CHAPTER
FIFTEEN

Excerpt from
"Water & Wastewater
Technology"

Hammer &
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SUSTAINABILITY AND CARBON FOOTPRINT*

This chapter presents introductory information on sustainability and carbon footprint considerations for water and wastewater systems. At the time of this writing, the metrics for reporting greenhouse gasses (GHG) are being developed, legislative debates continue in the United States, and individual states are adopting their own goals. For example, California Assembly Bill AB-32 committed the state to reduce emissions to 2000 levels by 2010, to 1990 levels by 2020, and to 80 percent below 1990 levels by 2050; and Florida adopted Executive Order 07-126 to reduce current levels by 10 percent by 2012, 25 percent by 2017, and 40 percent by 2025. A bill before the U.S. congress would require a reduction in carbon GHG and carbon footprints by major U.S. sources by 17 percent by year 2020 and 80 percent by 2050. The bill and EPA both require mandatory GHG reporting, but they specifically exempt wastewater treatment facilities with (Scope 1) emissions less than 25,000 metric tons of carbon dioxide equivalent per year (tonne CO_2/yr). However, water and wastewater systems represent a significant portion of the carbon footprint of public agencies, cities, and counties. Voluntary compliance, increasingly stringent state requirements, and future changes are expected. Sustainable uses of water were presented in Chapters 1 and 14. This chapter will focus on sustainability as it relates to carbon footprint.

15–1 WATER AND WASTEWATER SYSTEMS

Measurement of Carbon Footprint

The *Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*[1] was developed to provide consistent boundaries and avoid the possibility of undercounting or double counting GHG and carbon dioxide contributions. Even so, many details for water and wastewater treatment remain under development. The reporting standard divides carbon accounting into three scopes as shown in Figure 15–1. Scope 1 includes direct emissions resulting from physical/chemical processing and fugitive emissions. Scope 2 accounts for purchases of electricity where the GHG is

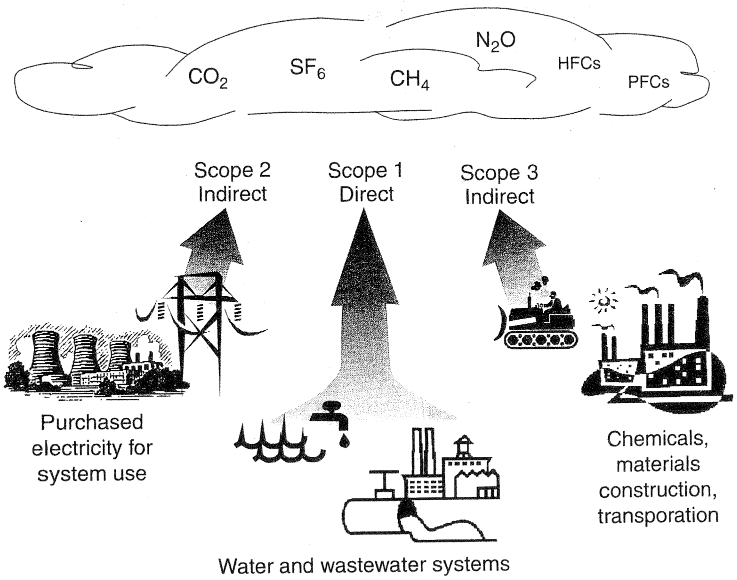

FIGURE 15–1 Greenhouse emission scopes for accounting and reporting. The largest greenhouse gas contribution from water and wastewater treatment is purchased electricity.

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*Carbon footprint is the total amount of GHG emissions caused directly or indirectly by individuals, product production, and waste treatment. GHG emissions are converted to an equivalent value in metric tons of carbon dioxide (tonne CO_2) for carbon footprint comparisons.

TABLE 15–1 Comparison of Energy Requirements for Potable Water Delivery

PROCESS	LOW	CONVENTIONAL	HIGH
Water supply kWh/MG	Gravity (no pumping) 0	River or shallow well 100	Deep well or long delivery 14,000
Water treatment kWh/MG	Chemical disinfection 100	Clarification-filtration 600	Desalination 16,000
Delivery kWh/MG	Close/flat 100	Distributed/flat 1300	Hilly 5000

produced by others, but remains attached to the electricity consumed by the processor. Scope 3 includes other supply chain GHG associated with chemicals, materials, and waste disposal associated with processing as well as employee commuting.

Carbon Footprint for Water Systems

Water treatment and distribution have almost no direct emissions under Scope 1. Chemical use, which may be significant at some facilities, and other Scope 3 GHG emissions are considered minimal and are typically excluded to avoid double counting. Even so, all water processors should consider the relative carbon footprint of various chemicals, their effectiveness, and optimize feed using instrumentation and monitoring. The largest source of GHG for water systems is purchased power under Scope 2. The energy required for water supply, treatment, and distribution vary greatly depending on the source of supply, treatment required, and distribution pumping requirements. Table 15–1 compares the range of energy required to supply, treat, and deliver potable water. The comparison is based on the relative energy measured in kilowatt hours (kWh) per million gallons of water (MG). Conventional treatment requires limited pumping from a river supply followed by treatment consisting of clarification and filtration, chlorine disinfection, and distribution through typical urban area that has few hills. This typical treatment requires about 2000 kWh/MG. For perspective, the water supply in the California east aqueduct system runs 350 miles from its origin on the San Joaquin-Sacramento River delta in Northern California to the city of Los Angeles in the south. The energy intensity of moving water supply from northern to southern California is approximately 9800 kWh/MG.

Example 15–1 A water utility in southern California was able to reduce water demand by 5 percent by lowering the water pressure in the distribution system by 10 percent. Conventional treatment is required with distribution in a distributed/flat area. If these savings were applied to the 2 million customers in southern California consuming 120 gpcd, what would be the carbon footprint reduction?

