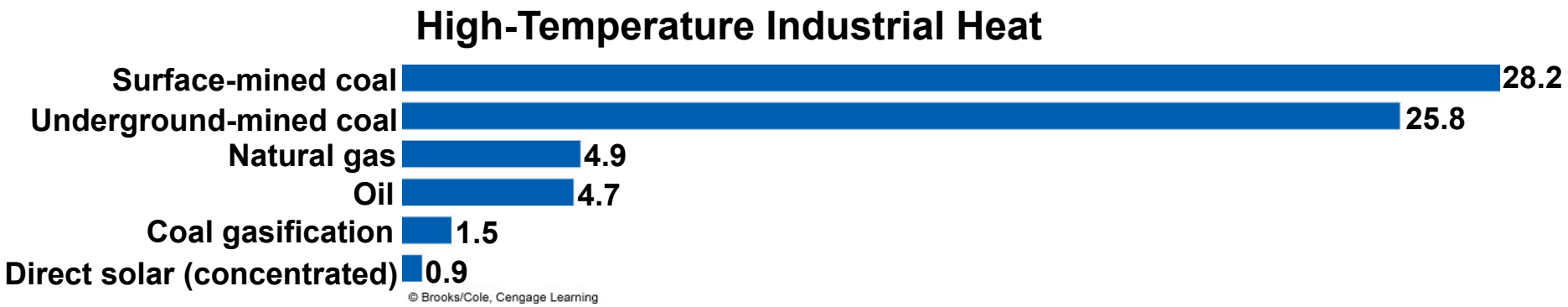
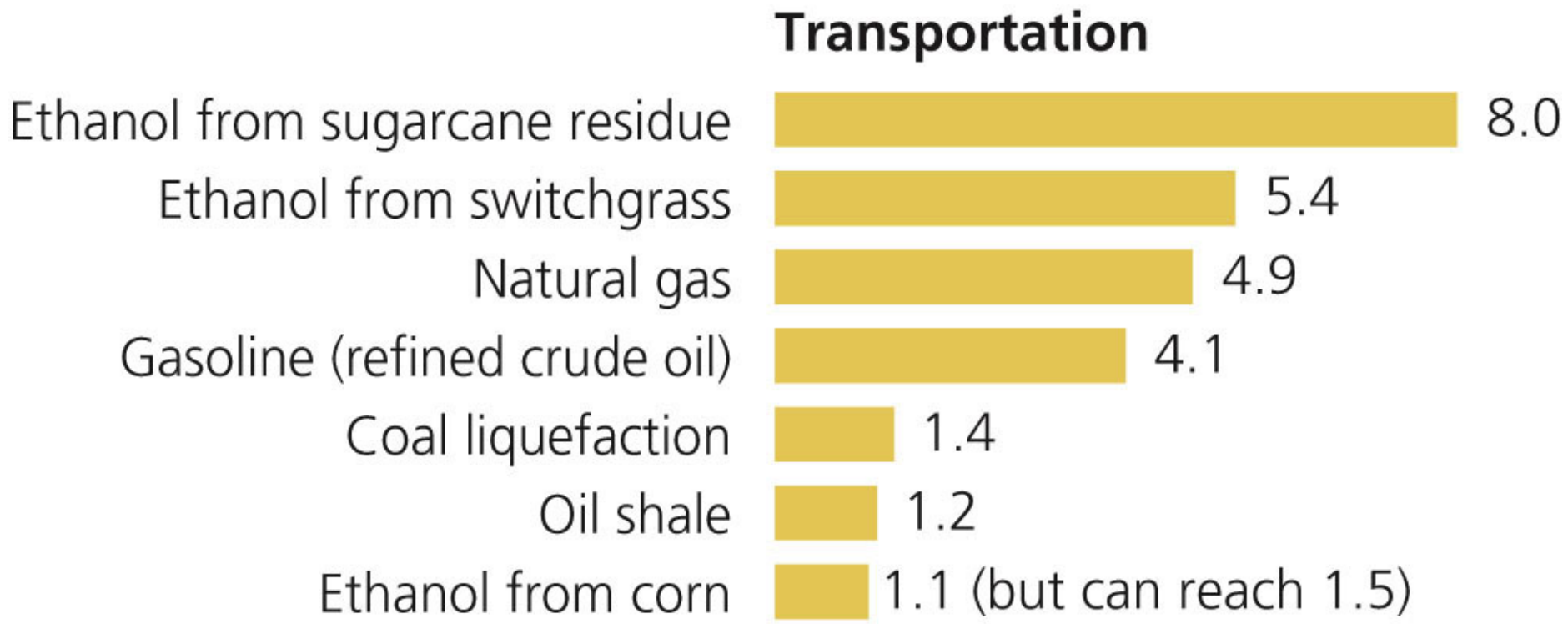


Fig. 15-A (2), p. 374



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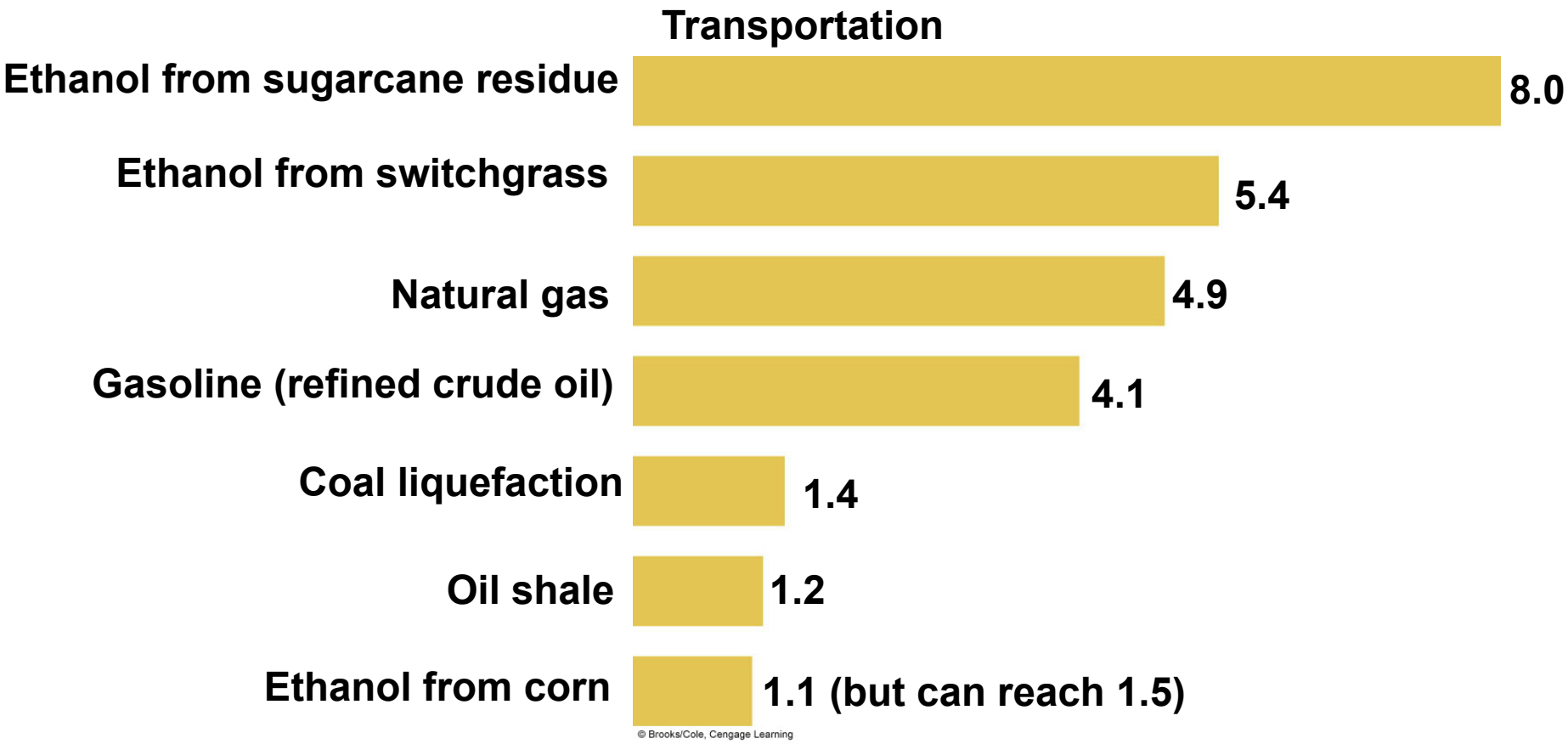

Fig. 15-A (3), p. 374

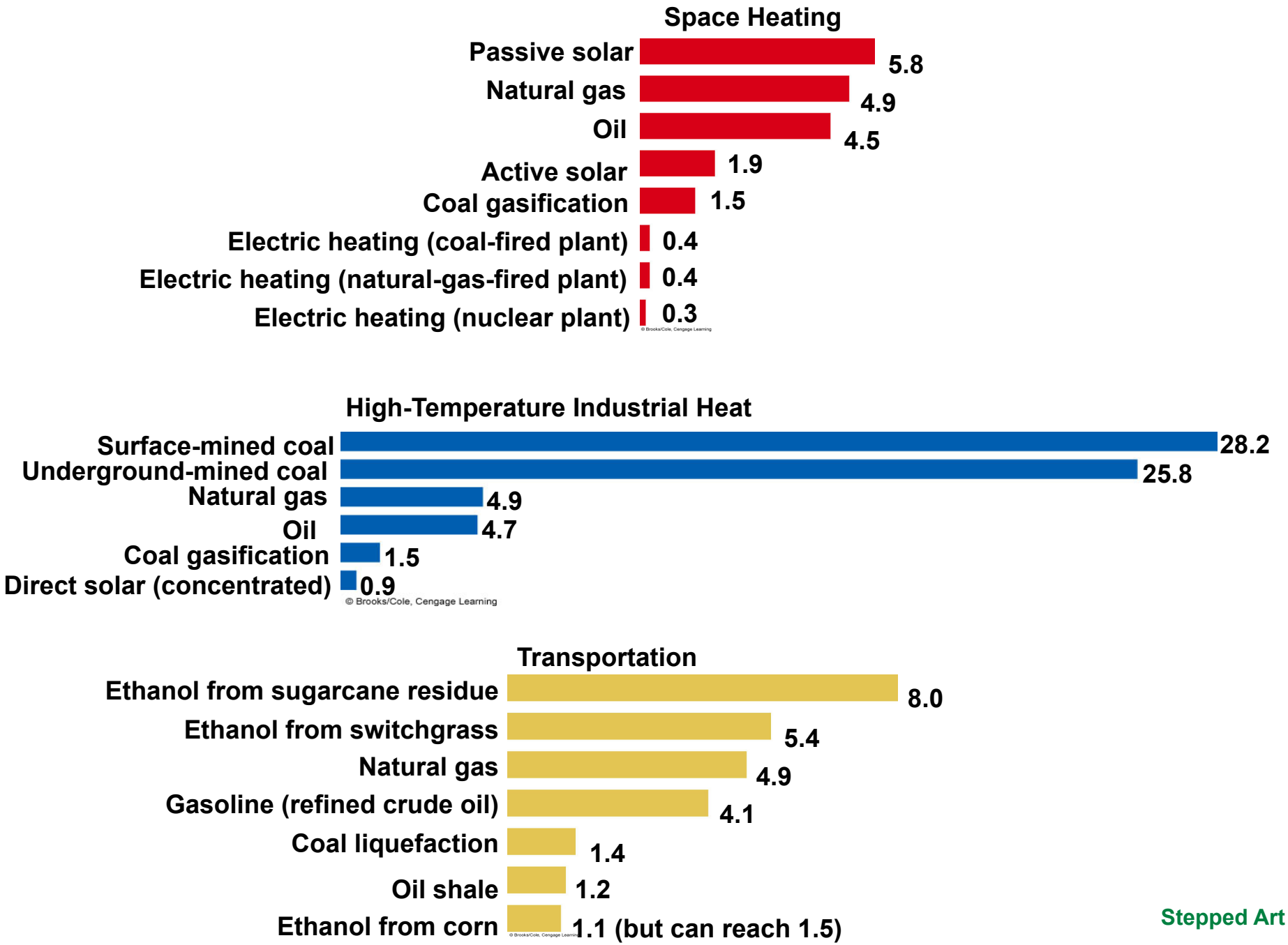

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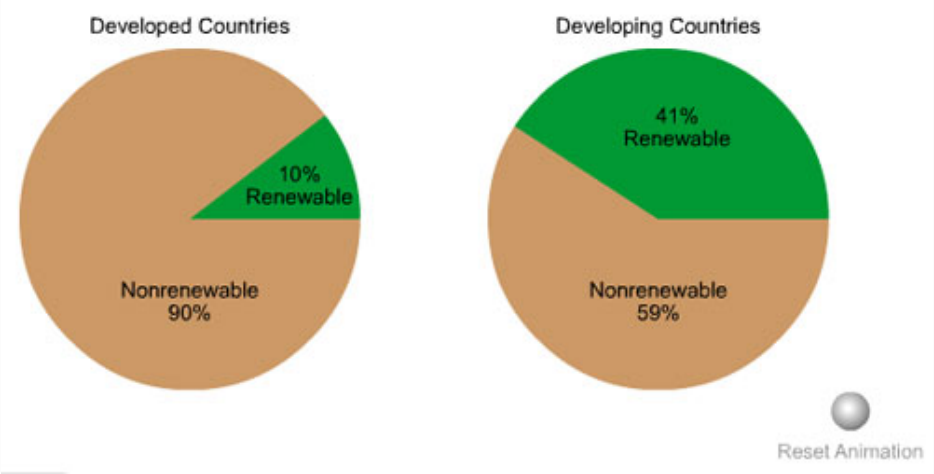
Fig. 15-A, p. 374

Animation: Energy use



PLAY

15-2 What Are the Advantages and Disadvantages of Oil?

