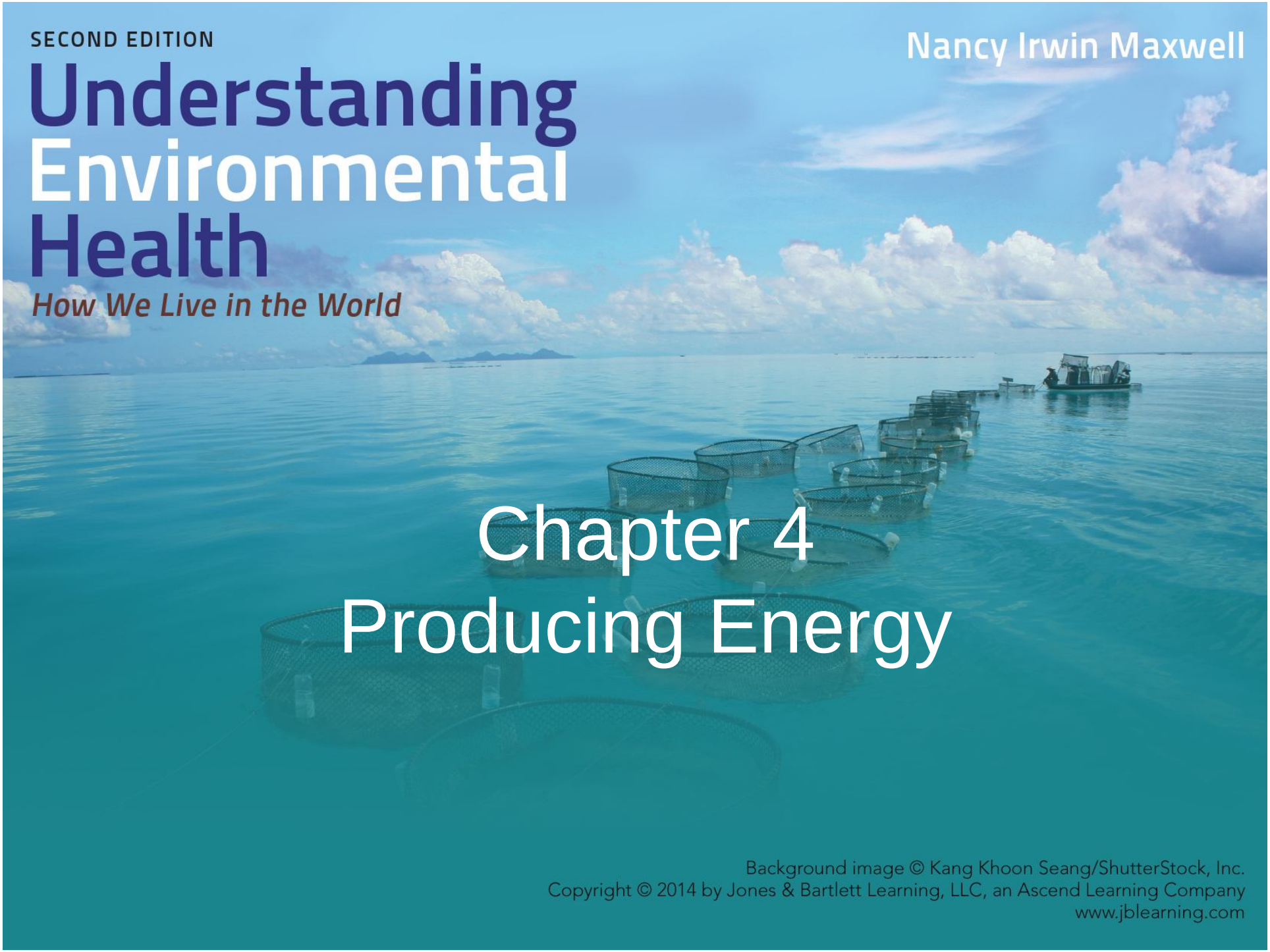


4.1 Energy from Fossil Fuels

4.2 Electricity from Nuclear Fuel

4.3 Alternatives to Fossil and Nuclear Fuels

Introduction

- Fuels—substances that release energy when they are changed (e.g., burned)
  - Fossil fuels (aka hydrocarbon fuels)
    - Formed from decayed plants and animals laid down millions of years ago
    - Oil, coal, natural gas
    - Nonrenewable

Extraction of Fossil Fuels

Environmental Impacts of Burning Fossil Fuels

Local and Regional Health Impacts of Burning Fossil Fuels

Global Climate Change

Regulation of Air Pollution from the Burning of Fossil Fuels

Extraction of fossil fuels

- Environmental and health effects of coal mining
  - Acid mine drainage
  - Surface mining (strip mining)
    - Destruction of landscape
  - Underground mining
    - Respiratory effects: fibrosis, pneumoconiosis, silicosis; “black lung”
    - Fire, explosion, acute injury

Extraction of fossil fuels

FIGURE 4.1 U.S. coal miners, circa 1930–1960, wear no respiratory protection as they operate a mechanized coal bin loader.

Source: Reprinted courtesy of CDC Public Health Image Library. ID# 9558. Content providers CDC/Barbara Jenkins, NIOSH. Available at: http://phil.cdc.gov/phil/home.asp. Accessed October 14, 2012.

Extraction of fossil fuels

- Environmental and health effects of oil and gas extraction
  - Hazards to workers, wastes of drilling
  - Oil spills—*Deepwater Horizon*, *Exxon Valdez,* oil pipelines
  - Fracking—destructive geologic effects, removal and pollution of large quantities of water, impacts on people and animals; very large scale

Extraction of fossil fuels

FIGURE 4.2 Shale basins in the lower 48 U.S. states.

Source: U.S. Department of Energy, *Modern Shale Gas Development in the United States: A Primer*. April 2009. Available at: www.netl.doe.gov/technologies/oil-gas/publications/EPreports/Shale_Gas_Primer_2009.pdf. Accessed March 28, 2012.

Extraction of fossil fuels

- Time horizon for fossil fuels
  - Coal[1]
    - Global proved reserves up to 130 years
    - US holds 27% of reserves
  - Oil and natural gas[1]
    - Global proved reserves about 40 years
    - Middle East holds 60% of oil, 40% of gas
  - "Proved reserves" may be conservative

Extraction of Fossil Fuels

Environmental Impacts of Burning Fossil Fuels

Local and Regional Health Impacts of Burning Fossil Fuels

Global Climate Change

Regulation of Air Pollution from the Burning of Fossil Fuels

Air pollution from burning fossil fuels

- Basic products of combustion: oxides and particulates
  - Key sources of pollutants: vehicles, electric power plants, heating of buildings, manufacturing
  - Combustion is oxidation; hence oxides of carbon, nitrogen, sulfur
  - Particulate matter
    - Complex mixture
    - Units: mg/m^3 or $\mu g/m^3$

Air pollution from burning fossil fuels

Table 4.1 Key Sources of Major Air Pollutants from the Burning of Fossil Fuels

Pollutant	*Sources of Pollutants*			
	Vehicles (gasoline, diesel)	Electric Power Plants (coal, oil)	Heating Buildings (oil, natural gas)	Manufacturing (coal, oil, natural gas)
Basic products of the combustion process				
Carbon dioxide (CO_2)	✓	✓	✓	✓
Carbon monoxide (CO)	✓			
Nitrous oxide (N_2O)	✓	✓		
Nitrogen dioxide (NO_2), Nitric oxide (NO)	✓	✓		
Sulfur dioxide (SO_2)		✓		(some)
Particulate matter (PM)	✓	✓	✓	✓

Air pollution from burning fossil fuels

- Other pollutants liberated by combustion
  - Mercury (neurotoxic)— present in coal
    - Converted to methylmercury; bioaccumulates and biomagnifies; high concentrations in large fish
  - Lead (neurotoxic)—gasoline additive
    - Burden of lead in soil
  - Volatile organic compounds
    - Some naturally present in oil; others added to gasoline
    - Released to air when oil or gasoline is burned

Air pollution from burning fossil fuels

Other pollutants liberated by combustion			
Mercury (from coal)		✓	(some)
Lead (from leaded gasoline)	✓		
Volatile organic compounds (from gasoline)	✓		

