Energy and Power

Man does not understand what energy is despite the fact that it is intrinsic to every part of his environment. We learn in school that energy represents the ability to do work, that literally nothing can be accomplished without the expenditure of energy and that energy exists in a variety of forms which can be characterized by mathematical formulae. We discover that it can be described as gravitational potential energy, elastic energy, radiant energy, heat energy and so forth, but we cannot state what energy actually *is*.

While this state of affairs may seem disconcerting, it does not represent any difficulty in what we are considering here. The United States could not have put a man on the moon if accomplishing that feat had meant understanding the force of gravity. What was required was a mathematical expression describing the action of gravity so that the proper flightpath of the Apollo spacecraft could be computed. Since Isaac Newton had obliged NASA by formulating his law of gravitation nearly three centuries earlier, that lack of understanding was not a barrier to success.

So it is with our study. We need only to understand the behaviour of energy in its various manifestations. Man has learned, for example, that energy is conserved; it is neither created nor destroyed in being transformed from one type to another. Thus, while we speak loosely of "consuming" energy, we really mean that we are *exploiting* it for some purpose. An important result of this law of nature — the law of energy conservation — is that one unit of measurement can therefore be used to quantify all forms of energy. In the SI (Système International) scheme of measurement being adopted in Canada, that unit is the *joule*. The reader is referred to Appendix A of this Report for a discussion of units and conversion factors.

Another fundamental energy relationship concerns the direction which energy transformations take. Exploiting energy invariably results in changing it to a less useful form. (This idea of the "usefulness" of various forms of energy is dealt with in a branch of physics known as thermodynamics — a subject which we need only touch upon here.) Although the concept is subtle, it has been well expressed by the American scientist M.K. Hubbert.

> ...not only is energy continuously transformed from one form to another in processes occurring on the earth, but these transformations occur irreversibly from a form of higher availability to one of lower availability. During the process the energy, while not destroyed, is progressively degraded in terms of its potential usefulness, and finally ends up as heat at the lowest environmental temperature. From this state there is nowhere else for the energy to go except by low-temperature, long-wavelength thermal radiation into the still colder regions of outer space. (Hubbert, 1974, p. 8)

Expressing the idea another way, there is no such thing as a perpetual motion machine because there are energy losses in any process.

In many situations we are interested in measuring how fast energy is being or can be delivered, for example at a power station. Power refers to the rate at which energy is being dissipated or converted. Since all types of energy are measurable in joules, it follows that the rates of all types of energy transformations are measurable in a common unit and the SI unit of power is the *watt*. One watt is defined as the delivery of one joule of energy per second. A 500 megawatt electrical generat-

The Equivalence of Energy and Mass

A profound extension to the law of conservation of energy was provided by Albert Einstein who showed theoretically that there is an equivalence between energy and mass. This equivalence was embodied in his famous equation: energy equals mass multiplied by the square of the velocity of light ($E = mc^2$). Einstein's equation is normally applied in circumstances which are far beyond man's everyday range of experience and only becomes relevant, for example, in examining the subject of nuclear energy.

We recognize that life on Earth is sustained by the output of an immense fusion reactor — the sun. Solar radiation dominates all other forms of energy delivered into the Earth's surface environment and that energy is the product of hydrogen nuclei fusing within the sun's core, in a process which converts mass into energy.