Energy Efficiency and Renewable Energy

Chapter 16

Core Case Study: Iceland's Vision of a Renewable-Energy Economy (1)

- Supplies 75% of its primary energy and almost all of its electrical energy using
  - Geothermal energy
  - Hydroelectric power
- No fossil fuel deposits: imports oil
- Bragi Arnason: "Dr. Hydrogen"
  - Energy vision

Core Case Study: Iceland's Vision of a Renewable-Energy Economy (2)

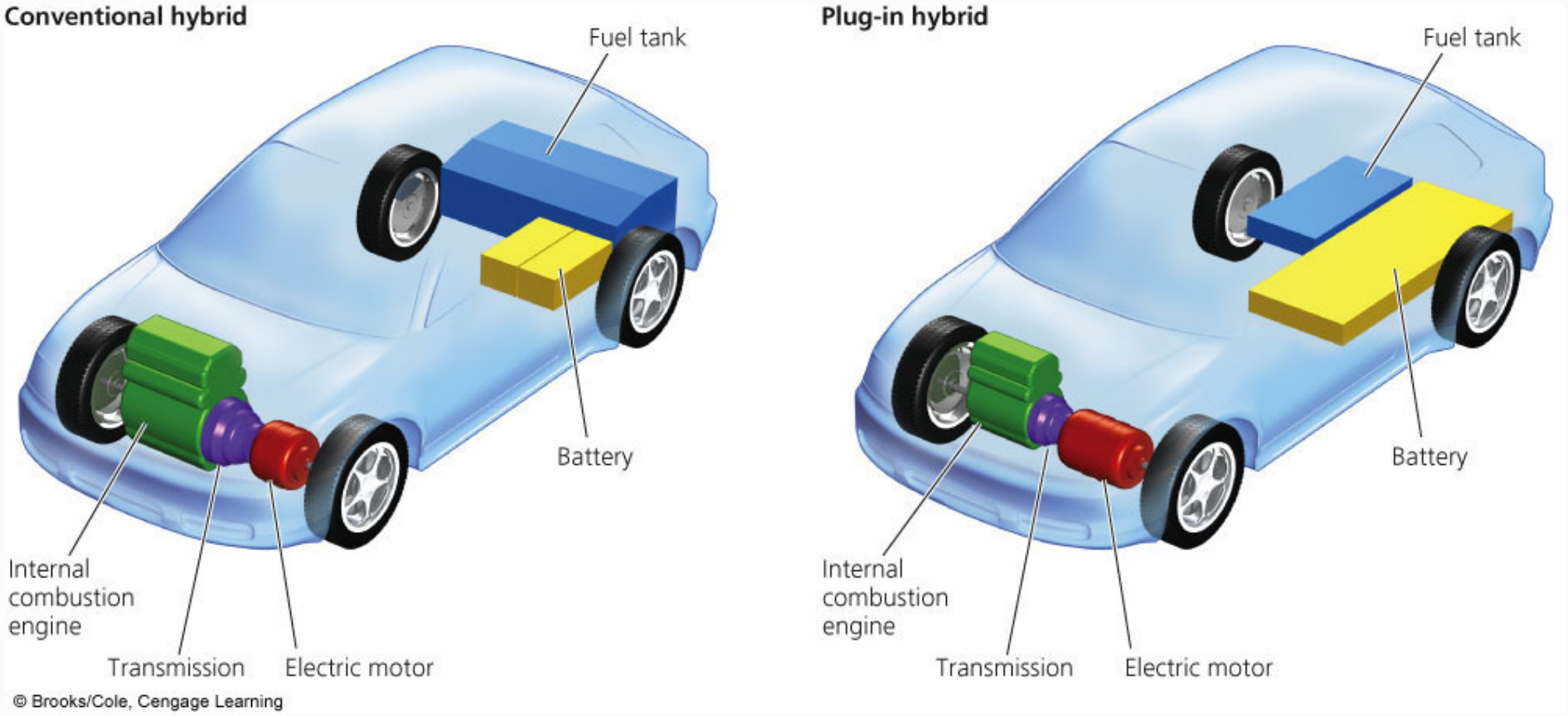
- 2003: World's first commercial hydrogen filling station
- 2003–2007: three prototype fuel-cell buses
- 2008: 10 Toyota Prius test vehicles
  - Hydrogen-fueled
- Whale-watching boat: partially powered by a hydrogen fuel cell

The Krafla Geothermal Power Station in Northern Iceland

More Energy-Efficient Vehicles Are on the Way

- Superefficient and ultralight cars
- Gasoline-electric hybrid car
- Plug-in hybrid electric vehicle
- Energy-efficient diesel car
- Electric vehicle with a fuel cell

Solutions: A Hybrid-Gasoline-Electric Engine Car and a Plug-in Hybrid Car



Science Focus: The Search for Better Batteries

- Current obstacles
  - Storage capacity
  - Overheating
  - Flammability
- In the future
  - **Lithium-ion battery**
  - **Ultracapacitor**
  - Viral battery
  - Using nanotechnology

We Can Design Buildings That Save Energy and Money (1)

- Green architecture
- Living or green roofs
- Straw bale houses
- U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED)

