NATURAL AND ADDITIONAL ENERGY

Marc A. Rosen
Department of Mechanical Engineering,
Ryerson Polytechnic University, Toronto, Ontario, Canada

Keywords: Natural energy, additional energy, renewable energy, sustainable development, efficiency, energy source, energy currency.

Contents

Summary

Energy is used in almost all facets of life and in all countries, and directly impacts living standards. Energy forms can be categorized in many ways, one of which is natural and additional energy. This article describes these energy categories and their applications. In

the article, energy forms, sources and carriers are discussed and energy-conversion technologies briefly described.

Then energy use is covered, along with the impact of energy use on the environment. Energy selection and efficiencies are described, along with efficiency-improvement measures. Finally, energy and sustainable development is discussed, and a case study is presented involving energy-utilization efficiency of a university.

1. Introduction

Energy is used in almost all facets of life and in all countries. Different regions and societies adapt to their environments and determine their own energy resources and energy uses. The standards of life achieved in countries are often a function of energy-related factors.

This article provides a basic understanding of natural and additional energy and describes some of the applications in which they are used. This knowledge forms a foundation for understanding various kinds of energy devices and systems and provides a basis for energy education, standards and agencies.

In this article, material is presented on energy forms, sources and carriers. Next, natural and additional energy are discussed and energy-conversion technologies briefly described. Then, energy use is discussed, both generally and in particular for countries, regions and sectors.

The impact of energy use on the environment is described and factors in energy selection are discussed. Efficiencies for energy use are presented, along with measures to improve energy efficiency. Then, the relation between energy and sustainable development is described. Finally, a case study involving many different energy types is presented, in which measures are implemented to increase the energy-utilization efficiency of a university.

This article is the first of a group on the topic of "energy, culture and standard of life." Subsequent articles on this topic cover energy use and living standards in different regions, the interaction of living standards with environmental limitations and energy savings, the effectiveness of energy production for maintaining living standards, and energy organizations.

2. Energy

Energy can exist in many forms, and can be converted from one form to another, using energy-conversion technologies. We use energy carriers (often simply referred to as energy), which are produced from energy sources, in all aspects of living.

Energy is characterized by the Laws of Thermodynamics. The First Law embodies the principle of conservation of energy, while the Second Law relates to the quality of energy, and often includes the concepts of entropy and exergy. Exergy, being critical to discussions of energy, is discussed further in Section 6 of this article.

2.1. Energy Forms, Sources and Carriers

Energy Forms. Energy comes in a variety of forms, including fossil fuels (e.g., coal, oil, natural gas), fossil fuel-based products (e.g., gasoline, diesel fuel), uranium, electricity, work (such as the mechanical energy in a rotating engine shaft), heat, heated substances (e.g., steam, hot air), light and other electromagnetic radiation.

Energy Sources. Energy resources (sometimes called primary energy forms) are found in the natural environment. Some are available in finite quantities (e.g., fossil fuels, fossil fuel-containing substances such as oil sands, peat and uranium). Some energy resources are renewable (or relatively renewable), including sunlight (or solar energy), falling water, wind, tides, geothermal heat, wood and other biomass fuels (when the growth rate exceeds or meets the rate of use). Energy resources are often processed from their raw forms prior to use.

Energy Carriers. Energy carriers (sometimes called energy currencies) are the energy forms that we transport and use, and include some energy resources (e.g., fossil fuels) and processed (or secondary) energy forms (e.g., gasoline, electricity, work and heat). The processed energy forms are not found in the environment.

The distinction between energy carriers and sources is important. Energy carriers can exist in a variety of forms and can be converted from one form to another, while energy sources are the original resource from which an energy carrier is produced. Misunderstanding sometimes results between energy sources and carriers because some energy sources are also energy carriers. For example, confusion is often associated with the use of hydrogen as an energy carrier. Hydrogen is not an energy source, but can be produced from a wide range of resources using various energy-conversion processes (e.g., water electrolysis, reforming of natural gas and coal gasification). Nevertheless, hydrogen is often erroneously referred to as an energy source, especially in discussions of its potential future role as a chemical energy carrier to replace fossil fuels.

2.2. Natural and Additional Energy

The types of energy discussed in the previous subsection can be categorized as follows:

- natural energy, which includes the energy received directly and indirectly from the sun as well as energy derived from other natural forces, and

- additional energy, which includes non-renewable energy resources as well as energy forms that do not exist naturally but are produced by people.

