Lecture Outlines

Chapter 21

Environment: The Science behind the Stories

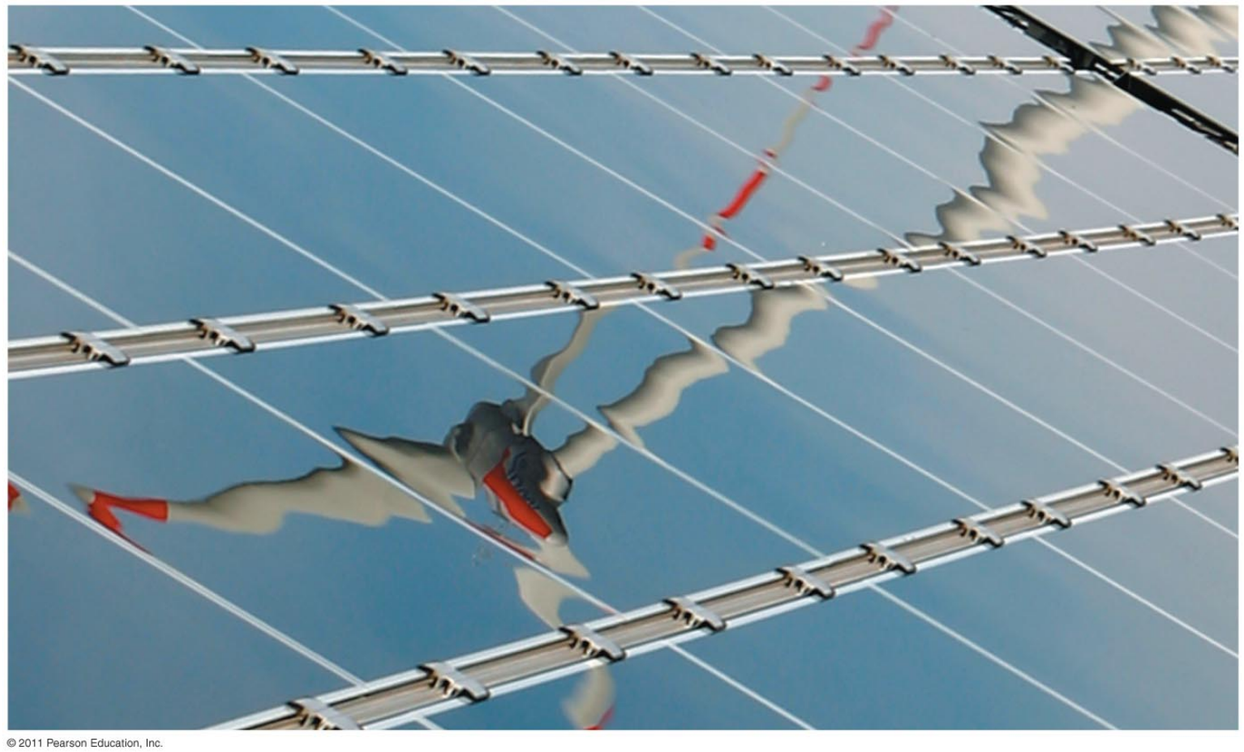
4th Edition

Withgott/Brennan

© 2011 Pearson Education, Inc.

This lecture will help you understand:

- The major sources of renewable energy
- Solar energy
- Wind energy
- Geothermal energy
- Ocean energy
- Hydrogen fuel cells



© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

Central Case: Germany goes solar

- Germany produces the world's most solar power
  - Yet it is cool and cloudy
- Its **feed-in tariff** system requires utilities to buy power from anyone who generates it
- German industries are world leaders in "green technologies"
- German leaders see renewables as a great economic opportunity

© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

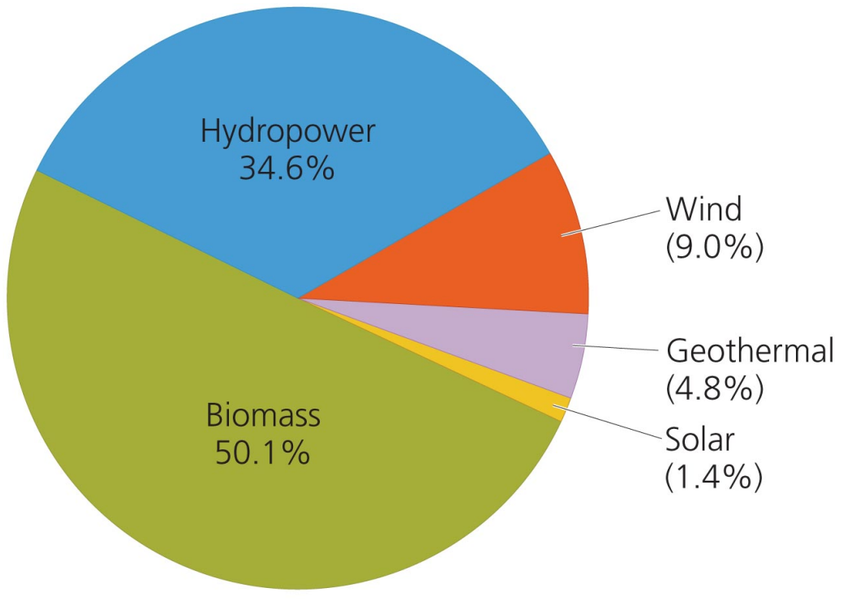
“New” renewable energy sources

- The economic, social, and environmental impacts of fossil fuels are intensifying
- “New” renewables are a group of alternative energy sources that include the sun, wind, geothermal heat, and ocean water
- They are referred to as “new” because:
  - They are not yet used on a wide scale
  - Their technologies are still in a rapid phase of development
  - They will play a much larger role in our future energy use

© 2011 Pearson Education, Inc.

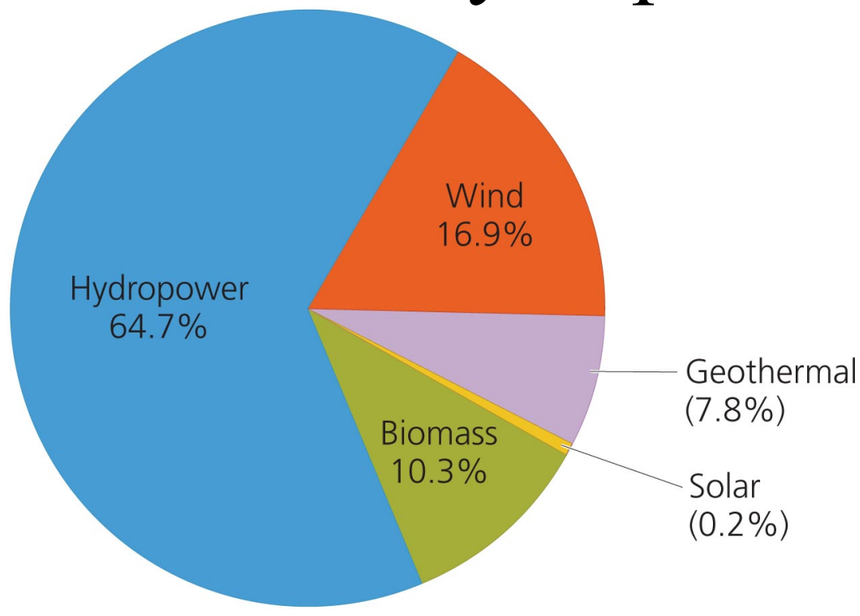
New renewables provide little of our energy

- New renewables provide energy for electricity, heating, fuel for vehicles
- Renewables provide only 1% of energy and 18% of our electricity
- Nations vary in the renewable sources they use
- Most U.S. renewable energy comes from hydropower



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

© 2011 Pearson Education, Inc.



(b) U.S. electricity generation from renewable sources

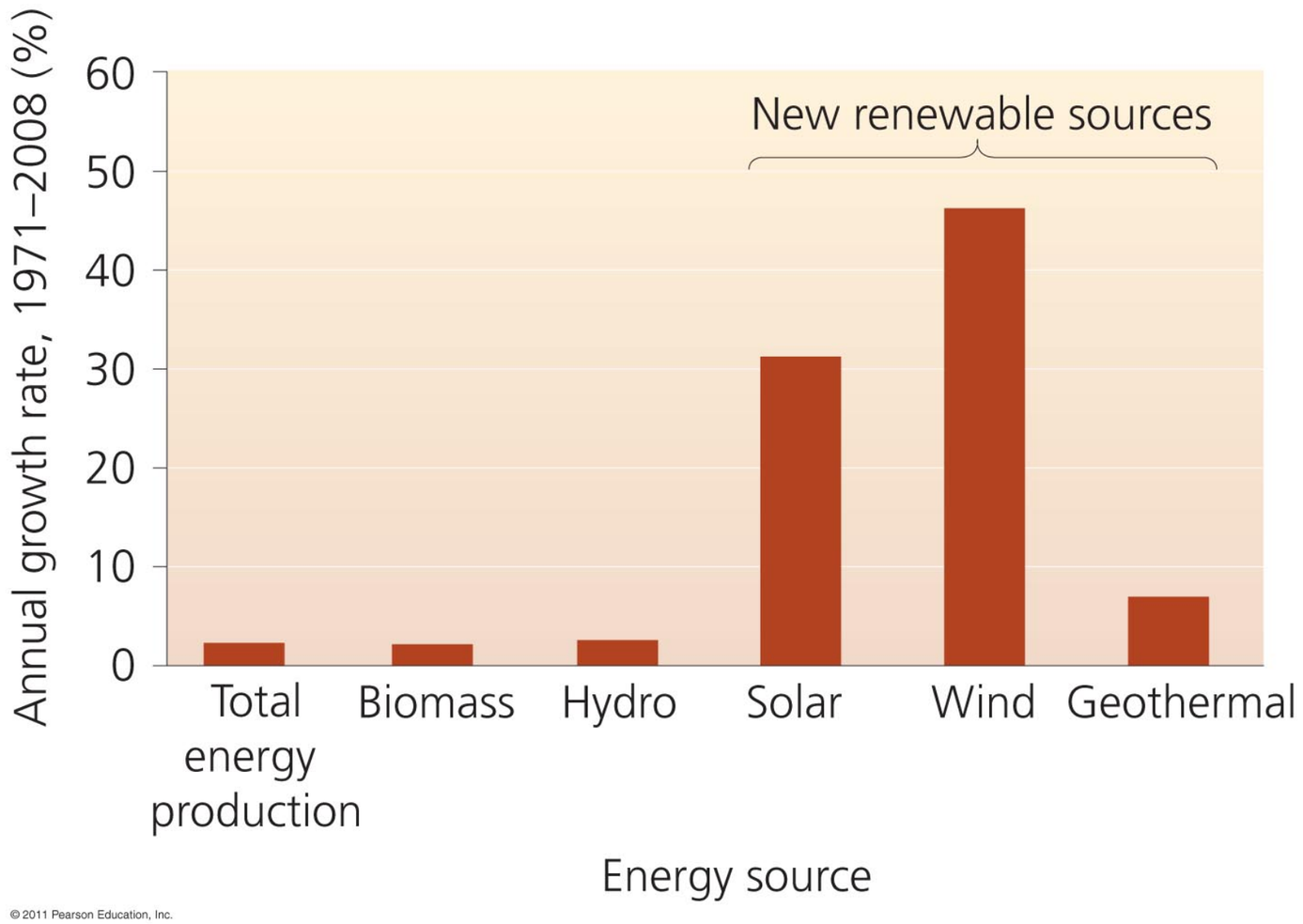
© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

The new renewables are growing fast

- They are growing faster than conventional energy sources
  - Wind power is growing at 50% *per year*
- Since these sources began at low levels, it will take time to build them up

In 2008, we added more energy from renewables than from fossil fuels and nuclear power



© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

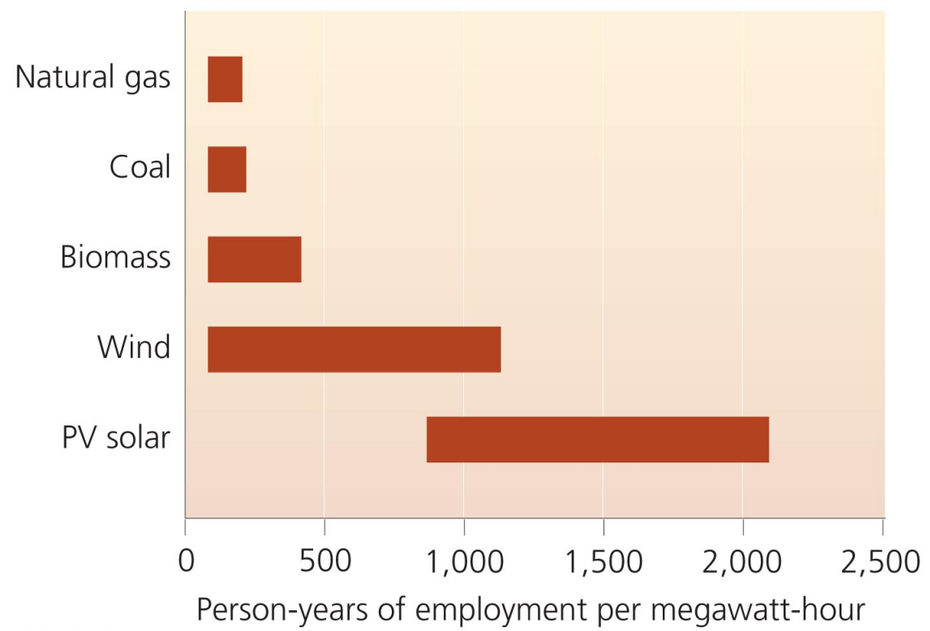
Use has expanded quickly because of:

- Growing concerns over diminishing fossil fuel supplies
- Environmental and health impacts of burning fossil fuels
- Advances in technology make it easier and cheaper
- Benefits of the new renewables include:
  - Alleviating air pollution and greenhouse gas emissions
  - They are inexhaustible, unlike fossil fuels
  - They help diversify a country's energy economy
  - They create jobs, income, and taxes, especially in rural areas

© 2011 Pearson Education, Inc.

New energy sources create jobs

- New technologies need labor
  - Generating more jobs than a fossil fuel economy
- Rapid growth will continue as:
  - Population and consumption grow
  - Energy demand increases
  - Fossil fuel supplies decline
  - People demand a cleaner environment



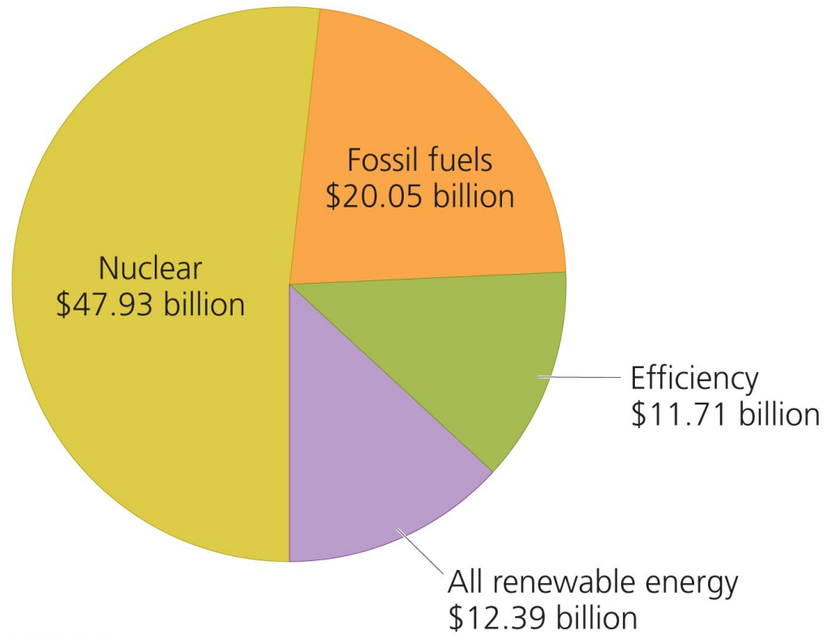
© 2011 Pearson Education, Inc.

Green-collar jobs = *design, installation, maintenance, and management of renewable energy technologies*

© 2011 Pearson Education, Inc.

Policy can accelerate our transition

- Can we switch soon enough to avoid damaging our environment and economy?
- Technological and economic barriers prevent rapidly switching to renewables
  - Remaining barriers are political
- Conventional sources get more government subsidies and tax breaks
  - Cheap fossil fuels hurt renewables
- Businesses and industries are reluctant
  - Short-term profits, unclear policy signals



© 2011 Pearson Education, Inc.

Solar energy

- The sun provides energy for Earth's processes
- Each square meter of Earth receives about 1 kilowatt of **solar energy** (energy from the sun)
  - 17 times the energy of a light bulb
- **Passive solar** energy = buildings are designed to maximize absorption of sunlight in winter
  - Keep cool in summer
- **Active solar** energy collection = uses technology to focus, move, or store solar energy
- Solar energy has been used for hundreds of years

© 2011 Pearson Education, Inc.

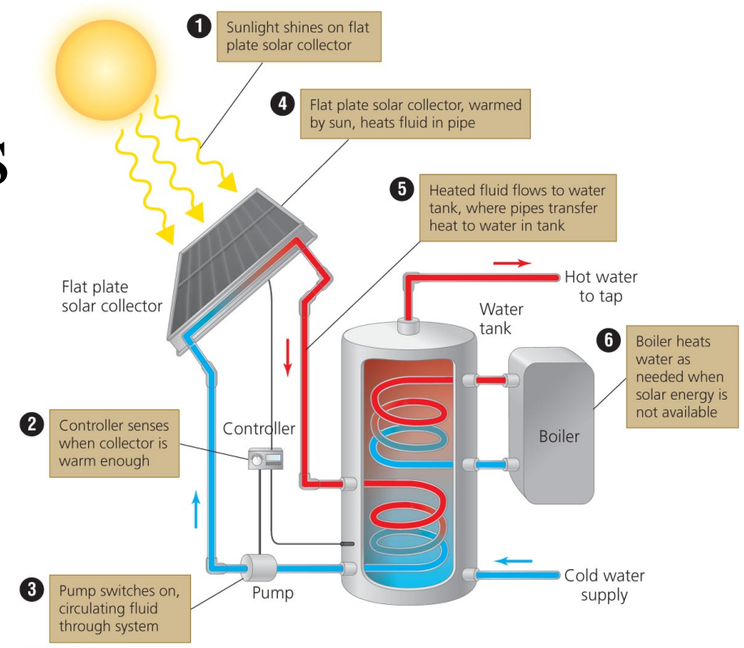
Passive solar is simple and effective

- Low, south-facing windows maximize heat in the winter
  - Overhangs on windows block summer light
- *Thermal mass* = construction materials that absorb, store, and release heat
  - Used in floors, roofs, and walls
- Vegetation protects buildings from temperature swings
- Passive solar methods conserve energy and reduce costs

© 2011 Pearson Education, Inc.

Active solar heats air and water

- *Flat plate solar collectors* = dark-colored, heat-absorbing metal plates mounted on rooftops
  - Water, air, or antifreeze runs through the collectors, transferring heat throughout the building
  - Heated water is stored and used later
- Most water heated by solar panels is used for swimming pools
- They can be used in isolated locations
  - For heating, cooling, water purification
- It is not restricted to wealthy, sunny regions



© 2011 Pearson Education, Inc.

Concentrating solar rays magnifies energy

Focusing solar energy on a single point magnifies its strength

(a) Solar cooker in India

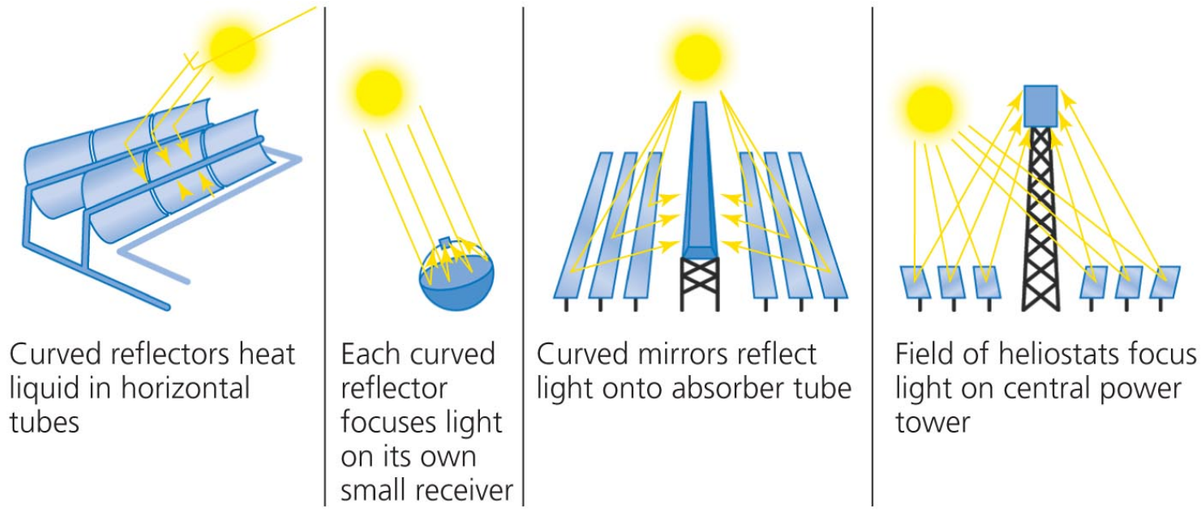
© 2011 Pearson Education, Inc.

- *Solar cookers* = simple, portable ovens that use reflectors to focus sunlight onto food
- **Concentrated solar power (CSP)** = technologies that concentrate solar energy
  - The trough approach uses curved mirrors that focus sunlight on synthetic oil in pipes
  - The heated oil drives turbines to produce electricity

© 2011 Pearson Education, Inc.

CSP techniques

- "Power tower" = mirrors concentrate sunlight onto a receiver on top of a tall tower
  - Heat is transported by air or fluids (molten salts) to a steam-driven generator to create electricity
  - Lenses or mirrors track the sun's movement



(b) Four methods of concentrating solar power

© 2011 Pearson Education, Inc.

(c) The Solar Two power tower facility in California

© 2011 Pearson Education, Inc.