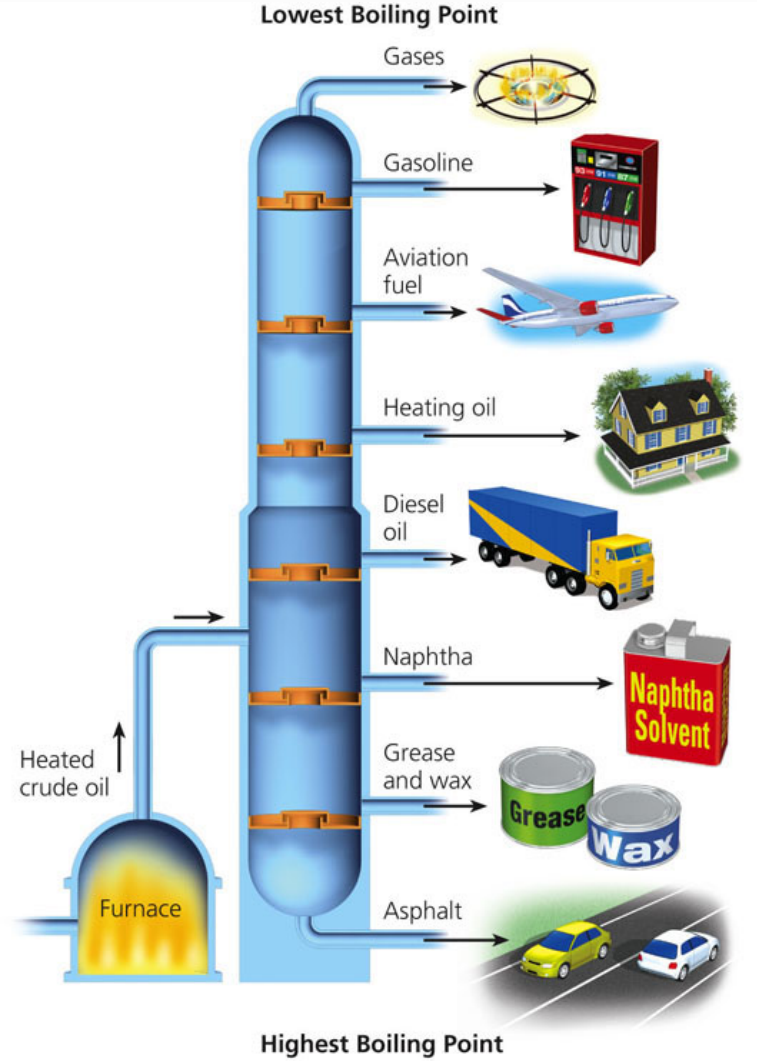
- ***Concept 15-2A*** *Conventional oil is currently abundant, has a high net energy yield, and is relatively inexpensive, but using it causes air and water pollution and releases greenhouse gases to the atmosphere.*

- ***Concept 15-2B*** *Heavy oils from oil sand and oil shale exist in potentially large supplies but have low net energy yields and higher environmental impacts than conventional oil has.*

We Depend Heavily on Oil

- **Petroleum**, or **crude oil = conventional**, or **light oil**
- **Fossil fuels**: **crude oil** and **natural gas**
- Oil extraction and refining
- **Petrochemicals**: products of oil distillation
- World oil consumption

Science: Refining Crude Oil



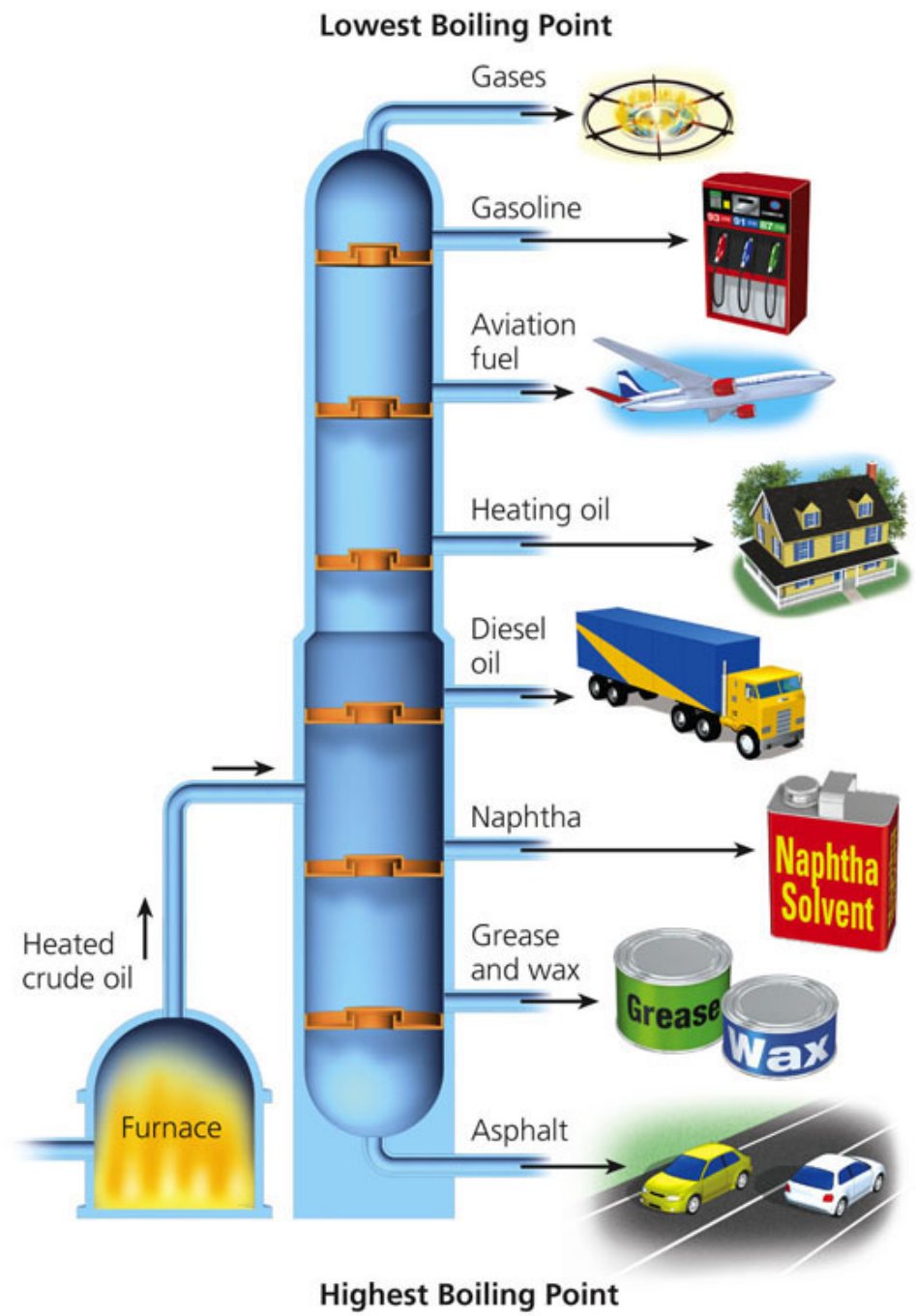


Fig. 15-4a, p. 375

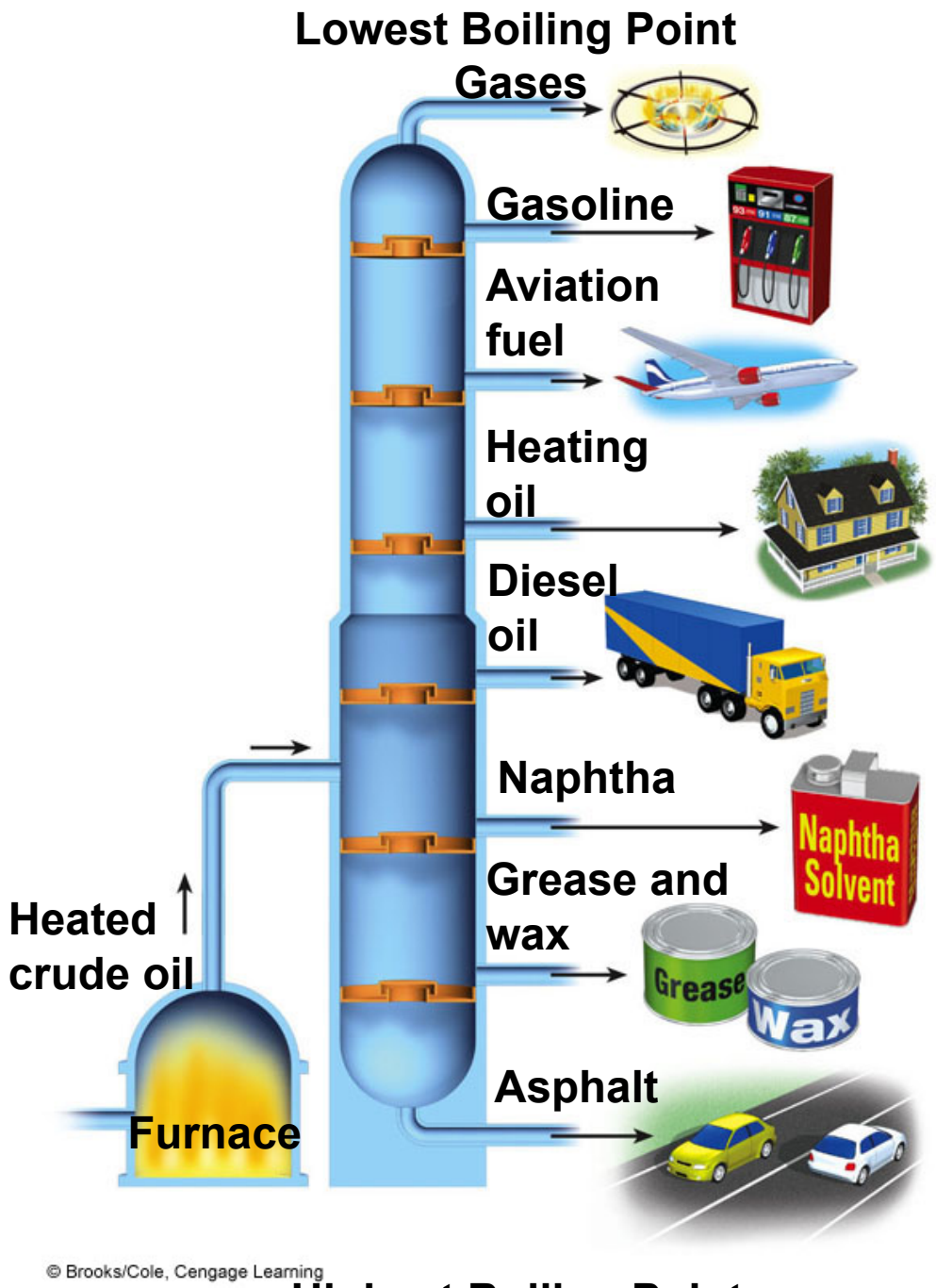


Fig. 15-4a, p. 375

Fig. 15-4b, p. 375

OPEC Controls Most of the World's Oil Supplies (1)

- 13 countries have at least 60% of the world's crude oil **reserves**
  - Saudi Arabia: 25%
  - Canada: 15%

- Oil production peaks and flow rates to consumers

OPEC Controls Most of the World's Oil Supplies (2)

- Possible effects of steeply rising oil prices
  - Reduce energy waste
  - Shift to non-carbon energy sources
  - Higher prices for products made with petrochemicals
  - Higher food prices; buy locally-produced food
  - Airfares higher
  - Smaller more fuel-efficient vehicles
  - Upgrade of public transportation

The United States Uses Much More Oil Than It Produces (1)

- Produces 9% of the world's oil
- Imports 60% of its oil
- About One-fourth of the world's conventional oil is controlled by countries that sponsor or condone terrorism

