RENEWABLE ENERGY SOURCES CHARGED WITH ENERGY FROM THE SUN AND ORIGINATED FROM EARTH–MOON INTERACTION

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Contents

Summary

The present theme considers some energy sources that are renewable. These energy sources are renewable in the sense that they are continually renewed, charged mainly by solar radiation, regardless of their utilization. In addition to energy sources charged by the sun, the subject of tidal energy, which originates from the gravitational interaction of the earth, moon, and sun, is also discussed.

The potential renewable energy sources treated here are biomass, wind energy, wave energy, temperature differences in the ocean, and between the ocean and ambient air, and tidal energy. The energy of river flows, which is also renewable, is dealt with elsewhere, along with other conventional energy sources.

The biomass consists of organic matter, mainly in the form of carbohydrates produced by photosynthesis from carbon dioxide and water. The exergy of carbohydrates exceeds that of the latter, and is therefore a potential energy source. Useful energy can be derived from biomass by thermochemical or biochemical processes converting it back to carbon dioxide and water. In the first case the biomass is oxidized by the ambient air oxygen. If the oxidation is complete, as it is in the case of combustion, the energy is evolving as heat at quite high temperatures; in the case of partial oxidation (gasification) the conversion products are carbon oxide and hydrogen which can be subsequently combusted again, producing carbon dioxide, water, and utilizable heat. In anaerobic conditions, some strains of bacteria can use a fraction of biomass energy to support their life: as a product of their activity biomass is converted to biogas, which mainly consists of methane and carbon dioxide, and which can be used as a substitute for conventional fuel. Sugar-containing biomass can be digested by yeast which converts the biomass to ethanol.

It is emphasized that primary biomass can be considered as a sustainable energy source if dedicated energy plantations are created where new trees or bushes are planted when the mature plants are cut down. In this case the use of biomass for energy needs does not contribute to an increase in carbon dioxide concentration in the atmosphere.

Wind energy is treated as the mechanical (kinetic) energy of air flow. It originates from non-uniform solar heating of the earth’s surface. Centuries ago this kinetic energy was already being converted by windmills into useful mechanical—and, more recently, electrical—energy, or used for the propulsion of vehicles. Modern efforts in many countries are directed at perfection of large-scale wind turbines, and the creation of wind farms delivering significant amounts of electricity to utilities. The main constraint on the use of wind energy is its irregularity. Some consideration is given to assessing

the energy which can be extracted from the wind at a given site, along with economic and environmental criteria for the deployment of large wind installations.

Waves originate from the wind blowing across a vast ocean surface. The movement of water in the wave is rather complicated, and includes up-and-down movements and the rotation of water masses. Hence wave energy is, like the wind, a mechanical energy containing both kinetic and potential constituents. Despite wave energy being quite concentrated, its conversion to useful energy is not as simple. Many possible schemes for wave energy utilization have been proposed, but they fall mainly into two types. With the first, the up-and-down movement of water is used to drive mechanical components and convert this movement into the rotation of an electrical generator rotor; with the second, the up-and-down movement of water is used either to produce a water head, which can be used to drive a hydraulic machine, or to compress air which can be used in an air turbine. As yet wave energy utilization has not been widespread, and has been restricted to local needs such as navigation buoys.

Temperature differences in the ocean, and between the ocean and ambient air, are an enormous potential energy source. In the equatorial and tropical regions of the world's oceans there exists a steady temperature difference between surface water (about 27–28 °C) and deep water (some 4 °C). This temperature difference, under thermodynamic laws, can be used to convert heat to mechanical work (electricity). The amount of mechanical energy derived in this case is limited by the Carnot efficiency of the proper cycle. Ocean thermal energy conversion (OTEC) can be realized by either open or closed cycle. In the first case the warm seawater is used as working fluid in the cycle. It is flash-evaporated and the resultant steam drives a turbine. At the turbine exhaust the steam is condensed by cold deep water raised from the ocean depth. If the condenser is of a surface type, desalinated water is produced which can be used to prepare drinking water. This can be a valuable by-product in regions lacking in potable water. In the closed cycle the warm surface water is used to evaporate some substance with a low boiling temperature (ammonia, for example, or some hydrocarbons), and its vapor drives a turbine. The vapor is liquefied in a condenser cooled by the deep ocean water, and pumped into the evaporator again.