Air pollution from burning fossil fuels

- Secondary pollutants formed in the atmosphere
  - Ozone
    - Key component of photochemical smog
    - Formed from NO_X, VOCs, and other chemicals in the presence of sunlight
  - Nitric acid and sulfuric acid from oxides of nitrogen and sulfur
    - Acid deposition (“acid rain”)

Extraction of Fossil Fuels

Environmental Impacts of Burning Fossil Fuels

Local and Regional Health Impacts of Burning Fossil Fuels

Global Climate Change

Regulation of Air Pollution from the Burning of Fossil Fuels

Local and regional health impacts of burning fossil fuels

- Particulates and pollutant gases
  - Sources and fate in respiratory system Particulates classified by size
    - PM_{10}—respirable
    - $PM_{2.5}$—"fine" (mostly from combustion)
    - Ultrafine particulates
  - Key respiratory effects of common pollutants

Local and regional health impacts of burning fossil fuels

Table 4.3 Likely Sources and Fates of Respirable Particulates, by Size Category

Diameter (microns)	Key Sources	Penetration and Fate in Body
2.5 to 10	Natural and mechanical sources	Settle out in trachea and bronchi; are removed via mucociliary escalator
0.1 to < 2.5	Combustion	Reach small airways and alveoli; in alveoli, are removed by macrophages
< 0.1 (ultrafine)	Combustion (especially of diesel fuel)	Can pass through alveolar wall into bloodstream

Local and regional health impacts

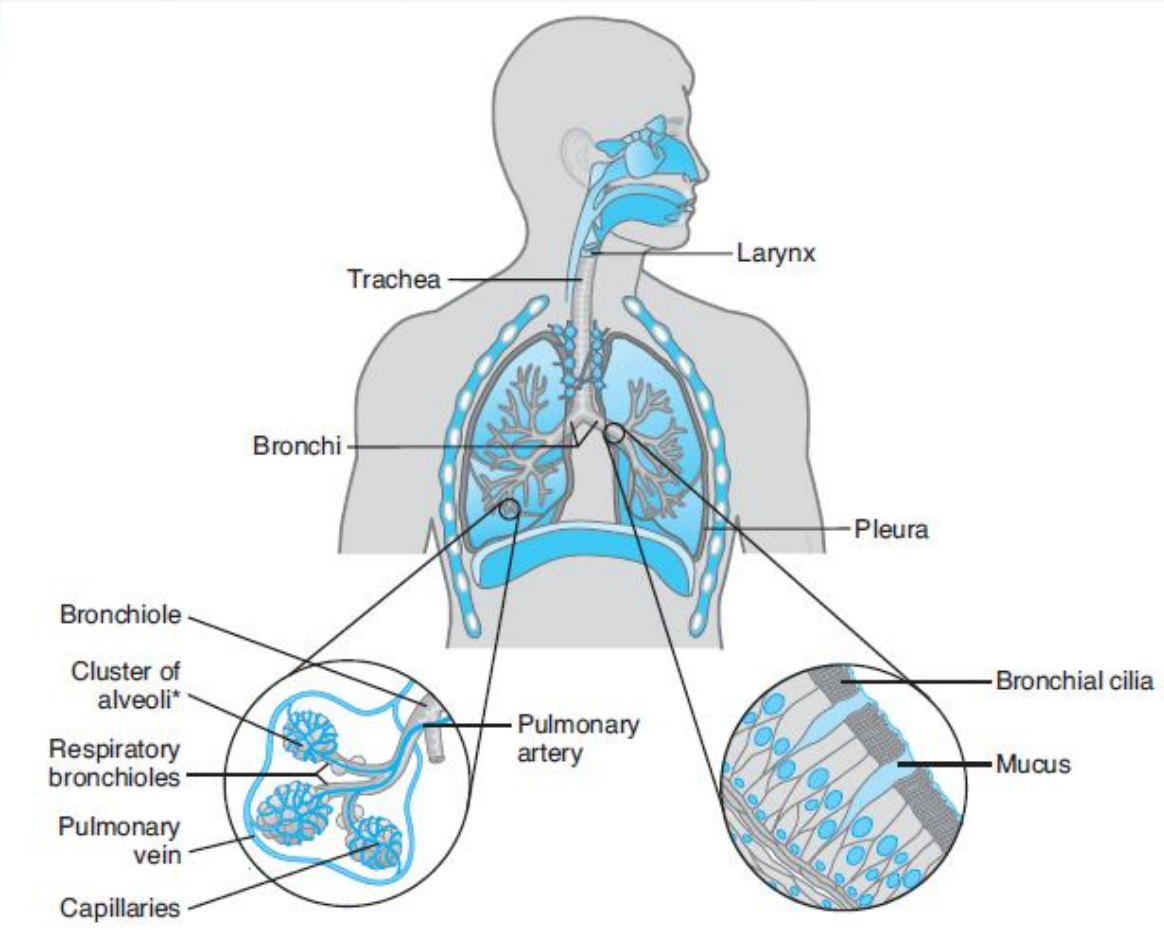


FIGURE 4.3 The human respiratory system.

Source: Modified from 2012 American Lung Association. www.lung.org.

Local and regional health impacts of burning fossil fuels

Table 4.4 Key Respiratory Effects of Common Air Pollutants

Pollutant	Effects in Respiratory System			
	Irritating Effects			
	Damage to Cells Lining the Respiratory Tract	Local Inflammation	Bronchoconstriction	Impairment of Immune Scavenger Cells in Alveoli
PM	✓	✓		✓
NO_2			(in asthmatics)	✓
SO_2			✓	
O_3	✓	✓	(in asthmatics)	

Source: Data from Bernstein JA. Health effects of air pollution. *J Allergy Clin Immunol*. 2004;114(5):1116–1123. Chen-Yeung MNW. Air pollution and health. *Hong Kong Med J*. 2000;6(4):390–398. Costa DL, Amdur MO, Air pollution. In: Klaasen, CD, ed. *Casarett & Doull's Toxicology: The Basic Science of Poisons*. New York: McGraw-Hill; 1996:857–882. Olivieri D, Scoditti E, Impact of environmental factors on lung defences. *Eur Respir Rev*. 2005;14:51–56.

Local and regional health impacts of burning fossil fuels

- Health impacts of particulates and pollutant gases
  - A turning point: the London Smog
  - PM, NO_2, SO_2, O_3 have been linked to:
    - Acute overall mortality and acute cardiovascular mortality [2, 3, 4]
    - Acute stroke mortality [5]
    - Acute morbidity (hospital admissions for: any respiratory disease, chronic obstructive pulmonary disease; any cardiovascular disease, heart failure) [3, 6]
    - Exacerbation of asthma [2, 7-11]

Local and regional health impacts of burning fossil fuels

- PM also linked to:
  - Long-term overall mortality, lung cancer mortality, acute and chronic cardiopulmonary mortality [12,13]
  - Cardiovascular mortality and hospitalizations [14]
  - Reduced life expectancy [15, 16]
  - Low birthweight, infant mortality [7]
- Greatest impact of air pollution on mortality is through effects on cardiovascular disease

Local and regional health impacts of burning fossil fuels

- Heavy metals: mercury and lead
  - Methylmercury; a neurotoxicant[17]
    - High prenatal exposures: mental retardation, cerebral palsy, deafness, blindness
    - Lower prenatal exposures: subtle effects on language, attention, memory[18-20]
    - Subgroups with high fish consumption
      - Canned tuna as inexpensive protein source

Local and regional health impacts of burning fossil fuels

- Lead; a neurotoxicant
  - Blood lead level (BLL), in μg/dl
    - 45 μg/dl—chelation recommended
    - 10 μg/dl—blood lead action level: reduce exposure
    - Considered to be no threshold for neurotoxic effects
  - Effects on [21,22]
    - IQ, cognitive & neurological performance more broadly
    - Cardiovascular mortality, increased lung cancer risk, kidney toxicity, high blood pressure, reproductive effects, oral health impacts
  - Heavier burden of exposure on poor, nonwhite populations [23-25]

