【Review】

Preface to special issue on “Renewable Energy”

Takao YAMASHITA
Professor
Graduate School for International Development and Cooperation, Hiroshima University
1-5-1 Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8529, Japan
E-mail: tkoyamashita@hiroshima-u.ac.jp

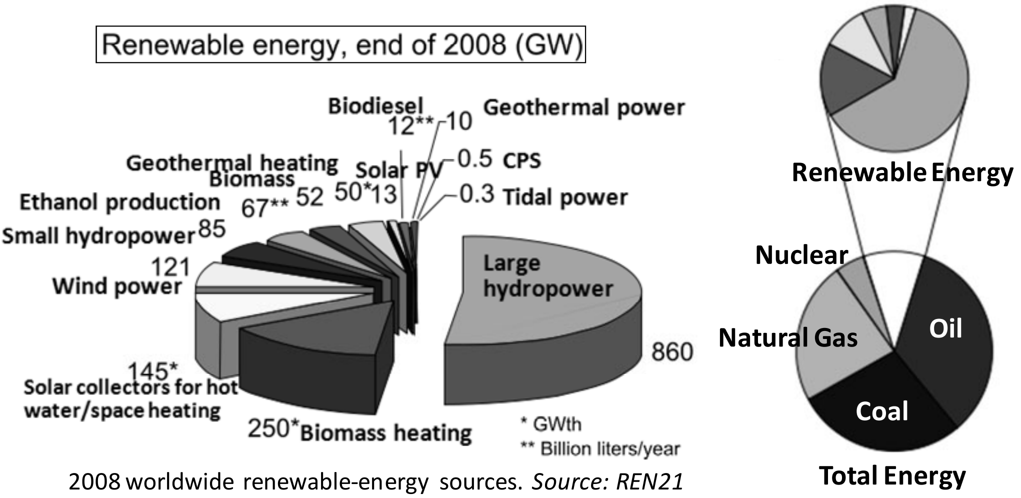
1. “Renewable energy” the status quo

The world is faced with twin threats, (1) inadequate and insecure supplies of energy at affordable prices, and (2) environmental damage due to overconsumption of energy (IEA 2006)[1]. Global demand for energy keeps growing. Society’s growing requirements for energy are resulting in significant changes in those same ecosystems, both in the search for energy sources, and as a result of energy use patterns. Given that energy is a fundamental requirement for supporting development in all economies, the challenge is to sustainably provide it without driving further loss of biodiversity. It is necessary to define the trade-offs required, and to develop appropriate mitigation and adaptation strategies. There is an intimate connection between energy, the environment and sustainable development. Clearly, a strong relation exists between energy efficiency and environmental impact. One of solutions to current environmental issues in terms of energy conservation is an effective utilization of renewable energy.

“Renewable energy” is the energy that comes from solar radiation, astronomical tide and geothermal heat which are naturally replenished. Solar radiation is the source of wind, wave and biomass. About 19% of global final energy consumption is shared by renewable energy in 2008 coming from traditional biomass with 13% and 3% from hydropower. New renewable energy such as, small hydropower, modern biomass, wind, solar, geothermal, and biofuels, account for 2.7% that are growing very rapidly (see Figure 1).

Wind power is growing at the rate of 30% annually, with a worldwide installed capacity of 157,900 (MW) in 2009, and is widely used in Europe, Asia, and the United States. At the end of 2009, cumulative global photovoltaic (PV) installations surpassed 21,000 MW and PV power stations are popular in Germany and Spain. Solar thermal power stations operate in the USA and Spain. Brazil has one of the largest renewable energy programs in the world, involving production of ethanol fuel from sugar cane, and ethanol now provides 18% of the country’s automotive fuel. Ethanol fuel is also widely available in the USA. During the five years from the end of 2004 through 2009, worldwide renewable energy capacity grew at rates of 10-60 %t annually for many technologies. For wind power and many other renewable technologies, growth accelerated in 2009 relative to the previous four years. More wind power capacity was added during 2009 than any other renewable technology. However, “grid-connected PV” increased the fastest of all renewables technologies, with a 60% annual average growth rate for the five years period. All forms of energy are expensive, but as time progresses, renewable energy generally gets cheaper, while fossil fuels generally get more expensive.

