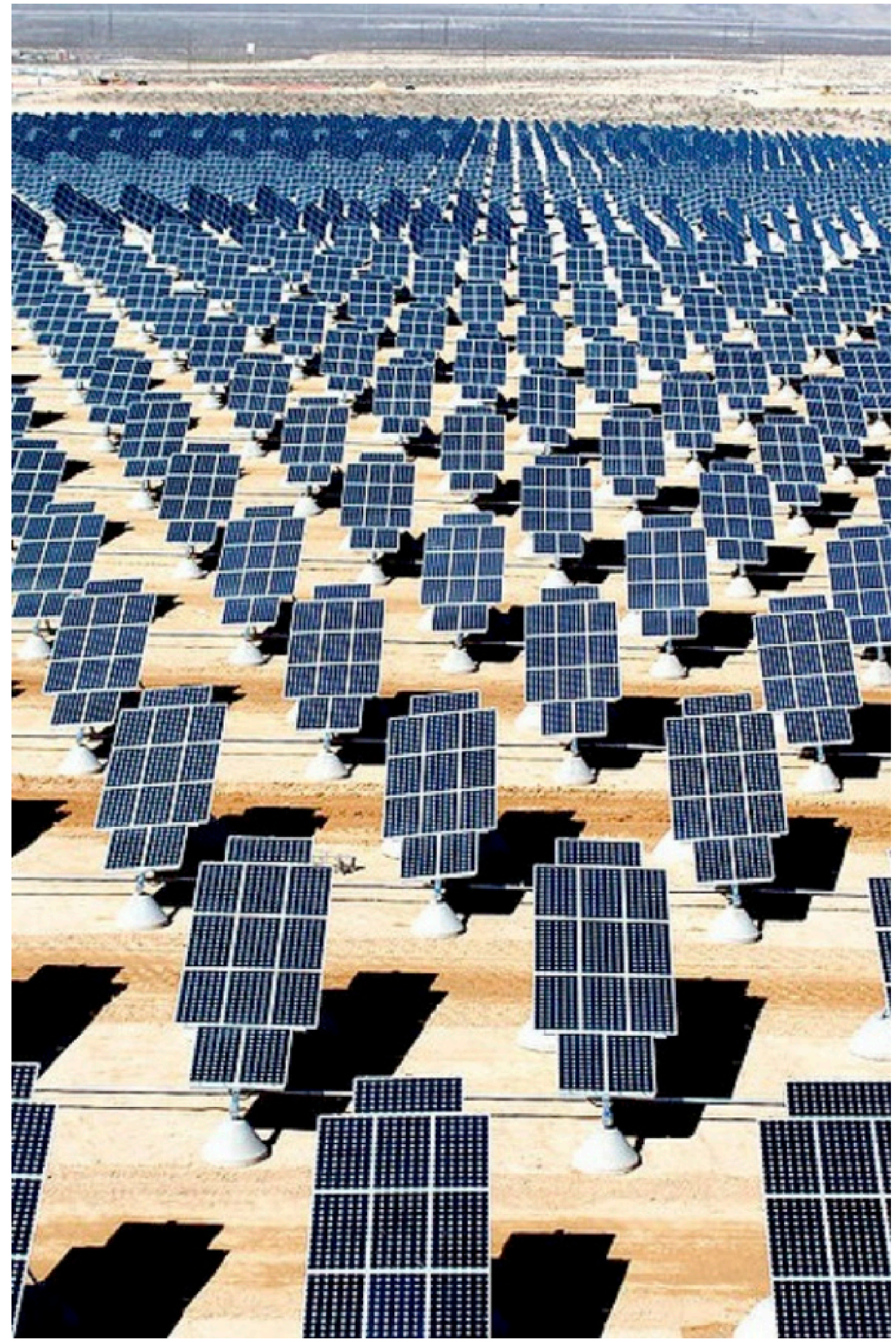
Renewable Energy

Chapter Objectives:

1. Define insolation.
2. Describe how the intensity of solar energy is affected by changes in the seasons and in latitude
3. Distinguish between active and passive solar heating systems for a house.
4. Discuss photovoltaic generation of electricity and the photoelectric effect.
5. Describe how solar-thermal electrical energy is produced and discuss limitations to its widespread use.
6. Describe the production of electricity from wind energy and discuss limitations to its widespread use.
7. Discuss the use of hydropower and its impact on the environment.
8. List and discuss the three methods of biomass conversion.
9. Describe the efficiency of producing various biofuels and how this impacts the environment.
10. Discuss problems with geothermal efficiencies and why such systems are not widespread.
11. Discuss the economics of all forms of renewable energy.



Introduction

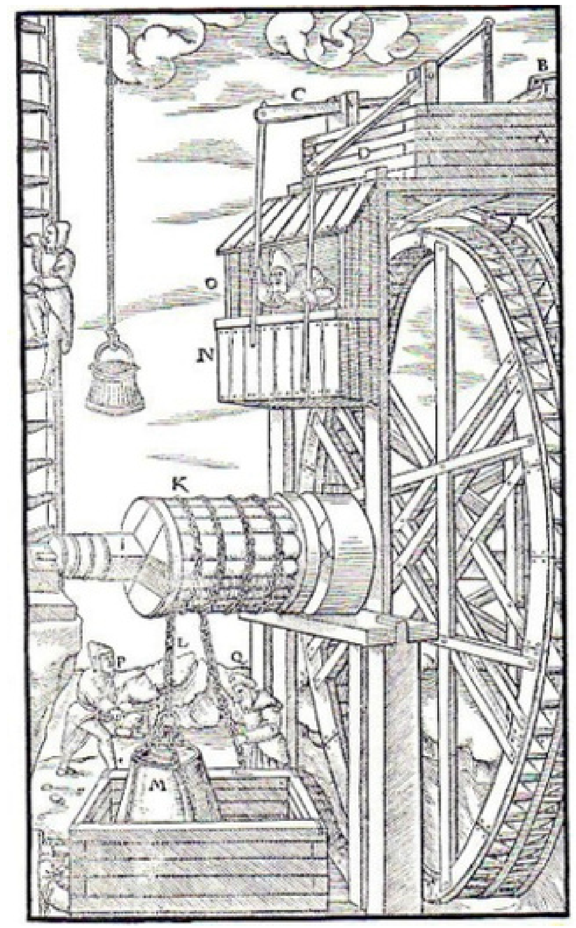
Over the last four chapters, we have discussed all of the forms of fossil fuels and nuclear energy. For the last sixty years in this country, these fuels have dominated production and consumption in the world. This has not always been the case, as other forms, ones that until recently were called alternative energy sources, dominated the landscape. In the future, these other forms will have to dominate again, as both fossil fuels and nuclear energy are finite resources that must one day come to an end. Before that time comes, we will either need to increase our usage of renewable forms of energy to maintain our lifestyles, or we must change our lifestyles to become less energy intensive.

What are these renewable forms of energy? They are fuels that are being replenished at the same rate that we are using them, i.e. they are not stored forms of energy. You are, most likely, aware of most of them: solar, wind, geothermal, and hydropower. If you live in some areas, you are probably aware of the less common ones, such as biofuels. In this chapter, we will discuss the main ones available today, their impact on the environment, and their prospects for usage in the future.

Hydroelectric Energy

Water has always been one of mankind's most vital resources. While the human body can go weeks without food, it can only survive for a couple of days without water consumption. Crops in the field will shrivel and die without a readily available supply. We use it for cleaning; we use it for cooking. And since almost the start of recorded history, we have used it as an energy source.

Some of the first recorded mentions of hydropower go back over 2,000 years ago to ancient Greece and Egypt, where water wheels were connected to grindstones to turn wheat into flour. Harnessing water for this laborious task allowed for large quantities of food to be processed, which allowed for job specialization and civilization to grow. Later, other cultures connected these same water wheels to rudimentary equipment such as lathes, saw blades, and looms in order to produce such goods as furniture and fabric. By the 1700's, factories were mass-producing these products, which allowed for even more specialization of jobs and the growth of large cities.



The invention of the electrical generator in the late 1800's produced a new way to exploit hydropower for the growth of civilization. By marrying water turbines to generators with belts and gears, a reliable source of electricity was created that could be used to power factories and businesses around the clock. The large supply of rivers and streams in the Eastern U.S. became a readily-available source of energy that was quickly exploited. The first hydroelectric power plant was built in Niagara Falls in 1881 to power street lights in the city. Before the end of that decade, over 200 additional power plants were built in the U.S.[1]

The creation of the Bureau of Reclamation in 1902 further sped the development of hydroelectric power in the U.S. The Bureau was created to "reclaim" arid lands in the U.S. and make them farmable and livable. This was to be done by providing irrigation water for homesteaders in the Western U.S. who had been lobbying for more water to operate their farms and ranches. In order to meet these needs, the Bureau set out on a dam building program throughout the region. Initially, the dams were funded by selling land and mineral leases. From 1902 to 1928, this resulted in about 60 dams being built, of which 7 had hydroelectric units attached. However, in 1928, the Boulder Canyon Project Act was passed, which started U.S. Treasury funding of projects as well as allowing the selling of electricity from hydroelectric facilities. Over the following 40 years, it resulted in over 160 additional dams being built, with 49 of these having hydroelectric facilities[2]. This dam building spurt created a massive increase in the amount of hydroelectric energy produced, tripling it from 1 quadrillion BTU's of energy to over 3 quadrillion by the late 1970's. Figure 1 shows a plot of the amount of renewable energy produced in the U.S. since the 1950's[3].

