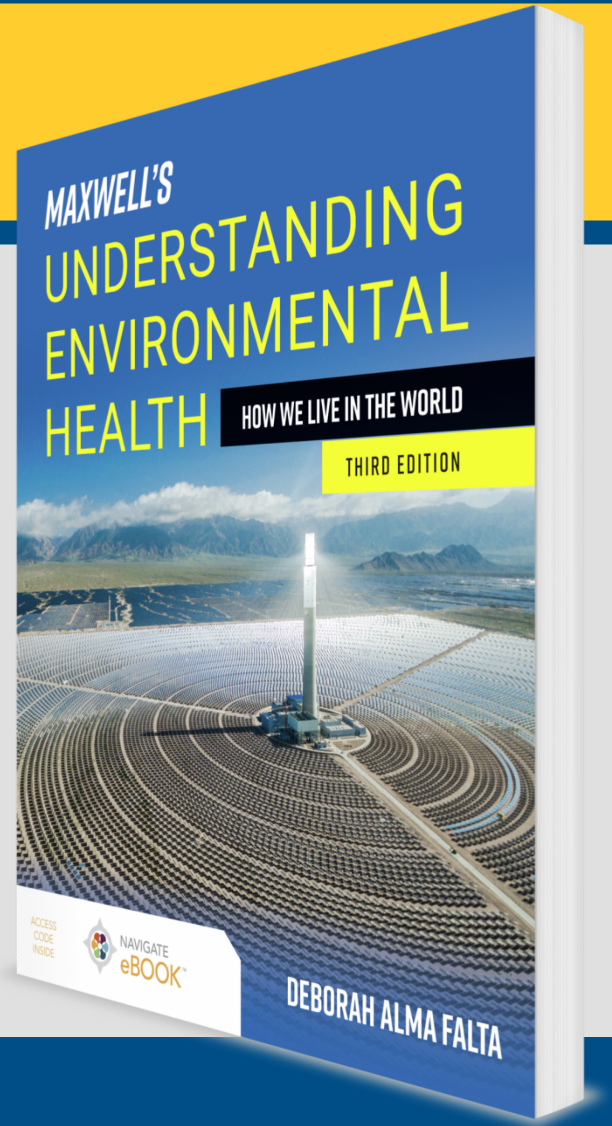
CHAPTER 8

Living in the World We've Made



8.1 The “Metabolism” of Communities

8.2 Management of Sewage Wastes

8.3 Drinking Water: Public Systems and Private Wells

8.4 Solid Waste and its Management

8.5 Urban Settings in Less-Developed Countries

8.6 The Built Environment

8.7 Sharing Global Impacts and Resources

Urban Metabolism in the 19th Century

Community Metabolism Today

Urban Metabolism in the 19th Century

- "Metabolism" of a community[1]: water supply, sewage, trash
- 19th century
  - Privy pits and cesspools
  - Tap water → water closet, larger volume of waste
  - Use of water to carry away sewage, at community level
  - Drinking water treatment
- Not until 20th century:
  - Sewage treatment
  - Trash as a large-scale phenomenon

Urban Metabolism in the 19th Century

Community Metabolism Today

Community Metabolism Today (1 of 3)

- Three fundamental features:
  - Unified water supply
  - Use of potable water to carry away sewage
  - Large quantities of water, sewage, trash, with interconnections among these waste streams

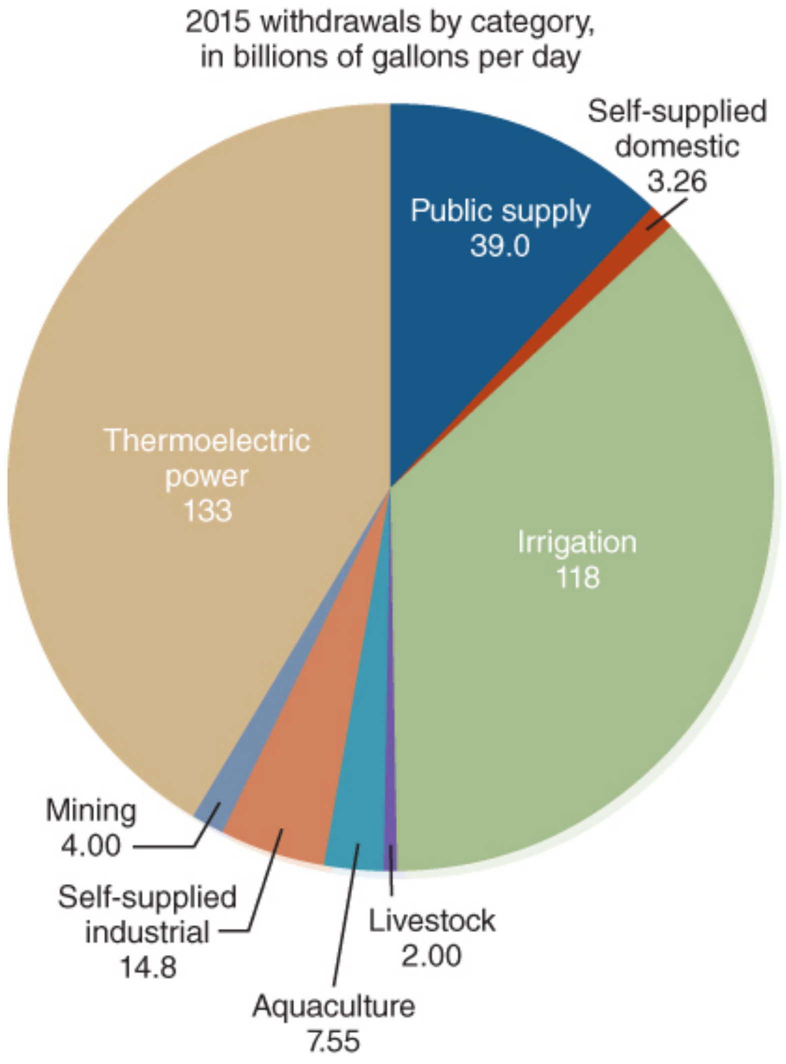


FIGURE 8.2 Use of water in the United States by sector, 2015.

U.S. Geological Survey. 2015 Withdrawls by Category, in Gallons per day. Available at: https://www.usgs.gov/mission-areas/water-resources/science/total-water-use?qt-science_center_objects=0#qt-science_center_objects

Community Metabolism Today (2 of 3)

- Municipal wastewater and municipal solid waste
  - Distinct, yet some overlap in contents

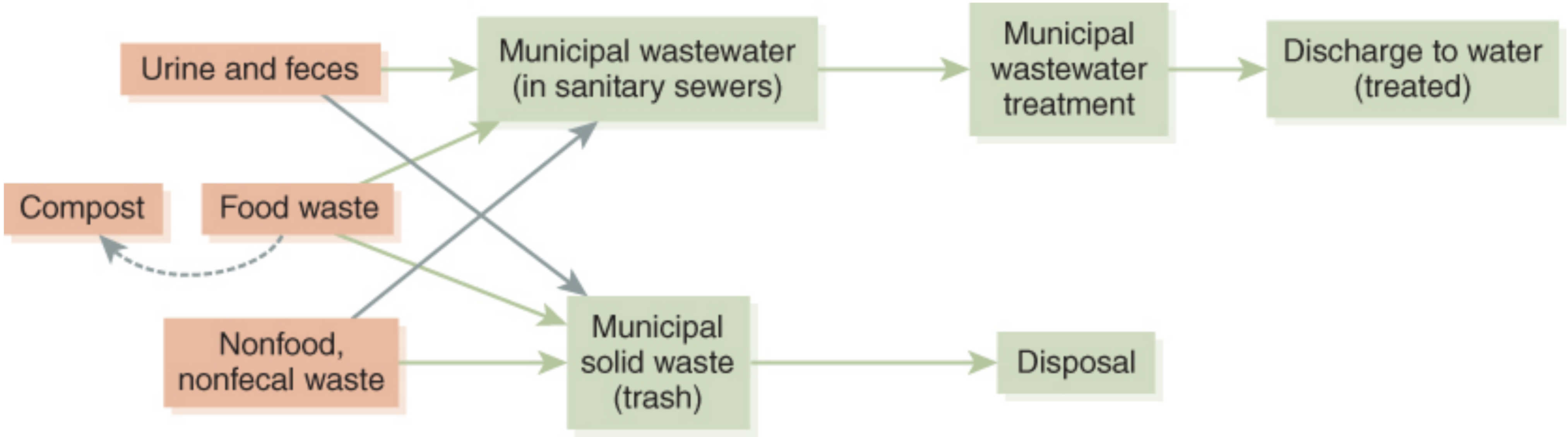


FIGURE 8.3 Contributors to municipal wastewater and municipal solid waste streams.

