Chapter 8
How Will Technology and Society Work Together?

The previous chapter has presented Vision 2050 as a road map to a sustainable earth. In earlier chapters, we have tried to demonstrate that this vision can become a reality only if scientists, industry leaders, and policy-makers around the globe work together to develop, implement, and share technologies for sustainability. However, this vision also requires the support and participation of the general public. For example, it would be impossible to make new products from waste materials without the cooperation of local citizens in recycling and without the creation of an infrastructure for separating and collecting garbage. In this chapter, let's consider the problems that arise at the point of contact between technology and society and how we can address these problems.

1 Forming a Total Infrastructure for Circulating Materials in Society

The Importance of Separation in Garbage Collection

Depending on how it is collected, household waste can be either a resource or a burden on the environment. We have seen that waste paper can be used as the raw material for paper, and waste plastic can be raw material for plastic. But although a mixture of paper and plastic might be useful as a source of energy, the mixture cannot be used as a raw material. Furthermore, if food waste is mixed in with the paper and plastic, the mixture cannot be used even as an energy source. If, for example, we tried to burn a mixture of paper, plastic and food waste to generate electricity, heat would be lost in vaporizing the water in the food waste. As a result, the efficiency in generating electricity would barely exceed ten percent, and that much electricity would be used up just operating the plant.

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Vision 2050: Roadmap for a Sustainable Earth.

Many of the recycling systems in operation today are not designed to produce high quality materials. Producing high quality materials from recycling requires an integrated system that includes separation during garbage collection and possibly even the redesign of products to make it easier to separate component materials during recycling. If we mix an artist's various paints together, all the bright colors turn to grey. Likewise, if we do not separate the different colors of glass we use in daily life when we recycle, the color of the recycled products will approach a dingy shade of grey. If we want to maintain a variety of different colors of glass in recycled products, we must develop an adequate collection system and recycling technology. However, the choice of whether to take on the trouble of a complex separation system or to make do with a single color of glass is a choice that the citizens of each society must make.

When I was in Switzerland, I noticed large metal containers set out in various locations for recycling. The Swiss separate their glass, paper and plastic, and put them in those containers. Glass is separated into three different containers by colors: clear, green, and brown. After collection, this glass is pulverized and impurities such as metals are removed. The pulverized glass is then melted down and reshaped into new products. There is no need to divide the glass by size or shape, but to make recycled products of a particular color, each color of glass must be collected separately.

Another way to recycle glass products is to reuse the glass product as it is. This is the case with glass beer bottles in Japan, a case often cited as an exemplar of recycling. It takes additional effort, but this form of recycling consumes even less energy while maintaining the color and quality of the original product.

There are many ways to recycle. And to maintain our present lifestyle, each society must set up a recycling system that combines different recycling methods in the way that best meets its needs. For example, a recycling system for glass might reuse beer bottles and other standardized glass products as they are, separate the remaining glass into several different colors that are melted down and formed into new glass products, and use natural resources to manufacture only the top quality products such as flower vases and ornaments made from lead crystal.

A Minimum Amount of Waste Emissions

The scenario for glass described above – where if waste materials are not separated, all recycled glass products will be a dingy grey – applies to other materials, such as metals and plastics. We have seen how, as a result of the "saturation of human artifacts," there will eventually be enough scrap to make all of the metal required by society. Consequently, a recycling society will recycle metals over and over. But if nothing is done about the impurities and additives in the metals, they will accumulate with each round of recycling until only low-quality recycled metals will remain.

In plastic products today, aesthetics, strength, and sealing properties are obtained by mixing different types of polymers or laminating different kinds of plastic in layers. However, if all plastics are recycled together without being separated into different types of polymers, we cannot expect to produce the same high quality in recycled products. At best, we will be able to use recycled plastic only for things like planters, park benches, and the filling material for car seats.

In a recycling society, to prevent the quality of materials from degrading, we must, in addition to separating waste material during the collection stage, do all that we can to prevent mixtures of different materials from forming in the first place. As you will discover in the next section, we can prevent mixtures by standardizing products and by developing new materials that perform at a high level without being mixed with other materials. Still, no matter how much we work to design materials and products to avoid mixtures and no matter how much we invest in a good separation system for recycling, some amount of impurities is bound to get mixed in. Therefore, we also need to develop technologies to increase the purity of recycled materials to the level of materials currently produced from natural resources by removing impurities with just a small amount of energy.

