CLEAN ENERGY GENERATION, INTEGRATION AND STORAGE (EEE-801)

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Lecture-3
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Introduction: The Age of the Electric Power System

- Hans Christian Oersted, 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. the magnitude of the emf induced in a circuit is proportional to the rate of change of the magnetic flux that cuts across the circuit.
- In 1801, an Italian physicist, Antonio Anastasio Volta 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, an Italian priest and physicist in 1829, and around the 1830s to Joseph Henry, an American scientist.

Introduction: The Age of the Electric Power System

- 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 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.

Introduction: The Age of the Electric Power System

- Figure 1.11 shows the U.S. production of electric power from 1920 – 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 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 U.S. rate of electric power consumption.

Introduction: The Age of the Electric Power System

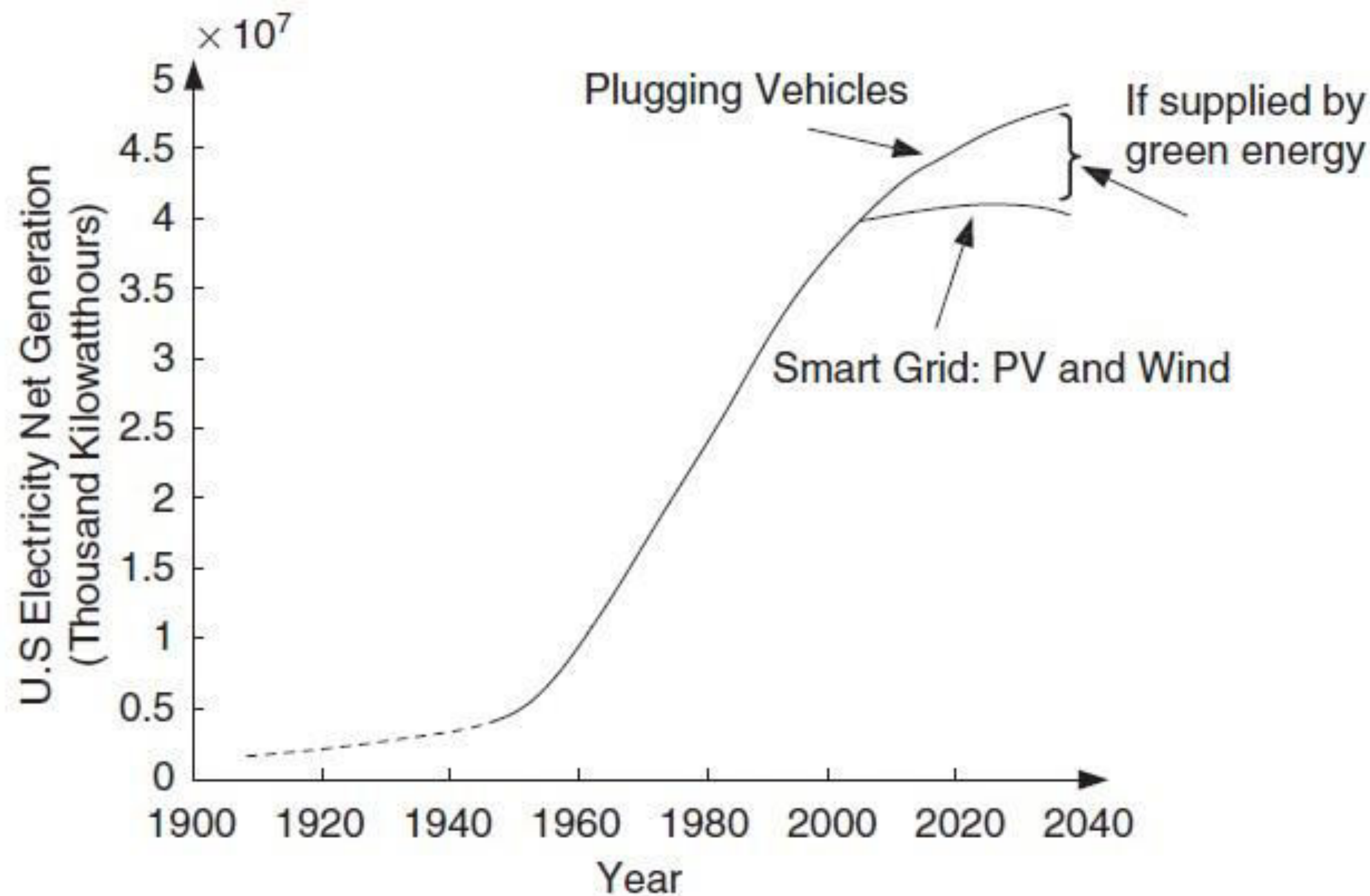


Figure 1.11 The U.S. Production of Electric Power 1920–1999.[19]

- 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 CO_2 production will accelerate.
- We can only hope that we can stop the trend of global warming as presented in Fig. 1.12.