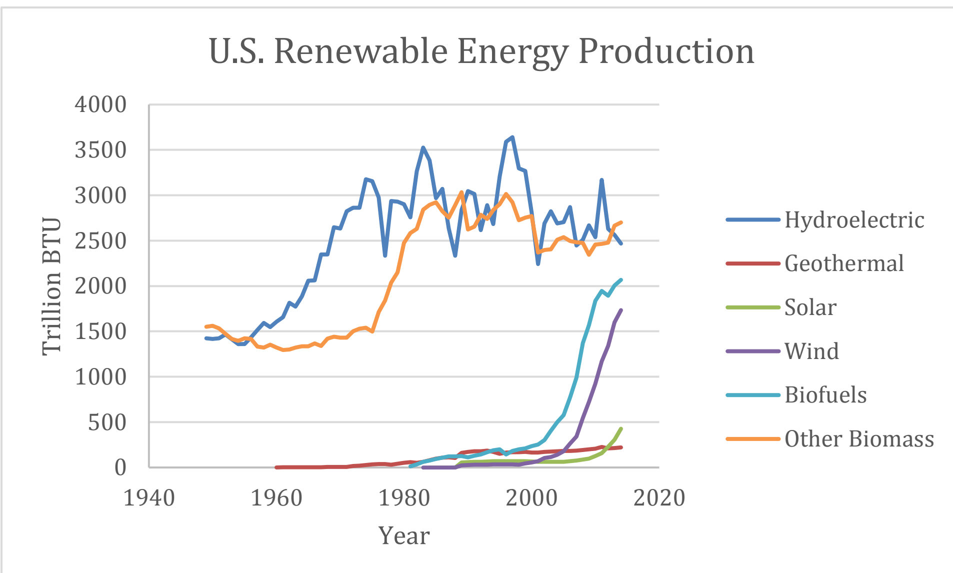


Figure 1: Renewable energy generation in the U.S.

The year 1968, though, saw the last major dam building projects for the Bureau passed by Congress. This was done with the Colorado River Basin Projects Act. Since that time, the Bureau has built fewer than 20 dams, and hydroelectric capacity has leveled off.

Environmental Problems

What happened to this resource that once showed such great potential for growth? At one time, hydroelectric power accounted for almost 40% of America's electrical consumption. Today, it is closer to 7%. From 1980 until today, there has been no appreciable increase in hydroelectric power production, while other forms of electricity production have been increasing. In the last decade or so, we have begun the process of tearing down dams rather than building them. The answer to this question of loss of enthusiasm for hydroelectric power is multi-faceted.

First of all, hydroelectric power is not as cheap as we often think. While there is no cost for fuel, as there is with coal and oil, there is a heavy cost for construction, upkeep, and land rights. The hydroelectric facilities that were built in the early part of the 1900's were usually built as part of a larger project to provide drinking and irrigation water for citizens of an area. The money made from selling electricity was used to offset the cost of building and maintaining the reservoir for these purposes. Furthermore, the dams that were built were done so in locations that the most geologically feasible. The spots that remained for dams after these were built were much less desirable, and would have required substantial amounts of engineering and construction to make them safe.

More importantly, conventional hydroelectric power is not as "clean" as we would like to believe. The dams built for these purposes have a substantial environmental impact. They convert a river ecosystem into a lake ecosystem overnight. While both of these systems have water, the type of plant and animal life in each can be radically different. Organisms that might get by fine in a river system can be completely wiped out by a lake system. A perfect example of this is the fate of the Pacific salmon, which needs to be able to navigate upstream in a river system to spawn. Even though mankind has tried many solutions to creating paths for salmon to use for migration, including building elaborate and expensive "ladder" systems along the dams, population numbers have continued to decrease in regions with these dams to the point were they are critical.

Building these hydroelectric dams also affects other ecosystems during this conversion process. Rivers and streams provide a natural means of transporting silt, sediment, and nutrients from steeper-sloped regions to fertile flatland and coastal regions. Many of the world's richest farmlands lie in flat regions near major river systems, where regular flooding deposits rich nutrients back to the soil. When water is stilled by entering a reservoir behind a dam, it loses its ability to keep sediments and nutrients suspended in solution, causing them to fall out of the water onto the bottom of the reservoir. When the water heads back downstream, it has lost all of the fertile material, meaning that few to no nutrients are put back into the soil. A prime example of this is what has happened along the Nile Delta region in Africa. For more than 3,000 years, farmers have been reaping tremendous yields of grains from the region without the aid of any type of natural or artificial fertilizers. However, within 30 years of the building of the Aswan Dam on the Nile River, chemical fertilizers became necessary in order to achieve profitable yields for farmers.

There are other environmental changes that are wrought by building dams. However, the one that seems to get the smallest amount of press and which might be its greatest effect is that dams are responsible for the release of greenhouse gases. At first, this seems absurd, as hydroelectric facilities do not involve any type of combustion. However, in filling up the reservoir, fast areas of land are covered in water. Before they are covered, many regions contain a fair amount of land-based plant material. After these regions are covered with water, the plants die and begin to breakdown. If there is enough oxygen in the water, this breakdown will result in the production of carbon dioxide, which is a greenhouse gas. This is exactly the same gas into which the plants would have been broken down if the plants had died above ground. However, after awhile, the oxygen levels at the bottom of the lake will not be sufficient to support this type of breakdown of plant material. In this type of low-oxygen environment, the material is broken down into methane, which is a much more serious type of greenhouse gas. Thus, hydroelectric dams are not totally free from greenhouse gas emissions.

Workings

How do hydroelectric dams work? What factors affect their performance? To answer these questions, let us first look at the physics behind hydroelectric power. As we learned in Chapter One, all forms of energy can be classified into one of two categories: kinetic energy or potential energy. Kinetic energy is the energy that an object has because of its motion relative to its surroundings, while potential energy is the energy that is stored in a system by virtue of forces between objects that are separated by some distance. If the objects are allowed to move under the influence of the force between them, then work is done as the force displaces the objects from their initial positions, and the potential energy is transferred to kinetic energy as the objects move.

For a hydroelectric dam, the distance through which the water will move is not large in relation to the size of Earth. Therefore, we can approximate the force on water with formula F = mg (Equation 1.8 from Chapter One). This being the case, the potential energy of water that is a height H above the base of a dam is given by

$$P.E. = F_{gravity} \times H = mgH = m \times 9.80\ m/sec^2 \times H$$

Behind a dam, there is water at all heights between the base and the top, which means that we would need to allow H to change if we want to calculate all of the potential energy behind a dam.

For the purposes of this discussion, though, we are going to assume that water continues to flow into the reservoir and keep the reservoir at the same height H.

The mass of the water that is falling is determined by how much volume it occupies. The relationship between the two is given by the formula mass = density x volume. For fresh water, the density is 1 gm/cm^3, which is equivalent to 1000 kg/m^3. Thus, our formula for the potential energy of a volume of water **V** that falls through a height **H** is

$$P.E. = (9800\ J/m^4) \times VH$$

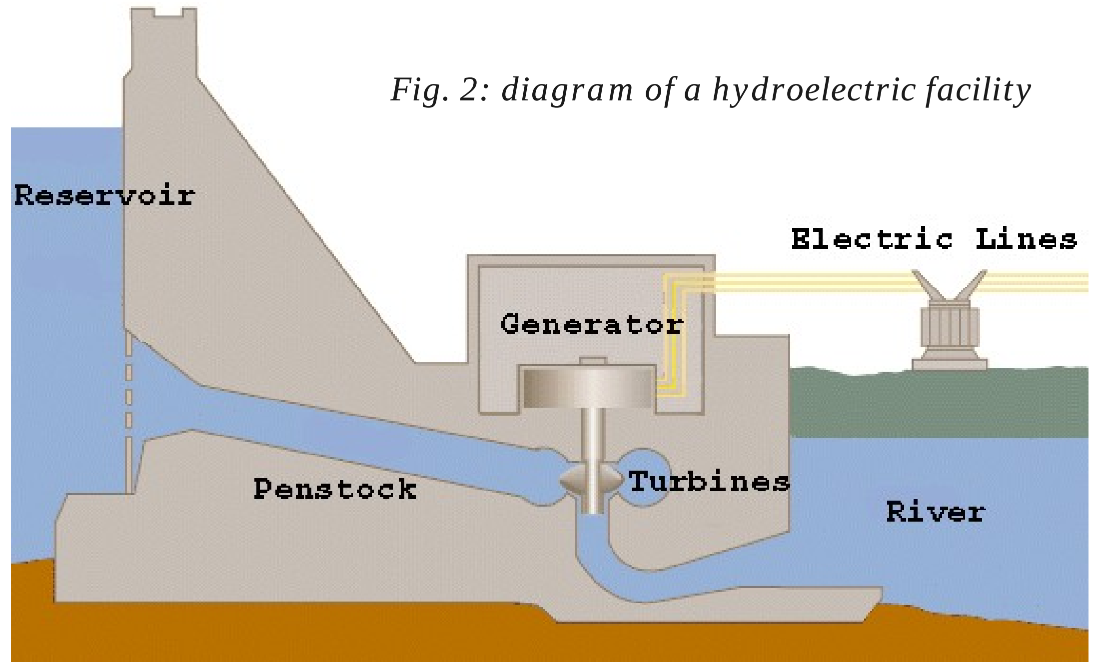
where J is the symbol for the unit of energy called the joule.

When we write about the water "falling", we are giving a somewhat false impression of how a hydroelectric dam works. Figure 2 is a diagram of a conventional hydroelectric facility. As you can see, the water does not fall onto the turbine to turn it. Instead, the water near the bottom of the dam is forced by the pressure of the water above it past the turbines. While this is not the same as falling onto the turbines, it turns out that it is equivalent mathematically. Therefore, the formula that we derived above for potential energy is the one used for a dam, where H is the difference in heights between the surface of the water in the reservoir and the turbine.

Turbine Generator

As with any system, this process is not 100% efficient. The water running through the pipes encounters drag forces from the pipe walls. The water hitting the turbines generates some heat, as does any type of collision. The water leaving the turbine still has some kinetic energy, which is energy not given to the turbine. Accounting for all of the energy losses in the system, the system is still about 80-90% efficient, which is one of the highest

Fig. 2: diagram of a hydroelectric facility



efficiencies for any type of electricity generating facility that we use in society today. The slight increases that you see in the production of hydroelectric plants since the 1970's in Figure 1 is due mostly to the increases in efficiencies of the turbine generators used in these facilities.

As stated previously, the amount of gravitational potential energy that an object has should depend upon the height through which it is allowed to fall. Theoretically, this dependence should be linear, i.e. the amount of gravitational potential energy an object is equal to some constant times the height of the object. Therefore, if everything else in the system is linear, this means that the amount of electrical energy produced should depend linearly on the height of the water.

It is this dependence that accounts for the variability in the year-to-year productions seen in Figure 1. When droughts strike a region, they cause the level of the reservoir to be drawn down, which reduces the amount of energy and power that the dam can generate. Theoretically, in high times, you should be able to make up these differences. However, when excessive water hits a region, the reservoir fills to capacity, and water is allowed to go over the top of the dam, thereby bypassing the generators.

