Chapter 7

How to Make a Sustainable Earth

In this chapter, we will summarize the ideas that we have introduced in the previous chapters and use them to develop "Vision 2050," a roadmap for achieving a sustainable human existence on the earth. In developing "Vision 2050," we will take a critical look at what the requirements will be for human society in 2050. Those requirements will give us the infrastructure necessary to support all humans on the earth in 2050. We will then see how we can achieve this necessary infrastructure through technology and well-coordinated development in both developed and developing countries.

To give a quantitative description of "Vision 2050," we will need to choose a base year for our discussion. We have chosen the year 1995 as the base year for "Vision 2050." We chose this year based on the availability of data as well as the milestone event that occurred in the late 1990's – the birth of the six billionth person on the planet. The first year of the millennium (or the last year of the previous millennium) may have been a more memorable choice. However, much of the dialog on attainment of a sustainable earth has centered on the Kyoto Protocol for CO_2 emissions reductions. The Kyoto Protocol, which we will look at next, takes 1990 as the base year. We have split the difference and used the year 1995.

1 The Significance of the Kyoto Protocol

The Inevitability of Global Warming

In December 1997, COP3 (the third session of the Conference of Parties to the United Nations Framework Convention on Climate Change) was held in Kyoto, Japan, and the Kyoto Protocol was adopted as an outline for reducing the emissions of CO_2, focusing in particular on the developed countries. The gist of the protocol was that, relative to 1990 levels, by 2010 Europe, the U.S. and Japan would reduce their emissions of CO_2 by 8%, 7% and 6% respectively.

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Vision 2050: Roadmap for a Sustainable Earth.

Many experts have expressed opposition to the Kyoto Protocol, claiming that "the reduction targets are too small," "flexible measures such as emissions trading will undermine the actual effect on emissions reduction," or "it will cause an adverse impact on global economic growth." So how valid are these criticisms? We have seen in Chapter 1 that the phenomenon of global warming is real, and that even if we could reduce emissions rates to those of 1990, global warming is likely to cause serious problems by the middle of the 21st century. Reducing CO_2 emissions in Europe, the U.S. and Japan by a small percentage is hardly enough to prevent the looming problems of global warming. The effectiveness of emissions trading also raises serious questions. Finally, depending on what mechanisms are used to implement the Kyoto Protocol, we cannot be sure that it will not adversely impact global economic growth.

However, there is no excuse for doing nothing. If measures for reducing CO_2 emissions are implemented in accord with the principles advocated in this book, the emissions reduction goals stipulated by the Kyoto Protocol could be achieved with at most only a small negative impact on economic growth. As a basic rule of thumb, we can consider reducing CO_2 emissions in the short term to mean reducing the use of energy. We saw in the previous chapters that there is still considerable potential for reducing energy use in both "making things" and "daily life." Moreover, in the long term these reductions will save money as well in both the manufacturing sector and the private sector.

In addition to making a small but concrete contribution towards mitigation of global warming, the Kyoto Protocol is a powerful symbol. Until now, human activity has traced a path focused only on expansion, and in response energy consumption has increased steadily. Thus the Kyoto Protocol is a milestone, marking a consensus among nations including the U.S. that we must make some changes to this headlong pace of expansion.

However, as we saw in figure 1-1, even after the Kyoto Protocol was agreed upon, the concentration of CO_2 in the atmosphere has continued to rise. It seems unlikely that even the moderate reduction stipulated by the agreement will be met by the deadline of 2010. If we continue in this way, we must face the possibility that a tremendous increase in global warming during the 21st century is inevitable.

A Gap Between the Developed World and the Developing World

The success of the Kyoto Protocol depended the stances taken by the U.S., the world's largest consumer of energy at the time, and by developing countries, whose demands for energy are predicted to constitute the bulk of increased energy consumption in the future. The U.S., which consumes one fourth of the world's energy, has made low energy prices a national strategy. The price of gasoline in the U.S. during the 1990's was about 30 cents per liter, and the price of electricity for industrial use was about 4 cents per kilowatt-hour. For comparison, in Japan, Korea and most of OECD Europe gasoline cost almost one dollar per liter, and in

Japan electricity cost more than 10 cents per kilowatt-hour. Through these low energy prices, the U.S. subsidized manufacturing and encouraged the use of automobiles. However, by bringing the U.S. into the discussion of how to reduce CO_2 emissions, participants in the Kyoto Conference, including Japan and Europe, hoped to pressure the U.S. into making reductions. Unfortunately, even though the White House was environment-friendly, U.S. leaders were not confident that the American people would support reducing energy consumption. Partly to avoid facing a heavy domestic backlash, the U.S. made their participation in the Kyoto Accords conditional on the inclusion of developing countries, where most of the future increase in CO_2 emissions is predicted to occur.

But the argument put forth by the developing countries was irrefutable. Of the total global CO_2 emissions, 75% are from the developed countries while the developing nations, home to 75% of the world's population, produce only 25% of the total CO_2 emissions. Clearly, the developing countries cannot be expected to take responsibility for current CO_2 emissions. Moreover, to increase their standard of living, developing nations must increase their consumption of energy in the future. Although this increased energy consumption will be accompanied by an unavoidable increase in CO_2 emissions, developing nations cannot be forced to maintain a standard of living below that of the developed world. And the inevitable increase in CO_2 emissions becomes even clearer when we consider the importance of continued economic growth in developing countries to the economies of the rest of the world.

According to the U.S. Department of Commerce website, on July 19, 1999, the human population of the earth reached 6 billion. As of the beginning of 2008, the population has become 6.6 billion. By 2025, the population is predicted to be almost 8 billion, and by 2050, about 9 billion. In Japan, Europe, and most of the other developed countries, national populations have peaked or are nearing their peaks. Therefore, most of the increase in the world population – an increase of 3 billion by 2050 – will occur in the developing countries.

As noted in Chapter 2, the current global population of more than 6.5 billion people consumes 7.5 billion tons of fossil fuel resources per year. Therefore, the global average fossil fuel consumption is slightly more than one ton per person. In comparison, the average amount of fossil fuels used per person in Japan, England, and Germany is about 2.7. In the U.S. the amount per person is over 5.5 – more than double the average of other developed countries. The average for Japan and the OECD countries of the EU is about 2.4, a value that is representative of developed countries other than the U.S. So if we assume that all 7.5 billion inhabitants predicted to be living in developing countries by 2050 will consume fossil fuels at this rate, the resulting fossil fuel consumption would be about 18 billion tons per year in the developing countries alone. Even if we assume that the consumption rate of 4.5 billion tons per year in the developed countries does not increase at all, the total global annual fossil fuel consumption rate in 2050 would be nearly 23 billion tons. This rate is almost four times the current rate of fossil fuel use, and about three times the total annual energy use today, including hydropower and nuclear power.