Solution

$$\text{Total water savings} = 0.05 \cdot 120 \cdot \frac{2{,}000{,}000}{1{,}000{,}000} = 12\ \text{mgd} \cdot 365 = 4380\ \text{MG/yr}$$

$$\text{Total energy saved} = (9800 + 600 + 1300) \cdot 4380 = 51{,}000{,}000\ \text{kWh} = 51{,}000\ \text{MWh}$$

State-level coefficients used to convert energy to carbon dioxide were developed by the Department of Energy Office of Policy.[3] The 3-year weighted average (1998–2000) in California is 0.275 tonne CO_2/MWh. (See Appendix for a list of states and emission coefficients for electric power.)

$$\text{Carbon footprint reduction} = 51{,}000 \cdot 0.275 = 14{,}000\ \text{tonne CO}_2\text{/yr}$$

Carbon Footprint for Wastewater

The inventory of U.S. Greenhouse Gas Emissions and Sinks[2] quantified the Scope 1—Direct Process GHG—and found that wastewater treatment contributes about 4 percent of the total methane and 2 percent of the nitrous oxide (in aquatic form). Due to the high methane emissions from landfills, wastewater treatment only represents about 12 percent of a city's emissions, but represents 30 to 60 percent of the energy cost. There is considerable debate regarding the emission factors and impact of nitrous oxide emissions because it is dissolved in the effluent water from treatment plants employing nitrification and denitrification. Nitrous oxide only impacts the environment as a GHG if it is released from solution. Other Scope 1 GHG results from operation of standby generators and on-site vehicles. Scope 3 emissions relative to chemical use, materials, and employee travel are typically excluded and fugitive emissions are negligible. Increasing levels of treatment often result in increasing levels of GHG through some nitrous oxide generation and significantly greater energy use. The breakdown of GHG produced by wastewater treatment is approximately 10 percent methane, 5 percent nitrous oxide, and 85 percent purchased power.

Energy required for collection systems, wastewater treatment, and disposal vary greatly depending on the degree and treatment strategy, degree of solids treatment,

TABLE 15–2 Comparison of Energy Requirements for Wastewater Treatment and Disposal

PROCESS	LOW	CONVENTIONAL	HIGH
Sewage collection kWh/MG	Gravity (no pumping) 0	Lift at plant 100	Multiple pumping 400
Wastewater treatment kWh/MG	Fixed film 1200	Activated sludge 2200	Advanced treatment 3400
Sludge treatment and disposal kWh/MG	Composting and land application 400	Digestion and land application 600	Pelletization 2400
Disposal kWh/MG	Gravity discharge 0	Pump for discharge 100	Significant discharge pumping 3000

and requirements associated with ultimate discharge. Table 15–2 compares the range of energy required to treat and dispose of wastewater. The comparison is based on the relative energy measured in kilowatt hours (kWh) per MG. Conventional wastewater treatment requires pumping at the treatment plant, primary and secondary treatment using activated-sludge processing, digestion, land application, and gravity discharge for a total energy demand of 3000 kWh/MG.

Water Use and Energy Intensity

The representation of water use and energy intensity varies depending on what demands are included in end-uses: residential, commercial, industrial, and/or agricultural. Figure 15–2 shows the water supply and wastewater disposal for a typical urban setting where annual water demands are 220 gallons per person per day (gpcd) and wastewater flow is 100 gpcd and the population is 100,000. The analysis does not show any water or wastewater contributions for industrial, manufacturing, or agricultural uses. Water loss in conveyance, distribution, and other city uses are accounted for in the water cycle. The figure shows water distribution and wastewater treatment as having the greatest energy demand, although the energy added by the end user in the form of household hot water, ice-making, and dish- and clothes washers is about twice the total energy required for all water and wastewater activities.

15–2 BECOMING CARBON NEUTRAL

A critical first step is to measure and monitor GHG production and electrical use. Submetering and monitoring at the motor control center is required to evaluate individual