Introduction: The Age of the Electric Power System

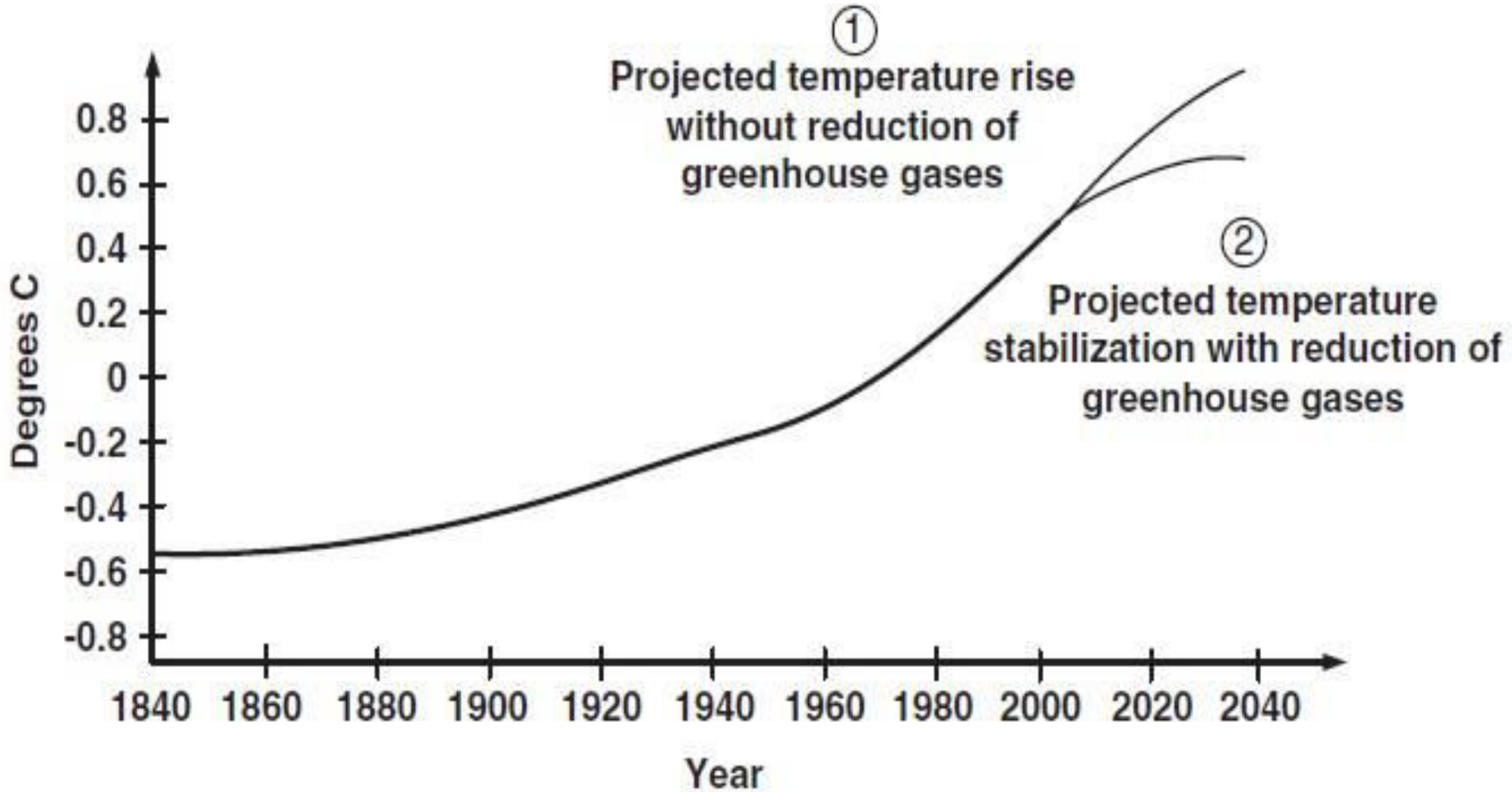


Figure 1.12 The Smooth Average of Published Records of Surface Temperature from 1840–2000.[20]

Introduction: 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.

