Chapter 5
Making Things and Recycling Things

As we saw in Chapter 1, it is likely that we will face a difficult state of affairs in the 21st century, caused by the three-pronged crises of depletion of oil resources, global warming, and massive generation of wastes. In the previous two chapters, we examined the use of energy for activities in transportation, homes and offices. Clearly there is still plenty of room for improving the energy efficiency of the "daily life" activities that make up half of the total human consumption of energy. Improvements in energy efficiency help us to solve the problems of oil resource depletion and global warming. How can we address the problem of massive generation of wastes? One way is to construct a material-recycling society where waste materials are recycled into new products through the human activities of "making things." However, because one half of the energy is consumed in "making things," if recycling consumes too much energy, we will end up undoing all that we have achieved through improvements in the energy efficiency of "daily life" activities. Therefore, what we must do first is determine whether recycling with high energy efficiency is possible.

1 The Theory of Recycling

Human Artifacts Will Eventually Become Saturated in Society

We are constantly purchasing new products as old products wear out, and new buildings, roads and other infrastructure are constantly being built as cities expand. As a result human artifacts are constantly accumulating in society. This accumulation is visible in the form of our modern cities, and each new city that emerges represents a new accumulation of human artifacts. However, the earth is limited, so it is impossible for the accumulation of human artifacts to continue forever. There must be some point at which the amount of human artifacts accumulated in society levels off or "saturates." By the "saturation" of human artifacts, we mean that the amount of materials in the human artifacts disposed each year is equal to

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the amount of materials that are required to manufacture new artifacts. Therefore, when human artifacts become saturated in society, if we can redistribute waste materials to places where they are required through recycling, we can put an end to the exploitation of natural resources.

In fact, there are signs that the saturation of human artifacts is already happening in developed countries. For example, the car ownership in almost all developed countries is more than one car for every two people. When car ownership reaches this level, the total number of cars in society approaches saturation, and demand for new cars becomes centered on replacement buying.

In Japan, which has a population of 127 million, currently there are about 50 million passenger cars. The average time that a car is used before it is disposed is about ten years in Japan, so we can estimate that the number of new cars sold each year for replacement buying will be 5 million. Although there is some variation from year to year, following 1989, the number of new cars registered each year has in fact peaked at between 4 and 5 million. In OECD Europe and the U.S., the vehicle ownership per person increased only slightly between 2000 and 2004. Therefore, in these countries as well, the number of cars is already nearing saturation.

Construction of buildings is another example of human artifact saturation. In the large cities of Japan and Europe it is already the norm that when a new building is to be constructed, an old building must be demolished to make room for the new building. Buildings constructed on land where no building existed before are becoming the exception. In figure 5-1, we can see this state of building saturation in the annual production of cement, which is the main material for the construction of buildings. The current total global cement production is 2.5 billion tons per year. Cement production in the U.S., which used to be the world's largest producer of cement, began to saturate at around 80 million tons per year from the 1970's.

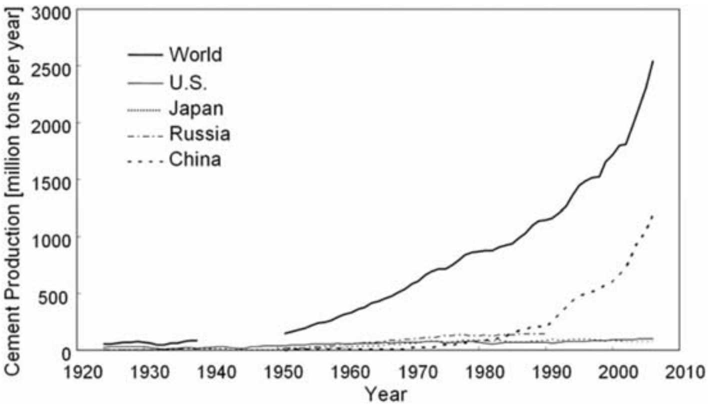

Fig. 5-1: Cement production in different countries (Data from UN Common Database, United Nations Statistics Division; and Mineral Commodity Summaries, U.S. Geological Survey)

In Japan, the amount of cement production, which grew rapidly following the war, has fluctuated between 70 million and 95 million tons per year from the second half of the 1970's, indicating a saturation of Japanese cement production. Data for Russia is limited, but it appears that Russian cement production has saturated as well.

