Future Energy: Opportunities and Challenges

Part II. Energy Sources

Chapter 5. Renewables

Future Energy:
Opportunities and Challenges

Thomas W. Kerlin

5
Renewables

The Main Points

- **The sun is the source of energy available in biofuels, as wind energy, as solar energy, and as hydroenergy.**
- **The average solar energy absorption by the earth is well known (about 1280 BTU per day per square foot).**
- **The average surface area needed to absorb a Quad of solar energy is around 50,000 acres.**
- **Processes that provide useful energy (such as biofuel production) involve capture of only a small fraction of incident solar energy.**
- **The earth must emit energy into space at the same rate that it receives energy from the sun.**

5.1 Introduction

Since fossil fuels will eventually run out, the future of civilization depends on developing and implementing alternative energy sources. The only options are renewable energy sources and nuclear energy. (Uranium for fission reactors is a large but finite resource. If fusion energy becomes a reality, the resource is so great that it is essentially limitless.) All the renewable sources–except geothermal energy and tidal energy–derive their energy from the sun.

This chapter deals with some general features that are common to the various renewable energy sources. The details are also important, and they are addressed in subsequent chapters.

5.2 The Solar Resource

In this section, we consider solar radiation as an energy resource. The sun may provide energy directly, as with solar space heating or water heating, or with electricity production via photovoltaic cells or solar heat engines (Chapter 6 provides details). The sun may also provide energy indirectly as with the production of plant matter through photosynthesis (Chapter 7), the production of wind by uneven heating of the earth (Chapter 8), its contribution to ocean currents by temperature differences and wind (Chapter 9), and through the production of rainwater that descends through hydroelectric plants (Chapter 9).

The average radiation intensity striking the earth's atmosphere is about 108 BTU per hour per square foot. Of this energy flow, about 34 BTU per hour per square foot are reflected back into space, 21 BTU per hour per square foot are absorbed in the atmosphere, and 53 BTU per hour per square foot are absorbed by the earth[1] (see Figure 5-1). This energy absorption rate is the global average and should be fairly representative of temperate zones such as the continental U.S.

Actual energy absorption rates in the continental U.S. vary with latitude and regional climates (such as desert vs. verdant regions). The average absorption in the U.S. varies from about 46 to 75 BTU per hour per square foot[2]. These values are known quite accurately.

Solar energy absorption statistics appear in Table 5-1.

The continental U.S. minimum (lowest incidence) values apply for northern U.S. states, and continental U.S. maximum (highest incidence) values apply for southwestern desert areas, where solar energy incidence is higher and reflection back to space by clouds is small. Appendix G provides a discussion of solar radiation intensities.

It is instructive to determine the number of acres of surface needed to absorb a Quad of energy (10^{15} BTU) per year. The results are shown in Table 5-2.

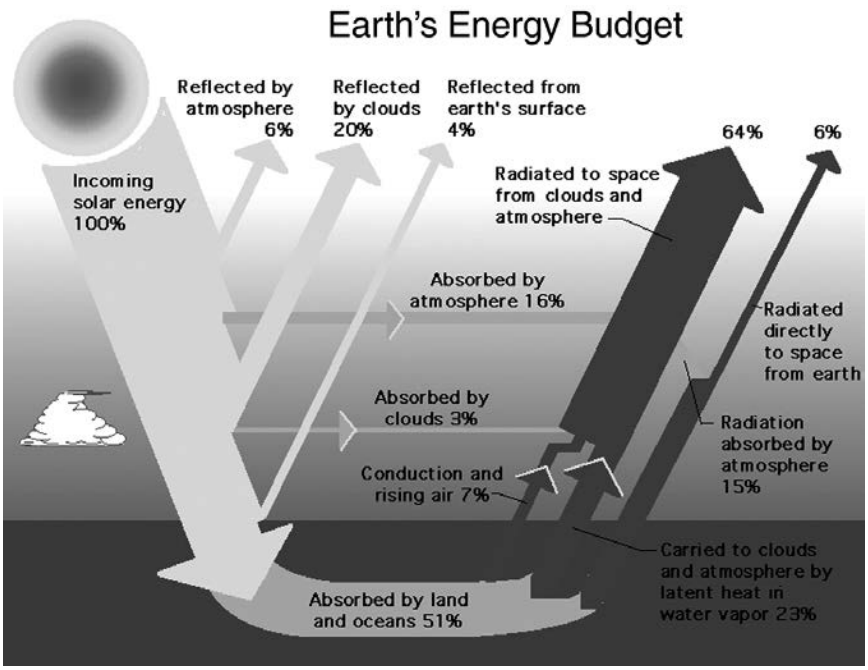

Figure 5-1. Earth's Energy Budget (courtesy of NASA)

Table 5-1. Solar Energy Absorption (Yearly Average)

	Site with Lowest Incidence in the Continental U.S.	Site with Highest Incidence in the Continental U.S.	Global Average
BTU per hour per square foot	46	75	53
BTU per day per square foot	1,100	1,800	1,280
Million BTU per day per acre	48	78	55
Million BTU per year per acre	17,000	28,000	20,000

Source: NASA

Table 5-2. Acreage Required to Absorb a Quad of Solar Energy

Solar Energy Absorption Rate (BTU per day per square foot)	Acres Required to Absorb One Quad per year
1,100 (U.S. minimum location)	57,200
1,800 (U.S. maximum location)	35,000
1,280 (global average)	49,100

(Note: The continental U.S. surface area is about 1.9 billion acres.)