The main types of energy in each of these categories are listed in Table 1.

Natural Energy
Direct solar radiation
Solar-related energy
Hydraulic energy (falling and running water, including large and small hydro)
Wave energy

Wind energy
Ocean thermal energy (from temperature difference between surface and deep waters of the ocean)
Biomass (where the rate of use does not exceed the rate of replenishment)
Non-solar-related energy
Geothermal energy (internal heat of the earth)
Tidal energy (from gravitational forces of the sun and moon and the rotation of the earth)
Additional Energy
Energy sources
Fossil fuels
Conventional
Coal
Oil
Natural gas
Alternative
Oil shales
Tar sands
Peat
Non-fossil fuels
Uranium
Fusion material (e.g., deuterium)
Wastes (which can be used as energy forms or converted to more useful energy forms)
Energy currencies
Work
Electricity
Thermal energy
Heat (or a heated medium such as hot air, steam, exhaust gases)
Cold (or a cooled medium such as cold brine, ice)
Secondary chemical fuels
Conventional
Oil products (e.g., gasoline, diesel fuel, naptha)
Synthetic gaseous fuels (e.g., from coal gasification)
Coal products (e.g., coke)
Non-conventional
Methanol
Ammonia
Hydrogen

Table 1.Types of Natural and Additional Energy

2.2.1. Natural Energy

Natural energy includes the solar radiation incident on the earth, and the energy forms that directly result from that radiation. Natural energy also includes the energy supplied by other natural forces, such as gravitation and the rotation of the earth. The types of natural energy are summarized in the top section of Table 1. It is this energy that makes possible the existence of ecosystems, human civilizations and life itself.

Solar Energy

Direct solar radiation is the main type of natural energy. The daily energy output of the sun is 8.33×10^{25} kWh, of which the earth receives 4.14×10^{15} kWh. At any instant, the rate solar energy is reaching the earth is 1.75×10^{17} W, which is about 20,000 times greater than the total energy-use rate of the world. Solar energy can be collected as heat and used for thermal processes such as space and water heating. In addition, it can be concentrated and used for high-temperature heating and for thermal electricity generation. Also, solar radiation can be converted directly to electricity in photovoltaic devices.

Most of the energy that enters the system of the earth and its atmosphere eventually exists back to space. This concept can be demonstrated by considering the earth-sun energy balance (see Figure 1). A general energy balance can be written as

Energy input – Energy output = Energy accumulation

This balance can be applied to the earth when

- the energy input is the short-wave solar radiation entering the atmosphere,

- the energy output is the long-wave radiation exiting the atmosphere to space, and

- the energy accumulation term is the increase in energy of the earth and its atmosphere.

The main implication of this global energy balance is that since the average temperature of the earth is relatively constant (excluding for the moment the impact of global warming), the energy accumulation term is zero. Therefore, the energy output is equal to the energy input for the planet.