Journal of International Development and Cooperation, Vol.17, No.3, 2011, pp. 1-10



2008 worldwide renewable-energy sources. *Source: REN21*

Figure 1. Worldwide renewable energy sources in 2008
(REN21: Renewable Energy Policy Network for the 21st Century). [2]

Al Gore, the 45th Vice President of the United States, has explained that renewable energy technologies are declining in price for three main reasons: [3]

“First, once the renewable infrastructure is built, the fuel is free forever. Unlike carbon-based fuels, the wind and the sun and the earth itself provide fuel that is free, in amounts that are effectively limitless.”

“Second, while fossil fuel technologies are more mature, renewable energy technologies are being rapidly improved. So innovation and ingenuity give us the ability to constantly increase the efficiency of renewable energy and continually reduce its cost.”

“Third, once the world makes a clear commitment to shifting toward renewable energy, the volume of production will itself sharply reduce the cost of each windmill and each solar panel, while adding yet more incentives for additional research and development to further speed up the innovation process.”

2. Knowledge base of energy

2.1 Form of energy and transformation

The term energy describes the amount of work which may potentially be done by forces or velocities (kinetic energies) within a system, without regard to limitations in transformation imposed by entropy. Energy in a system may be transformed so that it resides in a different state. Energy in many states may be used to do many varieties of physical work. Energy may be used in natural processes or machines, or else to provide some service to society (such as heat, light, or motion). For example, an internal combustion engine converts the potential chemical energy in gasoline and oxygen into heat, which is then transformed into the propulsive energy (kinetic energy that moves a vehicle.) A solar cell converts solar radiation into electrical energy that can then be used to light a bulb or power a computer. In general, most types of energy, save for thermal energy, may be converted to any other kind of energy, with a theoretical efficiency of 100%. Such efficiencies may even occur in practice, such as when potential energies are converted to kinetic energies, and vice versa. Conversion of other types of energies to heat also may occur with high or perfect efficiency.

Any energy form can be transformed into another (see Figure 2). When energy is in a form other than thermal energy, it can be transformed to any other type of energy with better efficiency. Due to the second law of thermodynamics that is an expression of the universal principle of decay observable in nature, thermal energy has a limit to the efficiency of the conversion to other forms of energy. This decay is measured and expressed in terms of "entropy," stating that the entropy of an isolated system can never decrease. Energy is a scalar physical quantity. In the International System of Units (SI), energy is measured in joules, but in some fields other units such as kilowatt-hours and kilocalories are also used.

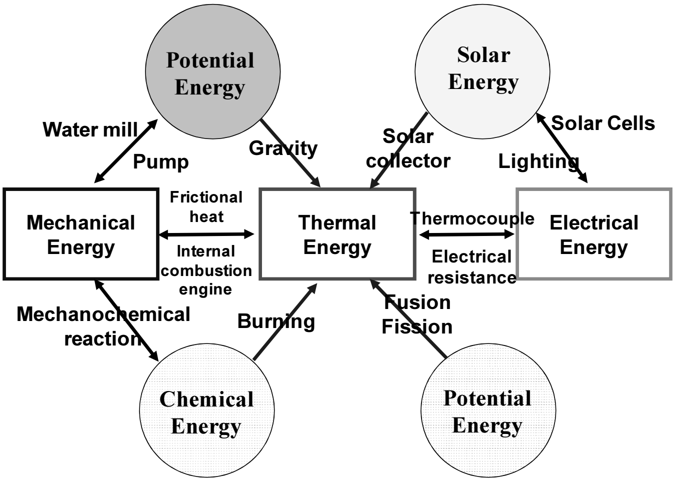


Figure 2. The form of energy and their transformation

2.2 Energy related properties and units

Mass: In everyday usage, *Mass* is often taken to mean *weight,* but in scientific use, they refer to different properties, such as the inertial mass of an object, that determines its acceleration in the presence of an applied force. According to Newton's second law of motion, if a body of mass m (kg) is subjected to a force $\mathbf{F}$(N), its acceleration (m/s^2) is given by a = $\mathbf{F}/m$.