Of course, the earth must emit exactly the same amount of energy that it absorbs to maintain a steady-state condition (constant average temperature). Using the sun's energy for human purposes means diverting a portion of the incoming solar energy stream, putting it to some use, and then returning the diverted energy stream to the earth in the form of heat, which is then radiated by the earth into space.

For example, consider the production of photoelectricity with solar cells. The cells extract energy from the incoming radiation and convert it into electricity. The electricity is then used to produce heat or mechanical work. Since mechanical work ultimately results entirely in heat, all of the photoelectric energy eventually becomes heat, which becomes part of the supply of energy that is radiated by the earth into space. In essence, we borrow energy from the energy stream flowing into the earth system and then return the same amount of energy in the form of earth radiation emissions.

This borrowed energy is dilute, so it must somehow be concentrated to serve human needs.

5.2.1 Solar to Usable Energy Conversions

Solar energy is the primary source for the following energy supplies:

- Direct solar heating and cooling. Solar radiation may be used directly for space heating or cooling and for water heating. (Yes, heat can be used to produce cooling. See Appendix K.)

- Solar electricity. Solar cells convert solar energy into electrical energy directly, and solar heat engines use solar energy to heat a fluid that drives a turbine-generator or Stirling engine.

- Bioenergy. Bioenergy is energy derived from plant matter. Plant matter, or biomass, is produced from water and carbon dioxide by photosynthesis using energy from the sun. The biomass produced can be burned or converted into biofuel, thereby making the bioenergy available for human uses.

- Wind energy. Uneven heating of the earth is the main initiator of atmospheric flows. Some of the wind's kinetic energy can be converted into mechanical work and electricity.

- Hydroenergy. Hydroenergy is energy derived from water motion. The sun evaporates water, some of which condenses and falls as rain at higher elevations. At naturally occurring sites or at dams, the sudden elevation change permits significant energy extraction. Moving water in rivers and in ocean currents possesses kinetic energy. Tides cause back-and-forth and up-and-down water movement. Waves cause up-and-down movement. All of these water movements are potentially useful for producing electricity.

A problem with all these processes that convert solar energy into an energy form that can replace nonrenewable fuels is the low energy density of the input. (There is a huge quantity of solar energy, but it falls on a huge surface.) A full assessment of the potential of renewables as an energy replacement for fossil fuels requires an assessment of the capacity for practical collection and concentration or storage (such as in biomass) of the energy received from the sun.

The transportation sector has the special requirement of energy source portability. Biomass can be converted into liquid or gaseous fuels suitable for use in transportation. Other renewable sources produce electricity, which can provide transportation energy using energy storage in systems such as batteries and gas compression systems or through storage in portable fuels such as hydrogen that can be produced from water with electricity, from fossil fuels or from biomass.

5.2.2 The Solar Spectrum and Solar Radiation Dispersion

The solar spectrum (wavelength distribution of solar radiation) is important because some processes for producing renewable energy sources depend on the wavelengths of the incident solar radiation. Photosynthesis and photoelectricity production are processes that operate only with certain wavelengths.

Most solar radiation lies within the visible spectrum. The earth, like the sun, is a radiation emitter, but the earth's radiation wavelengths are much longer than the sun's because of the earth's lower temperature (see Figures 5-2 and 5-3). The radiation from the earth extends well into the infrared region. This difference in the wavelengths of incoming solar radiation and outgoing radiation from the earth into space is the basis for the greenhouse effect. The tendency of chemicals in the atmosphere to absorb radiation depends on the wavelength of that radiation. Certain chemicals, when present in the atmosphere, react slightly with short wavelength incoming radiation, but they react strongly with long wavelength outgoing radiation. This interference with outgoing radiation traps the energy in the atmosphere, some of which re-radiates to the surface.