Currently, the largest producer of cement in the world is China. China produces an astonishing 1.2 billion tons, which is almost half of the global production. Of the major cement producing countries shown in figure 5-1, China is the only country whose production has increased significantly in the past decade, and that increase has accounted for almost all of the increase in global production during that time. There is no question that if someone who visited Shanghai at the end of the 20th century were to visit the city again today, that person would be stunned by the transformation that had taken place. In the span of just a few years, what was once a sprawling rural village has become a metropolis eclipsing the modern cities of Japan, Europe and America. The population of Shanghai is 13 million, more than that of Tokyo or any city in the U.S. or Europe. Expressways and subways run through the city, and the cluster of enormous buildings bring to mind the high-rise skylines of Manhattan in New York or Shinjuku in Tokyo. One part of the 1.2 billion tons of cement that is produced in China each year continues to go into the construction of modern cities such as the new Shanghai. However, even in those cities, at some point in the future the number of buildings will approach saturation.

The Raw Material for Iron Will Inevitably Change

Let's take a look at the production of iron from this perspective of artifact saturation. It is estimated that by the end of the 20th century, humanity had produced a total of 18 billion tons of iron and that about 10 billion tons of that iron was accumulated in society as human artifacts such as cars, buildings, and bridges (some estimates are higher, but we use this conservative estimate here). In other words, most of the iron that was made through the reduction of iron ore in the past has not been thrown away as garbage or recycled, but rather has accumulated as valuable parts of the social infrastructure. So what will happen in the future to this iron?

We can estimate the rate of generation of iron scrap from the amount of iron contained in the human artifacts accumulated in society and the average lifetime of those human artifacts. The average lifetime of human artifacts made of iron is about 30 years, so one thirtieth of the iron in accumulated human artifacts appears each year as scrap. Because the current amount of iron accumulation is about 10 billion tons, more than 300 million tons of scrap is being generated each year. The amount of human artifacts accumulated in society is continuing to increase, so the amount of scrap that is generated each year will also continue to increase.

The production of iron from iron ore in 1995 was 500 million tons per year. If this production were to continue unabated, and if we also assume that all of the iron products made will be recycled as scrap and used to make other iron products, then from 1995 to 2050, more than 25 billion tons of iron will have been newly accumulated within society. At that point, the total accumulation of iron, which in 1995 was about 10 billion tons, will exceed 35 billion tons. If one thirtieth of this accumulated iron becomes scrap each year, then from 2050 1.2 billion tons of scrap will be generated each year. Therefore, in 2050, the generation of scrap alone will exceed the total iron production in 1995 of 800 million tons per year.

As a consequence, all we need to do to create a material-recycling system for iron is reduce the production of iron made from iron ore and make efficient use of the scrap instead. In Japan, the total production of iron and steel has stayed the same at about 100 million tons per year since 1980, and in 1995, 67% of production was from iron ore and 33% was from scrap. The iron and steel industry in the U.S. has a much longer history than Japan, and as a result there is a lot more accumulation of iron products in U.S. cities. A lot of scrap is generated from these products, and so the fraction of the total iron and steel that is produced from scrap in the U.S. is much higher than in Japan. In 1995, it was more than 50%.

However, as we saw in Chapter 1, the current production of iron from iron ore is about 900 millions per year, almost double the production in 1995. Does this mean that we are headed away from recycling and towards disaster? Not necessarily. The important point is that the consumption rate of iron ore is already decreasing in the developed countries, which indicates that those countries are well into a transition to a recycling society based on the use of scrap. In developing countries, the demand for new iron products is large, so the production of iron from the reduction of iron ore will most likely continue for awhile. Most of the recent increase in production of iron from iron ore has occurred in China and India. However, eventually even those countries will move towards the same form of scrap-based recycling as the developed countries.

