

CHAPTER 1

ENERGY AND CIVILIZATION

1.1 INTRODUCTION

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 has escalated public health costs: Our health care dollars have been and are being spent to treat 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.

1.2 FOSSIL FUEL

It is estimated that fossil fuels—oil, natural gas, and coal—were produced 300 to 370 million years ago.¹ Over millions of years, the decomposition of the 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 such intense heat and pressure, the remains essentially were boiled into oil. If you check the word, “petroleum” in a dictionary, you will find it means “rock oil” or “oil from the earth.”

The ancient Sumerians, Assyrians, Persians, and Babylonians found oil on the banks 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.¹ Native Americans used oil to seal their canoes.¹

In fact, although our formally recorded history of humanity’s energy use is limited, we can project the impact of energy on early civilizations from artifacts and monuments. The legacy of our oldest societies and their use 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.²

1.3 DEPLETION OF ENERGY RESOURCES

Figure 1.1 depicts the time needed to develop various energy sources. Coal, oil, and natural gas take millions of years to form. The oil that was made more

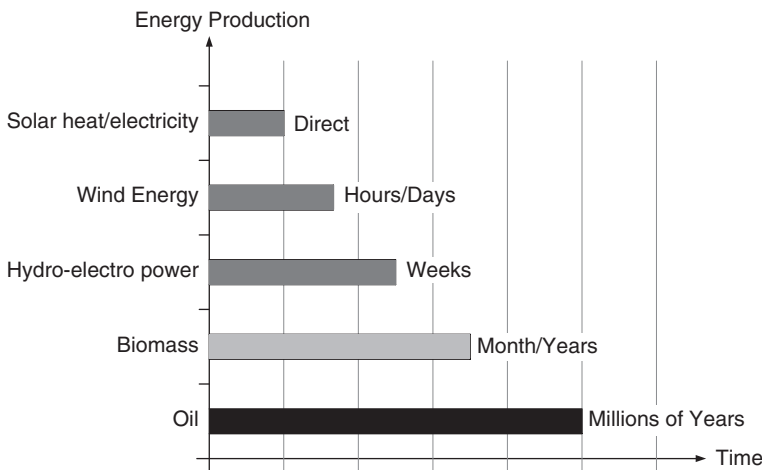


Figure 1.1 The Approximate Time Required for the Production of Various Energy Sources.

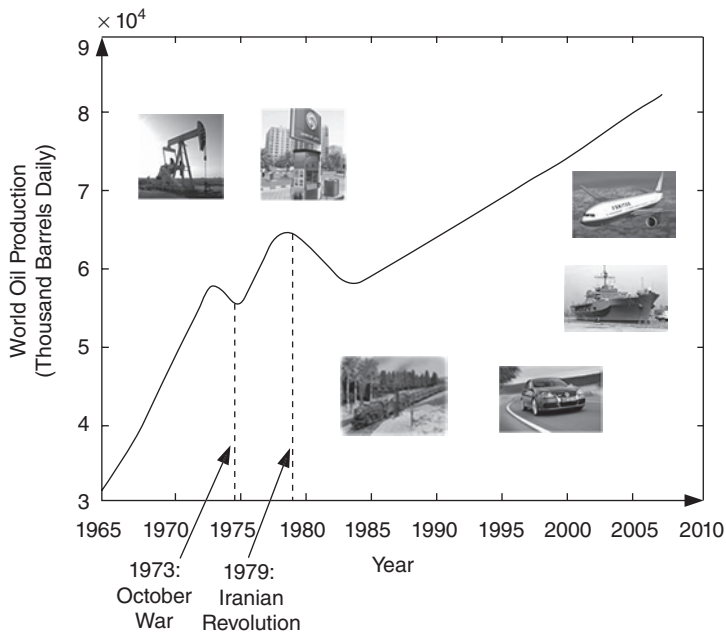


Figure 1.2 The World's Oil Production (Consumption) from 1965–2000 and Estimated from 2005–2009.³