Gravity of Earth: The *gravity of Earth,* denoted , refers to the acceleration that the Earth exerts to objects on or near its surface. This acceleration is measured in m/s^2 (equivalent to N/kg). It has an approximate value of 9.81 m/s^2, which means that, ignoring air resistance, the speed of an object falling freely near the Earth's surface increases by about 9.81 m/s every second.

Weight and Force: As one of common definitions, the *weight* of an object, often denoted by, W, is defined as being equal to the force exerted on it by gravity. This force is the product of the mass m of the object and the local gravitational acceleration, g. Expressed in a formula: $W = mg$. In the unit of measurement for weight is the same as that for *force,* the newton (symbol: **N**) , the unit of force. Eq.(1) indicates that 1 N is the force of Earth's gravity on an object with a mass of about 0.102 kg (=1 / 9.81 kg).

$$1\mathrm{N} = 1\mathrm{kg} \cdot 1\mathrm{m/s}^2 \tag{1}$$

On Earth's surface, a mass of 1kg exerts a force of approximately 9.8N [down] (or 1.0 kilogram-force; 1 kgf=9.80665 N by definition). The approximation of 1 kg corresponding to 10 N is sometimes used as a rule of thumb in everyday life and in engineering.

Calorie: The small calorie or gram calorie (symbol: cal) approximates the energy needed to increase the temperature of 1 gram of water by 1°C. This is about 4.2 joules.

$$1\text{cal} \approx 4.2\text{J} \tag{2}$$

The large calorie, kilogram calorie or food calorie (symbol: Cal) approximates the energy needed to increase the temperature of 1 kilogram of water by 1°C. This is exactly 1000 small calories or about 4.2 kilojoules.

$$1\text{Cal} \approx 4.2\text{kJ} \tag{3}$$

Watt and Joule: The *watt* (symbol: W) is a derived unit of power. The unit measures the rate of energy conversion (the electrical energy consumed in a second). It is defined as one joule per second.

$$\text{W} = \frac{\text{J}}{\text{s}} \tag{4}$$

One *joule* is defined as the amount of work done by a force of one newton moving an object through a distance of one metre. The work required to continuously produce one watt of power for one second; or one *watt second* (WsEs). This relationship can be used to define the watt.

Watt hour: The kilowatt hour, or *kilowatt-hour,* (symbol **kWh**) is a unit of energy equal to 1000 watt hours or 3.6 MJ(10^6J). Energy in watt hours is the multiplication of power in watts and time in hours.

Electric Current and Volt: *Electric current, I,* meansscharge, . Where, one coulomb is the amount of electric charge transported in one second by a steady current of one ampere as shown by Eq.(5).

$$1\text{C} = 1\text{A} \cdot 1\text{s} \tag{5}$$

$$\text{V} = \frac{\text{W}}{\text{A}} = \frac{\text{J}}{\text{A} \cdot \text{s}} = \frac{\text{N} \cdot \text{m}}{\text{A} \cdot \text{s}} = \frac{\text{kg} \cdot \text{m}^2}{\text{A} \cdot \text{s}^3} = \frac{\text{kg} \cdot \text{m}^2}{\text{C} \cdot \text{s}^2} = \frac{\text{N} \cdot \text{m}}{\text{C}} = \frac{\text{J}}{\text{C}} \tag{6}$$

$$\text{W} = \text{I} \cdot V \tag{7}$$

The *joule* (symbol **J**) is the energy expended in applying a force of one newton (N) through a distance of one metre (m), i.e. 1 Nm. Eq.(8) depicts the relation of dimensions.