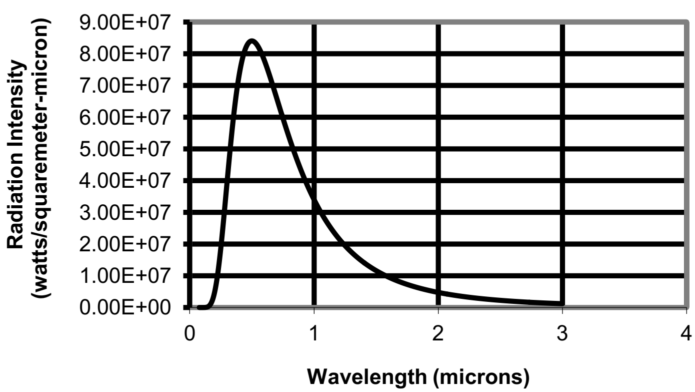

Figure 5-2. The Solar Spectrum

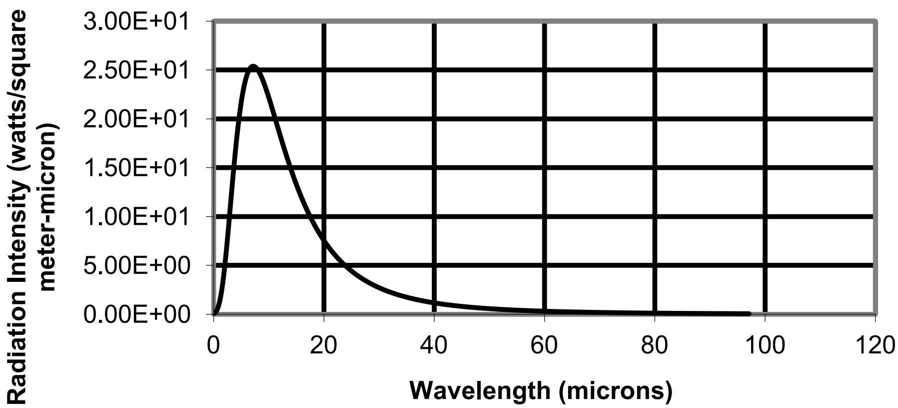

Figure 5-3. Earth's Radiation Spectrum

The radiation incident on the earth includes unscattered radiation and radiation that underwent scattering in the atmosphere. Typically, about 55 percent of absorbed radiation is unscattered, and 45 percent is scattered[3]. The unscattered radiation emanates from a point in space (the sun), and the scattered radiation emanates from the full atmospheric canopy. The significance of this is unscattered radiation can be focused with mirrors or lenses, and scattered radiation cannot. One important solar energy application requires focusable radiation. Sunlight is focused with lenses or mirrors on a boiler where high temperatures are achieved. This high temperature heat evaporates a liquid, and the vapor drives a turbine-generator.

5.3 Useful Energy Derived from Sunlight

Sunlight provides the energy for direct applications, in which solar energy is used as it is received, and for indirect applications, in which solar energy creates other energy forms that can be stored and then later transformed into useful energy. Direct applications of solar energy include producing electricity with photovoltaic systems or solar heat engines, space or water heating with solar collectors, and cooling with gas absorption refrigeration systems. The indirect applications include producing fuels from biomass, producing electricity with wind turbines, and producing electricity with hydroenergy systems. The stored energy is in the form of chemical energy for biomass, kinetic energy for wind, and kinetic or potential energy for hydroenergy.

5.4 Useful Energy from Non-Solar Sources

Renewable sources of energy include two that do not derive their energy from sunlight: geothermal energy and tidal energy (which is also a form of hydroenergy).

Geothermal energy is the result of residual heat remaining from the initial formation of the earth and from the radioactive decay of elements located in the interior of the earth. This energy causes the temperature to increase as depth increases. In some locations, the temperature is high enough near the surface to boil water or even melt rock. These shallow energy reservoirs can sometimes be tapped for practical applications such as heating or electricity production. Drilling into the earth can provide access to a much larger resource of stored geothermal energy located at greater depths.

Tidal energy is a form of hydroenergy, but it is placed in this section on non-solar sources because it results from gravitational effects rather than solar radiation. Tides fill estuaries, causing water flows and creating opportunities for impoundment and subsequent release through a turbine.

5.5 Using Renewables

The renewable energy sources discussed above are all of the currently known possibilities for large-scale energy production in the future. Some, possibly all, will become essential features of modern civilization. It is too early to know which ones will dominate or even participate in future energy production. All are currently undergoing major development efforts, and these efforts will surely continue.

The U.S. and all other developed countries have built huge and expensive infrastructures based on energy production with fossil fuels. Switching to renewables will require investment in new energy production and transport systems and changes in energy use facilities and equipment. The components of the new infrastructure are discussed in later chapters.

References

1. NASA "Earth's Radiation Budget Facts" at http://science-edu.larc.nasa.gov/EDDOCS/radiation_facts.html.

2. National Renewable Energy Laboratory "Solar Radiation Data Manual for Buildings" at http://rredc.nrel.gov/solar/pubs/bluebook.

3. "Fundamentals of Physical Geography" at http://www.physical geography.net.

Exercises

5-1. The diameter of the earth is around 7,926 miles (12,756 km), and the sun is approximately 93,000,000 miles (149,668,992 km) away. What fraction of the sun's energy strikes the earth's atmosphere? Estimate the total power output of the sun. (Hint: Consider the target area presented by the earth relative to all of the power flowing through a spherical shell at 93,000,000 miles.)

5-2. The albedo is defined as the fraction of incident radiation that is reflected. Use Figure 5-1 to estimate the earth's albedo.

5-3. One of the energy transport mechanisms shown in Figure 5-1 is by latent heat in water vapor. Explain how this process removes heat from the surface and deposits it in the atmosphere.

5-4. What would happen to energy absorption by the earth if an increase in particulate matter in the atmosphere caused an increase in reflection of incident solar radiation?

5-5. How much power (in BTUs per hour and in kilowatts) is radiated from the earth into outer space without absorption in the atmosphere?