Chapter 6
Introduction of Renewable Energy

The previous chapters have shown that there is considerable potential for energy conservation in the activities of "daily life." Furthermore, even for the activities of "making things," we can save energy resources through recycling in comparison to the present practice of production from natural resources. However, even if we can reduce the amount of energy that we consume in this way, we will still need a large amount of energy resources. We cannot continue to depend on fossil fuels. If we just consider the single issue of global warming caused by CO_2 emissions, it is clear that we do not have much time left to develop energy resources that can replace fossil fuels.

We have seen that it will probably not be possible to achieve the complete replacement of fossil fuels within the 21st century. However, this does not mean that we can just sit back and do nothing as we watch fossil fuel resources disappear. Rather, we must see this as a warning that only if we apply our best efforts towards the development of alternative energy resources now will it be possible for us to launch ourselves away from oil and other fossil fuels and make a soft landing to an alternative and sustainable energy system.

1 Could Intensification of Nuclear Power Be the Answer?

As we saw in Chapter 2, the options for alternative energy are limited to nuclear energy and renewable energy. To which of these should we entrust our future?

Types of Nuclear Power

Many experts claim that nuclear power is the answer. One benefit is that, because the nuclear reaction of uranium is used instead of the combustion of carbon, nuclear power causes essentially no greenhouse gas emissions. On the other hand, like

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fossil fuels, uranium is a non-renewable resource. While uranium does exist in rather large quantities under the earth's surface, most of it is Uranium 238, which cannot be used directly in nuclear fission. Only 0.7% of the uranium on the earth is Uranium 235, the fissionable form of uranium that can be used in conventional nuclear reactors. The amount of confirmed Uranium 235 reserves divided by the current production rate is currently just 45 years, which gives us some concern that the natural uranium resources may be exhausted. However, it is also said that if we look we can find all that we need. From the example of oil in the past, at least we can say that it is unlikely that the resources will actually be depleted in 45 years. However, this does not change the fact that current nuclear power generation is a technology that relies on a non-renewable resource.

One possible solution to this problem that has generated much interest is the use of breeder reactors. Currently, the concentration of Uranium 235 in the uranium needs to be enriched to about 2% for use as the fuel in nuclear power generation. The Uranium 238 is unused and must be disposed of in expensive containment facilities. However, if breeder reactors can be realized, it will be possible to transform the unreacted Uranium 238 that remains in the reactor into Plutonium 239, which is another fissionable material, by bombarding it with neutrons. All at once, the amount of nuclear power resources could be increased ten fold. This may seem like a perfect technology; however, unfortunately it is not without problems. Plutonium is even more dangerous than uranium, so the safety and non-proliferation issues are even more severe in the case of breeder reactors.

For a long time, people have hoped to develop a technology for producing electricity through the process of nuclear fusion. Production of electricity through nuclear fusion would work by the same principle as that which gives the sun its energy, so scientifically it should certainly be possible. If power generation through nuclear fusion could be realized, the amount of electricity that could be produced would be essentially limitless. However, considering that as of yet no one has been able to reach the critical state where the energy that is produced is greater than the energy that is supplied, and that people who were saying thirty years ago that "in thirty years we will construct a demonstration reactor" are still saying the same thing today, nuclear fusion will probably not be a viable energy source for the 21st century. If we are going to use nuclear energy, it will most likely have to be nuclear fission, with all of its resource, safety and nuclear proliferation related problems.

Concerns About Safety

Concerns regarding the safety of nuclear technology are numerous. While some of the fears may actually be unfounded, many of them are quite serious, such as the issue of nuclear weapon proliferation and the disposal of radioactive waste having a half-life of several thousand years. The contribution of nuclear power to the total global energy production is currently 5%, and it is not likely to increase much. If, for instance, we wanted to meet the total energy used today with nuclear power, that will mean constructing ten thousand plants the size of the Three Mile Island nuclear power plant around the world. The task of figuring out how to solve the issues related to accidents, terrorism and handling of radioactive waste would almost certainly exceed our current abilities.