$$1\text{J} = 1\text{N} \cdot \text{m} = 1\text{W} \cdot \text{s} \tag{8}$$

2.3 Electromagnetic wave

Thermal radiation is the transfer of energy by electromagnetic waves. All objects with a temperature above absolute zero radiate energy at a rate equal to their emissivity multiplied by the rate at which energy would radiate from them if they were a black body. Thermal radiation does not require the presence of a medium. For instance, the energy from the Sun travels through the vacuum of space before warming the Earth. Electromagnetic radiation is the only form of energy transfer that can occur in the absence of any form of matter.

Thermal energy is a direct result of the movement/vibration of atoms and molecules in a material. Since these atoms and molecules are composed of protons and electrons (charged particles), their movement/vibration result in the emission of electromagnetic radiation, which carries energy away from the material. At the same time, the surface is constantly bombarded by radiation from the surroundings, resulting in the transfer of energy to the surface. Since the amount of emitted radiation increases with increasing temperature, a net transfer of energy from higher temperatures to lower temperatures results.

Both reflectivity and emissivity of all bodies is dependent on the wavelength of the radiation. The temperature determines the wavelength distribution of the electromagnetic radiation as limited in intensity by Planck's law of black-body radiation. For any bodies the "reflectivity" depends on the wavelength distribution of incoming electromagnetic radiation (the temperature of the source of the radiation). The "emissivity" depends on the wave length distribution (the temperature of the body itself). For example, fresh snow, which is highly reflective to visible light (reflectivity about 0.90), appears white due to reflecting sunlight with its peak wavelength of about 0.5. Its emissivity is 0.99, however, its temperature is about -5°C with peak wavelength of about 12μm. Visible light is another form of electromagnetic radiation with a shorter wavelength, and therefore a higher frequency, than infrared radiation. The difference between visible light and the radiation from objects at conventional temperatures is a factor of about 20 in frequency and wavelength. The power that a black body emits at various frequencies is described by Planck's law. For spectral energy per unit volume of the radiative field in thermodynamic equilibrium, Planck's law (Rybicki, G. B.; Lightman, A. P. ,1979) [4] is written by,

$$U(\nu)=\frac{8\pi k_B\beta}{c^3}\frac{\nu^3}{\exp\left(\frac{\beta\nu}{T}\right)-1} \tag{9}$$

$$k_B\beta = h : \text{Planks' constant}$$

From Planck's law, Eq.(9), the EM wave energy spectra are shown in Figure 3. This diagram shows how the peak wavelength and total radiated amount vary with temperature of emitting source of black body. Although this plot shows relatively high temperatures, the same relationship holds true for any temperature down to absolute zero (0K:–273.15°C, minimum entropy, zero point energy, no molecular motion). Visible light is between 380 to 750 nm.

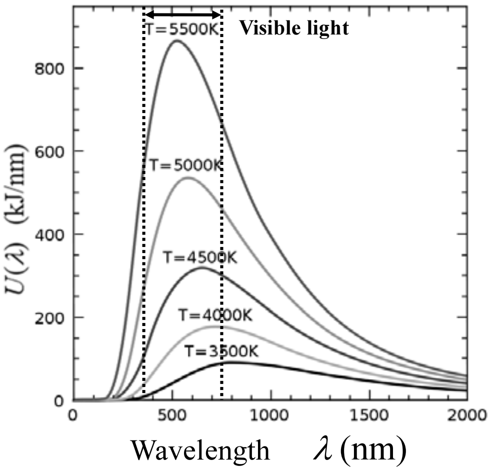


Figure 3. The power spectra by Planck's law for various temperatures of black body.