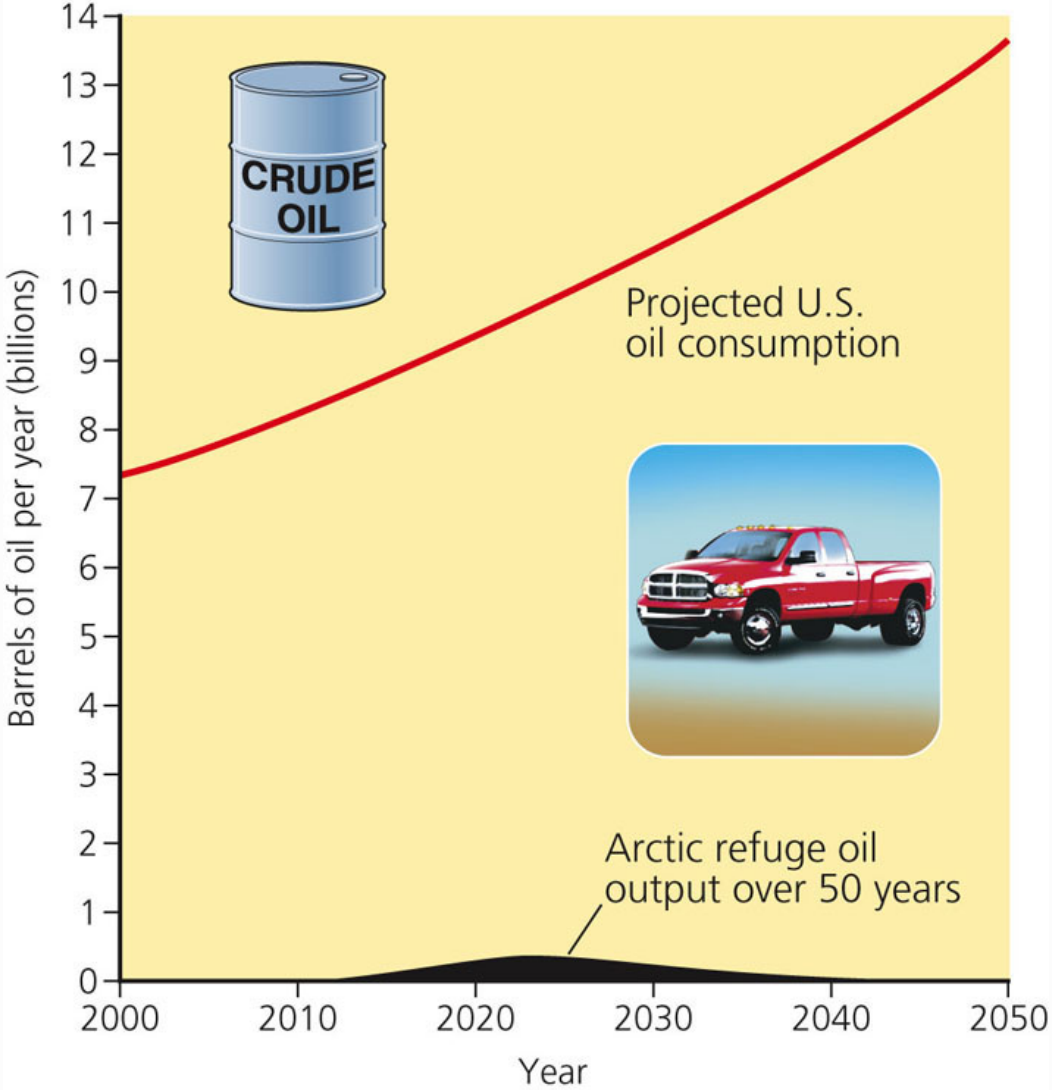
The United States Uses Much More Oil Than It Produces (2)

- Should we look for more oil reserves?
  - Extremely difficult
  - Expensive and financially risky
- A new role for bacteria in the oil industry

Case Study: Oil and the U.S. Arctic National Wildlife Refuge

- The Arctic National Wildlife Refuge (ANWR)
  - Not open to oil and gas development
  - Fragile tundra biome
- Oil companies lobbying since 1980 to begin exploratory drilling
  - Pros
  - Cons

The Amount of Oil That Might Be Found in the ANWR



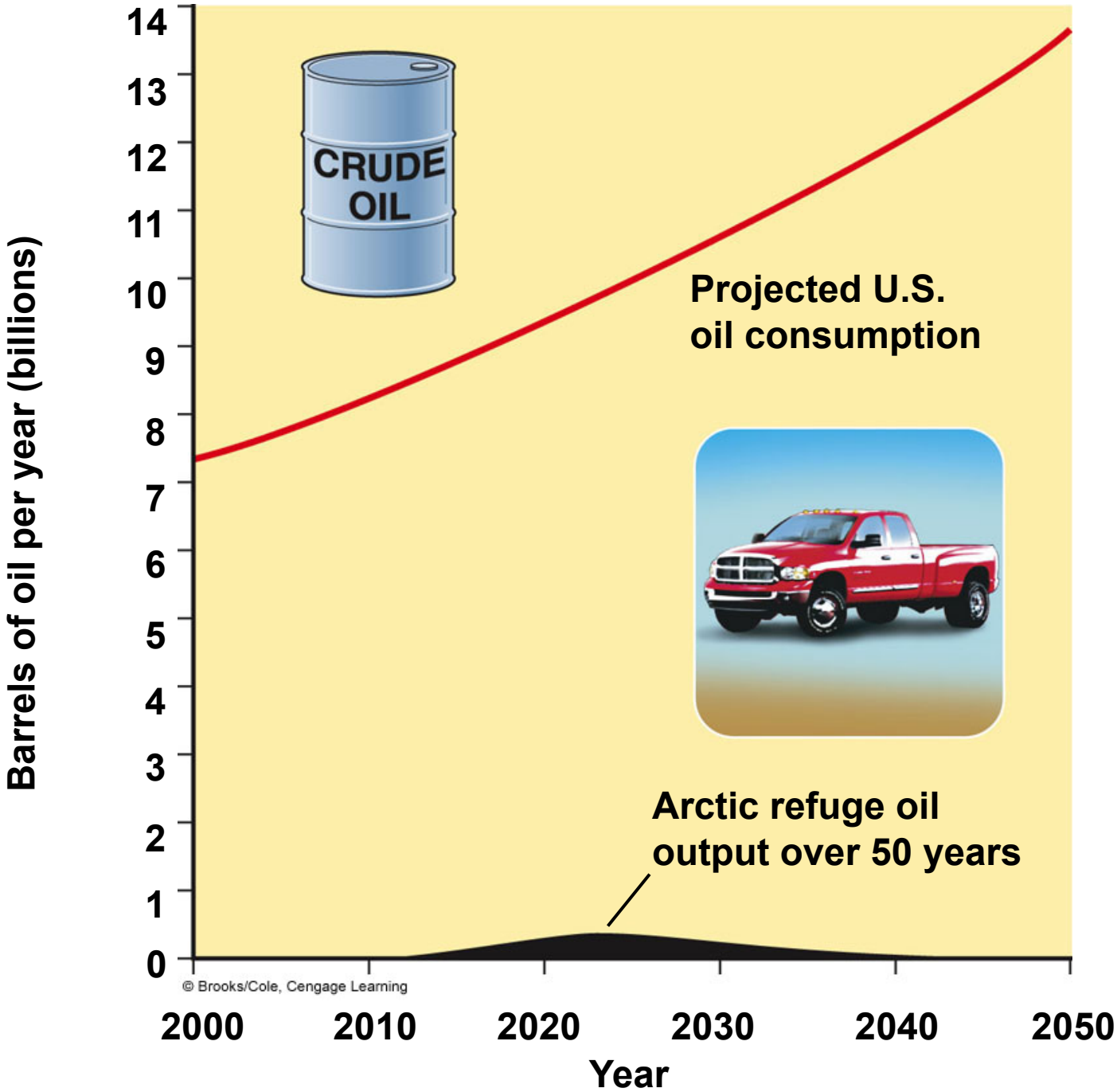

Barrels of oil per year (billions)
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
CRUDE OIL
Projected U.S. oil consumption
Arctic refuge oil output over 50 years
© Brooks/Cole, Cengage Learning
2000
2010
2020
2030
2040
2050
Year

Fig. 15-5, p. 378

Conventional Oil Has Advantages and Disadvantages

- Extraction, processing, and burning of nonrenewable oil and other fossil fuels
  - Advantages
  - Disadvantages

Trade-Offs: Conventional Oil, Advantages and Disadvantages

TRADE-OFFS

Conventional Oil

Advantages

- Ample supply for 42–93 years
- Low cost
- High net energy yield
- Easily transported within and between countries
- Low land use
- Technology is well developed
- Efficient distribution system

Disadvantages

- Need to find substitutes within 50 years
- Large government subsidies
- Environmental costs not included in market price
- Artificially low price encourages waste and discourages search for alternatives
- Pollutes air when produced and burned
- Releases CO_2 when burned
- Can cause water pollution

TRADE-OFFS

Conventional Oil

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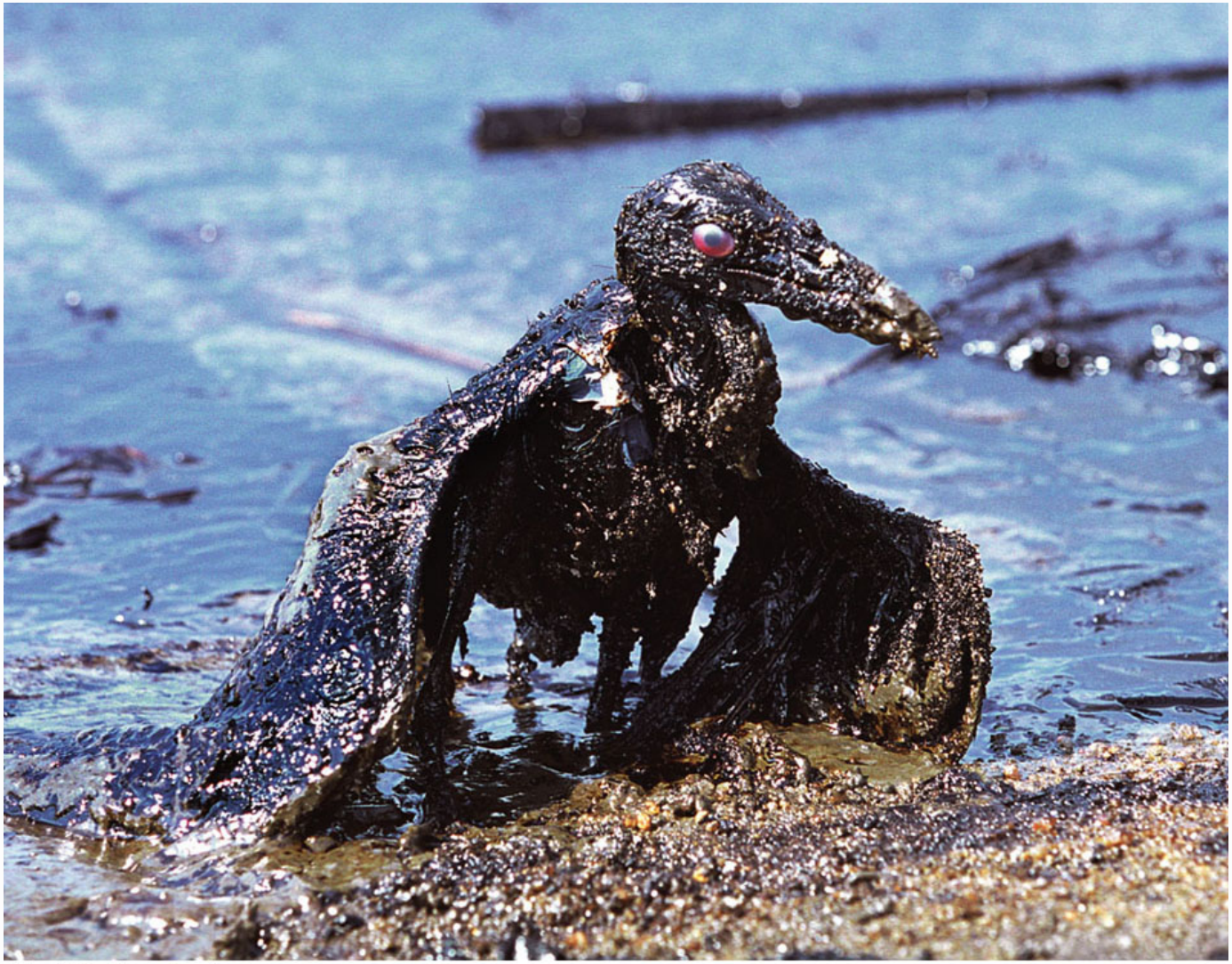
Pollutes air when produced and burned

Releases CO_2 when burned

Can cause water pollution

Fig. 15-6, p. 379

Bird Covered with Oil from an Oil Spill in Brazilian Waters



Will Heavy Oil Spills from Oil Sand Be a Viable Option?

- **Oil sand, tar sand** contains **bitumen**
- Canada and Venezuela: oil sand have more oil than in Saudi Arabia
- Extraction
  - Serious environmental impact before strip-mining
  - Low net energy yield: Is it cost effective?

