

PRESIDENTIAL ADDRESS

AVAILABLE ENERGY

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There is much current writing and discussion about energy and, in particular, the atomic and nuclear variety. Concerning the concept of energy, there is some careless thinking and frequent misconception. For we live in a universe filled with many different forms of energy which are never destroyed but which may be transformed. When energy is needed for any purpose, it must be supplied in a form suitable for the job intended. It is customary to think of such energy as available energy and to ignore other forms as if they did not exist, simply because they are not available.

To illustrate this, consider the immense amount of energy in an ocean. Such a supply is usually thought of as heat energy. Some of this energy goes to melt icebergs; is replenished by absorption of light from the sun; but cannot be used to propel a boat. To be available to operate a boat, the energy must be at a higher temperature than the ocean. Hence, the energy from burning fuel is available, in part at least, to drive the engine in the boat.

Fuel energy available for heating and for operating engines has been stored in the earth by plants and the like, having originally come from the sun. The sun sends out energy at such a tremendous rate that if all

that strikes the earth could be retained and stored, there would be enough in a few weeks to equal all that stored as gas, oil, coal, and oil-shale over the millions of years that the sun has been shining on the earth. This seems surprising, but plants are very inefficient at trapping and storing solar energy, yet no other general means has ever been devised. Solar energy is given off by our sun, whose effective surface temperature is about 6000°C. This is almost too hot to be used in an engine, but is so very diffused that only about 2 calories per square centimeter per minute is received from the sun at the earth.

To be available, energy must have appropriate temperature and concentration. In an engine, temperatures as high as 2000°C can be readily managed. Higher temperatures soon become troublesome, for there are no satisfactory materials for building engines which will be durable at such temperatures. Energy coming from known chemical reactions can maintain temperatures of a few thousand degrees. In internal combustion engines, turbines, and rockets, such energy is used for propulsion or transformation into electrical form.

Suppose Q_1 to be the heat of some chemical reaction in some mixture

such as a hydrocarbon and oxygen. This energy may be thought of as a quantity supplied to an engine. Receiving this energy allows the engine to do an amount of work, W . A large part of Q_1 is, however, always discarded, as hot gases for instance in an internal combustion engine, and also in cooling devices designed to assimilate the discarded part of Q_1 under circumstances as favorable as practicable. Calling the discarded energy Q_2 , the law of conservation of energy—also known as the first law of thermodynamics—says that

$$Q_1 = W + Q_2 \quad (1)$$

When fuels are burned in a furnace and used for heating, Q_1 is evolved at say 1500°C , W is zero, and Q_2 is equal to Q_1 , appearing as heat at the temperature level desired, say 20°C . Q_1 is available for use as heating energy only if its temperature is above 20°C . All the heat in the ocean cannot supply even heat to a boat unless the ocean temperature is higher than that desired in the boat. It is a characteristic of all heat energy that it cannot, of itself, flow uphill in temperature. This, in a superficial way, is a statement of the second law of thermodynamics.

The process suggested in equation (1) is not an entirely reversible process. However, heat to an amount Q_2 can be taken out of the inside of a refrigerator, for example by supplying an appropriate amount of work W with a motor or some equivalent device. The result of this process is

$$Q_2 + W = Q_1 \quad (2)$$

The heat Q_1 is rejected by the hot coil of a refrigerator to its surroundings while Q_2 is removed from the inside. Q_1 is greater than Q_2 by an

amount W . Equation (2) gives, in principle, the heat pump. In winter, for instance, Q_2 may be taken from the water in a deep well, an amount W added to it with a suitable motor, and the entire amount Q_1 used to heat the house. The only part of this energy which is supplied by a commercial fuel is W . Since Q_2 types of heat energy are available in essentially limitless supply, great savings on the more costly type of energy, represented by W , can be accomplished by using sources whose supply of Q_2 is almost available.

In the ideal engine, it is possible to get work W from heat Q_1 to an amount

$$Q_1 - Q_2 = W \quad \text{where} \quad \frac{Q_1}{Q_2} = \frac{T_1}{T_2} \quad (3)$$

T_1 and T_2 are the absolute temperatures of the hot, Q_1 , source and the cold, Q_2 , source respectively. Any actual engine will not do as well as equation (3). The efficiency of an engine is given by

$$\frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} < \frac{T_1 - T_2}{T_1} \quad (4)$$

In a case where fuel maintains T_1 at say $10,000^\circ\text{K}$ ($\text{K} = ^\circ\text{C}$ on absolute scale) and a cooler takes reject heat at 500°C , the efficiency will

always be less than $\frac{10,000 - 500}{10,000} =$

95 percent but may approach this 95 percent in an ideal case. (See equation 4).

This brings us to the atomic problem. In the bomb, temperatures of $100,000,000^\circ\text{K}$ are probable. But the efficiency of an engine run by such energy will be conceivably equal to

$$\frac{100,000,000 - 500}{100,000,000} = 99.9995 \text{ percent}$$

at best. This is very little better than the 95 percent efficiency. Furthermore, there is no material for construction which will hold together at even the $10,000^{\circ}\text{K}$. To use atomic nuclear energy, massive installations are necessary to lower the temperature of this energy to below the $10,000^{\circ}\text{K}$ level before it can be used for practical purposes. Only a very few processes above the $10,000^{\circ}\text{K}$ level are of any interest to the everyday world. One of these, the destruction by atomic bomb, we almost wish had never been discovered. Mankind lives at around 300°C . Processes involving energy at temperatures far from this value are dangerous and apt to be highly destructive. They are the really unavailable types of energy.

There is a vast supply of energy just below the 300°K level in this earth everywhere about us. Using a heat pump, it is quite possible to

make this energy available, and increasingly engineering is making it practical to utilize this energy for heating purposes. The plant which traps solar energy in fuel form maintains itself in this earth at suitable temperature and in a very real sense is able to trap the solar energy in a usable form. Solar energy traps designed to bypass the plant will surely use the heat pump also, for the solar energy comes from such a high temperature source that, to a large percentage, it may be thought of as a *W* form and is correspondingly useful if sufficiently concentrated.

The only practical advantage of nuclear energy is that it can be tremendously concentrated, though so far the process has been tremendously expensive. New processes unknown and unimagined as yet must be discovered if the possibilities of nuclear energy which can be associated with temperatures above $10,000^{\circ}\text{K}$ are to prove useful. These energies will then be "available" in the usual sense.