CHAPTER 1

ENERGY AND CIVILIZATION

1.1 INTRODUCTION: MOTIVATION

Energy technology plays a central role in societal, economic, and social development. Fossil fuel-based technologies have advanced our quality of life, but at the same time, these advancements have come at a very high price. Fossil fuel sources of energy are the primary cause of environmental pollution and degradation; they have irreversibly destroyed aspects of our environment. Global warming is a result of our fossil fuel consumption. For example, the fish in our lakes and rivers are contaminated with mercury, a byproduct of rapid industrialization. The processing and use of fossil fuels have escalated public health costs: Our health care dollars have been and are being spent on treating environmental pollution-related health problems, such as black lung disease in coal miners. Our relentless search for and need to control these valuable resources have promoted political strife. We are now dependent on an energy source that is unsustainable as our energy needs grow and we deplete our limited resources. As petroleum supplies dwindle, it will become increasingly urgent to find energy alternatives that are sustainable as well as safe for the environment and humanity.

Design of Smart Power Grid Renewable Energy Systems, Third Edition. Ali Keyhani.

Companion website: www.wiley.com/go/smartpowergrid3e

1.2 FOSSIL FUEL

Fossil fuels—oil, natural gas, and coal—formed in Earth around 300 million years ago. Over millions of years, the decomposition of flora and fauna remains that lived in the world's oceans produced the first oil. As the oceans receded, these remains were covered by layers of sand and earth and were subjected to severe climate changes: the Ice Age, volcanic eruption, and drought burying them even deeper in the Earth's crust and closer to the Earth's core. From the intense heat and pressure, the remains essentially were boiled into the oil. If you check the word, "petroleum" in a dictionary, you find it means "rock oil" or "oil from the earth."

The ancient Sumerians, Assyrians, Persians, and Babylonians found oil at the bank of the Karun and Euphrates rivers as it seeped above ground. Historically, humans have used oil for many purposes. The ancient Persians and Egyptians used liquid oil as a medicine for wounds. The Zoroastrians of Iran made their fire temples on top of percolating oil from the ground. Native Americans used oil to seal their canoes.

Up to the fifteenth century, history of humanity's energy use was limited. Regardless we can project the impact of energy on early civilizations from artifacts and monuments. The legacy of our oldest societies and their use of energy in the form of wood, wood charcoal, wind, and water power can be seen in the pyramids of Egypt, the Parthenon in Greece, the Persepolis in Iran, the Great Wall of China, and the Taj Mahal in India.

1.3 ENERGY USE AND INDUSTRIALIZATION

Figure 1.1 depicts the approximate time needed to develop various energy sources. Coal, oil, and natural gas fuels take millions of years to form. The oil that is consumed today was created more than a million years ago in the Earth's crust. Our first energy source was wood. Then wood charcoal and coal replaced wood, and oil began to replace some of our coal usages to the point that oil and gas now supply most of our energy needs.

Since the Industrial Revolution, we have used coal. Since 1800, for approximately 200 years, we have been using oil. However, our first energy source was wood and wood charcoal, which we used to cook food. Recorded history shows that humanity has been using wood energy for 10,000 years. In the near future we will exhaust oil and gas reserves. Oil and gas are not renewable: we must conserve energy and save our oil—and gas as well. Figure 1.2 depicts the world's oil production (consumption) from 1965 to 2000 and estimated from 2005 to 2009.

US oil production peaked around 1970. However, by using the fracking technology, oil production in the United States has rapidly increased (Section 1.14). Europe's oil production is limited except for the North Sea oil reserve; it depends entirely on oil production from other parts of

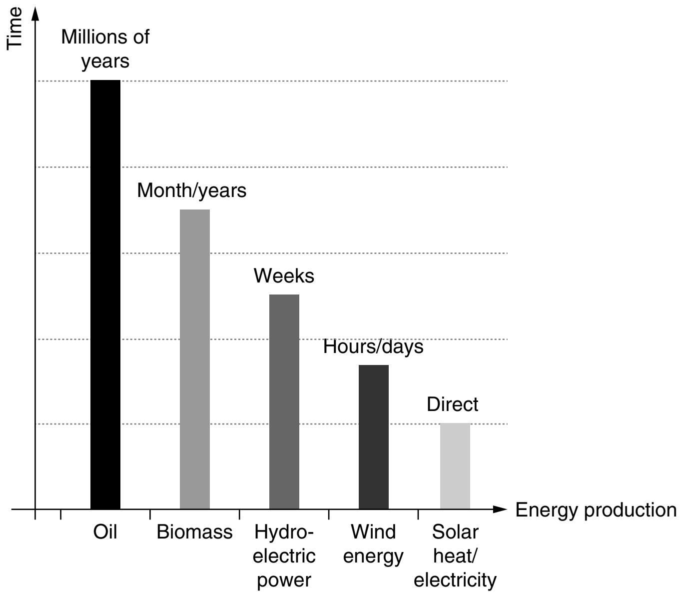

Figure 1.1 The approximate time required for the production of various energy sources.

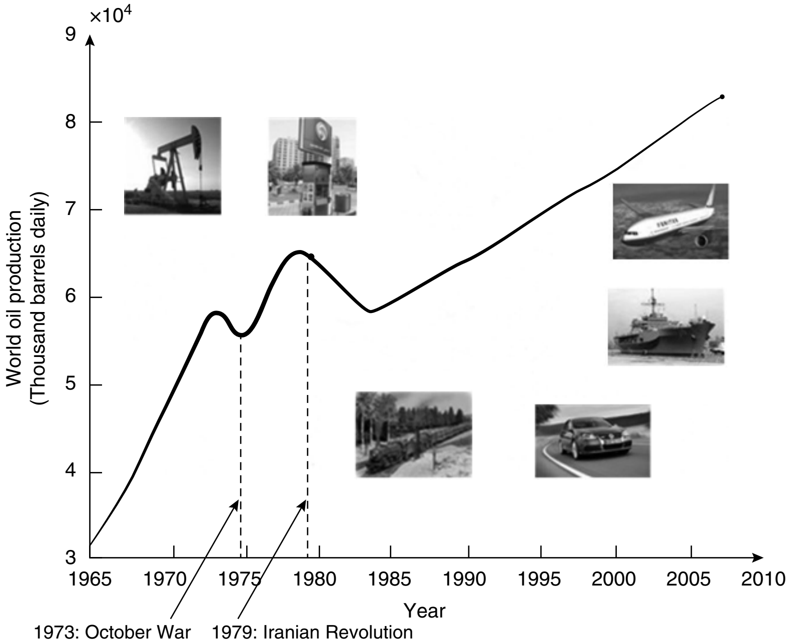

Figure 1.2 The world's oil production (consumption) from 1965 to 2000 and estimated from 2005 to 2009. Source: Based on Figure TS.2 from Solomon et al.

the world. In Asia, China, India, Japan, and Korea depend on imported oil. The rapid economic expansion of China, India, and Brazil are also rapidly depleting the world oil reserves. The Middle East has one of the largest oil reserves in the world. If the world reserves are used at the same rate as we do today, oil may run out in 40–100 years. Our natural gas reserves can be depleted in less than 60 years, and the coal reserves will be exhausted in 200 years. The impact of fossil fuel, coal, oil, and gas is manifested in climate change and the rise of temperature and sea level around the world. All can be said about the future is "Some things are so unexpected that no one is prepared for them." Predicting the future is a fool's game. However, we can empower every energy user to become an energy producer. We can develop a new energy economy based on renewable sources and create technology for conserving energy, reducing carbon footprints, and improving the quality of life on the planet. We can develop a distributed renewable energy system for every community and eliminate the long periods of blackout. We can make every energy user an energy producer by use of the solar and wind energy (https://en.wikipedia.org/wiki/Reserves-to-production_ratio).