We have seen that the ratio of confirmed oil reserves to the current annual consumption rate is 40 years. If our consumption of oil grows by three or four times this rate, by 2050 almost all known reserves will be depleted.

So how about the other fossil fuels?

Hope, but Do Not Expect Too Much . . .

There are many opinions about the lifetime of energy resources. Coal is said to have about 150 years of reserves as of 2007, so some experts claim that there is no need for concern. However, the prediction of 150 years is calculated based on the current rate of coal consumption, which is now much lower than that of oil. If we assume that coal will replace oil when oil is depleted, the lifetime of coal reserves will, of course, become shorter. For example, if the four-fold increase in energy consumption that we have calculated here is covered entirely by coal, coal will be depleted in just a couple decades. And most important, we must not forget that CO_2 emissions from coal are 1.5 times greater per unit of energy than emissions from oil.

Many people have put their faith in natural gas as a replacement for oil. The main component of natural gas is methane. Methane hydrides – ice-like substances formed from mixing water and methane – are said to exist in large quantities in the ocean floors and in the frozen soil of Siberia. Although many deposits of methane hydrides have indeed been confirmed, there have been few studies on how much energy would be consumed in extracting and processing this substance into usable energy. However, there is no doubt that if we were to use methane extracted from an ice-like substance on the ocean floor, it would consume more energy than is currently used in mining coal or in retrieving oil and gas from offshore oil fields. In addition, methane is also one of the greenhouse gases targeted by the Kyoto Protocol, and, per unit mass, the greenhouse effects of methane are over 20 times larger than those of CO_2. There is a concern that methane could be released into the atmosphere when methane hydrides are extracted, contributing further to the global warming effect.

Finally, there are unverified claims that a form of methane exists which is not the product of fossilization. The claim is that deep underground, inexhaustible pockets of methane exist that were produced directly from water and CO_2 long ago. It has been shown in laboratory experiments that if water and CO_2 coexist in the presence of some metal such as iron, then – under conditions of great heat and pressure – methane can form. So it is possible that these reservoirs of methane exist. However, there is as yet no proof of such reservoirs, nor have any been discovered in the several experimental drillings that have been carried out. It would be foolish to gamble the future of the human race on the chance that this theory will pan out.

We must assume that not just oil but all fossil fuel resources will be scarce by around 2050. And we must honor the agreement made in Kyoto, not only because it is an international agreement but also because it is a necessary first step towards planning the further reduction of CO_2 emissions and fossil fuel consumption into the future. Indications of global warming, oil depletion, and massive of waste are already apparent. We cannot deny the possibility that we are heading towards a potential catastrophe in the middle of the 21st century.

2 Vision 2050: A New Road to a Sustainable Earth

Three Preconditions

Okay, let's try to find a road out of this catastrophic situation. We will call this road "Vision 2050." But first we must set a few preconditions for our journey.

The first precondition is that developing countries must be guaranteed the right to modernize. No one in the developed world could convincingly argue that the citizens of developing countries should maintain their current living standards. While some might argue that people in developing countries are being seduced into adopting a modern civilization that consumes large amounts of energy, this argument is hardly persuasive when put forth by those enjoying a life of luxury to consign others to a life of poverty.

The second precondition is that the energy conservation required to achieve Vision 2050 cannot be based on unrealistic expectations of people making radical shifts in their lifestyles. The energy conservation needed to achieve Vision 2050 can be divided roughly into energy savings from changes in lifestyle and savings from increased efficiency through improved technologies. In Chapters 3 and 4, we have looked at potentials for savings through improved technology. However, it is more common for a discussion of energy conservation to begin by recommending changes in lifestyle. Although the primary goal of this book has been to show the potential for technologies to help us to achieve a sustainable earth, let's now consider briefly the potential savings from changes in lifestyle.

Many people today feel that there is something wrong with the societies that have developed in the last century – societies that encourage consumption. Is it really necessary to blast the air conditioner in the summer? Is it really sensible for stores to give us so many plastic bags, which we eventually throw away? Many people feel in their hearts that major lifestyle changes are necessary. And energy savings through lifestyle changes would, of course, help reduce energy consumption. For example, a 10% savings of energy through lifestyle changes would reduce energy consumption by 10% and thereby reduce the use of fossil fuels and CO_2 emissions by approximately 10%.

Another important lifestyle change would be to cut down on waste. We should be able to establish agreements among manufacturers, distributors, retailers, and consumers to cut back on excessive packaging and wasteful copying. If we are committed to conserving energy, we might begin using both sides of paper. We might prohibit driving cars for personal use in city centers. Such strategies for reducing energy consumption are within the realm of possibility, and in Vision 2050 we assume that there will be a contribution to savings from these lifestyle changes. However, it is dangerous to rely too much on the effect of these changes. We have seen that the increased energy consumption that will occur in the developing world may exceed three times the current energy use. It is unrealistic to expect that sustainability can be achieved through energy savings alone. We need to complement efforts to save energy through lifestyle changes with ways to increase the efficiency of energy consumption in both "making things" and "daily life" through technology.

The third precondition is that, as we saw in Chapter 6, the likelihood that we will succeed in replacing fossil fuels with renewable energy by 2050 is, unfortunately, almost zero. Many people have high expectations for renewable energy. However, aside from hydropower and the use of wood for fuel in developing countries, the contribution of renewable energy to total energy today is 1% – not nearly enough to form the basis for large-scale dependence on renewable energy by 2050. The problem is that it is difficult to engineer a system that can transform an energy source that is thinly spread out and variable over time into convenient forms of energy such as electricity and vehicle fuels that can be used whenever we want. So we must face the fact by 2050, we will still be somewhat dependent on fossil fuels.

The Basic Concepts

Figure 7-1 shows the levels of energy use for several scenarios. The situation in the base year, 1995, is shown as scenario (a). In 1995, the equivalent in carbon units of about 7.5 billion tons of energy resources was consumed. This includes 6 billion tons of fossil fuels plus 1.5 billion tons of non-fossil fuel energy sources, mainly wood, hydropower, and nuclear power. In the top figure for scenario (a), the dark part represents the 6 billion tons of fossil fuels, and the light part shows the contribution from the non-fossil fuel sources.