Local and regional health impacts of burning fossil fuels

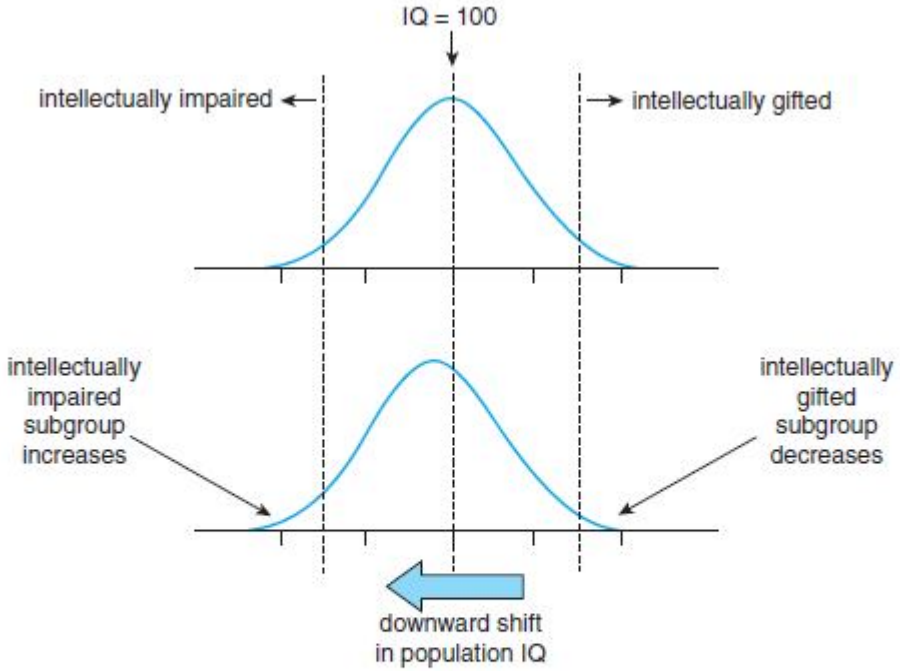


FIGURE 4.4 Decrease in intellectually gifted subgroup, and increase in intellectually impaired subgroup, with a small downward shift in population IQ.

Source: Reprinted from *Neuro Toxicology*, vol. 27; Gilbert SG, Weiss B. A rationale for lowering the blood lead action level from 10 to 2 μg/dL. 693–701; 2006; Figure 3, with permission from Elsevier.

Extraction of Fossil Fuels

Environmental Impacts of Burning Fossil Fuels

Local and Regional Health Impacts of Burning Fossil Fuels

Global Climate Change

Regulation of Air Pollution from the Burning of Fossil Fuels

Global climate change

- Anthropogenic gases and the enhanced greenhouse effect
  - Burning of fossil fuels puts sequestered carbon back into circulation as CO_2
  - Enhances natural greenhouse effect
  - CO_2 is single most influential greenhouse gas
  - Lesser greenhouse gases: methane, ozone, halocarbons, nitrous oxide

Global climate change

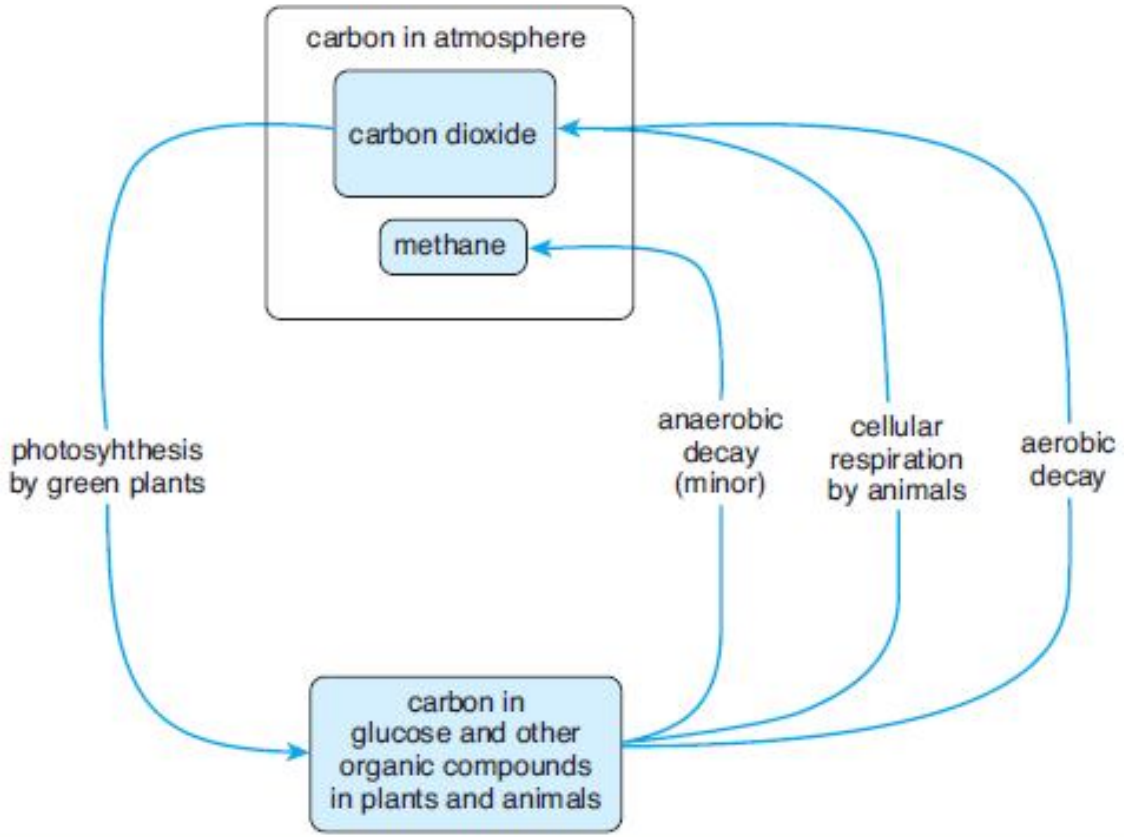


FIGURE 4.6 The global carbon cycle (excluding fossil fuels).