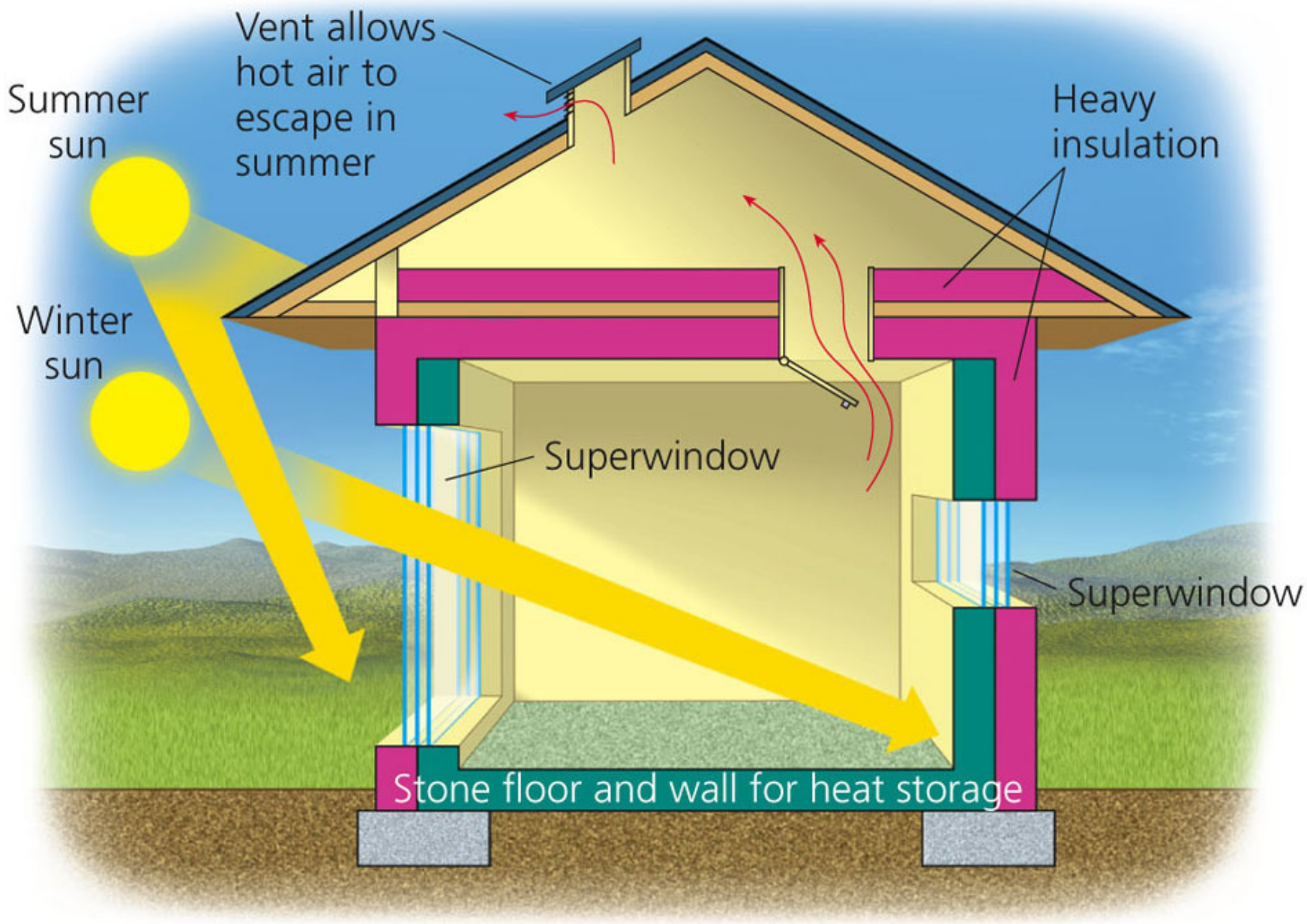
A Green or Living Roof in Chicago, IL (U.S.)

We Can Use Renewable Energy in Place of Nonrenewable Energy Sources

- Renewable energy
  - Solar energy: direct or indirect
  - Geothermal energy
- Benefits of shifting toward a variety of locally available renewable energy resources
- Forms of renewable energy would be cheaper if we eliminate
  - Inequitable subsidies
  - Inaccurate prices

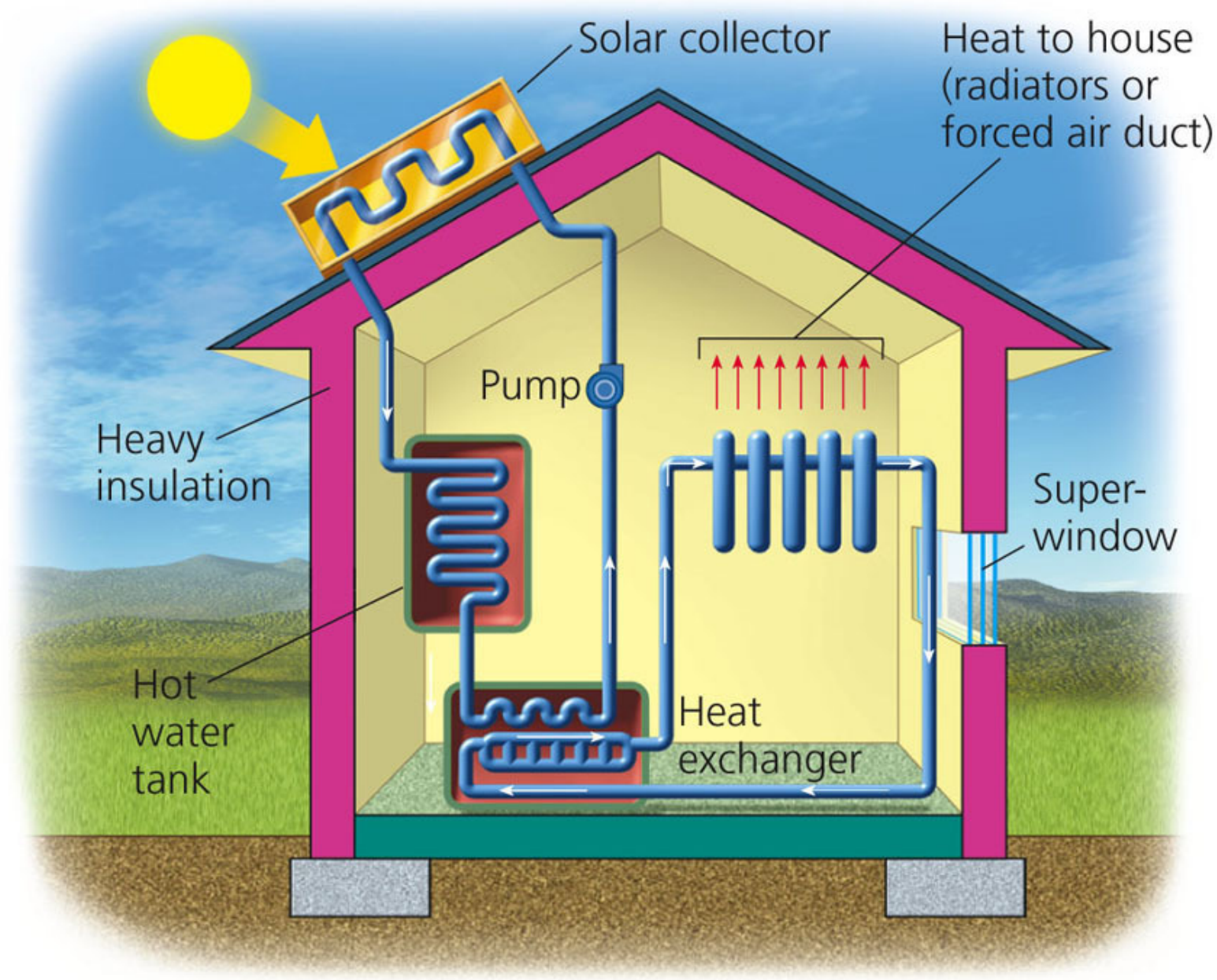
We Can Heat Buildings and Water with Solar Energy

