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Vision 2050
Roadmap for a Sustainable Earth

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Springer

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ISBN 978-4-431-09430-2 Tokyo Berlin Heidelberg New York
eISBN 978-4-431-09431-9

Library of Congress Control Number: 2008930108

Springer is a part of Springer Science+Business Media
springer.com
Printed in Japan

Typesetting: SNP Best-set Typesetter Ltd., Hong Kong
Printing and binding: Nikkei Printing, Japan

Printed on acid-free paper

Preface

Can we humans continue to live and work as we have until now within the resource limits of the earth? And can we sustain the earth's bountiful resources, including a clean and healthy environment, for generations to come? Recently, alarms have been sounded predicting a catastrophic future for the earth's environment and resources, and most informed people feel anxious about the dangers that may lie ahead. However, few of the people sounding these alarms have offered convincing plans of how we can navigate safely past the impending dangers. The goal of this book is to propose a concrete vision of a road to a sustainable future for humanity and the earth. By a "sustainable earth," we mean a way of living our lives and conducting the various activities that support our lifestyles within the bounds of the earth in such a way that we do not exceed those bounds, either by depleting non-renewable resources or by overloading the capacity of the earth and particularly the earth's biosphere for renewal. As we will see in this book, the sustainability of the earth is a dynamic process of circulations in large-scale and complex systems. Human society is one such system, and in order to make human existence on the earth sustainable, we must figure out how we can create a social infrastructure that sustains circulations matching those of the earth.

This book will show how – by virtue of science and technology – we can create an infrastructure for conserving energy and recycling materials by the year 2050. Furthermore, this book will show how that infrastructure will put us on the path towards maintaining high standards of living without depleting the earth's resources or despoiling the environment. Realizing this infrastructure will require that we establish a good relationship between society and technology. This relationship must be based on clear and honest communication between researchers in technology and stakeholders in society.

Since ancient times, human beings have developed and improved technologies: making tools, mastering fire, learning to plow the land. In tool-making, humans have progressed from shaping implements from stone, pottery, bronze and iron to manufacturing synthetic fibers and high-tech ceramics. In harnessing sources of energy, we have gone from burning wood to releasing the power of coal, oil, natural gas and nuclear energy. To improve agricultural yields, we have progressed from letting fields lie fallow to spreading manure to synthesizing chemical fertilizers. As a result of these technologies, human beings have flourished and populations have swelled. Although poverty remains a serious global problem, most people today, even in the developing world, live lives of health, wealth, comfort, and convenience unimaginable to our ancestors.

But impending depletion of resources and degradation of the environment have begun to threaten the civilization we have achieved. The seemingly boundless sky and vast ocean – which once seemed capable of absorbing every waste we threw out or spewed out – are now changing dramatically as a result of human activity. It is now obvious that the earth is but one small planet of limited size and resources. There are already clear indications of the serious problems posed by depletion of energy resources, by global warming, and by the massive generation of waste products. If we do not make changes in the way we use and reuse the earth's resources by the middle of the 21st century, these problems threaten to swamp the ship of human civilization.

As the negative side effects of our material civilization have become increasingly obvious, many people have begun to question our modern lifestyle. Awakened to the immensity of the garbage problem, the global warming problem, or some other threat to human civilization, many have come to feel that they must take action. If separating the garbage will help, many are prepared to do so. If solar energy is the solution, many who could afford it would be willing to install photovoltaic solar cells on their roofs. But one reason that people fail to follow through on these good intentions is that they are unsure what effect their efforts will actually have on global problems. In fact, many of us are doubtful whether our individual efforts will have any effect at all. As a result, many who fear for the environment and want to take action instead hesitate and end up doing nothing.

It is true that a variety of actions have been initiated that are intended to achieve a sustainable earth. Recycling is one example. Yet we still hear some experts claim that the cost of recycling makes it unrealistic or even that it is more harmful to the environment to recycle than not to recycle certain products. Some experts claim that solar cells are the energy trump card of the 21st century, but others say that such technologies are too expensive, and moreover they would scarcely contribute at all to the mitigation of the potential energy crisis. To take the first steps towards a sustainable earth, we need answers to these conflicting claims. More important, we need a comprehensive vision we can all share of what human civilization must look like at some point in the future for the sustainability of the earth to be assured. With such a shared vision, we could clearly evaluate the roles to be played by technologies such as solar cells and activities such as recycling.

