ENERGY

G. P. Rao, B. Makkawi, A. Woldai, R. J. Hornby and D. Al-Gobaisi
International Center for Water and Energy Systems, Abu Dhabi, UAE

Keywords : Albedo, Biomass, Breeder reactor, Entropy, Fuel cell, Geothermal gradient, Insolation, Wells' turbine

Contents

Summary

The role of energy in human activities is briefly discussed and the status of energy resources in the global scenario is outlined. Basics concepts of energy and energy systems are introduced with the help of simple illustrations with an emphasis on renewable energy sources and systems for a sustainable future. Sources are suggested for further reading in depth.

1. Humanity's Need for Energy

Since the dawn of civilization, humanity's level of development has been inextricably linked to the use of energy. All animals consume food to provide the energy needed for metabolism, movement and work, but ours is the only species which uses external energy, other than food, to any significant extent. The process began with the discovery of fire - a process in which the energy contained within organic molecules (primarily in wood) could be converted into heat. This provided the ability to cook food, and thus the ability to use a much wider range of food items. Fire also provided heating which enabled humans to survive in colder climates. The next breakthrough in harnessing energy came with the use of animals such as the donkey as a means of transport and a beast of burden, and oxen to till the soil. Fire was then used in the production of improved tools made of bronze and iron, which transformed the way of life for much of humanity. Machines, such as the wheel, were developed to permit more efficient use of external energy. The pyramids are a monument to the devices which must have been developed to provide mechanical advantage, although the energy used was still primarily manpower. Further harnessing of energy was achieved by the use of streams to turn a wheel, and, in due course, windmills. Wood or charcoal was burnt to produce lime, which permitted the construction of more elaborate buildings. Right up to the time of large-scale use of coal, which led to the Industrial Revolution, humans had only been using renewable energy, supplied by the sun.

Combustion of coal, followed by oil and natural gas, permitted a quantum leap in transportation (and hence trade) and manufacture of a vast range of products, all of which enabled human societies to become more complex, and, for most people at least, to enjoy an enhanced quality of life. Our consumption of energy continues to grow, despite major efforts at increasing efficiency.

Solar energy has thus permitted the development and civilization of the human race but we must not forget that it also facilitates the growth and survival of all forms of life and it drives the global circulation systems. Thus ocean currents, climate, rainfall and all freshwater resources, are dependent on the energy of the sun. Without the sun there would be no fresh water!

Thus for most of history, all activity, human and otherwise, was dependent on energy in the form of solar radiation. This can be regarded as *solar capital*. In relatively recent times humanity has learned to exploit the natural resources of the earth to produce energy, but this is using a legacy which is not being replaced. Coal, oil and natural gas are fossil fuels. For a few centuries they are providing an enormously useful bonus, but the reserves are being depleted and we can only rely on them for a few more generations. Fossil fuels represent a major component of what can be regarded as *earth capital*. This includes natural resources such as minerals and human resources. These two forms of capital support and sustain all life and all economies on earth.

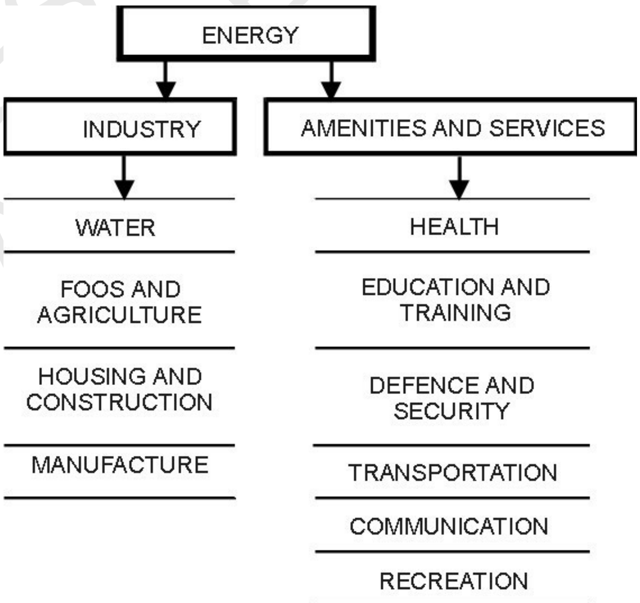

Figure 1. Energy for various sectors of human life and activity.

Thus energy is essential for all human activities, and by harnessing external energy on a massive scale, humans have managed to dominate the earth. Figure 1 indicates the range of human activities, driven by energy.