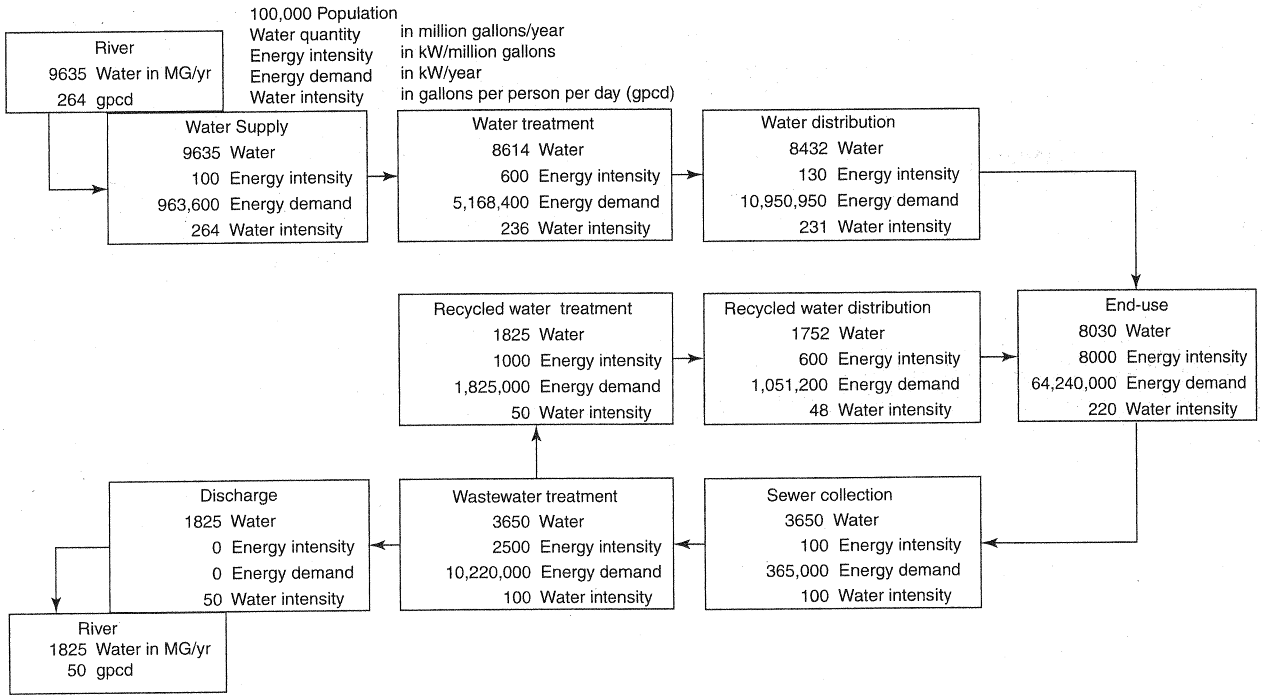

FIGURE 15–2 Energy intensity, water intensity, water quantity, and energy demand for a population of 100,000. The diagram traces water flow and energy from the source water supply through water treatment, distribution, use, sewer collection, wastewater treatment, and discharge. Also shown is the potential for recycled water treatment and distribution.

equipment and treatment process use. The cost of electricity may be under an industrial rate schedule or special schedule for public facilities. Time-of-day monitoring is critical to evaluate the value of reducing peak use charges. Many facilities are charged on a time-of-use rate structure with increased costs for on-peak use (typically 10 A.M. to 8 P.M., Monday through Friday) and lower costs for off-peak use. Reducing on-peak power consumption may be the first priority. Providing detailed information greatly improves the ability to manage energy and chemical use.

Opportunities to reduce the carbon footprint of water and wastewater systems include the following:

1. Maximum use of anaerobic digester gas for heating and power generation
2. Energy conservation (high-efficiency motors, use of variable speed drives, matching equipment power with demand)
3. Renewable energy (wind farms, photovoltaics, digest gas biofuel, thermal energy)
4. Chemical optimization (instrumentation, control, and monitoring)
5. Waste management (composting, agricultural land application, fuel pellets, reuse)
6. Green facilities [Leadership in Energy and Environmental Design (LEED) building design, adaptive use of buildings, wetlands, stream, and habitat restoration]
7. Watershed management (supply, reuse, stormwater, water quality, and storage)

Wastewater treatment can be 82 percent carbon neutral by making the best use of renewable energy and facilities used for treatment (see Figure 15–3). Cogeneration of electricity uses the digester gas produced at the wastewater treatment plant to generate electricity and create heat that can be used within the plant. Acid-phase digestion and optimization of the primary clarifiers improve digestion and digester gas generation. Fat, oil, and grease (FOG) collected at restaurants can be transported to the treatment plant and directly fed to the digester to generate additional digester gas. Reducing the inefficiency created by overdesign and employing environmental management systems (EMS) to reduce environmental impacts brings the carbon footprint down to about 18 percent of the original total energy demand. The remaining gap can be offset by finding additional sources of FOG or food wastes for digestion or by generating power using solar or wind technologies.

Carbon Footprint Reduction from Anaerobic Digestion

As discussed in Chapter 11, anaerobic digestion requires heat to maintain a liquid temperature between 90°F and 98°F and the destruction of volatile solids (VS) generates a gas containing 33 to 38 percent carbon dioxide, 55 to 65 percent methane, and a small concentration of nitrogen and hydrogen sulfide. This results in a gas that has 600 to 650 BTU/cu ft (in contrast to 1000 BTU/cu ft in natural gas). Between 12 and 18 cu ft of gas is generated per pound of VS destroyed, although, VS destruction, gas generation, and methane concentration vary greatly among wastewater treatment facilities. While it is common practice to use digester gas in the boiler to generate hot water for digester

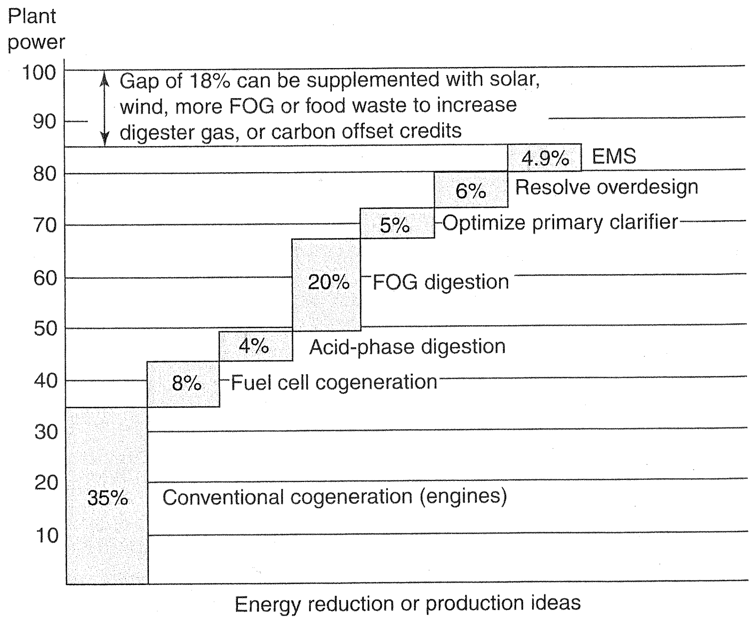

FIGURE 15–3 Steps to carbon neutral wastewater treatment. For a typical treatment plant, 42 percent of the total energy can be covered by cogeneration, 29 percent by improving gas generation, and 10.9 percent by improving design and using energy management systems. The 18 percent balance can be offset through green power generation.

heating, many plants use natural gas, thus all of the gas generated by digestion is burned in the waste gas burner (flair).