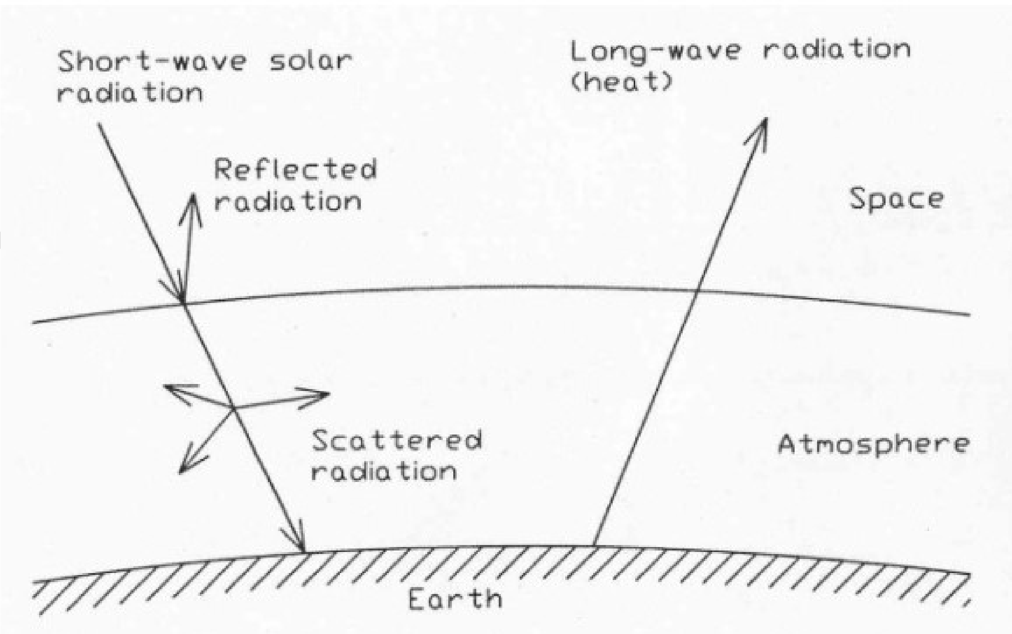

Figure 1. Earth-sun energy balance

It is noted that the phenomenon of global warming disrupts the earth-sun energy balance. The main cause of global warming is increased releases of atmospheric "greenhouse gases" that absorb radiation in the 8 to 20 micrometer region. When greenhouse-gas concentrations increase in the atmosphere, energy output from the earth and its atmosphere (Figure 1) is reduced while energy input remains constant. Thus, the energy accumulation term becomes positive, leading to an increase in the average temperature of the Earth. Eventually, if concentrations of greenhouse gases in the atmosphere stabilize at new levels, the energy balance is re-established but at some higher average planetary temperature.

Solar-Related Energy

Several types of natural energy are a consequence of solar radiation. The most common is hydraulic energy, which includes falling and running water in natural settings such as rivers and waterfalls. Large-scale hydroelectric generating installations are common and conventional. Most economically utilizable hydraulic resources have already been developed. Recently, interest has grown in the potential uses of small-scale hydro, which is considered less conventional.

Other forms of solar-derived energy are less common. Biomass energy includes wood and other forms of plants and organic matter. Biomass can act as a fuel itself, or be converted into more desirable fuels. Several fast-growing trees have been identified as good candidates for biomass energy production. Biomass energy is only a renewable resource when the rate at which it is used does not exceed the rate at which it is replenished. Wind energy is used extensively in some countries (e.g., Denmark) for electricity generation, but is not widespread. Ocean thermal energy arises from the temperature difference between surface and deep waters of the ocean. This temperature difference can be utilized to drive a heat engine, and several ocean thermal energy conversion (OTEC) devices have been tested. Wave energy systems have been proposed that take advantage of the motion of waves, although the potential contribution from wave energy is relatively small.

Non-Solar-Related Energy

The main types of natural energy in this category are geothermal energy, which exists as a consequence of the internal heat of the earth, and tidal energy, which is attributable to the gravitational forces of the sun and moon and the rotation of the earth. Both of these energy sources have been used in limited ways.

2.2.2. Additional Energy

Additional energy, which is often called secondary energy, includes both energy resources which are available in limited quantities and not renewable, and energy forms produced by humankind. Different types of additional energy are summarized in the bottom section of Table 1. This kind of energy is very much related to the stage of technological development of a society, and influences the evolution of life standards.

Two main categories exist for additional energy.

The first consists of energy resources that are not renewable. The most commonly used of these are fossil fuels, which are the basis for most industrialized countries. In addition to the conventional fossil fuels (coal, oil and natural gas), there exist alternative fossil fuels such as oil shales, tar sands and peat. Other non-renewable energy resources include uranium and fusion material (e.g., deuterium).

Wastes, which include recovered materials and energy that would otherwise be discarded, are also sometimes considered as an energy source in the category of additional energy. Such wastes can be used directly as energy forms or converted to more useful forms. Waste materials and waste heat can be recovered for utilization both within a facility and in other facilities where they are needed. For example, waste heat from hot gases (e.g., stack gases) and liquids (e.g., cooling-water discharges) can sometimes be recovered. Also, material wastes can be used in waste-to-energy incineration facilities, which burn garbage to provide heat and to generate electricity. Utilizing such wastes offsets the need for further supplies of external energy.

The second main category of additional energy is energy currencies that do not exist naturally. They include such basic energy forms as work, electricity and thermal energy. The latter can be either heat (or a heated medium such as hot air, steam, exhaust gases) or cold (or a cooled medium such as cold brine, ice). Thermal energy in the form of heat or cold can be transported to users over long distances in district heating and/or cooling systems. District heating systems use centralized heating facilities to produce a heated medium which is transported to many users connected along a district heating network. For example, buildings in the cores of many cities are often connected by pipes through which hot water or steam flows to provide space and water heating. Similarly, district cooling involves the central production of a cold medium, which is transported to users through a piping network to provide cooling. Many cities and industrial parks utilize such district energy systems.

