Measuring Energy and Power

In the science of mechanics, energy was originally defined in terms of work, which is the product of a force acting through a distance. In SI notation, the unit of energy is the joule and is defined as a force of 1 newton acting through a distance of 1 metre, or

1 joule = 1 newton-metre.

Other forms of energy such as heat were originally considered to be independent quantities and thus independent units of measurement were defined to quantify them. Now that we know that the various forms of energy are equivalent, however, we can use conversion factors to go from one type of measurement to another. Before the SI scheme was adopted, the energy content of such commodities as crude oil, petroleum products, natural gas and coal was normally expressed in British thermal units (Btu) while quantities of electrical energy were described in kilowatthours (kWh). The appropriate energy conversion factors are

1 Btu = 1,054 joules = 1.054 kilojoules, and

1 kWh = 3,600,000 joules = 3.6 megajoules.

Power is a measure of how fast energy is being or can be delivered. Thus power equals energy divided by time. The SI unit of power is the watt, which is defined as

$$1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}.$$

When work is being done at the rate of 1 joule per second, the power involved is 1 watt. Since all types of energy are measurable in joules, the *rates* of all types of energy transformations are measurable in watts. In the past, power was typically expressed in Btu per hour, watts or horsepower, so we require the power conversions

1 Btu per hour = 0.293 watt, and

1 horsepower = 746 watts.

When power is generated at a constant rate, the amount of energy produced in a given time is

energy = power x time.

In other words, 1 joule = 1 watt-second. To take a familiar example, we pay our electricity bills on the basis of the number of kilowatthours of electrical energy we have used over the billing period. To calculate the energy represented by one kilowatthour, we multiply power by time, or

1 kWh = 1,000 watts x 3,600 seconds (in one hour)

= 3,600,000 watt-seconds

= 3.6 megajoules.

ing station is one which is capable of delivering 500 million watts of electrical power.

Since the joule and the watt are small measures of energy and power, we will be working with multiples of these units. Five prefixes in the SI scheme cover most of the quantities used in this Report, as shown in the following examples.

SI PREFIX	SYMBOL	VALUE	EXAMPLE
kilo	k	10^3 (thousand)	kilovolts (kV)
mega	M	10^6 (million)	megatonnes (Mt)
giga	G	10^9 (billion)	gigawatthours (GWh)
tera	T	10^{12} (trillion)	terawatts (TW)
peta	P	10^{15} (quadrillion)	petajoules (PJ)

If the reader will keep in mind these five multipliers, then he will understand references to an electrical transmission line in kilovolts, to Canada's annual coal production in megatonnes, to Quebec's sale of electrical energy to the United States in gigawatthours, to world electrical generating capacity in terawatts, and to Canadian energy demand in petajoules.

Let us now consider the Earth's natural energy budget or the manner in which energy flows through our planet's surface environment. Since we are looking at rates of energy flow, we are concerned with measuring power. And, because the amounts of power involved are very large, the unit which we will employ is the terawatt (10^{12} watts or trillions of watts).

Energy inputs to our environment come from three sources: (1) solar radiation intercepted by the Earth; (2) tidal energy derived from the combined gravitational fields of the moon and sun; and (3) geothermal (or terrestrial) energy reaching the Earth's surface from its hot interior. Energy losses from the Earth can be considered in one of two categories. First, approximately 30% of the incoming solar radiation is directly reflected by the atmosphere into space as short-wave radiation. Second, the remaining solar energy, together with the geothermal and tidal energy, undergoes a sequence of irreversible degradations in our environment, reaching an end stage as heat at the lowest local temperature. In this state it is radiated from the Earth into space as long-wave thermal radiation.

Figure 2-1 is a generalized representation of the energy flow through the Earth's surface environment. As can be seen from the illustration, solar radiation dominates this flow, being estimated at a power of 174,000 x 10^{12} watts. The terrestrial energy flow is more than three orders of magnitude smaller at an estimated power of 32 x 10^{12} watts. Even smaller is the input of tidal energy at 3 x 10^{12} watts. In other words, the relative power inputs in units of terrawatts are:

solar radiation	174,000
geothermal power	32
tidal power	3