Community Metabolism Today (3 of 3)

- Municipal wastewater and storm runoff
  - Different makeup
  - Constant vs. episodic flow
- Municipal wastewater and industrial wastes
  - Industrial wastes discharged directly, or indirectly via municipal wastewater

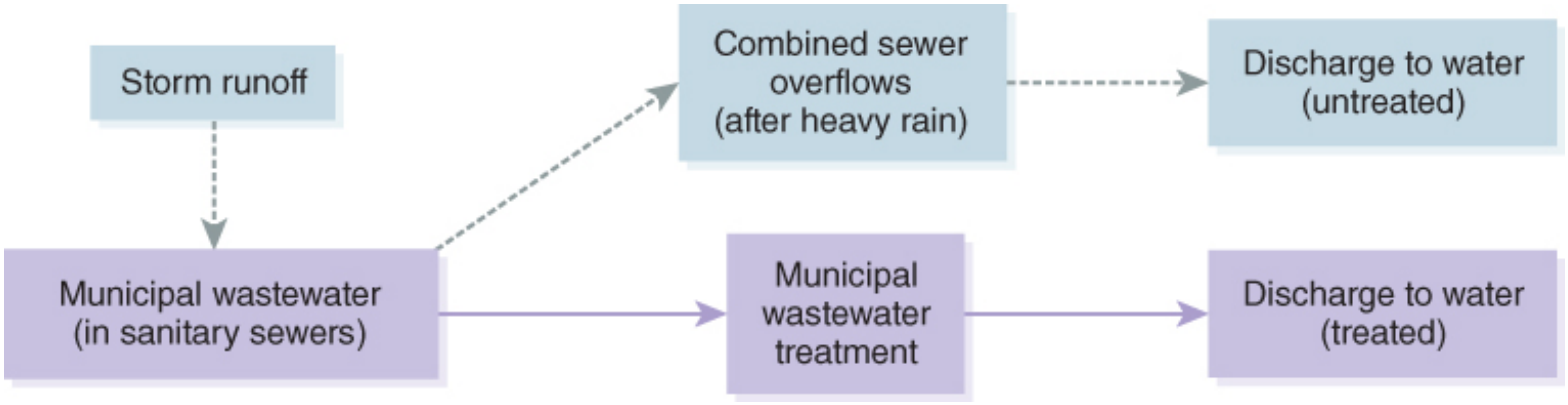


FIGURE 8.4 Use of combined sewer overflows to handle storm runoff.

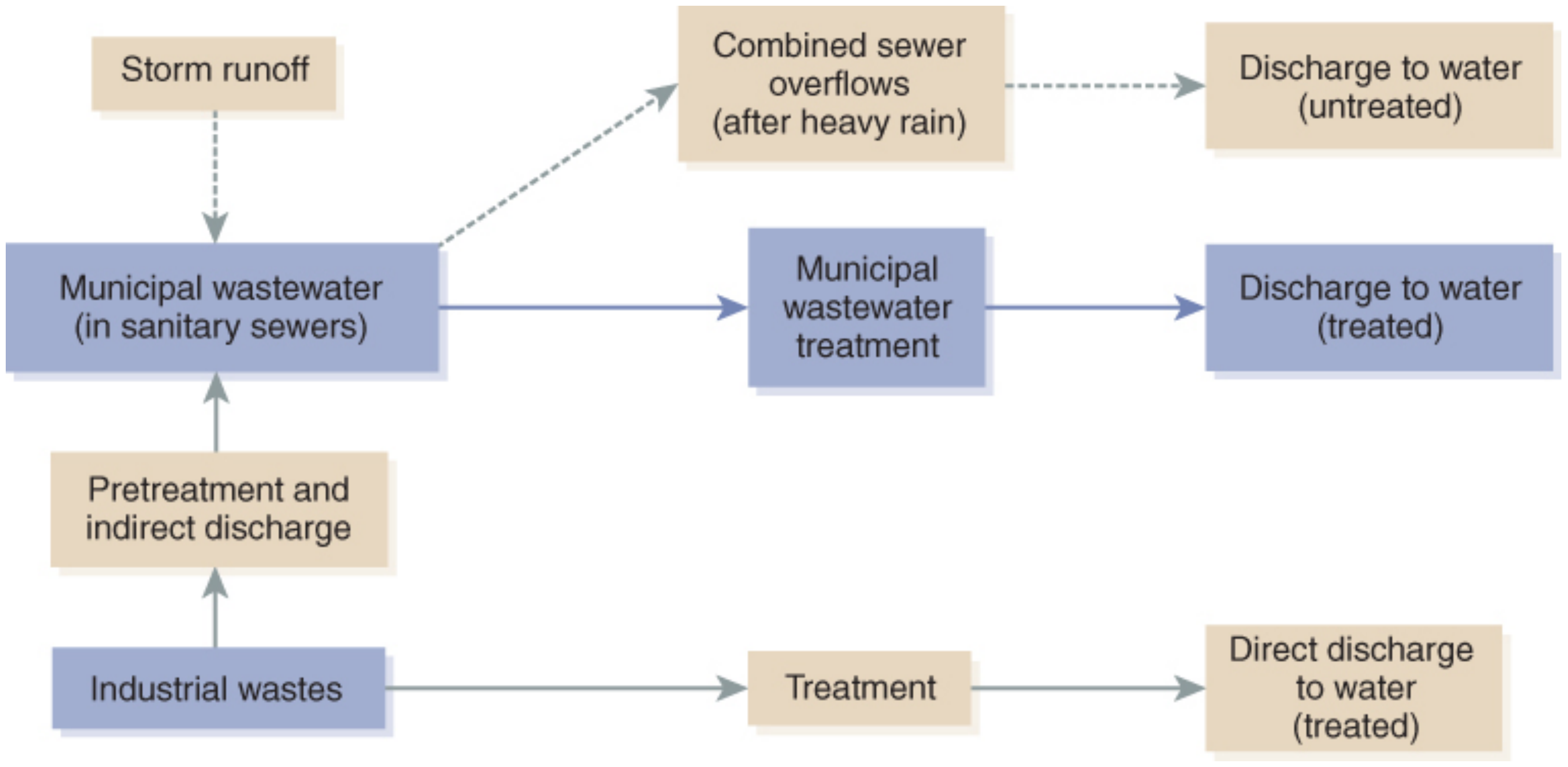


FIGURE 8.5 Direct and indirect discharge of industrial wastes.