Finally, although we should be able to collect most waste materials at a level of purity sufficient for recycling, there will inevitably be some waste that cannot be recycled, such as heavily rusted metal or rotted out concrete. And we will probably continue to obtain some materials from natural resources, particularly for products requiring the highest purity, such as lead crystal. But as long as the minimum amount of waste material that is too degraded to be recycled and the amount of natural resources needed for top quality products do not exceed the long-term regenerative processes of the earth, a society that has reached a saturation of human artifacts can still be made sustainable while maintaining the quality of the materials used in society as a whole.

Product Design and Standardization

To make a recycling society workable, we will probably need to regulate the design of many products. For example, a large percentage of drink bottles made of polyethylene terephthalate plastic, otherwise known as PET, are currently recycled. But because the caps of these bottles are often made from a different plastic or even from metal, a high level of impurities remains in the recycled plastic. We could require that the materials used for the caps of PET bottles be limited to PET. Similarly, while iron and aluminum can be recycled efficiently if collected separately, if they are mixed together, it is much more difficult to recycle them. Therefore, it might be appropriate to prohibit mixtures of iron and aluminum in a single product.

Developing new material technologies could make materials easier to separate for recycling. For example, we could invest in the development of single polymers having nearly the same high performance features as present-day plastics, which are made of a mixture of different polymers, a mixture that is difficult to recycle. Another promising example is developing new substances to treat the surface of metals such as iron and aluminum, substances that vaporize when the metal is melted. For example, the zinc used for the surface treatment of iron vaporizes when the iron is melted down for reuse; therefore, the accumulation of zinc as an impurity is extremely small. The zinc can be easily separated from the iron once it vaporizes, so the zinc can also be recycled. On the other hand, tin, which is used for the same surface treatment, does not vaporize at the melting temperature of iron. Therefore, it is necessary to find another way to remove tin impurities from recycled iron. Although it may be difficult to develop these technologies, it is certainly possible.

Standardizing the specifications for products and materials would also make recycling easier. In the automobile industry, specifications for the additives in steel for body parts or the composition of windshield glass differ from manufacturer to manufacturer. Although it is possible for the current production processes to create materials from natural resources meeting all of these different specifications, to recycle material from the scrap that is produced would take an excessive amount of energy. But by standardizing these specifications, we could make recycling much more efficient.

Choosing the Optimal Scale

One fundamental principle upon which our infrastructure for material recycling must be based is the “scale effect” of industrial manufacturing. As we showed in Chapter 5, in general recycling consumes less energy than producing goods from natural resources. But if we were to collect glass, pulverize it, melt it down, and form it into new products in every city district or town, the small-scale of these operations would result in an inefficient use of energy. There are many situations like this where, if the scale is small, the efficiency will be low.

If glass is melted down in a small furnace, a large quantity of excess fuel will be consumed as heat is lost through the furnace walls. In a large furnace, heat escapes less easily, so we need only enough fuel to supply the heat for melting. The critical factor here is the surface area of the furnace divided by the volume, called the “specific surface area.” The volume of a regularly shaped container such as a sphere increases at a faster rate than its surface area. Therefore, the specific surface area is smaller for a large furnace than a small one. A small specific surface area means less heat loss through the furnace walls. Also, the cost of equipment like furnaces and reactors per unit production capacity is generally proportional to the specific surface area. This is so because, while the amount of material used to build a furnace is proportional to its surface area, the capacity of the furnace is proportional to its volume. Therefore, a large furnace, with its greater capacity per unit of construction material, is not only more efficient to operate but also more economical to construct.

Process industries – such as glass factories, iron and steel mills, and petrochemical plants – have continued to increase the size of their plants to capitalize on these scale effects for energy efficiency and equipment cost. The same kind of scale effects apply to the production of materials through recycling. As a rule of thumb, the size of present-day plants for manufacturing a particular material is probably a reasonable target for a plant that recycles the same material. For example, irrespective of whether glass is created from natural resources or from recycled materials, the energy consumed during the melting and shaping processes will decrease if the scale is increased.

However, there are some situations where a larger scale may not be better. How to handle food waste is one major problem we must address to achieve the comprehensive circulation of materials required for a sustainable society. Food waste can impede recycling by being a source of contamination in the material to be recycled, by causing formation of toxic chlorine-based chemicals from the combustion of the chlorine in salt, and by reducing the efficiency of generating electricity due to the high water content. Food waste has a high water content, so we could collect and process this waste more efficiently if we could remove the water. It is easier and more efficient to remove water from food waste on a small scale because when the waste is divided into small amounts, it has a larger specific surface area. At the household level, water could be easily removed from food waste by drying it in a solar-heated compost box, spin drying it in a disposer, or using some other small-scale method. And if the water is removed where the food waste is generated, we will save energy in transporting the dry food waste to be recycled because it is lighter and easier to handle.