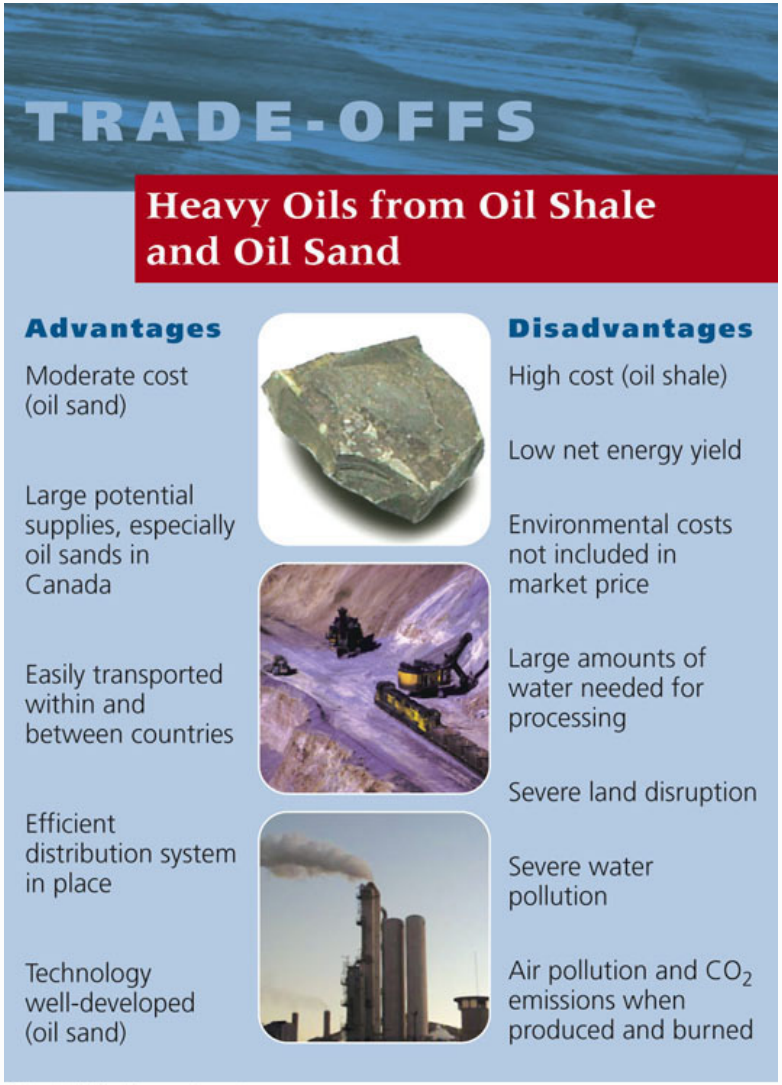
Will Oil Shales Be a Useable Resource?

- **Oil shales** contain **kerogen**
  - After distillation: **shale oil**

- 72% of the world's reserve is in arid areas of western United States; there is a catch!
  - Locked up in rock
  - Lack of water needed for extraction and processing
  - Low net energy yield

Oil Shale Rock and the Shale Oil Extracted from It

Trade-Offs: Heavy Oils from Oil Shale and Oil Sand



TRADE-OFFS

Heavy Oils from Oil Shale and Oil Sand

Advantages

Moderate cost (oil sand)

Large potential supplies, especially oil sands in Canada

Easily transported within and between countries

Efficient distribution system in place

Technology well-developed (oil sand)

Disadvantages

High cost (oil shale)

Low net energy yield

Environmental costs not included in market price

Large amounts of water needed for processing

Severe land disruption

Severe water pollution

Air pollution and CO_2 emissions when produced and burned

Fig. 15-9, p. 380

15-3 What Are the Advantages and Disadvantages of Natural Gas?

- ***Concept 15-3*** *Conventional natural gas is more plentiful than oil, has a high net energy yield and a fairly low cost, and has the lowest environmental impact of all fossil fuels.*

Natural Gas Is a Useful and Clean-Burning Fossil Fuel (1)

- **Natural gas:** mixture of gases
  - More than half is **CH_4**

- **Conventional natural gas**
  - Pipelines
  - **Liquefied petroleum gas (LPG)**
  - **Liquefied natural gas (LNG)** – low net energy yield

Natural Gas Is a Useful and Clean-Burning Fossil Fuel (2)

- Unconventional natural gas
  - Coal bed methane gas
  - Methane hydrate

Natural Gas Has More Advantages Than Disadvantages

- Will natural gas be the bridge fuel helping us make the transition to a more sustainable energy future?

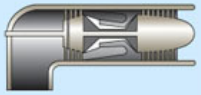
Trade-Offs: Conventional Natural Gas

TRADE-OFFS

Conventional Natural Gas

Advantages

- Ample supplies
- High net energy yield
- Low cost
- Less air pollution than other fossil fuels
- Lower CO_2 emissions than other fossil fuels
- Easily transported by pipeline
- Low land use
- Good fuel for fuel cells, gas turbines, and motor vehicles



Gas turbine

Disadvantages

- Nonrenewable resource
- Releases CO_2 when burned
- Government subsidies
- Environmental costs not included in market price
- Methane (a greenhouse gas) can leak from pipelines
- Difficult to transfer from one country to another
- Can be shipped across ocean only as highly explosive LNG

TRADE-OFFS

Conventional Natural Gas

Advantages

Ample supplies

High net energy yield

Low cost

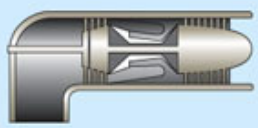
Less air pollution than other fossil fuels

Lower CO_2 emissions than other fossil fuels

Easily transported by pipeline

Low land use

Good fuel for fuel cells, gas turbines, and motor vehicles



Gas turbine

Disadvantages

Nonrenewable resource

Releases CO_2 when burned

Government subsidies

Environmental costs not included in market price

Methane (a greenhouse gas) can leak from pipelines

Difficult to transfer from one country to another

Can be shipped across ocean only as highly explosive LNG

Fig. 15-10, p. 382

15-4 What Are the Advantages and Disadvantages of Coal?

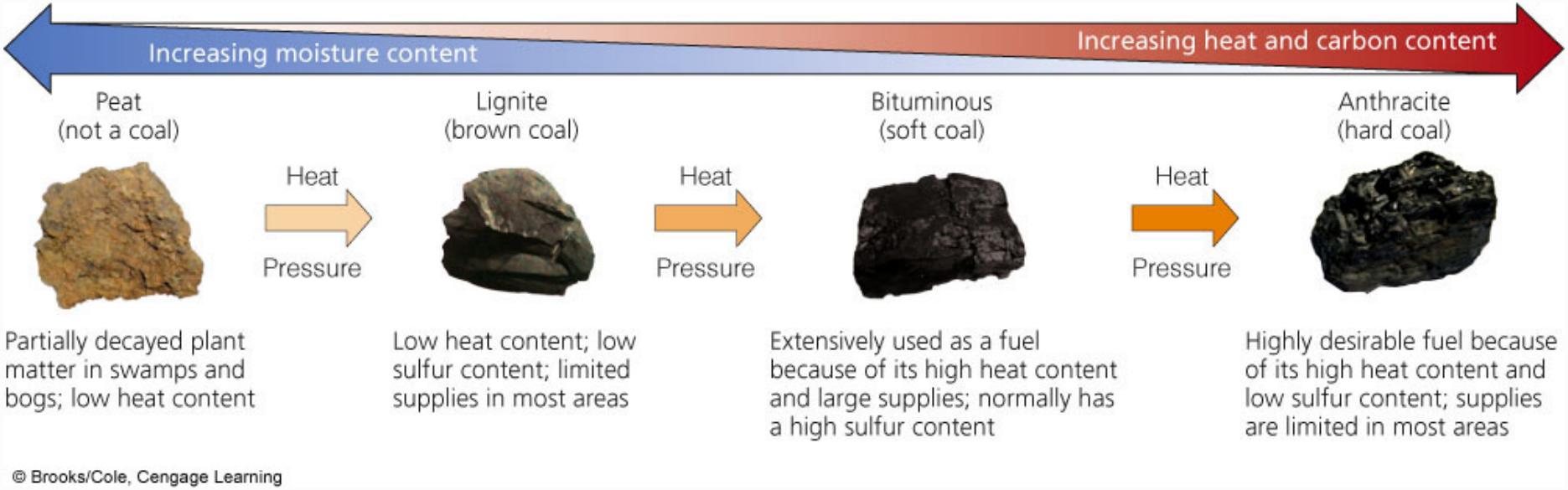
- ***Concept 15-4A*** *Conventional coal is very plentiful and has a high net energy yield and low cost, but it has a very high environmental impact.*

- ***Concept 15-4B*** *Gaseous and liquid fuels produced from coal could be plentiful, but they have lower net energy yields and higher environmental impacts than conventional coal has.*

Coal Comes in Several Forms and Is Burned Mostly to Produce Electricity

- **Coal**: solid fossil fuel
- Burned in 2100 power plants, generates 40% of the world's electricity
  - Inefficient
- Three largest coal-burning countries
  - China
  - United States
  - Canada