CSP facilities on just 100 mi^2 in Nevada could generate enough electricity for the entire U.S. economy

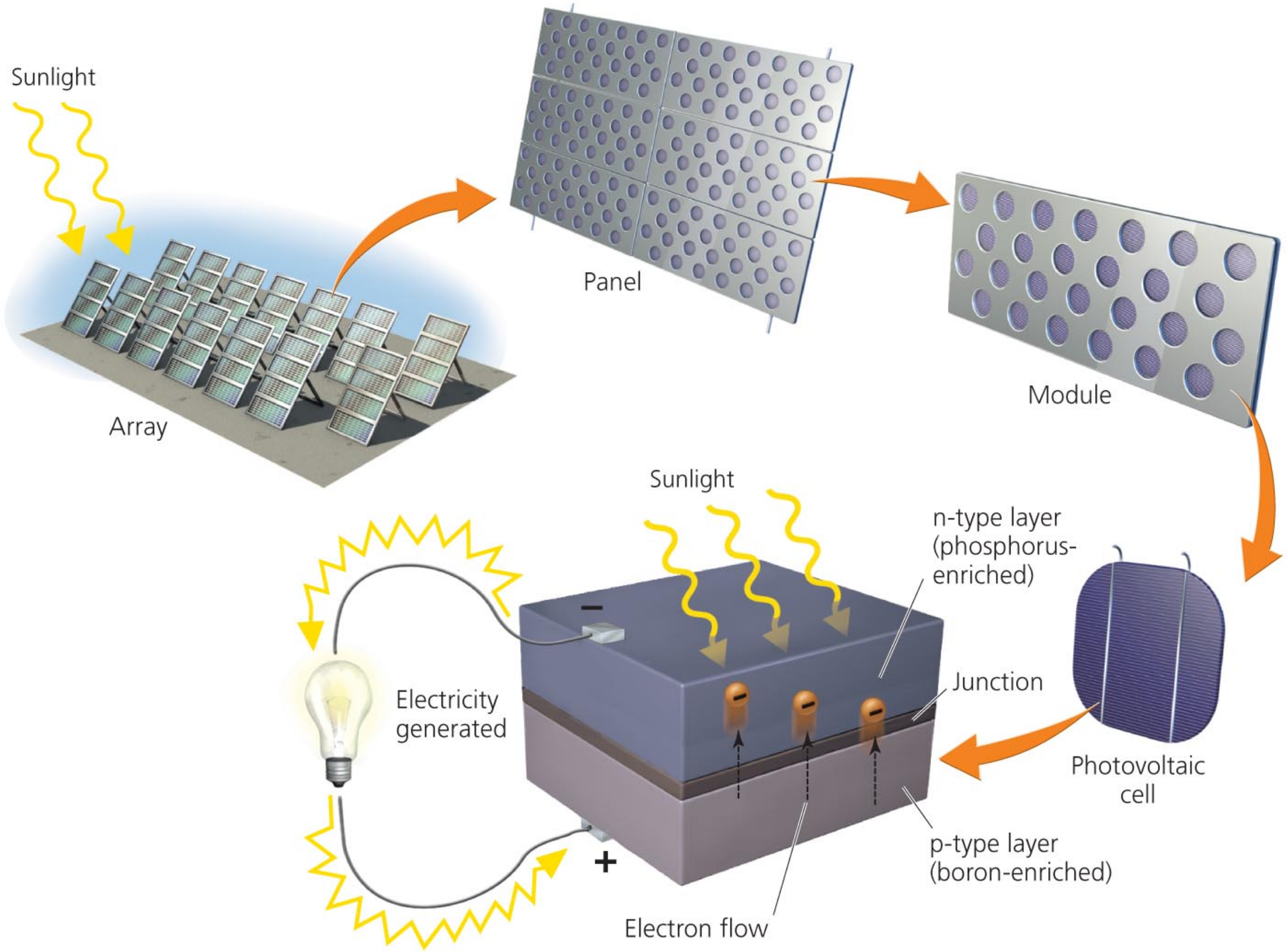
© 2011 Pearson Education, Inc.

Photovoltaic cells generate electricity

- **Photovoltaic (PV) cells** = convert sunlight directly into electrical energy
- The *photovoltaic* (*photoelectric*) *effect* occurs when light hits the PV cell and hits a plate made of silicon
  - Released electrons are attracted to the opposite plate
  - Wires connecting the two plates let electrons flow, creating an electric current
- Small PV cells are in watches and calculators
- On roofs, PV cells are arranged in modules, which comprise panels gathered into arrays

© 2011 Pearson Education, Inc.

A typical photovoltaic cell



© 2011 Pearson Education, Inc.

Variations on PV technology

- **Thin-film solar cells** = PV materials are compressed into thin sheets
  - Less efficient but cheaper
  - Can be incorporated into roofing shingles, roads, etc.
- **Net metering** = the value of the power the consumer provides is subtracted from the monthly utility bill
  - Producers of PV electricity can sell their power to a utility
- Feed-in tariffs pay producers more than the market price of power, so power producers turn a profit

© 2011 Pearson Education, Inc.

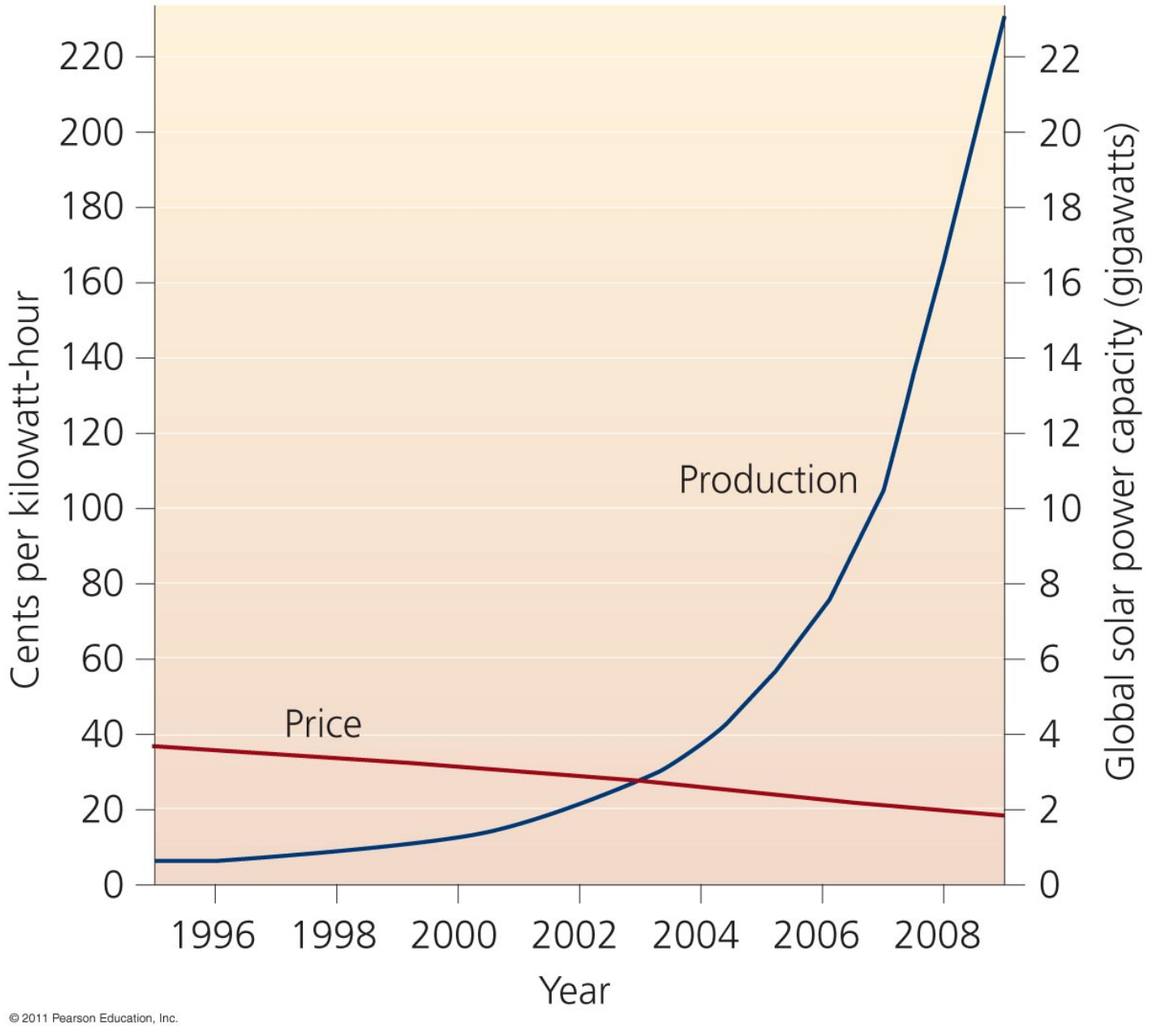
Solar power is fast growing

- Solar energy was pushed to the sidelines as fossil fuels dominated our economy
  - Funding has been erratic for research and development
- Because of a lack of investment, solar energy contributes only a miniscule part of energy production
  - But solar energy use has increased 31%/year since 1971
- Solar energy is attractive in developing nations, where hundreds of millions don't have electricity
- Some multinational fossil fuel companies are investing in solar energy

© 2011 Pearson Education, Inc.

Solar energy will continue to grow

- China leads the world in PV cell production
- The U.S. may recover its leadership
  - Due to tax credits and state initiatives
- Solar energy use should increase, due to:
  - Falling prices
  - Improved technologies
  - Economic incentives



© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

Solar energy offers many benefits

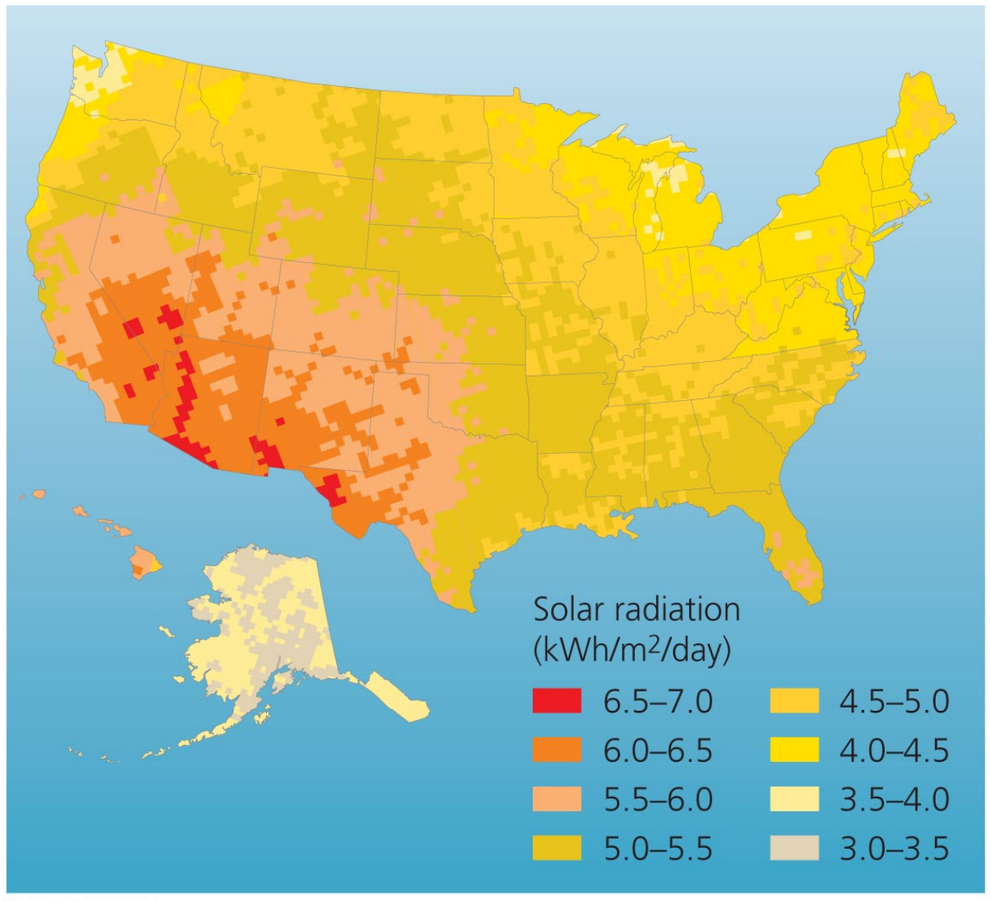
- Solar technologies use no fuels, are quiet and safe, contain no moving parts, and require little maintenance
- They allow local, decentralized control over power
- Developing nations can use solar cookers
  - Decreasing environmental and social stress
- PV owners can sell excess electricity to their local utility
- Green-collar jobs are being created
- It does not emit greenhouse gases and air pollution

A 5-kilowatt PV system in a home in Fort Worth would provide half its power needs, save $681/year, and prevent 5 tons of CO_2 emissions/year

© 2011 Pearson Education, Inc.