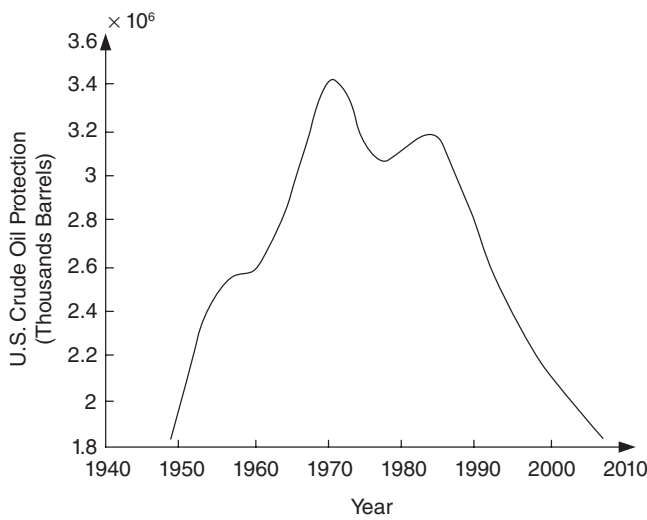


Figure 1.3 U.S. Oil Production/Consumption from 1940–2009.³

than a million years ago is being used today.¹ As we look at our energy use over the ages, it becomes clear that our new energy resources are substituting for old resources. Our first energy source was wood. Then coal replaced wood, and oil began to replace some of our coal usage to the point that oil now supplies most of our energy needs.

Since the Industrial Revolution, we have used coal. Since 1800, for approximately 200 years, we have used 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 5000 of the 100,000 years living on earth. Similarly, we have been using oil for 200 years of the 5000 years of recorded history. In the near future, we will exhaust our oil reserves. Oil is not renewable: we must conserve energy and save our oil—and gas as well.

The Middle East provides more than 50% of the oil imported to the United States. The United States' own oil production peaked around 1970. Europe's oil production is limited except for the North Sea oil reserve; it depends entirely on oil production from other parts of 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.

A closer look at Table 1.1 reveals that if the world reserves are used at the same rate as we do today, oil will run out in 40 years, our natural gas reserves will be depleted in less than 60 years, and our coal reserves will be exhausted in 200 years. No one can predict the future. However, we can empower every

TABLE 1.1 Proven Energy Resources around the World.^{3,4}

Region	Petroleum		Natural Gas		Coal	
	2002 Preserved Resources (10 ⁹ bbls)	R/P (Years)	2002 Proved Reserves (10 ¹² SCF)	R/P (years)	2002 Preserved Reserves (10 ⁹ tons)	R/P (years)
North America	49.9	10.3	52.4	9.4	257.8	240
South & Central America	98.6	42	250.2	68.8	21.8	404
Europe & Eurasia	97.5	17	2155.8	58.9	355.4	306
Middle East	685.6	92	1979.7	>100	????	>500
Africa	77.4	27.3	418.1	88.9	55.3	247
Asia-Pacific	38.7	13.7	445.3	41.8	292.5	126
World	1047.7	40.6	5501.5	60.7	984.5	204

Note: R/P = Reserves-to-production; bbls = billion barrels; SCF = standard cubic foot. R/P ratios represent the length of time that the remaining reserves would last if production were to continue at the previous year's rate. R/P is calculated by dividing remaining reserves at the end of the year by the production in that year.⁴ (Reprinted with permission from the BP Statistical Review of World Energy 2009.)

energy user in a new energy economy based on renewable sources to become an energy producer by conserving energy, reducing carbon footprints, and installing distributed renewable energy sources.

1.4 AN ALTERNATIVE ENERGY SOURCE: NUCLEAR ENERGY

In 1789, Martin Heinrich Klaproth,⁵ a German chemist, discovered uranium in the mineral pitchblende. Eugène-Melchior Péligot,⁶ a French chemist, was the first person to isolate the metal, but it was Antoine Becquerel,⁷ a French physicist, who recognized its radioactive properties almost 100 years later. In 1934, Enrico Fermi⁸ used the nuclear fuel to produce steam for the power industry. Later, he participated in building the first nuclear weapon used in World War II. The U.S. Department of Energy⁹ estimates 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 important source of energy; however, the fusion process causes additional radioactive waste products. The radioactive products will 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

Figure 1.4 depicts the process of solar radiation incident energy and reflected energy from the earth's surface and the earth atmosphere. Greenhouse gases in the earth's atmosphere emit and absorb radiation. This radiation is within the thermal infrared range. Since the burning of fossil fuel and the start of the Industrial Revolution, the carbon dioxide in the atmosphere has substantially increased as shown in Figures 1.5 and 1.6. The greenhouse gasses are primarily water vapor, carbon dioxide, carbon monoxide, ozone, and a number of other gases. Within the atmosphere of earth, greenhouse gasses are trapped.