Introduction: Hydrogen

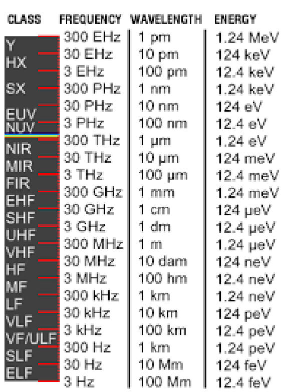
- Besides renewable sources, such as the wind and the sun, hydrogen (H) is an important source of clean, renewable energy.
- Hydrogen is abundantly available in the universe. Hydrogen is found in small quantities in the air. It's non - toxic. It's colorless and odorless.
- Hydrogen can be used as an 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.

Solar Cell

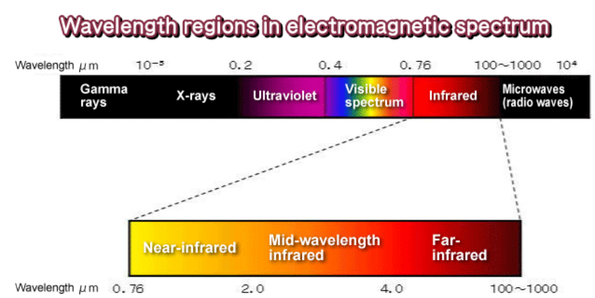
Introduction: Hydrogen

- 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 byproduct (H2O).
- 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.



Region	Frequency	Wavelength
Radio	< 3×10^9 Hz	> 10 cm
Microwave	$3 \times 10^9 - 3 \times 10^{11}$ Hz	10 – 0.1 cm
Infrared	$3 \times 10^{11} - 4 \times 10^{14}$ Hz	1000 – 0.7 µm
Visible	$4 \times 10^{14} - 7.5 \times 10^{14}$ Hz	700 – 400 nm
Ultraviolet	$7.5 \times 10^{14} - 3 \times 10^{16}$ Hz	400 – 10 nm
X-ray	$3 \times 10^{16} - 3 \times 10^{19}$ Hz	10 – 0.01 nm
γ-ray	> 3×10^{19} Hz	< 0.01 nm



Introduction: 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 to the 430 THz.
- 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.

- Problem 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 kW/m^2) · (Required area in m^2)

Required area in m^2 = 5,000/0.8 = 6,250 m^2

1 m^2 = 10.764 ft^2

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

- Problem 1.2: Compute the area in square meters and square feet needed to generate 8,000 kW of power. Assume the sun irradiant is equivalent to 0.8 sun of energy.

- **Solve it yourself !**

A = 8000kW/0.8 kW/m^2
A = 10000 m^2
Area in square meter
A = 107600 sq feet

Introduction: Solar and Photovoltaic

- 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.