Location is a drawback

- Not all regions are sunny enough to provide enough power, given current technology
  - Daily and seasonal variation also poses problems
  - We need storage (e.g., batteries) and back-up power



© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

Cost is a drawback

- Up-front costs are high
  - Solar power is the most expensive way to produce electricity
  - But prices have dropped and efficiency has increased
- Fossil fuels and nuclear energy are favored over solar
  - Government subsidies
  - Market prices don’t include their external costs
- Prices are declining and technologies are improving
  - PV cells are showing 20% efficiency and can be higher

© 2011 Pearson Education, Inc.

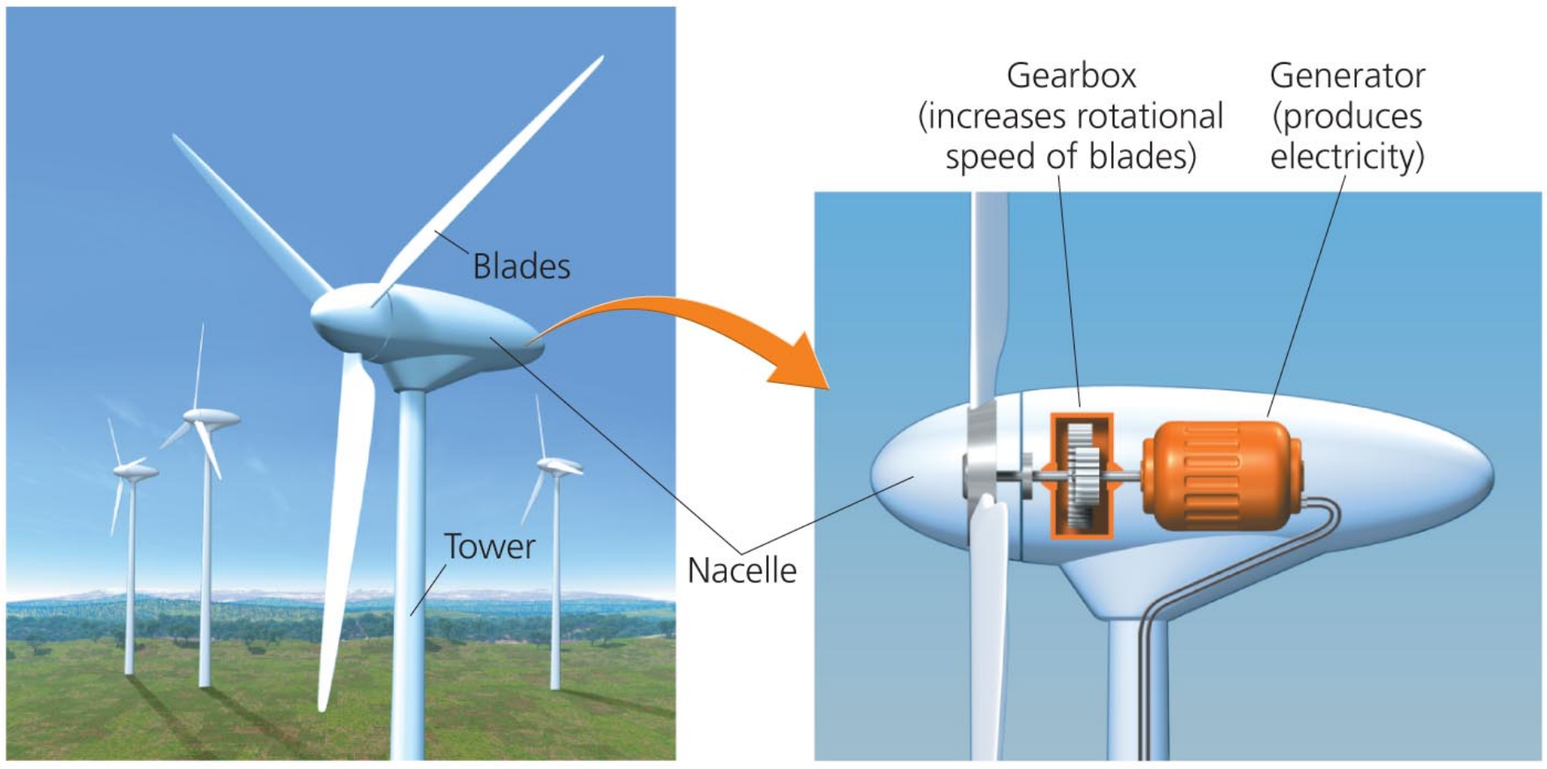
Wind has long been used for energy

- **Wind energy** = energy derived from movement of air
  - An indirect form of solar energy
- **Wind turbines** = devices that convert wind's kinetic energy into electric energy
- Windmills have been used for 800 years to pump water
- After the 1973 oil embargo, governments funded research and development
  - Moderate funding boosted technological progress
  - Today's wind turbines look like airplane propellers or helicopters

© 2011 Pearson Education, Inc.

Wind turbines turn kinetic to electric energy

- Wind blowing into a turbine turns the blades of the rotor
  - Which rotate machinery inside a compartment (*nacelle*) on top of a tall tower
- Towers are 45–105 m (148–344 ft) tall
  - Minimizing turbulence and maximizing wind speed



© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

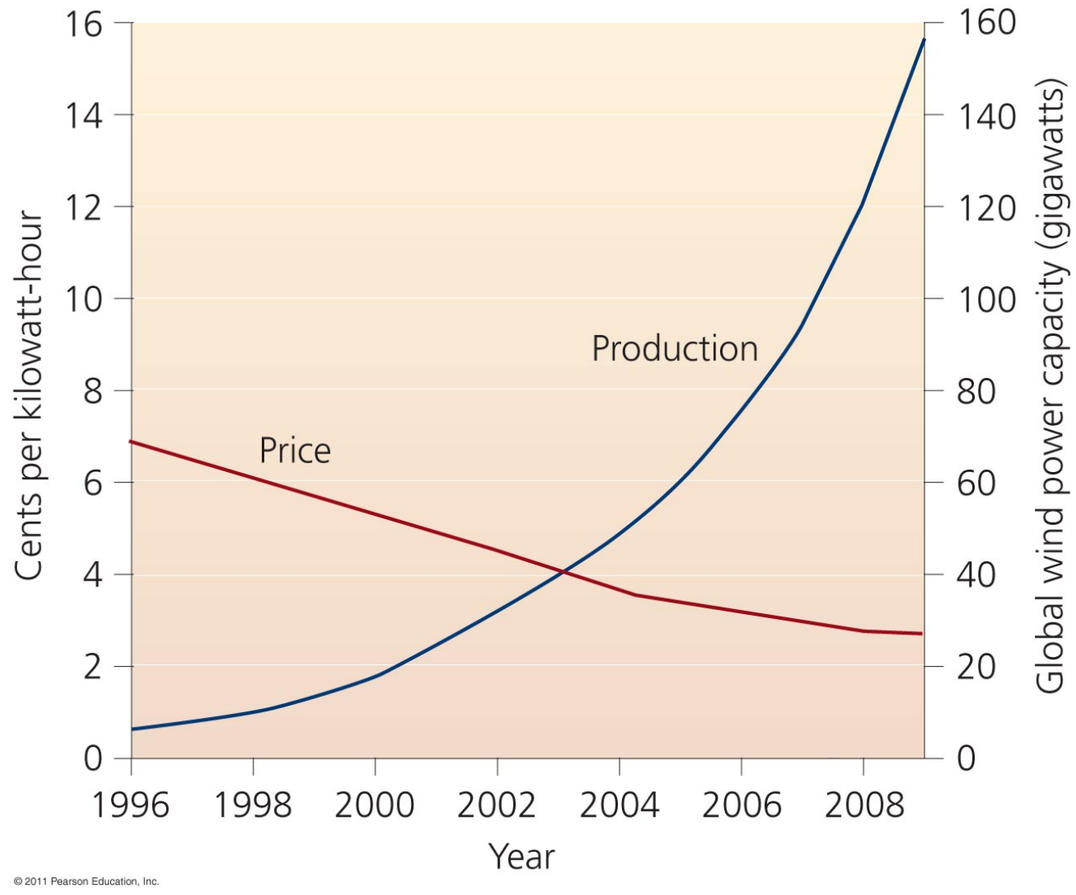
Wind farms

- *Wind farms* = turbines erected in groups of up to hundreds of turbines
- Turbines harness wind as efficiently as possible
  - Different turbines turn at different speeds
- Slight differences in wind speed yield significant differences in power output
  - If wind velocity doubles, energy quadruples
  - Increased speeds cause more air molecules to pass through the turbine, increasing power output

© 2011 Pearson Education, Inc.

Wind is the fastest-growing energy sector

- Wind power has doubled every 3 years in recent years
  - Five nations produce 75% of the world's wind power
  - But dozens of nations now produce wind power
- Electricity is almost as cheap as from fossil fuels
  - So wind power will grow
  - A long-term federal tax credit would increase wind power even more

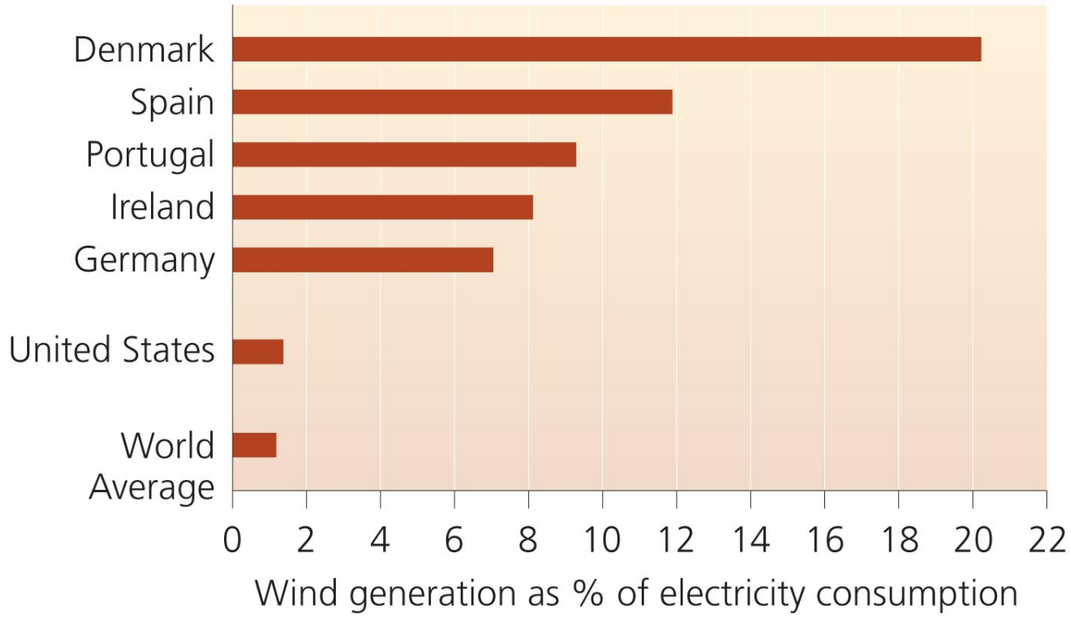


© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

Denmark leads the world in wind power

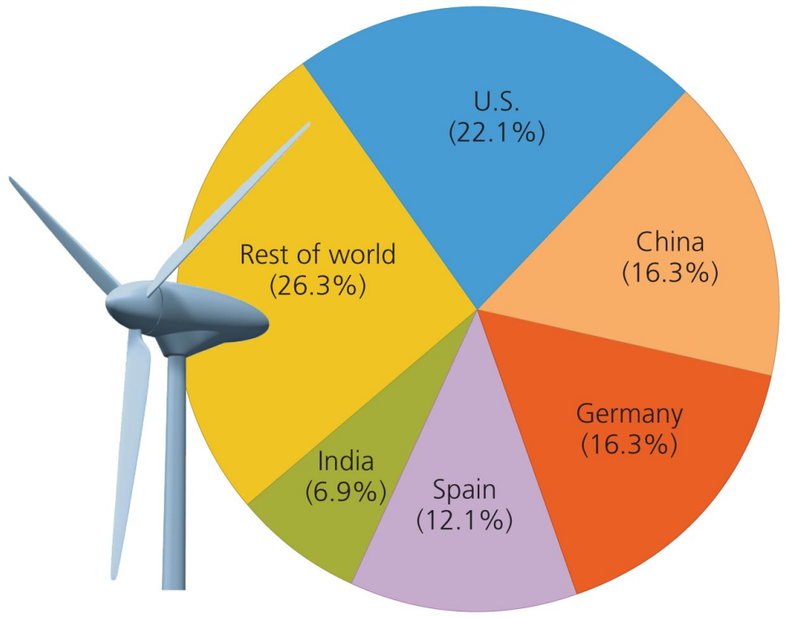
- Denmark gets the greatest percentage of its energy from wind power
- Texas generates the most wind power in the U.S.



