Chapter 1
Is the Earth Sustainable?

1 Changes from Which the Earth Recovers, and Changes from Which the Earth Does Not

The Continuous Renewal of the Circulating Earth

"Flowers bloom alike, year after year. But not people."
(Translation of an ancient Japanese proverb)

For millennia, human beings never questioned nature's continuous renewal. Each year the seasons changed, but as spring rolled round again, the same trees blossomed and bore fruit. Until today, humans have lived their lives assuming that this circulation of nature would always continue.

In spring, plants use the energy of sunlight to absorb carbon dioxide (CO_2) from the atmosphere together with water from their surroundings to produce roots, stems, branches, and leaves. This process is called photosynthesis. Through spring and summer, as land plants flourish around the world the amount of CO_2 in the atmosphere decreases. When those plants lose their leaves in the autumn, the fallen leaves are eaten by insects and other animals. A part of this is oxidized into CO_2 when those animals respire; that is, the leaves are breathed out as CO_2. The leaves that are not eaten, together with the feces and dead bodies of the animals, become organic matter in the soil. That organic matter is used by microorganisms and other denizens of the soil and eventually transformed back into CO_2. So after several years, all of the CO_2 from the atmosphere that was taken up by a plant during its lifetime is returned to the atmosphere. Carbon circulates around the earth in this way, and each year the earth has returned to its original state.

Like all other living things, humans have lived out their lives within the circulations of the earth. Agriculture is one human activity that traditionally has been relatively well adapted to the cycles of nature. If rice seedlings are planted in the

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rice fields in the spring, rice can be harvested in the autumn. After the rice plants are cut down and the rice is harvested, winter comes and the fields become desolate. However, if rice is planted the next spring, an abundant harvest will come again the following autumn. Fishing is another such activity. Even if pre-industrial fishermen took in large catches of salmon from early summer into the autumn, at the beginning of the next summer, the salmon would return.

The earth has always been a place of dynamic changes. But because it has always returned to its original state after each year, the earth has provided a reliable stage for human civilization.

Recently, though, this pattern of continuous renewal has started to derail. Our planet is being affected by continuous and dramatic changes – changes from which it does not recover each year.

Changes from Which the Earth Does Not Recover

One change from which the earth does not recover is the rising level of CO_2 in the atmosphere (see figure 1-1). For at least the last thousand years, the yearly average concentration of CO_2 in the earth's atmosphere remained nearly constant at 280 ppm (in volumetric terms). However, in the 19^{th} century, that concentration began to rise, and during the second half of the 20^{th} century, the rate of increase has accelerated dramatically. The concentration of CO_2 in the atmosphere at the end of 2007 was about 384 ppm. And if the CO_2 concentration continues to increase at the current rate, it will be double the pre-industrial concentration of 280 ppm by the end of the 21^{st} century. Actually, because the rate of increase itself is increasing, this doubling of the CO_2 concentration may occur even earlier.

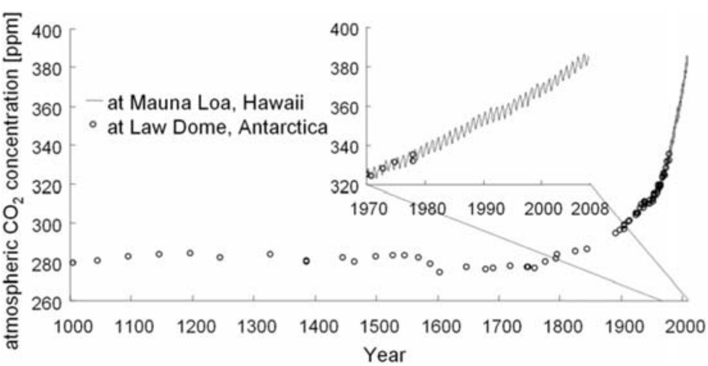

Fig. 1-1: Atmospheric CO_2 concentration from 1000 to 2008 (Data from National Oceanic and Atmospheric Administration: Dr. Pieter Tans, NOAA/ESRL and D.M. Etheridge et al., 2001, Law Dome Atmospheric CO_2 Data, 1GBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #2001-083. NOAA/NGDC Paleoclimatology Program, Boulder CO, U.S.)

The increase in the concentration of CO_2 is not likely to be directly harmful to humans and other living things. In fact, there is some evidence that plant growth is being enhanced by the increase and that as a result forests are becoming greener and more lush. However, the increased concentration of CO_2 in the atmosphere is thought to be indirectly changing the circulations of the earth – changes that could have far more serious impacts on human civilization than the increase in plant growth. Specifically, the increase in CO_2 concentration is believed to be inducing global warming.

We know for a fact that the average surface temperature of the earth is increasing. However, because the earth's temperature varies greatly with location and time of year, it is difficult to measure the average temperature of the earth reliably. Furthermore, the temperature of the earth is affected by sun spots and other solar activity. Even the eruption of a large volcano can affect the earth's temperature because the dust that is exploded into the atmosphere during an eruption reflects incoming sunlight, reducing the amount of sunlight that reaches the earth's surface. Many factors such as these affect our measurements of the earth's temperature and make it difficult to determine the relationship between CO_2 and temperature. However, techniques for assessing this relationship have become more and more accurate. According to the latest investigations by scientists at the IPCC (Intergovernmental Panel on Climate Change) reported in 2007, a rise in the average surface temperature of the earth of 0.74°C has occurred already. The major cause of this temperature rise is believed to be global warming from the increase of CO_2 in the atmosphere that has occurred over the past century.

How Long Does It Take for Ice to Melt?

One result of global warming that is raising fears is the rise of the sea level. According to the 2007 IPCC report, the current rate of sea level rise is 3.1 mm per year. At this rate, the sea level will rise nearly 12 cm by 2050. More alarming is the possibility that large parts of the ice currently land-locked in Antarctica and Greenland will slide into the ocean. Although ice is less dense than sea water, if large land-moored ice shelves break off into the ocean, they will raise the sea level. The ice will displace the water around it the same way that putting ice cubes in a full glass will cause it to overflow. Experts estimate that if all of the ice in Greenland were to slide into the ocean, the sea level would rise more than 600 cm. On the other hand, in the same way that a full glass of ice water will not overflow even if all of the ice in the glass melts, the ice in the Arctic, which is already in the water, will not increase the sea level much, even if it melts.

The fact that global warming will cause a rise in sea level is relatively well-known. And you might think that if we stabilized the CO_2 concentration in the atmosphere, the sea level would stop rising. But this is not true. The rise in sea level results from the melting of land ice in places like Antarctica and Greenland as well as from the thermal expansion of sea water as the temperature of the oceans increases. And it takes a long time to melt large chunks of inland ice and raise the temperature of entire oceans.

Little pieces of ice, such as shaved ice, melt quickly, and a piece of ice the size of an icicle may take at most a day to melt. A chunk of ice the size of a glacier would take a much longer time to melt. If we assume that a glacier melts only from the outside, then with a melting rate of 1 cm per day, it would take 300 years for a glacier 100 meters thick to melt. Heating an entire ocean also takes centuries. Even if we can stabilize the surface temperature of the earth at some level above its the pre-industrial temperature, glaciers will continue to melt bit by bit, and the temperature of the oceans will continue to increase little by little. As a result, the sea level will continue to rise until the oceans can absorb the excess CO_2, the atmospheric CO_2 concentration can decrease, and the earth's temperature can begin to return to its current value. This may take centuries.