Tidal Energy

One form of hydro energy that occasionally gets some press is tidal energy. Because of the differences in the gravitational force due to the Moon and the Sun on opposite sides of Earth, ocean water tends to bulge outward on opposite sides. These bulges cause tides twice a day as Earth completes a full rotation. Depending upon the topography of the ocean bottom in a particular location, the differences in the height of the water between high and low tide will vary from a few feet to tens of feet. In the Bay of Fundy region, the differences between high and low tide can be as much as 55 feet. These difference are regular and predictable, which means that any energy extracted from tides will be reliable.

There are many methods for extracting energy from the tides. Some systems put up a fence that is high enough to prevent the water from getting through. As the tide comes in, water builds up against the fence. Openings with generators in them allow the water through, which powers the generators. When the tide goes back out, the process is reversed, producing more electricity. Other systems look at having a closed column of air that is forced by the weight of the water as it moves up and down. Wind turbines connected at the top of the column are turned by the air escaping from the column, which produces electricity in generators attached to them. Currently, there are no tidal systems in the U.S., due mostly to the lack of any good tidal locations and the cost of such systems.

Future Prospects

The lack of any remaining good damming areas in the U.S means that hydroelectric power has peaked for now. In other countries, there is still growth in this sector, as there still remain good regions to dam. Sometimes, rivers are dammed even when feasibility of doing so is not so clear cut. As an example, the

Chinese government finished the Three Gorges Dam in 2008. This 1.5 mile dam on the Yangtze River flooded almost 60,000 square kilometers of land and displaced 1.3 million people from their homes. While it was filling up with water, large cracks more than a foot across became evident. While these cracks were filled, the presence of earthquakes in the region might ultimately doom this dam and the people that live downstream of it. This hydroelectric dam, though, will produce over 22 GW of electricity when all generators are in place, which will have a significant impact on meeting the energy needs of China.

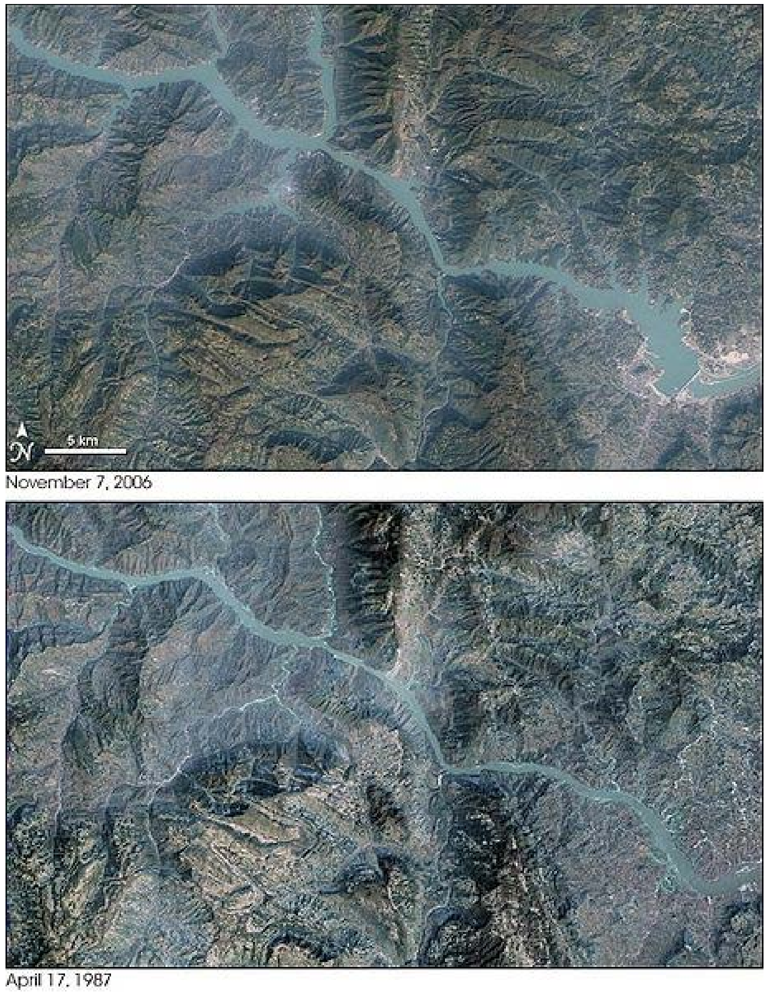


Fig. 3: flooding caused by the Three Gorges

The greatest prospect for hydroelectric power in the U.S. in the future comes from smaller, in-stream systems to operate much like a wind turbine. These systems extract kinetic energy from water that is flowing past a turbine without having to dam up the river to provide lift. While they do allow the river system to remain intact, the economics of these systems is not where it needs to be to make these systems work. With continued research, it is hoped that this barrier can be overcome.

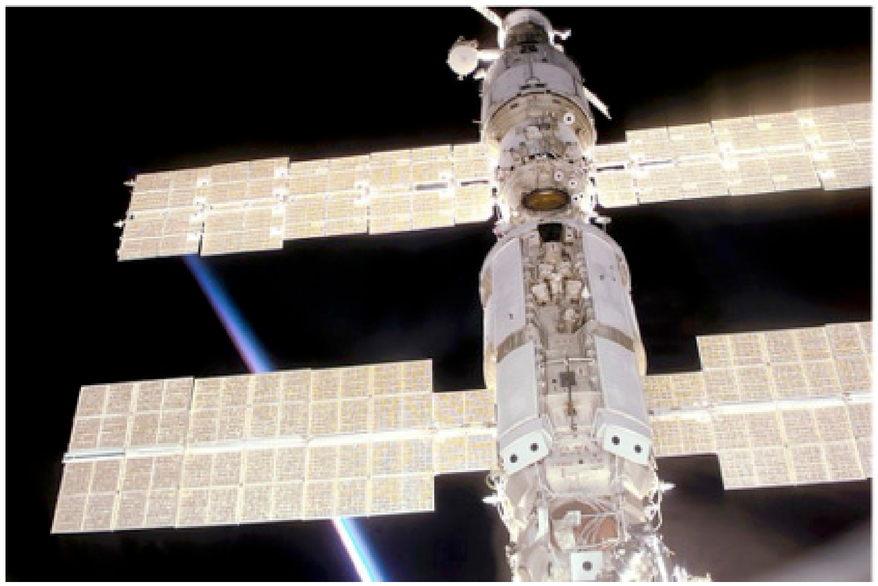
Solar

As with hydropower, solar energy has a long history. Many pre-historic cultures used it to warm their dwellings, dry their clothes, and cure their food. The importance of solar energy was so great that most cultures revered the Sun and created rudimentary observatories to track its location in the sky (ex. Stonehenge). Some found solar energy so important that they even codified its power in their laws. Ancient Romans relied so heavily on solar energy to heat their homes and bathhouses that it was illegal to build a house or dwelling so tall so as to block the sunlight of any neighbor[5].

Fig. 4: Anasazi dwellings in Arizona

Ancient Rome was not the only culture to rely heavily on the Sun for energy. The Anasazi cliff dwellers of the ancient American Southwest also used their knowledge of the Sun's motion in the sky to heat and cool their homes. They built their dwellings into the sides of cliffs that faced the south. In the winter, sunlight was able to shine on their homes, while the cliffs protected their homes from cold northern winds that might blow. In the summer, the overhangs from the cliffs shaded their homes from the Sun, and thus made it cooler.

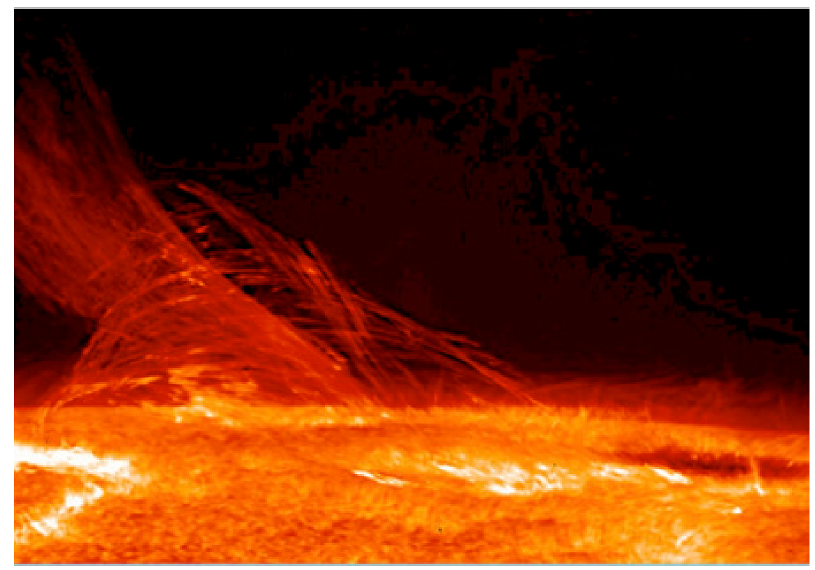
Just as with hydropower, solar energy began to wane as a conventional energy source as fossil fuels and nuclear energy became cheap and reliable. For the last half century, the expense and variability of using sunlight has relegated its use to unusual situations where fossils fuels and nuclear energy are not available or where they are prohibitive to use or maintain. A perfect example of this is on satellites, which need energy to power all on board computers and instrumentation. Using fossil fuels to power a satellite over its lifetime would require quantities of oxygen and fuel that would be prohibitive to shoot into orbit. Nuclear material would be fine for powering the spacecraft, but would become very problematic when the satellites life was over and it came crashing back to Earth. An example of solar energy that is closer to home are interstate call boxes that are in remote locations. Rather than spending a lot of money to run telephone and electric lines out to these call boxes, one can use a solar panel equipped with a battery and a cell or satellite phone.



Outside of these few types of uses, though, solar energy has seen limited usage until recently. Cheap prices for photovoltaic panels over the last five years has driven a huge increase in the amount of solar electricity production. As Figure 1 shows, solar electricity production has seen a fourfold increase in just five years from 2009 to 2014. If prices remain low, this trend can be expected to continue.

Solar Energy Basics

At its core, solar energy is actually nuclear energy. In the inner 25% of the Sun, hydrogen is fusing into helium at a rate of about 7×10^{11} kg of hydrogen every second. If this sounds like a lot, it is because it is: this is equivalent to the amount of mass that can be carried by 10 million railroad cars. There is no need to fear that we are going to run out of fuel anytime soon, though, as the Sun has enough hydrogen in the core to continue at this rate for another 5 billion years. This energy production, coupled with gravitational compression, keeps the Sun's center near a sweltering 16 million K, which is about 29 million ^{o}F.