2. Physical Concepts of Energy

The word "energy" is derived from the Greek "ergon" which signified work, vital power and vigor. Today energy signifies the ability to do work, and they commonly share the same units. Physical work can be defined as the movement of a body in the same direction as a force, and the energy required is the product of the mass and the distance moved. A moving body also contains energy as a result of its motion. The energy of a body of mass m and velocity v can be expressed as

$$W = \frac{1}{2} mv^2$$

The potential energy of a body can be regarded as equivalent to the work done to provide the body with that energy. Other forms of energy are more complex but they all have an equivalence. They include thermal energy, electromagnetic energy, chemical energy and nuclear energy. All these possess the ability to do work as a result of the energy contained within the component parts of their atoms and molecules.

As energy can be converted into heat, a useful measure of energy is its ability to raise the temperature of a body. The Imperial unit was the British Thermal Unit (Btu), which was the heat required to raise the temperature of 1 lb of water by 1°F. A more frequently used unit is the calorie - the heat required to raise the temperature of 1 g of water by 1°C. These units have now been largely replaced by the SI unit which is the joule (J), defined as the work done when the point of application of a force of one newton moves, in the direction of the force, a distance of 1 m. A Newton (N) is the SI unit of force, being the force required to give a mass of 1 kg an acceleration of 1 m s^{-2} (metre per second per second).

One Btu is equivalent to 1055.06 J, and one calorie is equivalent to 4.1868 J.

The rate at which energy is consumed is known as power, and the SI unit of power is the Watt, which is defined as 1 J s^{-1}. In electrical terms 1 watt is the rate of energy transformation by an electric current of one ampere flowing through a conductor the ends of which are maintained at a potential difference of one volt.

The concept of energy in society has become almost independent of the above physical parameters, but it is always possible to fall back on physical principles to ensure equivalence. In human society a distinction has arisen between primary energy and secondary energy. Primary energy refers to energy resources, and can be subdivided into fossil fuels, nuclear energy, geothermal energy (essentially the heat within the earth's core), and natural energy (renewable energy derived either directly or indirectly from the sun). Secondary energy is the form of energy into which humanity processes primary energy in order to make it more accessible and manageable. The most common form of secondary energy is electrical, but other kinds include thermal (stored heat), kinetic (e.g. a flywheel) and chemical (e.g. fuels such as petroleum, food and stored fats).

3. Non-renewable Energy Sources

3.1. Fossil fuels

Despite the abundance of solar energy, and the fact that all life on earth depends on this energy, the vast majority of the energy used by humanity comes from non-renewable sources, principally "fossil fuels" in the form of hydrocarbons deposited in the lithosphere over millions of years. These resources are rapidly being depleted, and humanity will have no option but to switch to renewable energies.

Fossil fuel deposits are the result of storage of the remains of dead vegetation or animals over a very long period of time. Carbon happens to be the key element of life and hence of the fossil fuels. This material moves through the so-called carbon cycle, which is depicted in Figure 2.

The global distribution of fossil fuels is very uneven. Most of the countries fortunate enough to have large resources of oil and natural gas have seen tremendous economic and infrastructure development. This is particularly true of the Arabian Gulf region. About half of the known remaining reserves of oil and gas are in the countries of the Middle East, including Iran. In global terms, these countries have relatively small populations, and they have been able to export most of their production. This is obviously very crucial to the future of the world's energy supplies and the global political economy. The energy content of some fossil fuels is as follows: Natural Gas: 5.8×10^7 J kg^{-1} and Petroleum: 4.4×10^7 J kg^{-1}. Therefore, 1 gallon of petroleum and 4.249 m^3 of natural gas (at standard pressure) have the same energy content.