Global warming caused by the increase in the concentration of CO_2 in the atmosphere and the resulting rise in sea level are only two examples of how the earth is beginning to change in ways from which it cannot recover through its annual cycles.

So why is the earth unable to recover in the way that it used to? To answer this question, let's look into the framework by which the earth has repeated its cycles of yearly recovery until now.

2 Mechanisms for Recovery

Circulating Ecosystems Powered by the Sun

In 1998, there was a huge forest fire in Indonesia. This fire burned for several months, and satellite images showed that smoke from the fire extended as far as the Malay Peninsula. The smoke from this vast fire is even believed to have caused an airplane crash killing all 234 people on board. Although a fire of this size is rare, forest fires occur each year around the world. However, once a fire is extinguished, even the fire in Indonesia, plants grow back and the forest recovers. After a forest fire, plant life in the form of seeds and underground shoots remain in the soil, and when spring comes around again, the greenery returns to the forest. A forest fire can even be a good thing for a forest ecosystem as it rids the forest of dead wood and parasites. In fact, one reason given for the ancient custom of burning the dead leaves on the *Wakakusa* Mountain in Nara prefecture of Japan every January is that it helps to preserve the plant life on the mountain. Therefore, even forest fires are a part of the circulations of the earth's biosphere.

Another example of nature's recovery can be seen in the fishing industry. If not fished into extinction, salmon, tuna, mackerel and other species of wild fish will restock a fishery year after year because uncaught the adult fish spawn and produce juveniles that grow in turn into adult fish. But this growth requires food. And the food chain in the ocean begins with phytoplankton. Like land plants, phytoplankton grow through photosynthesis. Many of them are captured by zooplankton, which are eaten by little fish, which are eaten in turn by bigger fish. When we get to the source of the food chain in the ocean, we find that it is photosynthesis using energy from the sun. A similar food chain occurs on land. Through photosynthesis, land plants grow foliage and bear fruit, which herbivores eat to grow and multiply. Carnivores prey on the herbivores to sustain themselves, and at the same time they keep the numbers of herbivores in check.

In summary, the basis for the cycles of life in the ecosystems on land and in the sea is photosynthesis, a process powered by the energy of the sun.

The Wind and Rain Also Are Caused by the Sun

In addition to these ecosystem cycles that are sustained by photosynthesis, weather-related phenomena such as wind and rain are also powered by the sun's energy. Rain happens when water on the land and the sea is heated by the sun, evaporates, forms clouds, and coalesces into droplets that fall as rain. After the rain falls to the earth, it soaks into the ground and feeds little creeks that feed into larger streams. Ultimately, these merge into rivers that flow into the oceans. In this way, water circulates on the surface of the earth, driven by the energy of the sun.

Wind is created when air flows from high pressure zones towards low pressure zones. Low pressure zones are regions where the sun has heated the air making it rise, and high pressure zones are regions that are relatively less heated. In fact, the energy of the sun is the source of all the forms of air circulation, including trade winds, typhoons, seasonal winds, and even local breezes.

Both rain and wind play important roles in the biosphere. As water circulates by falling as rain, gathering into rivers, and flowing into the oceans, it dissolves nutrients from rocks and soil. Those nutrients are absorbed by plants during photosynthesis, taken up by animals when they eat the plants, and returned to the ground and water when the animals urinate or pass feces. Winds transport a variety of materials, including seeds and nutrient-laden dust. Together with photosynthesis by plants, these are the phenomena upon which the circulations of ecosystems are based, and they all are powered by the energy of the sun.

The Amount of Elements in the Biosphere Is Constant

The part of the earth where all of these ecosystem cycles occur is called the "biosphere." The biosphere is completely contained within a thin shell about 20 km thick, from the peak of Mount Everest to the bottom of the Mariana Trench. To get a feel for how thin the biosphere is, try drawing a circle on a letter size piece of paper to represent the earth. No matter how sharp you make your pencil, the line that you draw will be thicker than the biosphere. Almost all human activity occurs within this single thin layer.

It may surprise you to learn that for over ten million years, the total amount of each chemical element in the biosphere has hardly changed at all. Chemical elements, such as carbon, oxygen and hydrogen, are neither created nor destroyed during the normal processes that occur on the earth's surface. For example, CO_2 is changed into carbohydrates by photosynthesis; however, the amount of carbon in the carbohydrates is the same as the amount that was in the CO_2. That is what scientists mean when they say that chemical elements are conserved during chemical reactions.

The only case in which chemical elements are not conserved is when the atomic nucleus is changed in a nuclear reaction. In a nuclear reactor, the nucleus of a chemical element called uranium is changed and a different element such as plutonium is created. Even in nature, forces such as cosmic rays can cause one chemical element to change into another chemical element. However, this amount is insignificant. Conservation of mass, and of chemical elements in particular, is one of the fundamental principles upon which science is based. (Another is conservation of energy, which will be introduced in Chapter 2.)

Although the chemical elements are conserved in constant amounts, we have seen that they are changed into various forms as they circulate through the biosphere driven by the energy of the sun. For example, nitrogen in the atmosphere, which occurs as a molecule containing two atoms of nitrogen, N_2, is taken up by nitrogen fixing bacteria living in the roots of plants and transformed into ammonia. Some of the ammonia is taken up by the plant, which converts it into proteins. The plant protein is consumed by animals, and some of the nitrogen consumed is excreted by the animals in the form of urea. Bacteria in the soil consume the urea and produce an oxidized form of nitrogen called nitrate. Other bacteria consume the nitrate and convert it back into N_2, thus completing the cycle. All of the other chemical elements in the biosphere follow the same kinds of circulations, eventually returning to their original state.

But changes from which the earth does not recover, changes we saw earlier in this chapter, are beginning to occur in this very same biosphere. Why has this happened? What has suddenly interrupted the cycles of the biosphere, cycles that have returned the earth to its original state each year for thousands of years? In the next section, we will take a look at what has changed in the last century.

3 A Massive Intervention by Humanity into the Biosphere

A Century of Expanding Human Activities

In this section, we will look at three graphs illustrating how much human activities expanded in the 20th century. The first graph shows the total human population on

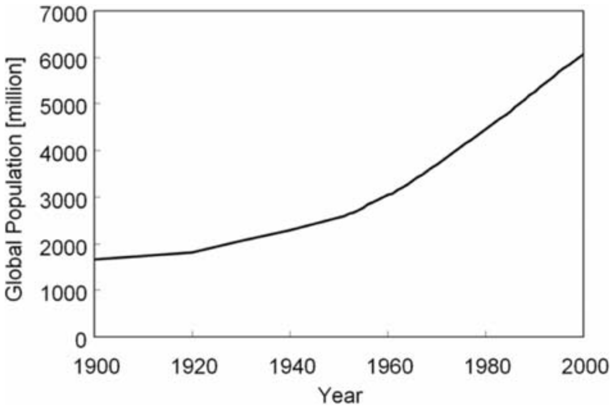

Fig. 1-2: Global population from 1900 to 2000 (Data from UN Common Database, United Nations Statistics Division)

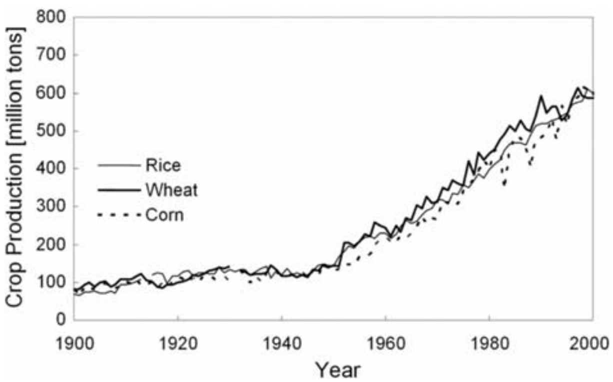

Fig. 1-3: Global production of the three major grains from 1900 to 2000 (Data from FAOSTAT database, Food and Agriculture Organization of the United Nations, the UN Common Database, United Nations Statistics Division, and B.R. Mitchell, International Historical Statistics, Palgrave Macmillan)

earth from 1900 to 2000 (figure 1-2). The human race entered the 20th century with 1.6 billion members and grew to 6 billion by the end of the century, an increase of almost four-fold. We use "billion" in the American English sense of one thousand million or 1,000,000,000.