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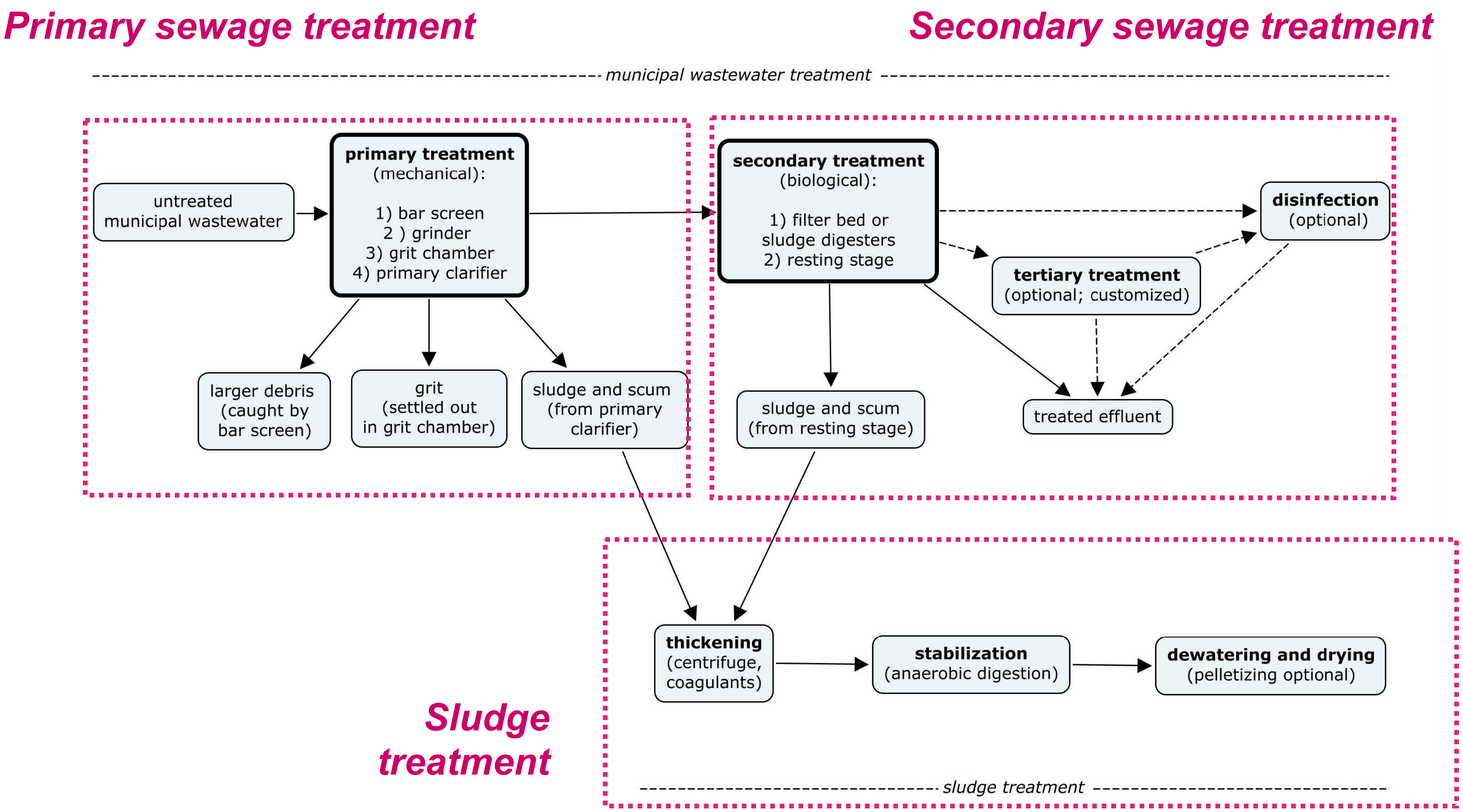
Municipal Wastewater Treatment

Smaller-Scale Systems for Sewage Treatment

Regulation of Municipal Wastewater Treatment in the United States

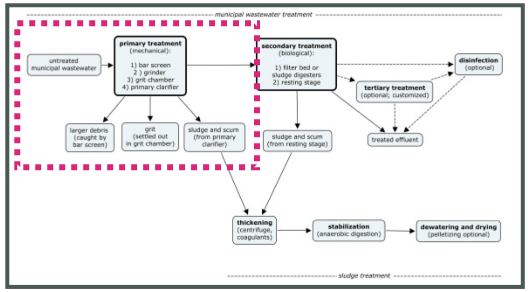
Municipal Wastewater Treatment (1 of 3)

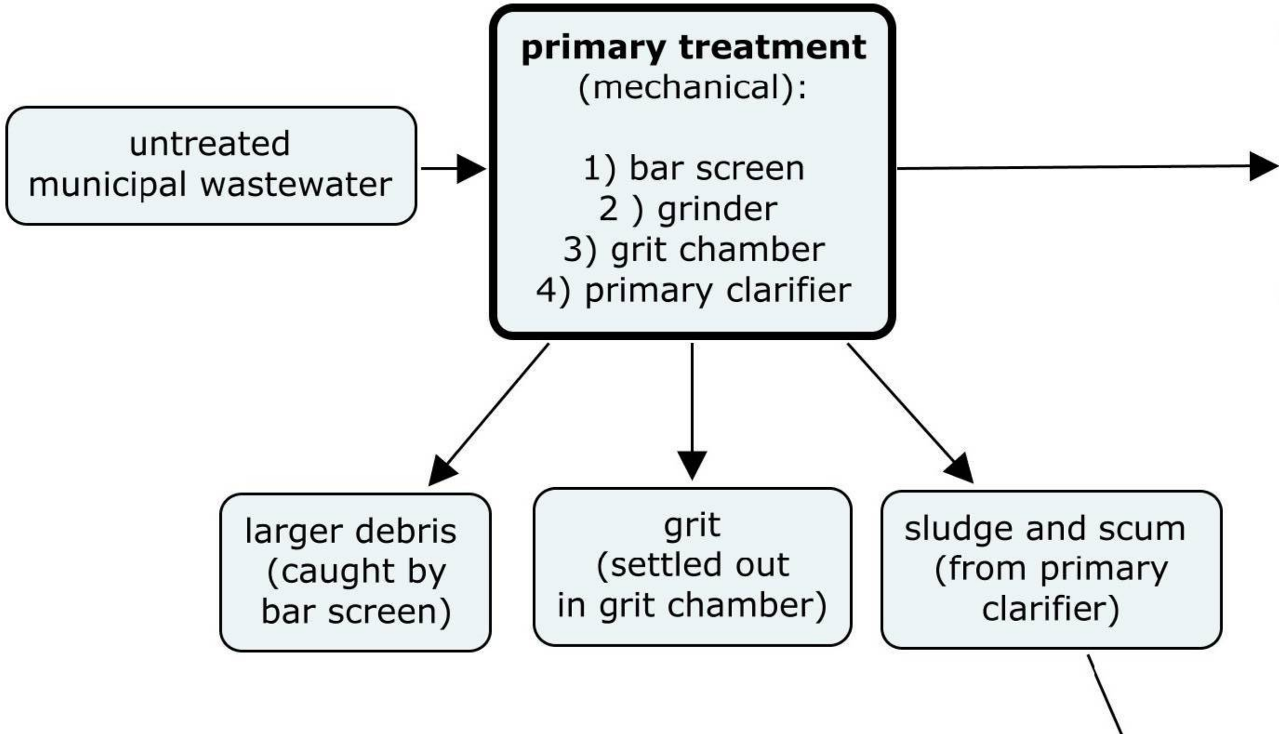
- Three related objectives of sewage treatment:
  - Remove pathogens
  - Remove organic matter (biochemical oxygen demand or BOD)
  - Remove suspended solids (turbidity)
- Basic processes of sewage treatment
- How these processes achieve objectives of sewage treatment



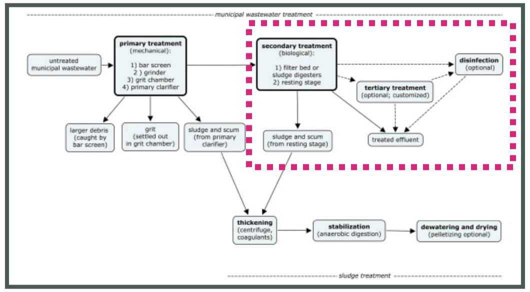
Primary sewage treatment
Secondary sewage treatment
municipal wastewater treatment
untreated municipal wastewater
primary treatment (mechanical):
1) bar screen
2) grinder
3) grit chamber
4) primary clarifier
larger debris (caught by bar screen)
grit (settled out in grit chamber)
sludge and scum (from primary clarifier)
secondary treatment (biological):
1) filter bed or sludge digesters
2) resting stage
disinfection (optional)
tertiary treatment (optional; customized)
sludge and scum (from resting stage)
treated effluent
thickening (centrifuge, coagulants)
stabilization (anaerobic digestion)
dewatering and drying (pelletizing optional)
Sludge treatment
sludge treatment