Students are encouraged to study up-to-date information on the world energy consumption and production from the Wikipedia (https://en.wikipedia.org/wiki/Energy_development#Fossil_fuels).

1.4 NUCLEAR ENERGY

In 1789, Martin Heinrich Klaproth, a German chemist, discovered uranium while studying the mineral pitchblende. Eugène-Melchior Péligot, a French chemist, was the first person to isolate the metal, but it was Antoine-César Becquerel, a French physicist, who recognized its radioactive properties almost 100 years later. In 1934, Enrico Fermi used nuclear fuel to produce steam for the power industry. Then, he participated in building the first nuclear weapon used in World War II. The US Department of Energy estimates that worldwide uranium resources are generally considered to be sufficient for at least several decades.

The amount of energy contained in a mass of hydrocarbon fuel such as gasoline is substantially lower in much less mass of nuclear fuel. This higher density of nuclear fission makes it an essential source of energy; however, the fusion process causes additional radioactive waste products. The radioactive products remain for a long time, giving rise to a nuclear waste problem. The counterbalance to a low carbon footprint of fission as an energy source is the concern about radioactive nuclear waste accumulation and the potential for nuclear destruction in a politically unstable world.

1.5 GLOBAL WARMING

Greenhouse gases in the Earth's atmosphere emit and absorb radiation. This radiation is within the thermal infrared (IR) range. Since the burning of fossil fuel and the start of the Industrial Revolution, greenhouse gases have accumulated in atmosphere. The greenhouse gases are primarily water vapor, carbon dioxide, carbon monoxide, ozone, and some other gases. Within the atmosphere of Earth, greenhouse gases are trapped.

Figure 1.3 depicts the process of solar radiation incident energy and reflected energy from the Earth's surface and the Earth's atmosphere. The solar radiation incident energy as depicted by circle 1 emitted from the sun and its energy is approximated as 343 W/m^2. Some of the solar radiation, represented by circles 2 and 4, is reflected from the Earth's surface and the Earth's atmosphere. The total reflected solar radiation is approximated as 103 W/m^2. Approximately 240 W/m^2 of solar radiation, depicted by circle 3, penetrates through the Earth's atmosphere. About half of the solar radiation (circle 5), approximately 168 W/m^2, is absorbed by the Earth's surface. This radiation (circle 6) is converted into heat energy. This process generates IR radiation in the form of the emission of a long wave back to Earth. A portion of the IR radiation is absorbed. Then, it is re-emitted by the greenhouse molecules trapped in the Earth's atmosphere. Circle 7 represents the IR radiation. Finally, some of the IR radiation (circle 8) passes through the atmosphere and into space. As the use of fossil fuel is accelerated, the carbon dioxide in the Earth's atmosphere is also accelerated.

The World Meteorological Organization (WMO) is the international body for the monitoring of climate change. The WMO has clearly stated

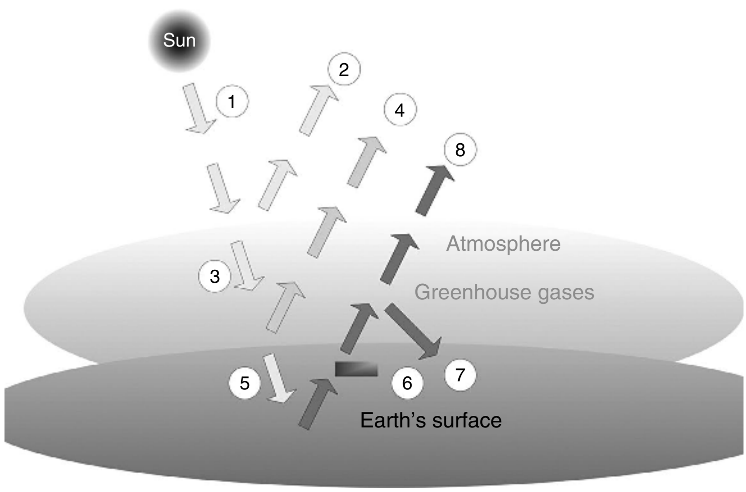

Figure 1.3 The effects of sun radiation on the surface of the Earth.

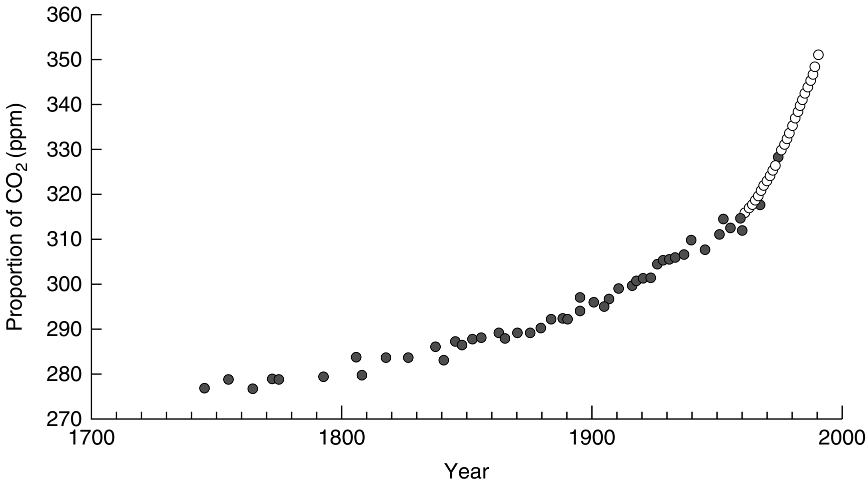

Figure 1.4 The production of CO_2 since 1700. Source: Based on Figure TS.2 from Solomon et al.

the potential environmental and socioeconomic consequences for the world economy if the current trend continues. In this respect, global warming is an engineering problem, not a moral crusade. Until we take serious steps to reduce our carbon footprints, pollution and the perilous deterioration of the environment continue.

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the WMO in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socioeconomic impacts. In the same year, the UN General Assembly endorsed the action by WMO and UNEP in jointly establishing the IPCC.

Figure 1.4 depicts the growth of carbon dioxide in our atmosphere in parts per million.

Figure 1.5 depicts the condition of CO_2 in the upper atmosphere. The *Y*-axis represents the magnitude of response. The *X*-axis is plotted to show the years into the future. The *Y*-axis, showing response efforts, does not have units. The CO_2 emission into the atmosphere has peaked during the last 100 years. If concentrated efforts are made to reduce the CO_2 emission and it is reduced over the next few hundred years to a lower level, the Earth's temperature will continue to rise.

Figure 1.6 depicts the stabilization of CO_2 over the subsequent centuries. The reduction of CO_2 reduces its impact on the Earth's atmosphere; nevertheless, the existing CO_2 in the atmosphere continues to raise the Earth's temperature by a few tenths of a degree. Figure 1.7 depicts temperature stabilization after reduction of CO_2 emission.

