3 UNITS AND UNIT CONVERSIONS

Abstract

The type of units used to describe the energy content of a resource depends on the resource itself. As a consequence, a variety of units are used in the energy industry. The conversion of one unit to another unit is essential for comparison purpose and also to prevent various mishaps. Scientists and engineers working in the energy related industry should know how to convert gallons to liters, and vice versa. The difference between energy content and power output should be clear to all professionals in the energy field. This chapter addresses various units used in the energy industry and their conversion from one unit to another unit.

3.1 Introduction

One of the most important endeavors of an engineer is to understand the units used in describing, evaluating, and comparing various systems. Two systems of units exist in science and engineering. These two systems are Système International d'unités (in short SI system) and British system. The SI system is also known as the Metric System. Currently, the United States, Liberia, and Myanmar are the only countries yet to adopt the metric system officially. In 1866, the use of the metric system was made legal but not mandatory in the United States by the Metric Act of 1866 (P.L. 39-183) [1]. Since then various other laws were passed in the U.S. Congress to promote the use of metric systems [2, 3].

From a historical perspective, energy has been measured by British units. The energy system may be the only system that was affected significantly when implementation of the metric system occurred. For example, Joules, the common measurement used in the metric system is seldom used in measuring energy resources in our day to day life. As can be seen from Table 3.1, the most common units used to measure various energy resources are still in British Units.

T.K. Ghosh and M.A. Prelas, *Energy Resources and Systems: Volume 1: Fundamentals and Non-Renewable Resources*, 77–87.

Table 3.1. Common measuring units used to describe common energy sources.

Energy source	Common measuring units
Oil	Million barrels
Coal	Million tonnes
Natural Gas	Billion standard cubic feet
Uranium	Thousand tonnes
Wood	Cord

The units for measuring energy sources and their conversion factors are given in Table 3.2. The conversion factors of various other units are given in Appendix III.

Table 3.2. Conversion factors for energy related units.

Unit	Multiply by	To obtain
Barrels of oil (bbl)	42	US gallons (gal)
Barrels of oil (bbl)	34.97	Imperial gallons (UK gal)
Barrels of oil (bbl)	0.136	Tonnes of oil equivalent (toe)
Barrels of oil (bbl)	0.1589873	Cubic meter (m^3)
Barrels of oil equivalent (boe)	5,658.53	Cubic feet (ft^3) of natural gas
Tonnes of oil equivalent (toe)	7.33*	Barrels of oil equivalent (boe)
Cubic yards (yd^3)	0.764555	Cubic meter (m^3)
Cubic feet (ft^3)	0.02831685	Cubic meter (m^3)
Cubic feet (ft^3) of natural gas	0.0001767	Barrels of oil equivalent (boe)
US gallons (gal)	0.0238095	Barrels (bbl)
US gallons (gal)	3.785412	Liters (l)
US gallons (gal)	0.8326394	Imperial gallons (UK gal)
Imperial gallons (UK gal)	1.201	US gallon (gal)
Imperial gallons (UK gal)	4.545	Liters (l)
Short tons	2,000	Pounds (lb)
Short tons	0.9071847	Metric tonnes (t)
Long tons	1.016047	Metric tonnes (t)
Long tons	2,240	Pounds (lb)
Metric tonnes (t)	1,000	Kilograms (kg)
Metric tonnes (t)	0.9842	Long tons
Metric tonnes (t)	1.102	Short tons
Pounds (lb)	0.45359237	Kilograms (kg)
Kilograms (kg)	2.2046	Pounds (lb)
Acres	0.40469	hectares (ha)
Square miles (mi^2)	2.589988	square kilometers (km^2)
Square yards (yd^2)	0.8361274	square meters (m^2)
Square feet (ft^2)	0.09290304	square meters (m^2)
Square inches (in^2)	6.4516	square centimeters (cm^2)
British Thermal Units (Btus)	1,055.05585262	joules (J)
Calories (cal)	4.1868	joules (J)
Kilowatt hours (kWh)	3.6	Megajoules (MJ)
Therms	100,000	British thermal units (Btus)

Unit	Multiply by	To obtain
Tonnes of oil equivalent	10,000,000	Kilocalories (kcal)
Tonnes of oil equivalent	396.83	Therms
Tonnes of oil equivalent	41.868	Gigajoules (GJ)
Tonnes of oil equivalent	11,630	Kilowatt hours (kWh)
Cubic feet (ft^3) of natural gas	1,025	British Thermal Units (Btus)

* This conversion can range from 6.5 to 7.9 depending on the type of crude oil

It is important to understand both the units and how to convert British units to metric units and vice versa. Various units used in energy systems and businesses are explained below and their conversion factors are given in Appendix III.