There are many obstacles to be overcome in order to create a commercial-scale OTEC power plant. The main one is the enormous size of the equipment, since the specific amount of energy in the surface water is quite small. In the open cycle scheme the turbine size also gets to be extremely large-scale since it operates at low pressure, whereas the steam density is very small. It is a problem to lift large amounts of cold water from depths of some 1,000 m. There are also environmental constraints connected with temperature distribution perturbation, which can influence the aquatic life. However, there is also a possibility of taking advantage of the deep, cold, nutrient-rich water which is lifted to the surface. This is known as deep ocean water application (DOWA), and can be highly supportive for the creation of OTEC power plants.

Use of air–water thermal energy conversion (AWTEC), which is possible in high latitudes, is perhaps a step further towards implementation as compared with OTEC. Several factors make the task of AWTEC more complicated. First, the requisite temperature difference between ocean or river water (+4 °C, minus 1 °C) and ambient air (around minus 20 °C) is only maintained during several months in winter; second, creation of AWTEC power plants will be hindered by the severe climate conditions; and, third, there has not been very much demand of late for bulk energy in the regions where such plants can be installed.

The tides originate from the gravitational interaction between the earth and the moon and, to a certain degree, the sun. The moon and the earth are rotating around their common center of gravity, producing centrifugal force. At the same time there is gravitational attraction between these celestial bodies. Superposition of these forces demonstrates itself in a rise in the water-level in the earth's oceans on both sides of the globe: facing the moon, and on the opposite side. As the earth rotates around its axis this water-level rise travels across the ocean at quite a high speed, and this is called a tide. With some simplification, at a given place the ocean level should rise and fall twice every twenty-four hours (the so-called semi-diurnal tide). In reality, owing to the moon's declination and the sun's influence, there are variations in the tide's occurrence and magnitude.

The height of the tide in the open ocean is rather small, but when the tide wave enters a bay or a river estuary its height is increased multifold, and in some places exceeds ten meters. To use the tidal energy it is necessary to fence off the bay, or the estuary, from the open sea by a dam, and install a number of hydraulic turbines inside the dam. The turbines can operate either one-way—for instance when the flood enters the bay—or two-way, when the water comes in and out from the basin. In some sense the tidal power plant (TPP) is similar to a low head hydraulic power plant (HPP), many of which are installed worldwide on rivers. However, there are considerable differences between the two types of plant.

First, there is the way TPPs are constructed. Existing projects are for the construction of large multi-megawatt TPP, in which case the area of the basin fenced off from the sea is many square kilometers and the dam has to be many kilometers long. Unlike the HPP it is not possible to erect the dam on a dry base, diverting the river flow to an artificial watercourse: it has to be built directly in the sea at the bay entrance. To simplify the works, and make them less expensive, a method has been devised whereby the dam sections are built onshore, tugged by sea to the proper place, and then submerged and placed on a foundation provided on the sea bottom.

Even when two-way turbines are used, the power produced by the TPP varies during the day. Moreover, it is also changing from day to day during the lunar month. Hence, in general, the power output of the TPP does not coincide with the load curve, and it is therefore expedient to integrate the TPP into a power system incorporating different types of power plant (fossil, nuclear, hydraulic). In that way it is possible to use the TPP, in periods when there is excess power in the system, as a pumping storage for operating the TPP turbines in a pump mode. The stored water is then discharged through the TPP turbines when peak power is needed.