We saw earlier that the 75% of the world's population living in developing countries, 4.5 billion people, consume just 25% of the total fossil fuel energy resources: 1.5 billion tons. As a rough estimate, we will consider that half of the total non-fossil fuel energy, about 0.75 billion tons carbon equivalent, is used in the developing countries (mainly biomass and hydropower) and the other half is used in the developed countries (mainly hydropower and nuclear power). Therefore, the 1.5 billion people in the developed world consume about 5.25 billion tons of energy resources and the 4.5 billion people in the developing world consume about 2.25 billion tons of energy resources. This results in an average energy use per person of 3.5 in developed countries and 0.4 in developing countries. The average use of fossil fuels per person is 3.0 in developed countries and 0.3 in developing countries. In the bottom figure for scenario (a), the hatched part

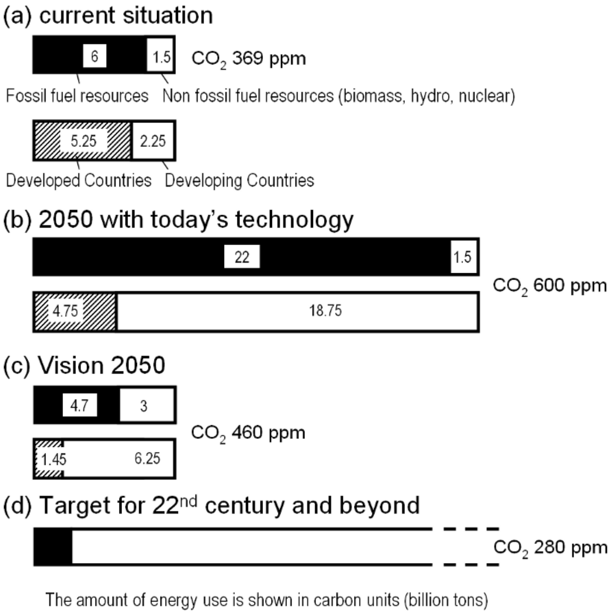

Fig. 7-1: Energy scenarios and CO_2 concentrations
Note: for each scenario, the top figure shows the distribution of energy consumption between fossil and non-fossil energy resources, and the bottom figure shows the distribution of energy consumption between developed and developing countries.

represents the 5.25 billion tons of energy resources in carbon units used by developed countries, and the light part shows the 2.25 billion tons of energy resources used by developing countries.

If in 2050, the 7.5 billion people predicted to be living in the developing countries have reached energy consumption rates equal to those of the developed countries today (excluding the U.S.), then we have seen that about 18 billion tons of fossil fuels will be necessary to meet the demands of those countries. We will assume that the amount of non-fossil fuel energy used in 2050 will be the same as it is today. As a result, the energy use per person in the developing countries will be about 2.5, which is considerably less than the current average for developed countries of 3.3. If the energy consumption of the developed countries remains the same as it was in 1995 – the equivalent of 5.25 billion tons of fossil fuels – and if the demand for energy in developing countries rises to 18 billion tons of fossil fuels plus the 0.75 billion tons of non-fossil fuel energy used today, then the total consumption of energy per year on the planet will be 24 billion tons of fossil fuel equivalent. Even if the people in the developed world were to reduce their fossil fuel consumption from the current average of 3 tons per person to the OECD Europe average of 2.4 tons per person through intensive energy savings efforts, they would still consume about 4 billion tons of fossil fuels, giving a total fossil fuel consumption of 22 billion tons per year and a total energy consumption of about 23.5 billion tons per year. This is over three times the amount of energy used today and is represented in the figure as scenario (b).

We have seen that when we use energy for some purpose or function, the energy efficiency differs remarkably depending on the technology. For example, driving a car for a distance of 10 km requires a different amount of energy depending on whether the car is powered by a normal combustion engine, a hybrid engine, or a fuel cell engine. If efficiency is increased, the same function of driving 10 km can be performed with that much less energy. The 23.5 billion tons in scenario (b) is the projected energy consumption in 2050 based on today's technologies and social institutions. If we can significantly increase energy efficiency, we can perform the same functions with less energy. Even if our need for energy-based functions triples by 2050, if the energy efficiency in performing these functions also triples, we can sustain the increased demand for the function while keeping energy consumption at the 1995 level.

However, even if we could keep the amount of energy consumption worldwide at the level in 1995, if we continue to rely on fossil fuels as the source of that energy, the problems of global warming and the depletion of fossil fuel reserves will remain unsolved. To address these problems, we need to bring into play as much renewable energy as possible by 2050. If we could develop an amount of renewable energy equal to the total amount of non-fossil fuel energy used today, about 1.5 billion tons carbon equivalent, then the amount of fossil fuel consumed each year could be reduced to 4.7 billion tons, which is just a little more than three quarters what it is was in 1995.

Scenario (c) in figure 7-1 shows the basic concept of Vision 2050. First, although the total energy-related functions required in the world will increase to three times that of the base year of 1995 shown in scenario (a), mainly due to the modernization in developing countries whose total population will increase from 4.5 to 7.5 billion, we will triple the efficiency of energy consumption for meeting this requirement. As a result, the actual energy consumed per person will be less than 1 ton carbon equivalent per person in both developed and developing countries, and the total energy consumption will remain almost the same as it is today. Second, by introducing an amount of renewable energy equivalent to the total amount of non-fossil fuel energy currently produced, the use of fossil fuels will be reduced to almost three quarters of what it was in 1995.

Scenario (d) depicts a situation for the 22nd century where only a tiny amount of fossil fuels is used together with far more renewable energy than is shown even in scenario (c). By following the road that is laid out in Vision 2050, we can make this scenario a reality by continuing to reduce fossil fuel consumption and to increase the use of renewable energy through the second half of the 21st century.

Figure 7-2 shows another way of looking at the three main scenarios in figure 7-1. In Chapter 1, we introduced an equation for the sustainability of human existence on the earth, where the impact of humans on the earth equals the product of the human population, the affluence of that population as measured by the functions of products and services consumed per person, and the impact on the earth of providing one unit of function, such as the energy resources consumed.