(b) Leading nations in proportion of energy from wind power

© 2011 Pearson Education, Inc.

Wind supplies 20% of Denmark's electricity needs



(a) Percentage of global wind power in each nation

© 2011 Pearson Education, Inc.

Wind power could meet 20% of the electrical needs of the entire U.S. by 2030

© 2011 Pearson Education, Inc.

Offshore sites hold promise

- Wind speeds are 20% greater over water than over land
  - Also less air turbulence over water
- Costs to erect and maintain turbines in water are higher
  - But more power is produced and it is more profitable
- Currently, turbines are limited to shallow water
- The first U.S. offshore wind farm will have 130 turbines
  - Off Cape Cod, Massachusetts

© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

Wind power has many benefits

- Wind produces no emissions once installed
  - Prevents the release of CO_2, SO_2, NO_x, mercury
- It is more efficient than conventional power sources
  - EROI = 23:1 (nuclear = 16:1; coal = 11:1)
- Turbines use less water than conventional power plants
- Local areas can become more self-sufficient
- Farmers and ranchers can lease their land
  - Produces extra revenue while still using the land
- Advancing technology is also reducing the cost of wind farm construction

© 2011 Pearson Education, Inc.

Wind power creates job opportunities

- 35,000 new U.S. jobs were created in 2008
  - 85,000 employees work in the wind industry
- Over 100 colleges and universities offer programs and degrees that train people for jobs in renewable energy

© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

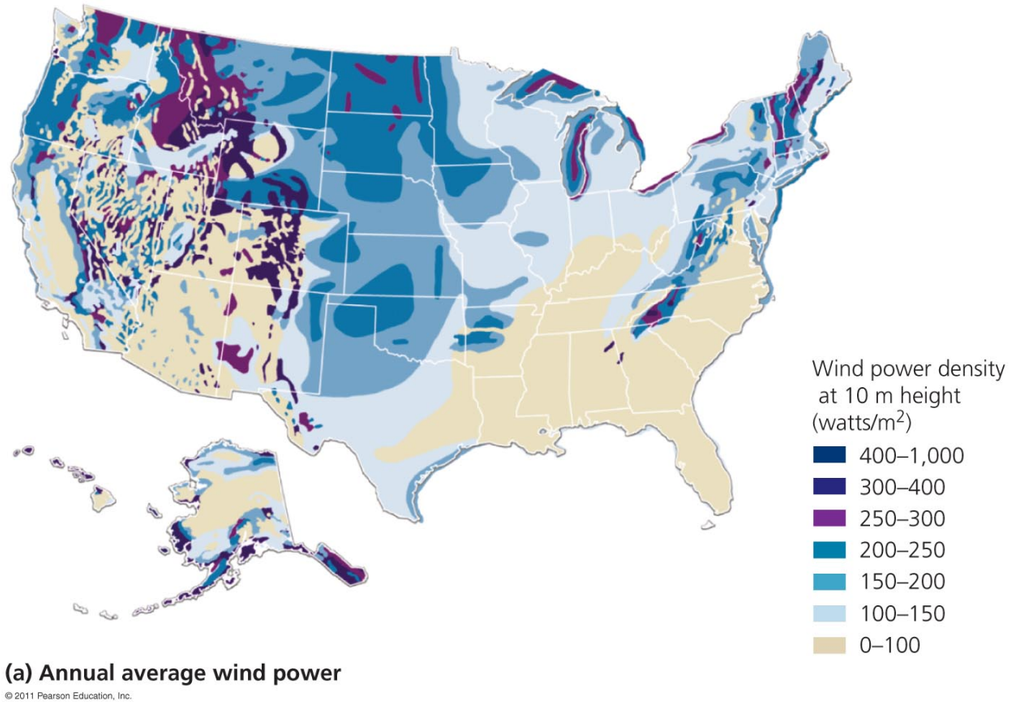
Wind power has some downsides

- We have no control over when wind will occur
  - Limitations on relying on it for electricity
  - Batteries or hydrogen fuel can store the energy
- Wind sources are not always near population centers that need energy
  - Transmission networks need to be expanded
- Local residents often oppose them
  - **Not-in-my-backyard (NIMBY)** syndrome
- Turbines threaten birds and bats, which can be killed when they fly into rotating blades

© 2011 Pearson Education, Inc.

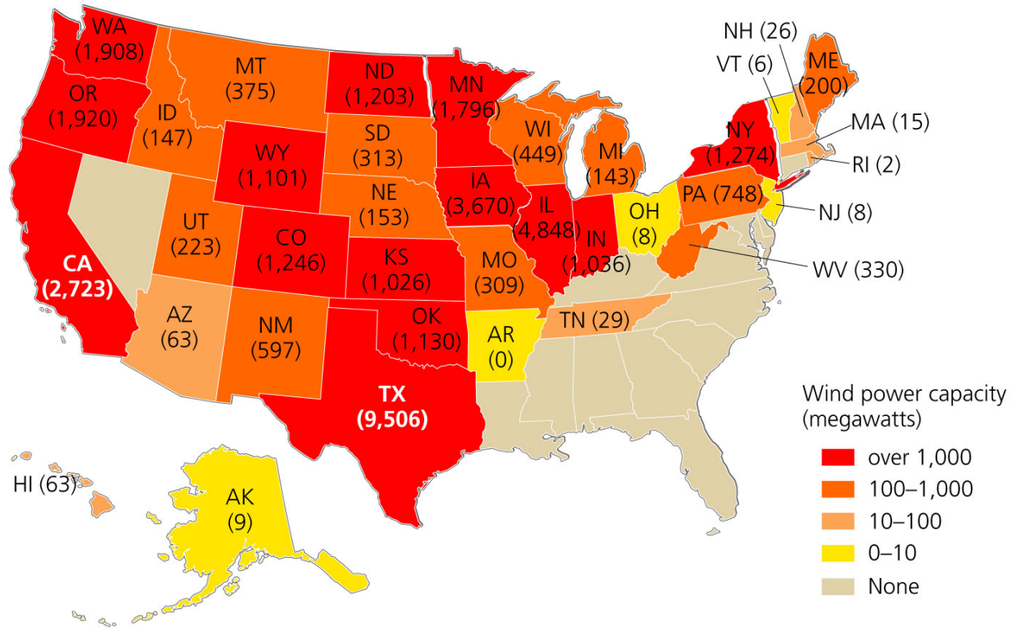
U.S. wind-generating capacity

Mountainous regions have the most wind and wind turbines



(a) Annual average wind power

© 2011 Pearson Education, Inc.



(b) Wind generating capacity, 2010

© 2011 Pearson Education, Inc.

15% of U.S. energy demand could be met using 16,600 mi² of land (less than 5% is occupied by turbines and roads)

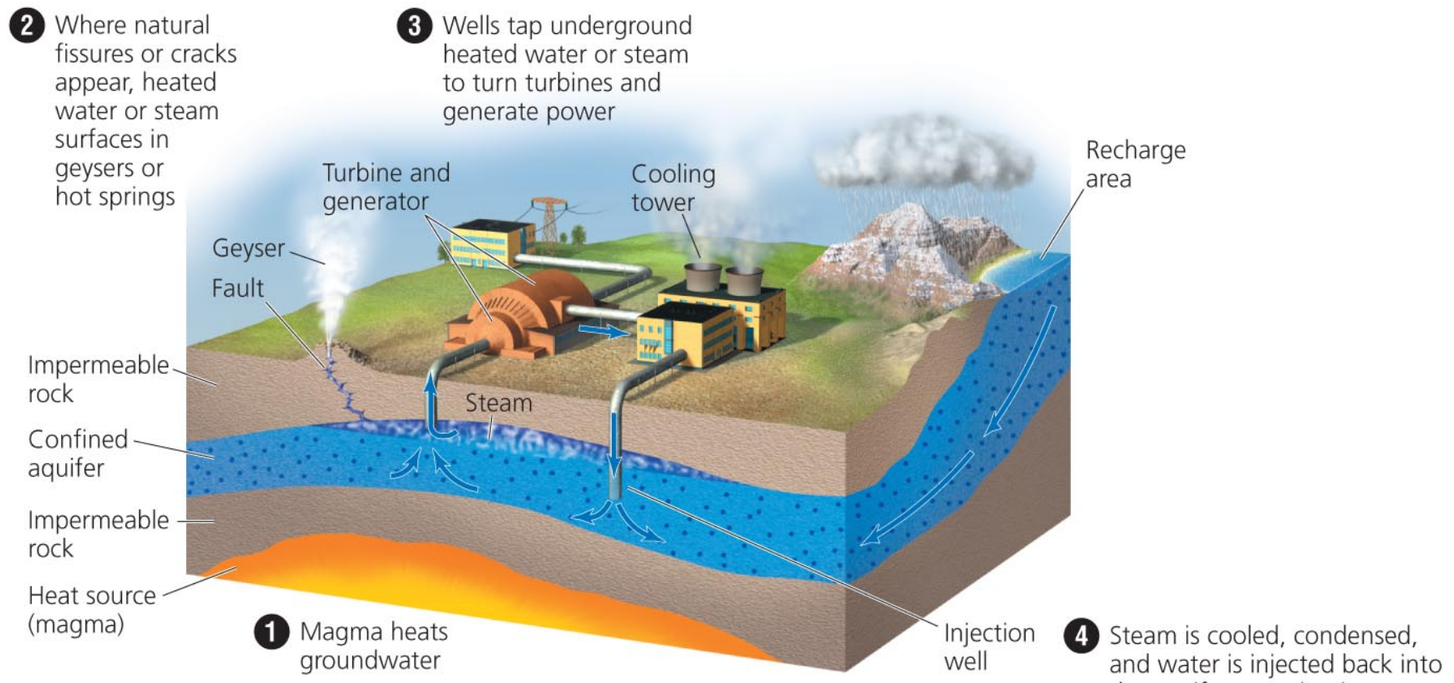
© 2011 Pearson Education, Inc.

Geothermal energy

- **Geothermal energy** = thermal energy from beneath Earth's surface
- Radioactive decay of elements under extremely high pressures deep inside the planet generates heat
  - Which rises through magma, fissures, and cracks
  - Or heats groundwater, which erupts as geysers or submarine hydrothermal vents
- Geothermal power plants use hot water and steam for heating homes, drying crops, and generating electricity
- Geothermal energy provides more electricity than solar
  - As much as wind

© 2011 Pearson Education, Inc.