Global climate change

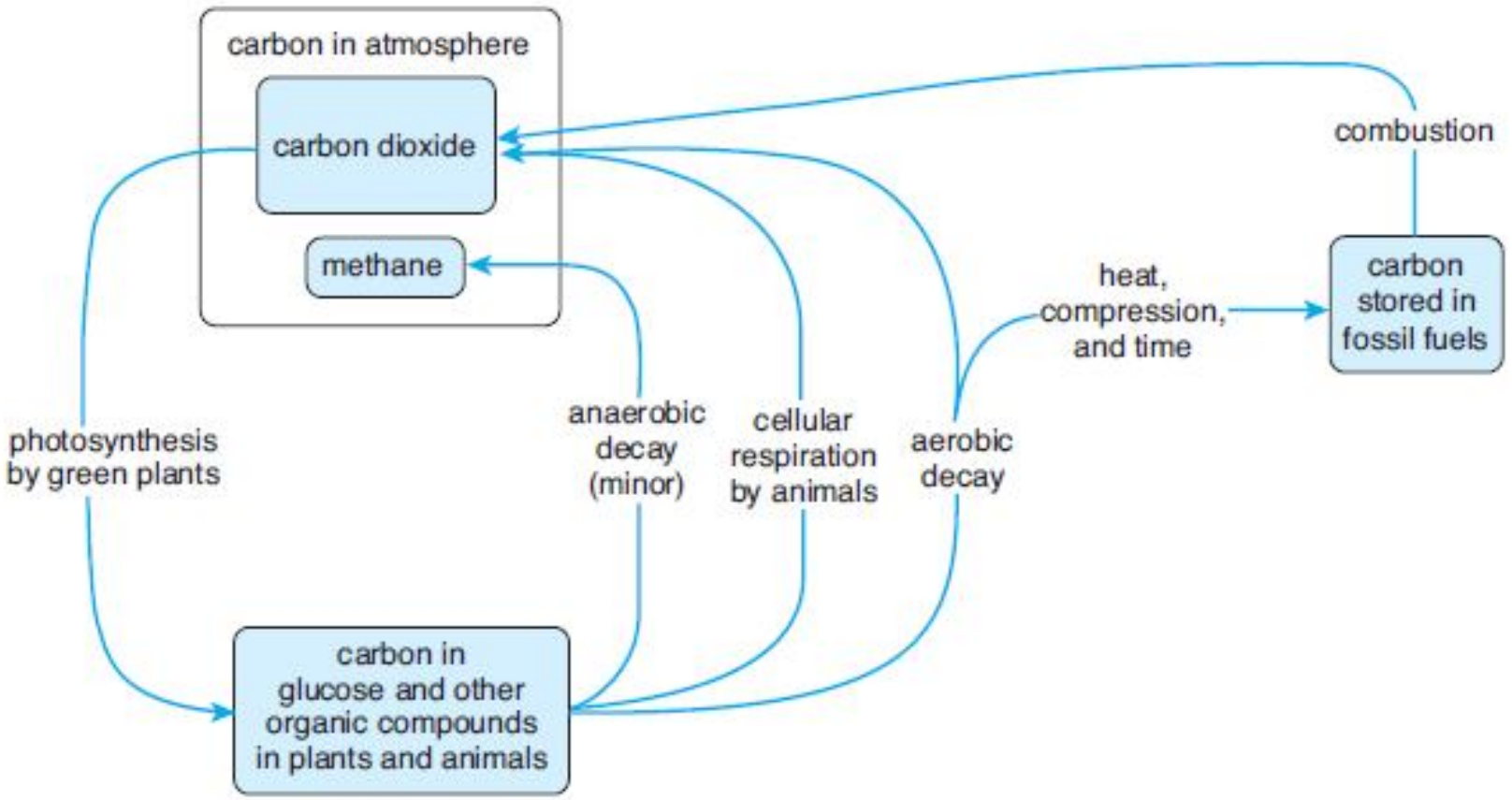


FIGURE 4.7 The global carbon cycle (including fossil fuels).

Global climate change

- Environmental impacts of global climate change
  - Interconnected changes [3]→
  - Predicted magnitude of changes [26]:

	Optimistic	Pessimistic
Rise in global average temperature	+1.8ºC	+4.0ºC
Rise in global average sea level	0.18 – 0.38 m	0.26 – 0.59 m

Global climate change

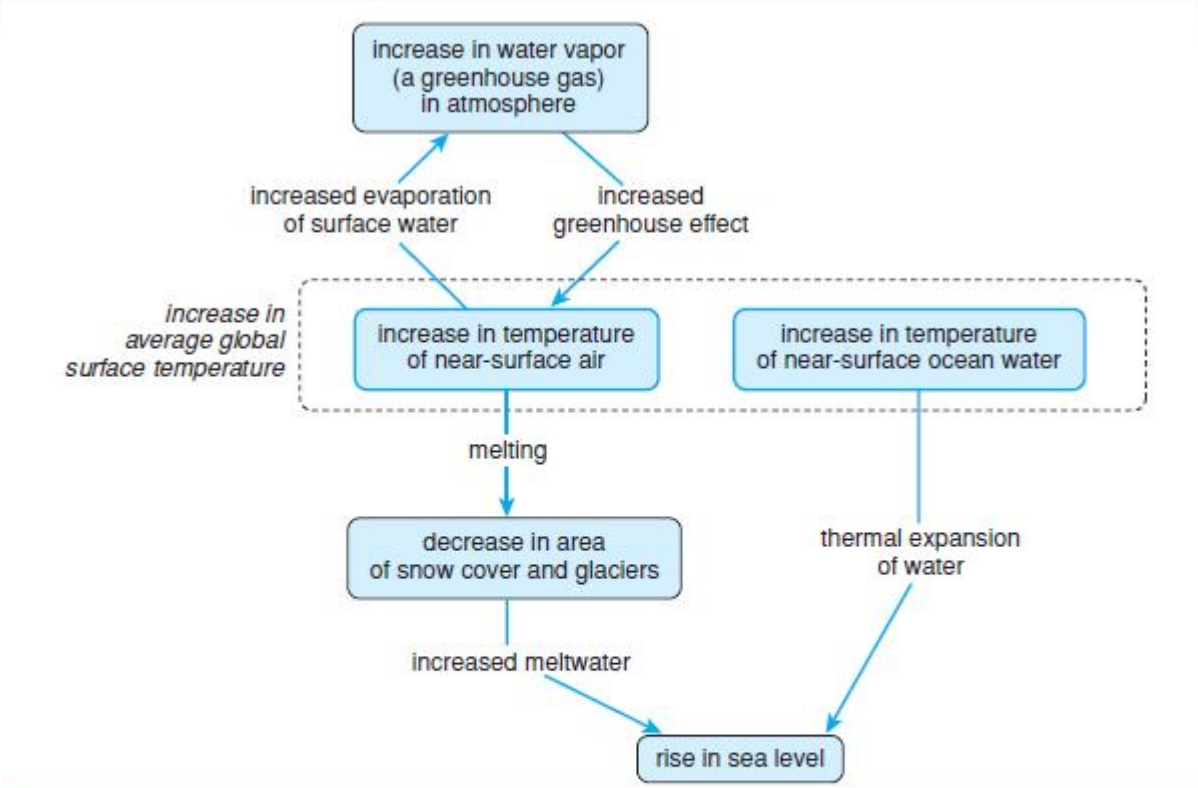


FIGURE 4.8 Connections among major climate-related environmental changes.

Source: Data from Intergovernmental Panel on Climate Change. IPPC, 2007: Technical Summary. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, England, and New York, NY: Cambridge University Press; 2007.

Global climate change

- Human health impacts of global climate change[27]
  - Higher temperatures → increased range of disease vectors
  - Coastal flooding → impacts on food supplies; refugees
  - Extreme weather events → crop failures, injuries, famine, infectious disease

Global climate change

- The Kyoto Protocol on global climate change
  - International agreement (2005) to reduce emissions of greenhouse gases
  - Industrialized nations agreed to reduce collective emissions for 2008-2012 to level 5.2% below 1990 levels
  - US declined to sign agreement

Extraction of Fossil Fuels

Environmental Impacts of Burning Fossil Fuels

Local and Regional Health Impacts of Burning Fossil Fuels

Global Climate Change

Regulation of Air Pollution from the Burning of Fossil Fuels

Regulation of air pollution from burning of fossil fuels

- US Clean Air Act
  - National Ambient Air Quality Standards (NAAQS): health-based limits on concentration in ambient air for 6 common pollutants called Criteria Air Pollutants →
  - National Emission Standards for 188 Hazardous Air Pollutants: emissions limits for long list of less common, more toxic pollutants
    - To date, only 7 of 188 listed have been regulated

Regulation of air pollutants

Table 4.6 Current National Ambient Air Quality Standards

Pollutant	Concentration	Averaging Time
Carbon monoxide	9 ppm	8-hour
	35 ppm	1-hour
Nitrogen dioxide	53 ppb	Annual
	100 ppb	1-hour
Sulfur dioxide	75 ppb	1-hour
Particulate matter (PM_{10})	150 $\mu g/m^3$	24-hour
Particulate matter ($PM_{2.5}$)	15 $\mu g/m^3$	Annual
	35 $\mu g/m^3$	24-hour
Lead	0.15 $\mu g/m^3$	Rolling 3-month average
Ozone	0.075 ppm	8-hour

Note: Units of parts per million (ppm) and parts per billion (ppb) are by volume. For additional detail on the form of the standard, see source.

Source: Adapted from U.S. Environmental Protection Agency. *National Ambient Air Quality Standards (NAAQS)*. Available at: www.epa.gov/air/criteria.html. Accessed March 23, 2012.