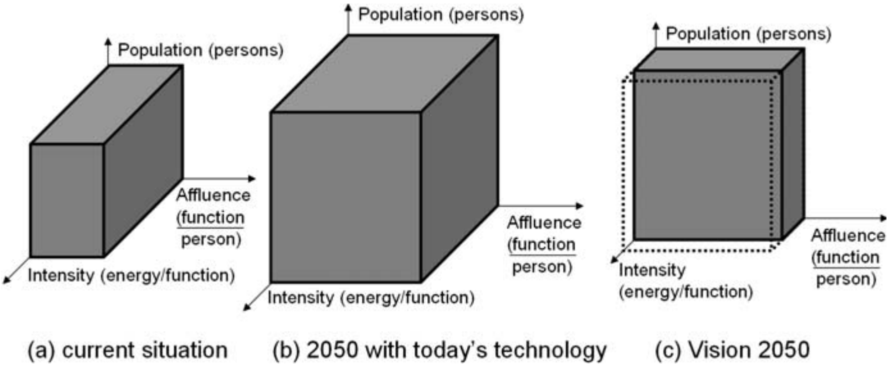

Fig. 7-2: Human impact on the earth for three scenarios

In figure 7-2, we show scenarios (a), (b), and (c) as three dimensional boxes whose volumes represent the impact of human civilization on the earth. In scenario (a), the population is lower and the affluence is smaller, mainly because of the low standard of living in developing countries. But the intensity, which is the inverse of energy efficiency, is high, so the overall impact on the earth is fairly large. In scenarios (b) and (c), population has increased about 50%, and affluence has almost doubled. The difference is that while the intensity in scenario (b) is the same as in scenario (a), it is one third in scenario (c). In fact, the volume of the box extending out to the dotted line in scenario (c) is almost the same as the volume of the box in scenario (a). Furthermore, when we consider the introduction of non-fossil fuel energy resources under Vision 2050, the actual impact on the earth in terms of fossil fuel resource consumption is just the volume of the grey box in scenario (c). This is another way of looking at Vision 2050.

A Crossroads

The increase in the concentration of CO_2 in the atmosphere is approximately proportional to the rate of emission of CO_2 by human activity. And currently, the concentration of CO_2 in the atmosphere is increasing at an annual rate of 2 ppm. So if we continue to emit CO_2 at the current rate, in fifty years – even without considering the population growth and economic growth in developing countries – the increase would be more than 100 ppm. Therefore, by 2050, the concentration of CO_2 in the atmosphere will rise from the 1995 value of 369 ppm to more than 469 ppm.

Let's use this approximation to estimate the CO_2 concentration in scenario (b) from figure 7-1. If we assume that the annual rate of fossil fuel consumption will increase linearly from 6 billion tons in 1995 to about 22 billion tons in 2050, a simple calculation shows that the concentration will reach about 600 ppm. This value far exceeds a doubling of pre-industrial levels. On the other hand, in the case of scenario (c) – where the rate of consumption of fossil fuels in 2050 is three quarters what it was in 1995 – the concentration will be 460 ppm. While considerably less than the 600 ppm of scenario (b), this is still a huge increase from the value of 369 ppm in 1995. Must we really accept this as the lowest level that we can hope to achieve? In fact, this value is only slightly less than the 469 ppm that would result if we continued with the current situation. It may seem like we will have done little to improve the situation. Remember, though, that per capita consumption of fossil fuels in 2050 will be reduced to 75% of the rate in 1995, so the rate at which the CO_2 concentration in the atmosphere increases after 2050 will be reduced proportionally.

At that point, if we can move to scenario (d), we will be able to slow the increase of CO_2 concentration even further, and eventually it will begin to decrease as CO_2 in the atmosphere is absorbed by the ocean. Therefore, although it is probably impossible to completely avoid global warming from the increase of CO_2 concentration in the atmosphere, if we can achieve Vision 2050, we will have paved the way for reducing CO_2 emissions in the future thereby reaching a stable atmospheric CO_2 concentration and an end to increased global warming by the 22nd century.

Obviously, an important factor in the future of the earth is the increase in the human population. However, as income levels in developing countries increase to match those in developed nations, population growth is predicted to decelerate. This relationship between income level and population growth has been confirmed by experience. So if, by 2050, the 7.5 billion people living in developing countries reach a standard of living comparable to that in developed countries today, the world's population should start to decline.

When our descendents look back on the history of this century, they will surely see the year 2050 as a milestone. Will a lifestyle of mass production and mass consumption spread to developing countries, causing energy consumption to exceed three times that of today? Will waste materials cover the surface of the earth? Will the concentration of CO_2 in the atmosphere increase to more than double its pre-industrial value? Or will we – through recycling our waste materials, tripling our energy efficiency, and doubling our use of renewable energy together with making moderate changes to our lifestyle – be successful in creating a path to a sustainable human community by the 22nd century? The crossroads that lies before us will determine upon which road this milestone will be laid.

3 Making Vision 2050 a Reality

Vision 2050 has three main parts: a three-fold increase in energy efficiency, a two-fold increase in use of renewable energy, and conversion to a system of material recycling. Now let's see how it will be possible to meet these conditions by 2050.

(1) A Three-fold Increase in Energy Use Efficiency

Reduce Energy Used in Transport, Homes and Offices to One Fourth

First, we can reduce gasoline used by cars to one-fourth what it was in 1995. We have already seen that we can cut energy consumption 75% by reducing a vehicle's weight and using hybrid engines, so doing that would be enough. In fact, as of 2007, new hybrid vehicles on the road have already cut energy consumption by about 50% compared to automobiles in 1995. Alternatively, we could combine these technologies with ways to reduce friction such as designing new kinds of tires. Or perhaps we could use fuel cells as a power source. What ever combination we use, reducing energy consumption for passenger cars to one fourth by 2050 should be an achievable target. And the same improvements in efficiency can be achieved for other vehicles, such as buses and trucks. If we take the average life of vehicles to be ten years, by 2050 the fourth generation of automobiles will be rolling off the production line. Consequently, it should be well within the realm of possibility to convert just about all of the vehicles in operation to this level of fuel efficiency by 2050.

We can effect a similar improvement in the energy efficiency of homes and offices. The main form of energy consumed here is electrical. Looking back to the data that we discussed on the use of energy in Japan, even if we consider that the average efficiency for thermal power plants in Japan today is 43% (using the high heating value), still fully two thirds of total energy resources consumed in Japan through "daily life" activities in offices and homes is used as electricity. Furthermore, the fraction of total energy consumed as electricity is increasing each year, so we can estimate that by 2050 around 80% of the total energy resources used in homes and offices will be used as electricity. Therefore, when we look at the possibilities for energy conservation in "daily life" activities at homes and offices, it will be reasonable to assume that all of this energy comes from electricity.