The goal of this book is to lay out a comprehensive vision of how we could work together to put our society on the path toward sustaining a high quality of life on a planet with limited resources, and of the concrete steps we must take to get there. The 21st century is a crossroads where humanity will decide whether to take the path towards a sustainable society or the path towards environmental degradation and resource depletion. With this choice in mind, this book will submit "Vision 2050," a comprehensive vision aimed at reversing the trend toward resource depletion and environment degradation by 2050. “Vision 2050” is a concrete plan for a society based on recycling of materials, renewable energy, and energy efficiency that can be achieved by the middle of the 21st century and that would put us on a path to a sustainable earth by the 22nd century. By making “Vision 2050” a reality, we should be able to safely navigate past the trilemma of depletion of oil resources, global warming, and massive generation of wastes, to achieve a social foundation for supporting the sustainable development of humanity.

To make the earth a sustainable foundation for human life, we must reduce the burden that we place on it. Re-evaluating our modern material lifestyle is certainly important. But will it be enough? Today’s global human population of 6.6 billion is predicted to reach 9 billion by the middle of the 21st century, and inevitably material consumption in the developing world will increase dramatically as a result. Because this population explosion will place a huge and ever-increasing burden on the earth’s resources, it is clear that just changing lifestyles will not be enough to achieve a sustainable earth. We must consider how we can further reduce the burden of humanity on the earth. One way to do this is by developing technologies to reduce the inflow of natural resources and the outflow of waste materials accompanying each unit of human activity. And as this book will demonstrate, the impact of such technologies can be tremendous.

Vision 2050 is a concrete proposal for how we can resolve the problems of an imperiled environment and shrinking resources while still enabling all peoples on the earth to achieve living standards enjoyed by those in developed countries today. Vision 2050 is based on three necessary conditions: 1) increasing the efficiency of energy use, 2) increasing the recycling of materials in manufactured goods and infrastructure (what we will call “human artifacts”) and 3) developing renewable sources of energy. Through the realization of an efficient recycling society, these conditions should be attainable. The key to achieving this kind of social infrastructure is establishing a circulation system from waste products to raw materials that takes over some of the burden that we are currently putting on the earth’s biosphere.

This book will show that the goal of creating an energy-efficient, recycling society is possible in part because our legacy from the 20th century is not all negative. Certainly the 20th century has left us many problems to clean up, such as pollution of the land, air and seas. Nearly all of the infrastructure and manufactured goods around us – buildings, railroads, highways, cars and household appliances – must be disposed of in the 21st century, a casting off that could result in a huge burden on the earth. However, under certain conditions, it is possible for us to consider these human artifacts as a positive inheritance even after they have reached the end of their intended use. In most of the world, human artifacts – that is all of the things that we manufacture – will approach a state of “artifact saturation” by the middle of the 21st century. This book will show that we can use technology not only to develop large-scale sources of renewable energy and to revolutionize our energy efficiency, but also to recycle almost all of the materials in the waste products from the previous century, thereby reducing the use of natural resources for manufacture of new products to near zero.

It cannot be denied that the twin titans of science and technology have given human beings the potential to destroy ourselves. But if we develop science and technology wisely, we can use them to create a sustainable environment supporting a comfortable lifestyle in a clean and beautiful planet that humanity can enjoy for generations to come. Therefore, we need to make the correct choices concerning the direction of technology, and these choices can be made and implemented only through the consensus of society. There has never been a time when a good relationship between society and technology has been more important.

The rest of the book is laid out as follows.

Chapter 1 explains the mechanisms by which the circulation system of the earth's biosphere has been sustained by the energy of the sun until now. In this chapter, we will examine the way in which human activities have been disrupting this circulation by considering the global life cycle of the basic materials used to produce human artifacts. Throughout, we will clarify the nature of the three potential world-wide catastrophes of "global warming," "fossil fuel depletion," and "massive generation of waste" – catastrophes that will occur if we continue to act as we have.

In **Chapter 2**, we will see the ways in which we consume energy for the two basic activities of "making things" and "daily life." We will need to study some of the subtle concepts of energy, particularly the law of conservation of energy, in order to explain why, despite the physical law that energy cannot be destroyed, the potential crisis of "depletion of energy" is real. Chapter 2 attempts to do this using non-scientific language and examples from everyday life. Finally, we will see how we can extend the lifetime of our current energy resources by increasing energy efficiency.

In **Chapter 3**, for each of the activities that contribute significantly to the consumption of energy by humanity, including manufacturing processes in "making things" and human activities in "daily life," we will see what the minimum amount of energy is that must be consumed in the ideal case. From these ideal energy consumption rates, we will estimate the minimum energy required for all of the people in the world to attain a living standard equal to that currently enjoyed by those in developed countries. This will give us a theoretical target for the reduction of energy use that can be attained through technology.

Chapter 4 compares the limits for energy consumption rates estimated in Chapter 3 with what is attainable by the current state of technology for human activities in "daily life." Specifically, we will examine the potential to improve the efficiency of automobiles as well as of energy-consuming appliances in homes and office buildings, such as air conditioners. Finally, we will take a look at the state of the art in technology for generating electric power in conventional thermal power plants and discuss what we can expect in the future.