Heat pumps are another example where sometimes better efficiency can be attained on a small scale. The efficiency of small scale heat pumps, such as air conditioners for home use, is not necessarily less than the efficiency of those used in large buildings. We have seen that one of the main factors determining the efficiency of a heat pump is the efficiency of heat transfer between the heating and cooling units and the air. Using lots of small indoor and outdoor heat pumps, such as home air conditioners, results in a larger area for transferring heat. Therefore, it could be at least as efficient to use individual air conditioning units for each room in your home as to use a central unit, particularly when you consider that a central unit must distribute the heating and cooling throughout your house, resulting in loss in the ventilation system as well as needless heating and cooling of unused rooms.

The point to keep in mind is that processes requiring area, such as drying and cooling, can be carried out on a small scale, but processes requiring volume, such as melting and chemical reactions, should be done on a large scale. In other words, when we want to minimize the loss of heat from a process, we should do that process on a large scale, but when we want to maximize heat transfer, it can be advantageous to do that process on a small scale. We must adopt this as a fundamental principle when we formulate a comprehensive plan for material circulation.

A Network System for Biomass Collection

Constructing the infrastructures in society to facilitate material circulation is important in other areas besides recycling. For example, to effectively use the residual by-products from agriculture and forestry as biomass to produce energy, we need a collection system. And to combust this biomass efficiently for generating electricity, we need a drying system.

Because drying requires surface area, it is inefficient to dry the biomass residuals on a large scale, after a huge quantity of residuals has been collected at a single location. It is better to use the energy of the sun to dry the residuals where they are produced – at the farm or lumber mill. Then we can collect the residuals in stages, starting with an initial drop-off point to which the producers of biomass bring the residuals over a distance similar to the distance they now transport harvested goods. From these initial drop-off sites, the dried biomass can be collected and carried to middle-level collection points, and so on. Transporting loose straw and husks wastes energy because of the bulkiness of the material. Energy could be saved by compressing the residuals into solid blocks that take up less room and are easier to handle. The optimal place to install equipment for compressing is probably the middle-level collection points. Finally, we must make the power generation plant at the final stage large enough because generating electricity by burning biomass is a process that benefits from a large-scale operation.

Dried biomass compressed into solid blocks, called "RDF" for refuse derived fuel, has a fuel value comparable to coal. Moreover, the content of pollutants, such as sulfur, is typically lower in biomass fuels than in fossil fuels. Judging from current levels of technology, if we could collect biomass on a sufficient scale, it should not be hard to convert it into convenient forms of energy, such as electricity or vehicle fuel.

But it is vital that such a system be constructed with the assent and understanding of the farmers and other participants, regarding factors such as the modes of transportation, the construction and layout of collection points, and the distribution of costs. The borderline between effectively harnessing a huge amount of natural energy and creating just another "burning oil field" lies in collaboration.

Production in the 20th century was a one-way flow from natural resources to human artifacts supplied to the market. Because of that one-way flow, technologies were developed independently for each plant. However, if we are to make the transition to producing goods from recycled artifacts, technology must be shared throughout a large social system that includes the standardization of human artifacts, the design of systems for collecting waste materials, and the development of methods for recycling. Because a society that efficiently recirculates materials depends on collaboration, a good relationship between society and technology is essential.

2 Making the Market Work for Sustainability

Can We Leave Things to the Invisible Hand of the Free Market?

After the end of the Cold War between the capitalist world and the communist world, the debunking of planned economies following the collapse of the Soviet Union created the impression that market principles, or “the invisible hand,” had prevailed over all other economic systems. In Japan, people have been clamoring for deregulation for years. It often seems as if all our problems would be solved if we just eliminated all regulations.

However, in a situation where the world’s population as a whole must respond with long-term vision to the environmental and energy problems threatening to undermine the foundations of civilization, can we leave the decisions solely to the “invisible hand” of the market? Probably not. As long as corporations act on short-term outlooks, the principles of the free market will never attain the level of cooperation required to meet the large-scale, long-term problems of sustainability. One problem is that many of the negative consequences of human activities, such as CO_2 emissions from transportation, are not properly priced for the market mechanisms to work. Recently, much concern has been raised about the environmental costs of purchasing goods produced in countries far away. There are many similar examples where excessive burdens on the earth occur as a result of mismatches between prices and environmental costs.