Regulation of air pollution from burning of fossil fuels

- Regulation of mobile sources of air pollution (vehicles):
  - Tailpipe emissions, with state inspections
  - Engine performance—e.g., mileage requirements
  - Fuel—unleaded gasoline, limits on VOCs in gas
- 2007 Supreme Court decision: CO_2 can be regulated as an air pollutant

4.1 Energy from Fossil Fuels

4.2 Electricity from Nuclear Fuel

4.3 Alternatives to Fossil and Nuclear Fuels

The Nuclear Fuel Cycle

Health Impacts of the Nuclear Fuel Cycle

Regulation of Activities in the Nuclear Fuel Cycle

The nuclear fuel cycle

- The front end of the nuclear fuel cycle →
  - Mining; piles of waste rock (tailings)
  - Milling
    - Yellowcake
    - Also leaves tailings Enrichment
    - *Increases* proportion U-235 by *removing* U-238 from yellowcake

The nuclear fuel cycle

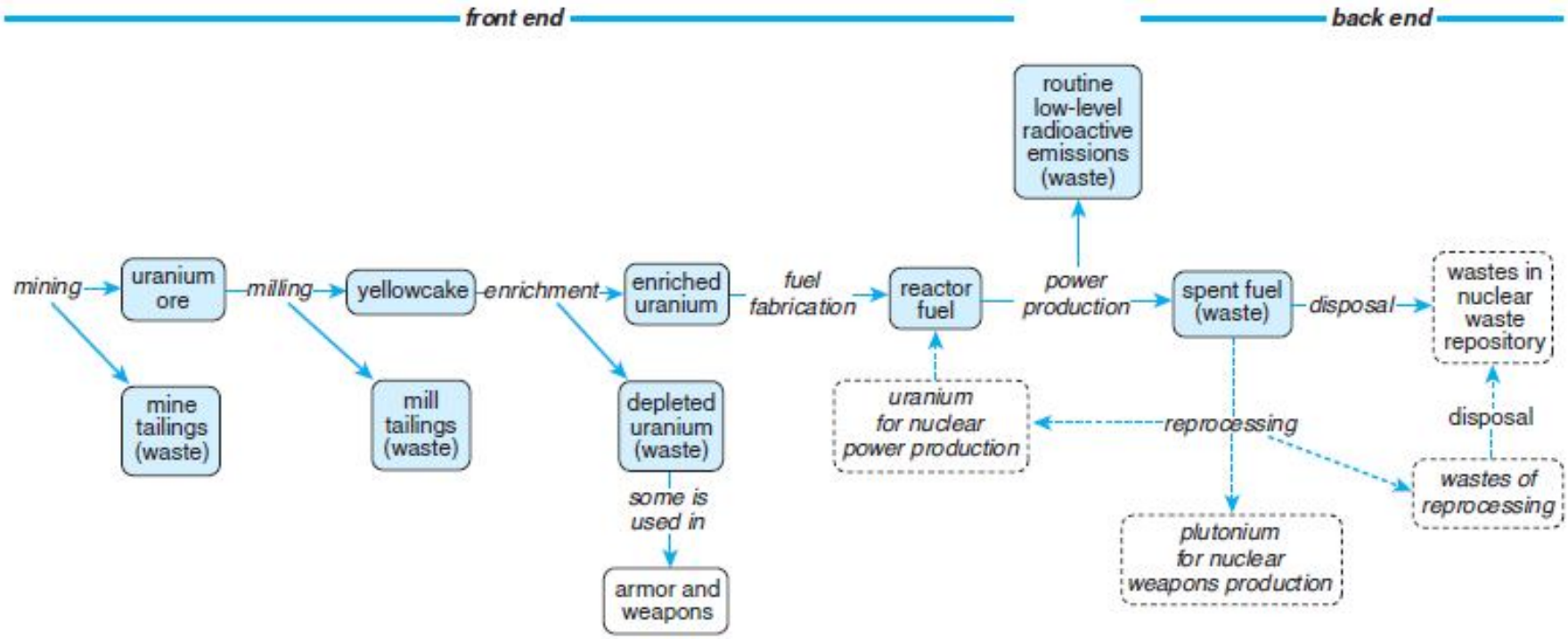


FIGURE 4.11 The nuclear fuel cycle.

The nuclear fuel cycle

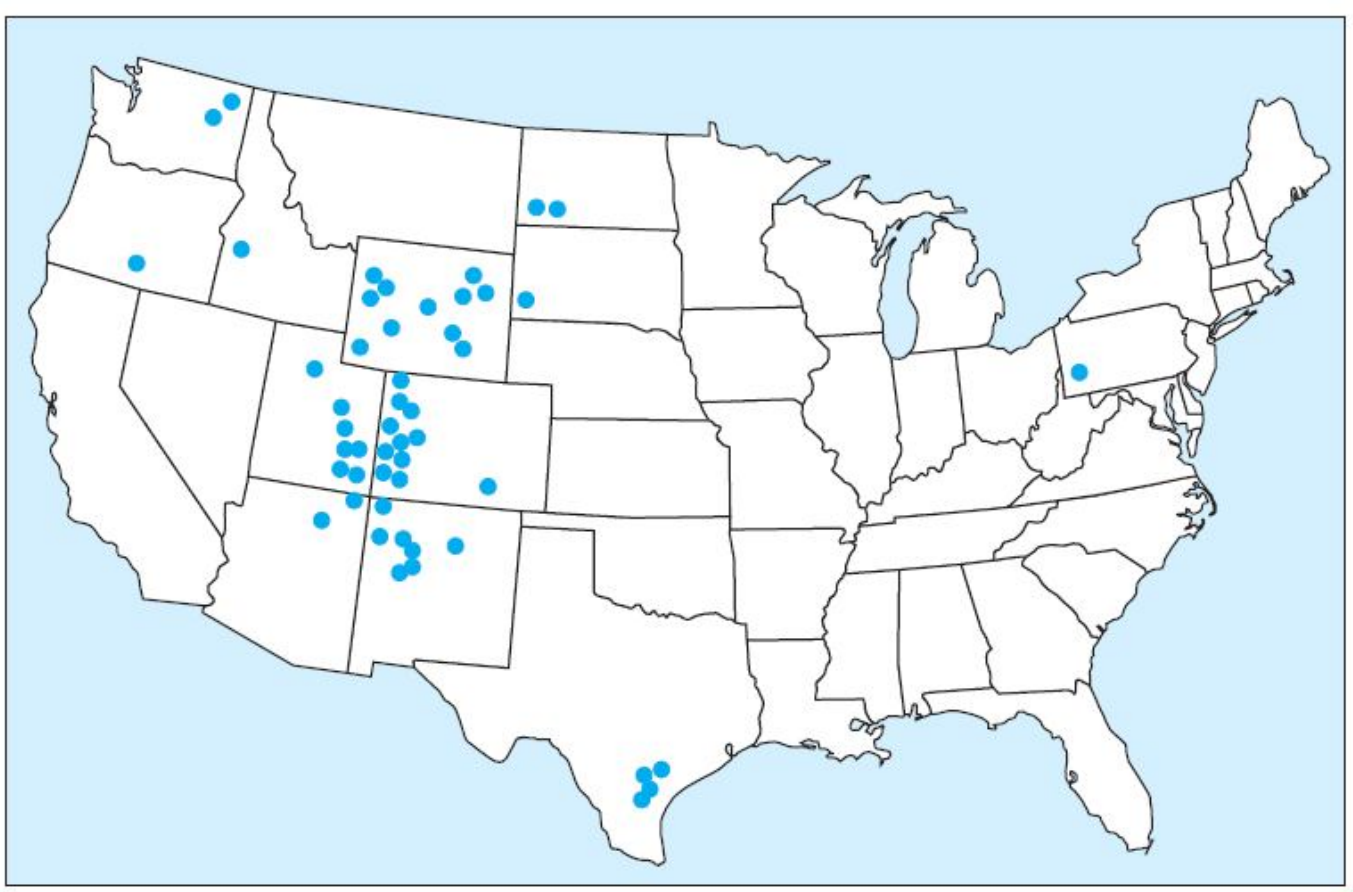


FIGURE 4.12 Locations of uranium mill tailings piles in the United States.

Source: Environmental Protection Agency. Uranium mill tailings. Available at: www.epa.gov/rpdweb00/docs/radwaste/402-k-94-001-umt.htm. Accessed: October 14, 2012.