Additional energy also includes secondary chemical fuels. Some conventional ones include oil-derived products such as gasoline, diesel fuel, naptha, as well as synthetic gaseous fuels (e.g., from coal gasification) and coal products (e.g., coke). The types of non-conventional chemical fuels proposed are numerous and include methanol, ammonia and hydrogen.

As many types of additional energy must be produced from energy resources or converted from other types of energy, it is important to understand and consider all steps the entire life cycle of an energy product. The following life stages are usually included in assessments:

- extraction or collection of raw energy resources,

- manufacturing and processing of the desired energy form(s),

- transportation and distribution of the energy to users,

- energy storage,

- use of the energy to provide services and tasks,

- recovery and re-use of output energy that would otherwise be wasted (e.g., waste heat recovery),

- recycling of wastes from any of the above steps, and

- disposal of final wastes (e.g., materials such as stack gases and solid wastes including ash).

For example, the life cycle of a general energy form may involve the following chain of events:

Raw resource → Finished resource → Energy product → Waste → Waste disposal

Two or more types of additional energy can be simultaneously produced in some systems. For example, cogeneration is a process which usually refers to the combined generation of electricity (or work) and heat (or a heated medium). Trigeneration refers to an extended cogeneration process in which cooling is provided as a third product.

Some examples of the different life cycles for electricity generation methods from a range of energy sources are presented in Table 2. In that table, methods based on fossil fuels and non-fossil resources are considered. In addition, electricity generation from different energy sources via a less conventional technology, fuel cells, is considered.

-
-
-

Bibliography

Bisio, A. and Boots, S., Eds. (1996). *The Wiley Encyclopedia of Energy and the Environment*. Toronto: Wiley-Interscience.
Claridge, D., O'Neal, D. and Roberts, M. (1991). Improving energy conservation retrofits with measured savings. *ASHRAE Journal* Oct., 14-22.
Goldemberg, J., Johansson, T.B., Reddy, A.K.N. and Williams, R.H. (1988). *Energy for a Sustainable World*. New York: Wiley.
Kotas, T.J. (1995). *The Exergy Method of Thermal Plant Analysis*, reprint edition. Melbourne, Florida: Krieger.
Liu, P.I. (1993). *Introduction to Energy and the Environment*. New York: Van Nostrand Reinhold.
O'Callaghan, P.W. (1993). *Energy Management*, New York: McGraw-Hill.
Organization for Economic Cooperation and Development. (1999). *Energy: The Next Fifty Years*. OECD: Washington, D.C.
Organization for Economic Cooperation and Development. (1998). *World Energy Outlook*. OECD: Washington, D.C.
Rosen, M.A. (1994). Assessment of various scenarios for utility-based cogeneration in Ontario. *Energy-The International Journal* **19**, 1143-1149.
Wilbur, L.C., Ed. (1985). *Handbook of Energy Systems Engineering: Production and Utilization*. Toronto: Wiley.
Winteringham, F.P.W. (1992). *Energy Use and the Environment*. Boca Raton, Florida: Lewis Publications.

Biographical Sketch

Dr. Marc A. Rosen is a professor in the Department of Mechanical Engineering at Ryerson Polytechnic University in Toronto, Canada. He recently completed a term as Department chair, and has served as Director of the Department's School of Aerospace Engineering. He has worked for such organizations as Imatra Power Company in Helsinki, Finland, Argonne National Laboratory outside Chicago, U.S.A. and the Institute for Hydrogen Systems, near Toronto.

Dr. Rosen obtained a B.A.Sc. (1981) in Engineering Science, and a M.A.Sc. (1983) and Ph.D. (1987) in Mechanical Engineering, all from the University of Toronto. He is a registered Professional Engineer in Ontario, and a founding associate editor for the "International Journal of Exergy." Dr. Rosen is a fellow of the Canadian Society for Mechanical Engineering, vice president of its Thermo-Fluids Engineering Technical Division and an editorial-board member of that society's journal *Transactions of the CSME*.

With over 40 research grants and contracts and 170 technical publications, Dr. Rosen is an active teacher and researcher in thermodynamics (particularly second-law, or exergy, analysis), energy-conversion technologies (e.g., cogeneration, district energy, thermal storage, renewable energy), and the environmental impact of energy and industrial systems.

Dr. Rosen has received many honours, including an Award of Excellence in Research and Technology Development from the Ontario Ministry of Environment and Energy in 1997, and the Sarwan Sahota/Ryerson distinguished scholar award in 1998.