If we cannot place our expectations on intensification of nuclear energy, we will need to focus our efforts into the development of renewable energy. Renewable energy exists in great abundance throughout the biosphere; the problem that renewable energy technologies attempt to address is how to transform that energy into forms that are easy to use, such as electricity and vehicle fuel. Numerous types of renewable energy technologies that have been proposed, ranging from solar heating and wind turbines to methods for generating electricity using the temperature difference created by the sun between the surface and deep waters of the ocean or using the osmotic pressure between salt water and fresh water that we saw in Chapter 2. However, here we will restrict our attention to those technologies that could be introduced at a significant scale in the near future.

2 Sunlight

Sufficient Amount and Excellent Quality

We can calculate the total amount of sunlight that shines down on the earth by multiplying the intensity of the solar irradiation outside the atmosphere that is directed perpendicular to the surface of the earth (which is 1.37 kW/m^2) by the cross-sectional area of the earth. This value is on the order of 10,000 times the total amount of energy that is used by humanity today, so the amount of sunlight energy is more than sufficient. The next problems that we must consider when using sunlight as an energy resource are its quality and density.

What is the quality of sunlight? We saw in Chapter 2 that all kinds of energy except for heat can at least theoretically be transformed with 100% efficiency and thus have the same value or quality. More accurately, all kinds of energy have equal quality except for the kinetic energy of randomly vibrating molecules that is the heat embodied in an object and the radiant energy that is produced by an object at high temperature such as the filament of a light bulb. Sunlight is radiant energy that is produced by the sun, so its quality is not as high as the other kinds of energy that we looked at in Chapter 2, such as electricity and work. Let's consider the quality of sunlight from two viewpoints.

The first is the temperature of the energy of sunlight if it is converted into heat. We saw that the value of heat is given by the temperature difference with the environment divided by the temperature of the heat, so the higher the temperature of the heat the higher its value is. The surface temperature of the sun is about 6000 °C, so sunlight has an energetic value equivalent to heat with a temperature of 6000 °C. Using the environment temperature of the earth, which is about 15 °C, we find that the temperature difference divided by the temperature is about 0.95. This means sunlight energy can be changed into electricity or work with 95% efficiency, so sunlight is energy having nearly the same quality as electricity.

The other way to think about the quality of sunlight is in terms of its wavelength. When sunlight passes through a prism or a drop of water, we see all of the colors of the rainbow. Sunlight is made up of a lot of electromagnetic waves having different wave lengths, each of which produces a different color of the rainbow. Because things like prisms and water droplets bend light to different degrees depending on the wavelength, sunlight can be divided up into different colors, as shown in figure 6-1. The wave lengths of visible light, the colors of the rainbow that we can see with the naked eye, range from 0.7 microns for red light, which is the longest, to 0.4 microns for violet light, which is the shortest. Therefore, visible light is made up of electromagnetic waves having wavelengths between 0.4 and 0.7 microns.

However, there are electromagnetic waves outside of the colors of the rainbow that exist in sunlight even though they cannot be seen by the human eye. The part with a wavelength longer than red light, more than 0.7 microns, is called “infrared radiation,” and those electromagnetic waves exist outside the red edge of the rainbow. The part with a wavelength shorter than violet light, less than 0.4 microns, is called “ultraviolet radiation,” and those electromagnetic waves exist outside the violet edge of the rainbow. The fraction of energy contained in each of the parts of sunlight shining on the earth from outer space is 9% for ultraviolet radiation, 47% for visible light, and 44% for infrared radiation. Ultraviolet radiation is absorbed by the ozone layer in the stratosphere, so just a tiny amount of that part reaches the earth’s surface.

The energetic quality of light, which can be thought of as a flow of energetic particles called “photons,” is determined by the wavelength. We can think of light with a short wavelength as the flow of particles of light having large amounts of energy, and light with a long wavelength as the flow of particles of light having small amounts of energy. For example, no matter how long you expose yourself to