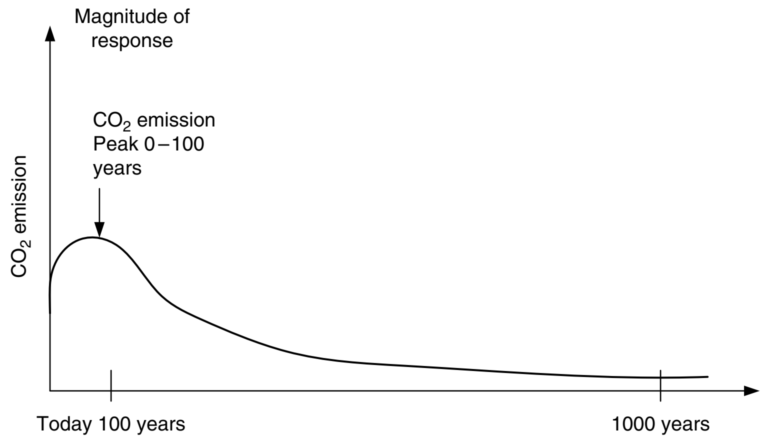

Figure 1.5 The effect of carbon dioxide concentration on temperature and sea level.

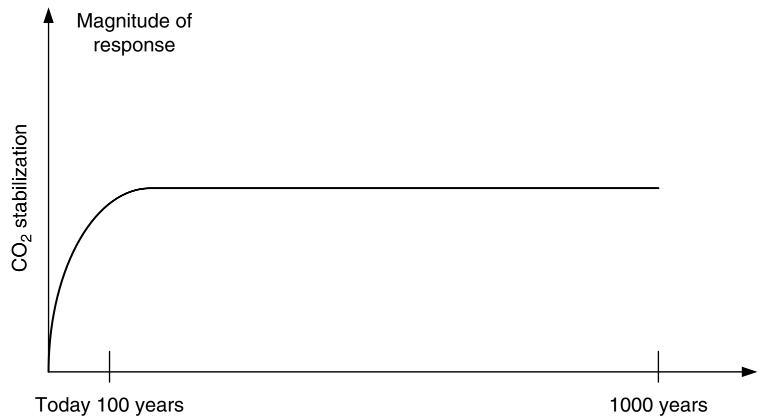

Figure 1.6 CO_2 stabilization has been achieved.

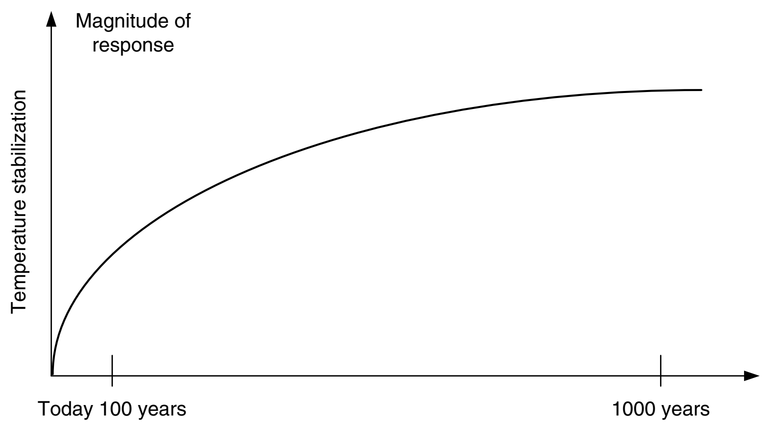

Figure 1.7 Temperature stabilization after reduction of CO_2 emission.

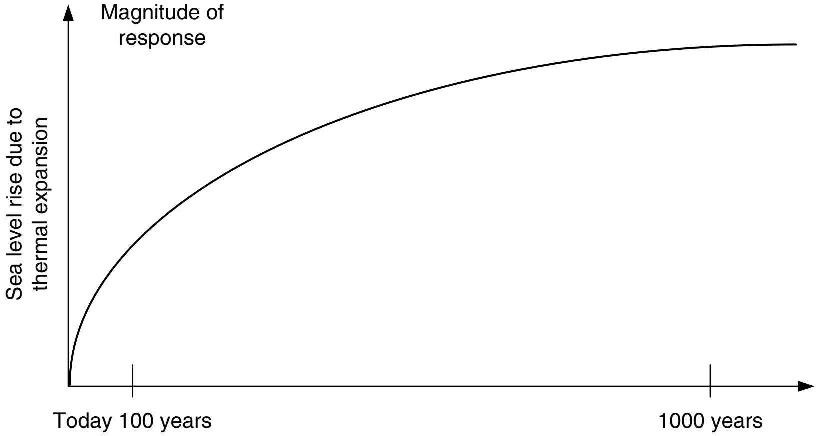

Figure 1.8 The sea level rise after the reduction of CO_2.

The rise in the temperature due to trapped CO_2 in the Earth's atmosphere impacts the thermal expansion of oceans. Figure 1.8 depicts the Earth's surface temperature stabilization over a few centuries.

As the ice sheets continue to melt due to rising temperatures over the next few centuries, the sea level also continues to rise. Figure 1.9 depicts the sea level rise after the reduction of CO_2 in the atmosphere. As a direct consequence of trapped CO_2 in the atmosphere, with its melting of the polar ice caps causing increased sea levels that bring coastal flooding, our pattern of life on Earth will be changed forever.

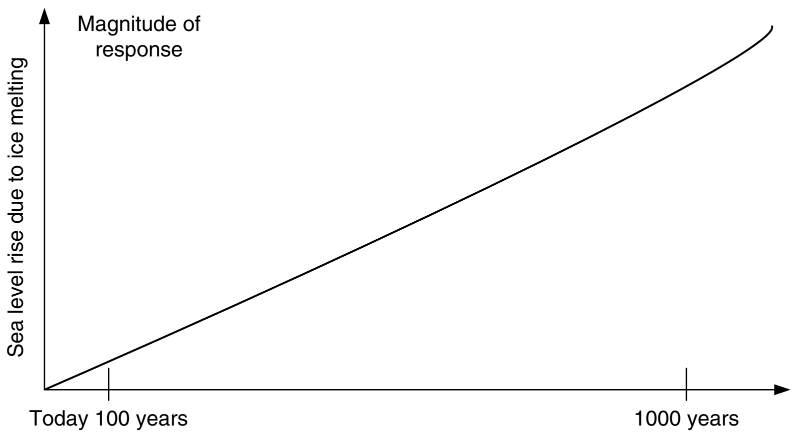

Figure 1.9 The sea level rise after the reduction of CO_2 in the atmosphere.

1.6 THE AGE OF THE ELECTRIC POWER GRID

Hans Christian Ørsted, a Danish physicist and chemist, discovered electromagnetism in 1820. Michael Faraday, an English chemist and physicist, worked for many years to convert electrical force into magnetic force. In 1831, Faraday's many years of effort were rewarded when he discovered electromagnetic induction; later, he invented the first dynamo and the first generator, a simple battery as a source of DC power simple battery. In 1801, an Italian physicist, Alessandro Giuseppe Antonio Anastasio Volta, invented the chemical battery. The second crucial technological development was the discovery of Faraday's law of induction. Faraday is credited with the invention of the induction phenomenon in 1831. However, recognition for the induction phenomenon is also accorded to Francesco Zantedeschi, an Italian priest and physicist in 1829, and around the 1830s to Joseph Henry, an American scientist.