- **Passive solar heating system**
- **Active solar heating system**
- Countries using solar energy to heat water



PASSIVE

Fig. 16-10a, p. 411



ACTIVE

Fig. 16-10b, p. 411

TRADE-OFFS

Passive or Active Solar Heating

Advantages

Energy is free

Net energy is moderate (active) to high (passive)

Quick installation

No CO_2 emissions
Very low air and water pollution

Very low land disturbance (built into roof or windows)

Moderate cost (passive)

Disadvantages

Need access to sun 60% of time

Sun can be blocked by trees and other structures

Environmental costs not included in market price

Need heat storage system

High cost (active)

Active system needs maintenance and repair

Active collectors unattractive

Fig. 16-11, p. 412

Rooftop Solar Hot Water on Apartment Buildings in Kunming, China

Case Study: The Rocky Mountain Institute—Solar Powered Office and Home

- Location: Snowmass, CO (U.S.)
- No conventional heating system
- Heating bills: <$50/year
- How is this possible?

Sustainable Energy: Rocky Mountain Institute in Colorado, U.S.

Trade-Offs: Solar Energy for High-Temperature Heat and Electricity

TRADE-OFFS

Solar Energy for High-Temperature Heat and Electricity

Advantages

- Moderate net energy
- Moderate environmental impact
- No CO_2 emissions
- Fast construction (1–2 years)
- Costs reduced with natural gas turbine backup

Disadvantages

- Low efficiency
- High costs
- Environmental costs not included in market price
- Needs backup or storage system
- Need access to sun most of the time
- Vulnerable to sabotage
- May disturb desert areas

Commercial Solar Power Tower Plant Near Seville in Southern Spain

Solutions: Woman in India Uses a Solar Cooker

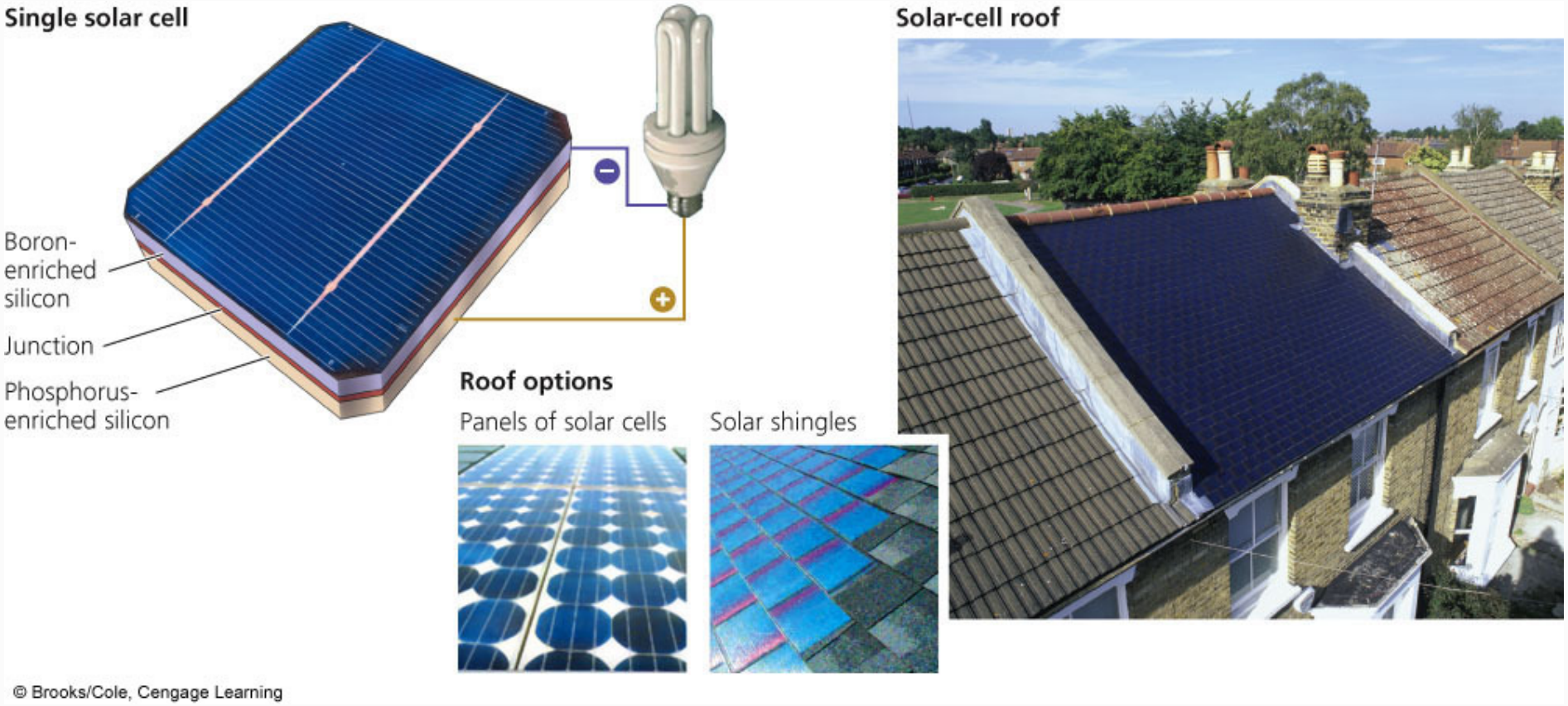
We Can Use Solar Cells to Produce Electricity (1)