The nuclear fuel cycle

- Nuclear power plants
  - 104 plants in US, mostly in eastern US →
  - Normal operations
    - Controlled nuclear fission chain reaction
    - Fuel rods, control rods
    - Containment building, cooling towers → →
  - Accidents at nuclear power plants
    - Unforgiving technology; mundane factors that cause accidents
    - Three Mile Island (1979)—worst US accident
    - Chernobyl (1986) and Fukushima (2011)—most serious accidents worldwide

The nuclear fuel cycle

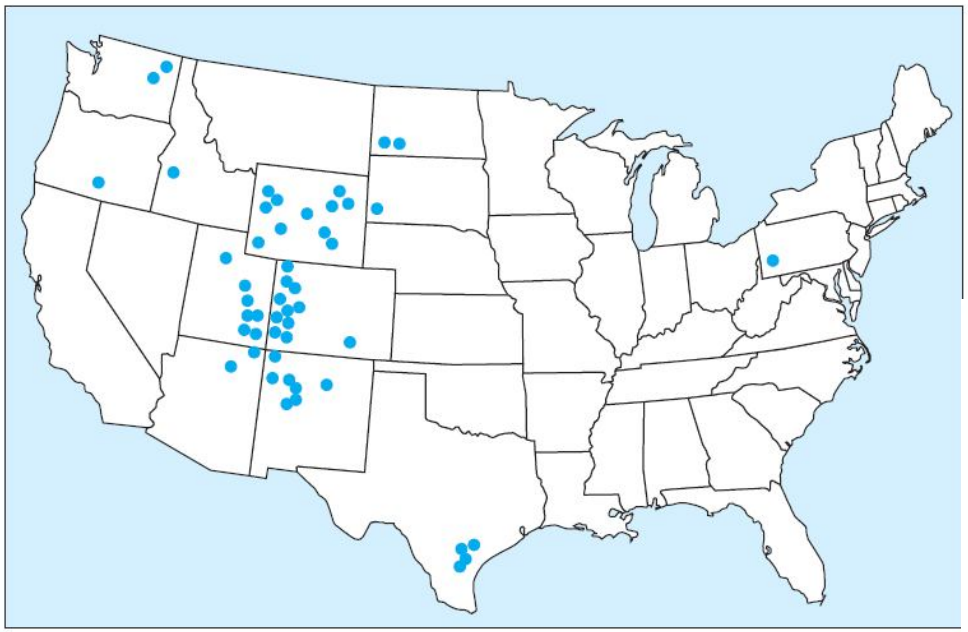


FIGURE 4.12 Locations of uranium mill tailings piles in the United States.

Source: Environmental Protection Agency. Uranium mill tailings. Available at: www.epa.gov/rpdweb00/docs/radwaste/402-k-94-001-umt.htm. Accessed: October 14, 2012.

FIGURE 4.13 Locations of operating nuclear power plants in the United States.

Source: Data from U.S. Energy Information Administration. *U.S. Nuclear Reactors: Reactor status list.* Available at: www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum.html. Accessed October 7, 2006.

The nuclear fuel cycle

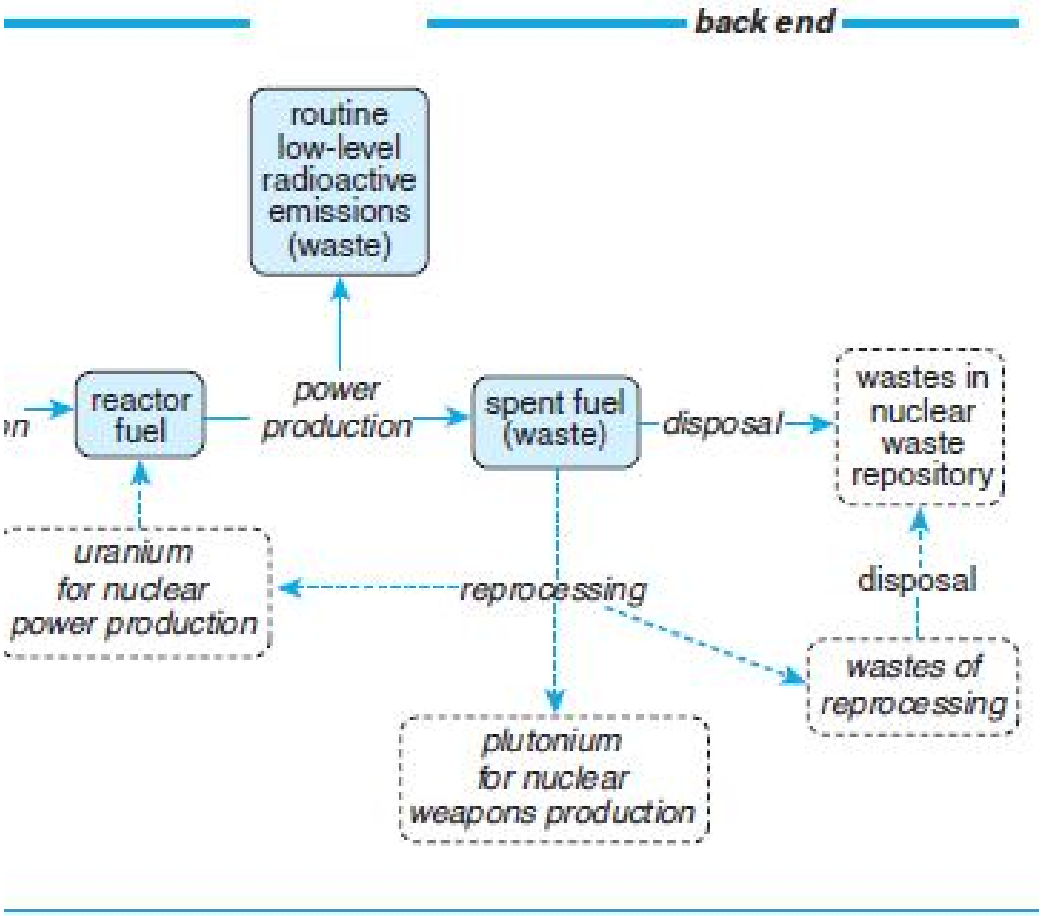
FIGURE 4.14 The Three Mile Island nuclear power plant in Pennsylvania was the site of the most serious accident at a U.S. commercial nuclear plant.

Source: Reprinted courtesy of CDC Public Health Image Library. ID# 1194. Content provider CDC. Available at: http://phil.cdc.gov/phil/home.asp. Accessed October 14, 2012.

The nuclear fuel cycle

- The back end of the nuclear fuel cycle
  - Spent nuclear fuel: highly radioactive, long-lived (300,000 years) [28]
  - Original plan: reprocess
  - Second plan: single permanent repository in Nevada
  - Current plan:[29] start over; one or more facilities; for interim and permanent storage
  - Meanwhile, spent fuel in interim storage

The nuclear fuel cycle



The nuclear fuel cycle

- Low-level radioactive wastes
  - From nuclear fuel cycle; medicine, research
  - Require only hundreds of years to be comparable to background radiation
  - States required to form compacts; as of May 2010, 40 states have done so [30]
  - But still only three active facilities in U.S.

The nuclear fuel cycle

- The future of nuclear power →
  - Until recently, moribund in US
  - In 2012, construction of two new plants in Georgia approved [31]
  - Potential for new nuclear technologies
  - Relatively long timeline for nuclear fuels
  - Blue Ribbon Commission on America's Nuclear Future; recommendations in 2012