The origins of geothermal energy



(a) Geothermal energy

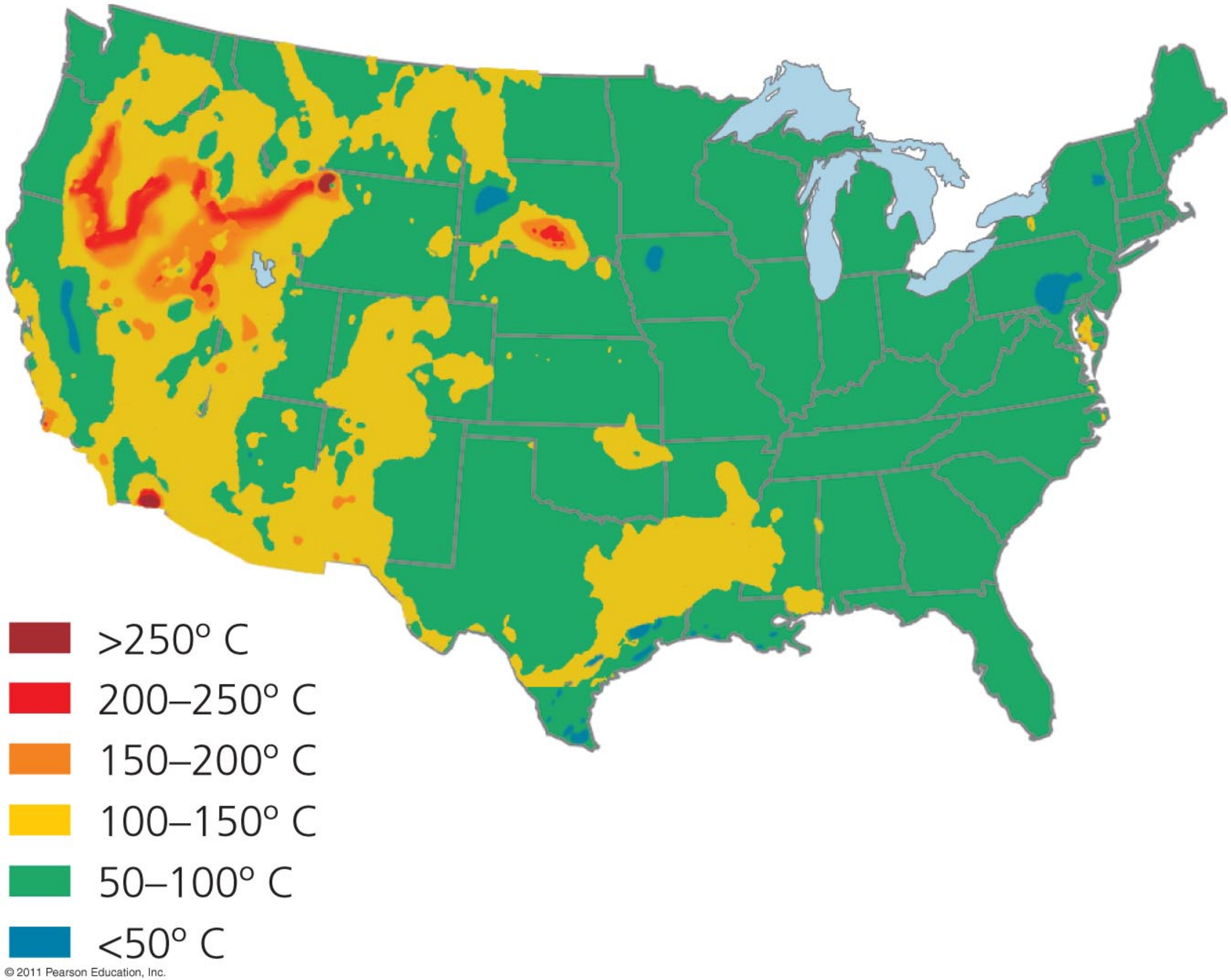
© 2011 Pearson Education, Inc.

(b) Nesjavellir geothermal power station, Iceland

© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

The U.S. is the leader in geothermal use



© 2011 Pearson Education, Inc.

Geothermal power has benefits and limits

- Geothermal power reduces emissions
  - Each megawatt of geothermal power prevents release of 15.5 million lb of CO_2 each year
- But it may not be sustainable if the plant withdraws water faster than it can be recharged
  - Water or wastewater can be injected into the ground
- Patterns of geothermal activity in the crust shift
- Water has salts and minerals that corrode equipment and pollute the air
- It is limited to areas where the energy can be trapped

© 2011 Pearson Education, Inc.

Enhanced geothermal systems

- **Enhanced geothermal systems (EGS)** = deep holes are drilled into the Earth
  - Cold water is pumped in and heats
  - It is withdrawn to generate electricity
- It could be used in many locations
- Heat resource below the U.S. could power the Earth's demands for millennia
- But EGS can trigger minor earthquakes
  - Our use of geothermal power will stay localized

© 2011 Pearson Education, Inc.

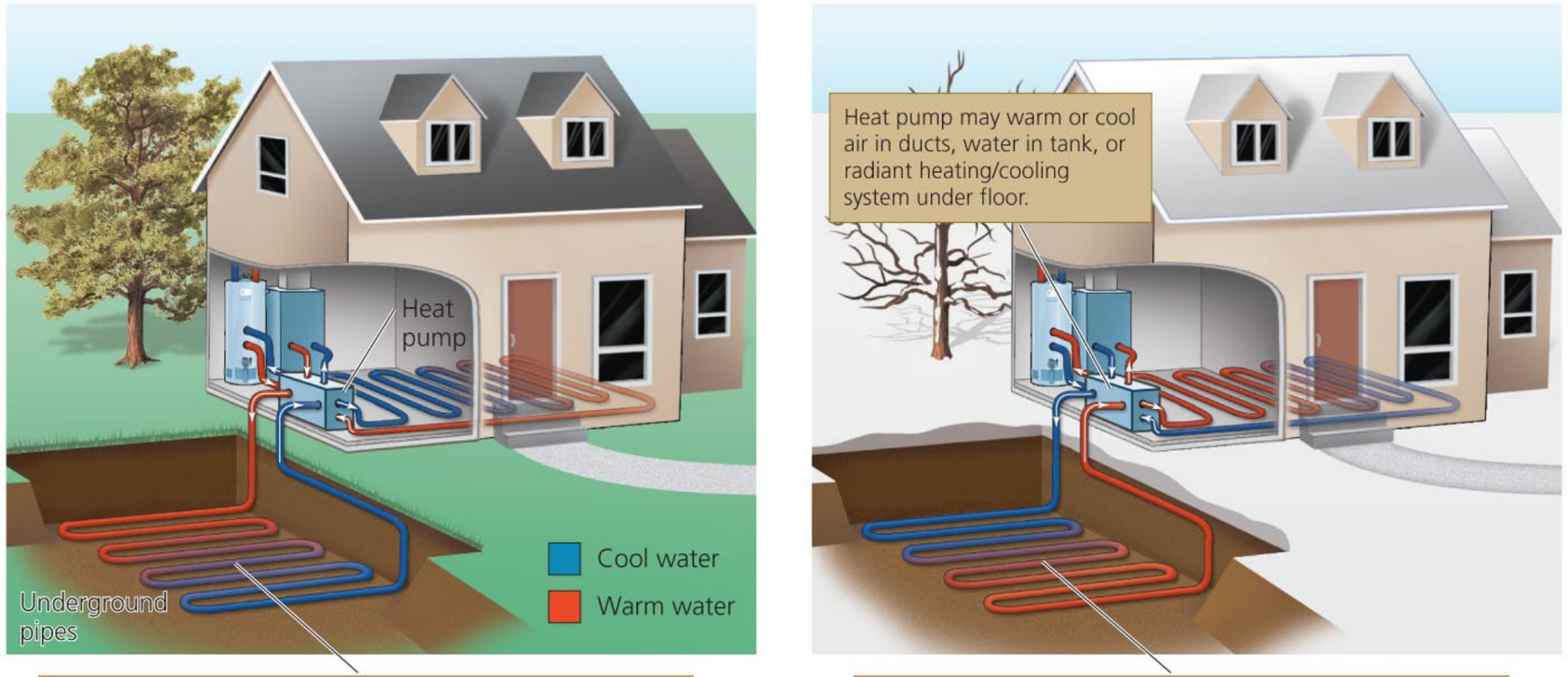
Heat pumps use temperature differences

- We can take advantage of natural temperature differences between the soil and air
  - Soil temperatures vary less than air temperatures
  - Soil temperatures are nearly constant year round
- **Ground source heat pumps (GSHPs)** = geothermal pumps heat buildings in the winter by transferring heat from the ground to the building
  - In summer, heat is transferred from the building to the ground

© 2011 Pearson Education, Inc.

GSHPs are efficient

- More than 600,000 U.S. homes use GSHPs
- GSHPs heat spaces 50–70% more efficiently
  - Cool spaces 20–40% more efficiently
  - Reduce electricity use 25–60%
  - Reduce emissions up to 70%



In summer, soil underground is cooler than surface air. Water flowing through the pipes transfers heat from the house to the ground, cooling the house.

In winter, soil underground is warmer than surface air. Water flowing through the pipes transfers heat from the ground to the house, warming the house.

© 2011 Pearson Education, Inc.

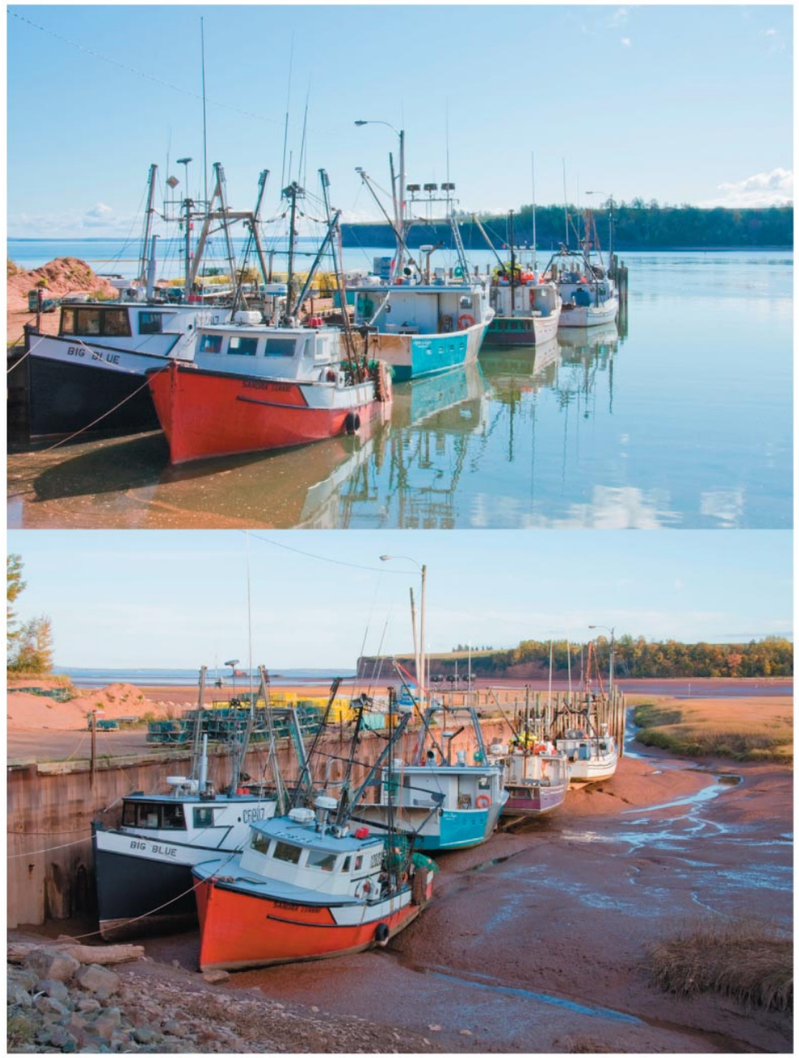
© 2011 Pearson Education, Inc.