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, depicted by circle 2 and circle 4, is reflected from the earth's surface and the earth's atmosphere. The total reflected solar radiation is approximated as 103 W per m^2 . Approximately 240 W per 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 per m^2 , is absorbed by the earth's surface. This radiation (circle 6) is converted into heat energy. This process generates infrared radiation in the form of the emission of a long wave back to earth. A portion of the infrared radiation is absorbed. Then, it is re-emitted

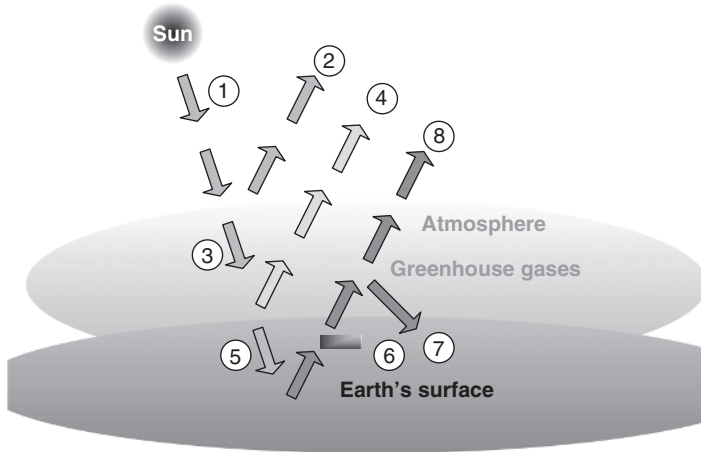


Figure 1.4 The Effects of Sun Radiation on the Surface of the Earth.

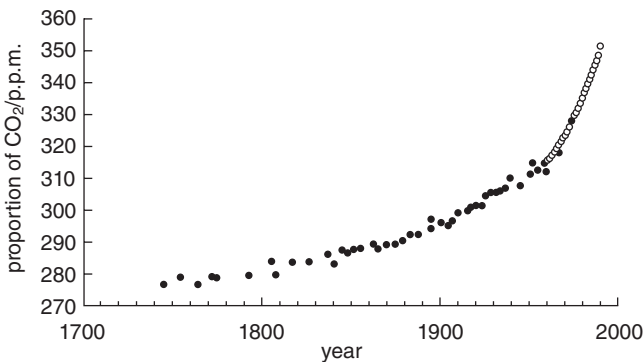


Figure 1.5 The Production of CO₂ since 1700. (Data from the Intergovernmental Panel on Climate Change, IPCC Third Annual Report.¹¹)

by the greenhouse molecules trapped in the earth's atmosphere. Circle 7 represents the infrared radiation. Finally, some of the infrared 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 growth of carbon dioxide in our atmosphere is shown in parts per million in Figure 1.5.

The World Meteorological Organization (WMO)¹⁰ is the international body for the monitoring of climate change. The WMO has clearly stated 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 our environment will continue.

Figure 1.6 depicts the condition of CO₂ in the upper atmosphere. The Y axis represents the magnitude of response. The X axis is plotted showing the years into future. The Y axis, showing response efforts, does not have units. The CO₂ emission into the atmosphere has peaked during the last 100 years. If concentrated efforts are made to reduce the CO₂ emission and it is reduced over the next few hundred years to a lower level, the earth temperature will still continue to rise, however, then stabilize. Figure 1.7 depicts the stabilization of CO₂ over the subsequent centuries.

The reduction of CO₂ will reduce its impact on the earth atmosphere; nevertheless, the existing CO₂ in the atmosphere will continue to raise the earth's temperature by a few tenths of a degree. The earth's surface temperature will stabilize over a few centuries as shown in Fig. 1.8.

The rise in the temperature due to trapped CO₂ in the earth's atmosphere will impact the thermal expansion of oceans. Consequently, the sea level will rise due to melting of ice sheets as shown in Fig. 1.10.