The concepts of recycling presented above are not limited to iron – the same thing can be said for other types of material production. Figure 5-2 gives a sketch of the transition of production that is necessary for achieving a sustainable society. Where we are on the horizontal axis depends on the material considered and the level of development of the country. For most materials considered on a global level, as a result of continued demand for new human artifacts in the near future, the accumulation of human artifacts will increase, and the generation of waste will also increase proportionally. However, by increasing the annual production of materials from recycling waste artifacts, we will begin to reduce the consumption of non-renewable natural resources. In this way, we should be able to circumvent the problem of the exhaustibility of non-renewable natural resources. Therefore, the real problem that we must address is the future of energy resources.

Let's think a bit more about the conclusion in the previous paragraph. It is often said that we must break away from our mass production / mass consumption civilization. However, we should consider carefully what this means. In order to meet the basic material demands of the more than six billion people living on the earth, we cannot avoid the need for producing a huge amount of materials. On the other hand, we have seen that the major threats to the sustainability of human society are

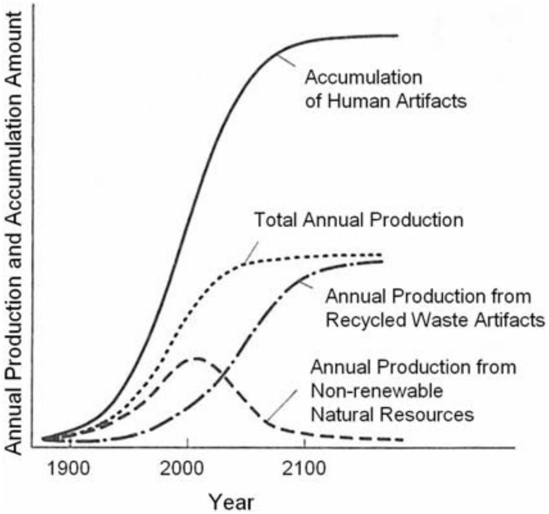

Fig. 5-2: A graph showing how the accumulation and production of human artifacts will progress in the 21st century

the depletion of resources, particularly oil, and the massive generation of wastes. It is not mass production itself that is the problem. Therefore, to achieve sustainability what we must aim for is to break away from a civilization based on massive consumption of the earth's natural resources and massive dumping of waste materials into the earth's environment. The warnings of scientists and other experts that the amount of resources and the capacity of the environment are limited and that human activities are already exceeding those limits are important. However, there is no need to despair. There is a solution.

2 Recycling That Is Also Energy Conservation

Many people have expressed negative opinions regarding recycling. Among them is the objection that if we recycle, we will use too much energy. Let's examine this criticism using the method of breaking down processes into elementary steps that we developed in Chapter 3.

The collection of scrap and other waste material is basically "transportation," and so theoretically the energy required for collection is zero. Of course, in reality we cannot avoid having to consume some energy to collect the waste material. However, for production from natural resources, we need to extract and transport raw materials from mines that often are in remote locations. At least in energy terms, in most cases the collection required for recycling is not much greater than the transport required for production from natural resources.

Some energy is required for the "separation" process of obtaining basic materials from mixtures of waste material. However, as we saw in Chapter 3, the relative size of that energy is 1, and so if we do the separation efficiently, it will not require a lot of energy. Therefore, the real problem is how much energy is consumed at the plant in the process of producing new basic materials from waste materials that have been collected and separated. In the next several sections, we will compare production from natural resources and from waste human artifacts for iron, aluminum, cement, and glass.

Reduction of Iron Ore: The Blast Furnace Method

We saw in Chapter 1 that of the 1.3 billion tons of iron produced each year, most is made in blast furnaces using iron ore as the raw material, but a significant fraction is made in electric arc furnaces using scrap as the raw material.

First, let's break down the production from iron ore into elementary steps. The production process occurs via the following three steps. First, the reduction reaction uses carbon to change iron ore into pig iron and CO_2. Next, the carbon contained in the pig iron is separated out and the concentrations of trace elements in the iron are adjusted as required by the product specifications. Finally, the iron material is shaped into iron products such as thin sheets and rounded bars. Therefore, the process consists of the steps reduction, separation, and shaping. Theoretically, the energy needed for shaping is zero, and in fact through advances in integrated iron and steel making such as the continuous casting process we will see next, the energy used to make iron into sheets and bars has been reduced dramatically. So most of the energy required for producing iron from iron ore is used in the reduction and separation steps. The relative size of the energy requirement is 1000 for reduction and 1 for separation. Therefore, if performed efficiently, the energy requirement for separation is negligible.