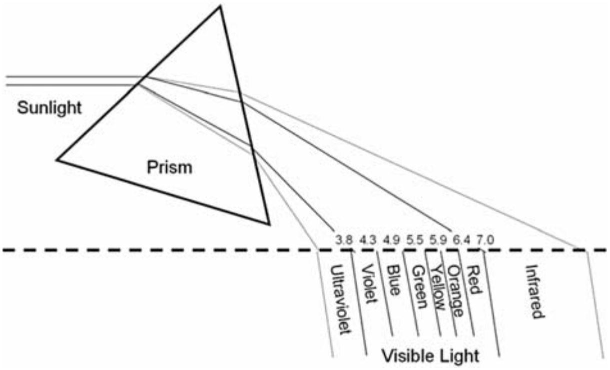

Fig. 6-1: The wavelengths of sunlight

infrared radiation, you will not get a sun tan. The reason is that the energy of one photon of infrared radiation is not enough to drive the chemical reaction of melanin that causes your skin to tan. If you stand in front of a hot stove or electric heater for a long time, you may get burned, but you will not get tanned. In order to cause the tanning reaction, the energy of ultraviolet photons is necessary. Likewise, photons having at least the energy of visible light are necessary to cause the reaction to split water; it is impossible to do with infrared radiation. Furthermore, as we might expect, visible light photons are necessary to drive the reactions of photosynthesis, and infrared radiation is not enough. That is why plants cannot grow in a room with no visible light, even if there is a strong source of infrared radiation such as a heat lamp. Finally, the wavelength of light also determines the maximum voltage at which electricity can be generated by a solar cell. With visible light, it is possible to generate electricity with more than 1.5 volts.

In summary, visible sunlight can cause the splitting of water or the reactions of photosynthesis, and with it we can make solar cells that have voltage sufficient for meeting electric power needs. Because almost half of sunlight energy is in the form of visible light, sunlight is clearly a high quality energy resource that can be used for a wide range of energy needs.

The Maximum Power of a Solar Car Is Two Horsepowers

The main problem with sunlight is its low density. As we saw in the previous section, the sunlight intensity outside the atmosphere is 1.37 kW per square meter; however, about 30% of that energy is reflected by clouds and dust and does not reach the earth's surface. When we add in the effects of the seasons, day and night, weather, and so on, the energy density of sunlight in Japan for example is no more than 200 W per square meter.

Can we make a car that runs on just solar cells? If we could, we would go a long way towards alleviating the energy resource problem. In fact, there is a solar car race that has been held since 1987, which gives us reason to hope. However, even the winners of the race cannot produce the horse-power required for regular driving conditions. If we cover a large car from roof to hood with solar cells having an electricity conversion efficiency of 15% such as those that are currently on the market, under the most intense solar irradiation at noon on a mid-summer's day, we can get about two horse-powers of propulsion force, and for average solar irradiation, we can only produce 0.4 horse-powers. Furthermore, under some weather conditions, such as cloudy or rainy days, the power level is even lower, and of course at night almost no power can be produced by the solar cells at all. Compared to the 100 horse-power engines of conventional automobiles, even under the best conditions, solar cars cannot provide enough power. In the solar car race, thin vehicles are made from light-weight materials, and solar cells are mounted on large wing-like structures on the vehicle. Even so the vehicles seem to move at a leisurely pace across the race track.

Prospects for the commercialization of solar cars are slim, solar powered commercial airplanes are nearly inconceivable, and even stationary solar cell power plants are difficult to construct because they require such a large area. All of these problems result from the low density of sunlight together with rapid fluctuations in time due to clouds and other factors. These are the main drawbacks of sunlight when looked at as an energy resource. In order to use sunlight as a source of energy, we need a large area to gather the energy and a way to store it for when the solar irradiation is weak. Two technologies that show particular promise for overcoming these kinds of problems are biomass and solar powered electricity generation.

We have seen that the theoretical maximum efficiency for converting sunlight into electricity or work is 95%. Because low density is the main problem with sunlight, we should try to get as close as possible to this theoretical efficiency in order to reduce the area required for collection. In the next sections, let's see what kind of efficiency can actually be obtained using biomass and solar powered electricity generation technologies.

Biomass Is 5%

Sunlight is absorbed by special bodies in plant cells called chloroplasts, and the absorbed sunlight gives its energy to the electrons in the chloroplasts. Photosynthesis is the process of using those electrons to synthesize fructose from CO_2 and water, and it occurs through many steps including dozens of enzymatic and ionic reactions. Fructose is a kind of carbohydrate, a chemical compound of carbon and water. Energetically, it is close to carbon, which means that its chemical energy content is comparable to coal. The efficiency of photosynthesis is high in the sense that all of the electrons that have absorbed sunlight are used. However, this does not mean that all of the energy of the solar irradiation can be used. There are two main reasons, and the essence of both is that, as we saw before, sunlight is composed of light with different wavelengths.