If we look at the global circulation of iron, the problem becomes clear. In Japan, at the start of the economic boom in the 20th century, iron scrap was imported. However, as a result of rapid economic growth, human artifacts made of iron accumulated, the amount of scrap generated domestically increased, and in 1992, export of scrap iron surpassed import. Currently, Japan exports 7.6 million tons of iron scrap, but it still imports 180 thousand tons. In the U.S., the situation is even more extreme. Since the 1950s, the U.S. has been a net exporter of iron scrap, but since the 1970s, the U.S. has also imported a substantial quantity of iron scrap. In 2007, although the U.S. exported 14.9 million tons of iron scrap, it also imported 4.8 million tons.

So why is it necessary to both export and import iron scrap instead of just exporting the difference? The reason is related to the nature of iron products in the U.S. and Japan. In the U.S. and Japan, demand for high-performance products is large, so high quality iron scrap such as unused cutoffs is needed. On the other hand, iron scrap generated from human artifacts that have reached the end of their product lives is often rusted, may have bits of concrete attached to it, and contains a lot of different impurities, so it is not easy to use in high quality products where composition and minute structure must be precisely controlled. As a result, low quality scrap has become overabundant in the U.S. and Japan, so it is exported. In developing countries, there is still a need for structural materials that can be made from cheap scrap, so there is a demand for even low quality scrap.

But as you have seen in this book, eventually low quality scrap from human artifacts will be generated in much larger amounts in countries around the world, and a surplus of low grade scrap will occur worldwide. On the flip side, the demand for high quality scrap will increase as developing countries begin manufacturing more high-performance products, resulting in a shortage of high quality scrap. At that point, how will the iron and steel companies respond? If we stood in the shoes of the executives of those companies, we would inevitably choose to continue the reduction of iron ore in blast furnaces. Rather than tackling the troublesome task of processing low grade scrap to produce high performance products, it is more economical in the short run to use the high purity pig iron made from iron ore, which is still in plentiful reserve. It is clear from this example that if we entrust the production of iron to the invisible hand of the market without any form of regulation, the circulation of iron will not happen. To achieve a material-recycling society, the market must be influenced in such a way that recycling becomes economically advantageous.

Guiding the Market

In the previous chapter, we saw how manufacturing industries have achieved tremendous reductions in energy use during the last few decades. As a result, the fraction of the total cost made up by energy cost in Japanese industries is just 20% for the highest consumer of energy: the cement industry. For chemicals, iron and steel, and paper and pulp, the fractions are 15%, 14% and 6%, respectively. Therefore, the economic drive to invest in energy conservation is considerably reduced. As long as fossil fuels continue to be as cheap as they are today, it is probably not advantageous for industries to invest further in energy conservation.

On the other hand, the general public cannot be expected to develop energy-conserving habits on a large scale either with the price system as it is now. With a car that gets 10 km per liter, a motorist who drives 10,000 km per year and pays one dollar per liter (or $4 per gallon) for gasoline will spend a thousand dollars a year on fuel. If that person were to buy a hybrid car with 50% better fuel efficiency, the annual savings would be five hundred dollars. Hybrid cars today cost over five thousand dollars more than conventional cars with equivalent performance features, so it would take more than ten years of fuel savings to pay back the difference. Because most people own their cars for no more than ten years, there is little economic incentive to purchase energy efficient automobiles. As a result, energy efficient automobiles, such as hybrid cars, are purchased primarily by consumers concerned about the environment and not by consumers responding to market forces.

One way to influence the market towards energy conservation is to raise the taxes on energy. As shown in figure 8-1, more than 50 cents per liter of the cost of gasoline sold in Japan today is tax. Many other countries impose similar or even larger levels of tax on gasoline. On the other hand, the tax on gasoline in the U.S.