By calculating the minimum energy needed for the reduction of iron and comparing it to the maximum energy that can be obtained from the combustion of carbon, we can find the minimum amount of carbon that is required for the reduction step. The theoretical minimum energy needed for making iron converts to 202 kg of carbon for the manufacture of one ton of iron. Currently, the value for large-scale integrated iron and steel works is about 600 kg. Therefore, we see that one third of the carbon is necessary for making iron even in the ideal case, and only two thirds of the carbon can be saved by even the most sophisticated technologies.

In the past, after the pig iron came out in molten form from the blast furnace, it was cooled into blocks for storage. The blocks of iron were later heated and shaped into thick plates, which were then left to cool once more. This process of reheating and cooling the iron was repeated until little by little the desired shape, such as a thin sheet that could be used for the body of a car, was obtained. The energy used to heat the iron each time was not recovered, so a large amount of fuel was consumed. To reduce this waste of fuel, the continuous casting process was introduced. In continuous casting, the steps from the production of pig iron at the blast furnace to the forming of iron sheets and bars are carried out in a continuous process so as to avoid repeated heating and cooling of the iron. Furthermore, other technologies were developed to recover some of the energy that was input as coke into the iron making process. One is to use the gas emitted from the blast furnace, which contains fuel such as carbon monoxide and hydrogen, to generate electricity. Another is to generate electricity using devices like top-pressure recovery turbines where a turbine for generating electricity is turned by the pressure of the exhaust gas. Through the application of these various technologies, the high present day overall efficiency of iron and steel making – 600 kg of coal per ton of iron – has been achieved.

However, currently almost none of the heat that is used for heating the iron ore in the blast furnace is recovered. Also, there are many steps in the process of shaping and forming, such as rolling and cutting, where energy is still wasted. We have seen that the energy needed for shaping and forming theoretically is zero, so any energy used for that purpose is waste. For example, in one process a slab of iron as much as one meter thick is rolled into thin sheets having a thickness of 0.7 mm for use in making automobile parts. Currently, this process is carried out by passing the iron slab through a large number of rollers that are powered by electricity. Even though each step of rolling may not consume so much energy, when the multiple steps are added up, the total energy consumption is rather large. Also, energy is used for processes such as surface treatment.

The difference between the ideal carbon consumption rate of 202 kg per ton of iron and the actual value of 600 kg is the result of the combination of these various small energy consuming steps. How much further conservation of energy will be achieved in new iron making facilities will depend on how much is invested in equipment for that purpose; however, it is unlikely that we will be able to reduce the carbon consumption to less than 400 kg per ton of iron in the foreseeable future.

Recycling of Iron: The Electric Arc Furnace Method

Iron is recycled in the following way. Iron products that have reached the end of their lifetimes are dismantled, and the iron is sorted from the other materials and collected as scrap. The scrap is melted, impurities are separated out, and the iron is shaped again and shipped out as iron products such as rods and sheets. The furnace where the scrap is melted, called an electric arc furnace, uses electricity to generate the heat for melting the scrap.

Dividing this process of making iron from recycled scrap into elementary steps, we have melting, separation, and shaping. Of these steps, the ones that require energy are melting and separation, and the sizes are 10 and 1, respectively. Therefore, the largest part is melting. Converting the heat that is required to melt iron into units of carbon, we find that 7.5 kg of carbon is sufficient to melt one ton of iron. This is about 27 times less than the ideal minimum value of 202 kg for the reduction of iron ore, so we see that recycling iron has the potential to be much more energy efficient than producing iron from natural ore.

In reality, recycling of iron today is not so efficient. The electric arc furnace melts the iron scrap by converting electricity directly into heat, which we have seen is an inefficient use of electricity. Furthermore, as with the processes that we looked at in Chapter 3, in order to melt the iron scrap quickly, the temperature of the electric arc furnace is made much higher than would be required in the ideal case. When we calculate the fuel consumed at a thermal power plant to generate the electricity that is currently used in iron scrap recycling, we find that 300 kg of fossil fuels are actually consumed for each ton of iron scrap. Still, this is just half of the 600 kg used in the blast furnace method, so for the manufacture of iron, even recycling using this rather inefficient method consumes much less energy than production from natural resources.

