PART I

ENERGY INFRASTRUCTURE SYSTEMS

CHAPTER 1

ENERGY IN INFRASTRUCTURES

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1.1 INFRASTRUCTURE SYSTEMS

As measured in 2015, around 1.2 billion people, constituting 17% of the global population, do not have electricity, and 2.7 billion people, constituting 38% of the global population, have risks on their health due to the reliance on the traditional use of biomass for cooking [1].

In order to discuss energy systems and conservation strategies in infrastructures, it is essential to analyze the infrastructure physical systems and their types, classifications, and energy requirements. It is possible to find a suitable definition of infrastructures as the fundamental facilities and systems that serve a region, area, community, city, or country, including the support facilities such as utilities, services, and transportation that are necessary for the economic development and perform all necessary functions. There are number of ways to classify infrastructures, such as size, criticality, use, occupancy, location, and surroundings. Infrastructures can support residential functions, commercial and public functions, transportation functions (including land, sea, air), and industrial functions. Infrastructures can be viewed as system of systems; for example, infrastructures include communications and cyber security, computational/technological, waste management, emergency and disaster management, defense and military, and other supporting infrastructures. The better we understand infrastructures, the better we design and operate energy systems in these infrastructures. Infrastructure modeling should support design and operational activities, with appropriate and comprehensive performance measures to evaluate design and operation features

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and alternatives. Requirement analysis of infrastructures should include energy demand, risk management, performance, and sustainability requirements.

1.1.1 Infrastructure Classifications

Energy use in infrastructures can be controlled and optimized based on the nature of loads and energy systems implemented in these infrastructures. For proper planning, design, and operation of energy systems to support these infrastructures, it is important to analyze the classifications of infrastructures. Figure 1.1 shows hierarchical classification of infrastructures based on nature, type, use, function, and energy requirements. There are interrelations among these infrastructures, for example, water infrastructures are linked to residential, industrial, and commercial. Similarly, energy and waste are linked to all other infrastructures.

In order to understand energy consumption in different regions, power consumption in Ontario has been selected, as presented in Figure 1.2, where it shows the consumption in residential, commercial, industrial, electric vehicle, transit, and others. Power consumption in residential is very close to that consumed in commercial, while industrial is the third dominating sector for power consumption.

1.1.2 Infrastructure Systems

Infrastructure system includes technical and technological infrastructures to support all functions and the management of life cycle activities in infrastructures including flow and control of information across all elements of the infrastructure systems. Modeling of processes of infrastructure systems includes players, roles,

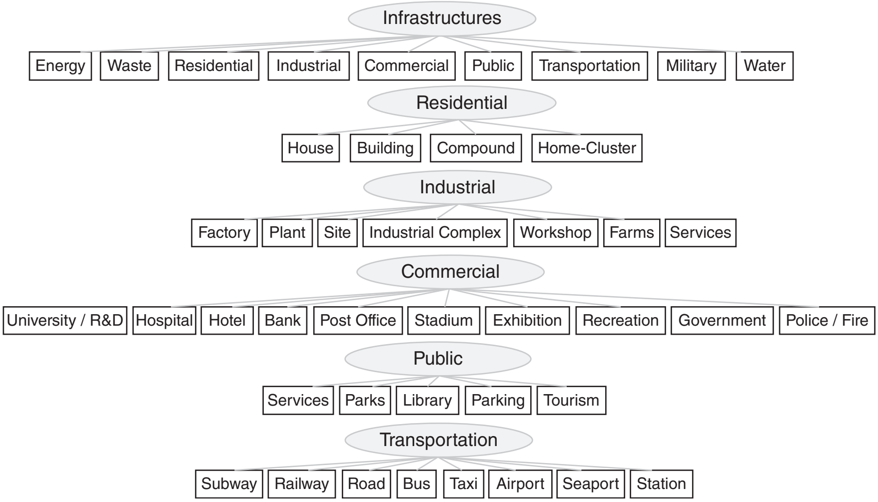


FIGURE 1.1 Infrastructure classifications.