Digester Gas Used for Heating

The initial application for digester gas is to heat the digester as pictured in Figure 15–4 and illustrated in the flow diagram in Figure 15–5. The figure shows the results of the calculation in Example 15–2 and the complete energy balance for summer, average, and winter conditions. Note that sufficient digester gas is available under all conditions to heat the digester and excess gas is burned in the waste gas burner to avoid release of methane. Pretreatment to meet air-quality requirements include hydrogen sulfide removal and a special burner to limit NOx production and operate on reduced gas pressure. In colder climates, all of the digester gas may be required to heat the digester in the winter.

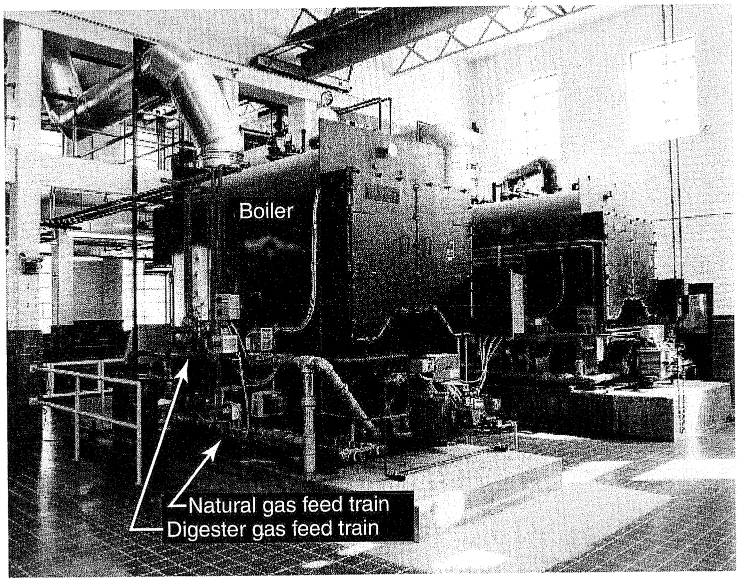

FIGURE 15–4 Dual fuel boilers operating on natural gas or digester gas. Hot water is distributed throughout the facility for digester and building heating.

(Photo Courtesy of HDR Engineering, Inc.)

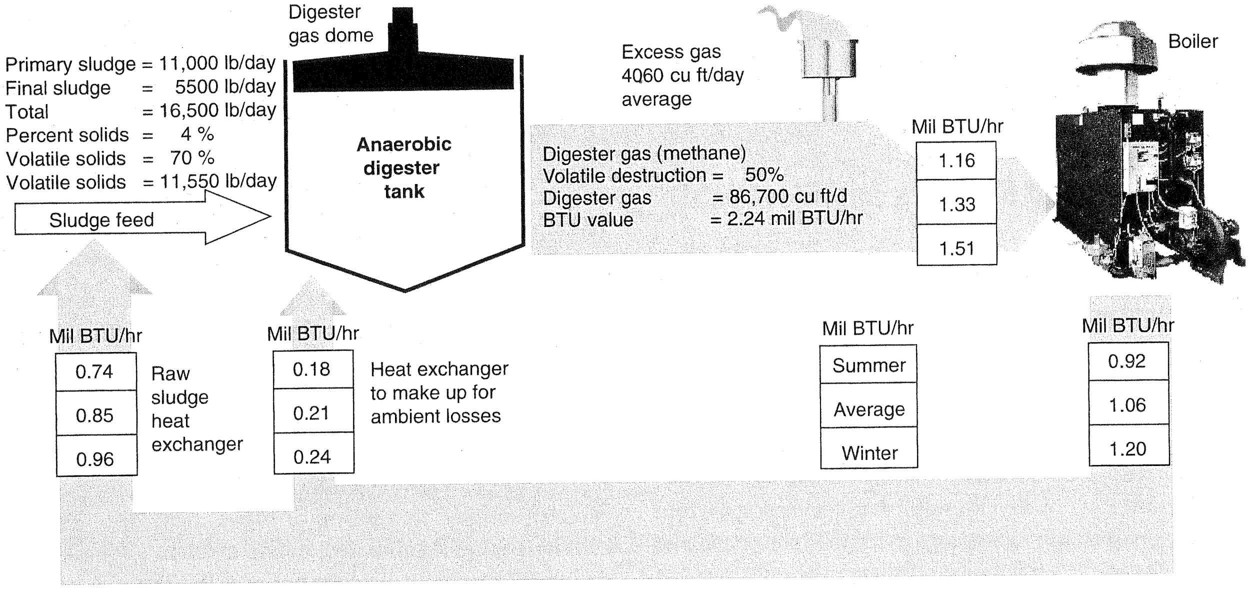

FIGURE 15–5 Distribution of heat generated from digester gas in a boiler to heat the raw sludge, ambient digester losses, and building heat. Values in mil BTU/hr are reported for summer, annual average, and winter temperature conditions. Sufficient energy is available in the digester gas to maintain a digester temperature of 98°F. Note that about $\frac{1}{3}$ of the gas produced is shown as excess gas in the waste gas burner, but could be used if additional head loads were available.

Example 15–2 Determine the excess gas production and carbon footprint reduction by replacing natural gas with digester gas to heat the digester to 98°F. The heat required to maintain digester temperature is about $\frac{1}{2}$ of the heat required to heat the raw sludge. Use a population of 100,000, 120 gpcd, 220 mg/l SS (50 percent primary removal), and secondary sludge production = 20 percent of the primary sludge removal. Wastewater temperatures range between 42°F in the winter to 55°F in the summer with an average of 48.5°F. Digester gas generation is about 15 cu ft/lb VSS destroyed and contains 620 BTU/cu ft. Assume the boiler is 80 percent efficient.