Let's summarize the points above. The blast furnace method of making iron from natural resources requires energy for the reduction of iron ore. The electric arc furnace method for recycling iron from iron scrap requires energy for melting. The sizes of the corresponding elementary steps of reduction and melting are 1000 and 10, respectively, so we can estimate roughly that the energy consumption for the electric arc method should be on the order of 100 times smaller. In fact, we saw that the melting heat of iron is about one twenty-seventh the heat of reduction. This is the basis for the energy savings of the electric arc furnace method. However, given that the melting heat is just one twenty-seventh the heat of reduction, why is it that conventional iron scrap recycling can only reduce energy consumption by half that used by the blast furnace?

One reason conventional iron scrap recycling does not achieve a higher reduction in energy consumption is that almost none of the heat energy generated in an electric arc furnace to melt the iron scrap is collected. As one example, this energy could be used to replace the electricity that is now consumed for the shaping and forming of the iron. However, the most important problem is that the heat for melting the iron scrap is currently supplied using electricity. The reason is that using electricity it is easy to obtain the high temperature of 1540 °C that is required for melting iron. However, combusting fossil fuels, converting about 40% of that heat into electricity using a thermal power plant, and then changing the electricity back into heat to melt the iron is terribly inefficient, as we saw in the comparison of using an electric heater versus a gas stove to heat a room. It is possible to develop technologies to melt iron scrap using fossil fuels directly, and researchers are currently working on practical applications. By using fossil fuels instead of electricity to melt the iron scrap, it should be possible to reduce the energy consumption of the electric arc furnace method by 50%, or 150 kg of carbon per ton of iron.

Electrolysis Versus Electric Melting of Aluminum

Next, let's take a look at aluminum. If we look at the production process from bauxite in terms of elementary steps, we have mining that is a form of transportation, melting of bauxite, electrolysis of the bauxite that is a form of reduction, and shaping. The steps that require energy are melting and electrolysis; however, because the sizes are 10 and 1000 respectively, we can see that most of the energy is consumed as electricity in the electrolysis of the bauxite. Currently, the electrolysis process is carried out at a voltage that is about twice the theoretical value, so about twice the ideal amount of electricity is consumed. Although the electricity for electrolysis of aluminum is usually provided by hydropower, even hydropower loses 15% of the potential energy of the hydropower resources in generating electricity. Therefore, the energy conservation potential is almost 60%.

The recycling of aluminum is quite widespread. The reason is that, like iron, the consumption of energy for recycling aluminum is small, and therefore it is sufficiently cost-effective to recycle aluminum even in pure economic terms. The heat of melting for aluminum is about 83 times less than the heat of reduction required for electrolysis of bauxite, and even in actual industrial applications, the electricity used in plants for aluminum remelting and rolling is no more than 3% that used for production from bauxite. Therefore, the energy-related benefit of recycling is even larger for aluminum than it is for iron in both theoretical and practical terms.

Recycling of Non-metal Mineral Materials

Looking in the same way at the process of cement manufacture, we see that it is made up of the following elementary steps: mining of limestone that is a form of transportation, pulverization that is a form of shaping, and the reaction of thermal decomposition that removes CO_2 from limestone to produce calcium oxide. Theoretically, other than the reaction, none of the steps need to consume energy. Furthermore, compared to the reduction step with an energy measure of 1000 that is required in the manufacture of metals such as iron and aluminum, the energy measure for reactions is just 100, so we can estimate that the theoretical energy consumption for making cement is about one tenth that required for metal. In reality, production of one ton of cement only requires 100 kg of fossil fuel, which is six times less than the amount used for iron making. Furthermore, this value is just 40% larger than the theoretical value of energy required to make cement, which is about 70 kg.

There are many types of cement. Normal cement, called "Ordinary Portland Cement," can be made up of as much as 5% materials from other processes, such as the byproduct of blast furnaces called "blast furnace slag," the residuals from combustion of coal called "fly ash," and even ordinary limestone. Another type of cement, called “Portland Cement Blends,” is characterized by a larger amount of additives. The different types are used for different purposes. In this way, waste materials from other processes are recycled as much as possible in the production of cement.