Heat from the core is first primarily radiated, and then primarily convected, to the Sun's surface, where it maintains a temperature of 5800 K[6].

From the surface of the Sun, the primary method of energy transport is electromagnetic radiation. This form of heat transport depends greatly upon the surface temperature of an object for the amount and type of energy. Stefan-Boltzmann's Law (Chapter Two) tells us that the amount of energy that is radiated per unit area of surface depends upon the temperature of the object to the fourth power, i.e. energy/area is proportional to T^4. This means that the amount of energy that is emitted by the Sun, and therefore, the amount of solar energy that we receive here on Earth, is critically dependent upon this surface temperature. A change of 1% in the temperature of the Sun (58 K) can result in a change of 4% in the amount of energy per unit area that we receive here. While this might not sound like a lot, it is more than enough to plunge us into brutal ice age or hellish global warming.

From Wien's Law (Chapter Two), we know that the wavelength at which the most energy for a perfect blackbody radiator will be radiated depends inversely upon the temperature of an object. Thus, as an object gets hotter, the peak radiation will come from shorter wavelengths, and vice-versa. For a surface that is 5800 K, the highest energy output will be at a wavelength of

$$\lambda_{max} = (.003 \text{ m K})/(5800 \text{ K})$$

$$\lambda_{max} = 5.2 \times 10^{-7} \text{ m} = 5200 \text{ angstroms}$$

This is in the green region of the visible spectrum. While our Sun is not a perfect blackbody radiator, it is close. The yellowish tint we attribute to the Sun is because of absorption of certain wavelengths in the atmosphere.

Our Sun radiates 1.6×10^7 watts of power per square meter from its surface at all wavelengths. However, by the time that it has reached the Earth's surface, this value is vastly reduced. Between the Sun's and Earth's surfaces, the energy density of the radiation is lessened by spreading and absorption. Light traveling from a spherical object such as the Sun must spread to fill all available space. While the total amount of energy of the radiation will remain the same, the amount of energy crossing any square meter of space will be reduced by the square of the distance between the object and the area in question. Since the Sun is almost 150 million kilometers from the Earth, the energy density per unit time of the sunlight reaching the upper atmosphere of the Earth is only 1340 W/m^2.

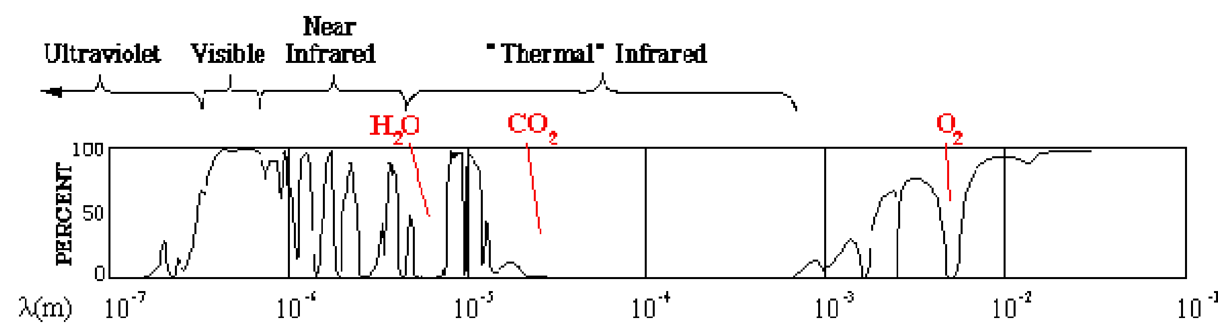


Figure 5: Sunlight transmitted through the atmosphere versus wavelength (Source: NOAA)

Traveling through the almost perfect vacuum of space, there is almost nothing to absorb or reflect any of this energy. Most of the absorption of the Sun's light occurs after it enters the Earth's atmosphere. The vast majority of the visible part of the spectrum gets through the atmosphere with little attenuation. What little doesn't get through is due to scattering by nitrogen and oxygen (blue appearance of the sky is due to this) and by absorption and reflection from clouds. Large portions of the non-visible part of the spectrum do not get through the atmosphere, though. Chemical species such as ozone, water vapor, and carbon dioxide all absorb wavelengths of light in the infrared and ultraviolet portion of the spectrum. Figure 5 shows a plot of the percentage of the Sun's energy that gets transmitted through the atmosphere versus wavelength on a cloudless day. As you can see, outside of the visible and radio parts of the spectrum, there are only a few small sections in the infrared through which the energy gets transmitted. On average, only about 50% of the Sun's energy that makes it to the top of the atmosphere actually gets down to the surface.

Latitude and Longitude

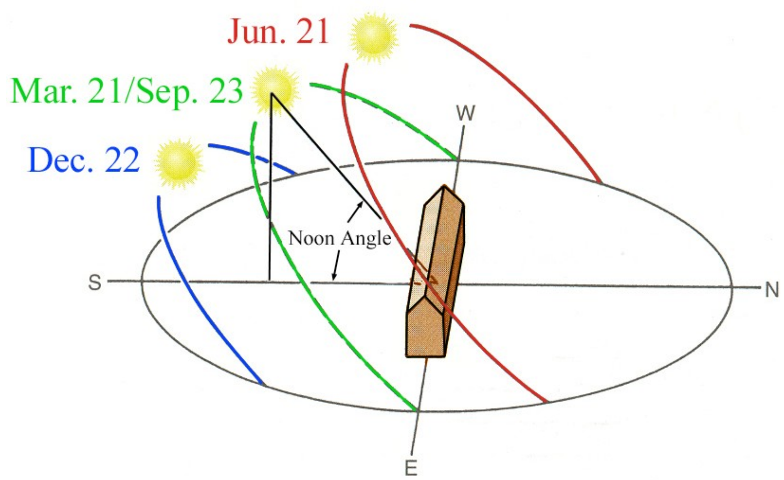
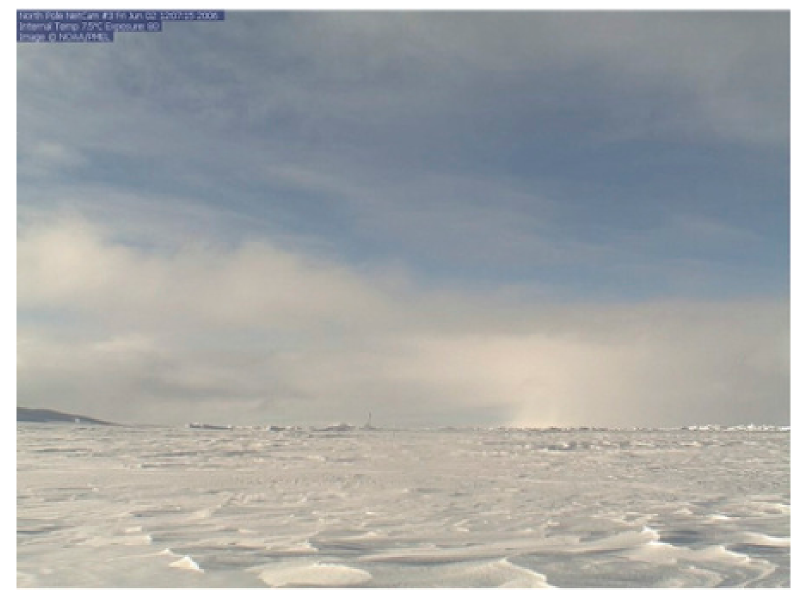


Fig. 6: diagram of the sun's path in the sky on different days

Spreading and absorption are not the only factors that affect the total amount of energy that the ground receives. One factor that seriously impacts it is the number of hours of sunlight a location receives in a day. If sunlight is striking a spot for more time during a day, then more total energy will be delivered, and vice versa. The amount of time that sunlight is shining during the day depends both on the location and the time of year. This is due to the fact that the Earth is a sphere that is spinning with its axis at an angle of 23.5° with respect to the vertical to the plane of its orbit around the Sun. This means that the path that the Sun will take in the sky on a given day changes. Figure 6 shows a diagram of a typical situation found in the continental U.S. As you can see, the length of the path that the Sun follows on these four different days varies, as does the noonday angle of the Sun. These different lengths correspond to different travel times, which means different amounts of daylight.

In the continental U.S., there are about 8-10 hours of sunlight on the Winter Solstice (December 22nd) and 14-16 hours of sunlight on the Summer Solstice (June 21st), depending upon at what degree of latitude you live. Sites that are further north have shorter days in the winter and longer days in the summer. At sites near the equator, the length of the path across the sky does not vary, which results in 12 hours of daylight everyday for those who live there. At the Poles, the situation is even stranger. There, the Sun is up for 6 months at a time, and is followed by 6 months of darkness.



The noonday angle of the Sun in the sky can also have an effect on a solar energy system unless it has a way to track the Sun. A system that can do this can always keep its collecting surface perpendicular to the Sun's rays, thereby allowing the most energy to strike it. If it cannot do this, then sunlight will always strike the system's collecting surface at some angle, thereby spreading the energy over a greater area and reducing the amount that actually strikes the surface. As we see from Figure 6, the angle of the Sun's rays changes throughout the year, as well as throughout the day. As previously stated, these angles will depend upon the location of the system on the Earth's surface.

Types of Solar Systems

When most people think of solar energy systems, they imagine photovoltaic panels like those found on solar-powered calculators or satellites. These devices are very portable and useful, as they convert light directly into electricity via the photoelectric effect. This ability to directly output electricity means that they can power a tremendous number of modern devices that we use. However, they do have one very serious drawback: low efficiency. Most commercially available photovoltaic panels only have efficiencies in the 10-20% range, with the ones having efficiencies close to 20% being the most expensive[7].