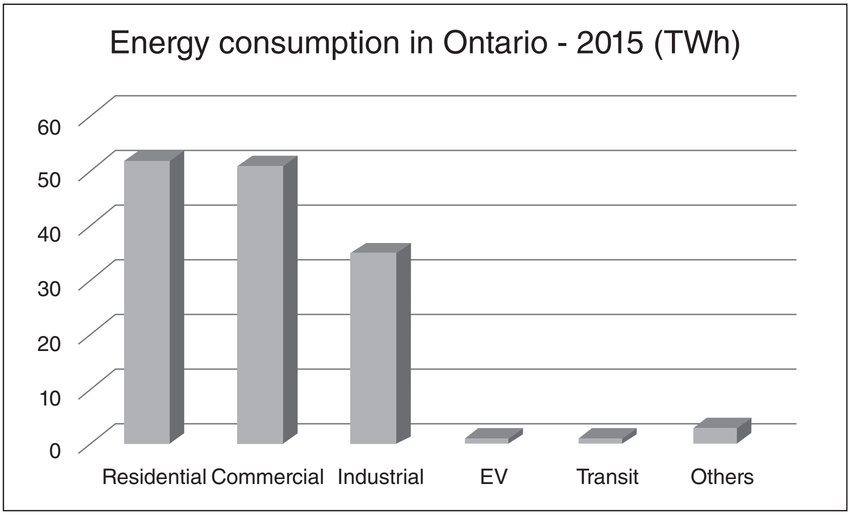


FIGURE 1.2 Power consumption in Ontario – 2015.

physical systems, functional modeling, financial modeling, planning, engineering design, operation, and management practices. One major component of infrastructure systems is the safety and protection systems to ensure the resiliency against hazardous, emergencies, and disaster situations and to sustain the stated target functions from the infrastructure systems.

1.2 ENERGY SYSTEMS IN RESIDENTIAL FACILITIES

Energy consumption in residential facilities constitutes one of the largest consumption of energy in cities and communities in Canada and worldwide. In 2015, energy consumption in residential facilities in Ontario is 52 TWh, which represents 36% of total energy consumption. Energy consumption in residential facilities include heating/cooling, electric loads, water heating, laundry, dishwashing, refrigerators and freezers, cooking, TV, lighting, and computer-related equipment, as shown in Figure 1.3. The highest energy use is in heating and cooling and ventilation, where it is clear the reduced use from 2013 to 2040. This can be justified by improved heating and cooling technologies and efficiencies. Electric loads and water heating are second largest energy use in the residential sector. Energy conservation strategies are widely adopted by utilities to reduce energy demand from utilities in residential facilities. Typically, utility grids supply energy to residential facilities. Energy conservation can represent around 1–3% of total energy demand in residential facilities. With the penetration of local distributed generation, energy can be supplied by

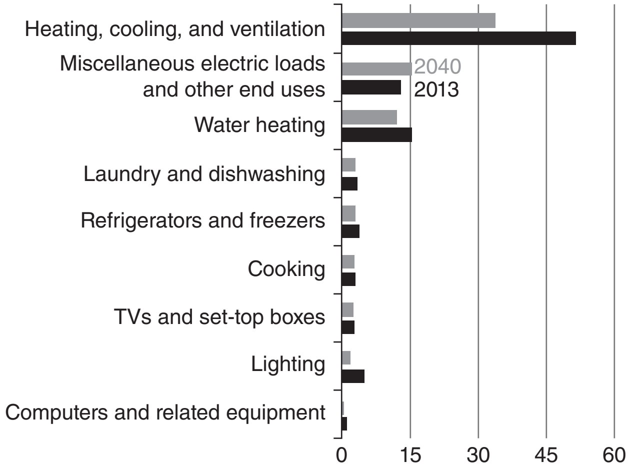


FIGURE 1.3 Residential sector delivered energy intensity for selected end uses in the Reference case, 2013 and 2040 (million Btu per household per year) [2].