The first reason is that, as was noted earlier in this chapter, the energy of infrared photons is too small to be absorbed by the chloroplasts in plants, so about 44% of the energy of sunlight cannot be used for photosynthesis. The second reason is that chloroplasts can only make use of the energy in a photon that is equivalent to that of a photon of red light. The excess energy of photons of light that is more energetic than red light, such as blue and violet, ends up becoming heat. In short, chloroplasts can only absorb photons of sunlight with wavelengths within the range of visible light, and furthermore, red is the only wavelength of light for which the process of photosynthesis is optimal.

Simply as a result of the suboptimal efficiency for using the energy of wavelengths of sunlight other than red light and the inability to use infrared light at all, the maximum efficiency of photosynthesis drops to less than 40%. Moreover, through energy losses during the many reaction steps leading to the production of fructose, efficiency drops further to about 10%. Furthermore, not all of the visible light in sunlight even reaches the chloroplasts in plants. If leaves absorbed all visible light then they would appear black, but in fact they appear green, which means that green light is reflected. Combined with several other factors that lower the efficiency of photosynthesis, we find that the theoretical efficiency limit for photosynthesis is only about 8%.

The carbohydrates produced from sunlight by photosynthesis are accumulated in the body of the plant as "biomass." Plants consume about half of the accumulated biomass themselves through respiration. Furthermore, plants only grow from spring to summer, lying dormant in autumn and winter. After all of these factors are taken into account, the maximum efficiency of biomass in the sense of the fraction of the year long solar irradiation energy that is available as harvestable biomass for human use ends up being less than 1%.

For example, rice is a crop that uses sunlight with relatively high efficiency. Thin leaves and stalks grow together densely, so that nearly all of the sunlight shining down on the rice field is collected. Rice has a high crop yield of about 10 tons per hectare, and if we include leaves and stalks, about 20 tons of biomass can be harvested. The overall efficiency, calculated as the ratio of the maximum value of energy that can be obtained from this biomass and the energy of the sunlight that shines on the rice field over the period of a year, is about 0.2%.

The period of growth in the case of rice planted in temperate regions is only from spring to summer, so solar energy cannot be collected all year round. On the other hand, in the tropics the growing season lasts all year. As one example, let's consider how sugar cane is cultivated in Brazil. A mid-summer sun shines all year round, so farmers do not need to cultivate sugar cane just from spring to autumn. Instead, the crop is grown until it is mature, and then it is harvested, irrespective of the time of year. In one region, a continuous growing process lasting for a period of a year and a half is practiced. The average yield for one such region when converted into an annual rate is 50 tons of dry weight per hectare. It is said that if irrigation is used, a yield of 90 tons could be achieved. In that case, the efficiency of biomass production would be slightly less than 1%. We can probably consider this to be the realistic maximum value for production efficiency of biomass on land.

What about the productivity of aquatic plants? Some varieties of green algae, such as chlorella, are known to consume very little of their photosynthesis products themselves. According to one research finding, a biomass production efficiency of close to 5% can be achieved by cultivating chlorella in water under conditions of optimal nutrients and solar irradiation. It is most likely that this value of 5% is the maximum efficiency of biomass production that could be commercialized in the next few decades.

Methods for Solar Thermal Power Generation

Two methods for generating electricity from sunlight that show particular promise for the 21^{st} century are thermal power generation using the same principles as a thermal power plant and direct power generation from sunlight using solar cells.

Solar thermal power generation involves using sunlight to change water into steam and spin a turbine. Several different configurations for doing this are being studied. One example involves heating oil and using it to evaporate steam. As shown in figure 6-2, in the focal point of a concave mirror made of a thin sheet of aluminum, a transparent tube is set through which oil flows and is heated by the focused sunlight. In essence, the sunlight concentrated by the concave mirror is collected to the power plant using the oil. If we define the power generation efficiency as the fraction of the sunlight shining on the concave mirror that is converted into electricity, it is possible to obtain an efficiency of at least 20%. If we can increase the temperature of the oil, the efficiency can be increased even more.