Nikola Tesla was the main contributor to the technology on which electric power is based and its use of alternating current. He is also known for his pioneering work in the field of electromagnetism in the late nineteenth and early twentieth centuries. Tesla put world electrification in motion. By the 1920s, electric power production using fossil fuels to generate the electricity had started around the world. Since then, electric power has been used to power tools and vehicles; to provide heat for residential, commercial, and industrial systems; and to provide our energy needs in our everyday lives. Figure 1.10 shows the US production of electric power from 1920 to 1999. The International Energy Agency (IEA) forecasts an average annual growth rate of 2.5% for world electricity demand. At the rate around 2.5%, the world electricity demand will double by 2030. The IEA forecasts that the world carbon dioxide emissions due to power generation will increase by 75% by 2030. In 2009, the world population was approximately 6.8 billion. The United Nations forecasts population growth to 8.2 billion by 2030. Without interventions to contain population growth, another 1.5 billion people will need electric power equivalent to five times the current US rate of electrical power consumption. Figure 1.10 also projects that we can slow the growth of electric power production from fossil fuels by replacing them with renewable sources and integrating the green energy sources in electric power grids. As more countries such as China, India, Brazil, Indonesia, and others modernize their economy, the rate of CO_2 production accelerates.

Figure 1.11 shows the mean smooth recorded temperature by the UNEP. We can only hope that we can stop the trend of global warming as presented in Figure 1.11.

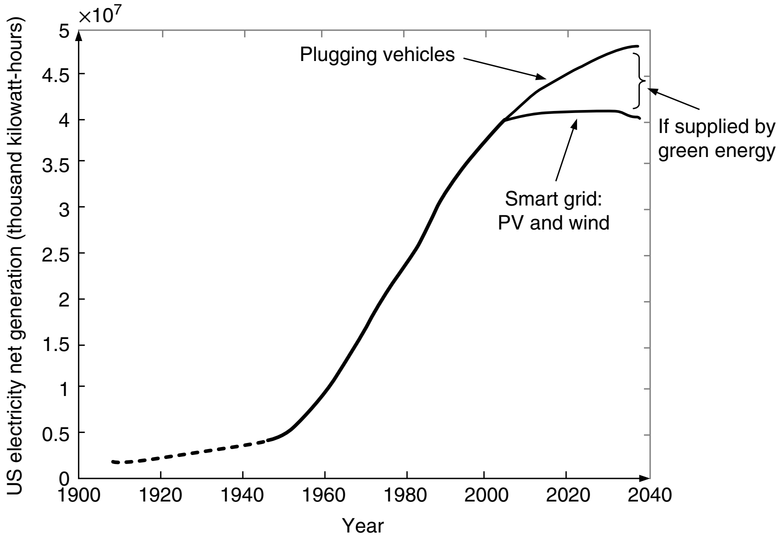

Figure 1.10 The US production of electric power from 1920 to 1999.

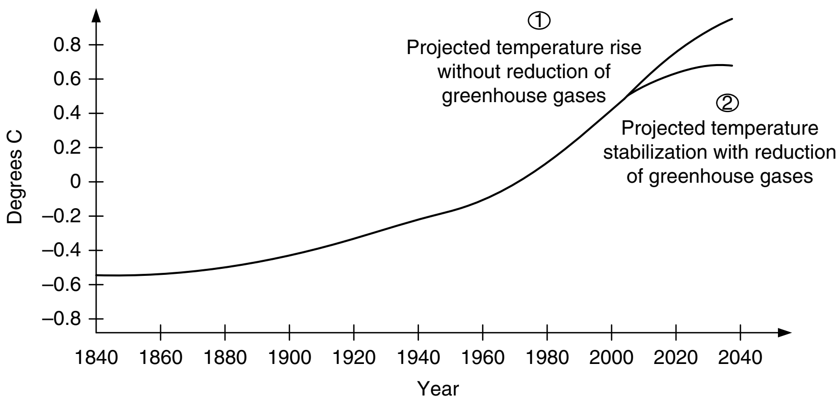

Figure 1.11 The smooth average of published records of surface temperature from 1840 to 2000.

1.7 GREEN AND RENEWABLE ENERGY SOURCES

To meet carbon reduction targets, it is important we begin to use sources of energy that are renewable and sustainable. The need for environmentally friendly methods of transportation and stationary power is urgent. We need to replace traditional fossil-fuel-based vehicles with electric cars and the stationary power from traditional fuels, coal, gas, and oil with green sources for sustainable energy fuel for the future.

1.8 HYDROGEN

Besides renewable sources, such as wind and the sun, hydrogen (H) is an important source of clean, renewable energy. It is abundantly available in the universe. It is found in small quantities in the air. It is nontoxic, colorless, and odorless.

Hydrogen can be used as an energy carrier, stored, and delivered to where it is needed. When hydrogen is used as a source of energy, it gives off only water and heat with no carbon emissions. Hydrogen has three times as much energy for the same quantity of oil. A hydrogen fuel cell is fundamentally different from a hydrogen combustion engine. In a hydrogen fuel cell, hydrogen atoms are divided into protons and electrons. The negatively charged electrons from hydrogen atoms create an electrical current with water as a by-product (H_2O). Hydrogen fuel cells are used to generate electric energy at stationary electric power generating stations for residential, commercial, and industrial loads. The fuel cell can also be used to provide electrical energy for an automotive system, that is, a hydrogen combustion engine. Hydrogen-based energy has the potential to become a significant energy source in the future, but many related technical problems must be solved for the construction of a new infrastructure for future energy systems.

1.9 SOLAR AND PHOTOVOLTAIC

Solar and photovoltaic (PV) energy are also important renewable energy sources. The sun, the Earth's primary source of energy, emits electromagnetic waves. It has invisible IR (heat) waves, as well as light waves. IR radiation has a wavelength between 0.7 and 300 micrometers (μm) or a frequency range between approximately 1 THz (terahertz; 10 to the power of 12) and 430 THz. Sunlight is defined by irradiance, meaning radiant energy of light. The solar irradiance at 1 peak sun-hour is equal to 1 kWh/m^2. We represent one sun as the brightness to provide an irradiance of about 1 kilowatt-hour (kWh) per square meter (m^2) at sea level and 0.8 suns about 800 Wh/m^2. One sun's energy has 523 watts of IR light, 445 watts of visible light, and 32 watts of ultraviolet (UV) light.

Example 1.1 Compute the area in meter per square and square feet needed to generate 5000 kWh of power. Assume the sun irradiance is equivalent to 0.8 sun of energy.

Solution

Power capacity of PV at 0.8 sun = 0.8 kWh/m^2

Capacity in kWh = (sun irradiance in kWh/m^2) × (required area in m^2)

Required area in m^2 = 5000 kWh/0.8 kWh/m^2 = 6250 m^2

1 m^2 = 10.764 ft^2

Required area in ft^2 = (6250) · (10.764) = 67,275 ft^2

Plants, algae, and some species of bacteria capture light energy from the sun, and through the process of photosynthesis, they make food (sugar) from carbon dioxide and water. As the thermal IR radiation from the sun reaches the Earth, some of the heat is absorbed by the Earth's surface, and some heat is reflected into space (see Figure 1.4). Highly reflective mirrors can be used to direct thermal radiation from the sun to provide a source of heat energy. The heat energy from the sun—solar thermal energy—can be used to heat water to a high temperature and pressurized conventionally to run a turbine generator.

Solar PV sources are arrays of cells of silicon materials that convert solar radiation into direct current electricity. The cost of a crystalline silicon wafer is very high, but new light-absorbent materials have significantly reduced the cost. The most common elements are amorphous silicon (a-Si), mainly O for p-type Si and C, and the transition metals, mainly Fe. These materials are silicon put into different forms or polycrystalline materials, such as cadmium telluride (CdTe) and copper indium (gallium) (CIS and CIGS). The front of the PV module is designed to allow maximum light energy to be captured by the Si materials. Each cell generates approximately 0.5 V. Normally, 36 cells are connected in series to provide a PV module producing 12 V.