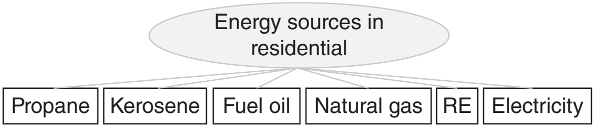
renewable energy technologies such as PV, energy storage, wind, gas generators, fuel cells, and geothermal systems.

There are a number of energy systems and technologies that are adopted in residential facilities, such as gas-fired water heaters, oil-fired water heaters, electric water heaters, heat pump water heaters, instantaneous water heaters, solar water heaters, gas-fired furnaces, oil-fired furnaces, gas-fired boilers, oil-fired boilers, room air conditioners, central air conditioners, air-source heat pumps, ground-source heat pumps, gas-source heat pumps, electric resistance furnaces, electric resistance unit heaters, cordwood stoves, wood pellet stoves, refrigerators-freezers, freezers, natural gas cooktops and stoves, clothes washers, clothes dryers, and dishwashers. Among the factors that are used to evaluate these energy systems are capacity, efficiency, energy factor (EF), combined energy factor (CEF), annual energy use, annual water use, average life, retail equipment costs, installation costs, and maintenance costs. These factors are used to evaluate the different energy systems in residential facilities to ensure most effective technology that can be applied in different regions and weather conditions.

Energy consumption in residential facilities can be viewed as in Figure 1.4, where it shows different types of energy sources, such as propane, kerosene, distillate fuel oil, natural gas, renewable energy, and electricity.

It is clear that electricity and natural gas represent the highest consumption from 2012 and projected till 2040. It is also noted that losses are quite high and energy conservation strategies will be essential for effective savings.

Energy prices for residential use are shown in Figure 1.5, which shows price of natural gas (NG) is the lowest, while electricity price is the highest.



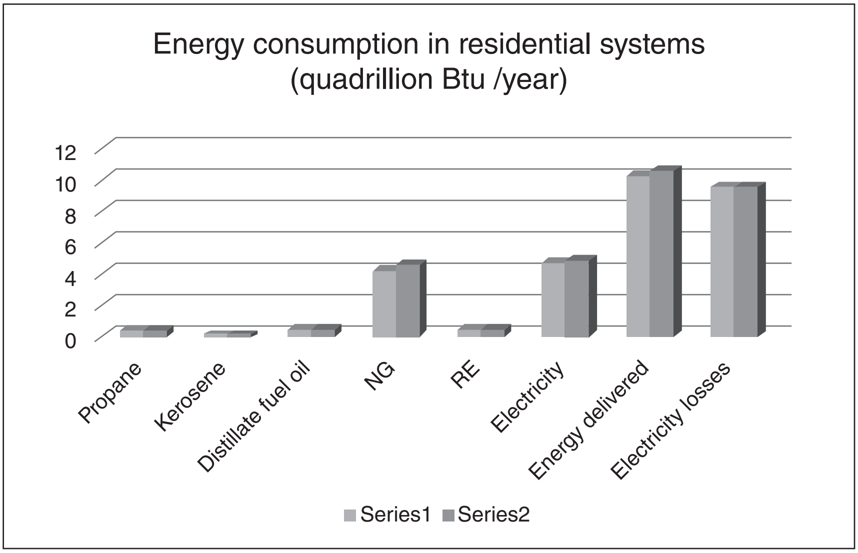


FIGURE 1.4 Energy consumption in residential systems, quadrillion Btu per year in the United States, 2012: gray, 2020: dark gray [2].