Solution Heat demand:
Raw sludge:

$$\text{Primary solids} = 100{,}000 \cdot 120/10^6 \cdot 220 \cdot 8.34 /2 = 11{,}000 \text{ lb/day}$$

$$\text{Secondary solids} = 5500 \text{ lb/ day Total solids} = 16{,}500 \text{ lbs/day at 4 percent solids,}$$

$$\text{sludge flow} = 413{,}000 \text{ lb/day}$$

$$\text{BTU to heat raw sludge} = 413{,}000 \cdot \frac{(98 - 48.5)}{24} = 852{,}000 \text{ BTU/hr BTU to maintain digester}$$

$$\text{temperature is approximately 20 percent of the total or } \frac{852{,}000}{0.8} \cdot 0.2 = 213{,}000$$

$$\text{BTU/hr, for a total heat demand} = 1{,}065{,}000\text{BTU/hr or } 1.065 \text{ mil BTU/hr average}$$

A boiler that is 80 percent efficient, and equivalent amount of natural gas is not used, the carbon footprint reduction is

$$= 1.065/0.8 \cdot 24 \cdot 365 \cdot 0.053 \text{ (tonne } CO_2\text{/mil BTU)} = 620 \text{ tonne } CO_2\text{/year}$$

Gas production:

$$\text{VSS destruction} = 0.5(16{,}500 \cdot 0.7) = 5780 \text{ lb/day}$$

$$\text{Gas produced} = 5780 \cdot 15 = 86{,}700 \text{ cu ft/day} \cdot \frac{620}{24} = 2.24 \text{ mil BTU/hr}$$

Excess gas to be discharged through the waste gas burner:

$$\text{Excess gas} = 5780 - \frac{1{,}065{,}000}{620} = 4060 \text{ cu ft/day}$$

Digester Gas Used for Work and Electrical Generation

Digester gas may be used in an engine directly coupled to a blower or pump and may be used in an engine-generator or fuel cell to generate electricity. Pretreatment requirements include hydrogen sulfide and siloxane removal. Figure 15–6 shows the storage and treatment of digester gas consisting of low-pressure gas storage, four iron sponges, and a high-pressure storage sphere. Engine-driven equipment, like that shown in Figure 15–7, is a well-established technology, while fuel cells are an evolving technology, with the main problem being digester gas cleaning and monitoring the effectiveness of hydrosulfide and siloxane pretreatment. Excess heat may be recovered from the engine cooling system and the exhaust. Figure 15–8 illustrates the use of digester gas in an engine for electrical generation. As a continuation of Example 15–2, the figure shows that sufficient gas is available to operate an engine-generator and heat the digester using waste heat from the engine (based on the calculations listed in Example 15–3). At some facilities, lower percent solids in the sludge feed, limited insulation, and cold winter temperatures do not generate sufficient heat in the winter. Supplemental heat from a backup boiler operating on natural gas may be used when digester gas supplies are inadequate. Engines are typically 30 to 35 percent efficient when directly coupled to a pump or blower and 25 to 30 percent efficient when connected to an electric generator. Heat recovered from the water jacket and exhaust can be used in lieu of the boiler to heat the digester, thus increasing the overall energy efficiency to 60 to 70 percent.

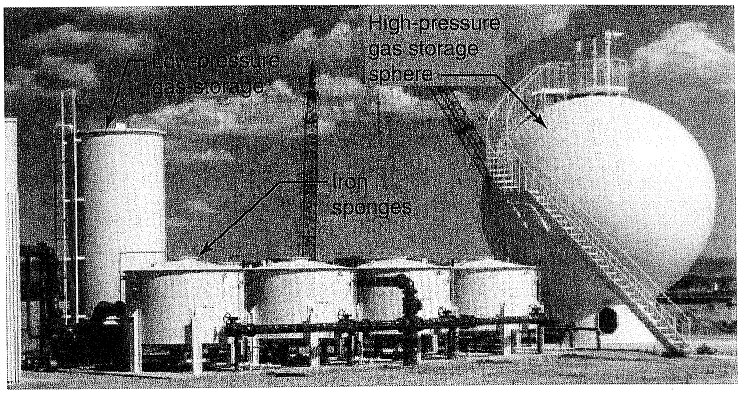

FIGURE 15–6 Low-pressure storage cylinder (left), four iron sponges, and high-pressure storage (right). Gas scrubbers consisting of iron pellets remove hydrogen sulfide. Low-pressure storage operates at 12 in. of water column and high-pressure sphere operates at 100 psi.

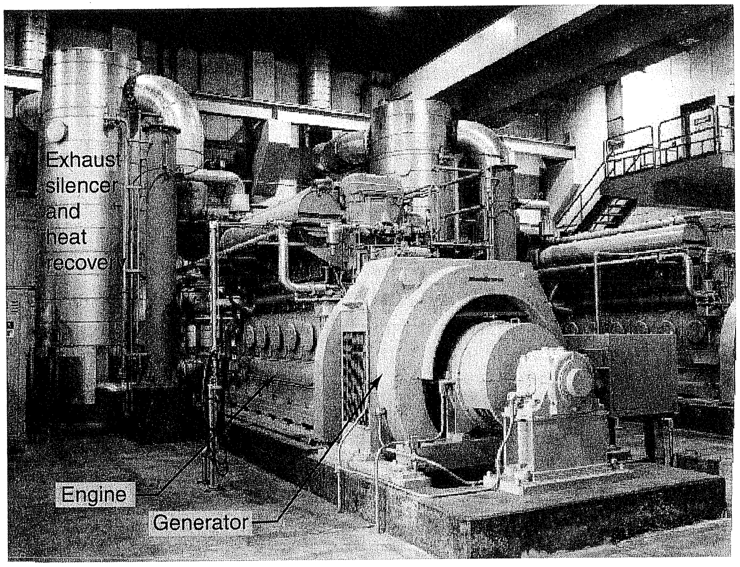

FIGURE 15–7 Engine-generators operating on digester gas. Hot water from engine jacket and exhaust are piped throughout the plant for digester and building heating.