Example 1.2 Compute the area in meter per square and square feet needed to generate 1000 kW of power. Assume the sun irradiant is equivalent to 0.4 sun of energy.

Solution

Power capacity of PV at 0.4 sun = 0.4 kWh/m^2

Required area in m^2 = 1000/0.4 = 2500 m^2

1 m^2 = 10.764 ft^2

Required area in ft^2 = $(2500) \cdot (10.764) = 26{,}910$ ft^2

1.9.1 Wind Power

Wind is developed by uneven heating of water and land, which causes the flow of air. Therefore, wind is air in motion. As the sun rises, the air over the land heats up faster than the air over water. The heated air above the land swells and rises, and the denser, colder air flows rapidly to take the place of heated air and in the process generating wind. However, during the night, the process reverses. A wind turbine has blades and captures the wind's kinetic energy. The blades are connected to a drive shaft that turns an electric generator to produce electricity.

Students are encouraged to obtain up-to-date information on the wind energy production and cost from https://www.eia.gov and http://energy.gov/eere/wind/about-doe-wind-program and NREL (https://www.nrel.gov). NREL is an excellent source for the updated commercialization of renewable energy sources.

1.9.2 Geothermal

Renewable geothermal energy refers to the heat produced deep under the Earth's surface. It is found in hot springs and geysers that come to the Earth's surface or in reservoirs deep beneath the ground. The Earth's core is made of iron surrounded by a layer of molten rocks or magma. Geothermal power plants are built on geothermal reservoirs, and the energy is primarily used to heat homes and commercial industry in the area.

1.10 BIOMASS

Biomass is a type of fuel that comes from organic matter like agricultural and forestry residue, municipal solid waste, or industrial waste. The organic matter used may be trees, animal fat, vegetable oil, rotting waste, and sewage. Biofuels, such as biodiesel fuels, are currently mixed with gasoline for fueling cars or are used to produce heat or as fuel (wood and straw) in power stations to produce electric power. Rotting waste and sewage generate methane gas, which is also a biomass energy source. However, some controversial issues surrounded the use of biofuel. Producing biofuel can involve cutting down forests, transforming the organic matter into energy can be expensive with higher carbon footprints, and agricultural products may be redirected instead of being used for food.

1.11 ETHANOL

Another source of energy is ethanol, which is produced from corn and sugar as well as other means. However, the analysis of the carbon cycle and the use of fossil fuels in the production of "agricultural" energy leaves many open questions: per year and unit area solar panels produce 100 times more electricity than corn ethanol.

As we conclude this section, we need always to remember the Royal Society of London's 1662 motto: "Nullius in verba" (Take Nobody's Word).

1.12 ENERGY UNITS AND CONVERSIONS

To estimate the carbon footprint of different classes of fossil fuels, we need to understand the energy conversion units. Because fossil fuels are supplied from different sources, we need to convert to equivalent energy measuring units to evaluate the use of all sources. The energy content of different fuels is measured by the heat that can be generated. One British thermal unit (Btu or BTU) requires 252 calories; it is equivalent to 1055 joules. The joule (J) is named after James Prescott Joule (born December 24, 1818), an English physicist and brewer who discovered the relationship between heat and mechanical work, which led to the fundamental theory of the conservation of energy.

TABLE 1.1 Carbon Footprint of Various Fossil Fuels for Production of 1 kWh of Electric Energy

Fuel Type	CO_2 Footprint (lb/kWh)
Wood	3.306
Coal-fired plant	2.117
Gas-fired plant	1.915
Oil-fired plant	1.314
Combined-cycle gas	0.992

TABLE 1.2 Carbon Footprint of Green and Renewable Sources for Production of 1 kWh of Electric Energy

Fuel Type	CO_2 Footprint (lb/kWh)
Hydroelectric	0.0088
PV	0.2204
Wind	0.03306

The Btu or BTU is a traditional unit of heat. One BTU of heat raises one pound of water one degree Fahrenheit (°F). Heat is also now known to be equivalent to energy. In the International System of Units (SI), energy is measured in joule; one BTU is about 1055 joules. For measurement of a large amount of energy, the term "quad" is used. A quad is a unit of energy equal to 10^{15} BTU or 1.055×10^{18} joules.

From your first course in physics, you may recall that one joule in the metric system is equal to the force of one newton (N) acting through one meter (m). Thus one joule is equal to one newton (N) times one meter (m) ($1\ J = 1\ N \times 1\ m$)—one watt equal to one joule per second.

Therefore, one joule is the amount of work required to produce one watt of power for one second. In the BTU's per hour unit, 3.41 Btu/h is equal to 1 W, and 1 BTU/h is equal to 0.2930 W (Tables 1.1 and 1.2).

Example 1.3 Compute the amount of energy in Wh needed to bring 100 lb of water from 0 to 212 °F.

Solution

Heat required = (100 lb) 212 °F = 21,200 BTU

Energy in Wh = (1055) · (21,200)/3600 = 6212.77 Wh

For direct current (DC) electricity

$$P = V \cdot I$$

where I represents the current through the load and V is the voltage across the load and unit of power, P, is in watts if the current is in amperes (A) and voltage in volts. Therefore, one kilowatt is a thousand watts. The energy consumption is expressed in kilowatt-hour (kWh). One kWh is the energy consumed by a load for one hour. kWh can also be expressed in joules, and one kilowatt-hour (kWh) is equal to 3.6 million joules. Recall from your introduction to chemistry course that one calorie (cal) is equal to 4.184 J. Therefore, it follows that thousand BTU is equal to 0.239 kWh—one MWh to 3.41 million BTU. Because power system generators are running on natural gas, oil, or coal, we express the energy from these types of fuel in kilowatts per hour. For example, one thousand cubic feet of gas (Mcf) can produce 301 kWh, and one hundred thousand BTU can produce 29.3 kWh of energy.

Example 1.4 Compute the amount of heat in BTU needed to generate 10 kWh.

Solution

One watt = one joule/second (j/s)

1000 W = 1000 j/s

1 kWh = 1 × 60 × 60 × 1000 = 3600 kj/s

10 kWh = 36,000 kj/s

One BTU = 1055.058 j/s

Heat in BTU needed for 10 kWh = 36,000,000/1055.058 = 34,121.3 BTU

The energy content of coal is measured in BTU produced. For example, a ton of coal can generate 25 million BTU: equivalently, it can generate 7325 kWh. Furthermore, one barrel of oil (i.e. 42 gallons) can produce 1700 kWh. Other units of interest are a barrel of liquid natural gas having 1030 BTU and one cubic foot of natural gas having 1030 BTU.

Example 1.5 Compute how many kWh is produced from 10 tons of coal.

Solution

One ton of coal = 25,000,000 BTU

10 ton of coal = 250,000,000 BTU

1 kWh = 3413 BTU

Energy used in kWh = (250,000,000)/3413 = 73,249.3 kWh

Example 1.6 Compute the CO_2 footprint of a residential home using 100 kWh of coal for one day.

Solution

One kWh of electric energy using a coal-fired plant produces 2.117 lb of CO_2 (https://www.eia.gov/tools).