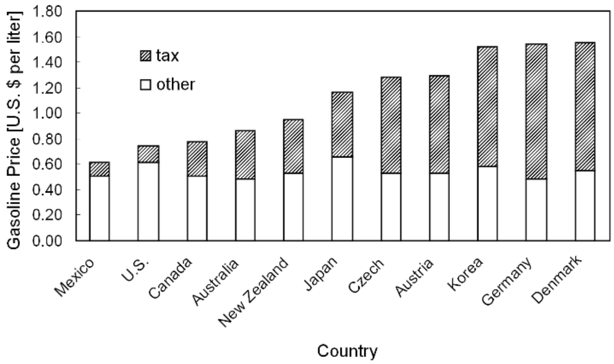

Fig. 8-1: The fraction of gasoline prices made up by tax in various countries (Data from International Energy Agency, Energy Prices and Taxes, 1st Quarter 2007)

is only about 13 cents per liter. This low tax rate accounts for most of the large difference between American and Japanese/European gasoline prices shown in figure 8-1.

Unfortunately, even the high gasoline tax imposed in Japan today is not enough to motivate people to purchase energy efficient cars for economic reasons alone. Therefore, more direct ways to tilt the market towards energy conservation are being considered. One approach, called the "top runner" method, places a tax on cars based on the amount of energy they consume, using the car with the lowest energy consumption rate as a benchmark. As a policy to promote energy conservation, this method makes sense. However, Japan's proposal to adopt a top-runner tax initially met with strong resistance from the EU, whose citizens tend to prefer cars with lower fuel efficiency. Only after several years of negotiations did the EU finally adopt a top-runner tax system.

Even in the EU, which took a leadership role in negotiating the control of CO_2 emissions at the Kyoto COP3 meeting, when discussions reach the point where policies directly affect domestic industries, national governments often are forced to change their stance. National self interest is often an obstacle to addressing global environmental problems: long term benefits to humanity can and do conflict with the short term interests of individual nations. But increasing the energy efficiency of automobiles is essential for meeting the Kyoto goals as well as for achieving a sustainable earth. So workable agreements must be adopted and enforced.

Similarly, the use of renewable energy sources will expand slowly if left to the forces of the free market. Many options for renewable energy require a steep initial investment. For example, installing solar cells to meet the electricity requirements of a single home costs about 20,000 U.S. dollars. Given current electricity prices, it would take many years for a home-owner to recover the investment costs through savings on electricity. However, we have seen that the energy needed to manufacture and install the solar cells can be recovered in two years, so from the overall perspective of conserving energy, installing solar cells is good. Different methods for adjusting the market to favor the introduction of renewable energy are being studied and applied. One example is the *Aachen* method in Germany, where electricity prices are raised by 1% and the added revenue is used to subsidize the development of renewable energy.

Another example is the Feed-in Law introduced in Germany in 1990. The Feed-in Law required utilities to connect small operators generating electricity from renewable energy technologies to the grid and to buy the electricity that they produce at close to the market price for final customers. This law was implemented to level the playing field of the energy market. The Feed-in Law was replaced in 2000 by the Renewable Energy Source Act. Under this act, the feed-in prices for electricity generated with renewable technologies are no longer linked to electricity retail prices; instead they are fixed for 20-year terms. Thus the generator is freed from the risk of being stuck with electricity it cannot sell. A sophisticated redistribution system ensures that the financial burden is evenly distributed to the end customer. The generator of renewable electricity is granted preferential access to the grid and has the right to be connected immediately. The feed-in prices offered to new installations will be lowered each year to take into account the decrease in investment costs for renewable energy as the technologies mature.

The “carbon-tax” method, whereby a tax is imposed that is directly proportional to the amount of CO_2 emissions, is another example of a mechanism used to guide the market towards sustainability. Already carbon-taxes have been put into effect in Sweden, Finland, the Netherlands, Denmark, Norway, Italy, and the United Kingdom. Carbon-taxes direct the market towards energy resources that have less carbon, many of which are renewable energy technologies. Results of a computer simulation reported by the National Institute for Environmental Studies in Japan show that by introducing a carbon-tax of 30 dollars per ton, Japan would be able to meet the Kyoto agreement.

Yet another example of how to moderate the force of free markets is the EU Emissions Trading System, initiated in 2005. This system is the world’s largest tradable permits program, applying to approximately 11,500 installations across the EU’s 25 member states. Many studies are being conducted on different aspects of this trading system, including efficiency and equity in distributing permits, implications of economy-wide programs versus regional ones, mechanisms for handling price uncertainties, different forms of targets, and issues in compliance and enforcement.

The development of ways to reform economic and political systems is outside the scope of this book. However, if adequate policies and guidelines are adopted, Vision 2050 is definitely within our reach.