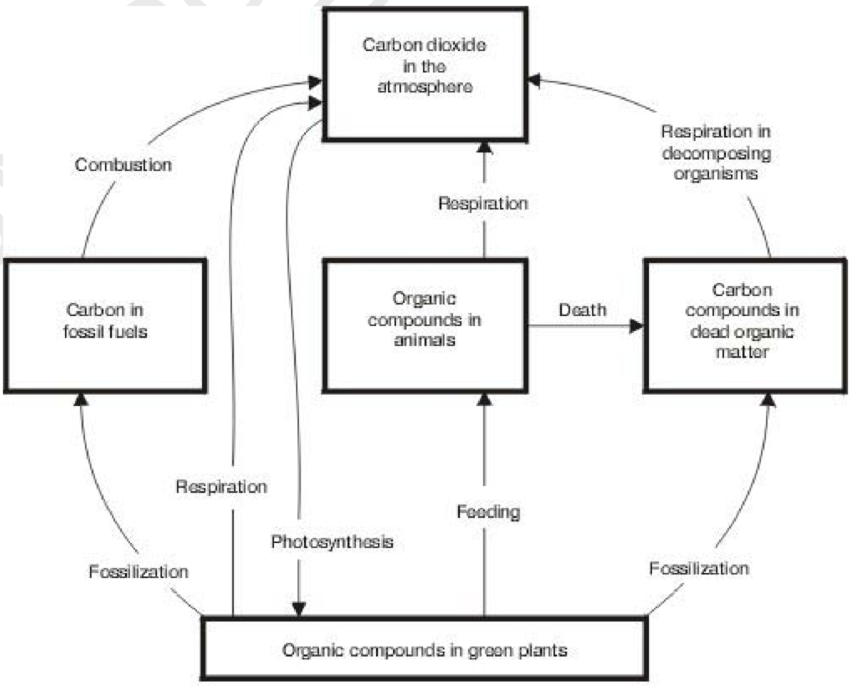

Figure 2. The carbon cycle in nature.

3.1.1. Oil

Petroleum geologists have estimated that the earth's original "fuel tank capacity" was about 2000 billion barrels of "conventional oil", or oil that can be made to flow from wells (i.e. excluding oil from tar sands and shale). Of this vast resources about 1600 billion barrels have so far been discovered, and just over 800 billion barrels had been used by the end of 1997. It is estimated that there may be a further 400 billion barrels of conventional oil yet to be found. With current annual global consumption of oil being approximately 25 billion barrels, and rising at 2 per cent per annum, the "business as usual" scenario would suggest that the remaining oil would be exhausted by 2050.

The supply of oil will undoubtedly be boosted by an increase of supplies from unconventional sources, notably the tar sands and shale of Canada and the "Orinoco sludge" of Venezuela. This oil can only be extracted using high-energy inputs, and at very high environmental costs. There will be strong political and international pressure against development of these resources, but, when world oil prices are high enough, production will inevitably increase. In theory, unconventional oil could stretch the world's oil supply by another 30 years. In practice, of course, the rate of consumption of oil will be heavily influenced by economic and many other factors, so that prediction in this area is very difficult. It is clear, however, that one of the most important of the influencing factors will be the relative cost of renewable energy and how quickly the world can switch to sustainable technologies. There is nothing to gain by deferring investment in this area, and everything to lose by postponing it any further.

Clearly, humanity needs to change over to renewable energy sources as quickly as possible. In terms of global aggregated figures, there is no doubt that at some point in the next few decades, the energy required to find and extract a barrel of oil will exceed the energy contained in the barrel. At that point it will only be economic to find and extract the barrel if part of the energy required is obtained from renewable sources. Sustainable solutions have to be developed through using less energy, switching to renewable energy and by stretching out the supply of non-renewable resources for as long as possible. Humanity probably has no more than one or two generations in which to achieve the transition from non-renewable to renewable energy.

3.1.2. Coal

Coal is usually classified into the following categories:

Type	Physical features	Characterization
Lignite	Brown to brownish black	Poorly consolidated, weathers rapidly and contains visible plant residues
Sub-bituminous	Black with dull or waxy luster	Weathers easily with faintly brown plant residues
Bituminous	Black, dense and brittle	Does not weather easily. Plant residues visible under microscope. Burns with short blue flame
Anthracite	Black, hard with glassy luster	Very hard and brittle. Burns with almost no smoke

Coal reserves of the world are more abundant than oil reserves, but it is a very dirty fuel, producing huge quantities of polluting ash and much larger emission of carbon dioxide and sulfur dioxide per unit of useful heat than is the case with either oil or gas. Carbon dioxide is the principle greenhouse gas contributing to global warming, and sulfur dioxide is the principle cause of acid rain. Coal mining has adverse effects on land use, landscape and human health. Its use has started to decline but at current rates of production the world's resources should be sufficient to last for a few centuries.

3.2. Nuclear energy

If one compares the energy per unit mass of different fuels, it is nuclear fuels which exceed all other resources by a very large margin. In fact, one kilogram of the best grade coal contains 3.4815×10^4 kJ (3.3×10^4 BTU) while an equal amount of nuclear fuel U^{235} contains 7.2795×10^{19} kJ (6.9×10^{19} BTU) of energy. Thus nuclear resources may run longer, but the risk of accidents, pollution, and the problems of nuclear wastes pose a great challenge. Nuclear energy processes are based on fission or fusion, the former being common in practice. Much research and development is needed to realize fusion based systems, which in theory offer many advantages, particularly from the environmental point of view.