3.2 Basic Energy Units

British Thermal Unit (BTU)

The *BTU* is defined as the amounts of energy required to raise one pound of water at its maximum density, which occurs at a temperature of 39.1 degrees Fahrenheit (^{o}F) by 1^{o}F at sea level.

Calorie (Cal)

Calorie is the equivalent of BTU in SI or Metric system of units. Calorie is defined as the amounts of energy required to raise 1 g of water by one degree Celsius (1^{o}C) from 14.5^{o}C to 15.5^{o}C at sea level.

Joule (J)

Joule is the unit of electrical, mechanical, and thermal energy in the SI system of units. Depending on its use, its definition or interpretation is different.

As a unit of electrical energy, joule is the energy equal to the work done when a current of 1 ampere is passed through a resistance of 1 ohm for 1 s.

As a unit of mechanical energy, it is the energy equal to the work done when a force of 1 Newton acts through a distance of 1 m in the direction the force is applied. This is also a unit of work which is equal to 10^7 units of work in the Centimeter, the Gram, and the Second (CGS) system of units (ergs, the unit of work or energy in the CGS system, equal to the work done by a force of 1 dyne acting through a distance of 1 cm).

As a unit of thermal energy, it is defined as the amount of energy required to raise the temperature of 1 kg of water by 1°C.

In terms of kinetic energy, one joule is equal to the energy of a mass of 2 kg moving at a velocity of one meter per second.

1 J/s = W

The conversion factors between these units are given below.

1 BTU	=	251.9 cal
	=	0.2519 kcal
	=	1055 J
	=	1.055 kJ
1 cal	=	3.9698×10^{-3} BTU
	=	4.1868 J
1 J	=	0.2388 cal
	=	$9.4786\ 10^{-4}$ BTU

3.2.1 Other Energy Units

Quad

A Quad is used when measuring large amounts of energy.

1 Quad = 10^{15} BTUs.

The United States used 101.6 quads per year in 2007.

Therm

A Therm is another energy unit mainly used to describe energy content of natural gas.

1 Therm = 100,000 BTU

Often a number of prefixes are used with the regular units to describe large amounts of energy. This is most common with the SI units. Some of these prefixes used to describe energy units are given in Table 3.3.

Table 3.3. Prefixes used to describe large energy units.

Unit	Equivalent
Kilowatt (kW)	1,000 (One Thousand) Watts
Megawatt (MW)	1,000,000 (One Million) Watts
Gigawatt (GW)	1,000,000,000 (One Billion) Watts
Terawatt (TW)	1,000,000,000,000 (One Trillion) Watts
Kilowatt-hours (kWh)	1,000 (One Thousand) Watt-hours
Megawatt-hours (MWh)	1,000,000 (One Million) Watt-hours
Gigawatt-hours (GWh)	1,000,000,000 (One Billion) Watt-hours
Terawatt-hours (TWh)	1,000,000,000,000 (One Trillion) Watt-hours

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, Electric Power Division [4].

Cord

A Cord is the unit of measure of wood that is equivalent to a pile of round wood 4 ft wide, 8 ft long and 4 ft high. It contains 128 ft^3 of wood and space. It may contain approximately 80–90 ft^3 of solid wood. A common, but fairly meaningless conversion is 500 board feet per cord.

3.3 Energy Content

It is important to understand the energy content of various energy resources that are available throughout the world. Various countries in the world are rich in certain resources. For example, the United States has very large coal reserves, it is rich in uranium reserves, it has a large amount of natural gas, it has a very good resource base of wind energy, it has a rich resource base of hydro, it has a large amount of land mass and therefore has access to solar energy, and it has a moderate amount of oil reserves. Other countries are not as well off as the United States. For example, France has a very poor energy resource base. It has chosen to go to an all nuclear energy economy. Japan has a very poor energy resource base and, like France, it too has chosen to go to an all nuclear energy economy. Other countries such as Canada and Russia are rich in resources like the United States. Countries in the Middle East are very rich in oil reserves. In order to compare the values of these resources, energy content of all the resources is described by a common unit, called *tonne of oil equivalent* (***toe***) or *tonne of coal equivalent* (***tce***). However, the use of *toe* is more common than *tce*. The Statistics Division of the United Nations Secretariat and the International Energy Agency defines one tonne of oil equivalent as 10^7 kcal, net calorific value (equivalent to 41.868 GJ). The ***toe*** of various energy sources is shown below.

1 t of crude oil = about 7.3 barrels
1 t of natural gas liquids = 45 GJ (net calorific value)
1,000 standard cubic meters of natural gas = 36 GJ (net calorific value)
1 t of uranium = 10,000–16,000 toe
1 t of peat = 0.2275 toe
1 t of fuelwood = 0.3215 toe

The average energy content of various energy sources in a common unit, such as BTU are given below.