Currently there are only a few TPP in operation in a number of countries, but it is clear that there are many sites worldwide where TPP could be installed, providing environmentally clean energy at reasonable prices.

1. Introduction

Renewable energy sources (RES) is a wide concept covering a whole gamut of energy sources, the characteristic feature of which is that they are renewed continually regardless of their utilization. Apart from tidal energy, all the RES are charged by the sun, just about the only energy source for our planet. The structure of this Encyclopedia is such that solar radiation *per se* as an energy source is treated in another theme. The present theme considers the most important energy sources *charged* by solar radiation. Here too there is an exception: the energy of river flows, widely used for power production, is also discussed elsewhere. Therefore the energy sources treated here are sometimes called non-traditional renewable energy sources (NRES). Tidal energy is also included in this theme, despite the fact that it does not originate in solar radiation.

The constitution of our planet is rather complicated in that it includes lithosphere, hydrosphere, and atmosphere, with different properties and hence with different responses to solar radiation. Along with non-uniformity of solar flux distribution across the earth's surface, it produces differences in pressure, temperature, chemical potential, and salinity of water. Those differences maintained by solar radiation are potential energy sources. In natural conditions these differences gradually disappear by irreversible dissipation processes, and the respective energy is ultimately emitted to space.

To use the RES means to interfere at one or another stage of solar energy transformation processes, and use the exergy for human needs. Fortunately in most cases there is enough time between absorption of solar energy by one or another media, and its emission to space as infrared radiation. This gives us the opportunity to harvest the abovementioned exergy.

To assess the energy arriving at the earth from the sun one can consider the sun as a sphere having a diameter of 1.4 million km, with a surface temperature of about 5,800 K, sending out radiation as a black body. In so far as the earth is located on an average distance of 150 million km from the sun, only a small fraction of this radiation, depending on the body angle, falls onto the earth. However, this amount of energy is still enormous and maintains all the processes occurring on the earth, life included.

The specific power of the solar radiation, namely the amount of solar energy arriving during 1 s at an area of 1 m^{-2} located perpendicular to the solar rays outside the earth atmosphere—the so-called solar constant—is about 1,340 W m^{-2}. The total power of solar radiation arriving at the earth is about $180*10^{15}$ W, whereas the corresponding annual energy is some $60*10^{23}$ J. It is about a factor of 15,000 more than the total energy recently used by humankind (some $4*10^{20}$ J per annum).

Not all the abovementioned radiation reaches the earth's surface. The average breakdown of the incoming radiation is illustrated in Figure 1. All energy arriving at the earth, apart from a small fraction which is absorbed by photosynthesis, is emitted again to space (according to steady state condition the total energy balance of the planet must be zero). However, between the arrival of the energy flux and its emission to space some delay can occur, owing to several transformations of the solar energy. A fraction of this energy shown in Figure 1 is directly—meaning immediately—reflected to space by the clouds. A significant part of the radiation reaching the earth's surface provides for evaporation of water. The evaporated water travels through the atmosphere for some time and then returns back as rain, dew, and snow, initiating the river flows. The energy of these flows is ultimately dissipated (converted to heat at ambient temperature and emitted to space as infrared radiation). Another part of energy is absorbed by dry land, oceans and seas, and the atmosphere. The absorption being non-uniform from place to place, during day and night, stimulates winds, ocean currents, produces temperature differences between land and sea, and so forth. Again, within some space of time, these flows and streams lose their energy due to friction, the temperature distribution is flattened due to heat conduction and convection, and the respective energy is dissipated.

For a rather small fraction of the solar radiation (less than 0.1 percent, not shown in Figure 1), which is used for photo-synthesis by the dry-land and aquatic flora, the time interval between absorption of solar energy and disengaging it can be rather long. This amount of energy is stored in the tissue of plants and recovered by natural processes after their death.