The nuclear fuel cycle

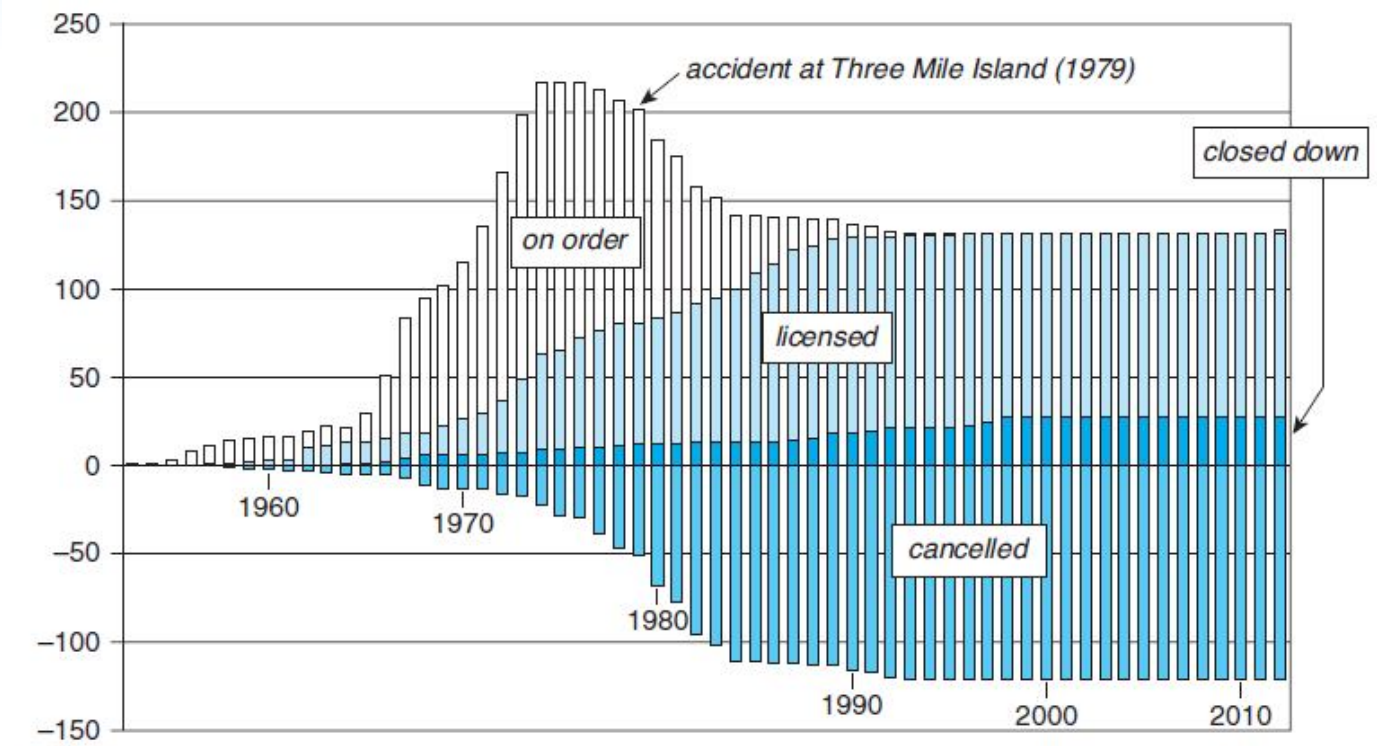


FIGURE 4.15 Number of nuclear power plants in the United States, 1953–2012.

Source: Data from U.S. Energy Information Administration. U.S. Nuclear Reactors: Reactor status list. Available at: www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum.html. Accessed: October 7, 2006; and Wald ML. Federal regulators approve two nuclear reactors in Georgia. *New York Times*. February 9, 2012; Available at: www.nytimes.com/2012/02/10/business/energy-environment/2-new-reactors-approved-in-georgia.html. Accessed November 19, 2012.

The Nuclear Fuel Cycle

Health Impacts of the Nuclear Fuel Cycle

Regulation of Activities in the Nuclear Fuel Cycle

Health impacts of the nuclear fuel cycle

- Radiation exposures and health effects of the nuclear fuel cycle
  - Front end: occupational radon exposures
  - Accidents at power plants; typically
    - Iodine-131 → thyroid cancer
    - Strontium-90 → leukemia
  - Back end: transportation of spent fuel

Health impacts of the nuclear fuel cycle

- Major accidents at reactors
  - Chernobyl (1986)
    - Dose-related increase in thyroid cancer in children and adolescents [32]
    - Evidence of increase in leukemia among cleanup workers [32]
    - Depression and PTSD in cleanup workers and mothers of young children [33]
  - Fukushima (2011)
    - Difficult to assess given disruption

Health impacts of the nuclear fuel cycle

- Health impacts at the back end
  - Uncertain, because plans for long-term storage remain uncertain
  - Any facility will be engineered to prevent releases of ionizing radiation
  - But time frame for radioactive decay is so long that nothing is certain
  - Transportation risks are real and near-term

The Nuclear Fuel Cycle

Health Impacts of the Nuclear Fuel Cycle

Regulation of Activities in the Nuclear Fuel Cycle

Regulation of activities in the nuclear fuel cycle

- Energy Reorganization Act of 1974 created Nuclear Regulatory Commission
  - Licenses reactors, sets emissions limits, responds to incidents, regulates storage of spent fuel
- Low-Level Radioactive Waste Policy Amendments Act of 1985
  - Calls for compacts
- Uranium Mill Tailings Radiation Control Act (1978)

4.1 Energy from Fossil Fuels

4.2 Electricity from Nuclear Fuel

4.3 Alternatives to Fossil and Nuclear Fuels

Energy Conservation and Efficiency

Freedom from Fuels

Biomass and Biomass Fuels

Nontraditional Fossil Fuels

The Hydrogen Fuel Cell

Regulatory Support for Alternatives to Fossil and Nuclear Fuels

Introduction

- Where does US energy come from? [34]
  - 83% from fossil sources
  - Rest nuclear, renewable
- How does the US consume energy? [34]
  - 40% for electric power
  - 30% for transportation
- Path taken by more developed countries not sustainable as global future

Energy conservation and efficiency

- Simple steps to use less energy; and to make devices more energy-efficient
- Change transportation habits in US
  - Lack of public transportation, reliance on cars
  - Turnaround in size of vehicles in 2010? →
- Alternative: the hybrid car
  - Power to transmission from combustion engine directly; or via electric motor / generator / battery

Energy conservation and efficiency

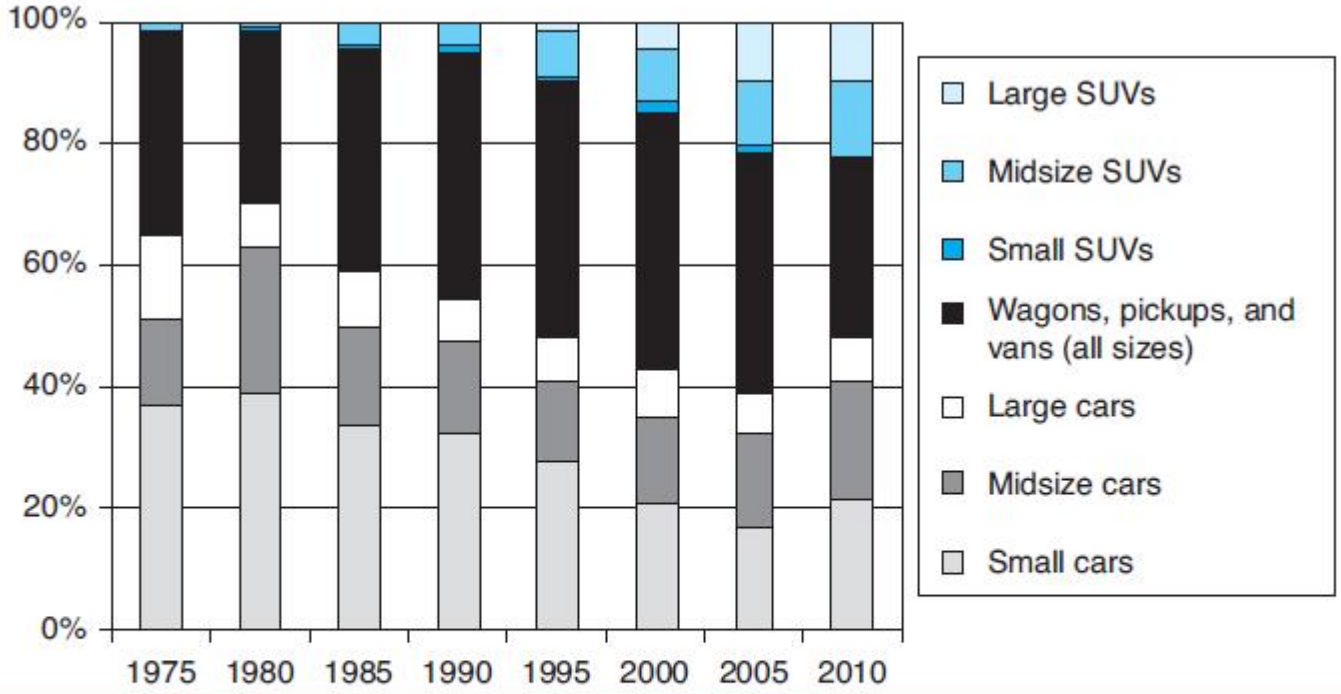


FIGURE 4.16 Market shares of light vehicles in the United States, by size class and model year, 1975–2010.