3 Projects for Vision 2050

To successfully introduce recycling systems and renewable energy, we must develop large-scale social infrastructures. Those infrastructures must be based on application-oriented research and draw on a wide range of ideas for creating a sustainable earth. Because these society-encompassing infrastructure systems must transcend the frameworks of industry, the development of such systems cannot be left to individual companies. Instead, we must turn to other institutions in society, such as governments, international agencies, non-profit organizations, and universities, to lead these development projects. These institutions must collaborate with companies in planning, promoting, and implementing the society-encompassing infrastructure projects needed to create a sustainable society.

To achieve Vision 2050, what kinds of projects do we need?

Design of Giant, Complex Systems

As one example of a society-encompassing system for Vision 2050, here is a hypothetical design for how we might establish a material-recycling society.

First, for each basic material, we must design a system for circulating the material that limits the degradation of quality during circulation as much as possible. For iron, we might design an overall framework that includes the separation and collection of iron scrap generated when products such as buildings and cars reach the end of their product lives, a recycling process that removes as many impurities as possible using a reasonable amount of energy, and an information system for monitoring and communicating the quantity of recycled iron that can be produced at each level of quality. But when we try to implement this system, we will discover that we will not be successful if we limit this design to only the iron and steel companies. Problems will arise, such as how to coordinate with other industries including construction and automobile manufacturing, how to induce people to separate the garbage they throw out, and how to arrange the collection and transportation of waste materials. Even after we resolve these problems, we must trace how the primary material, iron, will circulate in society, and estimate how the additives and impurities such as phosphorus, copper, zinc, tin and nickel will be distributed in the various iron products.

Next, we must design a similar process for aluminum, cement, plastics, and all the other basic materials. Manufactured products are usually composed of many materials, so adjusting the amounts of different materials used in each product will be necessary. For example, we must regulate the use of substances that impair the recycling of high quality iron. This regulation must include even additives in other materials used in the product together with iron. For example, if glass is used as a surface coating for a steel car fender and that glass contains copper, then when the fender is melted for recycling, the copper will mix with the iron. Also, for heavy, low cost materials such as concrete, reducing transportation costs is essential, so we must plan where and how to separate concrete from other materials to minimize cost and maximize efficiency. We must design specifications for products, methods for recycling, and methods for collection, and these methods must be coordinated in such a way that few conflicts arise. Furthermore, we must map out a scenario showing how we will convert those specifications and methods into a functioning reality. In particular, we must decide when to use regulatory mechanisms, when to use subsidies, and when to rely on the free market.

This kind of material-recycling society is a much more complex system than today's society of mass-production / mass-generation-of-waste. We cannot hope to create such a complex system just by thinking up catchy slogans. We will need vision and strong leadership together with opportunities where the various constituents of society can orchestrate their collective efforts to make a sustainable society. We must bridge the communication gap between different stakeholders in society and create design tools for helping those stakeholders to fine-tune the overall system by communicating their ideas and their needs. We will look at these challenges in the last section of this book.

The design of a material-recycling society is one project we must undertake right away to reach the goal of Vision 2050. On the other hand, even though we do not expect technologies such as solar cells to make large contributions by 2050, we must encourage their research and development now. Technologies not expected to be widespread until after 2050 do not have immediate economic payoffs, so they cannot be simply entrusted to the free market. Instead, they must be nurtured through the collective will of society.

A Large-Scale, High-Efficiency Manufacturing System for Solar Cells

In 1998, the number of solar cell arrays that had been installed on roof tops in Japan was about 10,000. By 2007, the number had increased to more than 400,000. On average, each array for home use has a capacity of about 3.5 kW, so the total peak power generation capacity is 1,400,000 kW. However, this is the amount of power generated when sunlight is strongest. To compare the power generation capacity of solar cells to that of thermal power plants, we need to account for both the daily variations and the seasonal variations of sunlight. The average power generation of solar cells calculated in this way decreases to about one tenth of the peak generation capacity. Therefore, considering that the total electricity generation capacity in Japan today is about 200 million kilowatts, less than a thousandth is provided by solar cells.

By installing solar cells on all of the roofs in Japan, it would be possible to meet over 20% of the current demand for electricity, or 6% of the total energy demand. However, even if the annual production capacity of solar cells could be increased to one hundred times the current capacity, it would still take more than one hundred years to produce that many cells. Another problem is that even now there is a shortage of high-purity silicon, the raw material for making solar cells. Up until now, solar cells have been manufactured using the surplus of extremely high-purity silicon made for semi-conductor applications, but this surplus has run out. Until an alternative supply of high-purity silicon can be found, it will be difficult to increase production of solar cells. This is one reason why the contribution of solar cells is set at only 3% in Vision 2050. However, by developing an industry to manufacture even this limited amount of solar cells, we will solidify the position of solar power as an energy ace for the latter half of the 21st century.