Another method that currently shows promise is a technique that uses a light focusing tower called a "heliostat." In this method, a large number of mirrors are placed in the area around the tower, the reflected light is focused to the collection point in the upper part of the tower, and water is converted to steam for power generation. It is expected that a power generation efficiency of at least 30% can be realized using this method.

The largest drawback of solar thermal power generation is that it only can make use of the direct solar irradiation part of sunlight; it cannot be applied to diffuse sunlight. If the sun is covered by a cloud, the direct solar irradiation is drastically reduced, so in both the focal point of the concave mirror and the collection point of the heliostat tower, reflected light will not be accumulated. Therefore, solar thermal power generation may be an effective technology in deserts where there few clouds to block the direct solar irradiation from the sun, but in highly populated regions that have large energy needs, the number of locations appropriate for this technology are few.

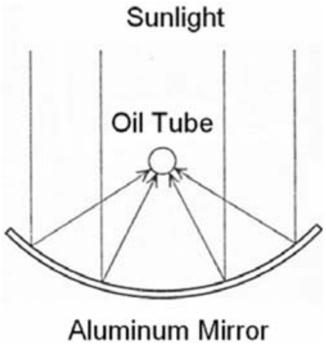

Fig. 6-2: A solar thermal power plant uses a concave mirror to concentrate the sunlight.

Solar Cells Are 40%

Figure 6-3 shows an array of solar cells installed on the roof of a home – for an ordinary home, it is possible to be almost entirely self-sufficient in terms of electricity using this kind of array. The mechanism by which solar cells generate electricity begins when silicon or some other semi-conductor material absorbs sunlight, and the electrons obtain energy. The mechanism up to this point is essentially the same as the first steps of photosynthesis where chloroplasts absorb light. However, in solar cells, these electrons are taken out directly as an electrical current, while in photosynthesis they are used to drive chemical reactions for producing carbohydrates.

We have seen that 95% of the energy of sunlight can theoretically be converted into electricity, so the theoretical maximum efficiency of solar cells is 95%. However, in actual use the efficiency drops considerably. One of the reasons is that efficiency is reduced at the initial steps where light is absorbed by the silicon electrons for exactly the same reason as with photosynthesis. Because there is not just one wavelength of sunlight, it is not possible to use all of the wavelengths optimally. Silicon can absorb electromagnetic radiation with a wavelength of 1 micron or less, which includes a part of infrared radiation, visible light, and ultraviolet radiation. However, most of infrared radiation has a wavelength greater than 1 micron, and that radiation cannot be used. Moreover, in the same way that we saw for photosynthesis, even for photons of highly energetic light, such as violet light, only the amount of energy of a photon of 1 micron infrared radiation can actually be used.

As a result of these factors, an efficiency of more than 40% cannot be achieved using the mechanisms of conventional solar cells (although there are technologies for concentrating sunlight to achieve much higher efficiencies). Furthermore, when we add in other losses due to factors such as impurities in the silicon and inefficiencies in the collection of the electrons, the efficiency of cells that are currently on the market drops to around 15 to 20%. Still, because the electrons that absorbed the light energy can be taken out directly as electrical current, the efficiency of

Fig. 6-3: Solar cells installed on a roof of a house (Courtesy of KYOCERA Solar Corporation)

solar cells is considerably larger than photosynthesis, which involves numerous chemical reaction steps in the production of carbohydrates.

One method for increasing efficiency of solar cells that shows promise for the future is making tandem cells. Rather than just using silicon, tandem cells are made by layering a variety of materials together in order to accommodate a wide range of wavelengths of sunlight optimally. If a solar cell could be manufactured using a continuous range of materials in tandem in such a way that all of the wavelengths of sunlight are perfectly optimized, the ideal efficiency would be 95%.

For example, current silicon solar cells with an efficiency of 15% are made of crystalline silicon. However, simply by layering a thin film of amorphous silicon on the surface, it is possible to raise the efficiency up to about 17%. Currently, the maximum efficiency for solar cells is reported to be 24.4% for silicon, 33.3% when using compound semiconductors, and over 40% for the most advanced concentrating photovoltaic cells.

Does Developing New Technologies Require Too Much Energy?

One of the arguments made by critics of solar cells is the statement that "a large amount of energy is needed to produce solar cells, and it would take 20 years for the cells to recover that energy." However, fortunately, this argument is incorrect.