We could triple the efficiency of air conditioners and other heat pumps by increasing the efficiency of compressors and decreasing the temperature difference in heat transfer. With additional measures such as increasing insulation in houses, we could increase the overall efficiency of heating and cooling by five times. Refrigerators are also heat pumps. Although some loss of efficiency, such as that from opening and closing the refrigerator, is unavoidable, we should be able to increase their efficiencies as well. In fact, during the period from 1995 to 2005, through advances in vacuum insulation and technologies for reducing energy loss when opening the refrigerator by using sensors and compartmenting the space with multiple doors, energy efficiency of refrigerators has tripled already. For lighting, we could develop light-emitting devices with twice the efficiency of fluorescent light bulbs. Then by reducing the proportion of highly wasteful incandescent bulbs, we could triple the efficiency of lighting homes and offices. Although the size of televisions will probably continue to increase, through the use of low-energy technologies such as LCD displays and semi-conductors, we could double the efficiency of televisions. Energy conservation for other appliances such as vacuum cleaners, rice cookers, and microwave ovens may be more difficult, but because these are in use for relatively short periods of time, the total energy they consume is not so large.

If all these improvements in efficiency were effected in homes and offices, we could reasonably expect to reduce energy consumption by up to 60% of 1995 levels.

Working from the other side, we can reduce the amount of fossil fuel consumed per unit of electricity that is used by these devices by improving the efficiency of power plants in generating electricity. In Vision 2050, we will set our goal to reduce fossil fuel consumption in this way by one third. We could achieve this by increasing our efficiency in generating electricity from the 1995 level of 38% to a level of 57% in 2050. Although the lifespan of electric power plants is long, we can assume that by 2050, all but the newest plants will have been replaced. Already, combined cycle power plants exist with efficiencies of 53%. If the top power plants in 2050 achieve efficiencies of 65% and if the most advanced power plants existing today with efficiencies of around 50% to 53% are the oldest plants remaining in 2050, that will raise the average efficiency to 57%. Note that as in the previous chapters, these thermal power plant efficiencies are all in terms of the higher-heating values.

Another possibility for increasing efficiency is that distributed electric power systems will become widespread. For example, by 2050, fuel cells may be available with a conversion efficiency of fuel to electricity of about 50%. Because fuel cells also generate usable heat, they can be used for co-generation of heat and power in individual buildings. Alternatively, other technologies for generating electricity on a small scale, such as combinations of small-scale gas turbines and steam turbines, might be developed to create highly efficient co-generation systems. When the value of the useful heat is converted to electricity and added to the total system output, it might be possible using such co-generative systems to achieve an overall efficiency equivalent to an electric power generation efficiency of 57%.

If we combine the effects of reducing energy consumption by 60% (through increased efficiency of appliances) with the effects of reducing fossil fuel consumption by 33% (through increased efficiency in generating electricity), we see that the consumption of fossil fuels for electricity supplied to homes and office buildings can indeed be reduced to $(1 - 0.6) \times (1 - 0.33)$, or about 25% of today's consumption rate.

Reduce Energy for Material Production to One Third

We can reduce the energy consumed in producing materials, particularly metals, through a combination of recycling, developing new technologies, and transferring technology. First, we can cut energy consumption by expanding the recycling of the different kinds of materials we use. If the current rate of producing goods from natural resources were to continue unabated, by 2050 we would reach the point where future production of all of the most important basic materials could be carried out through the use of scrap. However, in fact the proportion of products made from natural resources will decrease as the accumulation of human artifacts increases and recycling is expanded. Therefore, we probably will not reach the point of complete saturation by 2050.

Let's suppose that by 2050 scrap will constitute 80% of the material used in creating new products. By producing 80% of iron from recycled metal instead of iron ore and by melting the recycled metal in furnaces heated by fossil fuel instead of electricity, we could reduce energy consumption per unit of iron produced to one third that in 1995. Even now, aluminum can be produced from recycled materials using only one tenth the energy required in production from natural bauxite. So even if the efficiency of aluminum recycling does not improve at all, at the point where 80% of aluminum is recycled, the total energy consumed in production will decrease to about one fourth what it was in 1995.

Under Vision 2050, we will also, whenever possible, recycle materials other than metal, such as concrete, glass, plastic, and paper. The waste plastic and paper that have deteriorated too much for recycling can be reused as fuel for producing electricity. Recycling these materials will consume less energy than production from natural resources, though the savings will be smaller than in the case of metal. Still, through recycling, we should be able to reduce the energy consumed in production of non-metal goods to 80% of the levels in 1995.

By estimating the relative quantities of metal and non-metal goods that will be produced in 2050, we project that through these increases in the rate of recycling of basic materials, we could reduce the energy used in production of goods to 70% of the energy used in 1995.

The second way to reduce energy consumed in the production of basic materials is to improve technologies for manufacturing both from natural resources and recycled materials. Improving the efficiency of today's most advanced technologies by 30% is a reasonable target, and achieving that would reduce the energy consumed in manufacturing to 70% of what it is today.

Differences in Energy Efficiencies Among Countries

The third way in which we can reduce the energy consumed in production of basic materials is by transferring technologies from countries having the most advanced production processes to countries using old energy-wasting technologies. We will see here that the effects of technology transfer are both large and reliable.