- **Photovoltaic (PV) cells (solar cells)**
  - Convert solar energy to electric energy
- Design of solar cells
- Benefits of using solar cells
- Solar-cell power plants
  - Near Tucson, AZ (U.S.)
  - 2007: Portugal

We Can Use Solar Cells to Produce Electricity (3)

- Key problem
  - High cost of producing electricity
- Will the cost drop with
  - Mass production
  - New designs
  - Nanotechnology

Solutions: Solar Cells Can Provide Electricity Using Solar-Cell Roof Shingles



Solutions: Solar Cells Used to Provide Electricity for a Remote Village in Niger

Total Costs of Electricity from Different Sources in 2004

Table 16-1

Total Costs of Electricity from Different Sources in 2004
(in U.S. cents per kilowatt-hour)

Electricity Source	Generating Costs	Environmental Costs	Total Costs
Wind	4.7–6.3	0.1–0.3	4.8–6.6
Geothermal	4.8	1.0 (approximately)	5.8
Hydropower	4.9–8.5	0.3–1.1	5.2–9.6
Natural gas	5.2–6.5	1.1–4.5	6.3–11.0
Biomass	5.5–6.4	1.0–3.4	6.5–9.8
Nuclear*	5.9–12.0	0.2–0.7	6.1–12.7
Coal	4.5–5.4	3.0–17.0	7.5–22.4
Solar cells	12.4–26.0	0.7	13.1–26.7

*Plant only. Costs are much higher if entire nuclear fuel cycle is included.

The Solar Power Industry Is Expanding Rapidly

- Solar cells: 0.2% of the world's electricity
- 2040: could solar cells produce 16%?
- Nanosolar: California (U.S.)
- Germany: huge investment in solar cell technology
- General Electric: entered the solar cell market

Solar-Cell Power Plant in Arizona, U.S., Is the Largest Solar-Cell Power Plant

TRADE-OFFS

Solar Cells

Advantages

- Fairly high net energy yield
- Work on cloudy days
- Quick installation
- Easily expanded or moved
- No CO_2 emissions
- Low environmental impact
- Last 20–40 years
- Low land use (if on roof or built into walls or windows)
- Reduces dependence on fossil fuels

Disadvantages

- Need access to sun
- Low efficiency
- Need electricity storage system or backup
- Environmental costs not included in market price
- High costs (but should be competitive in 5–15 years)
- High land use (solar-cell power plants) could disrupt desert areas
- DC current must be converted to AC

Fig. 16-20, p. 417

We Can Produce Electricity from Falling and Flowing Water

- Hydropower
  - World's leading renewable energy source used to produce electricity
  - Hydroelectric power: Iceland
- Advantages
- Disadvantages
- **Micro-hydropower generators**

TRADE-OFFS

Large-Scale Hydropower

Advantages

Moderate to high net energy

High efficiency (80%)

Large untapped potential

Low-cost electricity

Long life span

No CO_2 emissions during operation in temperate areas

Can provide flood control below dam

Provides irrigation water

Reservoir useful for fishing and recreation

Disadvantages

High construction costs

High environmental impact from flooding land to form a reservoir

Environmental costs not included in market price

High CO_2 emissions from rapid biomass decay in shallow tropical reservoirs

Danger of collapse

Uproots people

Decreases fish harvest below dam

Decreases flow of natural fertilizer (silt) to land below dam

Fig. 16-21, p. 418

Tides and Waves Can Be Used to Produce Electricity (1)

- Produce electricity from flowing water
  - Ocean tides and waves
- So far, power systems are limited
  - Norway
  - New York City

Tides and Waves Can Be Used to Produce Electricity (2)

- Disadvantages
  - Few suitable sites
  - High costs
  - Equipment damaged by storms and corrosion