(Photo Courtesy of HDR Engineering, Inc.)

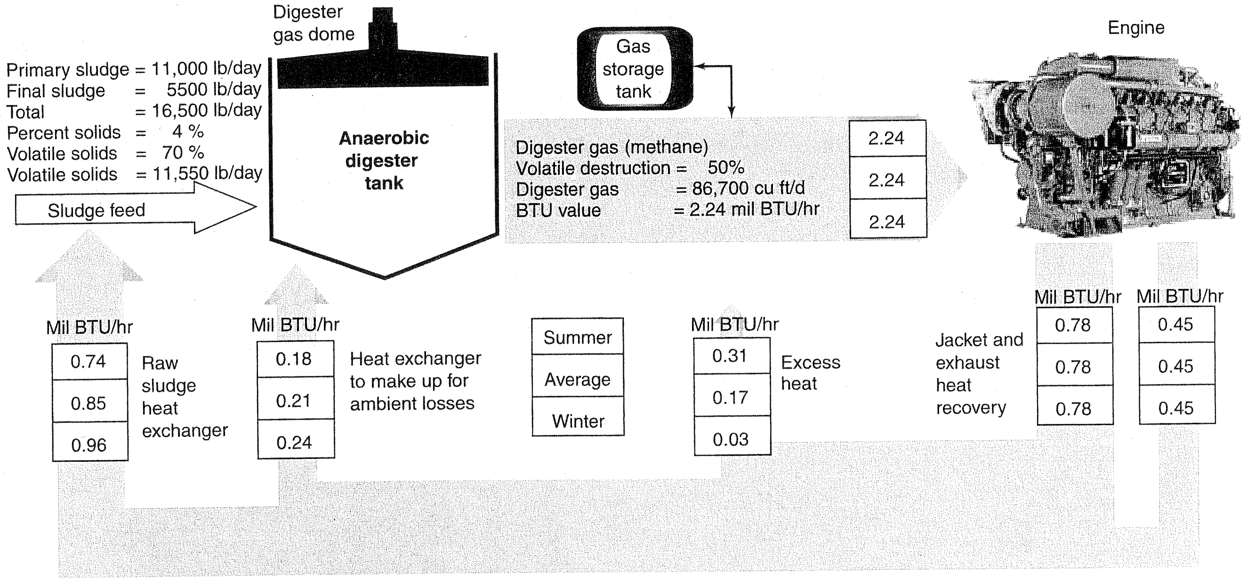

FIGURE 15–8 Distribution of heat generated from digester gas in an engine to heat the raw sludge, ambient digester losses, and building heat. Values in BTU/min are reported for summer, annual average, and winter temperature conditions. Sufficient energy is available from digester gas to maintain a digester temperature of 98°F and excess heat must be wasted. The engine also generates 184 kW of electrical power. Note that engine heat in the winter is just enough to cover the digester winter heating demands of 1.2 mil BTU/hr.

Example 15–3 Using the sludge and digester heating requirements from Example 15–2, determine the carbon footprint reduction by using an engine-generator to heat the digester and produce power in Kentucky. Also calculate the waste heat remaining. The engine-generator is 28 percent efficient in producing electricity, with 35 percent of the jacket heat and 20 percent of the exhaust heat available to meet heating demands (note that the final 17 percent of the energy is heat radiated into the room).

Solution Total heating demand:

Same as Example 15–2 1,065,000 BTU/hr or 1.065 mil BTU/hr average

Energy and heat generation:

All of the gas produced is used by the engines. Using the 2,240,000 BTU/hr in the digester gas, the generator produces 2,240,000 · 0.28 = 627,000 BTU/hr /3412 BTU/kWh = 184 kW with a carbon footprint of 184 · 124 · 365/1000 · 2.01 tonne/MWh in Kentucky = 3240 tonne CO_2/yr

Heat generation = 2.24 (0.35+0.20) = 1.23 mil BTU/hr, which is enough to cover the total digester heating demand. Note that the excess heat can be used for building heat or other heating uses.

The carbon footprint reduction is the total value of electricity generated + the natural gas not used for heating = 3240 + 620 = 3860 tonne CO_2/yr

Several methods may be employed to increase gas production to further reduce the carbon footprint. Chemical coagulant addition to the primary clarifier increases VSS capture and digester gas production. Grease, collected from area restaurants, is highly volatile and can be fed directly to the digester with a significant increase in gas production. Some agencies are experimenting with the collection of food waste, which is ground and fed directly to the digester. Dairy and poultry wastes are especially high in VS. Where the landfill is located close to the treatment facility, gas collected at the landfill can be used to generate additional power and heat.

Green Power Generation

To achieve carbon neutrality, solar, wind, small turbine generators, or another green power generation source is typically necessary. This textbook cover shows solar and wind power at the Atlantic County Utilities Authority (ACUA) wastewater treatment plant. A 7.5-megawatt wind farm and a 500-kilowatt solar power system deliver electricity to offset treatment needs and connect to the regional electric grid. Other energy conservation projects include use of landfill gas to generate additional power, use of geothermal heating and cooling systems to reduce power requirements, and vehicles that operate on biodiesel and hybrid power. The Deer Island WWTP, operated by the Massachusetts Water Resources Authority, includes wind, solar, hydroelectric, and digester gas power generation as well as efficiencies to reduce power demands. Two 1-megawatt hydroelectric generators were installed on the treated water outfall as effluent drops from the plant into the outfall tunnel. The facility also includes energy management systems including energy-efficient lighting.