Chapter 5 begins to lay out a path towards creation of a social infrastructure based on the recirculation of basic manufacturing materials by recycling. In particular, this chapter will demonstrate, both in theory and through analysis of the current situation in society, that using recycled materials for manufacturing is not only technologically possible but also economically sound because it will significantly reduce energy consumption.

Chapter 6 considers the types of energy resources that are potentially available for replacing non-renewable fossil fuels. This chapter will show us the current state worldwide in the use of renewable energy sources, such as solar cells, wind turbines, and geothermal energy generators, and it will outline possible future scenarios for implementing large-scale systems for generating energy, systems based on the most promising of the renewable energy sources.

Drawing together the discussions from the previous chapters, **Chapter 7** puts forth "Vision 2050" as a comprehensive roadmap for global sustainability that could realistically be achieved by 2050.

Chapter 8 looks at the synergistic relationship between society and technology that is needed to make the right decisions among the various choices for the future within the framework of Vision 2050. Several new approaches based on emerging technologies for helping to realize this synergy are introduced, focusing particularly on structuring expert scientific knowledge and sharing that knowledge in ways that are most beneficial and accessible to the people who can apply it towards the achievement of a sustainable human existence on the earth.

Contents

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 19th century, that concentration began to rise, and during the second half of the 20th 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 21st century. Actually, because the rate of increase itself is increasing, this doubling of the CO_2 concentration may occur even earlier.

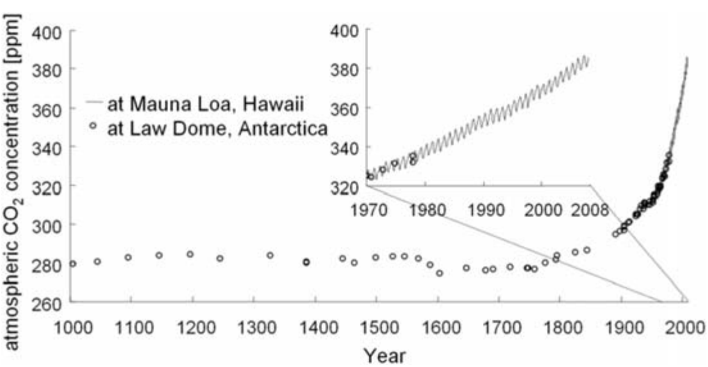

Fig. 1-1: Atmospheric CO_2 concentration from 1000 to 2008 (Data from National Oceanic and Atmospheric Administration: Dr. Pieter Tans, NOAA/ESRL and D.M. Etheridge et al., 2001, Law Dome Atmospheric CO_2 Data, 1GBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #2001-083. NOAA/NGDC 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 20^{th} century. The first graph shows the total human population on

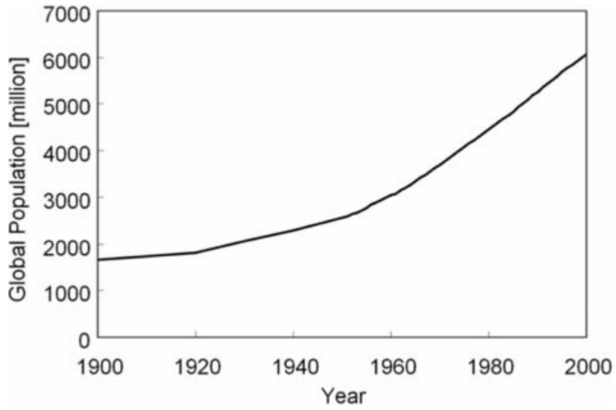

Fig. 1-2: Global population from 1900 to 2000 (Data from UN Common Database, United Nations Statistics Division)

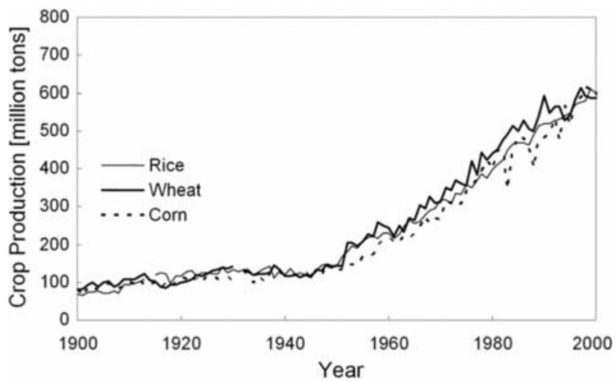

Fig. 1-3: Global production of the three major grains from 1900 to 2000 (Data from FAOSTAT database, Food and Agriculture Organization of the United Nations, the UN Common Database, United Nations Statistics Division, and B.R. Mitchell, International Historical Statistics, Palgrave Macmillan)

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