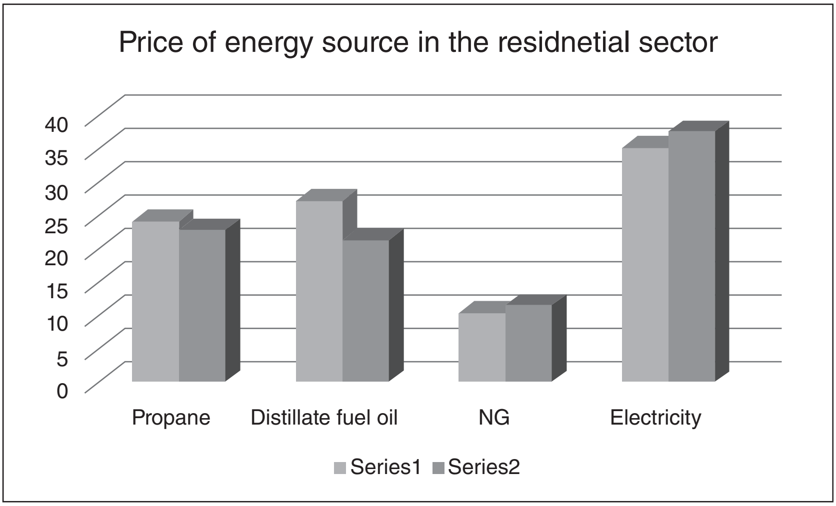


FIGURE 1.5 Energy prices in the residential sector, dollars per million Btu in the United States, 2012: gray, 2020: dark gray [2].

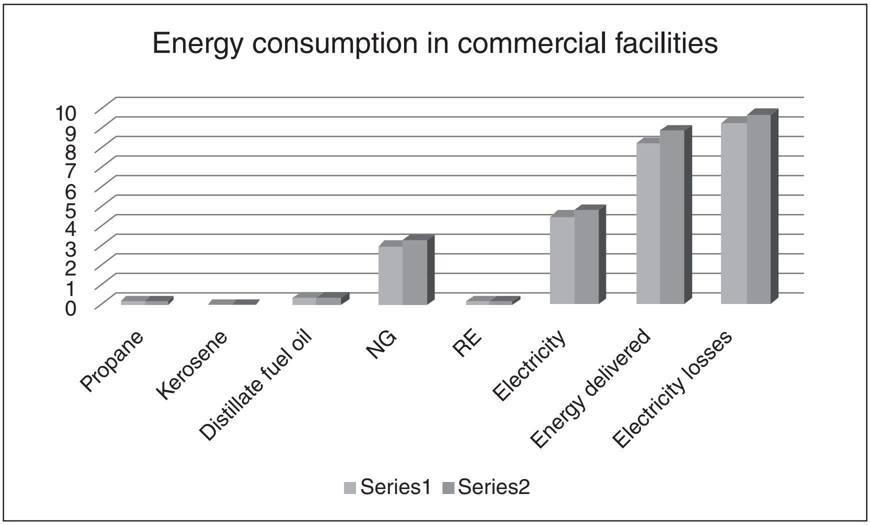


FIGURE 1.6 Energy consumption in commercial facilities in the United States, 2012: gray, 2020: dark gray [2].

1.3 ENERGY SYSTEMS IN COMMERCIAL FACILITIES

Energy consumption in commercial facilities, as stated by Department of Energy (DOE) [2], is shown in Figure 1.6. Electricity consumption is higher than NG use. While NG is cheaper than electricity, it is possible to provide better solution with increase in NG penetration in commercial use.

Also, energy prices in commercial facilities are shown in Figure 1.7.

It is shown that NG price for the residential sector is higher than NG price for the commercial sector.

1.4 ENERGY SYSTEMS IN INDUSTRIAL FACILITIES

In the industrial sector, Figure 1.8 shows the consumption from 2015 [2].

Also, energy prices in the industrial sector are shown in Figure 1.9, which shows the NG as the lowest clean energy source for the industrial sector.

1.5 ENERGY SYSTEMS IN TRANSPORTATION INFRASTRUCTURES

It is widely known that greenhouse gas (GHG) emission from transportation sector is high. The proper analysis of energy consumption in the transportation is important to address issues related to energy conservation with sustainability considerations, as shown in Figure 1.10.