Stages in Coal Formation over Millions of Years



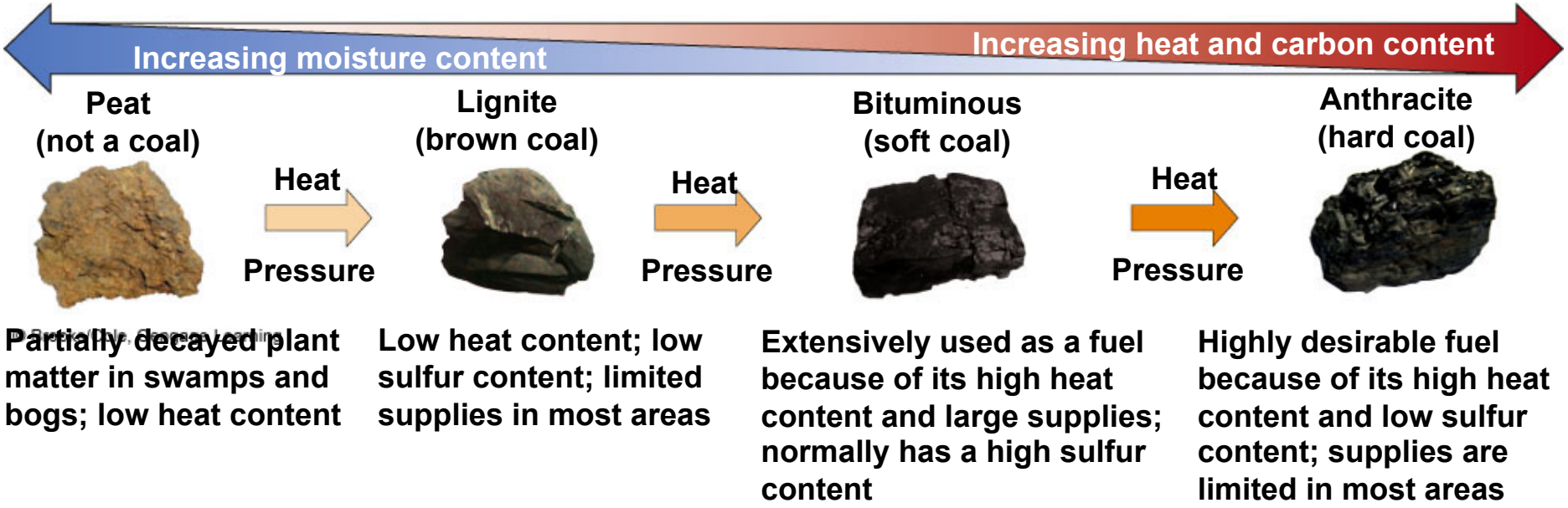


Fig. 15-11, p. 383

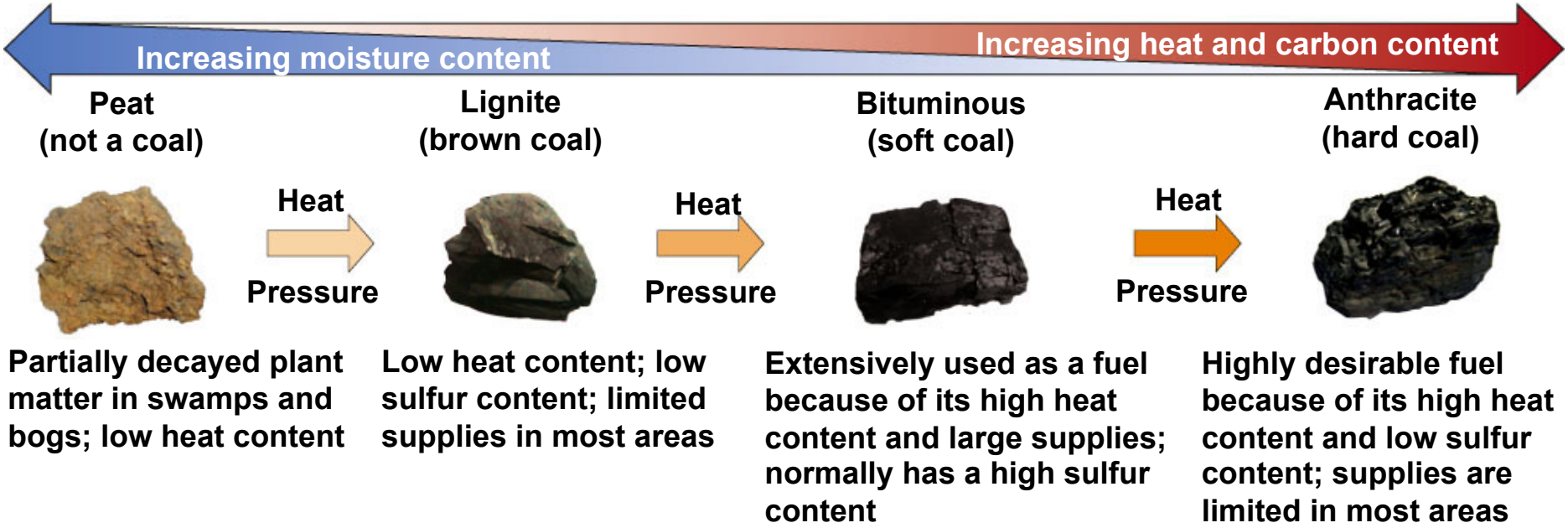


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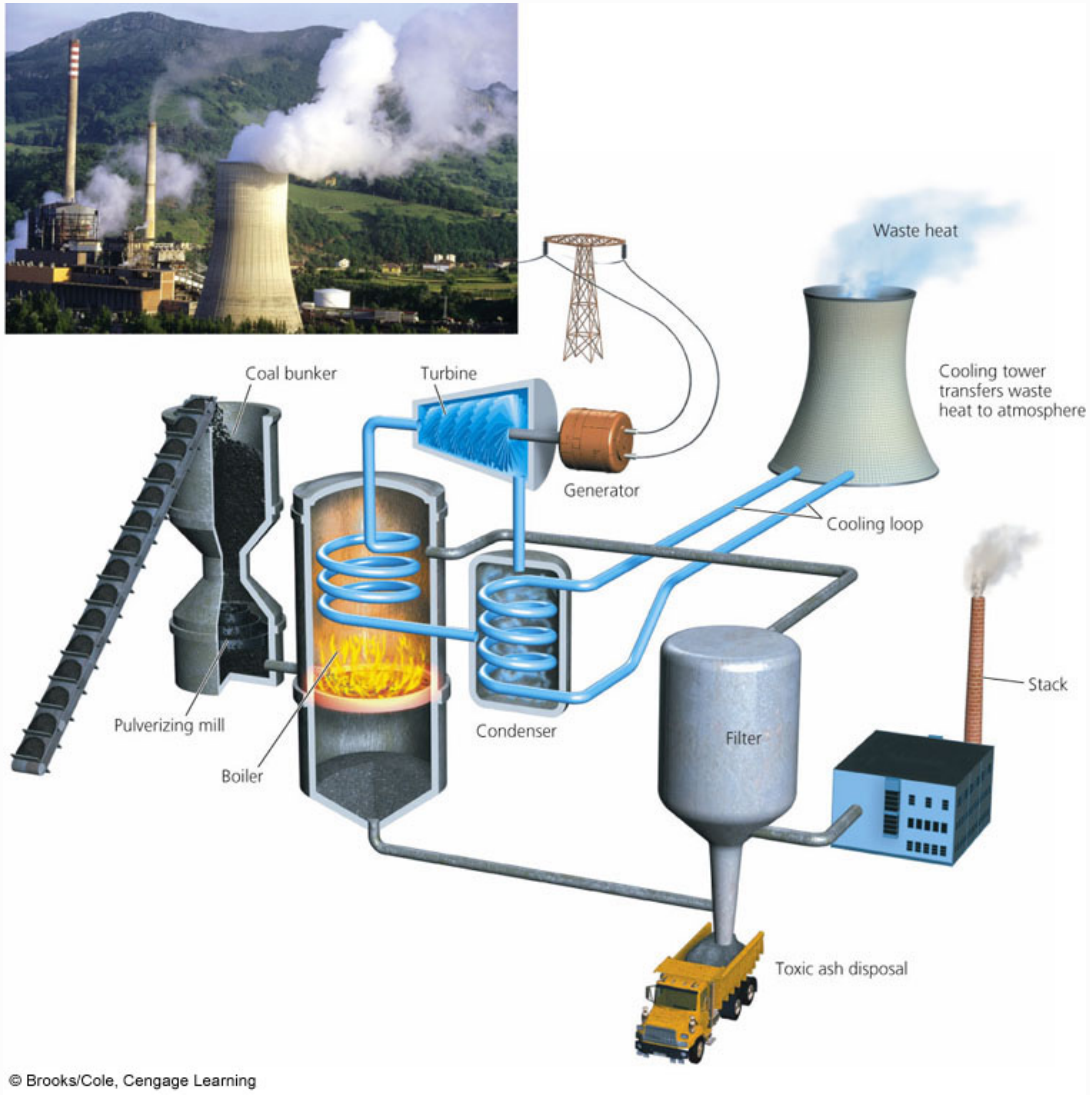
Fig. 15-11, p. 383

Science: Coal-Burning Power Plant



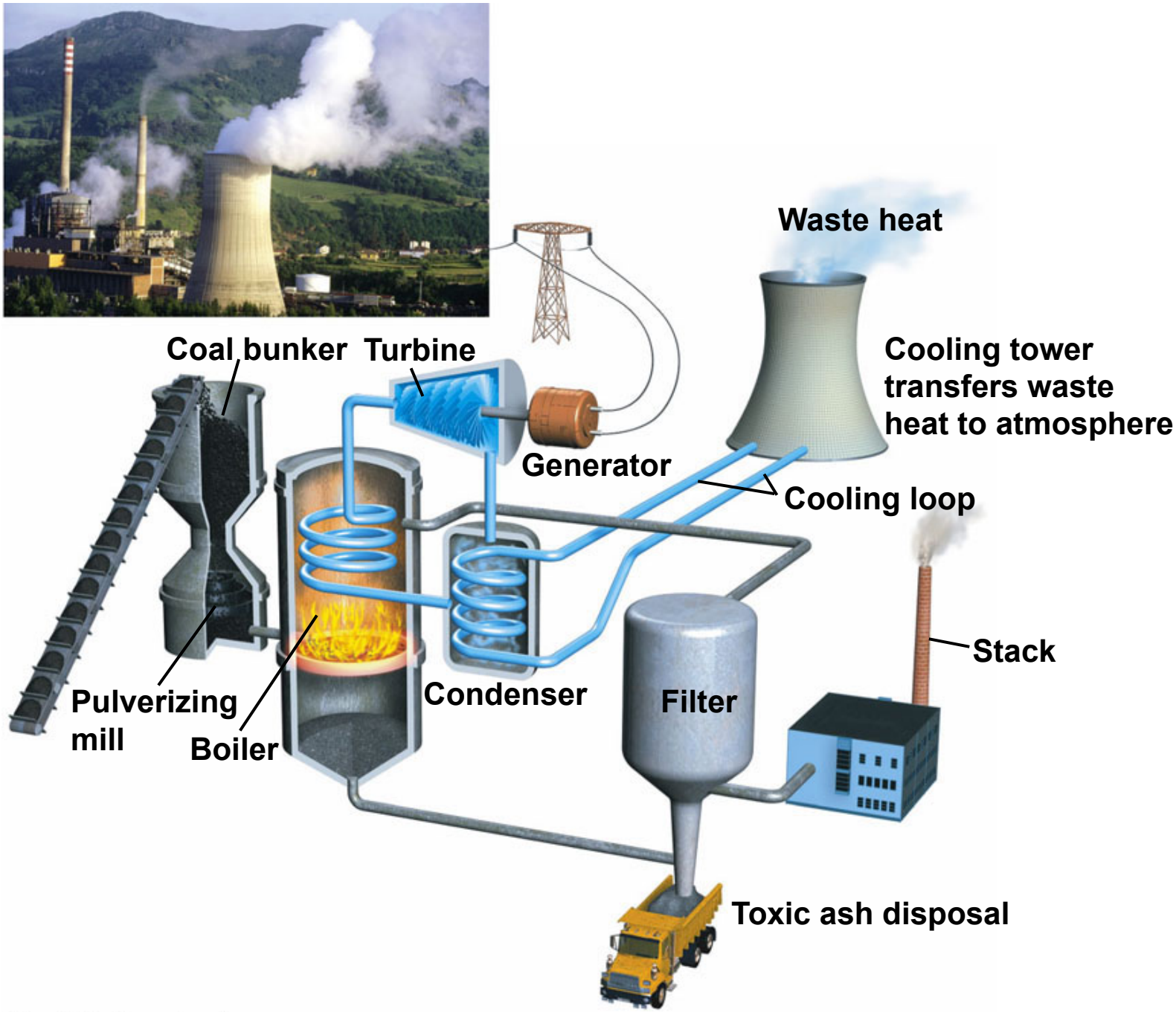


Fig. 15-12, p. 383

Coal Is a Plentiful but Dirty Fuel (1)

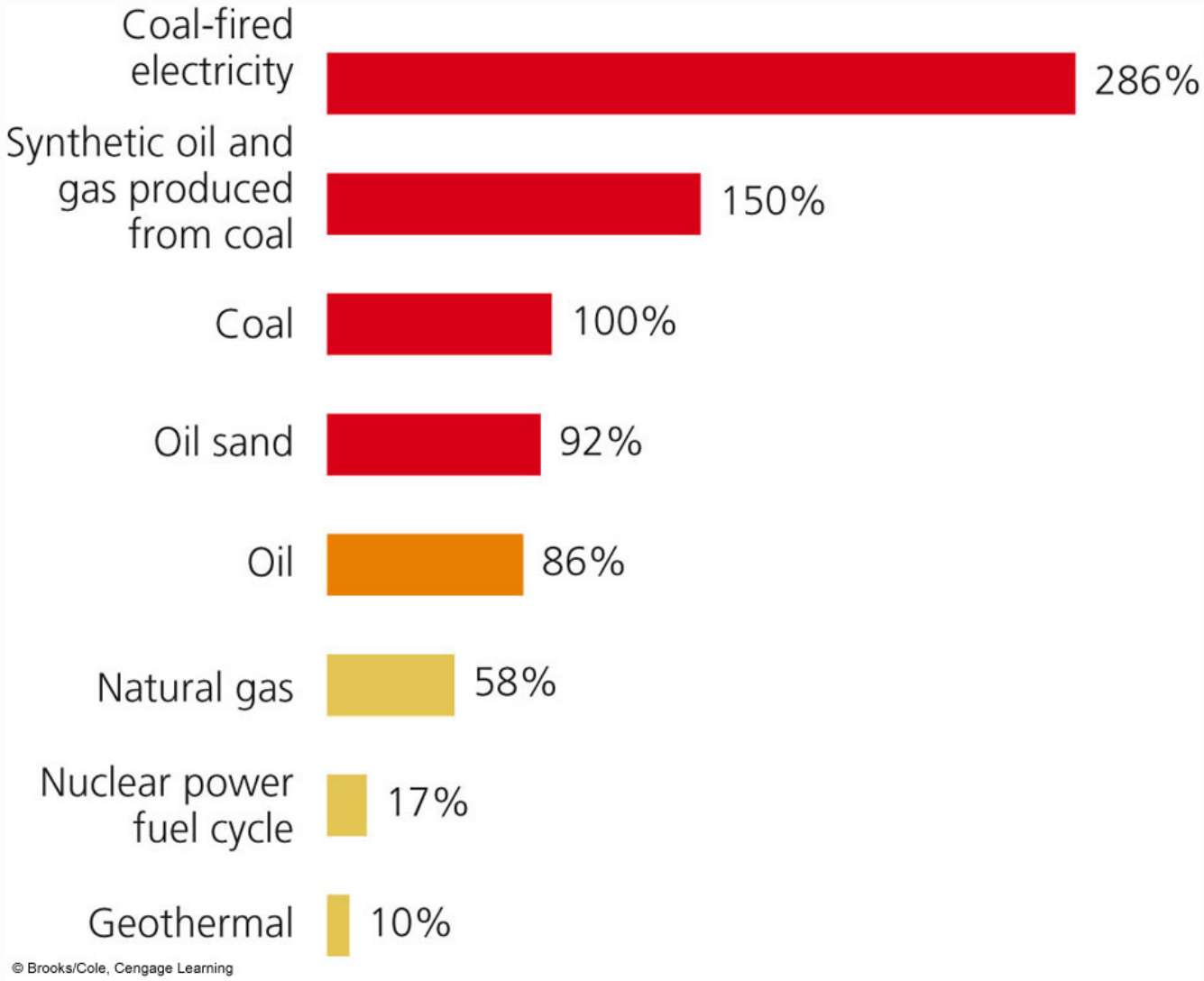
- World's most abundant fossil fuel
  - U.S. has 25%
- Environmental costs of burning coal
  - Severe air pollution
    - Sulfur released as SO_2
    - Large amount of soot
    - CO_2
    - Trace amounts of Hg and radioactive materials

Coal Is a Plentiful but Dirty Fuel (2)

- Environmentalists call for
  - Taxation on CO_2 production by power plants
  - Cleaner coal-burning plants