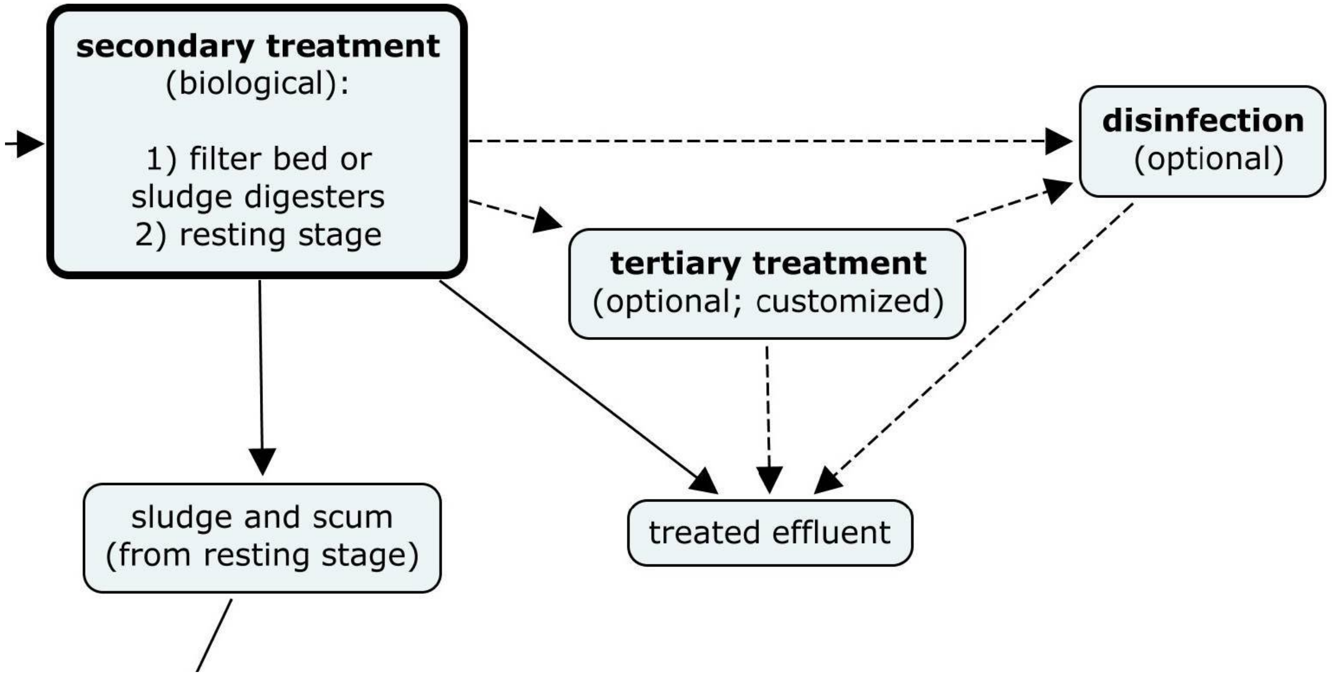
Primary sewage treatment



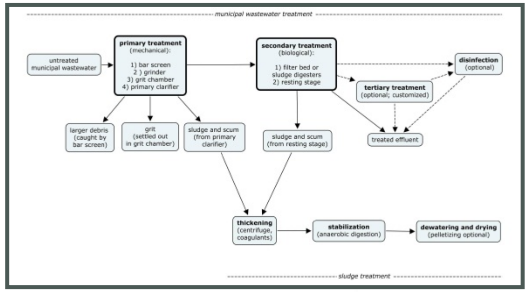


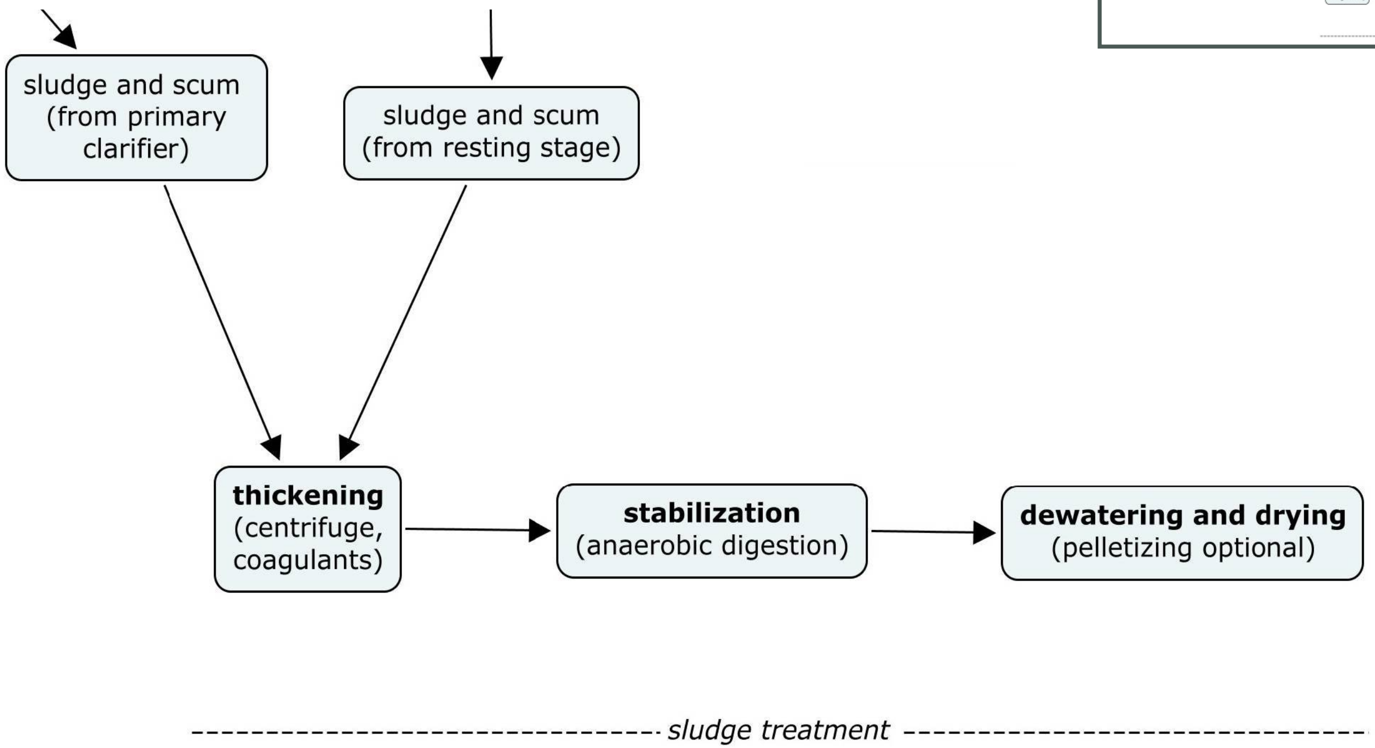
Secondary sewage treatment





Sludge treatment





Municipal Wastewater Treatment (2 of 3)

Table 8.1 Objectives and Effects of Municipal Wastewater Treatment

Objectives	Effects of Steps in Municipal Wastewater Treatment			
	Basic Treatment Steps		*Additional Optional Steps*	
	Primary (mechanical)	Secondary (biological)	Tertiary Treatment	Disinfection
Remove pathogens	Most survive	Many die off	—	Is effective
Remove organic waste (BOD)	Some is removed	Most is removed	Depends on treatment	—
Remove suspended solids	Some are removed	Most are removed	Depends on treatment	—
Remove chemicals	—	—	Depends on treatment	—

Municipal Wastewater Treatment (3 of 3)

- Land application of treated sewage sludge
  - Organic waste, rich in nutrients; solves disposal problem
  - But: contaminated with pathogens, metals, organic chemicals

Municipal Wastewater Treatment

Smaller-Scale Systems for Sewage Treatment

Regulation of Municipal Wastewater Treatment in the United States

Septic Systems and Constructed Wetlands

- Septic system = septic tank + leach field
  - Tank receives wastewater, material forms layers, all containing fecal bacteria
  - Liquid flows to leach field, trickles into soil; pathogens gradually die off
  - Periodically clean out and dispose of sludge