Energy prices in the transportation sector are shown in Figure 1.11.

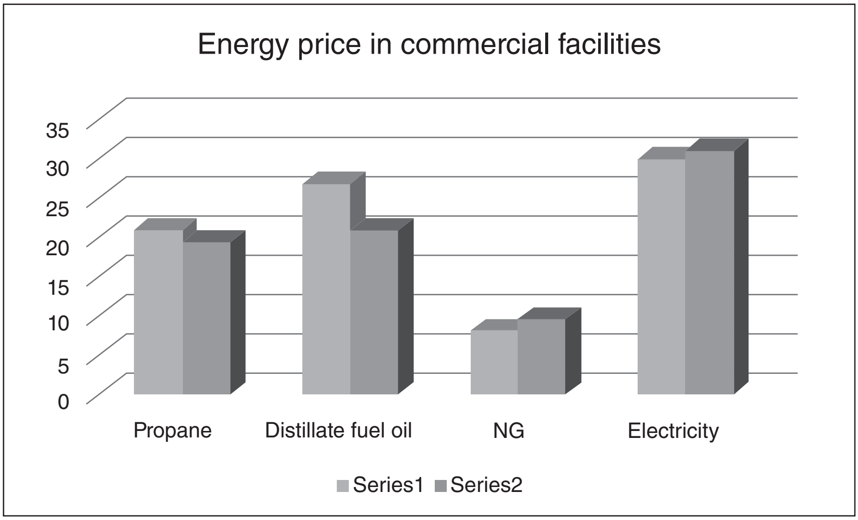
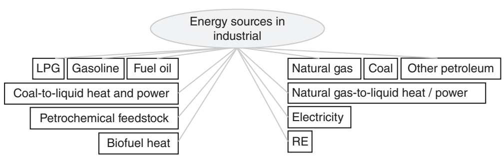


FIGURE 1.7 Energy prices in the commercial sector, dollars per million Btu in the United States, 2012: gray, 2020: dark gray [2].

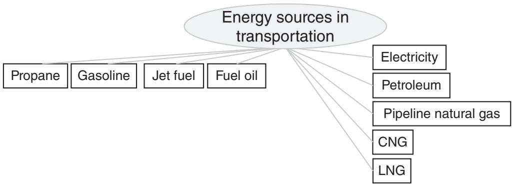


Sector and source	Reference case							Annual growth 2013–2040 (%)
	2012	2013	2020	2025	2030	2035	2040	
Industrial[4]								
Liquefied petroleum gases and other[5]	2.42	2.51	3.20	3.56	3.72	3.69	3.67	1.4%
Motor gasoline[2]	0.24	0.25	0.26	0.26	0.25	0.25	0.25	0.0%
Distillate fuel oil	1.28	1.31	1.42	1.38	1.36	1.34	1.35	0.1%
Residual fuel oil	0.07	0.06	0.10	0.14	0.13	0.13	0.13	2.9%
Petrochemical feedstocks	0.74	0.74	0.95	1.10	1.14	1.17	1.20	1.8%
Other petroleum[6]	3.33	3.52	3.67	3.80	3.83	3.89	3.99	0.5%
Petroleum and other liquids subtotal	8.08	8.40	9.61	10.24	10.44	10.47	10.59	0.9%
Netural gas	7.39	7.62	8.33	8.47	8.65	8.76	8.90	0.6%
Natural-gas-to-liquids heat and power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--
Lease and plant fuel[7]	1.43	1.52	1.87	1.98	2.10	2.18	2.29	1.5%
Natural gas subtotal	8.82	9.14	10.20	10.44	10.75	10.94	11.19	0.8%
Metallurgical coal	0.59	0.62	0.61	0.59	0.56	0.53	0.51	−0.7%
Other industrial coal	0.87	0.88	0.93	0.95	0.96	0.97	0.99	0.4%
Coal-to-liquids heat and power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--
Net coal coke imports	0.00	−0.02	0.00	−0.01	−0.03	−0.05	−0.06	4.5%
Coal subtotal	1.47	1.48	1.54	1.53	1.48	1.44	1.44	−0.1%
Biofuels heat and coproducts	0.73	0.72	0.80	0.80	0.80	0.81	0.86	0.6%
Renewable energy[8]	1.51	1.48	1.53	1.60	1.59	1.58	1.63	0.4%
Electricity	3.36	3.26	3.74	3.98	4.04	4.05	4.12	0.9%
Delivered energy	**23.97**	**24.48**	**27.42**	**28.58**	**29.10**	**29.29**	**29.82**	**0.7%**
Electricity related losses	6.87	6.72	7.51	7.88	7.88	7.83	7.85	0.6%
Total	**30.84**	**31.20**	**34.93**	**36.46**	**36.98**	**37.12**	**37.68**	**0.7%**