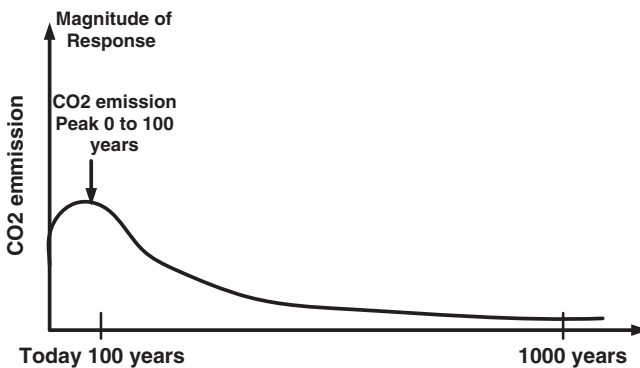


Figure 1.6 The Effect of Carbon Dioxide Concentration on Temperature and Sea Level. (Data from the Intergovernmental Panel on Climate Change, IPCC Third Annual Report.¹¹)

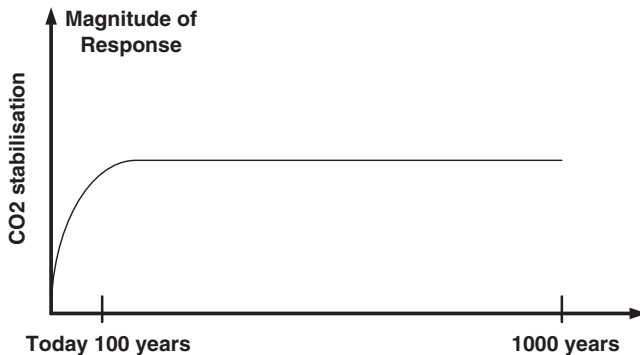


Figure 1.7 CO₂ Stabilisation after CO₂ Has Been Reduced. (Data from the Intergovernmental Panel on Climate Change, IPCC Third Annual Report.¹¹)

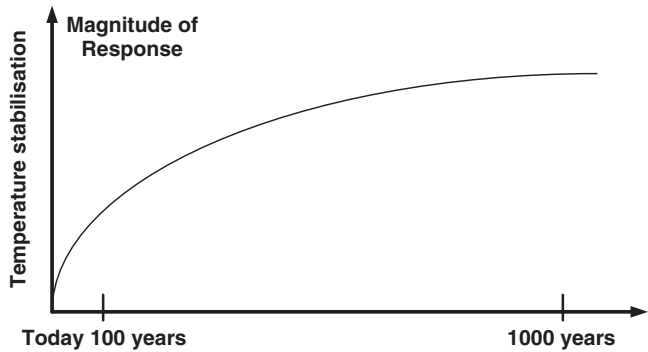


Figure 1.8 Temperature Stabilization after Reduction of CO₂ Emission.

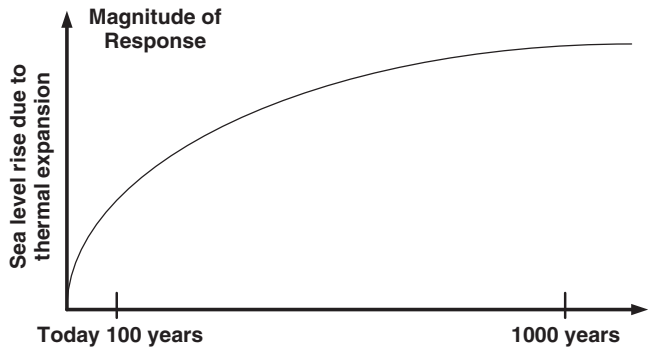


Figure 1.9 The Sea Level Rise after the Reduction of CO₂.

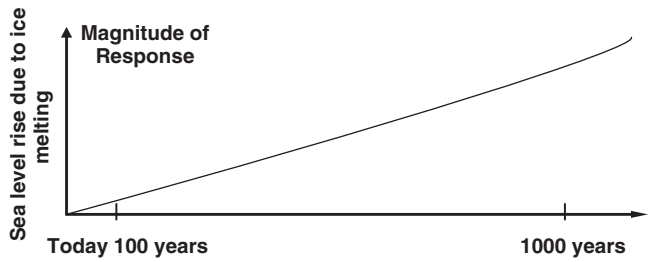


Figure 1.10 The Sea Level Rise after the Reduction of CO₂ in the Atmosphere.

As the ice sheets continue to melt due to rising temperatures over the next few centuries, the sea level will also continue to rise. Figures 1.6 through 1.10 depict the earth's conditions as a function of our level of response. As a direct consequence of trapped CO₂ 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.