Septic Systems and Constructed Wetlands

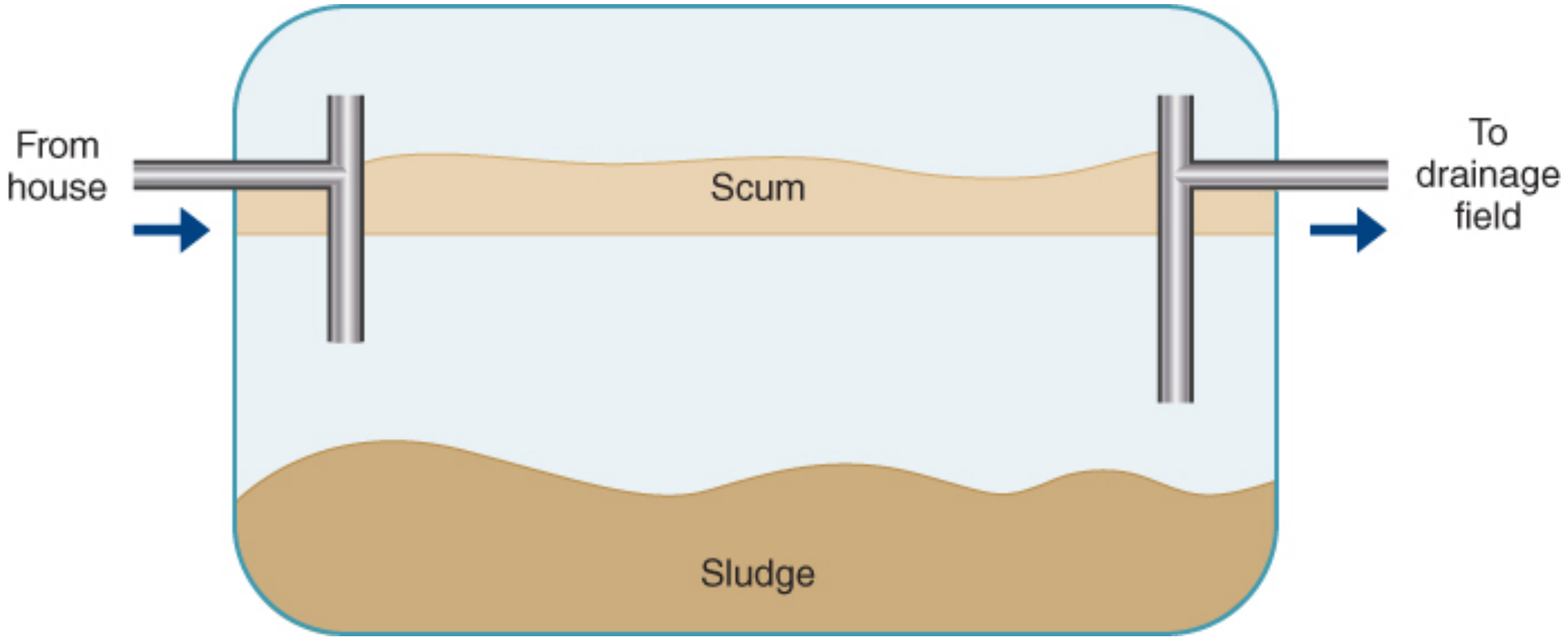


FIGURE 8.10 Schematic drawing of a septic tank (not to scale).

Septic Systems and Constructed Wetlands

- Constructed (artificial) wetland
  - Between septic tank and leach field;
  - Can serve cluster of households
- Enclosed artificial ecosystem
  - Microorganisms digest organic wastes
  - Cleaned water recycled for use in toilets
- Composting toilet useful in some settings (e.g., parks, camps, green buildings)

Septic Systems and Constructed Wetlands

FIGURE 8.11 This artificial ecosystem, known as a Living Machine, treats toilet wastes at a rest stop on the Vermont Turnpike.

Courtesy of Keith J. Maxwell

Municipal Wastewater Treatment

Smaller-Scale Systems for Sewage Treatment

Regulation of Municipal Wastewater Treatment in the United States

Regulation of Municipal Wastewater Treatment in the United States (1 of 2)

- Clean Water Act
  - Standards for ambient water quality
  - Requirement to use secondary sewage treatment (not just primary)
  - Permitting requirements for discharges (National Pollutant Discharge Elimination System)
    - Standards for effluent
    - Requirements for control technologies

Regulation of Municipal Wastewater Treatment in the United States (2 of 2)

- Effluent standards:
  - Fecal coliform organisms
  - Biochemical oxygen demand (BOD)
  - Fishable and swimmable waterways
  - Total Daily Maximum Loads (TDML)
    - Issues with point versus nonpoint source contributions

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Public Water Supplies

Household-Level Water Supply or Treatment

Regulation of Drinking Water in the United States

Public Water Supplies (1 of 5)

- Water supply in U.S.
  - Approximately 90% on public supplies[25]
  - 9+% have private wells
  - 0.5 to 1% have no piped water[25]
- About public water supplies
  - Delivers healthful water to many people
  - Large cities usually rely on surface sources

Public Water Supplies (2 of 5)

- Public system can also deliver a hazard to large numbers of people.
  - Lead from lead pipe
    - Widely used in U.S. because malleable, not prone to corrosion
    - In light of lead's known health impacts, more recent shift to copper and plastic pipe
    - Requirements for testing and response
  - Waterborne illness
    - Primary focus of municipal water treatment

Public Water Supplies (3 of 5)

- Basic treatment steps for drinking water
  - Initial settling (creates sludge)
  - Coagulation and flocculation (of tiny suspended particles)
  - Sedimentation (more sludge)
  - Filtering; often sand filter
- "Sludge" is mostly water; often handled as municipal wastewater

Public Water Supplies (4 of 5)

- Disinfection of drinking water
  - Treatment specifically to kill pathogens
  - In U.S., chlorination most common
    - Effective against bacteria; less so against protozoa (*Giardia*, *Cryptosporidium*) and viruses
    - Residual disinfection in distribution system
      - Water pipes have pipes and rough patches

FIGURE 8.12 This 10-year-old water supply pipe has accumulated mineral deposits that make its internal surface rough.

Courtesy of Keith J. Maxwell

Public Water Supplies (5 of 5)

- Residual chlorine can combine with organic matter, lead to disinfection byproducts
  - Trihalomethanes: with chronic exposure, increased risk of bladder cancer[30, 31]
- Chloramine as option for residual disinfection

- Fluoridation of drinking water
  - Prevents tooth decay
  - At higher concentrations, naturally occurring fluoride can cause fluorosis (mottling of teeth)

Public Water Supplies

Household-Level Water Supply or Treatment

Regulation of Drinking Water in the United States

Household-level Water Supply or Treatment

- Private wells
  - No federal standards; but some state/local[40]
  - Naturally occurring contaminants, depending on geology (e.g., radon, arsenic)
  - Vulnerable to contamination by upgradient land uses (e.g., agriculture, septic systems)
- Devices for home water treatment
  - Point-of-use systems installed at tap (e.g., carbon filter at kitchen sink)

Bottled Water

- Rapid increase in consumption during 1990s and early 2000s[41]
- Expensive; often groundwater source; not likely to be fluoridated[42]
- Regulated not as drinking water, but as packaged food

Public Water Supplies

Household-Level Water Supply or Treatment

Regulation of Drinking Water in the United States

Safe Drinking Water Act

- National Primary Drinking Water Regulations (standards for contaminants in public drinking water supply)
  - Maximum Contaminant Level Goal (MCLG)
    - No anticipated health effects
  - Maximum Contaminant Level (MCL) = enforceable standard
    - Considers health risks, benefits, costs

Regulation of Drinking Water in the United States

- For certain pathogens, EPA has set MCLGs of zero and MCLs that consist of specific testing regimen and test results[44]
  - *Cryptosporidium*, *Giardia*
  - Coliform bacteria
    - Staged testing for coliforms, fecal coliforms, *E. coli.*
    - Fecal coliform bacteria as indicator organisms for fecal contamination
- EPA has also set MCLGs and MCLs for turbidity, many chemicals
- Safe Drinking Water Act also calls for:
  - Watershed protection, regular monitoring of public supplies, public information on water quality

About Municipal Solid Waste

- Typical makeup on next slide
- Mundane, but hard to manage
  - Large total quantity; produced by large number of individual households
  - Varied; may include hazardous items
  - Food waste must be removed quickly
- Management options:
  - Produce less waste ("waste prevention")
  - Recycle, incinerate, landfill