The second graph illustrates how the production of agriculture has grown during the same period of time (figure 1-3). The production of agriculture as represented by the three major cereal grains – rice, wheat and corn – increased seven-fold. Because human population increased only four-fold, the average consumption of grain per person nearly doubled. The expansion of farmland area was one factor in creating this dramatic increase. However, particularly since the 1960's, the increase in agricultural production has been mainly due to increased yield from the same sized area. For example, from 1960 to 1995, the agricultural yield increased by 2.5 times. The main reason for this increase in efficiency is that a technique for manufacturing nitrogen fertilizer, which until the 1960's had to be obtained through nitrogen-fixing plants such as soybeans and other legumes, was successfully developed by synthesizing ammonia from nitrogen. However, this increase in efficiency may come at a cost. Experts say that in many parts of the world the large-scale agriculture made possible by the introduction of artificial fertilizer has seriously degraded the soil and therefore the ability of the land to produce the same agricultural yields each year. We may be getting some of our increased land productivity today at the cost of productivity in the future.

Fishery yields also increased as small fishing boats, which had been restricted to trawling the shorelines, were replaced with large ships that could fish the open seas. Furthermore, fishing nets and other equipment were improved, allowing the scale of fishing operations to become even bigger. However, these improvements in fishing practices meant that the fisheries were no longer able to completely recover each year. For example, when whaling was restricted to the shorelines, the cycles of nature could sustain the numbers of whales. But when whaling ships moved out into the Antarctic Ocean and began to hunt whales on a large scale, the numbers of whales diminished so much that concerns were raised that some whale species might become extinct. According to the State of World Fisheries and Aquaculture 2006 report of the UN Food and Agricultural Organization, over three quarters of the world fish stocks are being over fished.

The third graph shows production levels of iron and aluminum, two representatives of basic materials used to make the various goods and infrastructure components (figure 1-4). In the 20th century, production of steel increased twenty-fold,

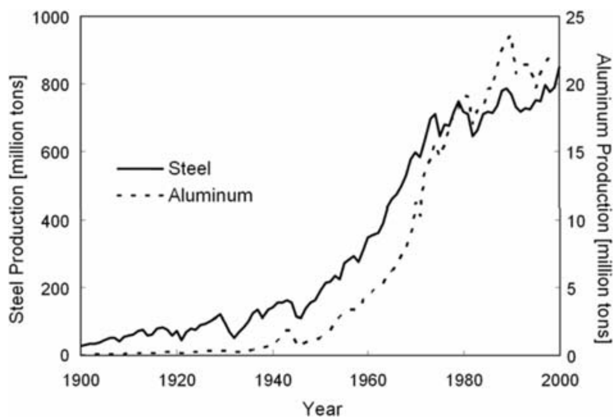

Fig. 1-4: Global production of iron and aluminum from 1900 to 2000 (Data from UN Common Database, United Nations Statistics Division and B.R. Mitchell, International Historical Statistics, Palgrave Macmillan)

and production of aluminum increased four thousand-fold. In fact, the production levels of almost all basic materials have increased from more than ten fold to several thousand-fold during the last century. Materials such as plastics and synthetic fibers did not even exist in the 19^{th} century. Thus, the expansion of manufacturing and manufacturing-related human activities in the 20^{th} century was particularly remarkable. And as we will see later in this chapter, the pressures of mining for resources and providing energy for manufacturing have also begun to disrupt the natural circulations in the biosphere.

There is a well-known equation among experts studying the sustainability of human existence on the earth. The equation states that the impact of humans on the earth equals the product of the human population, the affluence of that population as measured by the products and services consumed per person, and the impact on the earth of providing one unit of product or service. For example, the impact of food consumption is the human population times the average amount of food consumed per person times the amount of natural resources, such as water and land, needed to produce a given amount of food. The last factor in the equation – the size of the impact of providing a product which reflects the state of technology – is the inverse of the efficiency of the process providing that product. Since efficiency determines the factor in the equation where technology can play a role, it will be a major topic in this book.

Over the last few centuries, as the world's population has grown and the average per-person consumption of food and manufactured products has increased, the human impact on the biosphere has increased by orders of magnitude. Just in the last decade, human population has increased 10%, CO_2 emissions have increased about 25%, and production of basic materials such as iron and cement has nearly doubled. As a result of this impact, the biosphere is no longer able to return to its original state each year. In the next few sections, we shall look at human activities and the burdens each kind of activity imposes on the biosphere.

The Use of Fossil Fuel Resources

Human activities require energy. Once, this energy was obtained mainly by burning wood. However, as human activities expanded, wood burning was no longer enough to meet our energy needs. For example, charcoal was originally used in making iron. At that time, England was the leading producer of iron. But as a result of reckless lumbering to produce charcoal, the forests in England were so rapidly depleted that in the 16^{th} century, Queen Elisabeth I had to issue restrictions on the logging of forests. Thereafter, the iron industry in England declined, and countries richer in forests, such as Russia and Sweden, were able to become iron exporters. The reason that England could reclaim her hegemony in iron production during the industrial revolution was because of coal.

The use of coal resulted in an expansion of industry. But later coal was eclipsed by oil as the star of the energy show. Oil has higher energy content per ton than coal. Furthermore, because oil is a liquid, it is easier than coal to handle during extraction, to load onto ships, and to fill into combustion furnaces. The explosive expansion of industry in the latter half of the 20th century was made possible by the large-scale use of oil. However, the use of the fossil fuels coal and oil, and later natural gas, has come at the cost of unprecedented impacts on the biosphere. The reason is as follows.

Fossil fuels are composed mainly of carbon and hydrogen. When fossil fuels are burned with oxygen from the air, CO_2 and water are released as by-products. However, the CO_2 and water produced by burning fossil fuels contain carbon and hydrogen atoms that had been buried deep underground and therefore had not been involved in the circulation of chemical elements in the biosphere. In other words, the CO_2 and water released by burning fossil fuels is matter added by humans to the constant amount of elements being circulated through the earth's ecosystem by the energy of the sun. Furthermore, this new matter is added to the atmosphere, a medium which circulates more rapidly than the other parts of the biosphere, such as the ocean. The amount of water added through the burning of fossil fuels is insignificant in comparison to the total amount of water in the earth's atmosphere, but the increased amount of CO_2 can no longer be ignored.