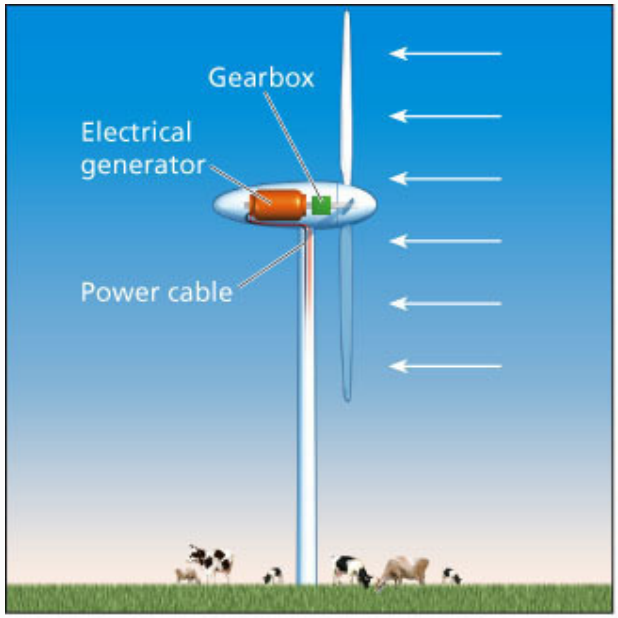
Using Wind to Produce Electricity Is an Important Step toward Sustainability (1)

- Wind: indirect form of solar energy
  - Captured by turbines
  - Converted into electrical energy
- Second fastest-growing source of energy
- What is the global potential for wind energy?
- Wind farms: on land and offshore

Using Wind to Produce Electricity Is an Important Step toward Sustainability (2)

- "Saudi Arabia of wind power"
  - North Dakota
  - South Dakota
  - Kansas
  - Texas
- How much electricity is possible with wind farms in those states?

Solutions: Wind Turbine and Wind Farms on Land and Offshore



Wind turbine

Wind farm

Wind farm (offshore)

Wind Energy Is Booming but Still Faces Challenges

- Advantages of wind energy

- Drawbacks
  - Windy areas may be sparsely populated
  - Winds die down; need back-up energy
  - Storage of wind energy
  - Kills migratory birds
  - “Not in my backyard”

TRADE-OFFS

Wind Power

Advantages

- Moderate to high net energy yield
- High efficiency
- Moderate capital cost
- Low electricity cost (and falling)
- Very low environmental impact
- No CO_2 emissions
- Quick construction
- Easily expanded
- Can be located at sea
- Land below turbines can be used to grow crops or graze livestock

Disadvantages

- Steady winds needed
- Backup systems needed when winds are low
- Plastic components produced from oil
- Environmental costs not included in market price
- High land use for wind farm
- Visual pollution
- Noise when located near populated areas
- Can kill birds and interfere with flights of migratory birds

Fig. 16-23, p. 421

We Can Get Energy by Burning Solid Biomass

- **Biofuels**

- Production of solid mass fuel
  - Plant fast-growing trees
  - Biomass plantations
  - Collect crop residues and animal manure

- Advantages

- Disadvantages

TRADE-OFFS

Solid Biomass

Advantages

Large potential supply in some areas

Moderate costs

No net CO_2 increase if harvested, burned, and replanted sustainably

Plantation can be located on semiarid land not needed for crops

Plantation can help restore degraded lands

Can make use of agricultural, timber, and urban wastes

Disadvantages

Nonrenewable if harvested unsustainably

Moderate to high environmental impact

Environmental costs not included in market price

Increases CO_2 emissions if harvested and burned unsustainably

Low photosynthetic efficiency

Soil erosion, water pollution, and loss of wildlife habitat

Plantations could compete with cropland

Often burned in inefficient and polluting open fires and stoves

Fig. 16-24, p. 422

We Can Convert Plants and Plant Wastes to Liquid Biofuels (1)

- Liquid biofuels
  - Biodiesel
  - Ethanol
- Biggest producers of biofuel
  - Brazil
  - The United States
  - The European Union
  - China

We Can Convert Plants and Plant Wastes to Liquid Biofuels (2)

- Major advantages over gasoline and diesel fuel produced from oil
  - Biofuel crops can be grown almost anywhere
  - No net increase in CO_2 emissions if managed properly
  - Available now

Case Study: Is Biodiesel the Answer?

- Biodiesel production from vegetable oil from various sources
- 95% produced by The European Union
- Jatropha shrub: promising new source
- Advantages
- Disadvantages

TRADE-OFFS

Biodiesel

Advantages

- Reduced CO emissions
- Reduced CO_2 emissions (78%)
- High net energy yield for oil palm crops
- Moderate net energy yield for rapeseed crops
- Reduced hydrocarbon emissions
- Better gas mileage (40%)
- Potentially renewable

Disadvantages

- Increased NO_x emissions and more smog
- Higher cost than regular diesel
- Environmental costs not included in market price
- Low net energy yield for soybean crops
- May compete with growing food on cropland and raise food prices
- Loss and degradation of biodiversity from crop plantations
- Can make engines hard to start in cold weather

Fig. 16-25, p. 424

Case Study: Is Ethanol the Answer? (1)

- Ethanol converted to **gasohol**
- Brazil: “Saudi Arabia of sugarcane”
  - Saved $50 billion in oil import costs since the 1970s
- United States: ethanol from corn
  - Reduce the need for oil imports?
  - Slow global warming?
  - Reduce air pollution?

Case Study: Is Ethanol the Answer? (2)

- **Cellulosic ethanol**: alternative to corn ethanol
- Sources
  - Switchgrass
  - Crop residues
  - Municipal wastes
- Advantages
- Disadvantages

Natural Capital: Rapidly Growing Switchgrass in Kansas, U.S.