- One barrel of crude oil equals to 42 gallons of crude oil, or 5.8 million BTUs
- One cubic foot (ft^3)of natural gas equals to 1032 BTUs
- One tonne of coal equals to 24 to 28 million BTUs
- One cord of wood equals to 15–24 million BTUs
- Solar heat is capable of providing 0.06 million BTUs per square foot per year
- A 10 m or 33 ft in diameter windmill located in the Great Plains region of the USA with an average wind speed of 20 mph can produce 49,000 kWh per year or 167 million BTUs per year.
- 1 kg of U-235 can produce 78,000 million BTUs.

Example 3.1

How many barrels of crude oil are needed to supply the USA's energy needs for the year 2007?

Solution

Data: US uses about 101.6 quad energy per year.
1 quad = 10^{15} BTU
1 barrel of oil contents about 5.8×10^6 BTU of energy

$$\#\,barrels = \frac{101.6 \times 10^{15}\ BTUs}{5.8 \times 10^6\ BTU/barrel} = 1.752 \times 10^{10}\ barrels$$

Example 3.2

How many cubic feet of gas are needed to supply the USA's energy needs for the year 2007?

Solution

$$\begin{aligned}\#\text{Cubic feet} &= 101.6 \times 10^{15}\ \text{BTUs}/(1.032 \times 10^3\ \text{BTU/ft}^3) \\ &= 9.845 \times 10^{13}\ \text{ft}^3\end{aligned}$$

Example 3.3

How many tons of coals are needed to supply the USA's energy needs for the year 2007?

Solution

$$\#\text{Tons} = 101.6 \times 10^{15} \text{ BTUs}/(24 \times 10^{6} \text{ BTU/t}) = 4.233 \times 10^{9} \text{ t}$$

Example 3.4

How many square feet of land for solar energy are needed to supply the USA's energy needs for the year 2007 (not considering the thermal energy conversion efficiency)?

Solution

$$\begin{aligned}\#\text{Square Feet} &= 101.6 \times 10^{15} \text{ BTUs} /(0.06 \times 10^{6} \text{ BTU/ft}^2) \\ &= 1.693 \times 10^{12} \text{ ft}^2\end{aligned}$$

This is about 61,101 square miles (Note: This is a square of about 247 by 247 miles.

The energy conversion problem is significant. The most cost effective solar cells are less than 10% efficient. Assuming 10% efficiency, to produce 101.6 Quads of electrical energy by solar cells would take a land area of 611,010 square miles (or a square of 782 by 782 miles). This is about the equivalent land area of Arizona, New Mexico, Colorado, Utah, Nevada and Idaho (Arizona covers 114,006 square miles, New Mexico covers 121,598 square miles, Colorado covers 104,100 square miles, Utah covers 84,904 square miles, Nevada covers 110,567, and Idaho covers 83,574 square miles), or alternatively we could choose Texas, California, Nevada and Utah (Texas covers 26,8601 square miles and California, covers 163,707 square miles).

Example 3.5

How many kg of U-235 are needed to supply the USA's energy needs for the year 2007?

Solution

$$\begin{aligned}\#\text{kg} &= 101.6 \times 10^{15} \text{ BTUs}/(78{,}000 \times 10^{6} \text{ BTU/kg}) = 1.295 \times 10^{6} \text{ kg} \\ &= 1.426 \times 10^{3} \text{ t}\end{aligned}$$

Example 3.6

In 2007 the energy used by the US for transportation was 29.10 quads. How many nuclear power plants would it take to produce enough hydrogen to provide the energy needed for transportation? Assume that the conversion efficiency from electricity to hydrogen using electrolysis is 50%. A typical nuclear power plant produces about 1,200 MW electric. Assume that a nuclear power plant operates at 90% of its capacity (capacity factor) for the year. The first step is to calculate the number of BTUs that a nuclear power plant produces in a year.

Energy Produced Per Plant $= 0.9 \times 1{,}200 \times 10^6$ W $\times$ 1 J/s-W $\times$ 1 year $\times$ 365 day/year $\times$ 24 h/day $\times$ 60 min/h $\times$ 60 s/min $\times$ 9.4786 10^{-4} BTU/J
$= 3.228 \times 10^{13}$ BTU/Power Plant

The next step is to calculate the energy in hydrogen converted by electrolysis using the electricity of the nuclear power plant.