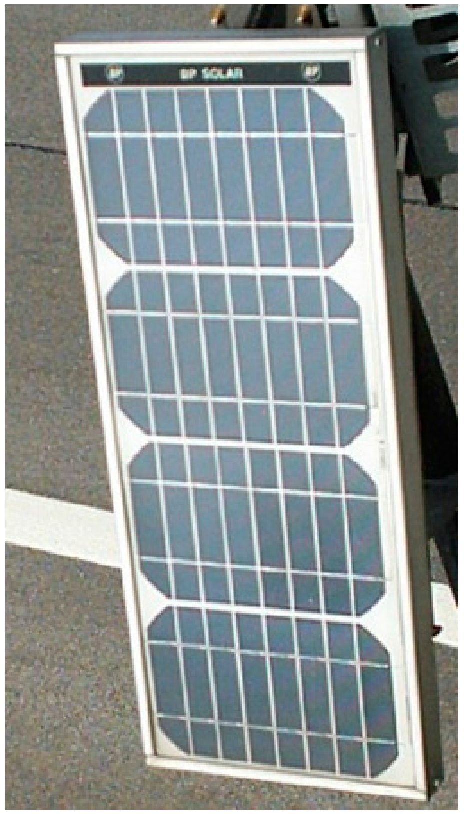
The reason for these low efficiencies has to do with the fact most of the energy in light cannot directly generate electricity. In 1839, Alexandre Becquerel noticed that light shown onto a metal was able to generate a potential difference. Later, in 1887, Heinrich Hertz was able to show that light of a particular energy was able to liberate electrons from the metal, and thereby generating a current when a potential difference was present. As you might remember from our discussion of metals in Chapter Three, metals are elements that are defined by their ability to readily give up electrons, which accounts for their use to transmit electricity.

Fig. 7: A. E. Becquerel

At the time, the conventional thinking was that light behaved as a wave. With this understanding of light, this phenomenon of freed electrons was explained by stating that the electromagnetic waves were jostling the electrons in the atoms and giving them energy. If the jostling was of a high enough amplitude, the thinking held that the electron could be freed from the atom when it acquired enough energy. This model of the effect proved erroneous when it was noted that only certain wavelengths of light caused electrons to be liberated no matter how bright the light was that was used. If light behaves like a wave, then the brighter the light is, the higher the amplitude of the wave and the greater the energy it has to deliver to the electrons. Experimentally, though, it was found that very dim blue light could free electrons from some metals while very bright light could not.

This contradiction was resolved by Albert Einstein in 1895. His treatise on the photoelectric effect (for which he won his only Nobel Prize) posited that light interacted with matter like a particle even if it traveled like a wave. These particles, called photons, where massless and contained an amount of energy that was proportional to the frequency of the light, i.e. $E = hf$, where E is the energy of the photon, h is a number called Planck's constant, and f is the frequency of the light. By this model, light with a higher frequency (for example, blue) has more energy that it can deliver to the electron than a lower frequency (for example, red).

This model explains why most photovoltaic panels are inefficient. Suppose that you design a panel such that the minimum energy to liberate an electron from the metal is that given for green photons. When white light strikes the panel, then all of the energy from green light will be sued to liberate the electrons. However, light of a frequency less than green (red, for example) will not liberate the electrons and will only cause the panel to get hotter. Further, light of frequencies greater than green (blue, for example) will liberate the electrons, but the excess energy between blue and green will be wasted.



Historically, the cost of photovoltaic cells to create electricity was 3-5 times the cost of coal or natural gas powered electrical plants. However, recent advances in manufacturing have lowered the costs, which has driven a boon in PV installation worldwide. In the U.S., PV power plants are being installed in numerous locations in the South where sunlight is readily available.

Photovoltaic systems are not the only way to convert sunlight into electricity. Solar thermal electrical systems use sunlight in order to boil water for a turbine generator, much like what happens in a normal power plant. In order to boil water using sunlight, one has to concentrate the light from a very large area into a very small area. This can be done with a magnifying glass, as any child who has ever attempted to burn leaves or paper on a sunny day can verify. However, for a large system that is going to create electricity, magnifying glasses are not useful, as such a large lens would have glass so thick that a great deal of the light would be absorbed by it. Instead, light is magnified by using curved mirrors to reflect the light to a focal point. Figure 8 shows a picture of such a system that is used for testing in New Mexico.

Solar thermal systems have efficiencies comparable to those of a coal, nuclear, or natural gas powered plant. The main impediment to their widespread use has to do with the cost of construction and upkeep. As it currently stands, these systems produce electricity at a cost that is slightly more than \$0.10/kWhr, which 1.5-2 times that of coal or natural

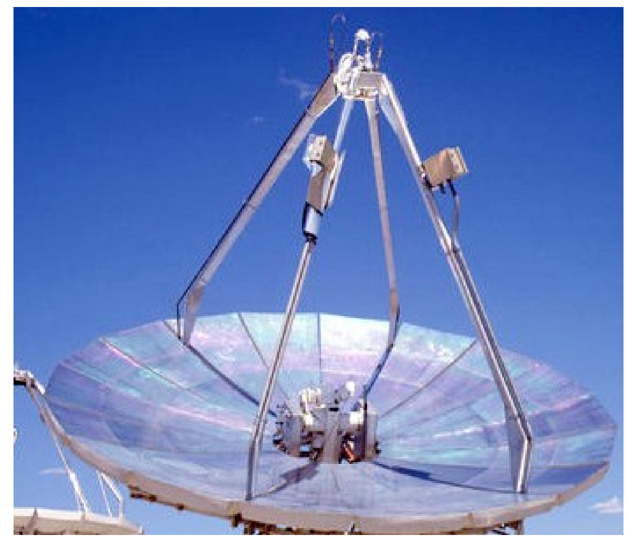


Fig. 8: Parabolic dish solar system

gas[8]. The price on these systems has been coming down, but it must continue to come down in order to make them economically feasible. If it does, large systems built in the desert southwest could supply a large percentage of the total electrical demand of the U.S.

Just as it was almost 2000 years ago, the greatest use of solar energy in the U.S. today is for heating. In most situations, it is used to either heat the air in a home or office or to supplement or replace the hot water system. This can be achieved by doing something as simple as installing a glass window on the south side of a house, or as complicated as a roof-mounted hot water system (See Figure 9). Because of the great flexibility and individuality in designing and building such system, there are no hard and fast numbers as to how much solar energy is being employed in this manner. The only data that can actually be measured is from industries that we know for sure are involved in the business of building solar thermal systems. In 2001, these companies sold over 11 million square feet of solar thermal collectors in the U.S[9]. However, we know that there is much more solar thermal energy that is being employed in the U.S. than just that being produced by these types of systems, which means that these figures represent a very low estimate to its use.

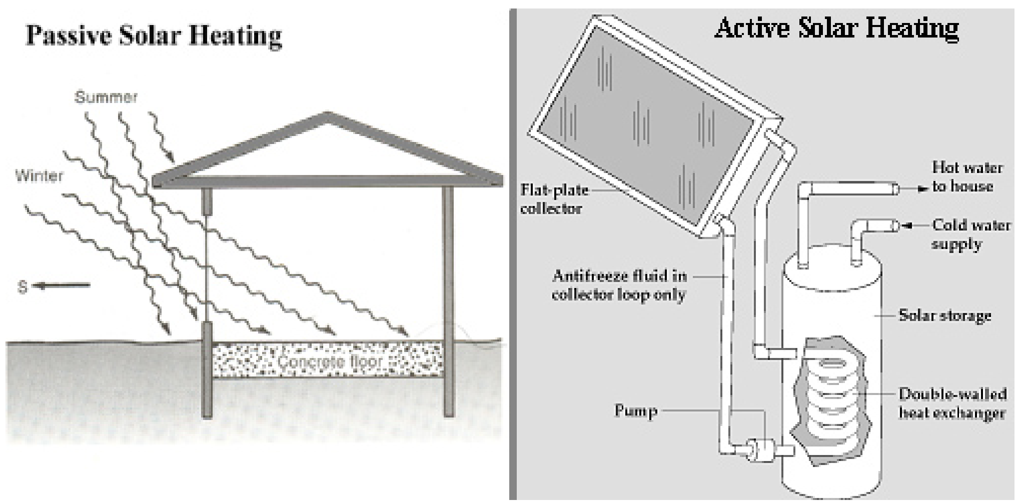


Figure 9: Active and passive solar heating systems (Source: DOE)

While there does exist a wide array of design types, we distinguish between the different systems for heating based upon whether they need an external power source to distribute the energy. An active solar heating system is one in which a pump or fan is used to transfer heat within the dwelling, while a passive solar heating system uses only the natural means of convection, conduction, and radiation to do this. Figure 9 shows an example of both of these systems. There are three elements in common in these two systems: a solar collection area, a heat transfer fluid, and a storage unit. The variety of materials and construction for these three is endless. Collection units can be boxes on a roof, windows on a home, or greenhouses attached to the home. The heat transfer fluids can be water, antifreeze, or air. Storage units can hot water heaters, a box of rocks, or an aquarium. The list of things that can be used in building a heating system is almost endless.

Wind

Like all other forms of renewable energy, wind energy has been in use for several millennia. The earliest records of its use date back as early as 5000 B.C., when simple sails were employed to transport boats along the Nile River. This form of transport proved to be no temporary phenomenon, as it was the primary method of boat transport well into the 1800s. The employment of rudimentary navigational techniques with it allowed humans to open worldwide trade routes, forever changing the face of the planet.

However, transportation was not the only use for wind energy. As with hydropower, people invented ways to harness wind to replace the backbreaking work of grinding grain to make flour. This technological achievement dates back as least as early as 200 B.C. in Persia and the Middle East. Farmers in China were also irrigating the crops in their field by this time, using windmills to pump water from underground wells.

It is this latter technological advance that was the predominate image of wind energy in the U.S. until recently. Farmers in the Central and Western U.S. have used metal windmills to provide water for their crops and livestock for almost 150 years in these regions. As fossil fuels began to replace renewable forms of energy during the 1800's, this was the last presence for wind energy in the U.S. It survived mostly because wind energy was so plentiful in the region, and because most farms were remote enough to limit the availability of fossil fuels. It was not until the Rural Electrification Administration programs that started in the 1930's began to bring fossil fuel energy to these farms and ranches that wind energy for irrigation began to disappear.

Spurred by industrialization and such programs as the REA, the U.S. experienced an increased need for electricity during the 1940's. This led to experimentation with the use of wind energy to drive generators. At the time, it was believed that windmill designs needed to be very large to produce the vast sums of electricity that would be needed. As an example, a windmill was built in 1940 at Grandpa's Knob in Vermont that had blades that were 175 feet in diameter and weighed 8 tons each. This windmill was able to produce 1.2 megawatts of electricity, but at a cost of $1,000 per kilowatt, which was very expensive for the time.