Wien's displacement law (J. Mehra, H. Rechenberg, 1982)[5] states that the wavelength distribution of radiated heat energy from a black body (an idealized object that absorbs all electromagnetic radiation falling on it) at any temperature has essentially the same shape as the distribution at any other temperature, except that each wavelength is displaced, or moved over, on the graph. The average heat energy in each mode with frequency V only depends on the combination, v / T. Restated in terms of the wavelength $\lambda=cv$, the distributions at corresponding wavelengths are related, where c is the speed of light. Because the speed of EM waves predicted by the wave equation coincided with the measured speed of light, c, that is about 30million km/s (the exact speed is 299,792,458m/s). Then, Maxwell concluded that light itself is an EM wave. From this general law, it follows that there is an inverse relationship between the wavelength of the peak of the emission of a black body and its temperature when expressed as a function of wavelength, and this less powerful consequence is often also called Wien's displacement lawin many textbooks.

$$\lambda_{\max} \cdot T = b \approx 2.9 \times 10^{-3} (\mathrm{m} \cdot \mathrm{K}) \tag{10}$$

Where, λ_{max} is the peak wavelength, T is the absolute temperature of the black body, and b is the Wien's displacement constant, equal to 2.8977685×10^{-3} (m·K).

For any given temperature, there is a frequency v_{max} at which the power emitted is a maximum. Wien's displacement law, and the fact that the frequency of light is inversely proportional to its wavelength, $v_{\mathrm{max}} \sim 1/\lambda_{\mathrm{max}}$ (the peak frequency v_{max} is proportional to the absolute temperature T of the black body, from Eq.(10)).

2.4 Solar radiation

The surface of the Sun, at a temperature of approximately 6000 K, emits radiation principally in the visible portion of the spectrum. The Earth's atmosphere is partly transparent to visible light, and the light reaching the Earth's surface is absorbed or reflected. The Earth's surface emits the absorbed radiation, approximating the behavior of a black body at 300 K with spectral peak at v_{max}. At these lower frequencies, the atmosphere is largely opaque and radiation from the Earth's surface is absorbed or scattered by the atmosphere. Though some radiation escapes into space, it is absorbed and subsequently re-emitted by atmospheric gases. It is this spectral selectivity of the atmosphere that is responsible for the planetary greenhouse effect, contributing to global warming and climate change in general.

The Stefan-Boltzmann law, also known as Stefan's law, states that the total energy radiated per unit surface area of a black body per unit time (known variously as the black-body irradiance, energy flux density, radiant flux, or the emissive power), W, is directly proportional to the fourth power of the black body's thermodynamic temperature T (also called absolute temperature).

$$W = 5.67 \times 10^{-8} \cdot T^{4} \qquad (\mathrm{W/m^2 \ or \ J/s/m^2}) \tag{11}$$

Generally, EM radiation is classified by wavelength into radio, microwave, infrared, the visible region we perceive as light, ultraviolet, X-rays and gamma rays. The behavior of EM radiation depends on its wavelength. Higher frequencies have shorter wavelengths, and lower frequencies have longer wavelengths. EM radiation with a wavelength (λ) between approximately 400 nm and 700 nm is directly detected by the human eye and perceived as visible light. Other wavelengths, especially nearby infrared (longer than 700nm) and ultraviolet (shorter than 400nm) are also sometimes referred to as light, especially when visibility to humans is not relevant (see Figure 4).