Fission based nuclear reactors are designed with the following components:

- Reactor core containing nuclear fuel rods (^{235}U, fissionable 3 per cent; ^{238}U, nonfissionable 97 per cent)
- Control rods (Boron/Cadmium)
- Moderator (Graphite/water)
- Coolant (Water/Sodium)

Figure 3 shows the essential features of a thermal reactor core and Figure 4 shows a liquid metal fast breeder reactor. Fast breeder reactors such as the one shown in Figure 4 are based on the fission of ^{238}U whose product Plutonium is fissionable:

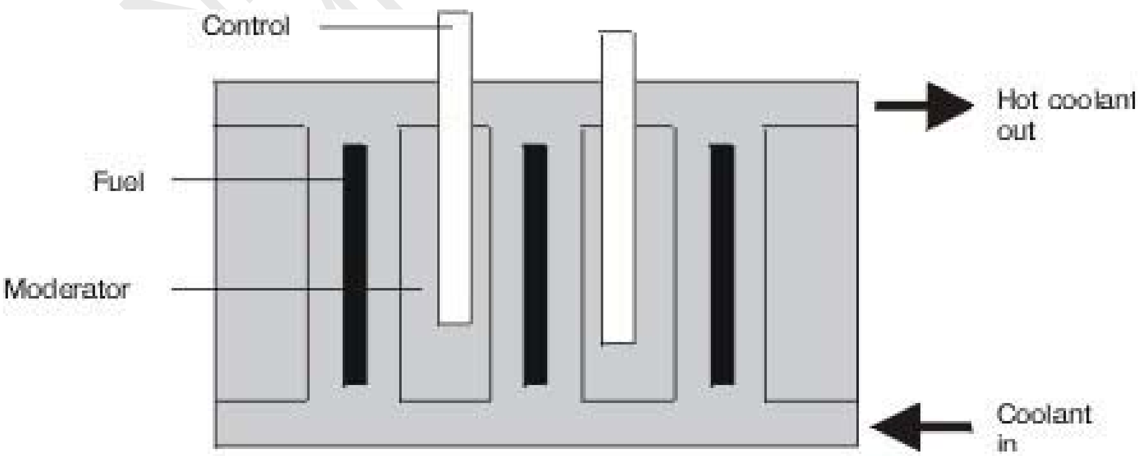

Figure 3. Schematic of a nuclear thermal reactor core.