According to the 2007 report of the IPCC, the increase in the concentration of CO_2 that was shown in figure 1-1 is caused by the enormous production CO_2 through the burning of fossil fuels together with a similarly large amount of CO_2 generated through the cutting down of forests. When forests are cut down, the felled trees will eventually be turned into CO_2. The amount of CO_2 produced each year by burning fossil fuels is estimated to be 7.5 billion tons in carbon units, which we will abbreviate as "tons-C." It is important to make this distinction, because the mass of a carbon atom is only about a quarter of the mass of CO_2. In this book, when we are talking about amounts of carbon-based materials such as CO_2 and fossil fuels, we will always use this measure of tons-C. The amount of CO_2 generated through the cutting down of forests is believed to be about 2.3 billion tons. When other emissions of CO_2 by human activities are added in, the total amount of CO_2 emitted each year through human activities is more than 10 billion tons.

The amount of CO_2 in the atmosphere at the end of the 20th century was about 700 billion tons, so human activities are increasing the CO_2 content in the atmosphere by more than 1% each year. A continuous annual increase in the atmospheric CO_2 concentration of this magnitude has never before been experienced in the history of human civilization. If we continue to emit CO_2 at the current rate, by the end of the 21st century, we will double the amount of CO_2 in the atmosphere today. Some portion of the 10 billion tons of CO_2 emitted into the atmosphere gets redistributed to the other parts of the biosphere. About half is absorbed by the oceans or taken up by new growth in the forests. The other half accumulates in the atmosphere. Therefore, the concentration of CO_2 in the atmosphere is linked to fundamental conditions on earth such as the surface temperature, which controls the rate of absorption by the oceans, and the rate of photosynthesis, which controls the uptake of CO_2 by plants.

Diminishment of Nature and Accumulation of Human Artifacts

When we turn our attention to the realm of living things, the increasing number of species that have become extinct is alarming. It is reported that over 100 species per day, mainly insects, are disappearing from the face of the earth. The IPCC report estimates that as many as 30% of all plant and animal species face the possibility of extinction if global warming continues unabated. Of course the diversity of species should be treasured in and of itself, but there is also concern that a reduction in species diversity could reduce the resilience of ecosystems to disaster and disease. And once a species becomes extinct, it is essentially gone forever.

The decimation of forests, particularly tropical rain forests, is also remarkable. According to the 2007 State of the World's Forests Report of the UN Food and Agriculture Organization, the rate of deforestation is decreasing; nevertheless, 130,000 km^2 of forests are cut down every year. One result of this rapid loss of forests is that deserts are encroaching at an unprecedented rate on populated areas around the world, such as the Sahel Strip at the southern fringe of the Sahara Desert. The 2007 State of the World's Forest Report estimates that 135 million people may be forced to leave their homes as a result of desertification. For example, it is reported that sub-Saharan Africa loses 1% of the productivity of its agricultural land each year to the expanding desert.

As our natural resources are diminishing, human artifacts such as buildings, roads, and cars are rapidly accumulating. The accumulation of human artifacts in the biosphere started to become conspicuous in the 20^{th} century. For example, although Tokyo has been a place where people have gathered since ancient times, most of the buildings, roads and cars we see there today were not there at the beginning of the 20^{th} century. We can see this accumulation in figure 1-4. The area under the lines showing the rate of production of iron and aluminum indicates the total amount of material produced by a certain time. It is clear that most of the basic materials used in human artifacts, such as iron and aluminum, were produced in the second half of the 20^{th} century.

As cities accumulate human artifacts, they are simultaneously disgorging huge amounts of waste. Recently, disputes have arisen around the world over the disposal of garbage. The fact is that the natural environment around cities is unable to absorb the massive amounts of waste we produce.

The Influence of Toxic Materials

Toxic materials produced by human activities, of which small amounts can wreak havoc on organisms and ecosystems, are also interrupting the cycles of the biosphere. Toxic materials have a long history. During the industrial revolution, for example, toxic materials contributed to the polluted and unsanitary conditions of the air and water in London. The danger of toxic materials and their effects on ecosystems became the focus of public debate in 1962, when Rachel Carson published *Silent Spring*. Japan, too, has suffered many environmental pollution incidents, including the heavy metal pollution from the *Ashio* copper mines, the mercury pollution in *Minamata* bay, and the air pollution at *Yokkaichi*. All of these incidents were the result of industrial emission of toxic materials.

Acid rain is a form of toxic pollution that transforms forests and lakes into barren landscapes. Acid rain is mainly caused by the combustion of fossil fuels. When fossil fuels are burned, sulfur in the fuels and nitrogen from the air combine with oxygen to create sulfur oxides and nitrogen oxides. When these compounds are emitted into the atmosphere, they react with cloud water to become strong acids, such as sulfuric acid and nitric acid. When the cloud water turns into rain, the sulfuric and nitric acids make the rain water highly acidic. This acid rain produces a range of adverse effects on ecosystems, buildings, and human health.

The damage caused by acid rain cannot be confined by borders between countries, making acid rain an international issue. At the time of the industrial revolution, sulfur and nitrogen oxides generated by burning coal in England were carried by the wind across the North Sea and ended up forming acid rain that caused damage to forests and lakes in Scandinavia. Similarly, in North America emissions from fossil fuel combustion at U.S. steel-making plants around the great lakes have caused extensive damage in Canada. And recently, reports have begun to appear that acid rain originating in China is influencing Korea and Japan.

Another example of toxic materials is CFCs (chlorofluorocarbons), often known by the brand name Freon. CFCs, which do not burn or change chemical form easily, are good cleaning agents. And they can easily be converted from a liquid to a gas and vice versa. When they hit the market in the 1930's, they were hailed as one of the best chemical compounds ever developed. However, these same chemical compounds are now known to be a major cause of the depletion of the ozone layer. In the ozone layer (which is a part of the stratosphere in the upper atmosphere) CFCs react with ozone resulting in the destruction of ozone molecules. Ozone in the stratosphere acts as a filter to absorb ultraviolet radiation in sunlight, radiation that would otherwise damage genetic structures in living cells. Thus there is concern that depletion of ozone in the stratosphere by CFCs will give rise to increased rates of skin cancer and other genetic disorders.

Many other problems related to a range of toxic materials – from residual agricultural chemicals to dioxins to endocrine disruptors – are now raising concern and drawing scrutiny.

The examples above make it clear that human activities are beginning to disturb the natural cycles in the biosphere. As summarized in figure 1-5, human activities transform mineral resources into artifacts such as manufactured goods and urban infrastructure. Some of these artifacts accumulate within a society. However, many are discarded back into the biosphere. As a result, the biosphere is being flooded with human artifacts that have ceased to be of use, together with the CO_2 generated from fossil fuels used to produce these artifacts and various toxic by-products. All of this waste spewed or tossed into the biosphere disturbs the workings of the biosphere.