1.6 THE AGE OF THE ELECTRIC POWER SYSTEM

Hans Christian Oersted,¹² a Danish physicist and chemist, discovered electromagnetism in 1820. Michael Faraday,¹³ 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, Antonio Anastasio Volta¹⁴ invented the chemical battery. Another important technological development was the discovery of Faraday's law of induction. Michael Faraday is credited with the discovery of the induction phenomenon in 1831. However, recognition for the induction phenomenon is also accorded to Francesco Zantedeschi,¹⁵ an Italian priest and physicist in 1829, and around the 1830s to Joseph Henry,¹⁶ an American scientist.

Nikola Tesla¹⁷ 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 19th and early 20th 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 1.11 shows the U.S. production of electric power from 1920–1999.¹⁸ 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 world carbon dioxide emissions due to power generation will increase by 75% by 2030. In 2009, the world population

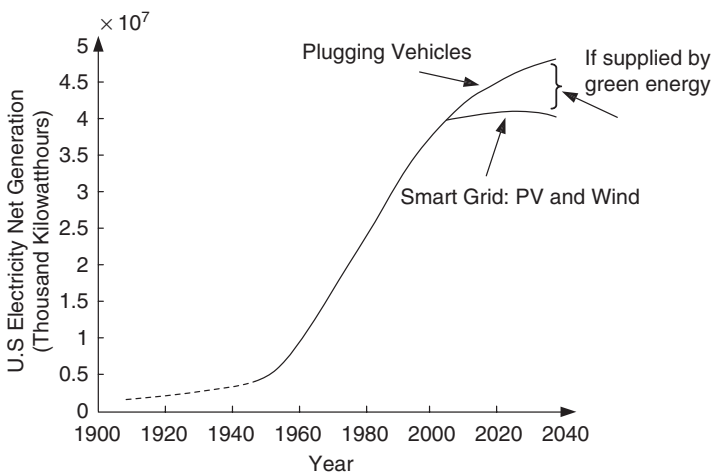


Figure 1.11 The U.S. Production of Electric Power 1920–1999.¹⁹

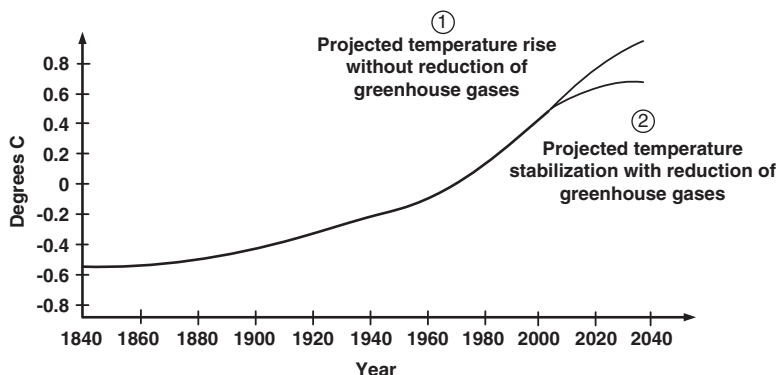


Figure 1.12 The Smooth Average of Published Records of Surface Temperature from 1840–2000.²⁰

was approximately 6.8 billion.¹⁹ 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 U.S. rate of electric power consumption.

Figure 1.11 also shows that we can slow the growth of electric power production from fossil fuels by replacing the fossil fuels with renewable sources and integrating the green energy sources in electric power grids. Figure 1.12 shows the mean smooth recorded temperature by the United Nations Environment Programme (UNEP). As more countries such as China, India, Brazil, Indonesia, and others modernize their economy, the rate of CO₂ production will accelerate. We can only hope that we can stop the trend of global warming as presented in Fig. 1.12.

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.

1.7.1 Hydrogen

Besides renewable sources, such as the wind and the sun, hydrogen (H) is an important source of clean, renewable energy. Hydrogen is abundantly available in the universe. Hydrogen is found in small quantities in the air. It's non-toxic. It's 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.^{21,22} A hydrogen fuel cell²¹ 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 byproduct (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 electric energy for an automotive system, i.e., a hydrogen combustion engine. Hydrogen-based energy has the potential to become a major energy source in the future, but there are many applied technical problems that must be solved; a new infrastructure will also be needed for this technology to take hold.

1.7.2 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 infrared (heat) waves, as well as light waves. Infrared (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) to the 430 THz.²³ Sunlight is defined by irradiance, meaning radiant energy of light. We define one sun as the brightness to provide an irradiance of about 1 kilowatt (kW) per square meter (m^2) at sea level and 0.8 sun about 800 W/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 square meters and square feet needed to generate 5,000 kW of power. Assume the sun irradiant is equivalent to 0.8 sun of energy.