It is important that each of these processes leads to a short or long delay between the moment when the solar radiation comes to the earth, and when it is again emitted to space as infrared radiation according to the earth surface and sky temperature.

It is well known from thermodynamics, that an object can only be considered as a source of useful energy (exergy) when it is not in an equilibrium with the environment. Charged with solar radiation our environment is never in an equilibrium state. The radiation creates differences of various parameters in the environment (the simplest of them are temperature and pressure), and those can be considered as energy sources charged by the sun.

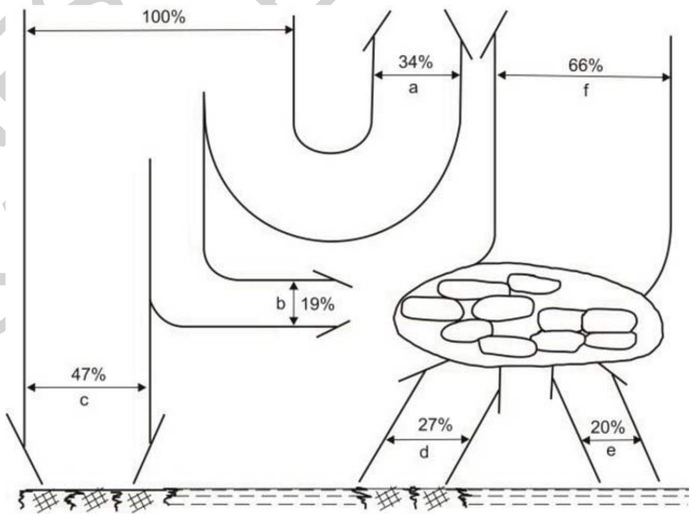

Figure 1. Balance of solar energy.
Notes: a—energy reflected by clouds; b—energy absorbed by the atmosphere; c—energy reaching the earth surface; d—energy emitted by the dry land; e —energy emitted by the ocean surface and spent for evaporation; f—the sum radiated to space.

The same applies to tides, initiated by gravitational interaction between earth, moon, and sun.

To use these potential energy sources means to interfere at one or another stage, to introduce some artificial device to make this transformation more reversible, and hence to produce what we call useful energy. Putting it more precisely, we are going to use the exergy of the energy source. After producing the useful effect the energy will be finally dissipated as heat at ambient temperature.

In this theme we are going to give an overview of how to obtain what we call useful energy by using the difference, which exists in nature, of some parameters. All these potential energy sources are renewable. It means that when we convert their energy to useful energy, the respective differences are renewed by solar radiation or by gravitational interaction of earth with moon and sun

2. Biomass as an Energy Source

The most unique renewable energy source is the primary biomass. Complicated photochemical processes initiated by solar radiation lead to transformation of inorganic substances (carbon dioxide, water, some minerals) into the organic tissue (mainly carbohydrates) of growing plants. This organic matter is not in equilibrium (in the thermodynamic sense) with its surroundings, and it is therefore a potential energy source, which can be considered as renewable since the photosynthesis is going on uninterrupted.

When speaking of biomass as an energy source and labeling it as renewable, one has to understand that fossil fuels are also a product of biomass conversion. This biomass, however, was produced long ago and has been stored for millions of years. Nowadays there is some restoration of the stock of fossil fuels (peat for example), but it is many orders of magnitude slower than their consumption, hence we term them non-renewable. Biomass is a very wide concept covering primary biomass (biomass produced directly by photosynthesis such as various plants growing on dry land—trees, shrubs, crops, grass—and seaweeds), and secondary biomass (agricultural wastes, food industry wastes, municipal wastes); in general any stuff containing organic matter (excluding synthetic organic matter) can be considered as biomass and hence as a potential energy source.