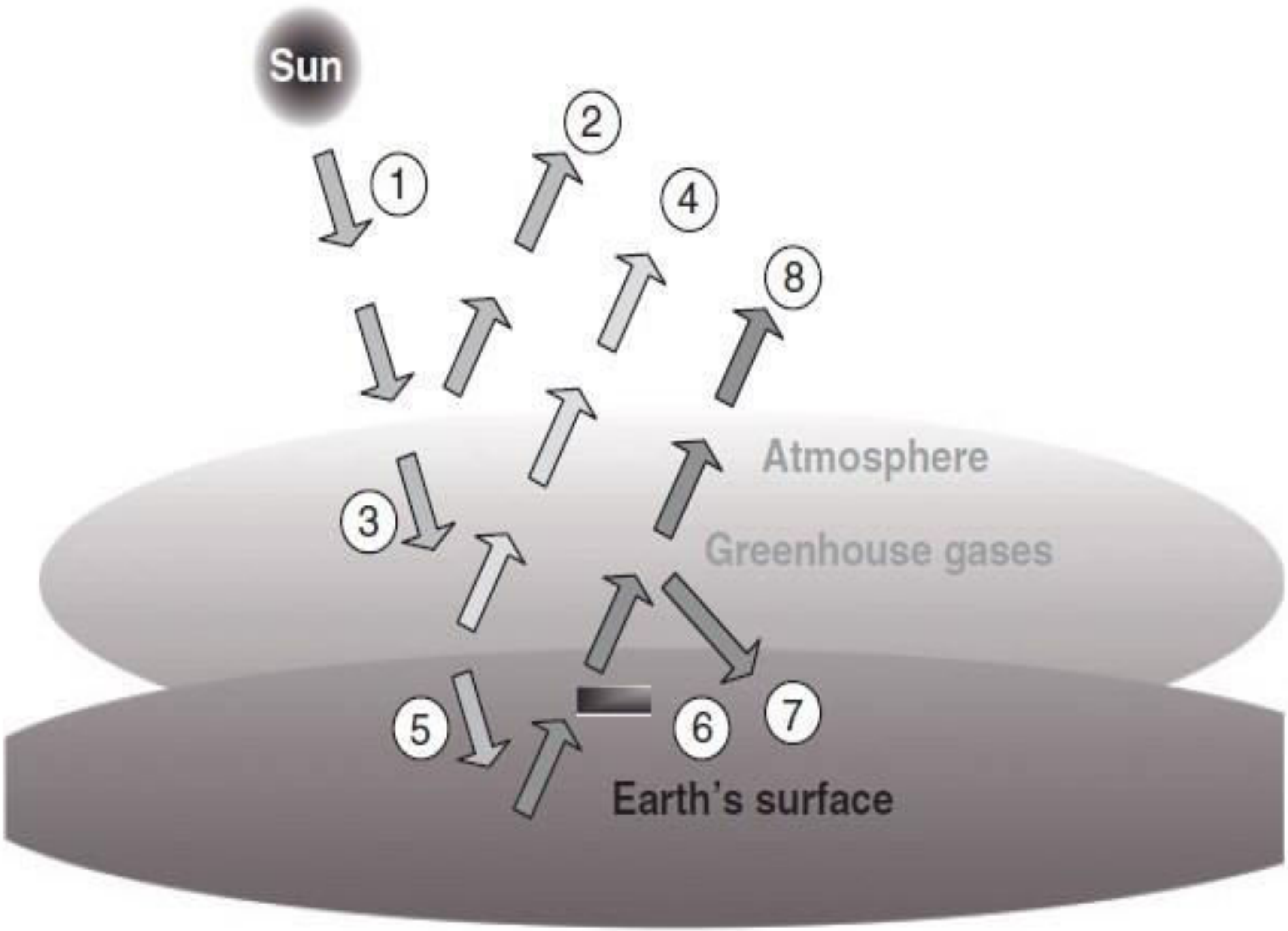


Figure 1.4 The Effects of Sun Radiation on the Surface of the Earth.

Introduction: Solar and Photovoltaic

- 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.
- Silicon is put into different forms or into polycrystalline materials, such as cadmium telluride (CdTe) and copper indium (gallium) (CIS and CIGS). copper indium gallium selenide solar cell.
- 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.

Introduction: 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.

Introduction: 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.
- 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.

- 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.

Introduction: 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 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.
- 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 J = 1 N × 1 m); it is also equal to one watt times one second (sec) (1 J = 1 W × 1 sec).

W = Watt (Power)

- 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.

1 watt= 3.412 BTU/h

Introduction: Energy Units And Conversions

- **Problem 1.3:** Compute the amount of energy in watts needed to bring 100 lb of water to 212 ° F.

Wrong method

Solution

Heat required = (100 lb) · 212°F = 2,1200 BTU

Energy in joules = 21200 BTU/ 1055 = 20.1 J   Here must be multiply instead of divide.

P (watt) = 3.41 BTU/h

P = 20.1/3.41 = 5.89 W

In engineering, power is defined as

P = I V

100 lb*212 = 21200 btu
Now
1 btu = 1055 joules
21200 btu = 21200*1055=22366000 joules
Now two methods
1. 21200 btu/3.41 = 6213.36 watt
2. As 1 joule = 1 W*s =>
 Watt=22366000 joules/(60*60) = 6212.7 watt

Energy Units and Conversions

1 Joule (J) is the MKS unit of energy, equal to the force of one Newton acting through one meter.
1 Watt is the power of a Joule of energy per second

Power = Current x Voltage (P = I V)
1 Watt is the power from a current of 1 Ampere flowing through 1 Volt.
1 kilowatt is a thousand Watts.
1 kilowatt-hour is the energy of one kilowatt power flowing for one hour. (E = P t).
1 kilowatt-hour (kWh) = 3.6×10^6 J = 3.6 million Joules

1 calorie of heat is the amount needed to raise 1 gram of water 1 degree Centigrade.
1 calorie (cal) = 4.184 J
(The Calories in food ratings are actually kilocalories.)