TRADE-OFFS

Ethanol Fuel

Advantages

High octane

Some reduction in CO_2 emissions (sugarcane bagasse)

High net energy yield (bagasse and switchgrass)

Reduced CO emissions

Can be sold as E85 or pure ethanol

Potentially renewable

Disadvantages

Lower driving range

Low net energy yield (corn)

Higher CO_2 emissions (corn)

Much higher cost

Environmental costs not included in market price

May compete with growing food and raise food prices

Higher NO_x emissions and more smog

Corrosive

Can make engines hard to start in cold weather

Fig. 16-27, p. 426

Getting Energy from the Earth's Internal Heat (1)

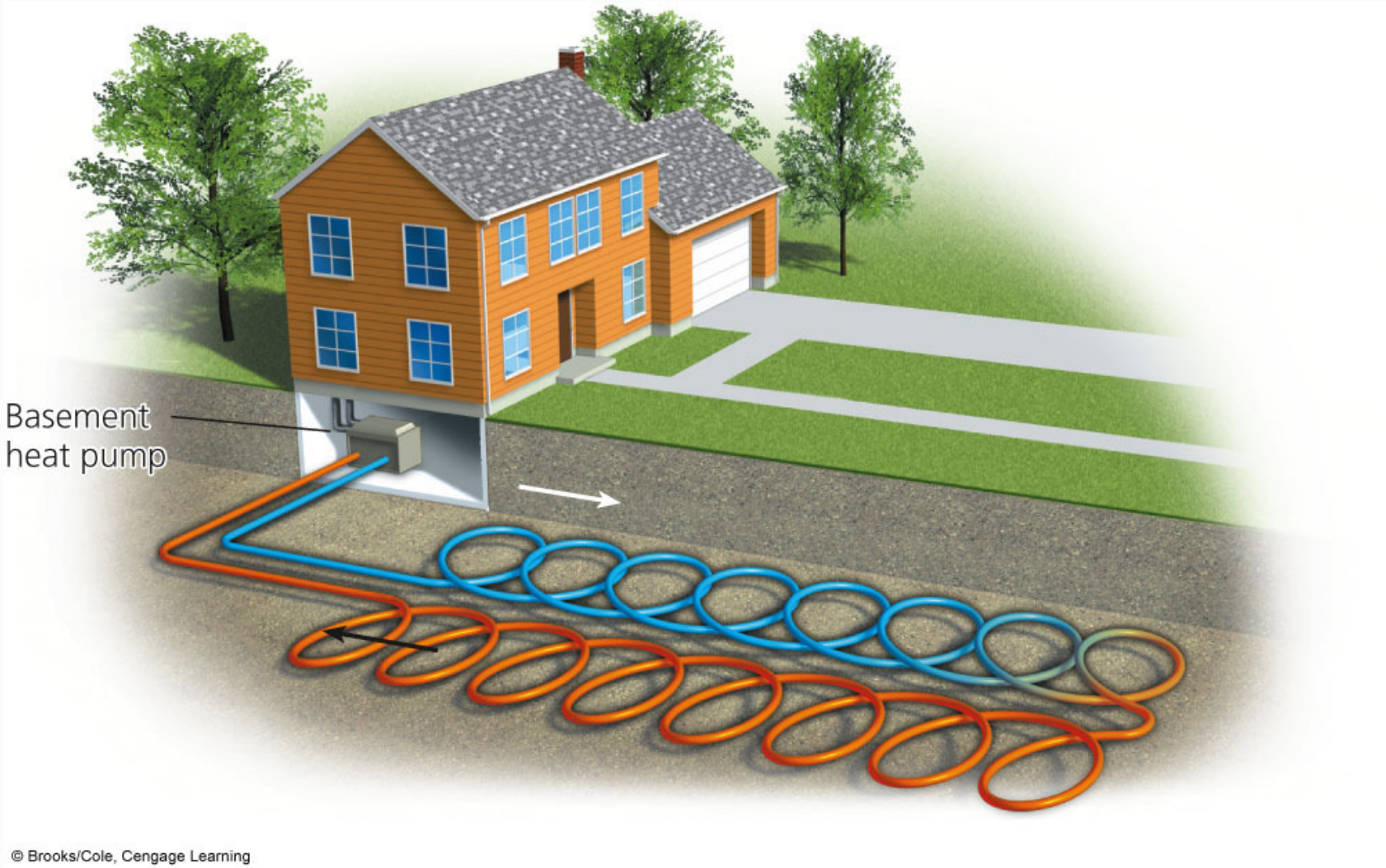
- **Geothermal energy**: heat stored in
  - Soil
  - Underground rocks
  - Fluids in the earth's mantle

- Geothermal heat pump system
  - Energy efficient and reliable
  - Environmentally clean
  - Cost effective to heat or cool a space

Getting Energy from the Earth's Internal Heat (2)

- **Hydrothermal reservoirs**
  - Iceland
- Geothermal energy: two problems
  - High cost of tapping large-scale hydrothermal reservoirs
  - Dry- or wet-steam geothermal reservoirs could be depleted
- Hot, dry rock: another potential source of geothermal energy?

Natural Capital: A Geothermal Heat Pump System Can Heat or Cool a House



TRADE-OFFS

Geothermal Energy

Advantages

Very high efficiency

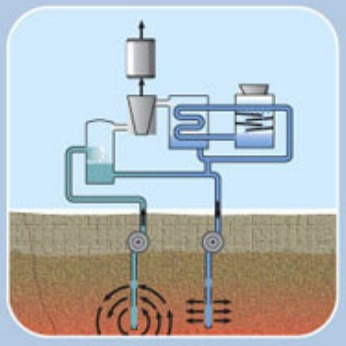
Moderate net energy at accessible sites

Lower CO_2 emissions than fossil fuels

Low cost at favorable sites

Low land use and disturbance

Moderate environmental impact



Disadvantages

Scarcity of suitable sites

Can be depleted if used too rapidly

Environmental costs not included in market price

CO_2 emissions

Moderate to high local air pollution

Noise and odor (H_2S)

High cost except at the most concentrated and accessible sources

Fig. 16-29, p. 428

Hydrogen Is a Promising Fuel but There Are Challenges (1)