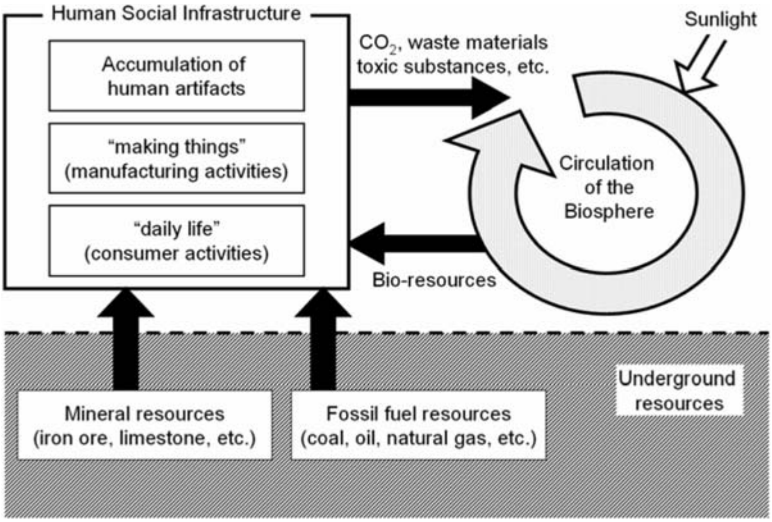

Fig. 1-5: The material interflows between the biosphere and human social infrastructure caused by human activities

4 The Flow of Materials Resulting from "Making Things"

Let's look at the picture shown in figure 1-5 from a different angle. Some human activities, such as agriculture and fisheries, make use of living resources indirectly derived from the sun. Therefore, as long as they are not carried out in excess, these activities do not cause damage to the circulation system of the biosphere. However, the activities of "making things" that involve the manufacture of artifacts using resources from underground are different. The reason is that activities of "making things" dig up materials that hitherto had been isolated underground and release them into the circulation system of the biosphere.

What materials are used to manufacture artifacts? Looking around, we see that paper and other wood products, metals such as iron and aluminum, non-metal minerals such as glass and concrete, and petroleum products such as plastics, rubber and synthetic fibers account for most of the materials used in human artifacts. The use of materials derived from animals, such as leather and shells, is miniscule in comparison.

In the following sections, we are going to look at the flow of these basic materials from when they are extracted from the earth as natural resources to when they are returned to the earth as waste. This is called the "lifecycle" of the materials, and it will give us a different perspective on the way human activities are disturbing the cycles of nature. In particular, we will see that there are three types of lifecycle: accumulation, one-way flow, and recirculation.

Accumulating Metals

First, let's look at the lifecycle of iron. Iron ore, the raw material for iron, is iron oxide – that is, iron bonded to oxygen. This iron ore is converted into iron in a huge reaction vessel, called a blast furnace or a shaft furnace, through the use of fossil fuels, mainly in the form of coke. Coke is a form of carbon produced by heating coal in the absence of oxygen. In the blast furnace, the carbon in coke bonds to the oxygen atoms, stripping them from the iron atoms in the iron ore, and producing pure iron. This chemical process is called the "reduction" of iron ore. The iron that is produced in a blast furnace is called "pig iron," and currently almost 900 million tons are produced each year worldwide. Pig iron is tempered with various additives, rolled, shaped, and cut; and its surface is treated in different ways to create the various iron and steel products that we see in the market.

A plant built around a blast furnace that carries out the entire process from reduction of iron ore to delivery of iron products is called an integrated iron and steel making works. In this integrated plant, about 600 kg of coke is used to produce one ton of steel. Because coke is made from coal, the production of each ton of steel consumes approximately 600 kg of fossil fuel resources.

As of the year 2007, the total production of iron worldwide has exceeded 1.3 billion tons. If only 900 million tons is from iron ore, where does the rest of the iron come from? When iron and steel products reach the end of their life spans, they are collected as scrap, melted down, and remanufactured to produce new iron and steel products. Globally, about 400 million tons of iron is produced from scrap. The fraction of total iron production that comes from scrap is therefore about one third. This fraction is often called the "recycle ratio," but this is a misleading expression. Saying that the recycle ratio is one third implies that two thirds of the iron is thrown away without recycling, but this is not the case. There is little accurate data on how much iron and steel is thrown away in garbage dumps, but it is thought to be far less than the amount recovered as scrap. Most of the difference between the amount of iron and steel that is supplied to the market and the amount that returns to the iron and steel making plants as scrap is accumulated in the infrastructure of society as artifacts.

Figure 1-6 shows a diagram summarizing the flow of iron in the biosphere. Many of the flows shown in the diagram cross international borders and oceans. Japan is a particularly good example because Japan has few natural resources and must import many of its raw materials from other countries. So let's look at a concrete example of the flow of iron ore from Brazil and coal from Australia to provide iron in Japan. Iron ore from Brazil is accumulated as iron in skyscrapers and highways in Japan, and coal that had been buried underground in Australia is released into the atmosphere as CO_2, where it contributes to the increase in global warming. Human artifacts eventually reach the end of their product lives, but most of the iron in them is made back into iron products. A small part of the iron is thrown away in garbage dumps, and over a long period of time, this iron rusts away and becomes

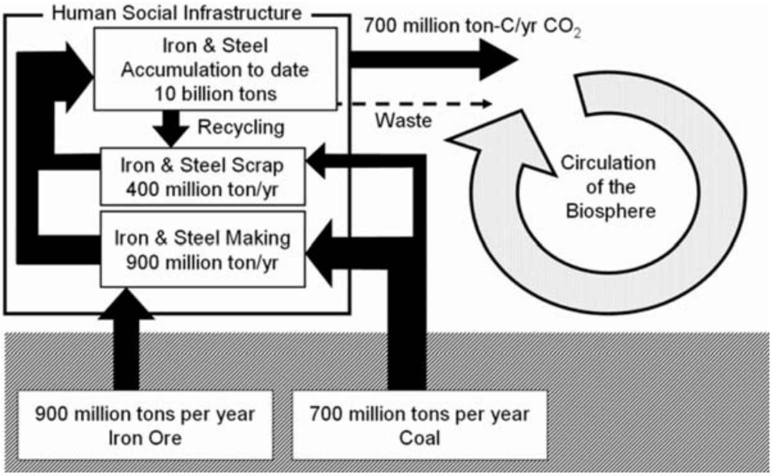

Fig. 1-6: The lifecycle of iron

iron oxide. This iron can be thought of as iron oxide that is transported from Brazil to a garbage dump in Japan. Similar flows occur between other producers and other consumers of natural resources for iron production. This is the lifecycle of iron in the biosphere, a lifecycle created by human activities.

Aluminum, the metal with the highest production level next to iron, is produced from ores comprised mainly of bauxite, or aluminum oxide. Because the bond between aluminum atoms and oxygen atoms is so strong, it is impossible to use carbon to remove the oxygen atoms through reduction as in the case of iron. Instead a different method is used. First, the bauxite is mixed with fluorides to reduce the melting point. Then the mixture of bauxite and fluorides is melted, and the molten bauxite is split into aluminum and oxygen through electrolysis.

The electricity used in this process accounts for nearly all the energy required to produce aluminum. And approximately 2% of the electricity generated in the world is consumed in producing aluminum. Countries like Japan, where the price of electricity is relatively high, do not produce their own aluminum. Instead, they import ingots of aluminum produced from bauxite in countries with cheap electricity, like the U.S. and Canada. Like steel, much of waste aluminum is recycled. The global production of aluminum from bauxite is more than 30 million tons per year, and the production from aluminum scrap is more than 10 million tons.

Let’s take a look at the global flow of aluminum for use in Japan. Bauxite dug from mines in Australia is transformed into ingots of aluminum using hydropower in Indonesia, ingots which are then transported to Japan. This raw aluminum is made into products such as cans and window frames. And when those products are no longer needed, most of the aluminum contained in them is recycled into new products that are circulated back into the market. The portion of aluminum thrown into garbage dumps is eventually converted back into aluminum oxide. So this portion of the flow is equivalent to transporting bauxite from Australia to a garbage dump in Japan.

The lifecycles of most metals currently operate in the same fashion as those shown for iron and aluminum. Recycling of rare metals such as platinum, cadmium, palladium, iridium, copper, and mercury has an even greater potential for making society more sustainable. One reason is that rare metals tend to be more costly to extract from natural resources. However, perhaps more importantly, rare metals are often highly toxic, making it necessary to use expensive disposal methods if the metals are not recycled.