A BTU (British Thermal Unit) is the amount of heat necessary to raise one pound of water by 1 degree Farenheit (F).
1 British Thermal Unit (BTU) = 1055 J (The Mechanical Equivalent of Heat Relation)
1 BTU = 252 cal = 1.055 kJ
1 Quad = 10^{15} BTU (World energy usage is about 300 Quads/year, US is about 100 Quads/year in 1996.)
1 therm = 100,000 BTU
1,000 kWh = 3.41 million BTU

Introduction: Energy Units And Conversions

- 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. The watt hours unit number 293.07 W·h converts to 1 cu ft N.G., one cubic foot of natural gas.

- **Problem 1.4:** Compute the amount of heat in BTU needed to generate 10 kWh.

Solution

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

1000 watts = 1000 j $\cdot$ sec

1 kWh = $1 \cdot 60 \cdot 60 \cdot 1000$ = 3600 kj $\cdot$ sec

10 kWh = 36000 kilo j $\cdot$ sec

One BTU = 1055.058 j $\cdot$ sec

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

Introduction: Energy Units And Conversions

- 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.

Multiply 3.41 with 301 = 1030 BTU

- Problem 1.5: Compute how many kWh can be produced from 10 tons of coal.

Solution

One ton of coal = 25,000,000 BTU

10 tons of coal = 250,000,000 BTU

1 kWh = 3413 BTU

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

- Problem 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 CO_2

Introduction: Energy Units And Conversions

- The carbon footprint can also be estimated in terms of carbon (C) rather 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 can be converted to emissions in CO_2 . The ratio of CO_2 /C is equal to 44/12 = 3.67. Thus, $CO_2 = 3.67C$. Conversely, $C = 0.2724CO_2$.

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

Solution

$$C = 0.2724\ CO_2$$

$$C = (0.2724).\ 211.7\ \text{lb} = \text{Antoine Becquerel (Bq)}\ 57.667\ \text{lb of C}$$

- The carbon footprints of coal is the highest among fossil fuels. Therefore, coal - fired plants produce the highest output rate of CO_2 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 CO_2 if coal is used to produce the electric power. For coal, this coefficient is approximated to be 2.3 lb CO_2 /kWh of electricity.

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

- Problem 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:

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

- Problem 1.9: Estimate the CO2 footprint of a 60 W bulb on for 24 hours.

Solution

$$\text{Carbon footprint} = (1.44 \text{ kWh}) \times (2.3 \text{ lb } CO_2/\text{kWh}) = 3.3 \text{ lb } CO_2$$

Introduction: Estimating The Cost of Energy

- 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.

Introduction: Estimating The Cost of Energy

- Again, energy consumption can be expressed as follows:

$$P = V \cdot I$$

- 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

$$P = \frac{dW}{dt}$$

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

$$W = P \cdot t$$

- 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

$$kWh = kW \times hour$$

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

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

- Problem. 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.

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

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

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

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

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

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

- 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.

- Problem. 1.11: For Example 1.10, 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?

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

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

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

$$\text{Therefore, for brand A, pounds of } CO_2 \text{ emitted} = \frac{11948640 \times 208000}{10^9}$$
$$= 2485.32 \text{ lb}$$

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

$$\text{Therefore, for brand B, pounds of } CO_2 \text{ emitted} = \frac{2987160 \times 208000}{10^9}$$
$$= 621.33 \text{ lb}$$

Brand B has a much lower carbon footprint.

Introduction: Estimating The Cost of Energy

- Problem. 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.

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

Energy consumed in one year $= 8760 \times 500 \times 10^{-3} = 4380$ kWh

$$= 4380 \times 3.41 \times 10^{3} = 14935800 \text{ BTU}$$

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

$$\text{Therefore, the carbon footprint for one year} = \frac{14935800 \times 164000}{10^{9}}$$

$$= 2449.47 \text{ lb}$$

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

$$= \frac{8}{24} \times \text{footprint for use in 24 h}$$

$$= \frac{1}{3} \times 2449.47 = 816.49 \text{ lb}$$