Solution

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

Capacity of 5,000 kW = $(1 \text{ kW/m}^2) \cdot (\text{Required area in } \text{m}^2)$

Required area in $\text{m}^2 = 5,000/0.8 = 6,250 \text{ m}^2$

$1 \text{ m}^2 = 10.764 \text{ ft}^2$

Required area in $\text{ft}^2 = (6250) \cdot (10.764) = 67,275 \text{ ft}^2$

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 earth's surface and some heat is reflected back into space as it can be seen in 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 in a conventional manner 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 materials are amorphous silicon (a-Si), mainly O for p-type Si and C and the transition metals, mainly Fe. Silicon is put into different forms or into 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 together in series to provide a PV module producing 12 V.

Example 1.2 Compute the area in square meters and square feet needed to generate 5,000 kW of power. Assume the sun irradiant is equivalent to 0.8 sun of energy.

Solution

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

Capacity of 5,000 kW = $(1 \text{ kW/m}^2) \cdot (\text{Required area in m}^2)$

Required area in $\text{m}^2 = 5,000/0.8 = 6,250 \text{ m}^2$

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Required area in $\text{ft}^2 = (6250) \cdot (10.764) = 67,275 \text{ ft}^2$

1.7.3 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.²⁴

1.7.4 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 fuel, 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.²⁵ However, there are a number of controversial issues

surrounding 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.

1.7.5 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 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.²⁵

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).

1.8 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 in terms of heat that can be generated. One British thermal unit (BTU) requires 252 calories; it is equivalent to 1055 joules. The joule (J) is named after James Prescott Joule²⁶ (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. One BTU of heat raises one pound of water one degree Fahrenheit (F). To measure the large amount of energy, the term “quad” is used. One quad is equivalent to 1015 BTU.

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). In terms of dimensions, one joule is equal to one Newton (N) times one meter (m) ($1 \text{ J} = 1 \text{ N} \times 1 \text{ m}$); it is also equal to one watt times one second (sec) ($1 \text{ J} = 1 \text{ W} \times 1 \text{ sec}$). Therefore, one joule is the amount of work required to produce one watt of power for one second. Therefore, 1 watt, normally shown as P is 3.41 BTU per hour.

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

Solution

$$\text{Heat required} = (100 \text{ lb}) \cdot 212^\circ\text{F} = 2,1200 \text{ BTU}$$

$$\text{Energy in joules} = 21200 \text{ BTU} / 1055 = 20.1 \text{ J}$$

$$P \text{ (watt)} = 3.41 \text{ BTU/h}$$

$$P = 20.1/3.41 = 5.89 \text{ W}$$

In engineering, power is defined as

$$P = I V$$

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 (amp) and voltage in volts. Therefore, one kilowatt is a thousand watts. The energy use is expressed in kilowatt-hour (kWh) and one kWh is the energy used by a load for one hour. This 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 hundred thousand BTU is equal to one thousand kWh; it is also equal 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 terms of 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

$$\text{One watt} = \text{one joule} \cdot \text{sec} \cdot (\text{j} \cdot \text{sec})$$

$$1000 \text{ watts} = 1000 \text{ j} \cdot \text{sec}$$

$$1 \text{ kWh} = 1 \cdot 60 \cdot 60 \cdot 1000 = 3600 \text{ kj} \cdot \text{sec}$$

$$10 \text{ kWh} = 36000 \text{ kilo j} \cdot \text{sec}$$

$$\text{One BTU} = 1055.058 \text{ j} \cdot \text{sec}$$

$$\text{Heat in BTU needed for 10 kWh} = 36,000,000/1055.058 = 34,121.3 \text{ BTU}$$

The energy content of coal is measured in terms of 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 has 1030 BTU and one cubic foot of natural gas has 1030 BTU.