Until this point, the numbers and graphs in this book showing the efficiencies of "making things" and of generating electricity with fossil-fuel fired power plants have been mainly for technologies in Japan. While this is in part because it has been easier for me to get information on technologies from my home country of Japan, it is also the case that many of the technologies in Japan are the most energy-efficient in the world. Thus using the figures from Japan has given me a chance to introduce examples of the highest levels of energy efficiency. The amount of energy consumed in production varies greatly, depending on the country in which the

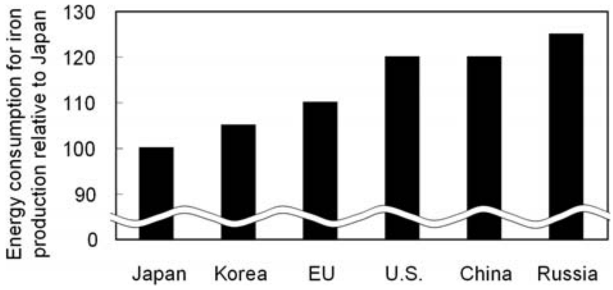

Fig. 7-3: Comparison of unit energy consumption rates of iron production in major iron producing countries relative to Japan (Courtesy of Japan Iron and Steel Federation)

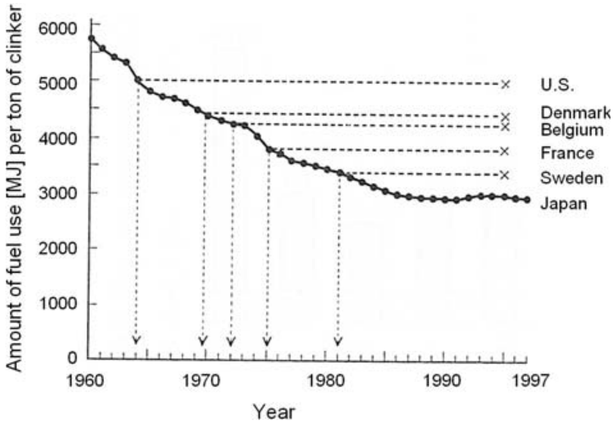

Fig. 7-4: Unit energy consumption rates for the Japanese cement industry from 1960 to 1997 and the positions of various countries in 1995 (Courtesy of Japan Cement Association)

goods are made. For example, in figure 7-3, we see that the energy consumed in making one ton of steel from iron ore varies as much as 25% – from Japan, with the highest efficiency, to countries with lower efficiency, such as China, Russia, and even the U.S.

Figure 7-4 shows a graph of how the amount of energy consumed in Japan to make one ton of cement changed from 1960 to 1995. The graph also shows comparisons with the energy efficiencies for cement making in other countries. Between 1960 and 1995, the energy consumed in making one ton of cement in Japan dropped by half. In comparison to Japan, most other countries used a much greater quantity of energy in 1995 to produce one ton of cement. The U.S., in particular, stands out – using 1.7 times more than Japan did at the time the graph was compiled. Thus the energy efficiency of 1995 U.S. technology in making cement corresponds to that of Japan in 1964.

This difference in energy consumption is a simple reflection of the rate at which each country has introduced new technologies to conserve energy. In the case of cement, the difference shows to what extent energy-saving technologies such as "suspension preheating" and more recently "new suspension preheating" have been introduced. These technologies thoroughly recover heat when coal is burned at high temperature, using the high-temperature gas emitted from the calcination furnace to preheat the powdered coal fed into the furnace. The term "suspension" comes from the way that the coal powder is suspended in the air by the high-temperature gas coming from below when the heat is recovered. In 1995, 87% of plants making cement in Japan used "new suspension" technology, and the remaining plants were all equipped with "suspension" technology. In the U.S., the number of plants using either technology was almost zero.

Just by introducing technologies of "suspension preheating" or "new suspension preheating" – already in use in Japan – to cement-making in the U.S. and the EU, we could conserve energy. And the investment capital for such a retooling could be recovered within a few years. The only reason these technologies have not been introduced already is the current unfavorable relationship between investment and return in many countries.

Not only is it possible to cut energy use through technology transfer, but doing so yields higher investment efficiency when considered at a global level. All that is necessary for benefiting from technology transfer is to come up with the capital needed to retrofit existing plants for the new technologies. However, improving cutting-edge technologies requires large investments in research and development. And because when we develop technologies for reducing the emissions we tackle first those emissions that are easiest to control, the return on investment in such research will inevitably decrease over time. Though there is still some potential for improving technology to increase energy efficiency in the production of basic materials and goods, the gaps between today's most advanced technologies in production and the theoretical limits are not as great as is the potential for improving the efficiency of transportation, homes, and offices.

In some countries today, the use of energy is particularly inefficient. In the countries of the former Soviet Union, for example, despite a much lower standard of living, the amount of energy consumed per capita is about the same as in Japan. Consequently, by improving technology, those countries should be able to achieve the same standard of living now enjoyed in developed countries without increasing current energy consumption at all.

By bringing energy efficiency world-wide up to the level of the most advanced current technologies, we could reduce energy consumption by as much as 30%, thereby reducing the energy required to "make things" to 70% of current levels.

If we combine the effects of the three ways for reducing energy consumption in production of materials – recycling, improving technology, and transferring technology – you can see that it would be possible to reduce the amount of energy consumed in producing material goods to $0.7 \times 0.7 \times 0.7$, or about one third.

In summary, in Vision 2050 we will cut energy consumed in transportation to one quarter of current levels, energy consumed in homes and offices to one quarter of current levels, energy consumed in “making things” to one third, and energy used in other industrial sectors – such as construction, home appliances, and heavy machinery – to one half. When the relative amounts of energy used in each of these sectors are taken into account, the resulting savings would mean that we would be using less than a third of the energy we are consuming today. In other words, by doing the things outlined above, we could – as stipulated by Vision 2050 – triple the efficiency of energy use.

The Potential for Energy Reduction

You may have noticed that the reduction goal for transportation and maintaining homes and offices is considerably larger than that for “making things.” Furthermore, in reaching the reduction goals in “making things,” the savings that we have projected will come through improvements in technology is just 30%, with the remaining savings to come from recycling and technology transfer.

The theoretical potentials for reducing energy in making steel and in driving automobiles are different. As demonstrated in Chapter 5, in making iron from iron ore, we must use energy to displace the oxygen atoms bound to the iron in iron ore. Currently, this energy is equivalent to one third of the total energy used by an iron mill. We can consider this energy to be internal energy “embodied” in the pig iron produced, or to put it differently, the pig iron produced by the iron mill inherently contains energy equivalent to 200 kg of the 600 kg of fossil fuels that are currently used to produce one ton of iron. Only the remaining two thirds of the energy is “lost” in the process, and so the reduction potential in the making of iron is just 400 kg of fossil fuel per ton of iron.

We saw in Chapter 3 that the theoretical minimum energy needed for transportation is zero. This means that the reduction potential for driving automobiles is the entire amount of fuel used. Therefore, it is clear that the reduction potential for transportation is much greater than the reduction potential in the production of iron.