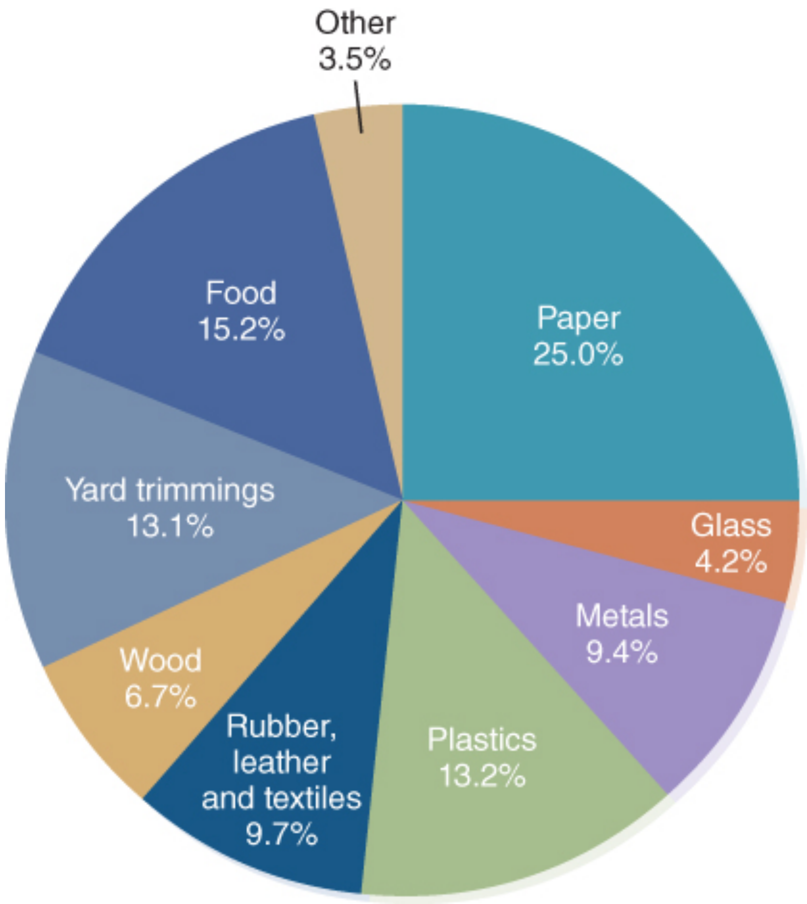
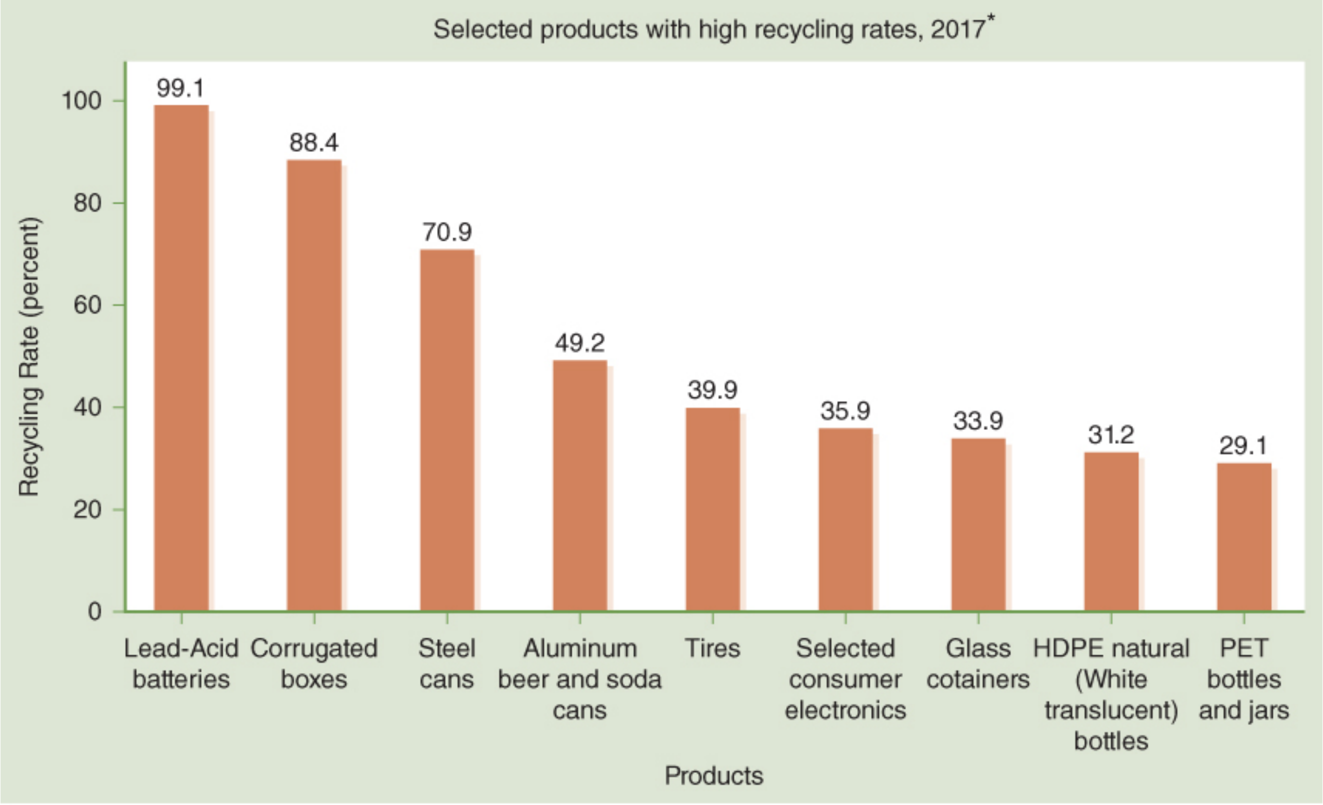


FIGURE 8.13 Makeup of municipal solid waste by material, 2017.

U.S. Environmental Protection Agency. Advancing Sustainable Materials Management: 2017 Fact Sheet Assessing Trends in Material Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling in the United States November 2019 pdf Available at: https://www.epa.gov/sites/production/files/2019-11/documents/2017_facts_and_figures_fact_sheet_final.pdf

Recycling

- Removes glass, metal, plastics, paper from waste stream before disposal
  - Sorted by consumers
  - Or sorted at materials recovery facility
- Plastic pollution case study
  - Future of U.S. recycling?



*Does not include combustion with energy recovery

FIGURE 8.16 U.S. Recycling rates

Advancing Sustainable Materials Management: 2017 Fact Sheet Assessing Trends in Material Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling in the United States, November 2019 produced by USEPA

Composting

- Removes organic materials before waste disposal
  - Municipal composting (yard trimmings)
  - Household composting
    - Outdoors: composting bin or pile
    - Indoors: vermicomposting[13]

Waste-to-Energy Incineration

- Incineration of waste to generate energy
  - Greatly decreases volume
  - Challenges:
    - Metals in waste stream → particulates (or mercury vapors) in emissions; must be captured
    - Plastics → dioxins and furans if temperature not high enough
    - Both fly ash and bottom ash must be captured and disposed of properly

Disposal in Landfills (1 of 2)

- Modern MSW landfill shown on next slide
  - Licensed, usually operated by corporation
  - Lined pit
  - Trash compacted in layers
  - Capped with clay
  - Systems collect and remove leachate, methane
  - Ongoing maintenance and monitoring

Disposal in Landfills (2 of 2)

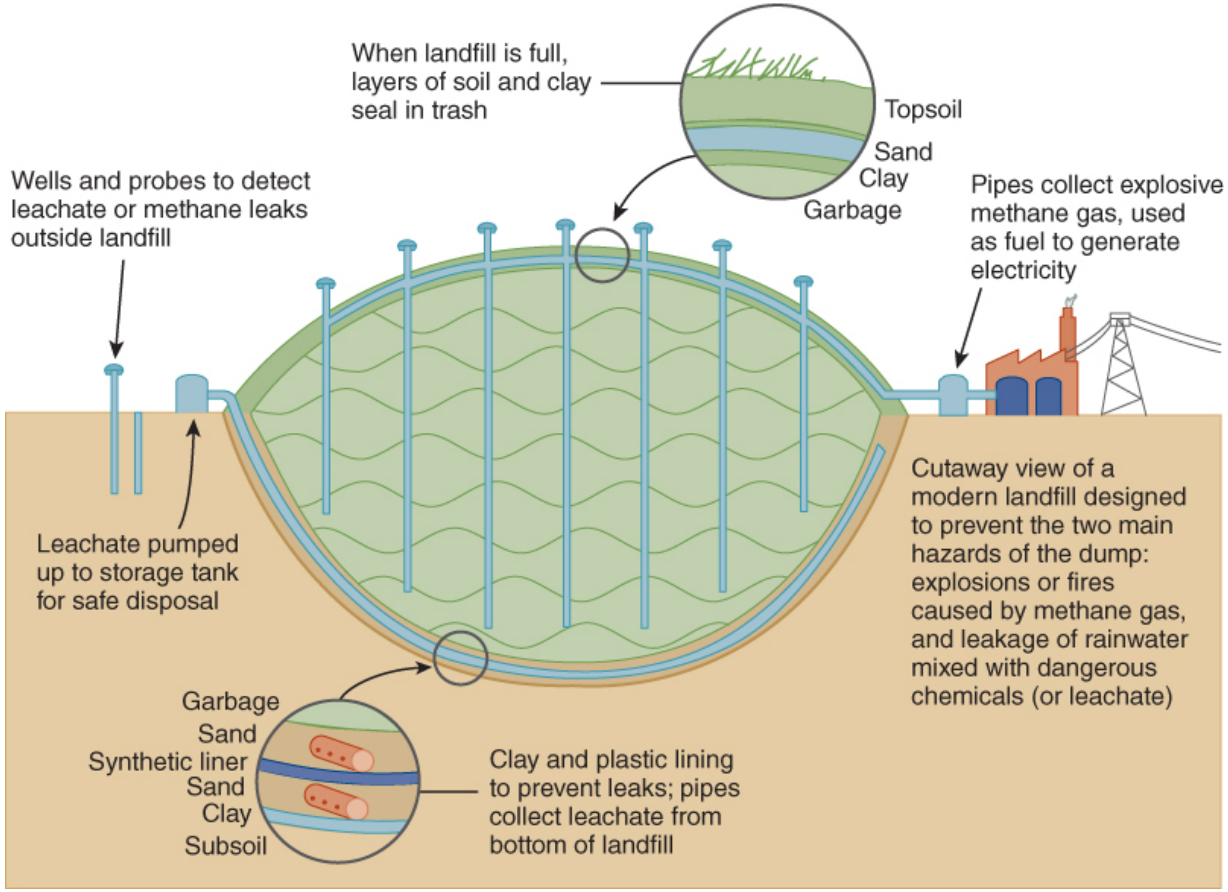


FIGURE 8.14 A schematic cross-section of a modern municipal solid waste landfill.