The other main non-metal mineral-based material, glass, is produced through the following steps: 1) mining of the raw materials silicon dioxide from quartz, calcium carbonate from limestone, and sodium carbonate from soda ash, 2) pulverization, 3) mixing, 4) melting, 5) thermal decomposition, the same reaction used in making cement, 6) melting, and 7) shaping. Mixing is the opposite of separation, and so because separation requires energy, we know that mixing is an energy producing process. Therefore, the only steps that require energy are melting and reaction, with sizes of 10 and 100, respectively. However, while the reaction only involves calcium carbonate, the melting process must be done for all of the materials, so the energy consumption for melting cannot be ignored. Currently, 200 kg of fossil fuels is used to produce one ton of glass. This is more than three times larger than the theoretical energy required for both the melting and the reaction, which corresponds to 60 kg of fossil fuels per ton of glass.

Why is the ratio between the current energy consumption rate and the theoretical value so different for glass and cement, if their manufacturing processes are almost identical? The main reason is the difference in the quality requirements of the products. Glass products have strict requirements for quality. For example, contamination by even a small amount of bubbles or other impurities cannot be allowed. Therefore, the manufacturing process must be carried out slowly and carefully. For that reason, the glass material needs to be kept hot for a longer time than the cement material, and this means a larger heat loss in actual production processes.

Currently, about 50% of glass is recycled. Although not to the extent of the recycling of aluminum and iron, the energy consumption of production from pulverized recycled glass, called “cullet,” is smaller than from natural materials. Therefore, like we have seen in the manufacture of other materials, recycling of glass is advantageous from an energy perspective.

Almost all of the cement that is produced in the world today is mixed with sand, gravel and water and used as concrete. As we saw in Chapter 1, after the concrete products reach the end of their product lives, the concrete is recycled by pulverizing it and using it in low-grade applications such as roadbeds. However, we also saw that in the future, this kind of demand will begin to decrease. Therefore, there will be a need for a full-fledged cement recycling process where cement is remade from the waste concrete produced, for example, during the demolition of a building. If we pulverize the concrete, separate out the sand and gravel, and heat the remaining material, which is calcium oxide hydrate, it is possible to recover the cement. The theoretical energy size for pulverization, separation and reaction is 0, 1, and 100 respectively. This is the same as the breakdown that we saw for the current cement production process. Therefore, technologically it should be possible to develop a recycling process that can be operated with the same level of energy consumption as the current cement production process. In the future, we may see pulverizing mixer trucks that can recover cement from concrete on site in place of concrete mixer trucks.

Recycling Is a Means for Energy Conservation

We have seen in the previous sections that there are still numerous possibilities for conserving energy in manufacture of metals, cement, and glass from natural materials. However, more importantly, we have also seen that the processes of separation and melting for recycling these materials from waste products actually consume less energy than the processes required for manufacture from natural materials. The difference is particularly large in the case of metals. Furthermore, we have seen that this is not only true in terms of the theoretical energy consumption required of all of the steps from collection to reuse, it is also true in actual recycling applications for metals and glass. Therefore, in most cases the criticism that recycling results in the waste of energy is just not true.

If we do come across a recycling process that results in a large consumption of energy, we should consider this to be an indication of large inefficiencies in the process. Just as we saw in the example of heating a room, the energy efficiency for recycling is strongly affected by the method that is used. For instance, if the waste material that is collected is a mixture of all kinds of substances jumbled together, consumption of a large amount of energy is probably unavoidable in order to recycle that material.

We saw in Chapter 1 that the amount of elements in the biosphere is constant. So what does it mean for a resource such as iron to become depleted? As we saw with energy in Chapter 2, the key is in what it means to be a valuable resource. The conditions for a potential resource, natural or manmade, to be valuable in terms of energy are as follows. First, the resource must have a high concentration of some basic material. Second, the resource must not contain too many elements that are difficult to separate. Third, the resource must exist in large amounts that are gathered together. Without these conditions, because elements exist throughout the biosphere, there would be no limit to the amount of available resources. For example, large amounts of almost all kinds of elements are contained in sea water, including metals and even uranium. However, because the concentration is extremely low, a huge amount of energy is needed to extract these elements from sea water. Therefore, as a resource, sea water cannot compete with mineral deposits under ground.