In addition, energy constitutes a smaller fraction of the total cost of “making things” than it does for transportation or running homes and offices. Here’s why: until now there has not been a strong demand for energy efficiency in products such as refrigerators, air conditioners, and cars. Instead, design and performance have been more important in giving a competitive edge to such products. The cost of electricity for a typical household, on the order of $1,000 per year, has not been a strong stimulus for energy conservation.

On the other hand, consumer preferences are not an issue in the design of processes for “making things.” The consumer is usually not interested in or concerned about the process used to produce the iron used in a car as long as the performance of the car is not affected. Therefore, controlling energy costs (along with improving efficiency in converting raw materials into products) has long been a large factor in reducing the cost of manufacturing products. For this reason, manufacturing companies have invested heavily in R&D and facility improvements, striving to increase energy efficiency in order to maintain their competitive edge.

In summary, Vision 2050 places a higher expectation on energy conservation in "daily life" activities such as transportation and running homes for the two reasons: 1) the gap between the present energy use and the theoretical limit is larger in the case of "daily life" activities, affording more opportunities for conservation, and 2) most efforts at energy conservation until now have been in the arena of "making things," which means that the yield on efforts for further energy conservation are likely to be minimal.

(2) Construction of a Material-Recycling System

Metal and Concrete

In 2050, we will probably still not have made a complete conversion from fossil fuels to renewable energy, and human artifacts will probably not have reached a state of complete saturation. However, by 2050 we need to create a launching platform that aims us in the direction of an ultimate state of complete conversion from fossil fuels and saturation of human artifacts by the end of the next century.

Let us take a look at the lifecycle of iron in Vision 2050. As the accumulated iron nears saturation, the amount of iron ore that is reduced will decrease, so the total amount of iron accumulation of 35 billion tons, which might have occurred if the present rate of production of 900 million tons per year from iron ore were continued unabated, will not be reached. The amount of iron accumulated by 2050 is predicted to be about 30 billion tons. If the average product life is the same 30 years that it is today, then one billion tons of scrap will be generated each year. We will use this scrap, minus a small amount of waste that is thrown away in garbage dumps, together with 200 million tons of iron ore as raw material for new iron. Thus, the world will produce 1.2 billion tons of iron per year in 2050, but 85% will come from scrap. Let us consider that in 2050 the global average consumption of coal per ton of iron will be 500 kg in the case of iron made in blast furnaces due to advances in technology that reduce coal consumption by 100 kg, and 150 kg in the case of production from scrap. The total coal consumption for iron production will then be about 250 million tons per year. Even though the amount of production will have not changed, the amount of coal consumption will become almost one third the present amount, which as we saw in figure 1-6 is about 700 million tons per year. This is a concrete example of the effect of the three-fold increase in energy efficiency for iron production due to recycling, technology transfer, and technology development that we discussed in the previous section.

After the quantity of iron accumulated in the cities, roads, and other durable products has reached about 39 billion tons, there will be enough scrap generated each year so that all of the iron that is needed can be produced from scrap. Furthermore, when all fossil fuel use is completely replaced by renewable energy sources, all of the energy for producing the iron from scrap will be supplied by renewable resources. This is the ultimate form of the lifecycle of iron that we should aim to realize in the 22nd century. Vision 2050 is different from this ultimate form, but compared to the present, it is much closer. The differences are that there is still some need for extraction of iron ore and fossil fuels, and also a part of the waste iron still winds up in garbage dumps. In fact, there will always be a fraction of waste generated that is useless scrap, unfit even for recycling. The next chapter will take a look at how we will treat this small amount of waste material that is not recycled in even Vision 2050.

Next, let us consider the lifecycle of concrete. Although waste concrete, produced for instance from the demolition of buildings, is currently used in low-grade applications such as road paving materials, we have see that as the amount of waste material grows, the fraction that is thrown away in garbage dumps will increase. In 2050, it is predicted that, like iron, the accumulation of concrete will reach three to five times the current amount, and the amount of waste concrete will grow in proportion. In fact, from 1995 to 2007 the worldwide production of concrete has nearly doubled, mainly due to increased output in China. To prevent the earth from being buried in waste concrete, it is necessary to construct a nearly perfect recycling system for concrete. One way would be to develop a technology for the regenerative pulverization of concrete, where waste concrete is pulverized into a sufficiently fine power so that the raw material for making cement can be recovered.

Paper and Plastic

Compared to iron and concrete, materials such as paper and plastic, which are used in artifacts with much shorter product lives, will saturate at smaller accumulation amounts. Therefore, for these materials it should be possible to arrive at a condition close to the ultimate recycling society even by 2050.

Today, already about half of the paper that is used is recycled, and most of the remainder is thrown away in garbage dumps where it is eventually released to the atmosphere as CO_2. In 2050, by increasing the recycle ratio, two thirds of used paper will be fed as raw material into the process of making new paper, and the remaining one third will be used as fuel. We will need to harvest a sufficient amount of trees to replace the one third of the waste paper that is used as fuel in order to maintain the annual production rate of paper, and we will replant trees at the same rate that they are harvested. We will develop paper manufacturing technologies by 2050 that make it possible to produce a ton of paper with just 200 kg of carbon – a 70% improvement over the present technology level. One third of the used paper will be used as fuel in papermaking, and by converting to carbon units, we find that this is exactly enough energy to produce new paper from the other two thirds of the used paper. Looking at this lifecycle of paper as a whole, we see that forests are being replanted and there is no consumption of fossil fuels, so the CO_2 concentration will not be increased. This is an example of a perfect recycling lifecycle.

The future state of technologies for manufacturing chemical products, as represented by plastic, is difficult to predict. Although currently almost all plastics are produced from oil, as long as there is a source of carbon and hydrogen, it is possible to synthesize plastic from raw materials other than the oil. One possible alternative to oil as the raw material for making plastics is biomass. For example, the process of making various chemical products from carbon monoxide and hydrogen synthesized with biomass as the raw material, called C1 chemistry from the fact that carbon monoxide is a feedstock with one atom of carbon, is technologically feasible even today. Also, researchers are developing ways for growing plants that produce the raw materials for plastics through biotechnology.

In all likelihood, society will continue to require a broad range of high performance chemical products. We must construct a system to supply society with materials that can meet these requirements, that can stand up to recycling, that have excellent combustion efficiency when they reach the end of their life cycle and are used as fuel, and that present no threat of releasing toxic substances such as dioxins or endocrine disruptors throughout their entire lifecycle.