The interest in windmills soon waned, as oil became plentiful following the end of World War II. Research that might have led to cheaper designs that produced the needed electricity went by the wayside, as the price of fossil fuels plummeted. It was not until the Oil Embargo of the early 1970's that work began again in earnest to develop such technology. Once again, interest was high while oil prices were high, but decreased when the price of a barrel of oil fell to all-time lows in the 1980's. Luckily, advances in technology had occurred that brought the price of producing electricity with windmills down. Currently, electricity can be produced at about 3-4 cents per kilowatt-hour with windmills under certain conditions, which is comparable to that produced from coal and natural gas [10,11].

Windmill Basics

The idea behind generating electricity from wind is quite simple. Wind is the manifestation of the kinetic energy of air molecules in the atmosphere. In order to use this kinetic energy for other purposes, all that one has to do is to have the wind hit a surface that is allowed to move. This will cause the kinetic energy of the wind to be converted to the kinetic energy of the moving object. Anyone who has ever been outside on a very windy days understands these concepts. The hard part about generating electricity from wind is doing it cheaply. To do this, a more fundamental knowledge about wind energy is needed.

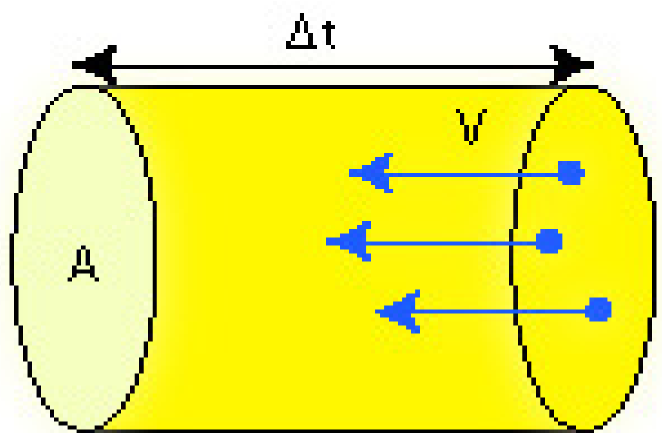


Figure 10: Diagram of wind tube

Let us imagine air that is moving through an area A with a velocity v as shown in Figure 10. From our section on energy, we know that the kinetic energy of an individual air molecule is given by the formula 1/2 mv^2. We want to consider a large system of air molecules, which means looking at a volume of particles. In a time Δt, the mass of the air that will flow through the area A is given by $m = \rho A v \Delta t$, where ρ is the density of the air. If we put these two formulae together, we get that the kinetic energy of the air that passes through an area A in a time Δt is given by the formula 1/2 ρ A v3 Δt. Since the energy per unit time is equal to the power, we get that the power in the wind moving through the area A is given by

$$P = K.E./\Delta t = 1/2\ \rho\ A\ v^3$$

While this is the power that is in the wind, this is not the power that you can get out of the wind. To understand why, consider how one would extract energy from the wind. As we stated above, this involves allowing the wind to hit an object and transfer its kinetic energy to the object. If the air that hits the object delivers all of its kinetic energy to the object, then the air comes to a complete standstill while the object begins to move. The problem with this is that the air that has just hit the object needs to get out of the way in order for more air that is behind to be able to hit the object. In other words, if you extracted all of the energy from the wind, you would begin piling up air in front of your object and thus cutting off the wind. Therefore, the air that hits your object must still have some kinetic energy in it in order for it to move out of the way to allow more air to hit it. In 1919, a German physicist by the name of Albert Betz[12] showed that the maximum amount of power that one can get from the wind is only 59% of that given by the formula above. In actuality, we will get less than this maximum amount. Therefore, we often write the formula for the power from a wind turbine as

$$P = 1/2\ C\ \rho\ A\ v^3$$

where the factor C depends on the actual design of the windmill that you build. The factors that affect the constant C are many and complicated.

We should note that the formula for power depends on two other factors. The first of these is the area of the wind that is captured. This linear relationship shows that the bigger a windmill is, the more power it will be able to output. This is why a lot of commercial wind farms rely on large turbines. The formula also shows that the power depends greatly on windspeed. This is not a linear relationship between the two variables, but a very strong dependence to the third power. This means that the difference in power between wind moving at 1 meter/second and wind moving at 2 meters/second is a factor of $2^3 = 8$. Therefore, the amount of energy that one will get out of a windmill depends tremendously upon the windspeed, and it is vitally important that the windmill be placed in a location where winds are strong.

Wind Basics

What factors affect windspeed? To answer this, we need to remember some meteorology basics. The driving force behind wind is sunlight, as you have no doubt seen described many times before. Materials at the Earth's surface absorb some of the energy from the Sun that gets through the atmosphere. This causes the surface to increase its temperature above its surroundings, which results in heat transfer back into the atmosphere. Some of this heat is transferred by conduction; some of it, by radiation in the infrared region which gets absorbed by greenhouse gases. Both of these methods cause the air near the surface to increase its temperature, which results in it expanding. This expansion causes a net reduction in the density of the air, and it rises as it becomes more buoyant. Thus, just like the water in a teakettle before it boils, the air undergoes convection.

This, though, is not the wind that we feel. This is vertical air movement, and not the horizontal movement that we need to drive windmills. It is just the first part of the process of wind creation. The air that rises takes a great deal of mass with it. Without the weight of the air pressing down in this area, the air pressure is reduced. This makes the surrounding air that is not rising higher in air pressure. The resulting pressure difference causes the surrounding air to rush toward the lower air pressure, giving us surface winds. This part of the process is known as advection.

Latitudinal Effects and Hadley Cells

This process can happen on large or small scales, creating either large wind patterns that persist over hundreds and thousands of miles or small patterns of just a few miles. What are some of the factors that affect it? One of the most obvious answers is latitude. As we discussed earlier, the closer the Sun's ray are to perpendicular when striking the Earth's surface, the higher the energy density of that sunlight. Since the Sun is more directly overhead near the equator throughout the year, the more energy it receives, and thus the hotter it gets. Thus, we expect to see a lot of warm air rising near the Equator. Conversely, we expect to see a lot of cold air descending near the poles.

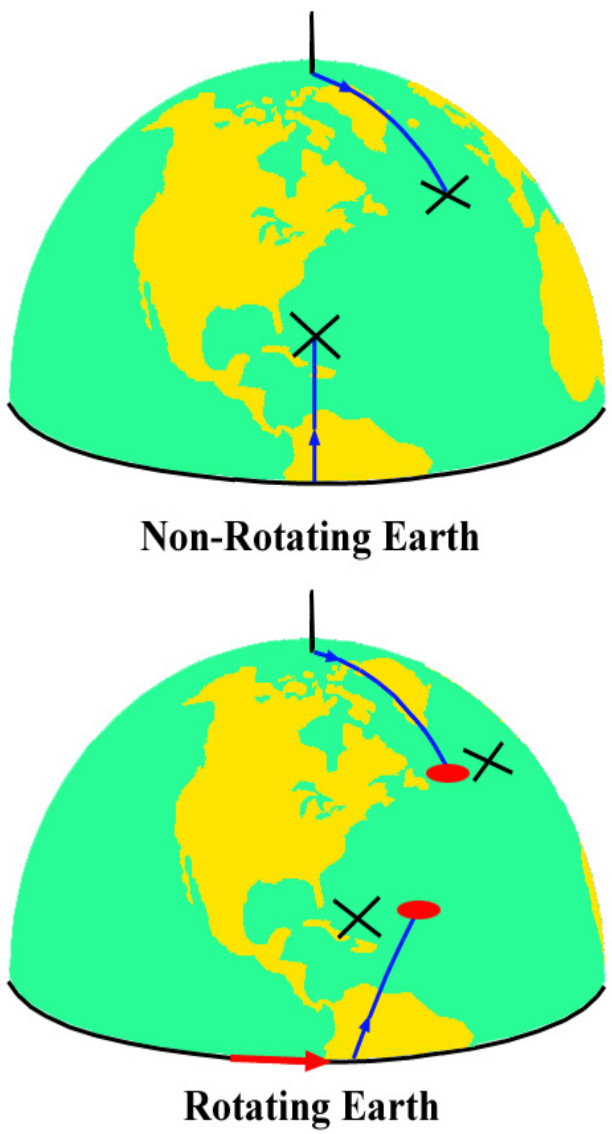


Figure 11: Coriolis Effect Diagram

If the Earth was not rotating, this latitudinal heating would result in two giant cells of air movement, rising near the Equator, moving in a straight line in the upper atmosphere directly to the poles, descending near the poles, and moving laterally from the poles to the Equator near the surface (See Figure 11). However, this does not occur because of the Coriolis effect, which causes this type of air cell to break up into three air cells in each hemisphere of Earth. To understand how it does this, we have to consider what the airflow looks like from above Earth.

The different parts of Earth are moving at different speeds relative to outer space because it is a spinning sphere. Since the North Pole is along the axis of rotation, it is not moving relative to an observer in outer space. The Equator, though, is moving at a speed of 1000 mph relative to this observer, as it must completed one circumference of Earth (about 25,000 miles) in a day (24 hours). Points between the North Pole and the Equator are moving at speeds between 0 and 1,000 mph depending on the latitude.

Therefore, in order for air to remain static with respect to a spinning Earth over the Equator, it must be moving at slightly more than 1000 miles per hour in the direction of the Earth's rotation. Air that is static over the poles, on the other hand, has zero velocity with respect to an observer in space. The velocity of static air as one moves from the poles to the Equator is a slowly increasing value between these two extremes. As long as air is static over the Earth, everything looks okay.

Now, consider air that is near the Equator moving toward the North Pole. As it moves to higher latitudes, it will be over a portion of Earth that is moving slower than 1000 miles per hour in the direction of the Earth's rotation. The initial velocity it had in this direction is, therefore, going to cause it to move eastward relative to the ground (See Figure 11). In essence, the air will appear to veer to the right as it heads poleward. Going to greater latitudes will only increase the curvature, as the Earth is moving slower in those locations. Eventually, the air will curve so much that it will start moving due east. Eventually, it will cool, contracting as it does and becoming denser. This will cause it to sink towards the Earth surface, where it will continue curving back toward the Equator. From outer space, the air will not look as if it curved at all. Observers there will note that the air has two components of velocity (one poleward, one in the direction of rotation) and is actually moving at an angle relative to a line of longitude. It will just look like it tried to move in a straight line on a curved surface. It is only to an observer on Earth that thinks that the air is static over the equator that will image that the air is curving do to some “force”. This is why the Coriolis effect is often misnamed the Coriolis force in some textbooks and online materials.