We can consider the recovery of materials from human artifacts that have been thrown away in the same manner. The first condition states that in order for waste products to be valuable resources, the concentration must not be significantly less than that of natural resources. Clearly the concentration of materials such as iron, glass and paper in waste products is not lower than in natural resources. The real problems are related to the second and third conditions: waste products contain elements that are difficult to separate, and waste products are generated in small amounts all throughout society. Therefore, there are two key points to raising the efficiency of recycling and the value of waste products as a resource. First, we must make sure that when products are thrown away, materials that are difficult to separate are not mixed in. Second, we must construct a system for efficiently collecting and transporting the waste products that are spread out in society's infrastructure.

Moreover, if we can succeed in constructing a comprehensive system based on the concepts we have seen here that encompasses the entire lifecycle of human artifacts from design to consumption and disposal, this will help us to reach our overall goal of realizing a material-recycling society with superb energy efficiency. We will come back to the issues related to realizing this system in Chapter 8.

3 Is It Bad to Burn Waste Paper and Plastic?

Even if We Burn Paper, It Can Still Be Recycled

We have seen here that recycling gives us the twin benefits of 1) reducing the amount of waste materials that get dumped in the biosphere and 2) conserving energy. However, we should keep in mind that when we recycle things, it is not always necessary that they be circulated as materials. This is important for two reasons. The first is that unavoidably some waste material will be generated whose quality is too degraded to be easily reused as a raw material for producing new material. The second is that we have a large need for energy. These considerations are particularly important for paper and plastic. First, let us consider the case of paper.

From the direct mail advertisements that bombard our mailboxes to the recent deluge of computer printouts, a huge amount of paper that seems almost criminal to throw away is being consumed each day. We saw in Chapter 1 that the production of paper from trees consumes a lot of energy. Like metals and glass, recycling paper if done efficiently can save energy. Currently, in Japan, the EU and the U.S., about 50% of waste paper is used together with new pulp in the production of paper. If we can increase this recycle ratio without stretching technological and economic limits, then it is desirable to do so. However, if we repeat the recycling of paper over and over, gradually the length of the fibers will become shorter, and the strength of the paper will decline. For this reason, the limit for the ratio of waste paper in the raw material for paper manufacture is said to be 70%. If we cannot recycle all of the waste paper directly due to this reason, what is the best alternative?

Currently, waste paper that is not recycled is incinerated together with municipal waste or simply buried in landfills. The paper buried in landfills decays or is consumed by microbes. Therefore, whether the waste paper is incinerated or buried in land fills, it eventually ends up as CO_2 in the atmosphere.

If we are going to burn the waste paper anyway, we should try to find a useful way to burn it. Just disposing the waste paper in incinerators or land fills is the same as "burning oil fields." However, if we burn the paper in a coal-fired power plant, we can reduce the amount of coal consumption by the amount of heat that is generated by the paper. Using waste paper in cement making plants or blast furnaces is also possible. Wherever fossil fuels are burned, if we can substitute waste paper for some of the fossil fuels, we can reduce the use of fossil fuel resources. The question we should ask is not whether or not burning is wasteful, but rather what is best in comparison to the current situation of waste paper disposal in incinerators or land fills.

In Chapter 2, we saw how the efficiency of heating depends greatly on the method that is used. When we use waste paper as a fuel, we must also consider what method will give the best efficiency.

For example, refuse power generation is one technology that is used for recycling garbage. The idea is to burn garbage and to use the heat for thermal power generation. Unfortunately, the power generation efficiency that can be achieved is little more than 10%, just a fifth of the efficiency of the most advanced power plants. In other words, fuel in normal power plants can be used five times more efficiently than in refuse power generation. Refuse power generation is also used to produce hot water. However, as we saw with cogeneration in the last chapter, in most cases the demand for hot water is much less than for electricity. So even if we can collect almost all of the heat from the combustion of garbage in the form of hot water, the value of that energy will be low.

If we can find a way to burn waste paper that reduces consumption of an amount of fossil fuels equivalent to the chemical energy of the paper, then it is probably alright to burn the paper. This may require us to find a way to efficiently remove water and other contaminants from the waste paper. However, if we can do this without using too much energy, all of the energy that we can obtain from burning the paper will be a positive effect in terms of depletion of fossil fuel resources.