The most common solar cells on the market today, silicon solar cells, are made by reducing the raw material silicon oxide to pure silicon, which is subsequently made into an extremely thin film just a few microns thick. The fragile film of silicon is then enclosed in a frame made of aluminum and glass. Currently, the process of reducing silicon oxide into crude silicon is done in countries where electricity is cheap. Then chemical companies and steel-making companies make high-purity silicon from the crude silicon, and electric appliance manufacturers make the solar cells. One fundamental principle for increasing efficiency that we saw in the iron and steel industry is integrated manufacturing. The same principle can be applied in solar cell manufacturing. If the steps from purification of the crude silicon to the production of solar cells were integrated into one continuous process, energy efficiency and efficiency in using raw material could be increased dramatically. In fact, a doctoral thesis from the University of Tokyo in 1999 showed that with process integration, the price of solar cells could be reduced to less than one tenth of what it was at that time.

Utilizing the Polar Regions and Outer Space

As we saw in Chapter 6, the biggest problem with wind power is its stability. But if wind farms were located at the North and South Poles, they might not suffer from this problem. Near the Poles, a wind called the *kataba* blows from the Polar Regions to the surrounding areas. Like the trade winds in the low latitudes and the westerlies in the mid-latitudes, the *kataba* wind is a global scale phenomenon created by the energy of the sun and the rotation of the earth. Unlike regional winds that blow intermittently, these global winds are steady. Although currently the *kataba* wind is not harnessed for any human purpose and so merely dissipates into heat, it has been said that this resource has the potential to supply all the energy required by human civilization today.

In developed countries there are few places to install solar cells other than on the roofs of buildings, and it is difficult, using only rooftop arrays, to generate enough power to make a large contribution to a country's supply of energy. Therefore, researchers are studying methods for setting up solar cell power plants in deserts and even on geostationary satellites. Locating power plants in remote areas raises the problem of how to transport the electricity to places where it is needed. Superconductors show promise for realizing a global network of high capacity transmission lines. Researchers are also looking at ways to transport the energy of electricity economically in the form of fuels such as hydrogen or methane.

Untapped sources of renewable energy might be easier to utilize in places where there are few people. However, producing electricity in remote areas like the Polar Regions and deserts raises other issues that must be resolved, including issues of international law and local culture. Once a plan for harnessing these sources of energy has been developed, the next step must be to form an international agreement between all of the affected nations for moving that plan to the experimental stage. Only after enough evidence has been gathered indicating that the plan will benefit all the nations affected with no harmful side effects will it be possible to proceed to full implementation.

Certainly other large-scale systems could be proposed in addition to the ones described above. And it is no easy task to decide which of these systems we should invest in. But one thing is certain: if we continue to leave such decisions to experts, bureaucrats, and entrepreneurs – who comprise only a tiny fraction of society – the result may not be what is best for society as a whole. Plans made without considering a range of perspectives are often flawed, and even a decision that could have been correct under certain conditions may not have the planned outcome without broad-based cooperation.

To establish a broad-based cooperation, we must create a forum for exchanging ideas and building consensus. Such a forum must exploit the most advanced technologies for gathering ideas and exploring them from different angles. We must evaluate not only intended consequences of a plan but also possible unintended ones, possibly by using small-scale experiments and computer simulations. Only by thoroughly examining many different ideas in such a forum can we build social consensus. In the final section of this book, let's consider the conditions needed for creating such a forum.

Designing the Komiyama House

But first I would like to tell you about another project for sustainability that is a bit smaller and, for me, quite literally closer to home. It was a project to redesign my own home. Five years ago, I decided to build a new house, and I made it my goal to see how much I could reduce the energy that I consumed in my own "daily life" activities. One of the first decisions in building my new house was to equip it with a rooftop solar cell array. At the time, the 3.6 kW solar cell system cost me 2,360,000 yen, or about 20,000 U.S. dollars. However, even in 2002, the Japanese government was offering subsidies to home owners installing solar technology. I received a rebate of 360,000 yen, so the actual cost to me was about 17,000 U.S. dollars. To this rooftop solar cell array, I added a high performance air conditioning system with a COP of 4, a heat pump for my hot water supply with a COP of about 3, and 1.4 watts per square meter per degree C of insulation. I bought new appliances with high energy efficiency. All of these investments in energy conservation cost me an additional 1,240,000 yen or about 10,000 U.S. dollars. As a result, my new home requires less than half of the energy needed to run my old home, and the solar cell array provides about two thirds of that energy. So my new 207 square meter home requires only a sixth as much electrical energy from the power grid as my old home – less than 3,000 kilowatt hours per year!