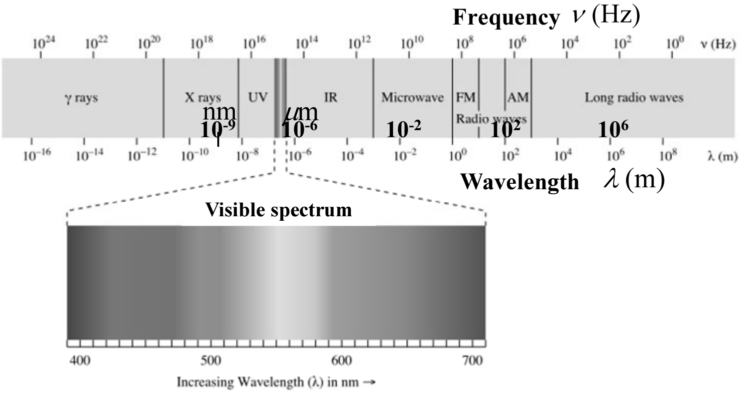
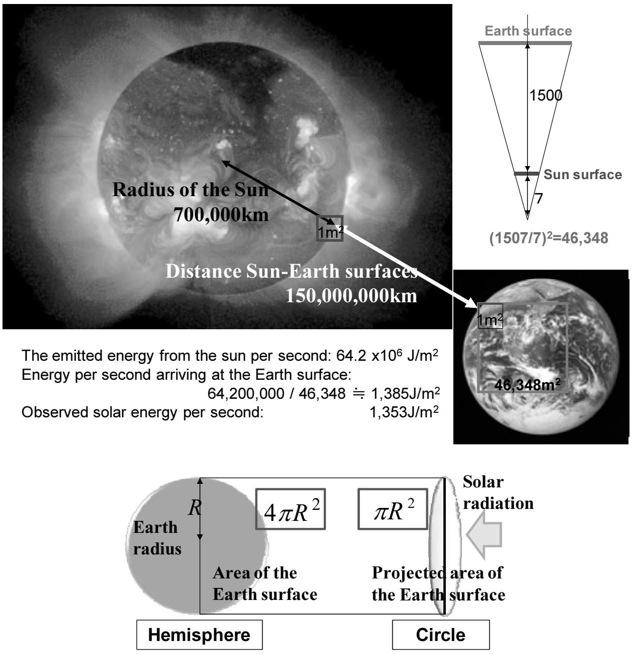


Figure 4. Electromagnetic spectrum with visible light. [6]

Setting the temperature of Sun surface is 6000K, and the peak wavelength of the solar spectrum is 500nm, it is possible to estimate the energy radiated per unit surface and temperature on the earth surface by using the Wien's displacement law and Stefan-Boltzmann law. The emitted energy from the Sun per second can be estimated as 64.2 x10^6 J/m^2 from the Stefan-Boltzmann law. If we have information that the surface to surface distance between the Earth and the Sun is 150,000,000km and the radius of the Sun is 700,000km, the energy per second arriving at the Earth surface (projection area) is calculated as 64,200,000 / 46,348≒1,385(J/m^2) (see upper of Figure 5). This is almost same as the observation of incoming radiation, 1,353J/m^2. The solar energy on the Earth surface can be estimated as 346.25W/m^2 by multiplying the factor 1/4 considering the ratio of projection plane (circle) and the spherical Earth surface (see bottom of Figure 5).



The emitted energy from the sun per second: 64.2 x10^6 J/m^2
Energy per second arriving at the Earth surface:
64,200,000 / 46,348 ≒ 1,385J/m^2
Observed solar energy per second: 1,353J/m^2

Figure 5. Calculation of the solar energy on the Earth surface.

About 30% of the sunlightthat reaches the top of the atmosphere is reflected back to space. Roughly two-thirds of this reflectivity is due to clouds and small particles in the atmosphere known as 'aerosols'. Some man-made aerosols also significantly reflect sunlight. The energy that is not reflected back to space is absorbed by the Earth's surface and atmosphere. This amount is approximately 240 (W/m^2). To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space. The Earth does this by emitting outgoing longwave radiation. Everything on Earth emits longwave radiation continuously. That is the heat energy one feels radiating out from a fire; the warmer an object, the more heat energy it radiates.

To emit 240 W/m^2, a surface would have to have a temperature of around-19°C. This is much colder than the conditions that actually exist at the Earth's surface (the global mean surface temperature is about 14°C).