We can harness energy from the oceans

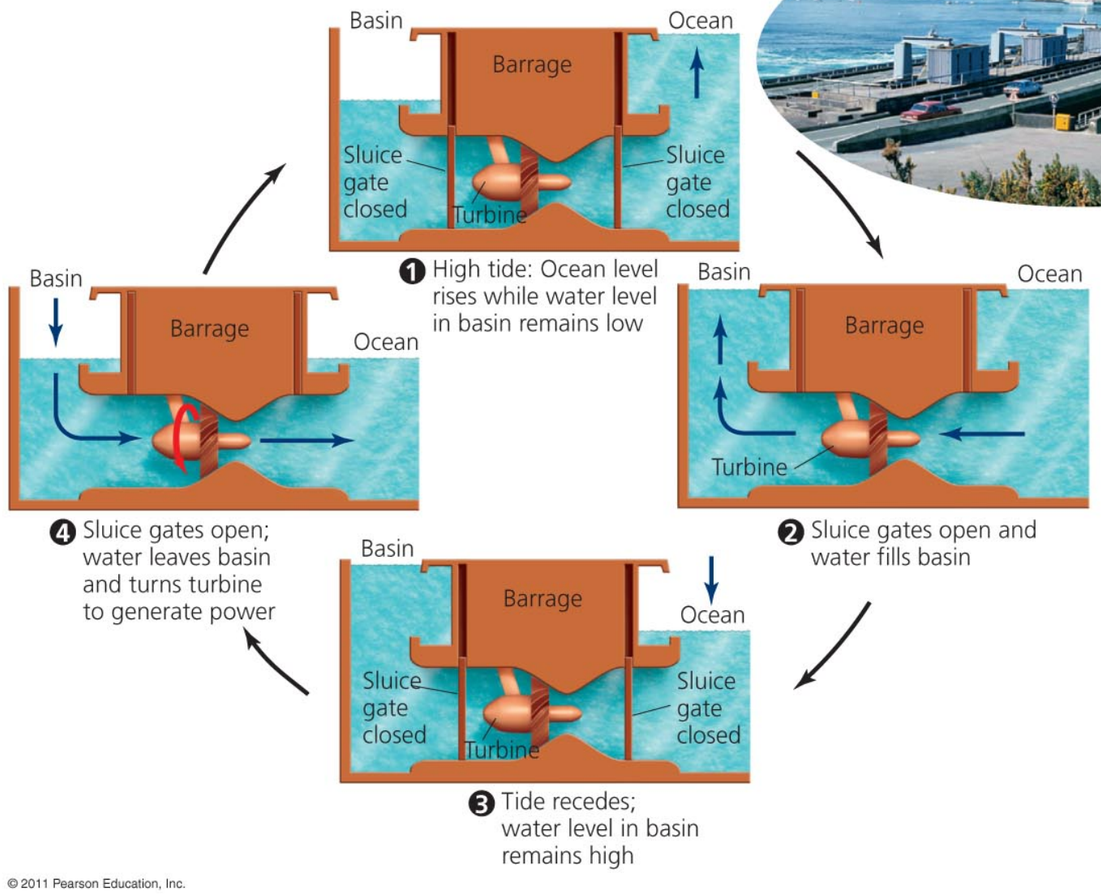
- Kinetic energy from the natural motion of ocean water can generate electrical power
- The rising and falling of ocean tides twice each day move large amounts of water
- Differences in height between low and high tides are especially great in long, narrow bays
- **Tidal energy** = dams cross the outlets of tidal basins
  - Water is trapped behind gates
  - Outgoing tides turn turbines to generate electricity
- Tidal stations don't release emissions
  - But they change the area's ecology

© 2011 Pearson Education, Inc.

Energy can be extracted from tidal movement



© 2011 Pearson Education, Inc.



© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

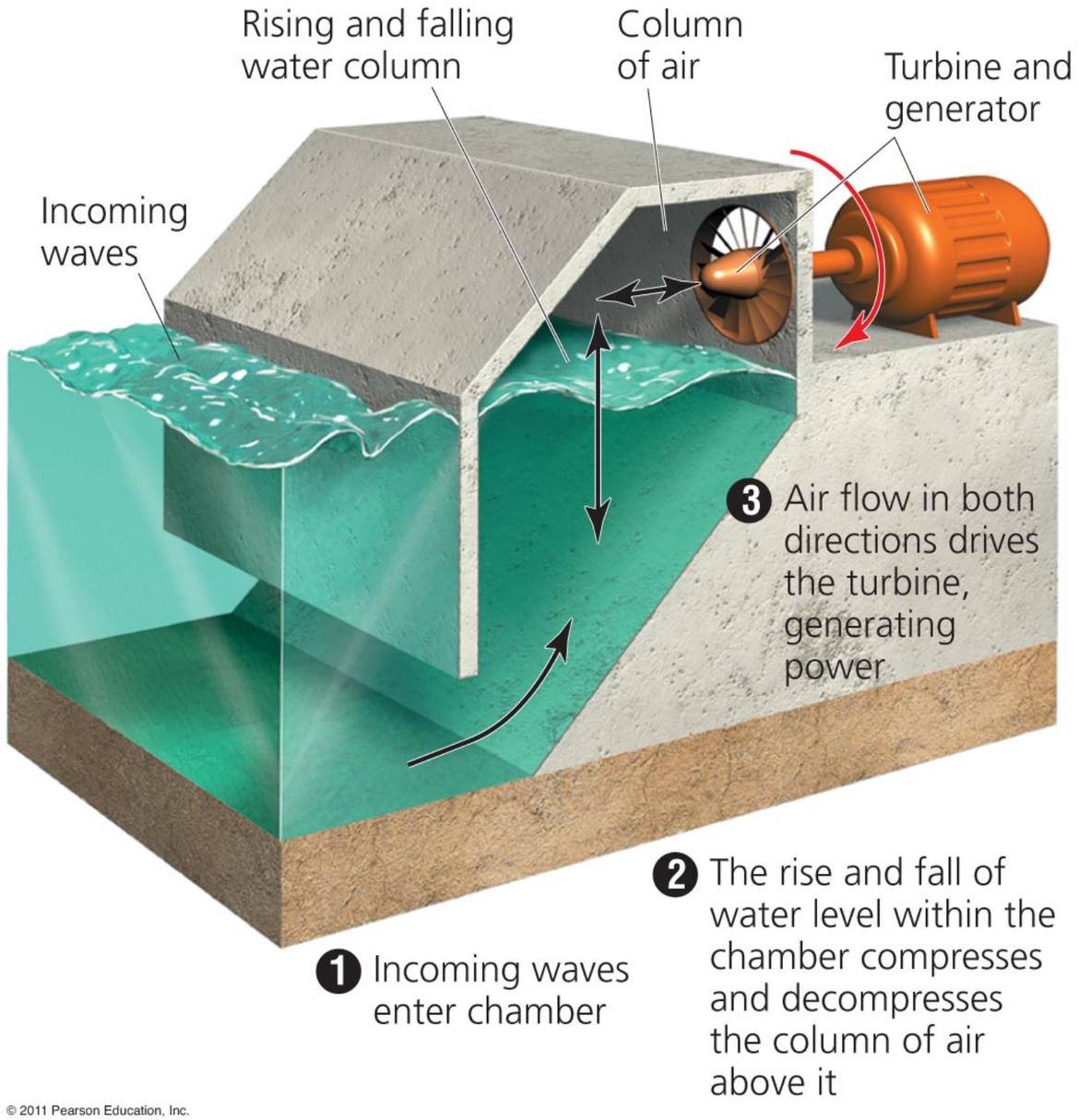
Wave energy

- **Wave energy** = the motion of waves is harnessed and converted from mechanical energy into electricity
- Many designs exist, but few have been adequately tested
- Some designs are for offshore facilities and involve floating devices that move up and down the waves
- Wave energy is greater at deep ocean sites
  - But transmitting electricity to shore is very expensive
- Another design uses the motion of ocean currents, such as the Gulf Stream
  - Underwater turbines have been erected off of Europe

© 2011 Pearson Education, Inc.

Coastal onshore facilities

- One coastal design uses rising and falling waves, which push air in and out of chambers, turning turbines to generate electricity
- No commercial wave energy facilities operate yet
  - But demonstration projects exist in Europe, Japan, and Oregon



© 2011 Pearson Education, Inc.

The ocean stores thermal energy

- Each day, tropical oceans absorb solar radiation equal to the heat content of 250 billion barrels of oil
- **Ocean thermal energy conversion (OTEC)** = uses temperature differences between the surface and deep water
- *Closed cycle* approach = warm surface water evaporates chemicals, which spin turbines to generate electricity
- *Open cycle* approach = warm surface water is evaporated in a vacuum and its steam turns turbines
- Costs are high, and no facility operates commercially yet

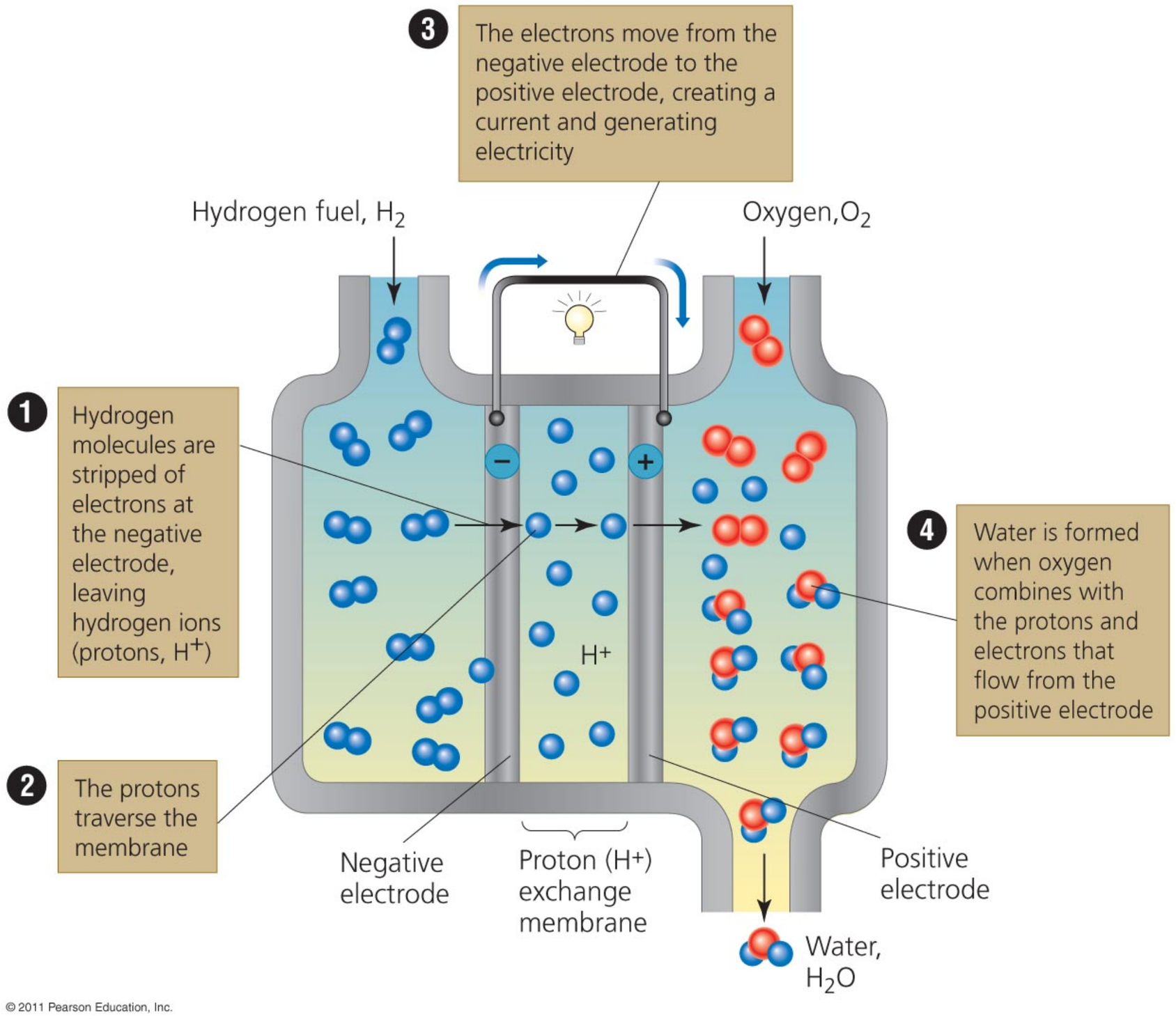
© 2011 Pearson Education, Inc.