The idea of using an energy system, such as solar cells, to save energy is based on the assumption that the amount of energy produced by the system will replace the consumption of an amount of conventional energy resources such as fossil fuels that is significantly larger than the amount of energy resources required to make the system in the first place. The length of time that an energy system must be operated to recover the energy consumed during the manufacture of the system is called the "energy payback time." Here we will take a look at what the energy payback time for solar cells is.

Solar cells are constructed from a variety of materials. The strength of the cell is provided by a frame of aluminum, the surface of the cell is protected by glass, and the power generating part of the cell is made of a semi-conductor such as silicon. Furthermore, in order to adjust for the imbalance of power generation between night and day, or between rain and shine, some kind of mechanism for storing the generated electricity or for exchanging power with the local electric power company is also needed. However, after listing up and evaluating all of the materials and processes that go into making solar cells, from the mining of resources to the manufacture of the silicon thin-film and the assembly of the whole cell, a study by the Society for Chemical Engineering of Japan found that in the case where cells manufactured using current technology are installed on rooftops in Japan, the energy payback time is only about two years.

Comparing Solar Cells and Biomass

Among the technologies for using renewable energy, solar cells and biomass are a pair of technologies that show great promise as sources of renewable energy for the future. They have considerably different characteristics. In terms of energy efficiency, solar cells are superior to biomass. We have seen that carrying out the cultivation of sugar cane in Brazil under the optimal conditions of sunlight and irrigation results in an efficiency of 1%. If we estimate that the silicon solar cells on the market will be able to reach an efficiency of 20%, the difference is twentyfold. This means that in order to obtain the same amount of energy, one twentieth of the area is sufficient if we use solar cells.

On the other hand, from the viewpoint of energy payback time, biomass has the upper hand. Figure 6-4 shows a concept diagram for a system where eucalyptus trees are planted and used as biomass in Western Australia. A circular area of land 25 km in diameter is divided into 12 sections like a clock. A drying site and power plant are set up in the center. Alternatively, in place of the power plant a chemical plant for manufacturing methanol or fuel oil could be used. Of the 12 sections, 11 sections are kept planted, and each year one section is harvested for biomass that is collected to the drying site at the center. At this scale, the system can produce an amount of fuel oil each year that is equivalent to 150,000 tons of crude oil, or if the system is used to generate electricity, it will have a generating capacity of 100,000 kW, which is the equivalent of a mid-sized coal-fired power plant. This system has been designed and evaluated based on the assumptions that the planting,

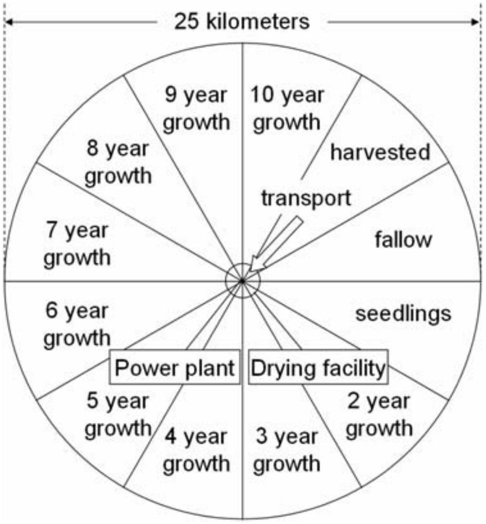

Fig. 6-4: A biomass utilization system

cultivation, and harvesting are all done mechanically and that an appropriate amount of fertilizer is applied. According to that evaluation, regardless of the form in which the final energy is obtained, the energy payback time is in the range of just 5 to 75 days. Therefore, the energy investment for this biomass system can be recovered in a much shorter time interval than in the case where solar cells are installed on rooftops, which we saw would take two years. Because the initial investment of biomass production can be recovered so quickly, biomass is probably better suited for quick applications than solar cells.

The fundamental differences between biomass as less efficient but more easily implemented and solar cells as more efficient but more costly and difficult to start up suggests an approach where biomass technology is used to facilitate the transition to solar cells. Land that is secured for cultivation of biomass and conversion to fuel could gradually be replaced with solar cells, which could increase the energy generation rate per unit area by more than twenty times.