The reason the Earth's surface is this warm is the presence of greenhouse gases, which act as a partial blanket for the longwave radiation coming from the surface. This blanketing is known as the natural greenhouse effect. The most important greenhouse gases are water vapour and carbon dioxide. The two most abundant constituents of the atmosphere - nitrogen and oxygen - have no such effect. Clouds, on the other hand, do exert a blanketing effect similar to that of the greenhouse gases; however, this effect is offset by their reflectivity, such that on average, clouds tend to have a cooling effect on climate (although locally one can feel the warming effect: cloudy nights tend to remain warmer than clear nights because the clouds radiate longwave energy back down to the surface). Human activities intensify the blanketing effect through the release of greenhouse gases. For instance, the amount of carbon dioxide in the atmosphere has increased by about 35% in the industrial era, and this increase is known to be due to human activities, primarily the combustion of fossil fuels and removal of forests. Thus, humankind has dramatically altered the chemical composition of the global atmosphere with substantial implications for climate. Because the Earth is a sphere, more solar energy arrives for a given surface area in the tropics than at higher latitudes, where sunlight strikes the atmosphere at a lower angle. Energy is transported from the equatorial areas to higher latitudes via atmospheric and oceanic circulations, including storm systems. Energy is also required to evaporate water from the sea or land surface, and this energy, called latent heat, is released when water vapour condenses in clouds (see Figure 6, Kiehl and Trenberth (1997)[7]).(from IPCC AR4 WG1, chapter 1)

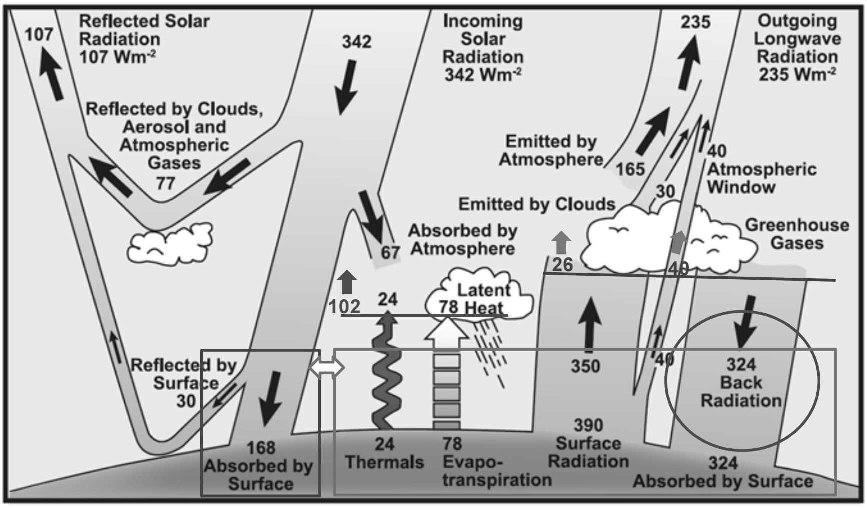


Figure 6. Estimation of the Earth's annual and global mean energy balance.

2.5 Renewable energy

Renewable energy obtained from natural phenomena such as sunlight, wind, tides and geothermal heat that are sometimes criticized for being intermittent. However geothermal resources from heat generated deep within the earth, ocean tides, hydropower, and biomass, biofuels, hydrogen derived from renewable resources provide us quite constant supply of energy. Deployment of renewable technologies, however, usually increases the diversity of electricity sources and, through local generation, contributes to the flexibility of the system and its resistance to central shocks. Renewable energy replaces conventional fuels in four distinct areas: power generation, hot water, transport fuels, and rural (off-grid) energy services.