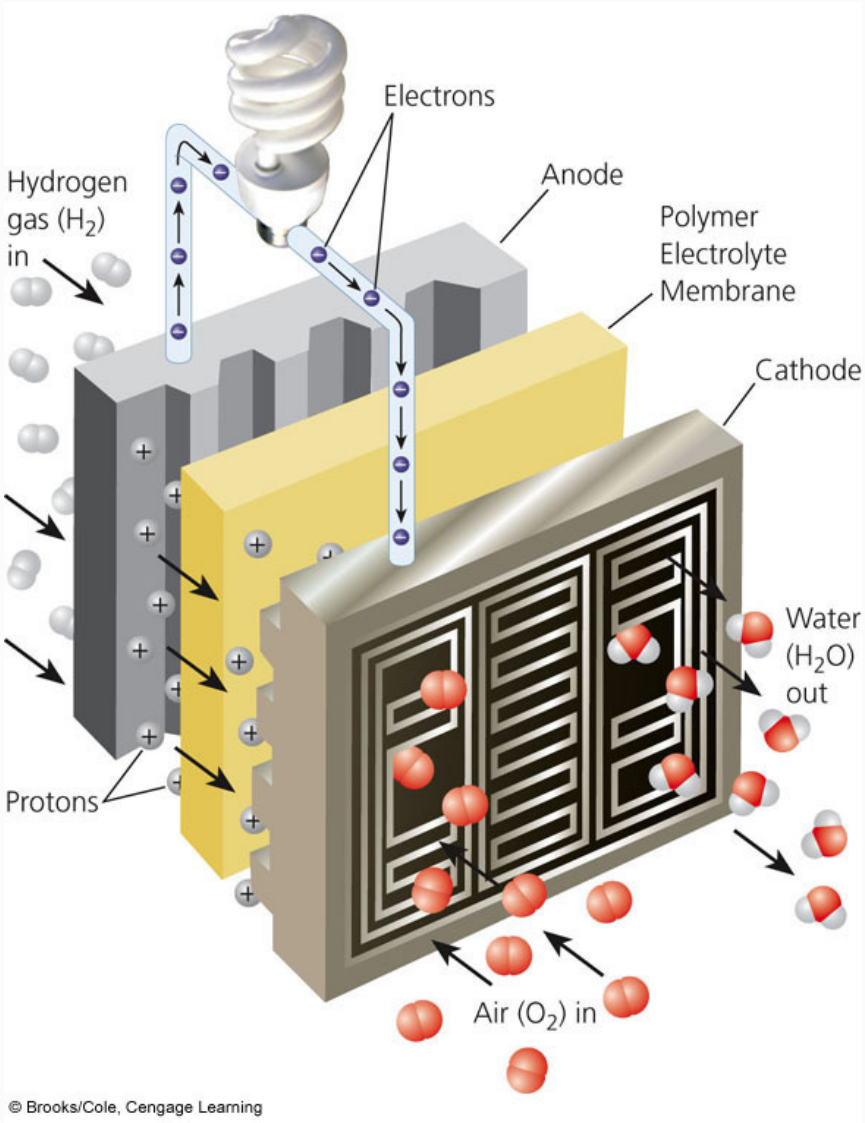
- Hydrogen as a fuel
  - Eliminate most of the air pollution problems
  - Reduce threats of global warming

- Some challenges
  - Chemically locked in water and organic compounds
  - Fuel cells are the best way to use hydrogen
  - CO_2 levels dependent on method of hydrogen production

Hydrogen Is a Promising Fuel but There Are Challenges (2)

- Production and storage of H_2
- Hydrogen-powered vehicles: prototypes available
- Can we produce hydrogen on demand?
- Larger fuel cells

A Fuel Cell Separates the Hydrogen Atoms' Electrons from Their Protons

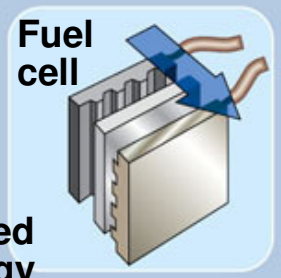


TRADE-OFFS

Hydrogen

Advantages

- Can be produced from plentiful water
- Low environmental impact
- Renewable if produced from renewable energy resources
- No CO_2 emissions if produced from water
- Good substitute for oil
- Competitive price if environmental and social costs are included in cost comparisons
- Easier to store than electricity
- Safer than gasoline and natural gas
- Nontoxic
- High efficiency (45–65%) in fuel cells



Disadvantages

- Not found as H_2 in nature
- Energy is needed to produce fuel
- Negative net energy
- CO_2 emissions if produced from carbon-containing compounds
- Environmental costs not included in market price
- Nonrenewable if generated by fossil fuels or nuclear power
- High costs (that may eventually come down)
- Will take 25 to 50 years to phase in
- Short driving range for current fuel-cell cars
- No fuel distribution system in place
- Excessive H_2 leaks may deplete ozone in the atmosphere

Fig. 16-31, p. 430

Choosing Energy Paths (1)

- How will energy policies be created?
- **Supply-side, hard-path** approach
- **Demand-side, soft-path** approach

Choosing Energy Paths (2)

- General conclusions about possible energy paths
  - Gradual shift to smaller, decentralized micropower systems
  - Transition to a diverse mix of locally available renewable energy resources Improved energy efficiency
    - How?
  - Fossil fuels will still be used in large amounts
    - Why?