Residential home carbon footprint for 100 kWh = (100) · (2.117) = 211.7 lb of CO_2

The carbon footprint can also be estimated by carbon (C) rather than CO_2. The molecular weight of C is 12 and CO_2 is 44. (Add the molecular weight of C, 12, to the molecular weight of O_2, 16 times 2 = 32, to get 44, the molecular weight of CO_2.) The emissions expressed in units of C are converted to emissions in CO_2. The ratio of CO_2/C is equal to 44/12 = 3.67. Thus, CO_2 = 3.67 C. Conversely, C = 0.2724 CO_2.

Example 1.7 Compute the CO_2 (carbon footprint) of a residential home using 100 kWh using coal per day.

Solution

One kWh of electric energy using a coal-fired plant has 2.117 lb of CO_2.

Residential home carbon footprint for 100 kWh = (100) · (2.117) = 211.7 lb.

The carbon footprints of coal are the highest among fossil fuels. Therefore, coal-fired plants produce the highest output rate of CO_2 per kWh. The use of fossil fuels also adds other gases to the atmosphere per unit of heat energy as shown in Table 1.3.

We can also estimate the carbon footprints for various electrical appliances corresponding to the method used to produce electrical energy. For example, one hour's use of a color television produces 0.64 pounds (lb) of CO_2 if coal is used to generate the electric power. For coal, this coefficient is approximated to be 2.3 lb CO_2/kWh of electricity.

Example 1.8 A light bulb is rated 60 W. If the light bulb is on for 24 hours, how much electric energy is consumed?

Solution

The energy consumed is given as

Energy consumed = (60 W) × (24 h)/(1000) = 1.44 kWh

TABLE 1.3 Fossil Fuel Emission Levels in Pounds per Billion Btu of Energy Input

Pollutant	Natural Gas	Oil	Coal
Carbon dioxide	117,000	164,000	208,000
Carbon monoxide	40	33	208
Nitrogen oxides	92	448	457
Sulfur dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Source: Based on data from the US Energy Information Administration (EIA) (April 1999). *Natural Gas 1998: Issues and Trends*. http://webapp1.dlib.indiana.edu/virtual_disk_library/index.cgi/4265704/FID1578/pdf/gas/056098.pdf.

Example 1.9 Estimate the CO_2 footprint of a 60 W bulb on for 24 hours.

Solution

Carbon footprint = (1.44 kWh) × (2.3 lb CO_2/kWh) = 3.3 lb CO_2

Large coal-fired power plants are highly economical if their carbon footprints and damage to the environment are overlooked. In general, a unit cost of electricity is an inverse function of the unit size. For example, for a 100 kW unit, the unit cost is $0.15/kWh for a natural gas turbine and $0.30/kWh for PV energy. Therefore, if environmental degradation is ignored, the electric energy produced from fossil fuel is cheaper based on the present price of fossil fuel. For a large coal-fired power plant, the unit of electrical energy is in the range of $0.04–$0.08/kWh. (Up-to-date information can be obtained from websites of NREL [https://www.nrel.gov] and EIA [http://www.eia.doe.gov].)

Green energy technology needs supporting governmental policies to promote electricity generation from green energy sources. Economic development in line with green energy policies is required for reducing the ecologic footprint of a developing world.

> Ancient air bubbles trapped in ice enable us to step back in time and see what Earth's atmosphere, and climate, were like in the distant past. They tell us that levels of carbon dioxide (CO_2) in the atmosphere are higher than they have been at any time in the past 400,000 years. During ice ages, CO_2 levels were around 200 parts per million (ppm), and during the warmer interglacial periods, they hovered around 280 ppm (see fluctuations in the graph). In 2013, CO_2 levels surpassed 400 ppm for the first time in recorded history. This recent rise in CO_2 shows a remarkably constant relationship with fossil-fuel burning based on the simple premise that about 60 percent of fossil-fuel emissions stay in the air. (https://climate.nasa.gov/climate_resources/24/graphic-the-relentless-rise-of-carbon-dioxide)

After thousands of years of burning wood and wood charcoal, the CO_2 concentration was at 288 parts per million by volume (ppmv) in 1850 just at the dawn of the Industrial Revolution. By the year 2000, CO_2 had risen to 369.5 ppmv, an increase of 37.6% over 250 years.

The exponential growth of CO_2 is closely related to the production of electric energy (see Figures 1.3 and 1.5).

1.13 ESTIMATING THE COST OF ENERGY

As we discussed, the cost of electric energy is measured by the power used over time. The power demand of any electrical appliance is inscribed on the appliance and included in its documentation or its nameplate. However, the power consumption of an appliance is also a function of the applied voltage and operating frequency. Therefore, the manufacturers provide on the nameplate of an appliance, the voltage rating, the power rating, and the frequency. For a light bulb, which is purely resistive, the voltage rating and power rating are marked on the light bulb. A light bulb rated at 50 W and 120 V means that if we apply 120 volts to the light bulb, 50 watts of energy is consumed.

Again, energy consumption is expressed as

$$P = V \cdot I \tag{1.1}$$

where the unit of power consumption, that is, P, is in watts. The unit of V is in volts and unit I is in amperes.

The rate of energy consumption can be written as

$$P = \frac{\mathrm{d}W}{\mathrm{d}t} \tag{1.2}$$

We can then write the energy consumed by loads (i.e. electrical appliances) as

$$W = P \cdot t \tag{1.3}$$

In the above the unit of W is in joules or watt-seconds. However, because the unit cost of electrical energy is expressed in dollars per kilowatts, we express the electric power consumption in kilowatt-hour:

$$\mathrm{kWh} = \mathrm{kW} \times \mathrm{hour} \tag{1.4}$$

If we let λ represent the cost of electric energy in \$/kWh,then the total cost is expressed as

$$\text{Energy cost (in dollars)} = \mathrm{kWh} \times \lambda \tag{1.5}$$

Example 1.10 Assume that you want to buy a computer. The brand A power consumption is rated as 400 W and 120 V and costs \$1000; brand B power consumption is rated at 100 W and 120 V and costs \$1010. Your electric company charges \$0.09/kWh on your monthly bill. Compute the cost of buying the computer and the operating expense if you use your computer for 3 years at a rate of 8 hours a day.

Solution

At 8 hours a day for 3 years, the total operating time is given as $8 \times 365 \times 3$ = 8760 hours.

$$\begin{aligned}\text{Brand A kWh energy consumption} &= \text{operating time} \times \text{kW of brand A}\\ &= 8760 \times 400 \times 10^{-3} = 3504\ \mathrm{kWh}\end{aligned}$$

TABLE 1.4 Fossil Fuel Emission Levels in Pounds per Billion BTU of Energy Input

Pollutant	Natural Gas	Oil	Coal
Carbon dioxide (CO_2)	117,000	164,000	208,000

$$\text{Brand B kWh energy consumption} = \text{operating time} \times \text{kW of brand B}$$
$$= 8760 \times 100 \times 10^{-3} = 876\,\text{kWh}$$

$$\text{Total cost for brand A} = \text{brand A kWh energy consumption} + \text{cost of brand A}$$
$$= 3504 \times 0.09 + 1000 = \$1315.36$$

$$\text{Total cost for brand B} = \text{brand B kWh energy consumption} + \text{cost of brand B}$$
$$= 876 \times 0.09 + 1010 = \$1088.84$$

Therefore, the total cost of operation and the price of brand B are much lower than brand A because the wattage of brand B is much less. Even though the price of brand A is lower, it is economical to buy brand B, because its operating cost is far lower than that of brand A.