The confirmed recoverable reserves of both iron and aluminum ore are large enough that even if production is continued at today's levels, they would last for two to three centuries. So we do not need to worry about depletion of these natural resources for a long time. However, as you will discover in this book, if we continue to use these natural resources to provide most of the basic materials that we use, we will end up consuming tremendous amounts of energy and covering the earth's surface in waste.

The One-Way Flow of Cement and Glass

Concrete and glass are the major non-metal minerals used in human activities. So what do their lifecycles look like?

Concrete is sand and gravel bound together with cement. Cement is calcium oxide formed when limestone is heated, driving off CO_2. About 100 kg of fossil fuels are consumed in producing one ton of cement. Concrete is used to construct buildings and highways, and most of the waste concrete generated when the buildings and highways are torn down is pulverized and used as low-grade materials in applications such as roadbeds. However, the demand for these low-grade materials is gradually decreasing. For example, in Japan of the total amount of 37 million tons of concrete waste generated in 1995, more than 10% was not recycled. Almost all of this concrete can be considered as having been thrown away in garbage dumps.

In short, the lifecycle of concrete unfolds as follows. Sand, gravel, and limestone are collected from rivers and mountains, made into concrete through the use of fossil fuels, and accumulated in the infrastructure of society. However, eventually all this concrete becomes waste material. Here is what the lifecycle of Japanese concrete looks like from a global perspective. Coal buried underground in America and other parts of the world is transformed into CO_2 and released into the atmosphere. Sand, gravel, and limestone from the rivers and mountains of Japan are accumulated in human artifacts such as buildings and highways. All of those artifacts are eventually torn down, and all of that concrete finally ends up in garbage dumps. So we see that the lifecycle of concrete is essentially a one-way flow – from the consumption of natural resources to burdens on the environment in the form of expanding garbage dumps and increasing CO_2 in the atmosphere (figure 1-7).

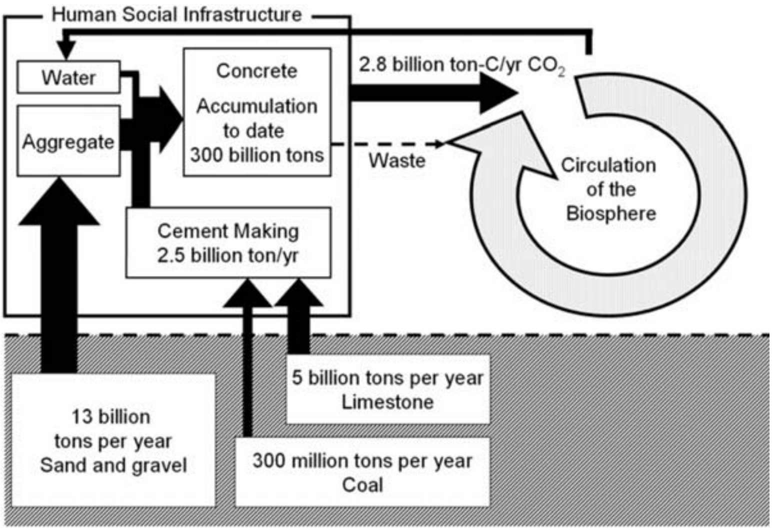

Fig. 1-7: The lifecycle of concrete

Glass products are formed by heating a mixture silicon oxide, sodium carbonate, and calcium carbonate to drive off CO_2, and then melting down, shaping, and solidifying the mixture. About 200 kg of fossil fuels are consumed in making one ton of glass. In Japan, the current recycle ratio of glass is about 50%, so on average glass from natural resources is used twice in manufactured products. However, in the end, the lifecycle of glass is almost the same as that of concrete. Silicon oxide, sodium carbonate, and calcium carbonate in quartz, soda ash, and limestone are collected from the rivers and mountains of Japan and other countries and eventually end up being transported to garbage dumps. At the same time, oil from places like the Middle East is emitted as CO_2 into the atmosphere.

Petroleum Products Are Also a One-Way Flow

Plastics and synthetic fibers are examples of large molecules called polymers that, unlike the molecules of CO_2 and nitrogen, are composed of long strings of atoms – strings ranging from tens to millions of atoms. Currently, the production of polymers worldwide is more than 200 million tons, and on average about two tons of oil is used to make one ton of plastic. Plastic is a special product in the sense that oil is used both as a raw material and as an energy source for manufacture. To produce one ton of plastic, almost equal amounts of oil are used as energy and as raw material. When petroleum products reach the end of their product lives, most are incinerated or thrown away. The plastic thrown into garbage dumps

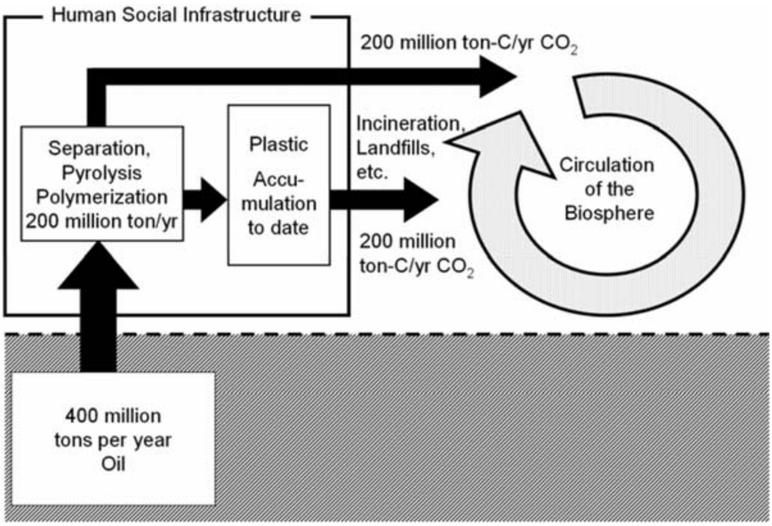

Fig. 1-8: The lifecycle of plastic

does not decompose quickly, but after a long time, it will eventually be oxidized into CO_2.

Consequently, seen from a global perspective, the lifecycle of plastic is just the transformation of oil from oil fields into CO_2 released into the atmosphere (figure 1-8).

Biomass Materials Are Recirculated

Iron, aluminum, concrete, glass and plastic have lifecycles that currently proceed in what is essentially a one-way flow from natural resources to release back to the environment as waste material and CO_2. In contrast, biomass is an example of a basic material that, in some cases, is recirculated even now.

Biological resources that are not used as food, such as wood and the husks of plants, are referred to as "biomass." Biomass materials include paper and lumber. Paper is made from trees; however, the process of making paper uses a rather large amount of fossil fuels. About half of a tree's wood consists of cellulose; the other half consists of lignin, a substance that keeps the trees rigid. Paper mills use only the cellulose to make paper. However, the lignin is not just thrown away; it is used as a fuel to generate electricity. Unfortunately, there is not enough lignin to supply all of the electricity required for paper production, so oil is used to cover the deficit. The worldwide production of paper is about 400 million tons per year, and about 300 kg of oil is used to make one ton of paper.

Currently, the recycle ratio for paper in Japan is about 50%. Although the recycle ratio varies from country to country, we can estimate that on average about half of the paper used in the world is recycled. Therefore, about half of the 400 million tons of paper produced per year is made from used paper. The rest of the used paper is either incinerated or thrown away in garbage dumps, where it is decomposed, oxidized, and finally becomes CO_2.