3 Hydropower and Wind Power

Potentials Large and Small

In general, assessments of renewable energy resources vary greatly depending on how the assessment is made. For instance, an upper limit for the quantity of hydropower and wind power resources can be estimated from the energy balance at a global scale, and a lower limit giving the amount of resources that we know for certain to exist can be obtained by adding up the results of individual surveys made at each resource site. However, the difference between these two values is large.

The size of a water resource for hydropower generation is its potential energy, which is just the amount of water multiplied by its height. The average rainfall around the world is about 1 meter per year. If we consider that this rain on average falls from a height of 1000 meters, then the amount of resources for hydropower generation if all of the rain water were collected at this height would be more than double the current global amount of energy usage.

However, to recover this amount of hydropower resources would require doing something drastic like collecting rain in a plastic sheet stretched over the entire sky of the earth and dropping that water through a 1000 meter long turbine to generate electricity. If we take just the part that falls to dry land, the value becomes one fourth, which is about half of the worldwide amount of energy usage. On the other hand, adding up the results of surveys of flow rates and heights of all known rivers around the world, the total amount of undeveloped hydropower resources remaining appears to be approximately the same order as the current developed hydropower resources (one estimate gives the potential hydropower resources that are economically viable as 9400 TWh, which is four times the current developed hydropower resources), which produce 5% of the total amount of energy use. Therefore, there is a more than two-fold difference between the estimate of the potential energy in the rain that falls to dry land and the estimate of water resources from surveys. It is difficult to imagine that any large rivers still remain undiscovered on the earth's surface, so we should probably take the survey-based estimate of unused water resources as the basis for decisions regarding hydropower.

If we include the westerlies and other major winds that blow at high altitudes, natural resources for wind power have an energetic value that is greater than that of water resources. However, when we limit the altitude of the wind resources that we can use, the amount becomes much smaller. For the height of current wind power generation facilities, the amount of wind resources is about the same level as the worldwide amount of energy consumption. Even this is a considerable amount of resources. However, with the wind powered electric generation technology available today, the generator will not work under conditions of weak winds, and when a wind blows that exceeds the design strength, then the operator must shut the generator down. As a result, the generator typically operates for only about 70 to 80 percent of the time on average, and even when it is operating, much of the time it is not operating at its maximum power output. In fact, a wind turbine that is rated at 1000 kW will typically only produce about 20% of its maximum power output each year. Furthermore, when we consider all of the conditions that are necessary for current wind powered electric generation, such as having a stable wind, having a low local population, and not being too far from a region with a demand for energy, it is not clear how many appropriate sites are in existence. Data with the reliability of the survey results for hydropower have yet to be obtained.

The Natural Circulations Are Concentrated

Hydropower is an excellent renewable energy that is clean and can be transformed with almost 100% efficiency into electricity, as we saw in Chapter 2. These benefits come from using water that is collected over a wide area over a relatively long period of time. Therefore, the major problems of solar energy that we saw earlier in this chapter, which are low density and rapid temporal fluctuations, are solved through the circulation of water. Although wind cannot be collected behind a dam, it also benefits from the circulation of air, which can collect the kinetic energy of wind over a wide area and direct it towards the position of the wind turbine.

However, one important problem with hydropower development is that valuable land becomes submerged. Take the example of the "three gorges dam" in China. This is a huge dam, whose construction began in 1994 and is scheduled to be completed in 2011. The completed dam will have a generation capacity of 22,500,000 kW, which is more than 2% of the total power generation capacity in China. It is said that 660 km^2 of land was submerged as a result of construction of this dam and that 1,130,000 people were forced to move. One way to alleviate this problem is to make a large number of small dams as shown in figure 6-5. Remember that hydropower gets electricity from the potential energy of water, which is determined by the product of the water amount and height. Therefore, so as long as we

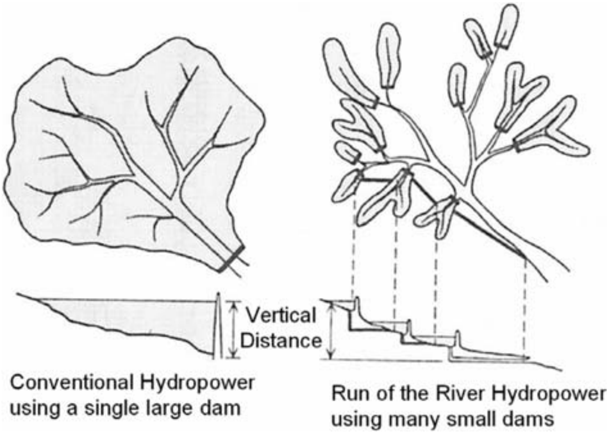

Fig. 6-5: Conventional hydropower versus run of the river hydropower
Note: the shaded area shows land that is flooded by the dam.