The carbon footprints of coal are highest among fossil fuels. Therefore, coal-fired plants produce the highest output rate of CO_2 per kWh. The use of fossil fuels also adds other gases to the atmosphere per unit of heat energy as shown in Table 1.4.

Example 1.11 For Example 1.7, let us assume that the electric energy is produced using coal, what is the amount of CO_2 in pounds that is emitted over 3 years into the environment?

What is your carbon footprint?

Solution

From Table 1.4, the pounds of CO_2 emission per billion BTU of energy input for coal is 208,000

One kWh = 3.41 thousand BTU.

Energy consumed for brand A over 3 years = $3504 \times 3.41 \times 10^3$ = 11,948,640 BTU

Therefore, for brand A, pounds of CO_2 emitted $= \dfrac{11{,}948{,}640 \times 208{,}000}{10^9} = 2485.32$ lb

Energy consumed for brand B over 3 years = $876 \times 3.41 \times 10^3$ = 2,987,160 BTU

Thus, for brand B, pounds of CO_2 emitted $= \dfrac{2{,}987{,}160 \times 208{,}000}{10^9} = 621.33$ lb

Brand B has a much lower carbon footprint.

Example 1.12 Assume that you have purchased a new high-powered computer with a gaming card and an old cathode ray tube (CRT) monitor. Assume that the power consumption is 500 W and the fuel used to generate electricity is oil. Compute the following:

(i) Carbon footprints if you leave them on 24/7.
(ii) Carbon footprint if it is turned on 8 hours a day.

Solution

(i) Hours in one year = 24 × 365 = 8760 hours

$$\text{Energy consumed in one year} = 8760 \times 500 \times 10^{-3} = 4380\,\text{kWh}$$
$$= 4380 \times 3.41 \times 10^{3} = 14,935,800\,\text{BTU}$$

From Table 1.4, pounds of CO_2 emission per billion per the BTU of energy input for oil is 164,000.

Therefore, the carbon footprint for one year $= \dfrac{14,935,800 \times 164,000}{10^9}$
$= 2449.47$ lb

(ii) Carbon footprint in the case of 8 hours/day use $= \dfrac{8}{24} \times$ footprint for use in 24 hours
$$= \frac{1}{3} \times 2449.47$$
$$= 816.49\ \text{lb}$$

1.14 NEW OIL BOOM–HYDRAULIC FRACTURING (FRACKING)

The new technology in oil and gas extraction from wells deep in the Earth's rock crust is known as hydraulic fracturing. The fracturing of the rocky crust of the Earth is accomplished by directing the pressurized mixture of water with sand and chemicals into the crust of Earth below the water lines. This technique of oil and gas extraction is known as fracking. Fracking is the method used in wells for shale gas, tight gas, tight oil, and coal seam gas and hard rock wells. It has raised environmental concerns. Water contamination, air quality, and migration of chemical to the ground surface have become a major concern of environmental groups. Fracking has reversed the decline of oil and gas production in the United States and has made the United States self-sufficient in oil and gas. Fracking methods have become a highly charged political issue. The price of the oil extracted from fracking is estimated to be around $60 per barrel (https://www.investopedia.com/articles/investing/

072215/can-fracking-survive-60-barrel.asp). Historically, the crude oil has reached an all-time high of \$145.31 per barrel in July of 2008 and a record low of \$1.17 per barrel in February of 1946 (https://tradingeconomics.com › Commodity).

1.15 ESTIMATION OF FUTURE CO_2

The rapidly growing electrification of the developing world and their reliance on fossil fuel vehicles increased, and the demand for energy has turned developed nations to mass production of fossil fuels for power and energy. The subsequent burning of these resources has increased the amount of carbon dioxide in the Earth's atmosphere. Using the measured proportion of CO_2 in the atmosphere over the last few centuries, we can estimate the carbon dioxide concentration in future years if energy production trends are unaltered. By fitting an exponential best-fit line to the recorded data using Microsoft Excel, we can estimate the best fit as presented in Equation (1.6). With the accelerated increase in electric transportation and electric generation since the 1900s, the burning of fossil fuels has caused a rising exponential trend in the carbon dioxide concentration:

$$\text{Concentration} = 1.853^{*}e^{(0.0146^{*}x)} + 277 \tag{1.6}$$

Here, x is the number of years since 1745 and "concentration" is the proportion of carbon dioxide in parts per million. The above equation was plotted against the available data in Figure 1.12 and projected out to the year 2100 to estimate the CO_2 concentration for the year 2100 in future. The estimated carbon dioxide proportion in the year 2100, if current trends continue, is about 610 parts per million, which is nearly double the present ratio of carbon dioxide in the atmosphere. Such data can show the importance of reducing the global carbon footprint by investing in clean energy technologies and more efficient power generation.

If this projection in carbon dioxide concentration would become a reality, the increased amount of CO_2 in the Earth's atmosphere would have disastrous effects. More carbon dioxide, as a significant greenhouse gas, would trap more of the sun's energy in the Earth's atmosphere. The increase in the greenhouse effect would increase the Earth's average temperature. The rising temperature would speed up the melting of the polar ice caps and the rising of sea levels. Global warming will significantly change the planet's weather patterns and ocean currents and reduce the amount of habitable land for a growing population. A dramatic increase in carbon dioxide concentration, as projected by the presented data, would have far-reaching effects on the planet's climate, ecosystem, and atmosphere. Figure 1.12 depicts recorded and estimated annual production of CO_2.

The IPCC (https://www.ipcc.ch/report/ar5/wg1/) report of 2013 on climate change and global warming due to man-made carbon footprints states that

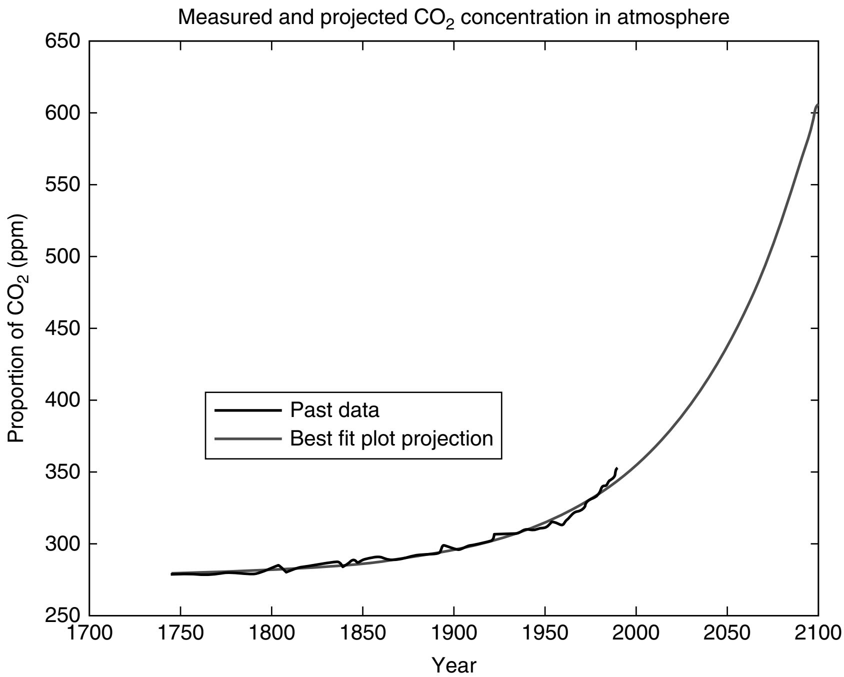

Figure 1.12 Recorded and estimated annual production of CO_2.