Hydrogen Energy Produced per Power Plant = 0.5 $\times$ 3.228 $\times 10^{13}$ BTU/Power Plant = 1.614 $\times 10^{13}$ BTU-Hydrogen/Power Plant

Number of Power Plants Needed for Transportation = 29.10 $\times 10^{15}$ BTU/1.614 $\times 10^{13}$ BTU/Power Plant = **1, 803 Power Plants**

3.4 Power

We are involved every day with energy and power. For example, automobiles and electrical motors are rated by Horsepower, light bulbs are sold by Watts, the price of natural gas is set by Therms, the consumption of electricity is defined by kilowatt-hours, and air conditioners are sold by Tons or BTUs per hour. Some of these are described by energy units, while others are by power unit. Energy is a fundamental unit. From fundamental units, one can derive other essential parameters. An example of this is power. Power is the rate at which energy is used. Power is defined as the energy per unit time. The units of power are:

- Kilowatt
- BTUs per hour – British Thermal Units per hour

Kilowatt

Kilowatt-hour (kWh) is the metric unit of energy. It may be defined as the work or energy equal to that expended by 1 kW in 1 h. One kilowatt-hour is equal to 3,600,000 J or 3.6 MJ, or 3,413 BTUs. Kilowatt, on the other hand, is the unit of power. It is an energy use rate of 1,000 J per second.

MMB/D

MMB/D (equivalent to a million barrels of oil per day) – if all of the energy used by the US, 101.6 quads in 2007, were from oil than the United States uses about 48 MMB/D.

Tara Watt

Tara Watt = TW = 1 trillion watts

Example 3.7

How many kilowatt-hours does a 1 GWe nuclear power plant produce in a year? Assume a capacity factor of 90%.

Solution

$$1 \text{ year} = 1 \text{ year} \times 365 \text{ days/year} \times 24 \text{ h/day} = 8{,}760 \text{ h}$$

$$\text{Energy} = 1 \times 10^6 \text{ kW} \times 0.90 \times 8{,}760 \text{ h} = 7.884 \times 10^9 \text{ kWh}$$

Example 3.8

How many BTUs is 7.884×10^9 kWh?

Solution

$$\text{Energy} = 3{,}413 \text{ BTUs/kWh} \times 7.884 \times 10^9 \text{ kWh} = 2.668 \times 10^{13} \text{ BTUs}$$

Example 3.9

How many Quads are in 2.668×10^{13} BTUs?

Solution

Energy = 2.668×10^{13} BTUs/(10^{15} BTUs/quad) = 2.668×10^{-2} quad

Example 3.10

How many MMB/D are in 2.668×10^{-2} quad?

Solution

Energy = 2.668×10^{-2} quad/(2.1 quad/MMB/D) = 1.284×10^{-2} MMB/D

Example 3.11

What percentage of the US energy use does a 1 GWe nuclear plant produce?

Solution

% of US Energy Produced = $100 \times 1.284 \times 10^{-2}$ MMB/D/(48 MMB/D) = 0.02675%

Example 3.12

It is given that a light bulb has a power rating 100 W. This is a rate at which the bulb uses energy. What will be the energy consumption of ten, 100 W bulbs in 1 h in British units?

Solution

Ten 100 W light bulbs turned on for 1 h is equivalent to:

100 W × 10 light bulbs × 1 h = 1,000 W hours = 1 kWh = 3,413 BTU

Example 3.13

How many 100 W light bulbs will be required to consume 101.6 quads of energy per year?

Solution

From the previous problem, one 100 W light bulb consumes 341.3 BTU per hour. There are 24 h in a day. There are 365 days in a year and therefore 8,760 h per year. Thus a single 100 W light bulb will use 2,989,788 BTUs per year if it is on for the whole year.

Number of light bulbs = $101.6 \times 10^{15}/2.989788 \times 10^{6}$ = 34 billion light bulbs

References

1. Metric Act of 1866, Public Law 39-183, U.S. Congress, 28 July 1866.
2. U.S. Metric Study Act of 1968, Public Law 90-472, U. S. Congress, 9 August 1968.
3. Metric Conversion Act of 1975, Public Law 94-168, U. S. Congress, 23 December 1975.
4. Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (3/23/2009) Electric Power.

Problems

1. The universal Gas-law constant in cal/(gmol K) is 1.987. What is its value in cubic centimeters atm/(gmol K), (lb.in^2) (ft^3)/(lbmol°R), (atm ft^3)/(lbmol°R), and (lb/ft^2) (ft^3)/(lbmol°R)?
2. The unit of viscosity in SI units is generally given in centipoise (g/(s cm). Convert 1 centipoise to British units (lb/(s ft).
3. Thermal conductivity of water at 32°F in British units is 0.32 Btu/(h)(ft^3)(°F/ft). Convert this to SI unit.
4. Calculate the energy content of (a) one barrel of crude oil (b) one cubic foot of natural gas (c) one short ton of coal (d) one cord of wood (e) 1 kg of U 235 in the following units (1) calorie, (2) joules, (3) ft-lb, and (4) kWh.