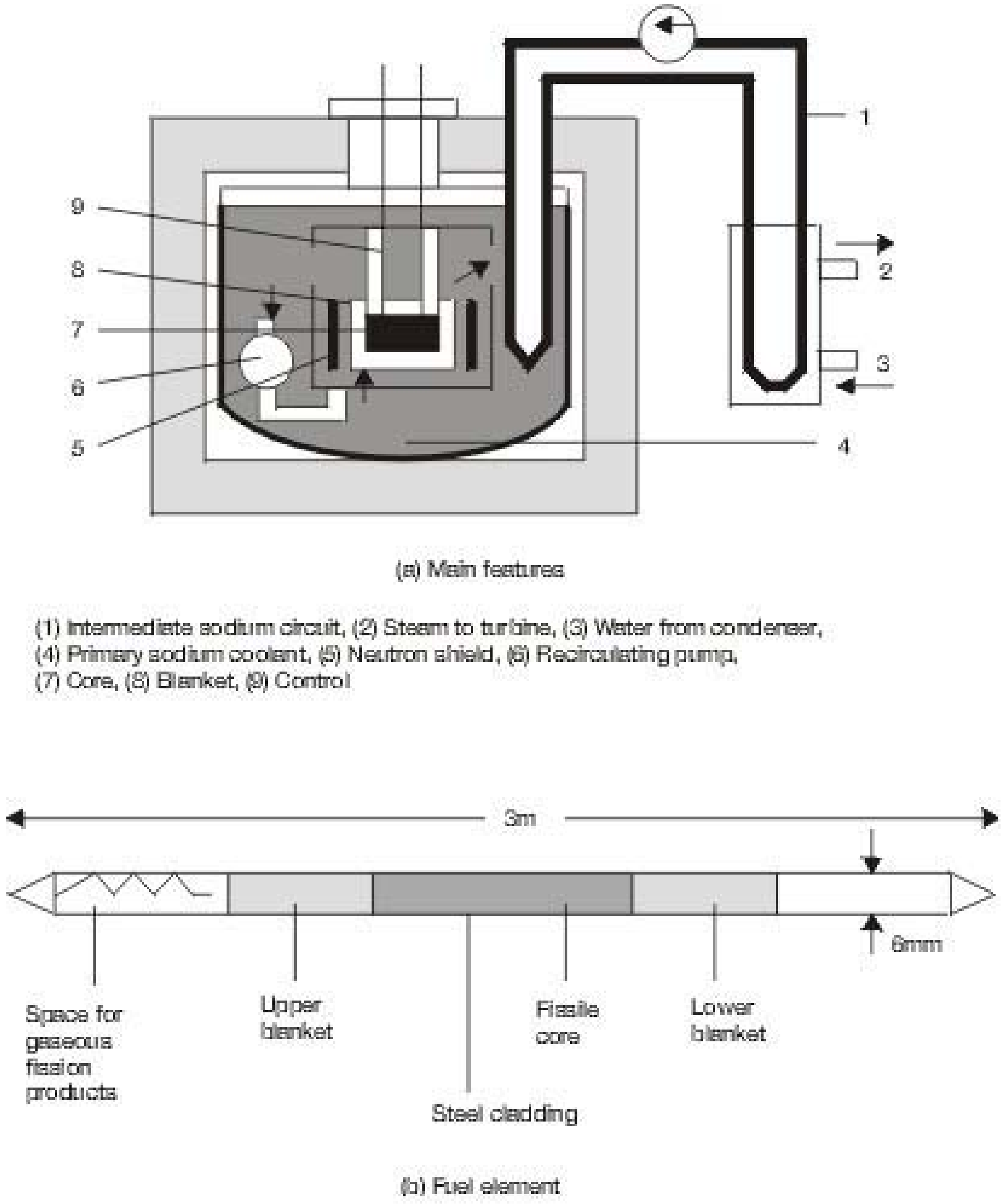

Figure 4. A liquid metal breeder reactor.

-
-
-

Bibliography and Suggestions for further study

Baker C (1991) *Tidal Power*. Peter Peregrinus. [This presents a comprehensive study of tidal power.]

Baria R (ed.) (1990) *Hot Dry Rock Geothermal Energy*. London: Robertson Scientific Publications.

Boyle G (ed.) (1996) *Renewable Energy*. The Open University and Oxford, UK. [This book extensively and attractively illustrates the basic principles of all forms of renewable energy systems. There is a chapter on integration that discusses how these systems may be integrated in the existing energy systems.]

Cassedy E S and Grossman P Z (1993*) Introduction to Energy - Resources, Technology, and Society*. Cambridge: Cambridge University Press.

Green M (1982) *Solar Cells*. Prentice Hall. [A physics oriented overview of solar cells.]

Hall D O and Rao K K (1987) *Photosynthesis*. 4th edition. London: Edward Arnold. [A concise but very useful presentation of biomass as an alternative renewable source of energy.]

Hoagland W (1995) Solar Energy. *Scientific American* 273, 170-173. [This is brief report critically analyzing the case for solar energy.]

Hughes E (1970) *Electrical Technology*. London: Longman.

Laughton M A (ed.) (1990) *Renewable Energy Resources*. Watt Committee Report No. 22. Section 2, Elsevier Scientific Publishers, Essex.

Patterson W (1995) *Power from Plants*. Earthscan. [Presents a well informed account of recent trends in electricity generation from biomass.]

Price R (1991) *Tidal Energy: Proceedings of the World Clean Energy Conference*. Geneva, 4-7 November, pp. 277-295. [This paper presents a useful review of tidal energy technology.]

Rogers G and Mayhew Y (1992) *Engineering Thermodynamics Work and Heat Transfer*. NY: Longman Scientific and Technical.

Ross D (1995) *Power from the Waves*. Oxford: Oxford University Press. [A popular presentation on the subject of wave energy.]

Shepard M L, Chaddock J B, Cocks F H and Harman C M (1978) *Introduction to Energy Technology*. Ann Arbor, USA: Ann Arbor Science Publishers.

Sorensen B (1991) Renewable Energy: A Technical Overview. *Energy Policy*. May.

Streeter V L and Wylie E B (1979) *Fluid Mechanics*. 7th edition. NY: McGraw Hill. [This is a well established text on the principles of fluid mechanics applicable to the understanding of the operation of turbines.]

Twidell J W and Weir A D (1986) *Renewable Energy Resources*. E.F. Spon [Chapter 12 in this book presents the principles of wave energy and is a good introduction to the subject.]