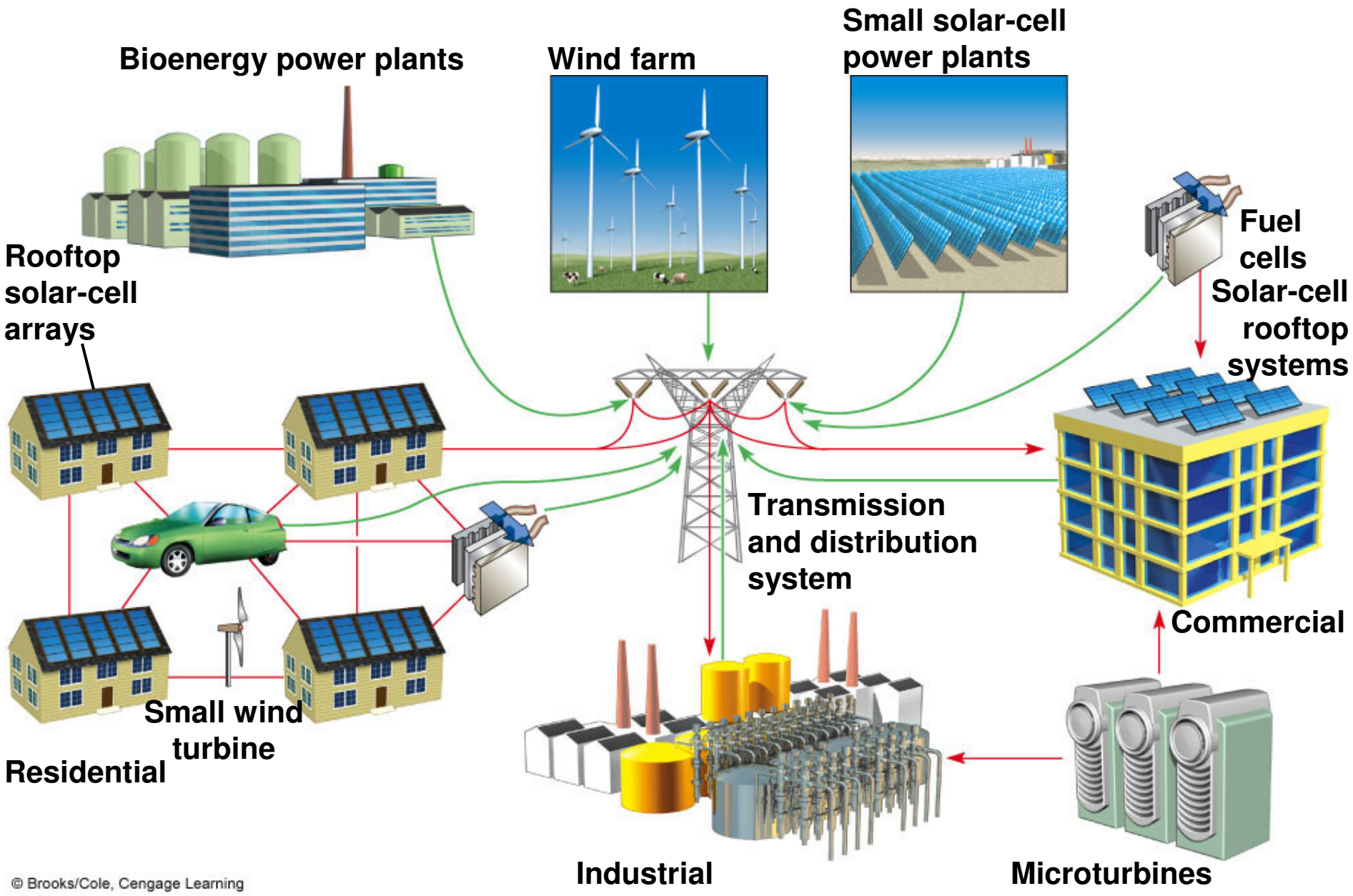


Fig. 16-32, p. 431

SOLUTIONS

Making the Transition to a More Sustainable Energy Future

Improve Energy Efficiency

Increase fuel-efficiency standards for vehicles, buildings, and appliances

Mandate government purchases of efficient vehicles and other devices

Provide large tax credits or feebates for buying efficient cars, houses, and appliances

Offer large tax credits for investments in energy efficiency

Reward utilities for reducing demand for electricity

Greatly increase energy efficiency research and development

More Renewable Energy

Greatly increase use of renewable energy

Provide large subsidies and tax credits for use of renewable energy

Include environmental costs in prices for all energy resources

Encourage government purchase of renewable energy devices

Greatly increase renewable energy research and development

Reduce Pollution and Health Risk

Cut coal use 50% by 2020

Phase out coal subsidies

Levy taxes on coal and oil use

Phase out nuclear power subsidies, tax breaks, and loan guarantees

Fig. 16-33, p. 432

Economics, Politics, Education, and Sustainable Energy Resources

- Government strategies:
  - Keep the prices of selected energy resources artificially low to encourage their use
  - Keep energy prices artificially high for selected resources to discourage their use
  - Consumer education

What Can you Do? Shifting to Sustainable Energy Use

WHAT CAN YOU DO?

Shifting to Sustainable Energy Use

- Get an energy audit done for your house or office
- Drive a car that gets at least 15 kilometers per liter (35 miles per gallon)
- Use a carpool to get to work or to school
- Walk, bike, and use mass transit
- Superinsulate your house and plug all air leaks
- Turn off lights, TV sets, computers, and other electronic equipment when they are not in use
- Wash laundry in warm or cold water
- Use passive solar heating
- For cooling, open windows and use ceiling fans or whole-house attic or window fans
- Turn thermostats down in winter and up in summer
- Buy the most energy-efficient home, lights, and appliances available
- Turn down the thermostat on water heaters to 43–49 °C (110–120 °F) and insulate hot water heaters and pipes

Case Study: California's Efforts to Improve Energy Efficiency

- High electricity costs
- Reduce energy waste
- Use of energy-efficient devices
- Strict building standards for energy efficiency