FIGURE 1.8 Energy consumption in the industrial sector [2].

Sector and source	Reference case							Annual growth 2013–2040 (%)
	2012	2013	2020	2025	2030	2035	2040	
Industrial[1]								
Propane	21.3	20.3	19.6	20.5	21.5	22.9	24.5	0.7%
Distillate fuel oil	27.4	27.3	21.2	23.5	26.1	29.2	32.7	0.7%
Residual fuel oil	20.6	20.0	13.3	15.1	17.2	19.7	23.5	0.6%
Natural gas[2]	3.8	4.6	6.2	6.9	6.8	7.5	8.8	2.5%
Metallurgical coal	7.3	5.5	5.8	6.2	6.7	6.9	7.2	1.0%
Other industrial coal	3.3	3.2	3.3	3.5	3.6	3.7	3.9	0.7%
Coal to liquids	--	--	--	--	--	--	--	--
Electricity	19.8	20.2	21.3	22.4	22.6	23.3	24.7	0.7%

FIGURE 1.9 Energy prices in the industrial sector, dollars per million Btu [2].



Sector and source	Reference case							Annual growth 2013–2040 (%)
	2012	2013	2020	2025	2030	2035	2040	
Transportation								
Propane	0.05	0.05	0.04	0.05	0.05	0.06	0.07	1.3%
Motor gasoline[2]	15.82	15.94	15.35	14.22	13.30	12.82	12.55	–0.9%
of which: E85[9]	0.01	0.02	0.03	0.12	0.20	0.24	0.28	10.0%
Jet fuel[10]	2.86	2.80	3.01	3.20	3.40	3.54	3.64	1.0%
Distillate fuel oil[11]	5.80	6.50	7.35	7.59	7.76	7.94	7.97	0.8%
Residual fuel oil	0.67	0.57	0.35	0.36	0.36	0.36	0.36	–1.6%
Other petroleum[12]	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.2%
Petroleum and other liquids subtotal	25.35	26.00	26.27	25.57	25.03	24.88	24.76	–0.2%
Pipeline fuel natural gas	0.75	0.88	0.85	0.90	0.94	0.94	0.96	0.3%
Compressed/liquefied natural gas	0.04	0.05	0.07	0.10	0.17	0.31	0.71	10.3%
Liquid hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--
Electricity	0.02	0.02	0.03	0.04	0.04	0.05	0.06	3.4%
Delivered energy	**26.16**	**26.96**	**27.22**	**26.60**	**26.18**	**26.19**	**26.49**	**–0.1%**
Electricity related losses	0.05	0.05	0.06	0.07	0.08	0.10	0.12	3.1%
Total	**26.20**	**27.01**	**27.29**	**26.67**	**26.27**	**26.29**	**26.61**	**–0.1%**

FIGURE 1.10 Energy consumption in the transportation sector [2].