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

Solution

$$\text{One ton of coal} = 25,000,000 \text{ BTU}$$

$$10 \text{ tons of coal} = 250,000,000 \text{ BTU}$$

$$1 \text{ kWh} = 3413 \text{ BTU}$$

$$\text{Energy used in kWh} = (250,000,000)/3413 = 73,249.3 \text{ kWh}$$

TABLE 1.2 Carbon Footprint of Various Fossil Fuels for Production of 1 kWh of Electric Energy.²⁷

Fuel Type	CO ₂ Footprint (lb)
Wood	3.306
Coal-fired plant	2.117
Gas-fired plant	1.915
Oil-fired plant	1.314
Combined-cycle gas	0.992

TABLE 1.3 Carbon Footprint of Green and Renewable Sources for Production of 1 kWh of Electric Energy.²⁷

Fuel Type	CO ₂ Footprint (lb)
Hydroelectric	0.0088
PV	0.2204
Wind	0.03306

Example 1.6 Compute the CO₂ footprint of a residential home using 100 kWh coal for one day.

Solution

1 kWh of electric energy using a coal fire plant has 2.117 lb.

Residential home carbon footprint for 100 kWh = $(100) \cdot (2.117) = 211.7$ lb of CO₂

The carbon footprint can also be estimated in terms of carbon (C) rather CO₂. The molecular weight of C is 12 and CO₂ is 44. (Add the molecular weight of C, 12 to the molecular weight of O₂, 16 times 2 = 32, to get 44, the molecular weight of CO₂.) The emissions expressed in units of C can be converted to emissions in CO₂. The ratio of CO₂/C is equal to $44/12 = 3.67$. Thus, CO₂ = 3.67 C. Conversely, C = 0.2724 CO₂.

Example 1.7 Compute the carbon footprint of 100 kWh of energy if coal is used to produce it.

Solution

C = 0.2724 CO₂

C = $(0.2724) \cdot 211.7$ lb = Antoine Becquerel (Bq) 57.667 lb of C

TABLE 1.4 Fossil Fuel Emission Levels in Pounds per Billion BTU of Energy Input.²⁷

Pollutant	Natural Gas	Oil	Coal
Carbon dioxide (CO ₂)	117,000	164,000	208,000
Carbon monoxide, CO	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

The carbon footprints of coal is the highest among fossil fuels. Therefore, coal-fired plants produce the highest output rate of CO₂ per kilowatt-hour. The use of fossil fuels also adds other gasses to the atmosphere per unit of heat energy as shown in Table 1.4.

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 CO₂ if coal is used to produce the electric power. For coal, this coefficient is approximated to be 2.3 lb CO₂/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 used is given as:

$$\text{Energy consumed} = (60 \text{ W}) \times (24 \text{ h}) / (1000) = 1.44 \text{ kWh}$$

Example 1.9 Estimate the CO₂ footprint of a 60 W bulb on for 24 hours.

Solution

$$\text{Carbon footprint} = (1.44 \text{ kWh}) \times (2.3 \text{ lb CO}_2/\text{kWh}) = 3.3 \text{ lb CO}_2$$

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 \$.30/kWh for PV energy. Therefore, if the 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 electric energy is in the range of \$.04/kWh to \$.08/kWh. Green energy technology needs supporting

governmental policies to promote electricity generation from green energy sources. Economic development in line with green energy policies will be needed for lessening the ecologic footprint of a developing world.

After thousands of years of burning wood and wood charcoal, CO₂ concentration was at 288 parts per million by volume (ppmv) in 1850 just at the dawn of the Industrial Revolution. By the year of 2000, CO₂ had risen to 369.5 ppmv, an increase of 37.6% over 250 years. The exponential growth of CO₂ is closely related to the production of electric energy (see Figs. 1.4 and 1.6).

1.9 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/or included in its documentation or in 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 may be rated at 50 W and 120 V. This means that if we apply 120 volts to the light bulb, we will consume 50 watts.

Again, energy consumption can be expressed as follows:

$$P = V \cdot I \quad (1.1)$$

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

$$P = \frac{dW}{dt} \quad (1.2)$$

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

$$W = P \cdot t \quad (1.3)$$

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

$$kWh = kW \times \text{hour} \quad (1.4)$$

Therefore, if we let λ represent the cost of electric energy in \$/kWh,
Then the total cost can be expressed as

$$\text{Energy Cost (in dollars)} = kWh \times \lambda \quad (1.5)$$

Example 1.10 Let us assume that you want to buy a computer. You see two computers: brand A is rated as 400 W and 120 V and costs \$1000; brand B is rated as 100 watts and 120 volts and costs \$1010. Your electric company charges \$.09/kWh on your monthly bill. You are interested in the total cost, that is the cost of buying the computer and the operating cost if you use your computer for 3 years at the rate of 8 hours a day.