A hydrogen economy

- A hydrogen economy would provide a clean, safe, and efficient energy system by using the world's simplest and most abundant element (hydrogen) as fuel
- Electricity produced from intermittent sources (sun, wind) would be used to produce hydrogen
- Fuel cells (hydrogen batteries) would use hydrogen to produce electricity to power cars, homes, computers, etc.
- Governments are funding research into hydrogen and fuel cell technology

© 2011 Pearson Education, Inc.

A typical hydrogen fuel cell

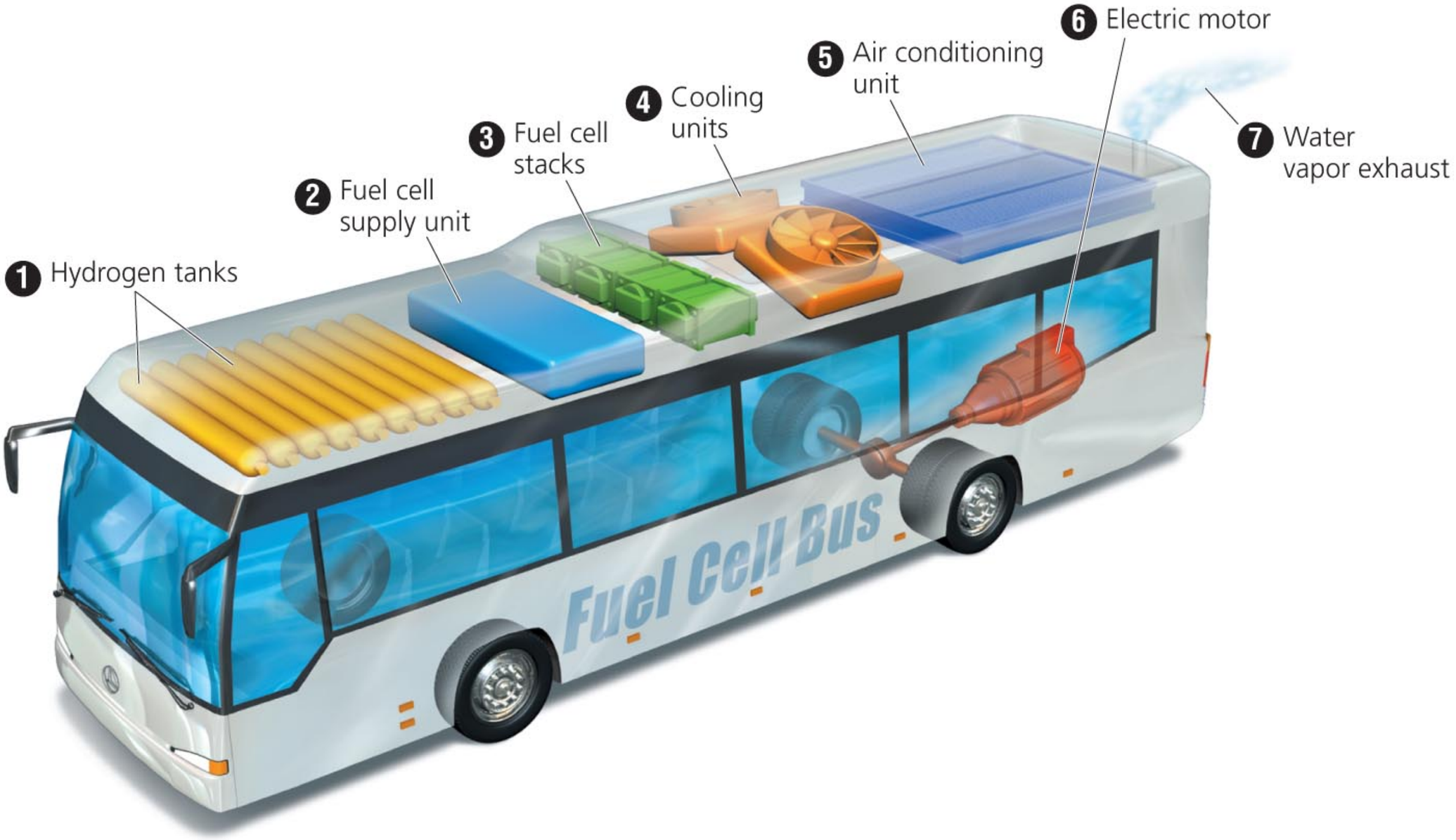


© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

A hydrogen-fueled bus

Germany is one of several nations with hydrogen-fueled city buses



© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

Production of hydrogen fuel

- Hydrogen gas does not exist freely on Earth
  - Energy is used to force molecules to release the hydrogen
- **Electrolysis** = electricity splits hydrogen from water

$$2H_2O \Rightarrow 2H_2 + O_2$$

  - It may cause pollution, depending on the source of electricity
- The environmental impact of hydrogen production depends on the source of hydrogen
  - Using methane produces the greenhouse gas CO_2

$$CH_4 + 2H_2O \Rightarrow 4H_2 + CO_2$$

© 2011 Pearson Education, Inc.

Fuel cells can produce electricity

- Once isolated, hydrogen gas can be used as a fuel to produce electricity within fuel cells
- The chemical reaction is the reverse of electrolysis

$$2H_2 + O_2 \Rightarrow 2H_2O$$

- The movement of the hydrogen's electrons from one electrode to the other creates electricity

© 2011 Pearson Education, Inc.

Hydrogen and fuel cells have costs and benefits

- Need massive and costly development of infrastructure
- Leakage of hydrogen can deplete stratospheric ozone
- We will never run out of hydrogen
- It can be clean and nontoxic to use
- It may produce few greenhouse gases and pollutants
- If kept under pressure, it is no more dangerous than gasoline in tanks
- Cells are up to 90% energy efficient
- Fuel cells are silent and nonpolluting and won't need to be recharged

© 2011 Pearson Education, Inc.

Conclusion

- The decline of fossil fuels and concern over global climate change, health impacts, and security have convinced many people we need to shift to renewable energy
- Renewable sources include solar, wind, geothermal, and ocean energy sources and hydrogen fuel
- Renewable energy sources have been held back by inadequate funding and by artificially cheap prices for nonrenewable resources
- But we can shift smoothly to renewable energy

© 2011 Pearson Education, Inc.

QUESTION: Review

Which of these is NOT a benefit of solar energy?

a) It is quiet, but requires maintenance of its moving parts.
b) It allows local, decentralized control over power.
c) It decreases environmental and social stress.
d) It does not emit greenhouse gases.

© 2011 Pearson Education, Inc.

QUESTION: Review

Which energy source has doubled every three years and its cost of electric production is almost as cheap as fossil fuels?

a) Solar
b) Wind
c) Geothermal
d) Hydrogen

© 2011 Pearson Education, Inc.

QUESTION: Review

When would geothermal energy NOT be renewable?

a) When the Earth cools down
b) When too much salt is put into the substance holding the hot water
c) When too much hot water is extracted
d) Never, geothermal energy can not be depleted

© 2011 Pearson Education, Inc.

QUESTION: Review

What is a major drawback of hydrogen fuel?

a) It could pollute if facilities are built too large.
b) It could pollute if fossil fuels are used to produce the hydrogen.
c) There is a slight danger of causing earthquakes during production.
d) People will never want to use it.

© 2011 Pearson Education, Inc.

QUESTION: Review

Which energy source does NOT emit greenhouse gases, but has great potential to disrupt or change ecosystems?

a) Solar cells
b) Wind farms
c) Geothermal sources
d) Tidal energy

© 2011 Pearson Education, Inc.

QUESTION: Interpreting Graphs and Data

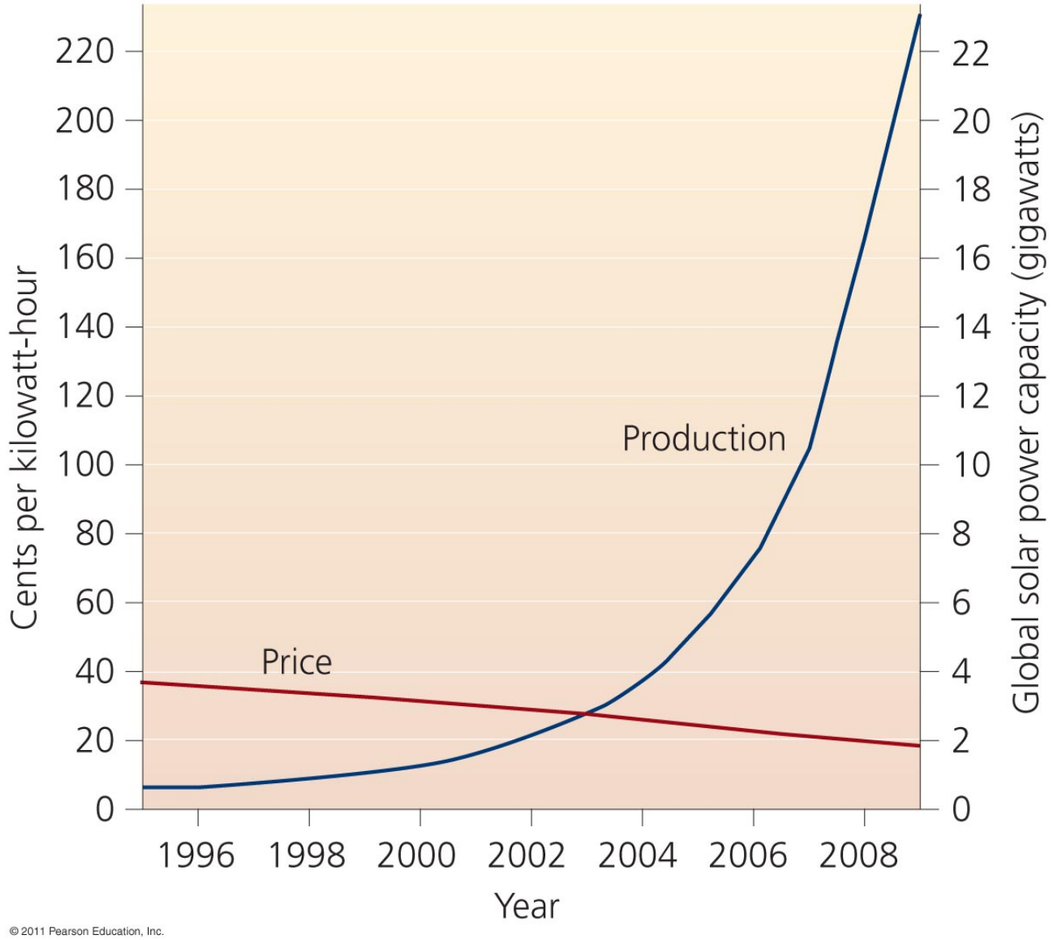
What conclusions can you draw from this graph?

a) Production of PV cells grew and prices fell.

b) Production of PV cells fell and prices also fell.

c) Production of PV cells grew and prices increased.

d) Production of PV cells fell and prices increased.



© 2011 Pearson Education, Inc.

© 2011 Pearson Education, Inc.

QUESTION: Weighing the Issues

Which energy source would you most support in your housing community?

a) Solar
b) Wind
c) Nuclear
d) Coal

© 2011 Pearson Education, Inc.