Air Pollution from a Coal-Burning Industrial Plant in India

CO_2 Emissions Per Unit of Electrical Energy Produced for Energy Sources



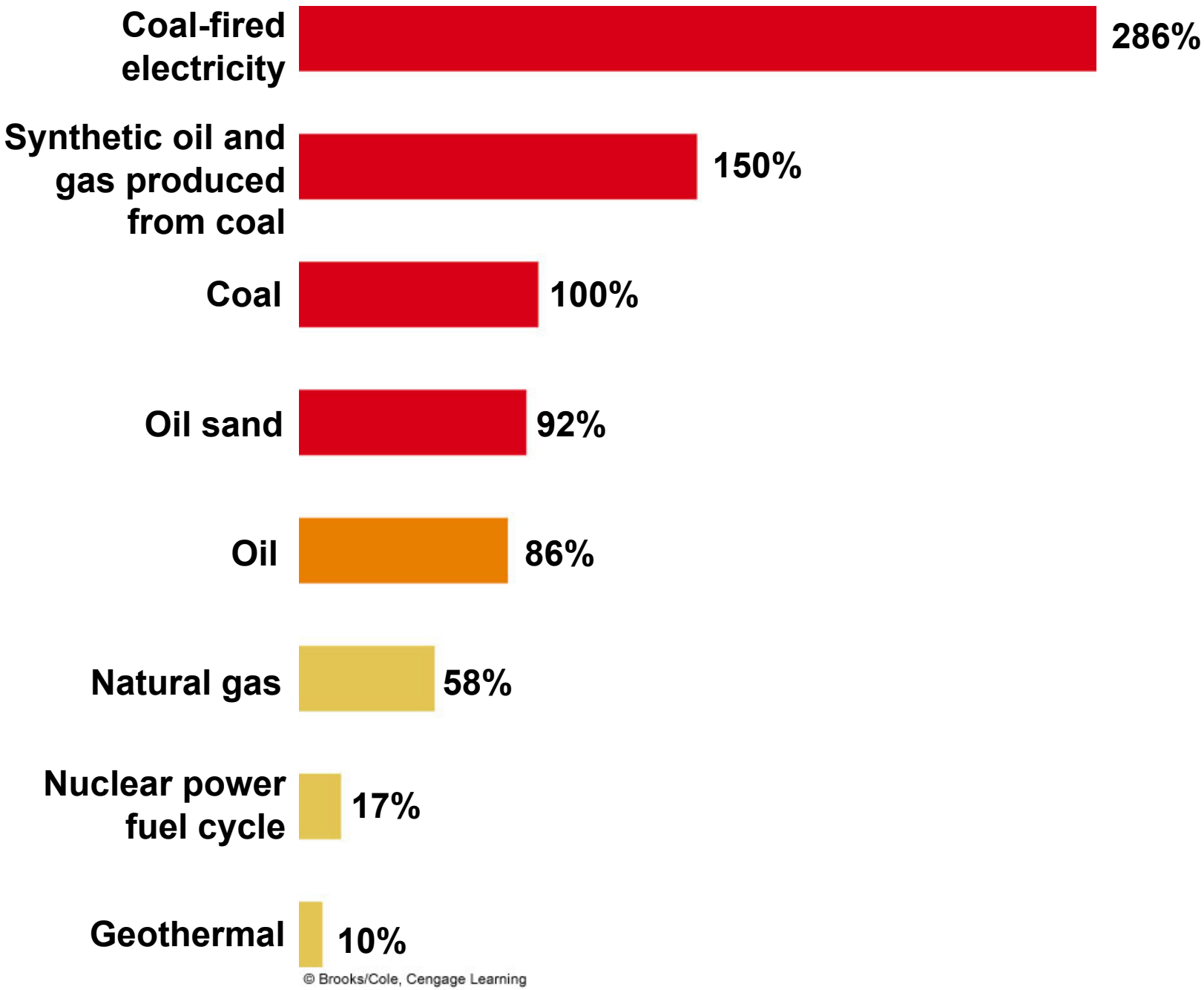


Fig. 15-14, p. 384

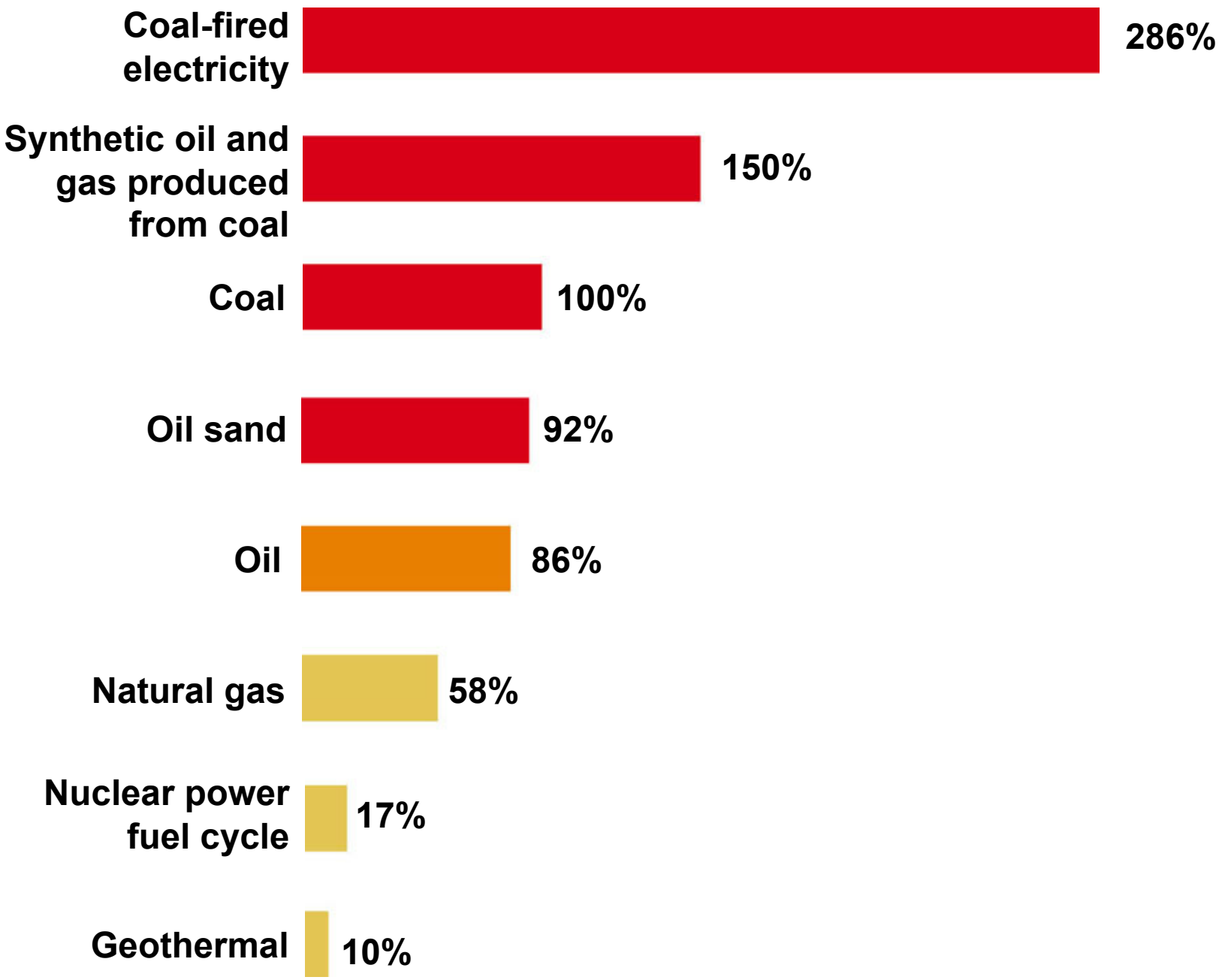


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Fig. 15-14, p. 384

Case Study: Coal Consumption in China

- Burns more coal than the United States, Europe, and Japan combined
- Coal–burning plants: Inefficient or non-existent pollution controls
- Leading area for SO_2 pollution: health hazard
- Acid rain due to coal burning
- Hg showing up in salmon off the western coast of the United States
- Air quality of Korea and Japan impacted

Coal Has Advantages and Disadvantages

- Single biggest air polluter in coal-burning countries
- One-fourth of the annul CO_2 emissions
- Many opposed to new coal-burning power plants
- Advantages
- Disadvantages

Trade-Offs: Coal, Advantages and Disadvantages as an Energy Resource

TRADE-OFFS

Coal

Advantages	Disadvantages
Ample supplies (225–900 years)	Severe land disturbance, air pollution, and water pollution
High net energy yield	Severe threat to human health when burned
Low cost	Environmental costs not included in market price
Well-developed technology	Large government subsidies
Air pollution can be reduced with improved technology	High CO_2 emissions when produced and burned
	Radioactive particle and toxic mercury emissions

TRADE-OFFS

Coal

Advantages

Ample supplies (225–900 years)

High net energy yield

Low cost

Well-developed technology

Air pollution can be reduced with improved technology

Disadvantages

Severe land disturbance, air pollution, and water pollution

Severe threat to human health when burned

Environmental costs not included in market price

Large government subsidies

High CO_2 emissions when produced and burned

Radioactive particle and toxic mercury emissions

Fig. 15-15, p. 385

We Can Convert Coal into Gaseous and Liquid Fuels

- **Conversion of solid coal to**
  - **Synthetic natural gas (SNG)** by **coal gasification**
  - Methanol or synthetic gasoline by **coal liquefaction**

- Are there benefits to using these synthetic fuels?

Trade-Offs: Synthetic Fuels

TRADE-OFFS

Synthetic fuels

Advantages	Disadvantages
Large potential supply	Low to moderate net energy yield
	Higher cost than coal
Vehicle fuel	Requires mining 50% more coal
	Environmental costs not included in market price
Moderate cost	High environmental impact
	Large government subsidies
Lower air pollution than coal when burned	High water use
	Higher CO_2 emissions than coal

TRADE-OFFS

Synthetic fuels

Advantages

Large potential supply

Vehicle fuel

Moderate cost

Lower air pollution than coal when burned

Disadvantages

Low to moderate net energy yield

Higher cost than coal

Requires mining 50% more coal

Environmental costs not included in market price

High environmental impact

Large government subsidies

High water use

Higher CO_2 emissions than coal

Fig. 15-16, p. 386

15-5 What Are the Advantages and Disadvantages of Nuclear Energy?

- ***Concept 15-5*** *Nuclear power has a low environmental impact and a very low accident risk, but high costs, a low net energy yield, long-lived radioactive wastes, vulnerability to sabotage, and the potential for spreading nuclear weapons technology have limited its use.*

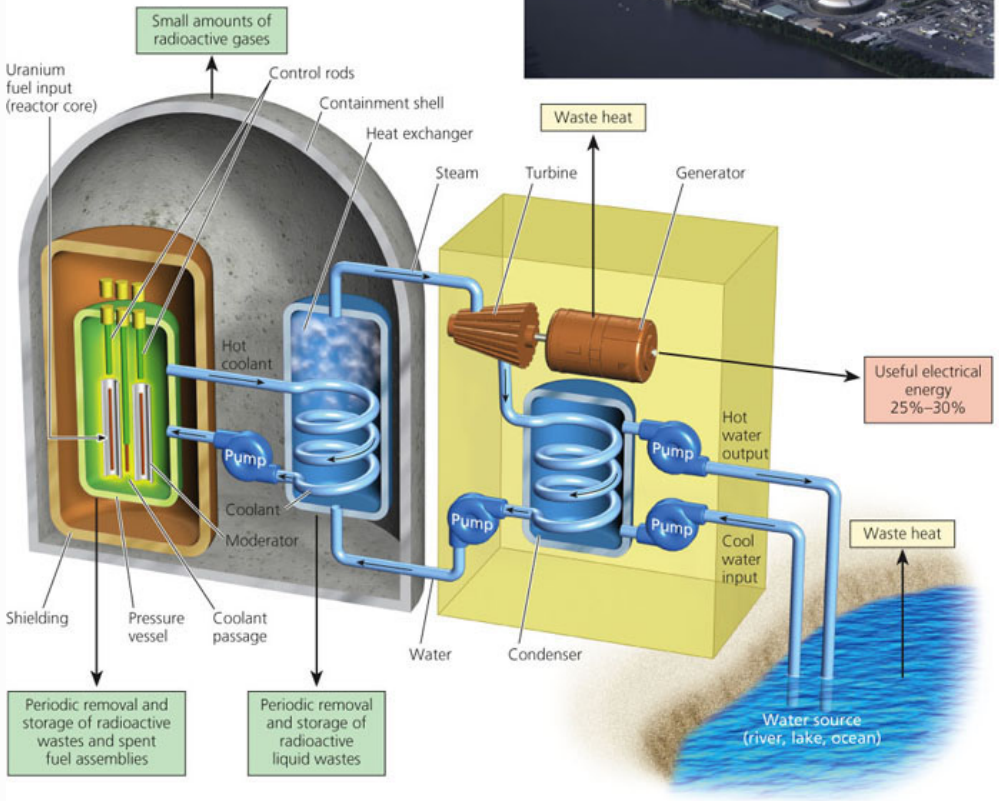
How Does a Nuclear Fission Reactor Work? (1)