Renewable power generators are spread across many countries, and wind power alone already provides a significant share of electricity in some areas, for example, 14 %t in the U.S. state of Iowa, 40 % in the northern German state of Schleswig-Holstein, and 20 % in Denmark. Some countries get most of their power from renewables, including Iceland (100 %), Brazil (85 %), Austria (62 %), New Zealand (65 %), and Sweden (54 %). Solar hot water makes an important contribution in many countries, most notably in China, which now has 70 % of the global total (180 GWth). Most of these systems are installed on multi-family apartment buildings and meet a portion of the hot water needs of an estimated 50-60 million households in China. Worldwide, total installed solar water heating systems meet a portion of the water heating needs of over 70 million households. The use of biomass for heating continues to grow as well. In Sweden, national use of biomass energy has surpassed that of oil. Direct geothermal for heating is also growing rapidly. Renewable biofuels have contributed to a significant decline in oil consumption in developed countries as Transport fuels. The 93 billion liters of biofuels produced worldwide in 2009 displaced the equivalent of an estimated 68 billion liters of gasoline, equal to about 5 % of world gasoline production. [3]

3. Afterword

This special issue of IDEC Journal in 2010 invites papers contributed by IDEC students and teachers who do research on the renewable energy and its application to establishment of low carbon society which are crucial for the all lives and global sustainability. The special issue of Renewable Energy addresses issues of photovoltaics, solar thermal, biomass, ocean energy, geothermal etc. This special issue contains papers written by two exchange students of the Joint Master Degree Programme for Sustainable Development that has been conducted with five universities in Europe (University of Graz, Ca’ Foscari University Venice, Leipzig University, Utrecht University, Basel University) and Hiroshima University since 2009. The Biomass Research Center, National Institute of Advanced Industrial Science and Technology has moved to Higashi-Hiroshima from Kure in 2010. The Chugoku Electric Power Co., Inc. kindly contributes to this special issue introducing their approaches for stable energy supply with consideration of global and regional environmental issues with the presentation panels.

It is our great pleasure to have contributions of six reports to this special issue of IDEC Journal as follows;

1. Johann Koinegg (University of Graz): “Overview of the progress in photovoltaic sector in Europe”
2. Lee HanSoo (Hiroshima University) : “Ocean renewable energy: Tidal power in the Yellow Sea”
3. Marco Cinelli (Ca’ Foscari University Venice): “Analysis of Feed-in and Tradable Green Certificates (TGC) support mechanisms for renewable energy in Europe”
4. Tetsu Kubota, et al. (Hiroshima University): “Energy Consumption and Air-Conditioning Usage in Residential Buildings of Malaysia”
5. Osamu Higashi, et al. (Hiroshima University): “International Cooperation for Building Low-Carbon and Water-Saving Society -Case Study of Japan and China -”

6. Kinya Sakanishi (The Biomass Research Center, National Institute of Advanced Industrial Science and Technology) : “Bio-Fuel Production Technologies from Ligno-cellulosic Biomass and Asian Biomass Strategy”

The author expects that this special issue will inspire a lot of students and young researchers to create new/wise idea on renewable energy use in the low-carbon society that may be the key of sustainable development of our planet. The color version of the reports in this special issue is available in the web-site of IDEC, of which URL is http://www.hiroshima-u.ac.jp/en/idec/tohodec/.

References

[1] IEA (2006): RENEWABLES IN GLOBAL ENERGY SUPPLY An IEA Fact Sheet, IEA Publications, 34p., 2007.
[2] REN21: http://www.ren21.net/pdf/RE_GSR_2009_Update.pdf
[3] http://en.wikipedia.org/wiki/Renewable_energy
[4] Rybicki, G. B.; Lightman, A. P. (1979): Radiative Processes in Astrophysics. New York: John Wiley & Sons.
[5] Mehra, J. and H. Rechenberg (1982): The Historical Development of Quantum Theory. 1. New York: Springer-Verlag.
[6] http://en.wikipedia.org/wiki/Electromagnetic_radiation
[7] Kiehl, J., and K. Trenberth (1997): Earth’s annual global mean energy budget. Bull. Am. Meteorol. Soc., 78, 197-206.