"the globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06]°C, over the period 1880 to 2012, when multiple independently produced datasets exist" (http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf).

The IPCC recommendation states that "Mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases." Mitigation, together with adaptation to climate change, contributes to the objective expressed in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC): "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

1.16 THE PARIS AGREEMENT | UNFCCC

The main objective of Paris Agreement is as stated as follows: "Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change." The readers are encouraged to read the 29 articles of the convention that state the commitment of signing nations to keep the planet earth ecosystem for future generation (https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement).

As of September 21, 2018, the US government has withdrawn from the Paris accord.

1.17 ENERGY UTILIZATION AND ECONOMIC GROWTH

According to the Independent Statistics and Analysis of the US Energy Information Administration (EIA) (https://www.eia.gov/), EIA's Annual Energy Outlook provides modeled projections of domestic energy markets through 2050. Energy production and utilization is a function of economic growth and interest rate set by the central bankers, oil price, and oil consumption around the world. EIA presents macroeconomic growth, technological progress, energy policies, and energy impact on the environment. The Zero Emission Vehicle program in California and the nine other states that chose to adopt California's vehicle emission standard has an impact on the production of electric energy and consumption. Students are encouraged to study the EIA reports in PDF and PowerPoint presentation at https://www.eia.gov/outlooks/aeo/. The *Electric Power Monthly* (www.eia.gov/electricity/monthly/) of EIA provides energy statistics from US government and up-to-date cost of various electric power assets. Also, an up-to-date research information can be obtained from the National Renewable Energy Laboratory (NREL) (https://www.nrel.gov/). NREL is dedicated to research, development, commercialization, and deployment of renewable energy and energy efficiency technologies. NREL conducts studies in all aspects of renewable energy and storage (https://www.nrel.gov/esif/labs-energy-storage.html) and learning about the capabilities, infrastructure, and research at the energy systems integration facility's energy storage laboratory and practical issues with a solar resource and PV systems.

Sustainable energy production and efficient utilization of available energy resources, thereby reducing or eliminating our carbon footprint, are some of our greatest challenges in the twenty-first century. This book addresses the problem of sustainable electric energy production as part of the design of building efficient microgrids and distributed generation and smart renewable energy grids.

1.18 CONCLUSION

In this chapter, we have studied a brief history of energy sources and their utilization. The development of human civilization is the direct consequence of harnessing the Earth's energy sources. We have used the power of the wind, the sun, and wood for thousands of years. However, as new sources such as coal, oil, and gas have been discovered, we have continuously substituted a new source of energy in place of an old source. Now, we have the power to harness the solar and wind energy to make every energy user an energy producer.

Global warming and environmental degradation have forced us to reexamine our energy use and resulting carbon footprints that every human must consider and be aware of its consequences. In the following chapters, we study the basic concept of power system operation, power system modeling, and the smart power grid, as well as the design of microgrids of distributed renewable energy systems.

PROBLEMS

1.1 Perform the following:

(i) Write a 3000-word report summarizing the Kyoto Protocol (http://unfccc.int/kyoto_protocol/items/2830.php).

(ii) Write a 3000-word report summarizing the Paris Agreement that builds upon the Convention and for the first time brings all nations into a common cause to undertake ambitious efforts to combat climate change (*The Paris Agreement | UNFCCC*. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement).

(iii) Compute the simple operating margin CO_2 footprint factor for a power grid load of 6000 MW if it is supplied by 50 coal-fired units with a capacity of 100 MW, 10 oil-fired generators with a capacity of 50 MW, and 10 gas-fired generators with a capacity of 50 MW or if the grid load of 6000 MW is supplied equally from gas-fired and wind- and solar-powered generators each.

1.2 Using the data given in Table 1.4, perform the following:

(i) The carbon footprint of 500 W if coal is used to produce the electric power.

(ii) The carbon footprint of a 500 W bulb if natural gas is used to provide the electrical power.

(iii) The carbon footprint of a 500 W bulb if the wind is used to generate the electrical power.

(iv) The carbon footprint of a 500 W bulb if PV energy is used to provide the electrical power.

1.3 Compute the money saved in one month by using a compact fluorescent light (CFL) bulb (18 W) instead of using an incandescent lamp (60 W) if the cost of electricity is \$0.12 per kWh. Assume the lights are used for 10 hours a day.

1.4 Compute the carbon footprint of the lamps of problem 1 if natural gas is used as fuel to generate electricity. How much more will the carbon footprint be increased if the fuel used is coal?

1.5 Will an electric oven rated at 240 V and 1200 W provide the same heat if connected to a voltage of 120 V? If not, how much power will it consume now?

1.6 Assume the emission factor of producing electric power by PV cells is 100 g of CO_2 per kWh, by wind power is 15 g of CO_2 per kWh, and by coal is 1000 g of CO_2 per kWh. Find the ratio of CO_2 emission when (a) 15% of power comes from wind farms, (b) 5% from a PV source, and (c) the rest from coal as opposed to when all power is supplied by coal-run power stations.

1.7 Compute the operating margin of the emission factor of a power plant with three units with the following specifications over one year:

Unit	Generation (MW)	Emission factor (lb of CO_2/MWh)
1	160	1000
2	200	950
3	210	920

1.8 Assume the initial cost to set up a thermal power plant of 100 MW is 2 million dollars and that of a PV farm of the same capacity is 300 million dollars and the running cost of the thermal power plant is $90 per MWh and that of PV farm is $12 per MWh. Compute the time in years needed for the PV farm to become the most economical if 90% of the plant capacity is utilized in each case.

1.9 Consider a feeder that is rated 120 V and serving five light bulbs. Loads are rated 120 V and 120 W. All light loads are connected in parallel. If the feeder voltage is dropped by 20%, compute the following:

(i) The power consumption by the loads on the feeder in watts.
(ii) The percentage of reduction in illumination by the feeders.
(iii) The amount of carbon footprint if coal is used to produce the energy.

1.10 The same as problem 1.8, except a refrigerator rated 120 V and 120 W is also connected to the feeder and voltage is dropped by 30%.

(i) Compute the power consumption by the loads on the feeder in watts.
(ii) Compute the percentage of reduction in illumination by the feeders.
(iii) Do you expect any of the loads on the feeder to be damaged?

(iv) Compute the amount of carbon footprint if coal is used to produce the energy.

(Hint: A 40 W incandescent light bulb produces approximately 500 lm of light.)

1.11 The same as problem 1.9, except a refrigerator rated 120 W is also connected to the feeder and voltage is raised by 30%.

(i) Compute the power consumption by the loads on the feeder in watts.

(ii) Compute the percentage of reduction in illumination by the feeders.

(iii) Do you expect any of the loads on the feeder to be damaged?

(iv) Compute the amount of carbon footprint if coal is used to produce the energy.

1.12 Compute the CO_2 emission factor in pounds of CO_2 per BTU for a unit in a plant that is fueled by coal, oil, and natural gas if 0.3 million tons of coal, 0.1 million barrels of oil, and 0.8 million cubic feet of gas have been consumed over one year. The average power produced over the period was 210 MW. Use the following data and the data of Table 1.4 for computation: a ton of coal has 25 million BTU, a barrel (i.e. 42 gallons) of oil has 5.6 million BTU, and a cubic foot of natural gas has 1030 BTU.

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