In a similar fashion, we can follow air that is leaving the North Pole and heading toward the Equator. This air has no velocity in the direction of the Earth’s rotation. As it goes to lower latitudes, it will be over land that does have velocity in this direction. Therefore, the air will appear to curve westward, or to the right, as it tries to proceed toward the equator. Eventually, it will warm as it picks up energy from the surface, expand, and then rise into the atmosphere. As it does, it continues to curve and head back to the North Pole, never reaching the equator. Because of its size and the speed of its rotation, the Earth forms three different “cells” of air circulation in each hemisphere. These cells are called Hadley cells, and they form the large-scale wind patterns that we see. They are driven by predominate low-pressure systems near the equator and high-pressure systems near the poles.

This same thing happens in the Southern Hemisphere, but the directions are reversed. Air moving from the Equator to the South Pole appears to veer to the left, while air moving from the South Pole to the Equator also appears to veer to the left. Because of this, we find that air moving from high-pressure systems move in a clockwise fashion in the Northern Hemisphere, but in a counter-clockwise manner in the Southern Hemisphere. Of course, low-pressure systems such as tornados and hurricanes move in the opposite directions (counter-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere). It should be noted that this is a large-scale phenomenon and does not apply to small scale systems such as water going down the drain in a tub or toilet.

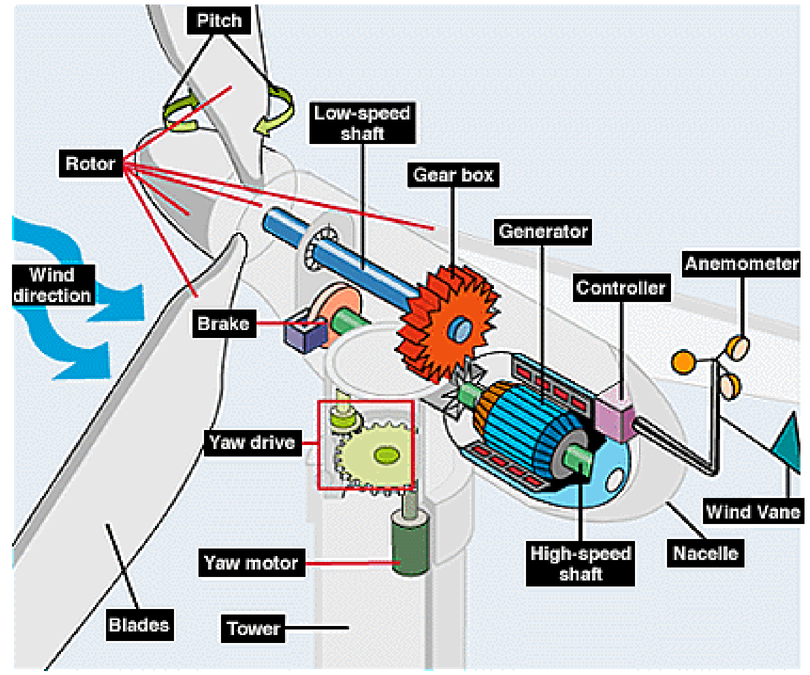


Figure 12: Diagram of a wind turbine (DOE)

Other Factors

While these large-scale wind motions in the atmosphere drive a lot of weather patterns that we see, they are not solely responsible for surface winds. If they were, we could almost be assured that wind would always blow in the same direction all of the time. Surface winds can also be affected by disparities in the rates of heating of land and water. Near a beach, solar energy shines equally on both the water and the land surface. However, water has a heat capacity that is nearly 8 times that of soil and rock. This means that an equivalent amount of energy put into both water and soil will result in the soil increasing its temperature 8 times that of the water, i.e. the soil will get hotter than the water faster. The air that is over the land, therefore, will get hotter than the air that is over the water, and rise faster. This upward air movement over the land will create a local low pressure, and higher pressure air over the water will be forced in to replace it.

At night, when the Sun has set, the process will be reversed. The soil will cool off faster than the water. After a while, the air that is over the land will be cooler than the air over the water. Now, the air over the water will become more buoyant and rise into the atmosphere. The air over the land will have a greater air pressure, and be pushed out towards the water by the pressure difference. If you have ever travelled to the seashore, you have probably experienced this phenomenon. During the middle of the day while the Sun is out, the wind will be blowing in from the ocean toward the beach. Around midnight or so, the wind will reverse and begin to blow out to sea. Currents that are flowing in the water can modify this effect immensely. If cold water is being brought towards the surface of the ocean near the beach, this can cause the difference between in temperatures between the land and the water during the daytime to increase, and vice versa.

Mountains can also play a role in creating and modifying the wind. Their affect depends a great deal upon the number of them, their orientation, and their shape and height. For instance, a mountain chain can create a “wall” to airflow. This can block pressure systems from moving across them. If a high pressure system does force the wind over the mountains, the air can be “squeezed” as it passes over the mountains, resulting in high wind speeds in mountain passes and on the lee side of the range as it descends. Mountains can also generates wind, as when a shallow, cold air mass descends down a mountainside and produces strong winds. The reverse of this can also happen when heated air in a valley descends up the side of a mountain.

Biofuels

Fig. 13: Henry Ford

Given our reliance on cars propelled by petroleum, it might surprise many people to learn that some of the first cars ran on alternative energy. Henry Ford ran his first cars on ethanol derived from fermented corn. Rudolf Diesel powered the engine that would later bear his name with peanut oil. These early pioneers were not trying to be “green”; they were just using some of the most reliable liquid energy sources of their time. While oil drilling was started in 1857, there was really no infrastructure for creating and delivering petroleum by the 1890s when the first cars were coming out. If you were going to create a car to run on liquid fuel, going with ethanol or plant oil as a fuel source made more sense than any other type of energy.

Since that time, biofuels have generally remained in the background of the energy landscape, with occasional forays into the foreground when oil prices got too high. For example, during the oil price spikes of the 1970s, biofuels began to get a lot of press. In particular, ethanol made a comeback as a possible fuel for cars and a way for America to gain energy independence from OPEC. This possibility of a revolution in biofuels played out for several years until the oil price drops of the 1980s as OPEC countries had to sell off oil to pay for wars.

Biofuels were able to make a comeback in the 1990’s because of two factors. The first of these was the need for a less toxic oxygenated fuel additive for gasoline. Cities like Los Angeles, Denver, and Houston had air quality that violated the Clean Air Act during the 1980s and 1990s, especially during certain times of the year, such as winter in Denver, when

temperature inversions caused air to be trapped near the ground. To limit these violations, cities across the country were mandated to sell only gasoline that contained oxygenated additives that would reduce the amount of smog created during those times of the year. The leading that was used in most cities was MTBE; however, this additive was found to be particularly toxic and fouled groundwater when it leaked from gasoline tanks. Ethanol was the most popular replacement for MTBE, as it was plentiful, less harmful, and relatively cheap.

The second factor that helped biofuels was the growth of the farm lobby. Changes in farm policies during the 1970s allowed for very large agriculture conglomerates, such as Archers Daniels Midland and Cargill, to grow in size and power. They created a very effective lobbying group in Washington and began to get legislation passed that favored subsidies for their products. One of their more successful efforts was the creation of corn subsidies that promoted the conversion of corn kernels into ethanol for use in gasoline. In some years, this brought in over $500 million in subsidies to ADM alone.

Today, the electronic fuel systems of most cars means that there is really no need for the oxygenated fuels. However, the growth of the infrastructure for biofuels, combined with higher fuel costs, means that the industry continues to see growth both in the U.S. and worldwide. To get a better sense of the impact of these fuels on environment, let us look at how these fuels are produced.

Methods of Biomass Conversion

Organic material can be used as a fuel source one of three ways. The first, and oldest, of these methods is direct burning, or pyrolysis. Since the earliest times, mankind has burned organic material as a fuel source. Mostly, this has involved the burning of wood, as it has the highest energy value per dry weight. In some ancient cultures, such as those on the Greek islands, the burning of wood had to be limited, as growth of new wood did not keep up with demand. The use of wood for this type of energy source is fairly limited, which has significantly reduced this problem. However, there have been proposal over the last several decades to increase the size of fast growing tree plantations, such as eucalyptus, in order to develop a carbon neutral supply of fuel.

The second method for extracting energy from organic material is thermal decomposition. This method involves the application of heat in order to break certain bonds in order to convert solid organic material into a liquid source. This is very similar to coal liquefaction or gasification. It can be done quite simply by heating organic material, such as wood, in an oxygen-deprived environment. For example, if you were to cut up wood, put it in a sealed container, and heat it, you would notice, after a short period, smoke coming off of the wood. If you condensed this smoke by cooling, it would produce a liquid feel, such as methanol, which is often called wood alcohol. After a period of time over which most of the water and hydrogen are burned from the wood chips, you would be left with black charcoal, which you could further decompose by adding more heat and water vapor.

The last method for breaking down organic material into a liquid fueled is biochemical conversion. This can be done by either introducing bacteria that feed on organic material under the right conditions, or by the addition of chemicals that will break down the organic matter into the fueled source of choice. The first of these is done on sugars or cellulose, while the second of these is done on plant-based oils. Both of these techniques have a large environmental impact.

Ethanol

In the movie "Oklahoma", the main character starts the film singing a song with the line "and the corn is as high as an elephant's eye" as he rides a horse through the fields. Driving across the Midwest during the summer today is likely to exact the same response in any driver. Corn is the name of the game across the entire region, as it is a crop at is likely to rule the land. Thirty years ago, the federal government was paying farmers not to grow corn in an effort to stabilize the price. Today, corn is likely to draw a price of over four dollars a bushel, a price that is comparable, adjusted for inflation, to the high prices paid during food shortages during World War II.

The reason for this high price is the use of corn as sugar. If you are eating or drinking something sweet today, it is likely that the sweetness comes from corn, as high fructose corn syrup is used in everything from sodas to hamburgers. We are also pouring that sugar into our cars, although we must convert it to a different energy source: ethanol.

Converting corn to ethanol is a very easy process, and has been done for thousands of years. Corn kernels are made of mostly starch, although there is a small sugar content to start. If the corn is placed in warm water (about 155 ^oF) for an hour or so, enzymes naturally found in the corn will break down the starch into sugar. After a long enough time, the sugar water can be squeezed from the corn kernels and placed in an airtight vat. Yeast can be added to this solution and allowed to operate over several days to weeks. In the anaerobic environment of the vat, the yeast will break down the sugar into ethanol (in an oxygen rich environment, they break the sugar down into carbon dioxide and water). Once the sugar is completely used up, the solution will have about 8-10% ethanol. Heating the solution to about 70 ^oC will boil off the ethanol, which can be condensed to produce a pure variety of ethanol that can either be blended into gasoline or sold as moonshine. The residual corn can be used to feed cattle or can be spread on the land as a fertilizer.