- Controlled nuclear fission reaction in a **reactor**
  - **Light-water reactors**
- Fueled by uranium ore and packed as pellets in **fuel rods** and **fuel assemblies**
- **Control rods** absorb neutrons

How Does a Nuclear Fission Reactor Work? (2)

- Water is the usual **coolant**
- **Containment shell** around the core for protection
- **Water-filled pools or dry casks** for storage of radioactive spent fuel rod assemblies

Light-Water-Moderated and -Cooled Nuclear Power Plant with Water Reactor



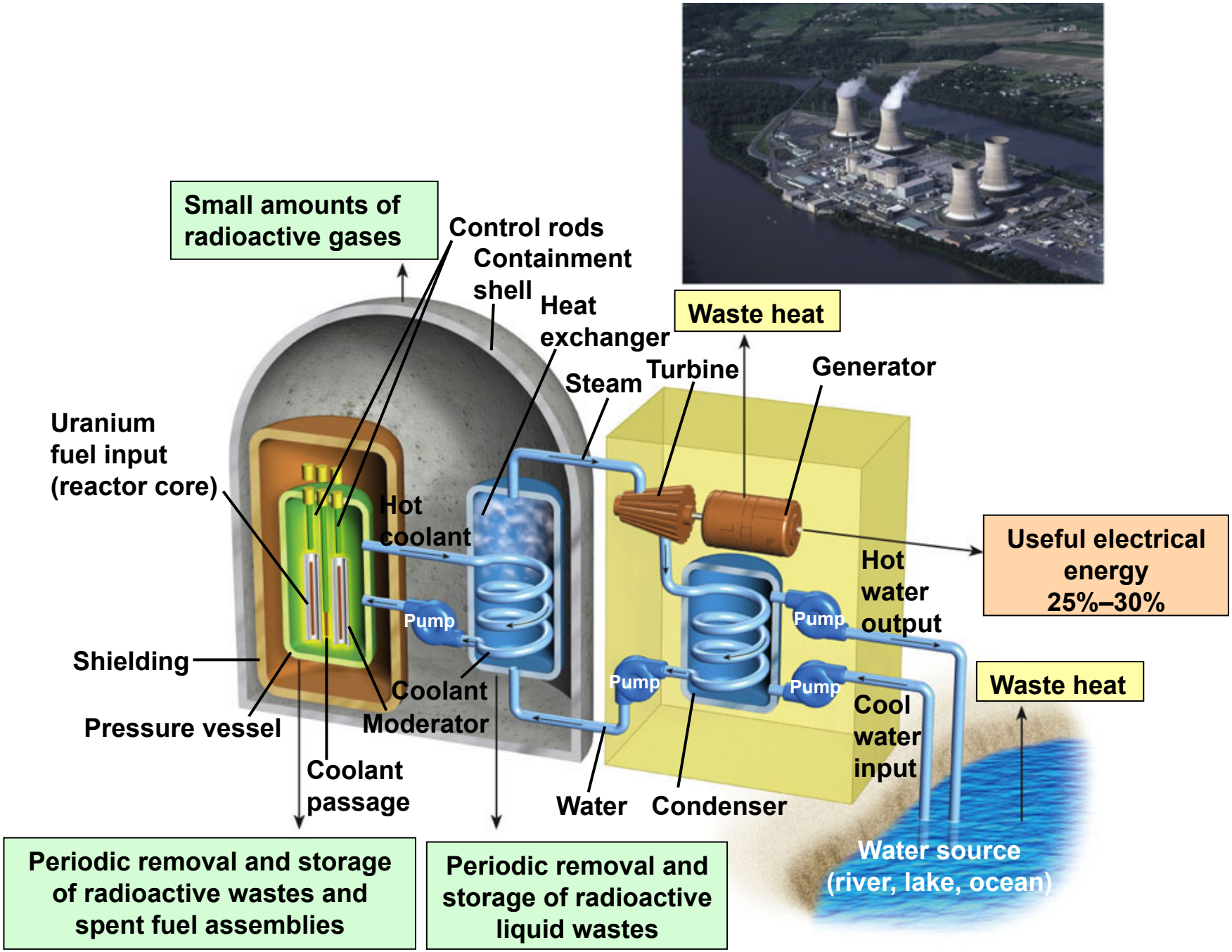
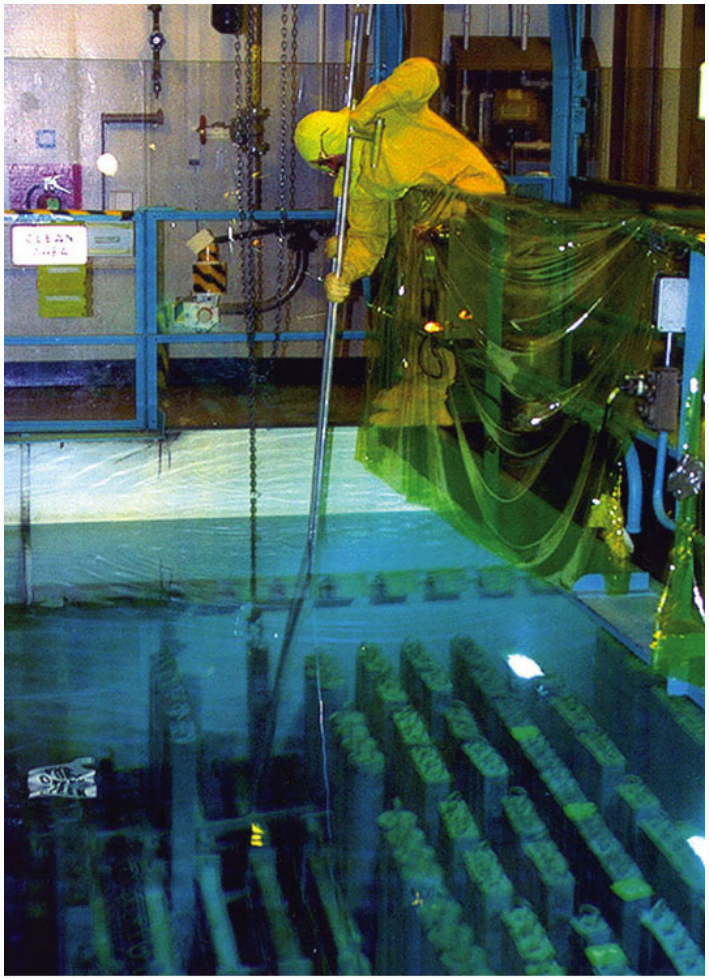


Fig. 15-17, p. 387

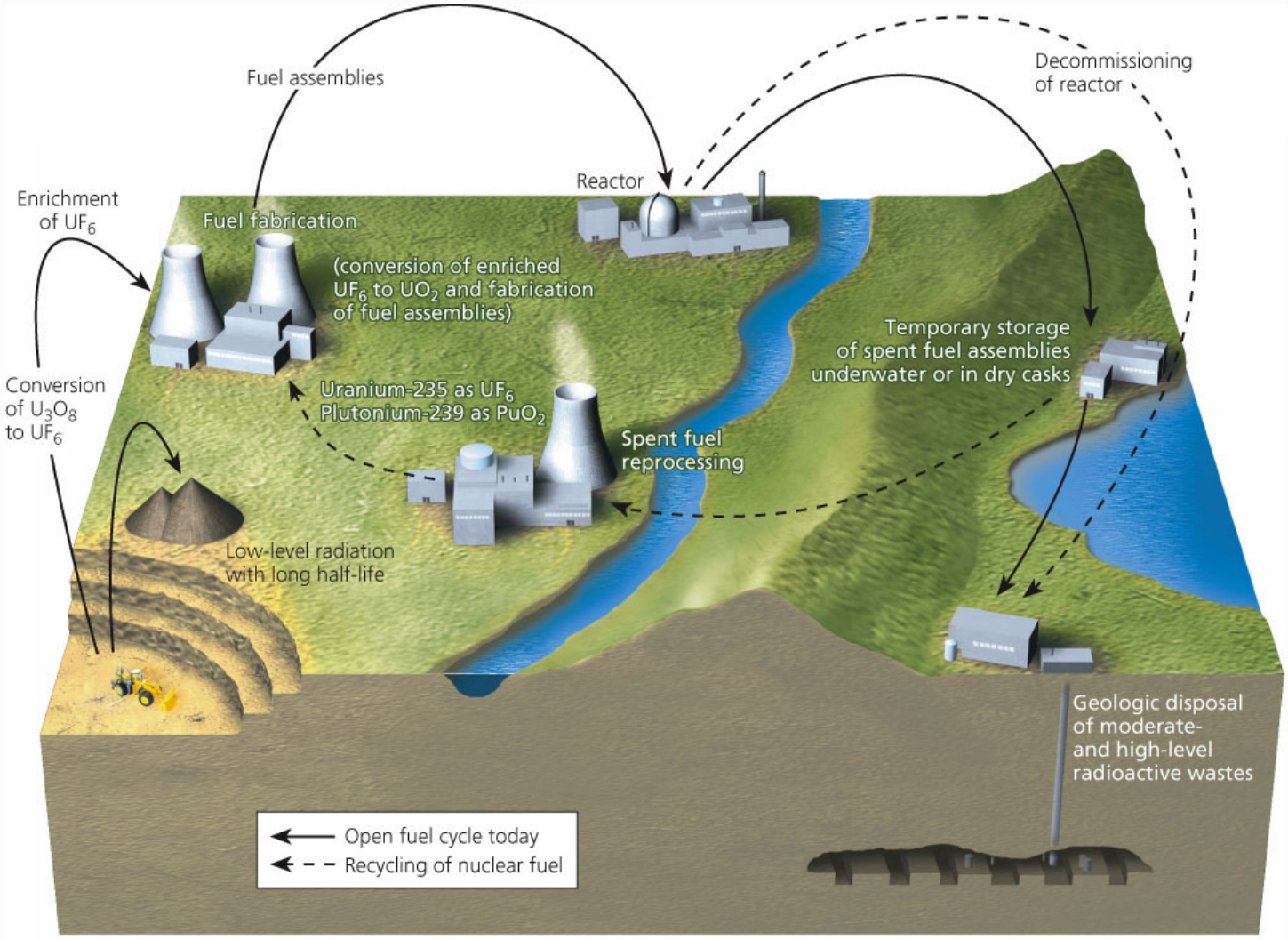
After 3 or 4 Years in a Reactor, Spent Fuel Rods Are Removed and Stored in Water



What Is the Nuclear Fuel Cycle?

- Mine the uranium
- Process the uranium to make the fuel
- Use it in the reactor
- Safely store the radioactive waste
- **Decommission** the reactor

Science: The Nuclear Fuel Cycle



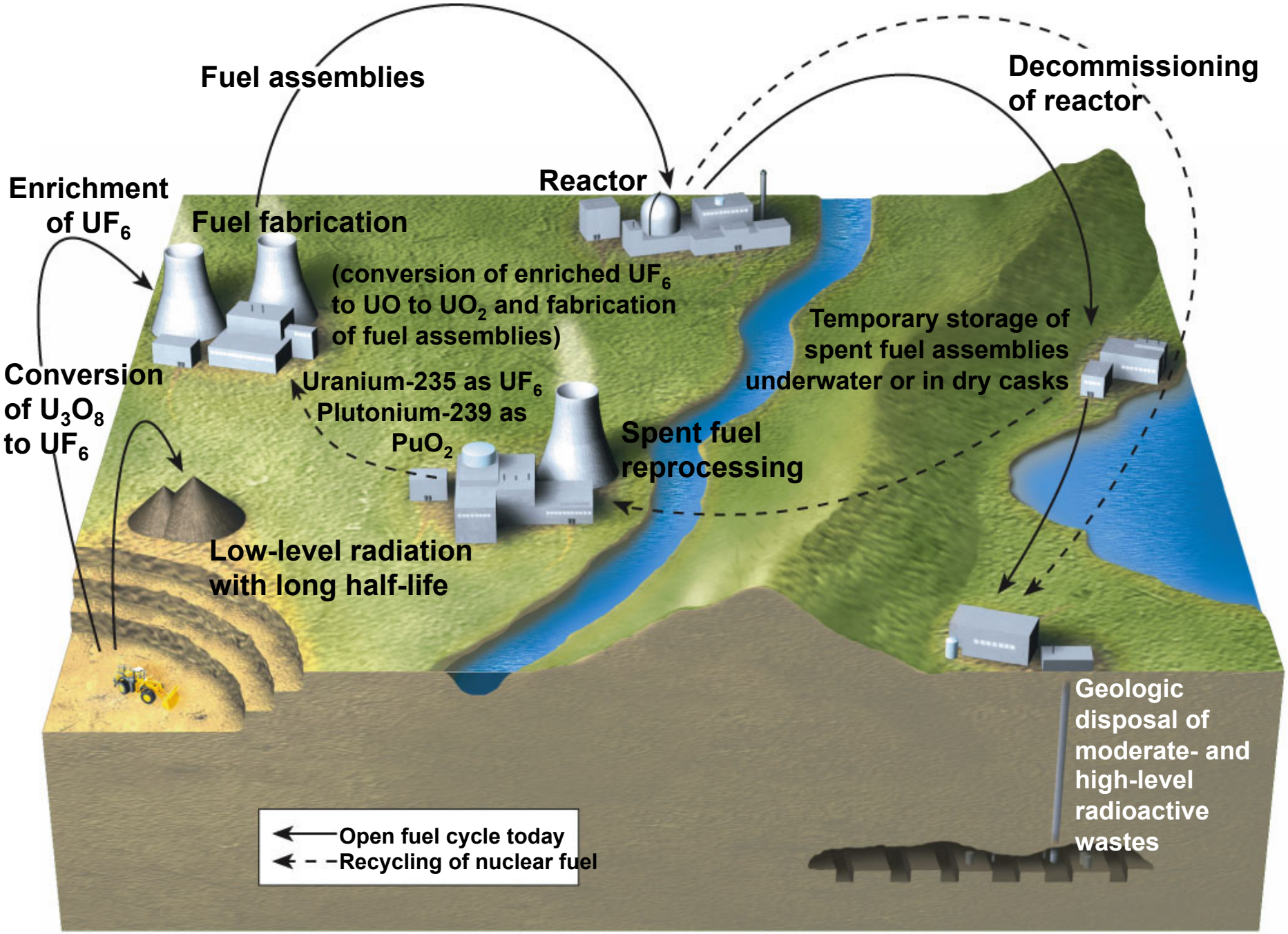


Fig. 15-19, p. 389

What Happened to Nuclear Power?