accumulate the same amount of water over the same vertical distance by building many small dams in the catchment area flowing into the location where the single large-scale dam was to be constructed, we can generate the same amount of electricity, even though the total land area flooded is much smaller. This way is also easier to implement economically.

4 Geothermal Energy and Tides

We can imagine geothermal power generation as digging a deep hole and burying a U-shaped steel pipe that reaches the hot mantle of the earth. When we pump water into the pipe, it will turn to steam as it travels down to the earth's mantle and back, and that steam can be used to turn a turbine and generate electricity. Currently, there are still only a small number of applications of this technology, mainly because only heat close to the surface can be used economically. Places that have geothermal heat near the surface are places where hot springs and geysers most easily upwell. Such locations are often natural parks or tourist attractions where development is difficult, so it is not likely that the use of geothermal energy will expand rapidly.

On the other hand, the amount of heat contained within the earth is tremendous, and if we could find a way to tap into that energy, the amount of geothermal resources would rival the energy from the sun. Many ideas for geothermal technologies have been suggested, such as power generation using high-temperature rocks and ways to tap in to geothermal resources deep below the earth's surface in a cost effective manner. However, methods for actually implementing these ideas have not yet been established. One example of a concrete method that has been proposed for power generation using high-temperature rocks involves jetting water out of a steel pipe underground at extreme pressures. The high pressure water jet breaks up the high-temperature rocks underground and is heated through contact with the rock fragments. The water is then collected at a high pressure and high temperature at a different location on the surface, where it is used to generate electricity at a thermal power plant. In order to extract heat from large rocks, they must be broken up into small enough pieces that the contact area between the water and the rock fragments is sufficient. Experiments are being conducted, and promising results have been reported. However, the technology development is still at the stage of feasibility research studies, and it has not yet reached a level where one could say that the prospects are sufficiently developed for practical application.

The ebb and flow of the tides caused by the gravitational attraction of the moon and the sun can be used to obtain energy. All we need to do is build a flood gate at the entrance of a bay. We open the flood gate when the tide is rising, and allow the tide to flow into the bay. Then when the tide begins to ebb, we close the flood gate and force the water accumulated inside the bay to return to the ocean through the same kind of generator that is used in hydropower plants.

One power plant that uses this kind of tidal electricity generation has actually been in operation since 1967 in Reims, France. The power generation capacity of the plant is 260 kW, which is about the size of a small hydropower plant. However, due to the large number of features that are required for the coastal region to be suitable for this kind of electricity generation, such as large tides and bays with small mouths, finding appropriate sites is difficult. Therefore, we probably cannot expect a large contribution from this technology.

In this chapter, we have seen that energy from the sun and the earth's core exists in practically limitless amounts, and its quality is also high. However, the energy from the sun is difficult to harness because of its low density and temporal instability, and few reliable methods for harnessing energy from the earth's core have been sufficiently developed for commercial applications. Probably the only methods that could reliably overcome the problems of density and instability and could be deployable on a large scale within the 21st century are solar cells, solar thermal power generation, biomass, and deep geothermal power generation. While the technologies currently available are still expensive and difficult to commercialize, it is almost certain that some excellent technology that is well suited for a material-recycling society could be developed in the not too distant future. However, in order to realize that possibility, we must invest our efforts in research and development of the most promising technology options existing today.

Development of technologies and systems that can generate large amounts of energy at the quality and cost of what is currently obtained from fossil fuel resources will take some time. The task of replacing the majority of fossil fuel resources with renewable energy will most likely take until the end of the 21st century. Oil, and possibly all of the fossil fuels that we currently depend on, will be completely depleted on this time scale. Consequently, together with speeding the development of renewable energy, we must work to reduce fossil fuel consumption in order to make time for the expansion of the practical application and scale of technologies that use renewable energy.