Ethanol can also be created from other sources of sugar. In Brazil, the government has come to rely on cane sugar as its source of ethanol after the price spikes of the 1970s drove them in that direction. Today, they have become a completely oil independent country, and nearly 85% of cars in the country can run on gasoline or ethanol. One major difference between corn and sugar cane is that the stalks of cane contain up to 20% sugar, which means that they do not need to go through an enzymatic change to convert starch to sugar. This allows for twice as much sugar per acre of land used, and save energy on conversion. The cane stalks are just crushed to release the sugar, and the leftover stalks are used either as a feed supplement or burned in the boilers that separate the ethanol from water.

A third way to create ethanol from plant matter is to break down the cellulose in the plant's stalks, leaves, and roots into simple sugars. This requires special acids and treatments by genetically altered bacteria. At present, this process is uneconomical, but if it can be perfected, it would be a great boon for energy independence. We could save the corn for eating and use the rest of the plant to create the liquid fuel, which would greatly reduce the waste in the process.

In the U.S., we will have a tough time matching this goal of complete oil independence through ethanol, as we could only replace about 12% of our total gasoline usage if we converted all corn into ethanol. This means that, barring some new way of creating ethanol, we will always be limited to using it as an additive. Over the last decade, there has been some push to replace more of our gasoline with it, as the creation of E85 fuels (85% ethanol and 15% gasoline) shows. One problem with this is that these fuels are not as efficient as gasoline. Since the ethanol burns cooler, it gives fewer miles per gallon when burned in a standard engine. One way to increase the efficiency is to increase the compression in the chamber, which will allow it to burn hotter. However, in cars that burn E85 fuel, there is a reduction in efficiency of up to 30% over the same vehicles that burn straight gasoline. While this difference in efficiency can be made up with a difference in cost, this has severely limited the expansion of ethanol as a sole source of energy.

Biogas

In Chapter 8, we discussed how natural gas is formed from organic material, such as oil or coal. A similar process can be employed to create methane from waste organic material without any further energy inputs. All that is required is a sufficient quantity of organic material in an anaerobic environment, the correct enzymes and bacteria, insulation to keep it warm, and some sort of collection infrastructure. These criteria can be met at any large animal farm, wastewater treatment plant, or landfill. The criteria could also be met on a much smaller scale, such as a family's septic tank. However, the small size does not currently make such a structure a feasible source of biogas.

The process for conversion is quite simple. The organic material needs to be kept moist and warm to create a livable environment for the bacteria and enzymes that will break it down. If oxygen is allowed into the system, the bacteria will operate aerobically, which means that they will produce water and carbon dioxide as a byproduct. By putting the material in a sealed environment, oxygen can be kept out, which will cause the bacteria to operate anaerobically and produce methane and other combustible gases as a byproduct. A simple system of pipes that do not allow oxygen in to the sealed environment can be used to extract the gaseous fuels.

For large-scale waste from an animal farm, such as a cattle or hog CAFO (centralized animal feeding operation), the manure can be captured and put into a digester. The same is true for a wastewater treatment plant. In a modern landfill, the organic material is ultimately buried in the ground, sandwiched between layers of clay and plastic. In such a situation, the gases need to be removed from the system, as they could cause an eruption or explosion. Releasing the gases to the atmosphere directly would do serious damage, as methane and the other byproducts are greenhouse gases. At locations in which the biogas is not used as an energy source, it must be burned off.

The amount of volatile compounds created by these processes depends upon the type of digester and the source of the waste. An average system will create a gas that is at least 50% methane and about 25% carbon dioxide. The moist conditions of the digester means that there will also be some water vapor. The most troublesome contaminants in biogas are siloxanes, which are generated from compounds in the waste usually associated with soaps and detergents. These compounds contain silicon, and when burned, can create silicon dioxide (quartz). When biogas containing these siloxanes is burned in an engine, the silicon dioxide that is generated will form grit that will eventually wear down and ruin the pistons or turbines.

For this reason, they must be removed before they can be used to generate electricity. While not impossible, this does increase the cost of using this source of energy.

Biodiesel

Converting sugar and carbohydrates into ethanol or methane is not the only way to create a fluid fuel from plant matter. This can also be done by extracting the oils from plants and animals. As previously mentioned, Rudolph Diesel used peanut oil in his engines back in the 1800s. Today, the most used plant in the U.S. for biodiesel production is soybean; in Germany, which is the leading biodiesel producer, it is canola that is used the most.

The process by which biodiesel is created is quite simple. The oil-bearing parts of the plants (normally the seed) is squeezed, and the oil is allowed to separate from the other liquids. From this point, the plant oil is treated just like petroleum, as the different molecules in the oil are refined into diesel. The oil can also be used first before it becomes biodiesel. For example, the oil could be used to fry food. After the oil has been used to the point where it is imparting bad flavors to the fuel, it can be reclaimed and used as a fuel. If you ever find yourself behind a bus that smells like French fries, you can be pretty sure that the driver is burning biodiesel.

In recent years, a new form of biodiesel has been getting press as a possible alternative fuel. Instead of using a foodstuff, such as soybean, corn, or canola, scientists have been investigating the use of oil derived from algae. Algae can be grown in any nutrient-rich source of water, such as ocean water or water from a wastewater treatment plant. Initial research focused on growing algae in shallow ponds, but the economics and the loss of water and land made the venture unprofitable. Today, research is centered on growing the algae in clear plastic bags and tubes that can be suspended in the air to allow for more plant growth per acre. The algae are fed wastewater as a nutrient source, and carbon dioxide can be pumped into the system from a nearby coal-burning plant. Since the system is contained, the amount of water lost is limited, and the amount of carbon dioxide taken in by the plants reduces greenhouse gases in the atmosphere. To date, this type of system has not been made profitable on a large scale, but research is continuing.

Economics

Using biofuels comes with a price. The most obvious issue is the use of foodstuffs to produce fuel that could go to feeding the world's hungry. Biofuels derived from corn, soybean, canola, and sugar cane could just as easily have gone into your mouth as into your car. The world produces enough food to feed about 7.5 billion people; the world's population is approaching 7.3 billion. Within several years, we will surpass this mark as to how much food we can grow. Unless we find some other way to grow food, the use of it to produce fuel will begin to get closer scrutiny from an ethical standpoint.

Beyond the ethical issue, the use of biofuels has several economic and ecological issues. The energy that is created from these sources required fuel in order to grow it. Land has to be tilled, irrigated, and harvested, all of which require fuel on our modern farms. The fertilizers and pesticides we use are also derived from petroleum and natural gas. The energy that we get from these fuels is also not equivalent to that derived from petroleum, as a gallon of ethanol has almost a third less energy than a gallon of oil. When all of these factors are figured into the equation, ethanol derived from corn enhances our energy situation very little, as it requires 1.0 units of energy from petroleum to produce 1.3 units of energy from the corn ethanol. Because sugar cane has more sugar, requires less fertilizer and tilling, and can be grown denser, 1 unit of petroleum energy yield 8 units of sugar cane ethanol energy. Biodiesel is somewhere between the two, as 1 unit of petroleum energy gives 2.5 units of biodiesel energy. The holy grail of biofuels is the creation of cellulosic ethanol, which could give us much as 36 units of ethanol energy for every 1 unit of petroleum energy input.

In discussing the economics of biofuels, we must also consider the cost to the environment. The production of corn in the U.S. has gone through the roof over the last 20 years. Driving across Midwestern states, such as Illinois or Iowa, is an exercise in viewing corn, as mile after mile of farmland is planted for this. Corn is fairly harmful to the ecosystem, as it requires heavy tilling, which results sediment runoff in rain. It also requires a great deal of water, which depletes our aquifers. The heavy reliance on pesticides causes the runoff of toxic substances into our rivers and streams.

Geothermal Energy

The forms of renewable energy mentioned so far come in a direct or indirect way from the Sun. Water is drawn up into the atmosphere because sunlight causes it to evaporate. Wind is generated by differential heating of the surface of Earth by the Sun. Plants grow due to sunlight. The one form of renewable energy that does not have an origin of the Sun is geothermal energy. The temperature at the center of Earth is estimated to be over 5,000 K, while the surface is closer to 300 K. From Chapter 2, this means that heat will flow from the center out to the surface, causing the temperature at depths below the surface to be hotter than the surface. Near the surface, the temperature increases at a rate of about 30 K per kilometer.

This situation means that we could power a heat engine by tapping into the internal rock and allowing heat to flow to the surface. The problem is that this would be a very inefficient process, as the temperatures that we find at the depth of our longest boreholes is not enough to be any more efficient than 10-15%. Given the expense of drilling holes, running the system, and dealing with repairs does not make such a system economically feasible. The only places that such systems would work is where much hotter rock from near the mantle has come to the surface, i.e. volcanoes. In these locations, geothermal electrical systems are possible. However, there limited locations across the globe and the hazards involved in running such a system limits their availability.

This is not to say that geothermal energy is not valuable. On the contrary, geothermal energy could be one of our greatest resources. However, its use should be limited to providing a hot or a cold reservoir for the heat pumps that we use to maintain the temperatures in our living spaces. As we have already pointed out, the greatest energy uses in our homes is to maintain the temperature. Geothermal heat pumps operate by having one of the coils buried in the ground where the temperature is somewhere between 50-70 ^{o}F year round. During the winter, there are able to extract heat from the ground much easier than they can from the air. In the summer, the heat pump will dump the waste heat into the ground, which is probably cooler than the house and much less the air outside. This can increase the efficiency of the heat pump by up to 50%.

Discussion Questions

1. How much insolation do we receive locally on an average day during the year?

2. Why is it hot during the summer and cold during the winter?

3. What are the 4 main parts of an active solar heating system?

4. How cost effective are solar technologies?

5. What is the average efficiency of photovoltaics?

6. Isn't there a conspiracy by the oil companies to stop solar energy?

7. How do you create ethanol fuel? Is it useful?

8. What is the problem with burning wood as a fuel source?

9. What are four major challenges to widespread wind energy use?

10. If geothermal energy is free, why are there not geothermal plants everywhere? Are there any promising geothermal systems?

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