Sector and source	Reference case							Annual growth 2013–2040 (%)
	2012	2013	2020	2025	2030	2035	2040	
Transportation								
Propane	25.3	24.6	24.0	24.7	25.5	26.5	27.6	0.4%
E85[3]	35.7	33.1	30.4	29.0	31.2	33.2	35.4	0.3%
Motor gasoline[4]	30.7	29.3	22.5	24.3	26.4	29.1	32.3	0.4%
Jet fuel[5]	23.0	21.8	16.1	18.3	21.3	24.5	28.3	1.0%
Diesel fuel (distillate fuel oil)[6]	28.8	28.2	23.1	25.5	28.0	31.1	34.7	0.8%
Residual fuel oil	20.0	19.3	11.7	13.3	15.4	17.6	20.3	0.2%
Natural gas[7]	20.4	17.6	17.8	16.8	15.7	17.1	19.6	0.4%
Electricity	27.8	28.5	30.2	32.3	32.9	33.9	36.0	0.9%

FIGURE 1.11 Energy prices in the transportation sector, dollars per million Btu [2].

1.6 ENERGY PRODUCTION AND SUPPLY INFRASTRUCTURES

Energy demand and the associated loads include power/electricity, thermal, fuel, water, and their links to the required work. Due to the variations in these loads, energy production and supply chains should provide adequate flexibility and adaptation to local and regional energy needs.

Energy production and supply chains are integrated with R&D chains to support development and implementation of advanced energy systems in different infrastructures, as shown in Figure 1.12.

Energy life cycle includes energy sources development and treatment, energy conversion, storage and transportation, and energy utilization. This includes all energy sources, fossil fuels, renewables, emerging energy technologies, hydrogen, bioenergy, and nuclear energy. The development of energy systems for different infrastructures might vary, based on resources availability, nature of infrastructures, weather, external and geopolitical factors, and the regional requirements. The proposed analysis requires accurate estimation of energy demand, consumption, and load profiles, which are the basis for proper energy system development.

The presented energy production and supply infrastructures show different sources and technologies ranging from hydrogen, biomass/biofuel, nuclear, thermal power, hydropower, wind, photovoltaic, geothermal, and other emerging energy technologies. All are mapped via energy infrastructures to supply energy to different loads such as residential, commercial, and industrial facilities, as well as transportation networks.

With the advancement in energy conversion and generation technologies, it is possible to cover energy needs with a combination of electricity, thermal, fuel, and even water. For example, to cover heating requirements, we can have CHP to provide heat, or electric heater, or heat pumps with water circulation. The selection of the type of energy technology and required amount of energy supply will vary,

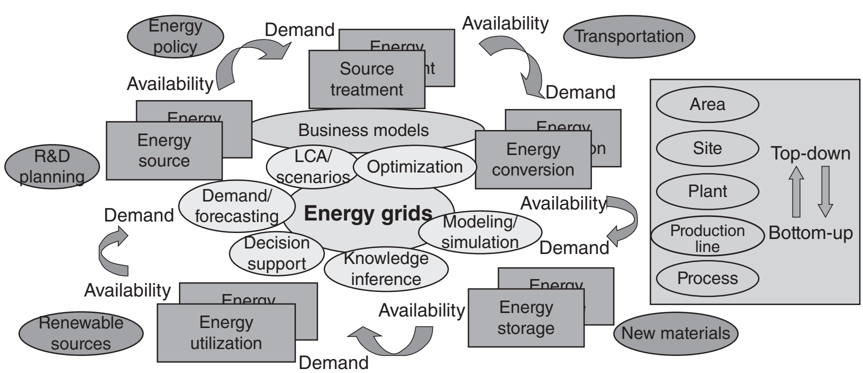


FIGURE 1.12 Life cycle engineering of energy in infrastructures.