Fertilizer from Biological Phosphorus Removal

As described in Section 13–8, enhanced biological phosphorus removal uses an anaerobic zone to release phosphorus followed by an aerobic zone where additional phosphorus is absorbed by the bacteria. For plants with anaerobic digestion, phosphorus is again released from the bacteria and ferric chloride must be added to chemically tie up the phosphorus as iron orthophosphate ($(FePO_4)_2 \cdot 5H_2O$). Iron orthophosphate is removed with the sludge, which if applied to agricultural property is a benefit for its fertilizer value, but if the sludge is disposed of in a landfill or incinerated, the fertilizer value is lost.

Without the ferric addition, the high concentration of orthophosphate has a tendency to form struvite also known as ammonium magnesium phosphate ($(NH_4)MgPO_4 \cdot 6H_2O$). The crystals precipitate and scale in pipes and biosolids handling equipment immediately following anaerobic digestion. The first U.S. struvite recovery system is located at the Clean Water Services, Durham Treatment Facility in Tigard, Oregon. The process uses manganese chloride in a controlled pH vessel to precipitate struvite. A photo of the process tank is shown in Figure 15–9.

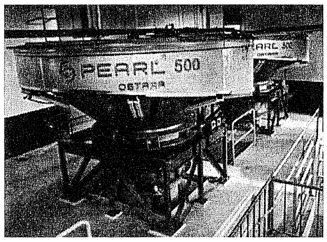

FIGURE 15–9 Tanks used to precipitate fertilizer from anaerobic digester dewatered recycle flow marketed as Pearl 500.

(Courtesy of Ostara Nutrient Recover Technologies)

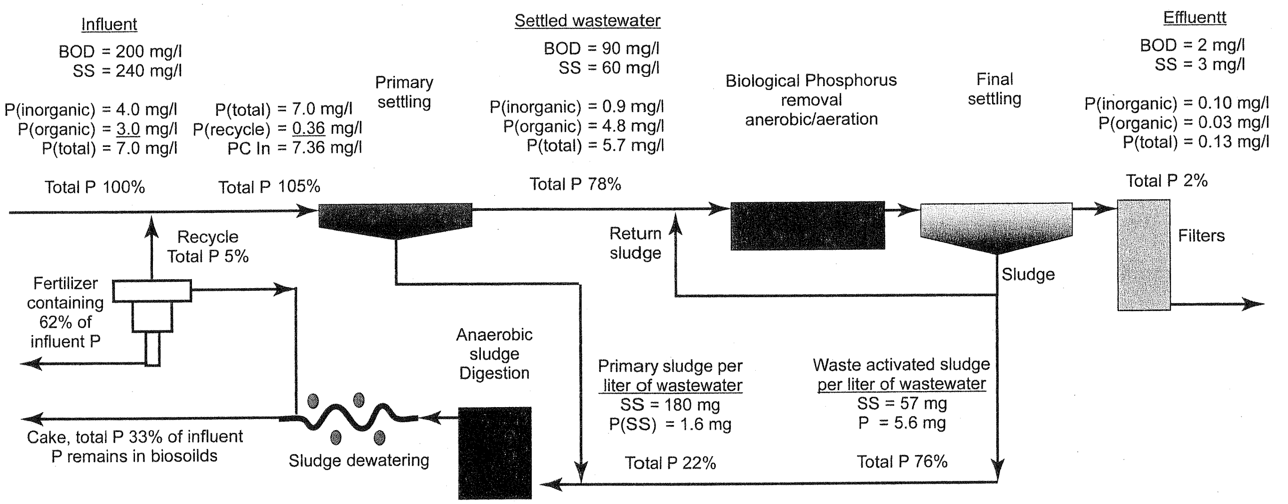

FIGURE 15–10 Diagram tracing wastewater phosphorus through a treatment plant using a controlled process to make struvite as marketable fertilizer product. Of 100 percent influent phosphorus, 2 percent remains in the effluent wastewater, 36 percent remains entrained with the biosolids cake, and 62 percent is removed as fertilizer.

Integration into the treatment process is illustrated in Figure 15–10 using an influent flow of 10 MGD and total phosphorus concentration of 7 mg/l. Approximately 2 percent of the influent phosphorus is discharged in the plant effluent with another 36 percent entrained in the dewatered biological solids. Approximately 62 percent of the phosphorus is removed as fertilizer. This results in an annual production of 66 tons/year P and 630 tons/year as fertilizer. Commercial fertilizer production requires a significant amount of natural gas and energy to convert airborne nitrogen to ammonia and mined potash to a concentrated liquid or solid product. Depending on the source, about one and one-half tons of CO_2 is offset per ton of wastewater fertilizer generated.

15–3 SUSTAINABLE DESIGN OPPORTUNITIES

LEED Green Building Rating System, developed by the U.S. Green Building Council, provides standards and metric measures for sustainable building construction. Although these do not directly apply to water and wastewater systems, the principles of sustainability can be adapted for system planning. LEED can be directly applied to maintenance, laboratory, administration, and other buildings. Points are awarded in the areas of sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovative and design process. Opportunities for water and wastewater systems are listed in Table 15–3.