In summary, the lifecycle of paper begins with the harvesting of trees as raw material, and after the paper is used twice on average, it is released into the atmosphere as CO_2. The trees harvested to produce paper grow by acquiring CO_2 from the atmosphere. If the forests cut down to make paper are not replanted, the cycle of biomass material is not complete and the flow is one-way, like the flow for glass and cement. However, if the same number of trees that is harvested is replanted, the lifecycle proceeds from trees to paper to CO_2 and back to trees. This is essentially the same as the natural circulation of trees growing, dying, and decomposing. Therefore, biomass has a recirculating lifecycle that can be sustained in the biosphere. When we look at the overall lifecycle of paper produced this way, we see that the chief impact on the biosphere comes from the 300 kg of fossil fuels consumed per ton of paper, oil taken from the oil fields and released as CO_2 in the atmosphere (figure 1-9).

How about the lifecycle of lumber, the other major biomass material? If a wooden house is torn down at the end of its life and the wood is thrown into a garbage dump, the lifecycle will be a one-way flow. However, in making lumber, fossil fuels are used only to harvest, transport, and shape the wood. These processes consume far less energy than separating lignin from wood to make paper. Therefore,

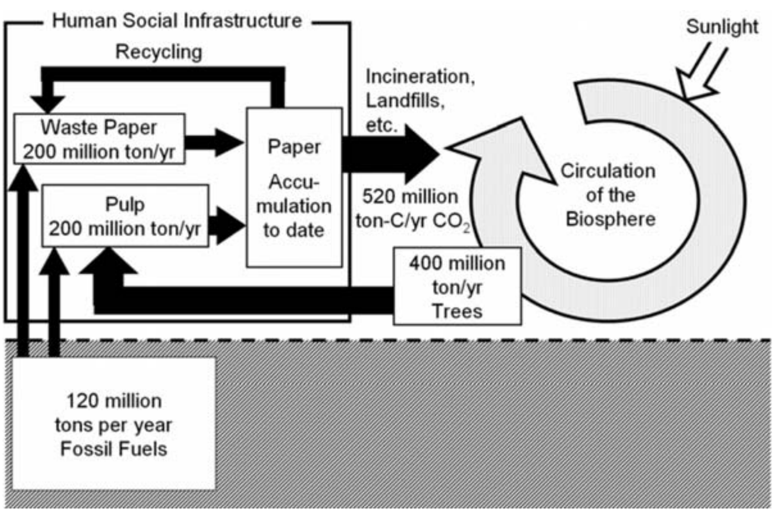

Fig. 1-9: The lifecycle of paper

as long as the trees that are cut down are replanted, consumption of lumber is sustainable. In essence, this lifecycle is the same as the circulation of biomass that occurred in nature before humans began to disturb it.

Sustainable Lifecycles and Non-sustainable Lifecycles

Looking from a global perspective at the processes for producing basic materials, we see that the consequences of "mass production / mass consumption" are quite different for different materials. The point to keep in mind is that it is possible to manufacture each of these materials in a sustainable way and a non-sustainable way. A large fraction of discarded iron and aluminum products is currently recovered as scrap and reused. But many metal products are still discarded without recycling. Most of the waste concrete produced when buildings and bridges are demolished is used for purposes such as road beds. However, as the demand for road bed and other low-grade materials decreases, the amount of concrete that is thrown away will increase. In some regions of the world, renewable forestry is practiced so that as trees are cut down, others are planted. But in other regions, forests are cut down without replanting, and the bare terrain is left to become a desert.

When materials are reused or resources replaced, the resources are not consumed in a one-way flow; instead they are circulated through human society twice or more. However, material flows that proceed directly from resource to waste should give us cause for alarm. For human activities to "fit" in the biosphere, they must circulate in the same way that natural biosphere activities do. Right now, we too often extract resources from the earth to make products and then return the discarded products to the earth, relying on the earth's natural circulations to complete the cycle back to resources. That is a "one-way" flow, and it has begun to overwhelm the capacity of the earth to stay in balance.

It is clear that our activities of "making things" are disrupting the natural circulations of the biosphere. However, those are not the only human activities threatening the earth. Our normal day-to-day activities such as driving cars, using air conditioning, and lighting our homes also have a great impact. We will call these "daily life" activities.

This book is based on the premise that the essential problem of sustainability is that human activities of "making things" and "daily life" are not carried out in accordance with any overall global vision. Without such a vision, we do not know what the future consequences of our present activities will be. In other words, we do not know whether activities touted as beneficial for the environment will actually result in the consequences we intend. This lack of a global vision is, I suggest, the reason for the widespread feeling of helplessness in regard to the sustainability of the earth. Human civilization has already consumed more than 40% of the forests that existed in the past and more than 50% of the recoverable oil resources. We cannot dismiss these numbers as groundless fears. We must, instead, find a way to marshal our efforts to achieve a sustainable earth. In the next section, you will see why.

5 What Happens if We Continue with "Business as Usual"?

Oil Reserves Will Become Depleted

Until this point, we have examined the present-day lifecycles of metals, cement and glass, plastics and paper – lifecycles driven by the human activities of manufacturing and consumption. If we continue with "business as usual," what will the earth be like by the middle of the 21st century?

We have seen that the production of all basic materials requires the combustion of large quantities of fossil fuels. To make one ton of plastic, we must burn one ton of oil. To make one ton of iron takes 600 kg of coal. We need 300 kg of fossil fuels to make one ton of paper, 200 kg to make one ton of glass, and 100 kg to make one ton of concrete. If we continue to use oil to provide the energy for manufacturing these materials, world oil reserves will almost certainly be depleted by the end of the 21st century.

It has been said that oil reserves will last at least another 40 years, but how is this number arrived at? The life expectancy of the world oil reserves is calculated as the total amount of confirmed reserves divided by the current annual consumption rate. Consequently, if new oil reserves are discovered and the amount of confirmed reserves is increased, the projected life expectancy will increase. On the other hand, if the annual consumption rate increases, the expected lifetime of the reserves will decrease. The reason that oil reserves have not yet been depleted, even though more than 40 years ago people were saying that oil reserves would only last 30 or 40 years, is that until now new oil fields have been discovered at a rate comparable to the rate of oil consumption.

However, the number of new oil fields discovered each year is decreasing, and the size of the newly discovered oil fields is getting smaller. In addition, more and more of the major existing oil fields are nearing the end of their reserves. For example, in the U.S., which in addition to being the largest oil consumer is the largest oil producer after Saudi Arabia and Russia, oil fields have already exceeded their peak output levels, and since the 1990's, the production rate there has been declining continuously. In 1998, the ratio of remaining reserves to annual production was less than ten years, and it was predicted at that time that, even with the discovery of new oil fields, after ten years the reserves would be almost completely depleted. According to more recent figures for 2006, the ratio of remaining reserves to annual production was still about ten years. However, the production rate declined by more than 20% from 1998 to 2006, despite the rise of world oil prices. This is a clear indication that the U.S. oil reserves are running out. The situation of the British oil fields in the North Sea is similar.