U.S. Environmental Protection Agency, Resource Conservation and Recovery Act (RCRA). Available at: www.epa.gov/superfund/students/clas_act/haz-ed/ff_06.htm. Accessed December 13, 2007

Handling of Household Hazardous Wastes (1 of 2)

- Same criteria: corrosive, toxic, ignitable, reactive
- Separate handling not required by federal law; many cities/towns do have programs

FIGURE 8.15 This bottle of liquid chlordane, which sat in a garage for 20 years after the sale of the pesticide was prohibited in the United States, was turned in at a municipal collection day for household hazardous wastes.

Handling of Household Hazardous Wastes

Table 8.2 **Alternatives to Using Hazardous Household Products**

Instead of	Substitute
Drain Cleaner	Use a plunger or plumber's snake
Glass Cleaner	Mix one tablespoon of vinegar or lemon juice in one quart of water; spray on and use newspaper to dry.
Furniture Polish	Mix one teaspoon of lemon juice in a pint of mineral or vegetable oil and wipe furniture.
Rug Deodorizer	Use baking soda instead
Silver Polish	Boil two to three inches of water in shallow pan with one teaspoon salt, one teaspoon baking soda, and a sheet of aluminum foil. Submerge silver completely and boil for a few minutes. Wipe away tarnish when cooled.
Mothballs	Use cedar chips, lavender flowers, rosemary, or white peppercorns.

Data from U.S. Environmental Protection Agency. *Hazardous Waste Source Reduction Around the Home*. Retrieved July 30, 2020 from: https://www.epa.gov/hw/household-hazardous-waste-hhw.

Medical Waste

- Produced by health care facilities
  - Infectious, hazardous, radioactive
  - Federal incinerator emissions limits; but much regulation is state or local

Regulation of Municipal Solid Waste in the United States

- Resource Conservation and Recovery Act
  - No open dumping; requirements for landfill features, groundwater monitoring
  - Encourages source reduction, recycling, waste-to-energy technologies
  - Does not directly apply to households
- Clean Air Act
  - Governs incinerator emissions

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Urban Settings In Less-Developed Countries

- Global population: more than half urban
- Two-thirds of the global population expected to live in urban settings by 2050[56]
- Emergence of megacities >10 million, most in less-developed countries

Top 20 Largest Cities in 2000 and 2020 (Continued)

Table 8.3 Top 20 Largest Cities in 2000 and 2020

Rank in 2000	Name	Population (millions)	Rank in 2020	Name	Population (millions)
1	Mexico City, Mexico	26.3	1	Tokyo, Japan	37.28
2	Sao Paulo, Brazil	24	2	Mumbai (Bombay), India	25.97
3	Tokyo, Japan	17.1	3	Delhi, India	25.83
4	Calcutta, India	16.6	4	Dhaka, Bangladesh	22.04
5	Mumbai (Bombay), India	16	5	Mexico City, Mexico	21.81
6	New York City, USA	15.5	6	São Paulo, Brazil	21.57
7	Seoul, Republic of Korea	13.5	7	Lagos, Nigeria	21.51
8	Shanghai, China	13.5	8	Jakarta, Indonesia	20.77
9	Rio de Janeiro, Brazil	13.3	9	New York City, USA	20.43
10	Delhi, India	13.3	10	Karachi, Pakistan	18.94
11	Buenos Aires, Argentina	13.2	11	Calcutta, India	18.54

Top 20 Largest Cities in 2000 and 2020 (Continued)

Table 8.3 Top 20 Largest Cities in 2000 and 2020

Rank in 2000	Name	Population (millions)	Rank in 2020	Name	Population (millions)
12	Cairo, Egypt	13.2	12	Buenos Aires, Argentina	15.48
13	Jakarta, Indonesia	12.8	13	Cairo, Egypt	14.02
14	Bagdad, Iraq	12.8	14	Manila, Philippines	13.4
15	Teheran, Iran	12.7	15	Los Angeles, USA	13.25
16	Karachi, Pakistan	12.2	16	Rio de Janeiro, Brazil	13.23
17	Istanbul, Turkey	11.9	17	Istanbul, Turkey	12.76
18	Los Angeles, USA	11.2	18	Shanghai, China	12.63
19	Dacca, Bangladesh	11.2	19	Moscow, Russia	11.73
20	Manila, Philippines	11.1	20	Osaka, Japan	11.53

Data from United Nations Department of International and Social Affairs, Estimates and Projections of Urban, Rural and City Populations. 1950-2025: The 1982 Assessment, (New York: United Nations, 1985). p.147 Defense Mapping Agency Hydrographic Topographic Center, World Per Index (10th Edition), 1986 Publication No. 150 Website: https://meteor.geol.iastate.edu/gccourse/issues/pop/cities.html For 2020: Retrieved from 8/4/2020 from https://www.macrotrends.net/cities/largest-cities-by-population

Urban Settings In Less-Developed Countries

- Poverty, crowding, poor housing, lack of sanitation and clean water[57]
- Air pollution, toxic wastes, fires, traffic accidents, violence[57]
- Conditions conducive to infectious disease
  - Standing water, poor sanitation, crowding

Urban Settings In Less-Developed Countries (3 of 3)

FIGURE 8.17 Slum dwellings in an Ecuadoran city perch over sewage-contaminated water.

Courtesy of CDC Public Health Image Library. ID# 5323. Content provider: CDC. Available at: http://phil.cdc.gov/phil/home.asp. Accessed October 30, 2012

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The Built Environment in More-Developed Countries (1 of 2)

- Suburban sprawl
  - Low-intensity construction; separation of land uses through zoning
  - Extensive road systems, heavy traffic
  - High per-capita energy use in suburbs (single-family homes, need car)
  - Concern with contribution to rising obesity
    - Push for more urban *green space*
      - Redevelopment use for *brownfields*

The Built Environment in More-Developed Countries (2 of 2)

FIGURE 8.19 Suburban residential developments like this one, with its curving cul-de-sacs and large homes, all similar in design, are found all across the United States.

Courtesy of Craig L. Patterson

Indoor Environmental Health Hazards (1 of 3)

- Indoor settings are enclosed spaces.
- Americans spend[60]
  - 87% of their time indoors
  - 69% of their time in their homes
- Working adults: time indoors at work
- Children: time indoors at school

Indoor Environmental Health Hazards (2 of 3)