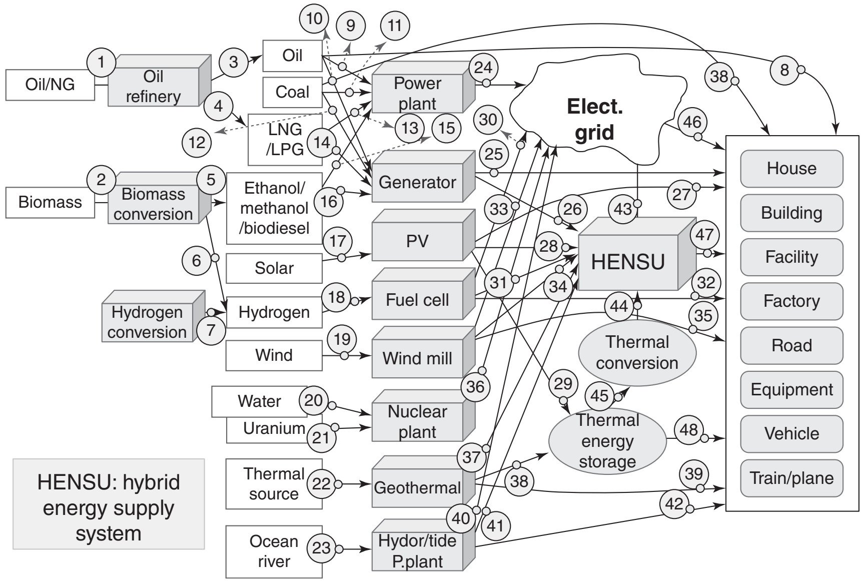


FIGURE 1.13 Energy production and supply infrastructures.

based on number of factors such as installation/operation costs, source/supply availability and costs, infrastructure requirements/limitations, and other corporate and regional requirements and regulations. Figure 1.13 shows possible energy infrastructures from different sources to variety of loads with different sizes and scales. It is possible to plan energy supply in infrastructures based on different scenarios such as electricity grids, natural gas grids, hydrogen grids, and/or mixture of these sources along with emerging energy technologies.

1.7 CONCLUSION

This chapter presented a summary of energy sources and their deployment in infrastructures, where energy is the backbone of improved infrastructure performance. This includes residential, commercial, industrial, and transportation and energy infrastructures. This chapter presented analysis and study of energy in infrastructures with all infrastructure classifications. The corresponding energy expenditures for each sector is viewed in Figure 1.14, which shows highest expenditures are in the transportation sector, followed by the residential sector. This introductory chapter explored energy in infrastructures and the corresponding classifications that will support energy conservation planning, operation, and control.

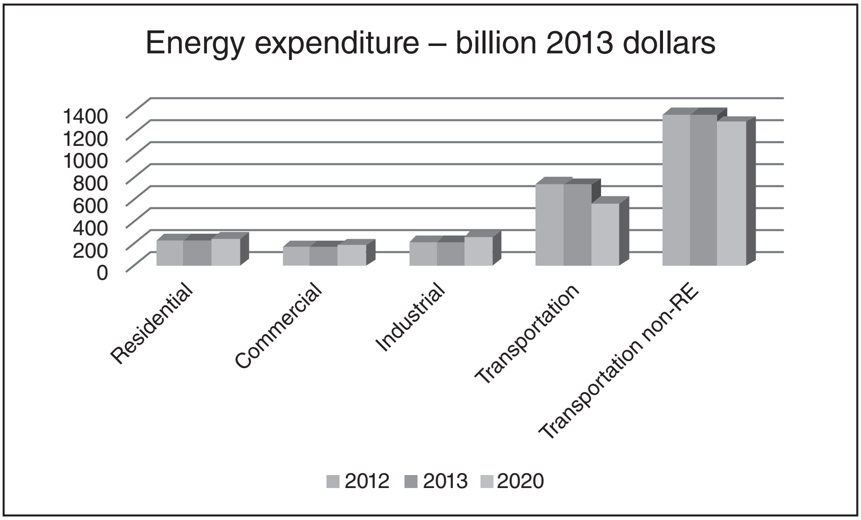


FIGURE 1.14 Price analysis of nonrenewable energy in different sectors.

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1. World Energy Outlook (2015) International Energy Agency.
2. Annual Energy Outlook (2015) DOE/EIA-0383(2015).