2.1. Biomass Origin

The variety of what we call primary biomass or flora is extremely wide. It encompasses giant sequoia trees as well as unicellular water-plants. All of them have a unique feature in common: they use solar radiation to produce organic matter (mainly various carbohydrates as well as some amount of fats and proteins) by means of photosynthesis from carbon dioxide and water. The gross photosynthesis reaction can be written as:

$$xCO_2 + yH_2O + h\nu \rightarrow (x + y/4 - z/2)O_2 + [C_x H_y O_z] + y/2\ H_2O, \qquad (1)$$

where hν stands for quantum of solar radiation; [C_x H_y O_z] is a generalized formula for a carbohydrate; for example the formula for grape-sugar (glucose) is [C_6 H_{12} O_6], for cellulose [C_6 H_{10} O_5], for saccharose – [C_{12} H_{22} O_{11}].

Thus one can say that photosynthesis is simultaneously a kind of biochemical conversion and storage of solar energy.

What follows is the energy balance of a green leaf which is the main “manufacturer” of biomass. For photosynthesis the leaf uses two parts of solar spectrum, the blue and the red. The green part of the spectrum (some 20 percent of the total energy) is reflected, determining the green color of the leaf. The conversion efficiency of the absorbed radiation into a molecule of carbohydrate (glucose) is about 28 percent. About 40 percent of the energy stored in the produced carbohydrate is spent by the plant during the night (the so-called “dark respiration” of the plant). The overall efficiency of the green leaf, defined as ratio of energy absorbed in the produced biomass to the total solar energy arriving at the leaf, is about 6.7 percent.

This maximum efficiency corresponds to the C_4 plants (so-called because their primary photosynthesis product contains four carbon atoms). There are not many species of C_4 type: corn, sugar cane, and some others, growing mainly in rather hot areas. More prevalent are the C_3 plants (their primary products contain three carbon atoms): wheat, rice, other grains, and trees. These plants are widespread in temperate climate, and account for about 95 percent of the global amount of biomass. The efficiency of C_3 plants is less than for C_4 (some 3 percent) because, in addition to dark respiration, they lose about 30 percent of energy already stored as biomass due to photo-respiration, a process which is going on in parallel with absorption of solar light.

Despite the global photosynthesis consuming only a minor fraction of solar radiation arriving at the earth surface, the annual global biomass production is estimated as 220 billion t (dry mass), which is equivalent to about 3,700 EJ according to the average lower heating value of biomass (some 17 GJ per dry ton). This amount of energy exceeds the global human energy consumption by a factor of ten.

During its life span the plant absorbs the solar energy and produces organic matter, the biomass. In nature when the plant dies several processes occur which drive the abovementioned photosynthesis reaction in the opposite direction: the organic matter is decomposed mainly by aerobic bacteria, returning the spent solar energy as heat at ambient temperature, and emitting the proper amount of CO_2 and H_2O to the atmosphere.

Sometimes the dying plant may enter an environment deprived of oxygen (for example is absorbed by a swamp). In this case the organic matter is retained and over millions of years can be transformed into coal, oil, or natural gas, the main energy sources for recent civilization. The biomass cannot be considered solely as energy source. Fauna representatives are not able to obtain the energy necessary to support their life directly from solar radiation. They consume either primary photosynthesis products (grass, crops, various fruits, and vegetables) or, in the case of the carnivorous species, humankind included, meat or fish, which appears to be a secondary product.

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Biographical Sketch

Evald E. Shpilrain was born July 9 1926, at Rostov on Don, USSR, and graduated from the Moscow Power Engineering Institute in 1948. In 1951 he submitted his thesis on *Experimental study of liquid oxygen heat capacity* and gained his degree as Candidate of Technical Sciences. From 1952 to 1954 he worked as an Engineer at the Design Institute for Energy Installations in Non-Ferrous Metallurgy, and from 1954 to 1978 he was associated professor and afterwards full Professor at the Thermophysics Chair in the Moscow Power Engineering Institute. In 1964 he was awarded a Doctorate in Technical Sciences (Thesis: *Thermophysical properties of alkali metal vapors*).

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