Source: Data from U.S. Department of Energy, Transportation Energy Data Book. Available at: http://cta.ornl.gov/data/download31.shtml. Accessed October 14, 2012.

Energy conservation and efficiency

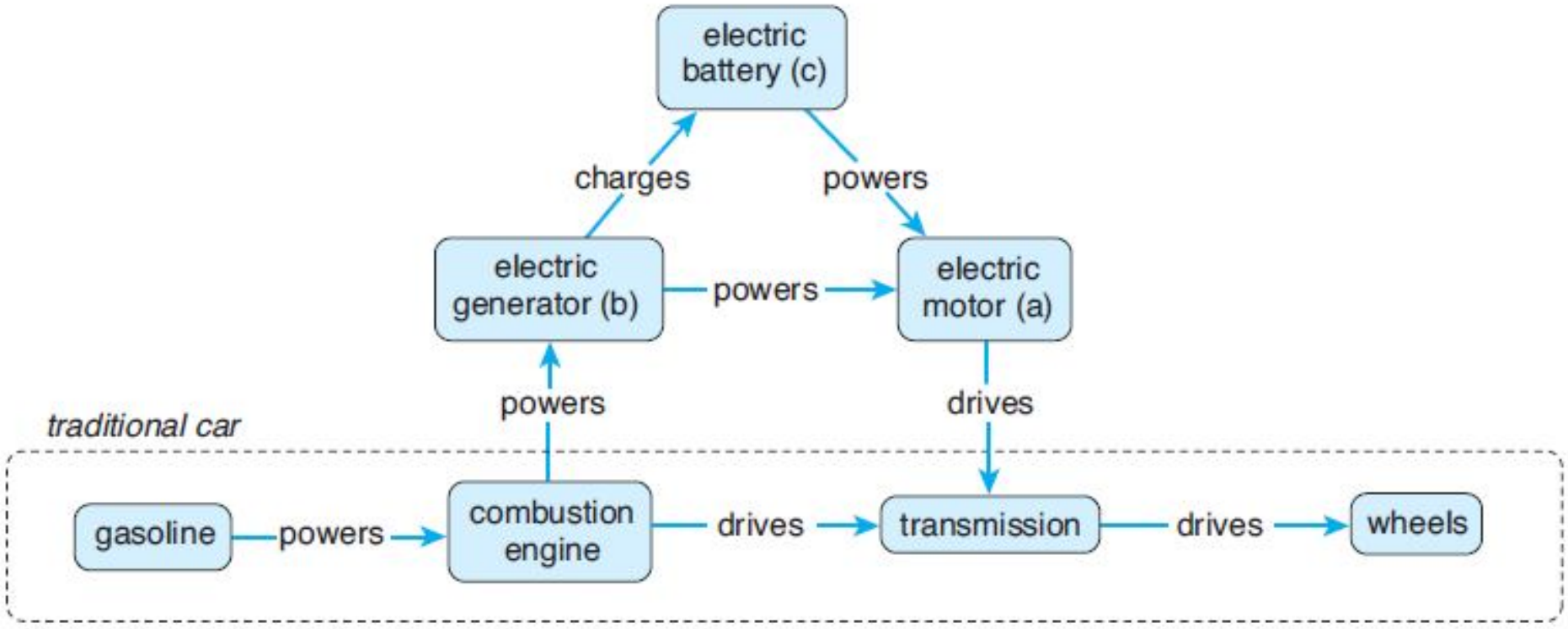


FIGURE 4.17 Schematic configuration of a hybrid car.

Energy Conservation and Efficiency

Freedom from Fuels

Biomass and Biomass Fuels

Nontraditional Fossil Fuels

The Hydrogen Fuel Cell

Regulatory Support for Alternatives to Fossil and Nuclear Fuels

Freedom from fuels

- Wind power
  - Modern turbine →
  - Often installed in grids (wind farms)
  - Potential negatives
    - Noise; visual impact
    - Harm to birds; weigh against ecological benefits

FIGURE 4.19 This modern wind turbine is one of two now generating electricity for the coastal town of Hull, Massachusetts.

Freedom from fuels

- Large-scale hydropower
  - Large dam has environmental impacts
- Solar energy
  - Challenges: sunlight is variable and low-intensity energy source
  - Solar collection panels; photovoltaic cell
- Geothermal energy
  - Availability depends on local geology

Energy Conservation and Efficiency

Freedom from Fuels

Biomass and Biomass Fuels

Nontraditional Fossil Fuels

The Hydrogen Fuel Cell

Regulatory Support for Alternatives to Fossil and Nuclear Fuels

Fuels derived from biomass

- Biomass energy—stored in plant material or animal dung (biomass)
- Biomass fuels (derived from biomass)
  - Gaseous—biogas
  - Liquid: ethanol, biodiesel;
  - Advantage: carbon-neutral
  - Limitation: require energy plantations; compete with food crops [35, 36]

Biomass as fuel

- Wood, charcoal, peat, straw, brush, dung
- "Alternative"; but not always benign
  - Open fires, simple stoves
  - Very high particulate concentrations [37]
  - Women and girls highly exposed [38]
  - Respiratory and other health effects [39-42]

Energy Conservation and Efficiency

Freedom from Fuels

Biomass and Biomass Fuels

Nontraditional Fossil Fuels

The Hydrogen Fuel Cell

Regulatory Support for Alternatives to Fossil and Nuclear Fuels

Nontraditional fossil fuels

- Blends of fossil and biomass fuels
  - Diesel / ethanol
  - Gasoline / ethanol
- Vehicle fuels derived from fossil fuels
  - Less pollution, & less energy, per gallon
  - Hard to integrate into marketplace

Energy Conservation and Efficiency

Freedom from Fuels

Biomass and Biomass Fuels

Nontraditional Fossil Fuels

The Hydrogen Fuel Cell

Regulatory Support for Alternatives to Fossil and Nuclear Fuels

The hydrogen fuel cell

- Environmentally benign, but:
  - What is source of hydrogen?
  - How much energy to produce hydrogen fuel?

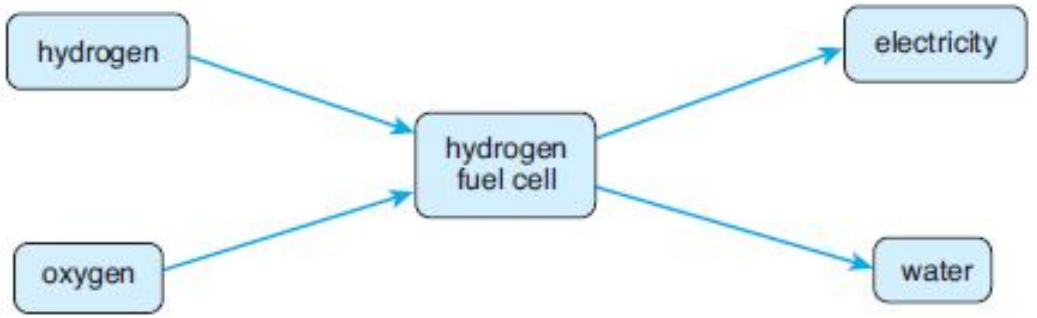


FIGURE 4.21 A conceptual model of a hydrogen fuel cell.

Energy Conservation and Efficiency

Freedom from Fuels

Biomass and Biomass Fuels

Nontraditional Fossil Fuels

The Hydrogen Fuel Cell

Regulatory Support for Alternatives to Fossil and Nuclear Fuels

Regulatory support for alternatives to fossil and nuclear fuels

- Energy Policy Act of 2005
  - Incentives for energy producers
  - Income tax credits
    - Hybrid vehicles, home improvements
  - US government to get 7.5% of power from renewable sources by 2013
  - Also substantial supports for traditional energy sectors

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