On the other hand, the rate of fossil fuel consumption worldwide continues to increase. It is a telling fact that China, home to one fourth of the world's population, changed from being an exporter to an importer for fossil fuels during first half of the 1990's. The increase in fossil fuel consumption resulting from the economic growth occurring in South East Asia is also remarkable. These changes in the world oil market all point towards the impending reality of oil depletion. In the past, human civilization has experienced two energy crises. However, those crises were caused more by political and economic factors driving up the price of oil, such as propagandistic reports that oil reserves might eventually be depleted, rather than real evidence that oil depletion could occur in the near future. Between 2050 and 2100, oil depletion may become a reality, leading to a different, more fundamental, sort of crisis.

Global Warming Will Alter the Earth's Climate

The second catastrophic event that is almost certain to occur in the 21st century is global warming. Despite the clear messages from authorities such as the IPCC, some people still claim that there is scientific uncertainty about global warming. But just looking at the mechanisms by which global warming occurs, it is clear that global warming is an undeniable reality.

The earth's surface temperature is sustained by heat from the sun. Without the sun, the earth would cool down to near the temperature of outer space, which is about −270°C. The reason that your hands get warm when you hold them up to a wood stove is that energy radiates from the hot stove and heats your hands. The higher the temperature of an object, the more energy radiates from its surface, mostly as infrared radiation, which we feel as heat. The energy radiating from the sun shines on the earth at a rate of approximately 1.4 kW per square meter, and this energy heats the earth. However, as shown in figure 1-10, energy is also released from the earth's surface into outer space in the form of infrared radiation. In fact, the temperature of the earth's surface is just high enough that it releases an amount of energy into space exactly equal to the energy arriving from the sun. If the temperature increases, the amount of infrared radiation leaving the earth increases, causing the temperature to fall. If the temperature decreases, the amount of infrared radiation becomes smaller causing the temperature to rise. Therefore, the earth's surface temperature is maintained by a balance of energy radiation. If the earth had no atmosphere, the balance temperature would be 5°C.

The earth's atmosphere affects this balance temperature in two ways. The first effect comes from the clouds and particles in the atmosphere, which reflect part of the sunlight and keep it from reaching the earth's surface. The fraction of sunlight that is reflected is about 30%. This reflected sunlight reduces the balance temperature by 23°C. Without the second effect of the atmosphere, that would result in a surface temperature on earth of −18°C.

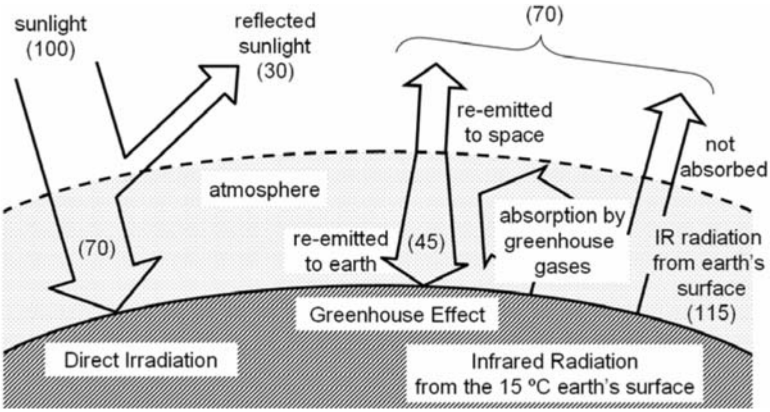

Fig. 1-10: The energy balance determining the temperature of the earth's surface

The second effect of the atmosphere is the absorption of infrared radiation emitted from the earth's surface by molecules of particular gases, such as water vapor and CO_2. These radiation-absorbing molecules are called "greenhouse gases" because they trap heat in the same way as the glass roofs of greenhouses. After molecules absorb infrared radiation moving from the surface of the earth towards outer space, they re-emit it immediately, but only half of the re-emitted radiation is released towards outer space. The other half is redirected back towards the earth's surface. Some of the infrared radiation released towards outer space is reabsorbed by molecules in the atmosphere still further from the earth's surface, and half of that radiation is re-released in the direction of the earth's surface.

This absorption and emission continues until the radiation is returned to the earth's surface or escapes into outer space. The result is that an amount of infrared radiation equivalent to more than 60% of the sunlight that reaches the earth's surface is captured by the atmosphere and returned to the earth's surface. This is the greenhouse effect, and it currently raises the temperature of the earth's surface by about 33°C.

The net result of a 23°C temperature decrease from reflection and a 33°C temperature increase from the greenhouse effect is an increase in 10°C, which when added to the 5°C temperature of the earth without its atmosphere gives us the actual average temperature of the earth's surface: 15°C.

Venus, the planet next to the earth in proximity to the sun, has a surface temperature of 400°C, and Mars, the planet next to the earth in distance from the sun, has a surface temperature of −50°C. Both these temperatures are determined by the same mechanisms that regulate the earth's temperature. Therefore, if the concentration of a greenhouse gas such as CO_2 increases, it is reasonable to conclude that the greenhouse effect will increase. Scientists predict that the rise in the earth's average temperature when the concentration of CO_2 doubles will be 3°C. Looking back at the rate of increase in CO_2 concentration shown in figure 1-1, it is clear that by the middle of the 21st century a significant increase in global warming from CO_2 emissions is inevitable.

No one knows for sure what the effects on the earth and on human civilization will be from such an increase in global warming. However, we do know that it will mark an unprecedented change in the history of human civilization. Certainly, fundamental changes will occur in the earth's climate, such as rainfall patterns, with resulting effects on crop productivity. As we saw earlier, the level of the oceans is already rising, and there is reason to believe that the rise could be large enough to cause significant parts of the world's coastlines and entire island nations to disappear beneath the sea. If we continue with business as usual, it is almost certain that by the middle of the 21st century the earth's energy balance will require us to make major changes in the way we live.

The Earth Will Become Buried in Human Waste

The third crisis that we will face by the middle of the 21st century is the accumulation of massive amounts of waste material.

As we saw in figure 1-4, of all human artifacts existing in society today, most of them were produced in the latter half of the 20th century, and there is no sign of decline in the rate of production. These human artifacts accumulate mainly in cities, where the greatest population increases have occurred in the 20th century. And people are continuing to migrate to the cities, particularly in developing countries. It is predicted that by the middle of the 21st century, 70% of the world population will be living in cities. As existing cities expand and new cities are built, the accumulations of human artifacts will also grow. However, all things must reach an end. The life span for products such as automobiles and household appliances is about 10 years, and for buildings it is around 40 to 50 years. Therefore, almost all of the human artifacts that we see in the cities today will reach the end of their life spans by the middle of the 21st century. When the mountains of human artifacts accumulated in the second half of the 20th century reach the end of their product lives, a massive generation of waste materials like nothing we have seen before will begin. If this waste material is thrown away as garbage, dumps will have to be created all over the surface of the earth to hold it all.

Around the world, it is becoming difficult to obtain sites for garbage dumps. Intense debates have sprung up when plans to create garbage dumps are announced that involve destroying fragile ecosystems such as tidal wetlands. On the other hand, illegal dumping of garbage has become conspicuous on islands of the *Seto* Inland Sea, in suburbs of major cities, and in forestlands everywhere. And this is just the beginning.

These phenomena – depletion of oil, global warming, and the massive generation of waste – are natural results of the explosive expansion of human activities in the 20th century. And it is under these severe circumstances that we enter the 21st century.

Powered by the energy of the sun, the earth has maintained the various cycles of nature within the thin layer of the biosphere since before human civilization began. Now human activities are threatening to disrupt these cycles. To achieve a sustainable earth, it is up to us to figure out how to construct a sustainable circulation system for our own activities, a system fits within the natural circulations of the earth. The purpose of this book is to show that this can be done.