TABLE 15–3 Sustainable Design Opportunities

AREAS	OPPORTUNITIES
Sustainable sites	Limit grading, restore cleared areas, reduce heat islands on roof and pavement
Water efficiency	Aquifer storage and recovery for enhancing water supply
	Efficient water-quality enhancement by exceeding regulatory requirements
	Use recycled water for processes, irrigation, fire flow, and off-site uses
	Xeriscape
	Reduce stormwater by enhancing percolation and capturing runoff through retention basins; limit roadways and consider pervious pavement and green roofs
	Reduce sweater intrusion to groundwater aquifers
	Reduce pressure in distribution system
Energy and atmosphere	Energy conservation
	Maximize use of methane for heat and power
	Fine-bubble aeration with deep basins
	Automatic blower control for dissolved oxygen
	Premium efficiency motors
	Right-size pumps and use variable-speed drives
	Energy-efficient lighting

(Continued)

TABLE 15–3 Sustainable Design Opportunities (continued)

	Reduce unoccupied building temperature
	Consider green power—solar and wind
	LEED buildings
	Consider green roofs to reduce HVAC requirements
	Reduce GHG emissions
	Implement alternative energy
Materials and resources	Use recycled construction materials
	Agricultural use of biosolids
	Use of biofilters for odor control
Indoor environmental quality	Reduce use of VOCs and noise levels, and improve safety
Innovative and design processes	Incorporate habitat enhancement for aquatic, wildlife, and native plant species.

15–4 BALANCE BETWEEN SUSTAINABILITY AND ADVANCED WASTEWATER TREATMENT

Advanced wastewater treatment, as presented in Chapter 13, includes additional energy requirements (for nitrification aeration) and chemical use (for denitrification and phosphorus removal) compared with the requirements for wastewater reuse, presented in Chapter 14. Many professionals agree that wastewater treatment to meet water reuse requirements is more sustainable not only because the water reduces freshwater demands but because the treatment requirements have a lower carbon footprint as compared with that additional treatment required to meet surface-discharge permit requirements.

Table 15–4 lists the carbon footprint for increasing levels of treatment for comparison. The comparison is based on a theoretical 10-mgd treatment plant with typical influent values for BOD, suspended solids, nitrogen, and phosphorus. The carbon footprint for electricity is based on the national average CO_2 emissions. The total carbon footprint includes the impacts of chemicals, sludge treatment, and biosolids disposal. Each facility has the same relative capability to reduce the carbon footprint through anaerobic digester and cogeneration; however, no credit was included. Note how electrical consumption dominates the total carbon footprint in all cases.

The table shows a 4 percent increase in carbon footprint from conventional activated sludge to filtration for unrestricted reuse. Advanced nutrient removal, as required to meet surface-water discharge requirements for the Panhandle watershed region in Florida (when stream dilution is 5:1, see Table 5–5), is just over double the carbon footprint of that for reuse. Developing water reuse would not only halve the carbon footprint, but would reduce water required from other sources. Reverse-osmosis treatment significantly increases the carbon footprint by 180 percent over that for reuse. However, in some cases the additional treatment to produce the water quality necessary for indirect reuse is warranted. In Example 15–1, 12 mgd of water transferred from water from northern to southern California results in 14,000 CO_2/yr or about 11,700 CO_2/yr for 10 mgd. In comparison, indirect reuse using reverse osmosis in Orange County, as described in Chapter 14, contributes 7500 CO_2/yr for 10 mgd and results in a lower carbon footprint.

TABLE 15–4 Comparison of Electrical and Total Carbon Footprint (without Energy Recovery) for Various Levels of Wastewater Treatment

TREATMENT	CONVENTIONAL ACTIVATED SLUDGE	ACTIVATED SLUDGE WITH FILTRATION FOR UNRESTRICTED REUSE	ADVANCED NUTRIENT REMOVAL WITH FILTRATION	REVERSE OSMOSIS
Figure reference	11–27	13–2 a	13–19 followed by filtration	13–9 b
Discharge requirements	30 mg/l BOD 30 mg/l TSS	<2 NTU <2.2 Coliform 17 mg/l N	2 mg/l TSS 4–8 mg/l N 0.2 mg/l P	0 TSS <2 mg/l N 0.02 mg/l P
Carbon footprint from electricity (tonne CO_2/yr)	2200	2300	4300	6700
Total carbon footprint (tonne CO_2/yr)	2600	2700	5800	7500

REFERENCES

1. *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard (Revised Edition)*, World Business Council for Sustainable Development, World Resources Institute, March 2004.
2. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007*, U.S. Environmental Protection Agency, EPA, April 15, 2009.
3. *Updated State-level Greenhouse Gas Emission Coefficients for Electricity Generation 1998–2000*, Energy Information Administration Office of Integrated Analysis and Forecasting Energy Information Administration U.S. Department of Energy, April 2002.

PROBLEMS

15–1 What is a carbon footprint and what are the key contributors to the carbon footprint of wastewater treatment plants?

15–2 A city is trying to decide if they should construct a deep well with chemical disinfection and distribution over hilly terrain or construct a desalination facility where disinfection would not be required. (a) What is energy intensity of each alternative? (b) What is the carbon footprint of each alternative? (c) What would you recommend?

15–3 (a) What can be done to create a carbon neutral wastewater treatment facility? (b) What can be done to create a carbon neutral water treatment facility?

15–4 Referring to Figure 15–2, compare the total energy intensity for the water supply with wastewater treatment including the production of recycled water. Which has the greater energy intensity: water supply, wastewater treatment and reuse, or household use?

15–5 Referring to Figure 15–2, a city does not currently recycle water. To expand the water supply by 1500 mil gal/yr, a new water source was identified with an energy intensity of 800 kW/mil gal, should the city expand the water system or develop recycled water capabilities?

15–6 Referring to Figure 15–5, verify the calculation of carbon footprint reduction during winter?

15–7 What constituents must be scrubbed from digester gas prior to use in engines?