Solution

At 8 hours a day for 3 years, the total operating time is

$$\text{Operating Time} = 8 \times 365 \times 3 = 8760 \text{ hours.}$$

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

$$\begin{aligned} \text{Brand B kWh energy consumption} &= \text{Operating Time} \times \text{kW of brand B} \\ &= 8760 \times 100 \times 10^{-3} = 876 \text{ kWh} \end{aligned}$$

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

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

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

Example 1.11 For Example 1.8, let us assume that the electric energy is produced using coal, what is the amount of CO₂ in pounds that is emitted over 3 years into the environment?

What is your carbon footprint?

Solution

From the Table 1.4, the pounds of CO₂ emission per billion BTU of energy input for coal is 208,000.

$$1 \text{ kWh} = 3.41 \text{ thousand BTU}$$

$$\begin{aligned}\text{Energy consumed for brand A over 3 years} &= 3504 \times 3.41 \times 10^3 \\ &= 11948640 \text{ BTU}\end{aligned}$$

$$\begin{aligned}\text{Therefore, for brand A, pounds of CO}_2 \text{ emitted} &= \frac{11948640 \times 208000}{10^9} \\ &= 2485.32 \text{ lb}\end{aligned}$$

$$\text{Energy consumed for brand B over 3 years} = 876 \times 3.41 \times 10^3 = 2987160 \text{ BTU}$$

$$\begin{aligned}\text{Therefore, for brand B, pounds of CO}_2 \text{ emitted} &= \frac{2987160 \times 208000}{10^9} \\ &= 621.33 \text{ lb}\end{aligned}$$

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 CRT (cathode ray tube) 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 off 8 hours a day.

Solution

$$i) \text{ Hours in one year} = 24 \times 365 = 8760 \text{ h}$$

$$\begin{aligned}\text{Energy consumed in one year} &= 8760 \times 500 \times 10^{-3} = 4380 \text{ kWh} \\ &= 4380 \times 3.41 \times 10^3 = 14935800 \text{ BTU}\end{aligned}$$

From Table 1.4, pounds of CO₂ emission per billion The BTU of energy input for oil is 164,000.

$$\begin{aligned}\text{Therefore, the carbon footprint for one year} &= \frac{14935800 \times 164000}{10^9} \\ &= 2449.47 \text{ lb}\end{aligned}$$

- ii) Carbon footprint in the case of 8 h/day use

$$\begin{aligned}&= \frac{8}{24} \times \text{footprint for use in 24 h} \\ &= \frac{1}{3} \times 2449.47 = 816.49 \text{ lb}\end{aligned}$$

1.10 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 energy 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.

Global warming and environmental degradation have forced us to reexamine our energy use and consequent carbon footprints, a topic we also have addressed in this chapter. In the following chapters, we will study the basic concept of power system operation, power system modeling, and the smart power grid system, as well as the design of smart microgrid rentable energy systems.

PROBLEMS

- 1.1** Writing Assignment. Write a 3000 word report summarizing the Kyoto Protocol. Compute the simple operating margin CO_2 factor for the year 2020 if the system load of 6000 MW is supplied by 10 coal 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.
 - i)* The system load of 6000 MW supplied from only coal units
 - ii)* The system load of 6000 MW supplied equally from gas units and wind and solar power
- 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 produce the electric power
 - iii)* The carbon footprint of a 500 W bulb if wind is used to produce the electric power
 - iv)* The carbon footprint of a 500 W bulb if PV energy is used to produce the electric power
- 1.3** Compute the money saved in one month by using CFL (compact fluorescent light) 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** If the emission factor of producing electric power by PV cells is 100 g of CO₂ per kWh, by wind power is 15 g of CO₂ per kWh, and by coal is 1000 g of CO₂ per kWh, then find the ratio of CO₂ 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** If 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 then find 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:
- The power consumption by the loads on the feeder in watts
 - The percentage of reduction in illumination by the feeders
 - 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%.
- Compute the power consumption by the loads on the feeder in watts
 - Compute the percentage of reduction in illumination by the feeders
 - Do you expect any of the loads on the feeder to be damaged?
 - Compute the amount of carbon footprint if coal is used to produce the energy

(Hint: a 40 W incandescent light bulb produces approximately 500 lumens 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 CO₂ emission factor in pounds of CO₂ 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; a cubic foot of natural gas has 1030 BTU.

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