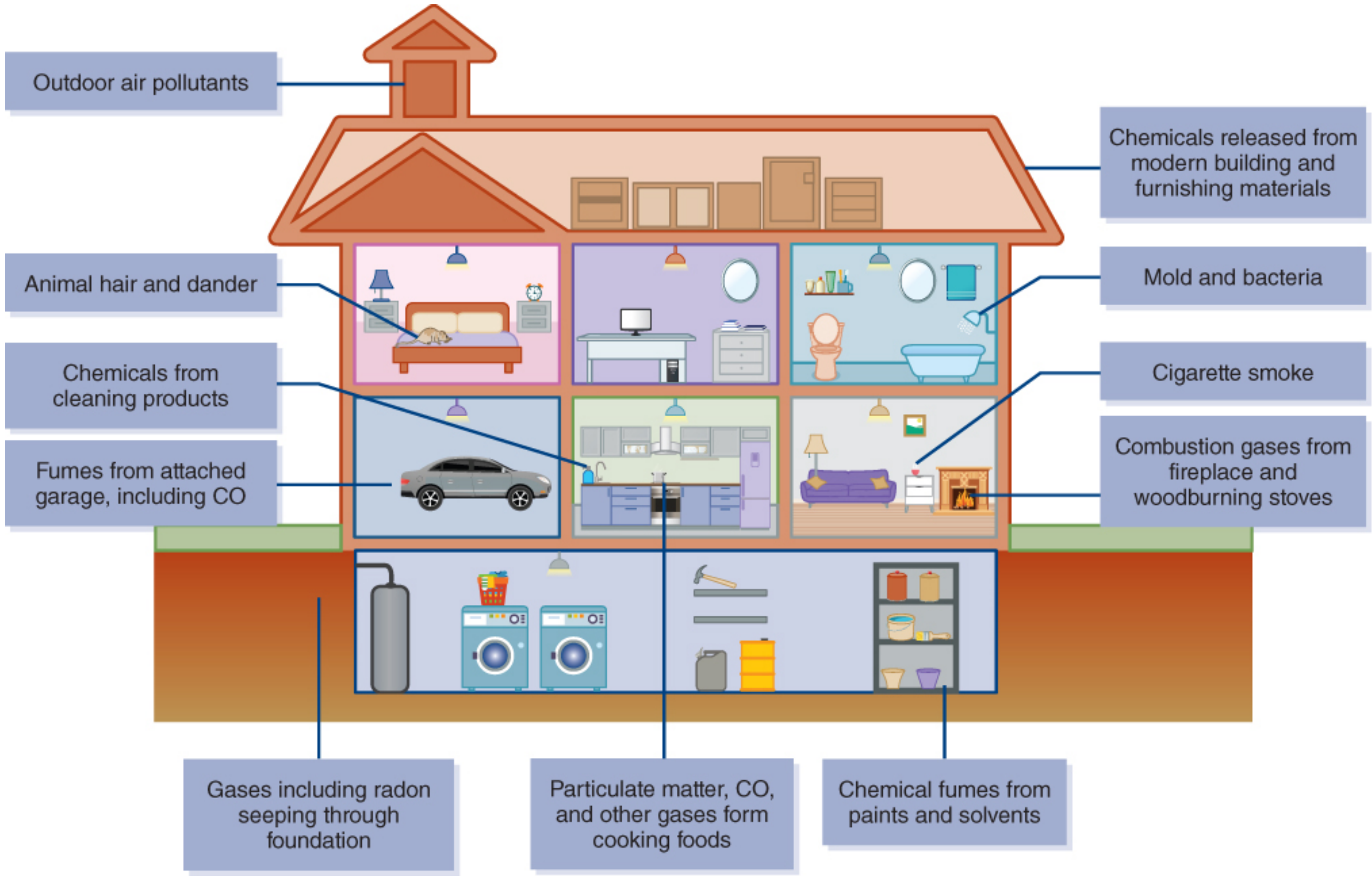

FIGURE 8.21 Sources of Indoor Air Pollution.

U.S. Environmental Protection Agency. Sources of Indoor Air Pollution. Available at: https://www.epa.gov/expobox/exposure-assessment-tools-media-air

Indoor Environmental Health Hazards (3 of 3)

- Tobacco smoke
- Radon and sources of nonionizing radiation
- Other indoor respiratory hazards
  - Asbestos
  - Formaldehyde
  - Molds and other biological contaminants
- Personal care products
- Products for housekeeping
- Household pesticides

Tobacco Smoke

- If there is a smoker in the home, tobacco smoke dwarfs contribution from other indoor air pollutants, such as indoor woodstoves.[60]
- Evidence on health hazards of smoking:[63]
  - Emphysema, heart disease, heart attack, stroke
  - Cancer: mouth, pharynx, larynx, lung, bladder, esophagus, stomach, kidney, pancreas, cervix; probably female breast cancer and primary liver cancer
  - Hearing loss
  - During pregnancy: increased risk of stillbirth, low birth weight, SIDS
- Environmental tobacco smoke (secondhand smoke):[63]
  - Adults: heart disease, heart attack, lung cancer, hearing loss
  - Children: SIDS, asthma, hearing loss

Radon Gas in Buildings

- Natural hazard in some regions
  - Seeps into house, especially basement
  - Volatilizes from tap water (groundwater); accumulates in indoor air
  - Begins series of rapid breakdowns
  - Radon and some progeny are alpha emitters; lung cancer risk
  - Often simple to detect and remediate

Sources of Nonionizing Radiation

- Cellular phones
  - Emit microwave radiation
  - IARC Group 2B classification (*possibly* carcinogenic)
    - Concern is brain cancer (near ear)
  - Known distracted driving fatality risk

- Tanning salons/tanning beds
  - Emit mainly UV-A radiation; Group 1 carcinogen

Other Indoor Respiratory Hazards

- Asbestos
  - In industrialized countries, nearly everyone has asbestos fibers in lungs[25]
  - Some risk of cancer, not fibrotic disease
- Formaldehyde
  - Pressed wood products, crease-proof fabrics
  - Gas at room temperature; moves into indoor air
  - Respiratory irritation, asthma, cancer
- Molds and other biological contaminants
  - Bacteria, pollens
  - Usually occur where there is water or dampness
  - Flooding damage may pose respiratory or allergic responses

Personal Care Products

- Deliberately applied to body; habitual use
  - Exposure hard to document
    - Individuals use a changing list of products.
    - Products have a changing list of ingredients.
    - Not all ingredients listed on label
  - Toxicity of many ingredients not well known
    - e.g., only recent attention to phthalates as endocrine disruptors
- Heavily marketed, especially to women
- Wide use of antimicrobial products[80] contributes to antibiotic resistance

Products for Housekeeping, Including Pesticides

- Products advertised to make home feel clean and smell good; many contain respiratory irritants
  - Cleaning products, laundry products
  - Air fresheners, toilet bowl cleaners
- Antibacterial sprays and soaps
- Pesticides used in the home
  - Special risk to children
  - Illegal household pesticides

Products for Housekeeping, Including Pesticides (2 of 2)

FIGURE 8.22 This illegal pesticide, known as Chinese chalk, resembles ordinary blackboard chalk.

Courtesy of Dion Lerman, Pennsylvania Integrated Pest Management Program/Pennsylvania State University

Sick Building Syndrome

- Nonspecific symptoms experienced by occupants of a building
- “Sick building” designation
  - A building whose occupants experience such symptoms
- Building-related illness
  - Specific diagnosable illness, linked to specific feature of building

Regulation Related to Hazards of Modern Life (1 of 2)

- The indoor environment
  - EPA: Technical assistance and education/ outreach on lead hazards
  - EPA: Financial support and technical assistance for states' radon programs
  - Consumer Product Safety Commission: main focus on packaging and labeling

Regulation Related to Hazards of Modern Life (2 of 2)

- Cigarettes and cosmetics
  - Cigarettes: no smoking on domestic flights; no ads on TV or radio; warnings on packages
  - Cosmetic products and ingredients
    - No premarket approval; safety review by trade group
    - Some ingredients prohibited in cosmetics

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Quantifying the Impacts of Development

Facing a Challenging Future

Quantifying the Impacts of Development

- The impact equation:

$$\text{Impact} = \text{Population} \times \text{Consumption}$$

$$\text{or } I = P \times C$$

- *C* can be expanded, yielding the IPAT equation:

$$I = P \times A \times T$$

where A = affluence and T = technology

Quantifying the Impacts of Development

- Carrying capacity: maximum impact an ecosystem (or the earth) can support for extended period
- Sustainable development: development whose impact can be maintained over many generations
- Ecological footprint (a measure of impact):[93] the area on the earth's surface required to provide resources for, and absorb the wastes of, a person or population with a given lifestyle

Quantifying the Impacts of Development (3 of 3)

- Components of the ecological footprint:[93]
  - Built-up land area
  - Area needed to produce food on land
  - Area needed to produce food at sea
  - Forested area needed to produce wood products
  - Forested area needed to absorb CO_2 from burning fossil fuels (carbon footprint)

The global ecological footprint in 2018 was 1.7 planet Earths, meaning that global ecological resources were being used up 1.6 times faster than they could be replenished

Quantifying the Impacts of Development

Facing a Challenging Future

Facing a Challenging Future (1 of 2)

- Key ecological and demographic realities:
  - Western-style development not sustainable globally
  - Enormous disparities between ecological footprints of richer and poorer countries
  - Future strain on global carrying capacity will be driven by regions with largest populations (China and India, both with increasing per capita footprints)

Facing a Challenging Future (2 of 2)

- A daunting challenge: designing a global future that is both more sustainable and more equitable
- Technology, re-oriented towards the “green,” may become part of the solution
- Compelling concerns
  - Growing burden of ecological debt
  - Reality of global connectedness
  - Global climate, hanging in the balance