In summary, each of the major basic materials – metals, ceramic materials, paper, and plastic – show Vision 2050 lifecycles with their own special characteristics. However, in comparison to the present, each of the lifecycles we have seen here contributes to the reduction of the factors that are interfering with the circulations in the biosphere – the amount of CO_2 emissions, the amount of waste material disposed in landfills, and the amount of underground resources that are extracted – and therefore each one can form a part of a sound intermediate stage towards the ultimate goal of a perfect recycling society.

(3) Development of Renewable Energy

Aim to Double the Present Amount

As shown in figure 7-1, in Vision 2050, we will reduce the use of fossil fuels to three quarters of what it is today. This reduction is absolutely necessary in order to control global warming from CO_2. In order to achieve this reduction while still providing the same amount of energy as today, we will introduce a supply of energy equivalent to one fourth of the current consumption of fossil fuels through the development of renewable energy. Because the renewable energy resources that we introduce will not emit any CO_2, CO_2 emissions will be reduced by the amount of renewable energy that is introduced: that is by 25%.

Hydropower already supplies 5% of the global energy demand. The conversion efficiency to electricity for hydropower is high, so as long as we take care not to cause other environmental problems such as the submersion of large regions of land, as an energy resource it is ideal. Consequently, in Vision 2050 we will develop new hydropower at a scale similar to the present. We will develop applications with electric power demand for that hydropower such as aluminum production close by the hydropower plants, and we will also locate hydropower plants so as best to meet to the increase in electric power demand in developing countries. The development of hydropower in Iceland as a source of power for aluminum production could be a good model for this process.

Another important issue that is related to material circulation is the problem of what to do with the biomass that is currently being thrown away. Used paper is one example that we have already looked at, but other kinds of biomass are also thrown away in large amounts. In fields where the autumn harvest has been finished, we sometimes come across the picturesque view of straw being burned in the fields; however, this is essentially just the same as "burning oil fields." It has been estimated through conversion to carbon units that about two billion tons of unused residual biomass is generated from agriculture and forestry worldwide. Even if we are only able to utilize half of this biomass effectively, we could still substitute for the equivalent of one billion tons of fossil fuels.

If we construct an efficient and effective collection and reuse system for municipal waste, which is something that we need now anyway, or for residual materials from agriculture and forestry, which we have seen could be a large resource, such a system would be usable almost immediately. Also, we could create biomass energy plantations using available land such as fields that are lying fallow, to develop another 900 million tons of biomass production, or 15% of the fossil fuel consumption in 1995. Of course we must be careful not to reduce the world production capacity of food grains, and having a shared vision such as Vision 2050 should help us to do that, by making the tradeoffs involved in each choice clear to all people concerned.

It should be possible to develop enough solar power to produce electricity equivalent to 200 million tons of fossil fuels, or 3% of the 1995 fossil fuel consumption. We could also pursue the development of wind power and geothermal power, taking care not to cause other environmental problems. In Vision 2050 we will act to advance the development of all kinds of renewable energy by mapping out the improvement of energy technologies through scientific research and by building up a manufacturing infrastructure for enabling these technologies to spread throughout society.

Summarizing the above, we will aim to achieve the new development of hydropower equivalent to 5% of the current fossil fuel consumption, biomass such as agricultural and forestry residuals and municipal waste equivalent to 15%, solar cells equivalent to 3%, and the equivalent of about 2% of current fossil fuel consumption from other renewable energy sources such as wind and geothermal. This gives us a total of 25% of 1995 fossil fuel consumption, or 1.5 billion tons of fossil fuels, that will be substituted by renewable energy sources in Vision 2050.

The fraction of energy generation made up by solar cells in Vision 2050 is just 3%, which is considerably less than that of biomass and even of hydropower. Why can we not aim to achieve more? The reason is that, even if the technology is achieved, we will probably not be able to develop the total amount of energy supplied by solar cells in 2050 to a scale that greatly exceeds 3% of the total energy demand. As a general rule, it takes time to go from the development of an energy technology to the actual widespread penetration of that technology into the market. In particular, solar cell technology has the characteristic of a large initial investment cost and almost zero running cost. After the cells are manufactured and put into place, there is essentially no additional cost, and eventually the cells will pay for themselves. However, the initial cost to make and install the cells is still formidable. On the other hand, although investment costs for biomass energy systems are low, costs are incurred when collecting the biomass and transforming it into an easy to use form of energy such as electricity. Furthermore, while it is expected that commercial solar cells may reach conversion efficiencies of as much as 40%, we saw in Chapter 6 that the limit for biomass is about 5%. Consequently, while biomass is a technology that can be used right now due to the low investment cost, it has considerably less potential for being a major player in the future than solar cells. This is one important way in which the characteristics of different renewable energy technologies are different.

We might begin to create a solar power infrastructure by installing solar cells on the roof tops of city buildings and then expand the development of solar power into other applications. Through the cycle whereby increase in demand drives progress of technology, technology will improve, and gradually a solar cell infrastructure and industry will become established that will prepare the way for a much larger contribution of solar power in the second half of the 21st century. More generally, in Vision 2050 we need to plan out what kind of human artifacts we should begin to accumulate in the social infrastructure. Because solar cell technology is characterized by high initial costs followed by near zero running costs, in exchange for not expecting an excessively large contribution in Vision 2050, we must work to set the stage for a greater contribution to come later.

Towards a Perfectly Recycling Society

In the previous sections, we have seen how it is possible to move towards the establishment of a completely sustainable, perfectly recycling society from the second half of the 21st century using Vision 2050 as a road map. Moreover, rather than just being sustainable, it will be a society that lets us expand our lifestyles even further. The global amount of energy consumption will be almost the same as it is today at the point when this intermediate target of Vision 2050 is reached, and that is just about one ten thousandth of the total amount of the energy that shines down on the earth from the sun. Both biomass and solar power have the potential to provide more than enough energy to meet our energy needs today, so there is plenty of room to increase our energy use through the development of these resources. What we need to do in Vision 2050 is to move towards a breakaway from fossil fuels and spur on the acceleration of the introduction of renewable energy and recycling technologies.

Through well-planned development of technologies for a sustainable earth, we will eventually be able to supply much more energy for human consumption than we do today. For example, by exploiting just two ten thousandths of the sun's energy, we would be able to use twice as much energy as we do now. Electric vehicles that run completely clean, houses that are equipped with comfortable heating and cooling systems, beautiful and healthy oceans and forests that are located right next to large cities, all maintained using renewable energy – this vision of the future is not just a dream.