So why is it that we feel burning paper is wasteful? One reason is probably our concern that consuming paper results in the destruction of forests. However, if we are careful in managing the forests and replanting the trees in a sustainable way, then burning paper to produce electricity, for example, can actually be considered as a form of natural solar-powered energy system. The other important reason for our resistance to the idea of burning paper is our lack of recognition that in reality we are already burning an amount of oil that is more than ten times the amount of paper we use. For example, in comparison to the 2.7 tons of fossil fuels in carbon units that Japanese people use per person each year, the amount of paper use is just a little more than 0.2 tons. There is no reason that we must not burn waste paper at the end of its lifecycle. What we must do in order to make the production of paper sustainable is replant the trees after they are harvested for making pulp and reduce the current amount of 300 kg of fossil fuels that are burned in the manufacture of one ton of paper. Furthermore, although not treated in this book, we must also address the problem of consumption – do we really need to use this much paper?

Using Plastic as Fuel

We can use the same kind of thinking when we consider the optimal way to recycle plastic. Currently, the largest natural resource consumed by humans is the 7.5

billion tons of fossil fuels in carbon units each year that we saw in Chapter 2. Of this, the amount that is made into materials is just the 200 million tons of plastics, synthetic fibers and other petrochemical materials manufactured each year. Therefore, 7.3 billion tons of fossil fuels or almost 98% of the total consumption are burned to provide energy for "making things" and "daily life" activities.

We can divide the methods for using waste plastic into four basic types: 1) reuse of the waste plastic as is, 2) reuse after reshaping, 3) use of thermal decomposition to transform the waste plastic back into its raw material form such as ethylene, and 4) use of the waste plastic as fuel. If it is possible to reuse a plastic product as is or reshape it into a recycled product having about the same value as the original product, then that is probably the best thing to do. The energy for shaping is small, so even if we have to reshape the plastic into new products, this would still let us save nearly all of the one ton of oil consumed per ton of plastic when made from naphtha.

For the third type of recycling, where thermal decomposition is used to return the plastic to raw material form, we must be careful to consider the size of the energy consumption that would be required. As we saw at the end of Chapter 3, thermal decomposition is also the most energy intensive step in the production of plastic from naphtha. Therefore, it is not impossible that in the worst case more than one ton of oil will be consumed to recycle a ton of plastic. Also, we must take care in situations where high quality products are reused to make low quality items such as park benches and planters. If the waste plastic is reused in products that are actually needed, then it may be alright to do this. However, in some situations today recycling is done for its own sake with little consideration of how much demand there will be for the recycled products, and in other situations the recycled products are products that could have been made through the consumption of less resources if a different material was used. In these situations, it may be better to use the waste plastic as a fuel to substitute for fossil fuel resources.

For example, currently one of the most promising methods to recycle waste plastic is to use it as a substitute for coke in the reduction of iron ore. If plastic is preprocessed to remove chlorine and other impurities and then heat-treated, we can obtain grains of carbon that have almost the same characteristics as coke made from coal. Even with the technology available today, it is said that 70% of the chemical energy of waste plastic can be reused as a substitute for coke, which is excellent performance for a recycling process.

From the previous discussion, it is clear that particularly for paper and plastic, we need to consider the pros and cons of different options for recycling and reuse of waste materials from a global perspective rather than just from a single aspect such as whether or not waste products are recycled into other material products.

In a society where human artifacts have reached saturation, there are two paths for the human artifacts that have reached the end of their product lives: they can be thrown away or they can be recycled. We can imagine what would happen if we choose to throw human artifacts away by thinking about the fate of modern cities. We have seen that cities represent the accumulation of human artifacts. If we take the average lifespan of human artifacts to be 50 years, then after 50 years, an amount of waste material equivalent to all of the cities that exist today will have to be disposed of somewhere in the biosphere. If the number of cities continues to grow, and those cities are also disposed of every 50 years, then the earth will end up being turned into a garbage dump. Therefore, if we want to achieve a sustainable earth, there is no alternative but for us to work to create a material-recycling society. The point of this chapter is that not only is "making things" by recycling possible, it can also contribute to the conservation of energy resources.