- Slowest-growing energy source and expected to decline more

- Why?
  - Economics
  - Poor management
  - Low net yield of energy of the nuclear fuel cycle
  - Safety concerns
  - Need for greater government subsidies
  - Concerns of transporting uranium

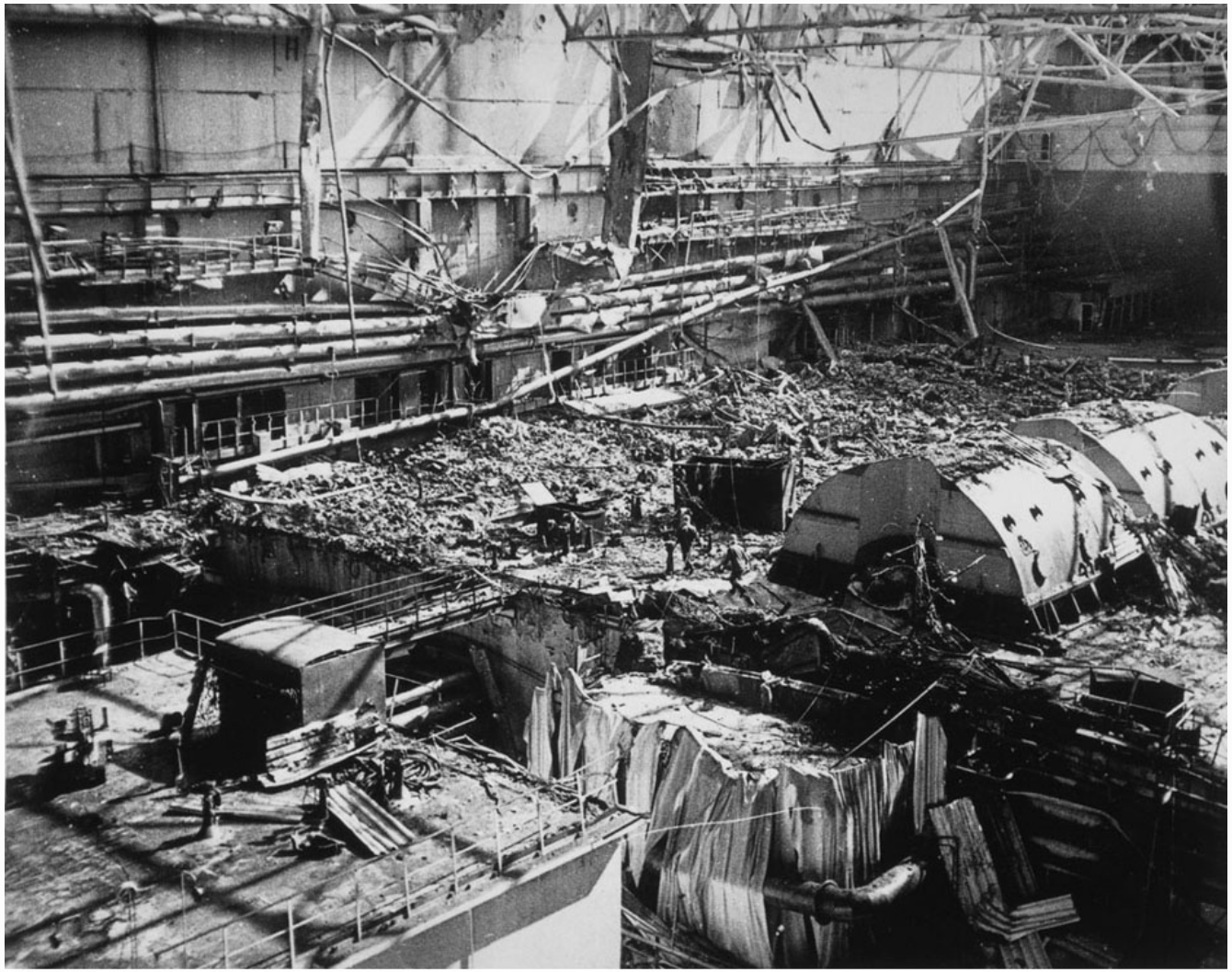
Case Study: Worst Commercial Nuclear Power Plant Accident in the U.S.

- Three Mile Island
  - March 29, 1979
  - Near Harrisburg, PA, U.S.
  - Nuclear reactor lost its coolant
  - Led to a partial uncovering and melting of the radioactive core
  - Unknown amounts of radioactivity escaped
  - People fled the area
  - Increased public concerns for safety
    - Led to improved safety regulations in the U.S.

Case Study: Worst Nuclear Power Plant Accident in the World

- Chernobyl
  - April 26, 1986
  - In Chernobyl, Ukraine
  - Series of explosions caused the roof of a reactor building to blow off
  - Partial meltdown and fire for 10 days
  - Huge radioactive cloud spread over many countries and eventually the world
  - 350,000 people left their homes
  - Effects on human health, water supply, and agriculture

Remains of a Nuclear Reactor at the Chernobyl Nuclear Power Plant



Nuclear Power Has Advantages and Disadvantages

- Advantages
- Disadvantages

Trade-Offs: Conventional Nuclear Fuel Cycle, Advantages and Disadvantages

TRADE-OFFS

Conventional Nuclear Fuel Cycle

Advantages

Large fuel supply

Low environmental impact (without accidents)

Emits 1/6 as much CO_2 as coal

Moderate land disruption and water pollution (without accidents)

Moderate land use

Low risk of accidents because of multiple safety systems (except for Chernobyl-type reactors)

Disadvantages

Cannot compete economically without huge government subsidies

Low net energy yield

High environmental impact (with major accidents)

Environmental costs not included in market price

Risk of catastrophic accidents

No widely acceptable solution for long-term storage of radioactive wastes

Subject to terrorist attacks

Spreads knowledge and technology for building nuclear weapons

TRADE-OFFS

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Fig. 15-21, p. 391

Trade-Offs: Coal versus Nuclear to Produce Electricity

TRADE-OFFS

Coal vs. Nuclear

Coal	Nuclear
Ample supply	Ample supply of uranium
High net energy yield	Low net energy yield
Very high air pollution	Low air pollution
High CO_2 emissions	Low CO_2 emissions
High land disruption from surface mining	Much lower land disruption from surface mining
High land use	Moderate land use
Low cost (with huge subsidies)	High cost (even with huge subsidies)

TRADE-OFFS

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Fig. 15-22, p. 392

Nuclear Power Plants Are Vulnerable to Terrorists Acts

- Explosions or meltdowns possible at the power plants
- Storage pools and casks are more vulnerable to attack
- 60 countries have or have the ability to build nuclear weapons

Dealing with Radioactive Wastes Produced by Nuclear Power Is a Difficult Problem

- **High-level radioactive wastes**
  - Must be stored safely for 10,000–240,000 years
- Where to store it
  - Deep burial: safest and cheapest option
  - Would any method of burial last long enough?
  - There is still no facility
- Can the harmful isotopes be changed into harmless isotopes?

Case Study: Experts Disagree about What to Do with Radioactive Wastes in the U.S.

- 1985: plans in the U.S. to build a repository for high-level radioactive wastes in the Yucca Mountain desert region (Nevada)

- Problems
  - Cost: $58–100 billion
  - Large number of shipments to the site: protection from attack?
  - Rock fractures
  - Earthquake zone
  - Decrease national security

What Do We Do with Worn-Out Nuclear Power Plants?

- Decommission or retire the power plant

- Some options
  - Dismantle the plant and safely store the radioactive materials
  - Enclose the plant behind a physical barrier with full-time security until a storage facility has been built
  - Enclose the plant in a tomb
    - Monitor this for thousands of years

Can Nuclear Power Lessen Dependence on Imported Oil, Reduce Global Warming?

- Nuclear power plants: no CO_2 emission
- Nuclear fuel cycle: emits CO_2
- Opposing views on nuclear power and global warming
  - Nuclear power advocates
  - 2003 study by MIT researchers
  - 2007: Oxford Research Group

Will Nuclear Fusion Save Us?

- "**Nuclear fusion** is the power of the future and always will be"
- Still in the laboratory phase after 50 years of research and $34 billion dollars
- 2006: U.S., China, Russia, Japan, South Korea, and European Union
  - Will build a large-scale experimental nuclear fusion reactor by 2040

Experts Disagree about the Future of Nuclear Power

- Proponents of nuclear power
  - Fund more research and development
  - Pilot-plant testing of potentially cheaper and safer reactors
  - Test breeder fission and nuclear fusion
- Opponents of nuclear power
  - Fund rapid development of energy efficient and renewable energy resources

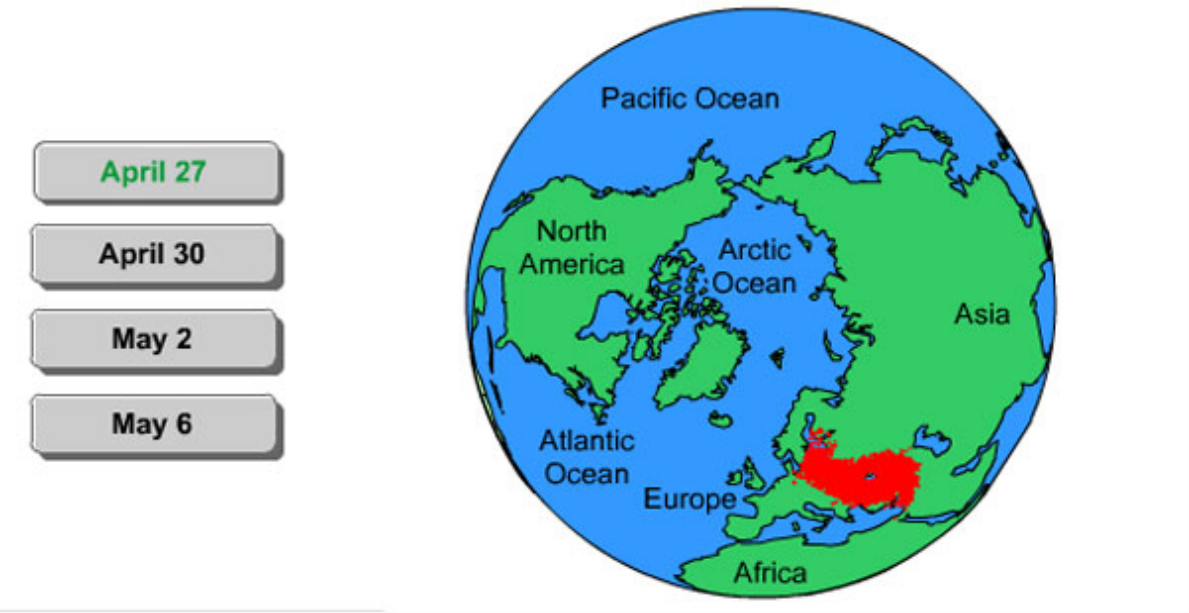
Science Focus: Are New and Safer Nuclear Reactors the Answer? (1)

- **Advanced light-water reactors (ALWR)**
  - Built-in **passive safety features**
- **High-temperature-gas-cooled reactors (HTGC)**
- **Pebble bed modular reactor (PBMR)**
  - Pros: no need to shut down for refueling
  - Cons
- **Breeder nuclear fission reactors**

Science Focus: Are New and Safer Nuclear Reactors the Answer? (2)

- New Generation nuclear reactors must satisfy these five criteria
  - Safe-runaway chain reaction is impossible
  - Fuel can not be used for nuclear weapons
  - Easily disposed of fuel
  - Nuclear fuel cycle must generate a higher net energy yield than other alternative fuels, without huge government subsidies
  - Emit fewer greenhouse gases than other fuels

Animation: Chernobyl fallout



PLAY

Video: Nuclear energy

PLAY