Another step I took to reduce my "carbon footprint" was to trade in my old Toyota sedan for a new Toyota Prius. The Prius, a hybrid car, cost 679,000 yen more than a comparable Toyota Corolla, a little less than 6,000 U.S. dollars. By adjusting my driving a bit with the help of the friendly dashboard interface, I reduced my gasoline consumption about three-fold. As a result, my total energy use fell from 20,800 kilowatt hours per year in 2002 to 4,000 kilowatt hours in 2008. And the total cost to me was just 3,770,000 yen, or about 33,000 U.S. dollars.

4 Rebuilding the Relationship Between Technology and Society

The Problem of Dioxins

Developing a plan based on energy and recycling to establish a civilization that can be sustained on the earth requires that we model a complex system in which multiple elements interact through many intertwined relationships. There is unlikely to be a single optimal solution. Instead, we must choose from among several solutions, each of which is almost optimal but has some particular drawbacks.

As an example, let's consider the complexity of the problem of dioxins. "Dioxin" is a generic term for a group of mainly carcinogenic chemical compounds with a complex molecular structure containing chlorine in addition to the carbon, hydrogen and oxygen found in substances such as carbohydrates. Dioxins are sometimes emitted when garbage is incinerated. But if the incineration is carried out at a high enough temperature, no dioxins will be formed.

Because dioxins contain chlorine, dioxins will be formed only if there is chlorine in the garbage at the time of combustion. One source of chlorine in garbage is polyvinyl chloride (PVC), a type of plastic with a wide range of applications. Another source is the plastic wrap used for food products, which has a similar molecular structure. Recently, there has been talk of banning the use of these plastics, but even if we stopped producing PVC, dioxins would still be created. The reason is that food refuse also contains a source of chlorine: sodium chloride or ordinary table salt. So to eliminate all sources of chlorine, we would have to exclude food refuse from garbage incinerators.

If we did ban PVC to keep chlorine out of the garbage incinerator, then another problem would emerge – we would face a shortage of caustic soda. Chlorine is produced through the electrolysis of sodium chloride. During the electrolysis of sodium chloride, chlorine is created at the anode and caustic soda is created at the cathode. Because PVC is one of the main commercial uses of chlorine, chlorine would no longer be in demand if PVC were banned. As a result, the electrolysis of sodium chloride will no longer be economically viable, and the supply of caustic soda would dwindle. Because caustic soda has many important applications, such as in making soap and in neutralizing waste water, this shortage would be a problem.

If banning PVC is problematic, we could consider replacing existing incinerators with ones able to withstand high-temperature combustion. Then we could incinerate garbage containing PVC and food refuse without releasing dioxins. But is this really the best option? If you consider the question from the point of view espoused in this book, you may ask whether we should be using fossil fuels or electricity to burn garbage containing valuable energy resources such as plastic and paper at high temperatures just to prevent the formation of dioxins. After all, you have already seen that incineration of garbage is not an efficient way to produce electricity.

So how should we solve the problem of dioxins? In the previous chapters, you have seen that it should be possible to create an energy-efficient system for circulating materials, a system that can reuse waste such as paper and plastic either by recycling or by making fuel. The key is to separate those waste materials from food refuse and other garbage. If at the collection point, plastics are separated from other garbage, this plastic waste – even if PVC is mixed in – is not so difficult to process. Technologies are already available that use heat treatment to get rid of the chlorine and then use the treated waste as a coke substitute in blast furnaces. Thus it is possible to save fossil fuel resources equivalent to the amount of garbage reused while preventing the formation of hazardous dioxins. This example suggests that by carefully evaluating the way we manage our resources, including our waste materials, we can make Vision 2050 a reality.

Currently, in Japan garbage disposal is the responsibility of the local municipalities. What if one municipality takes measures to control the emissions of dioxins by improving its incinerators? That decision, in and of itself, may not be a bad idea, but in terms energy efficiency it is far from ideal. What we discover is that a choice that may seem good on a small scale – good for one municipality – may work against constructing a large-scale system that would be even better. In today's society, problems and stakeholder interests are intertwined in such a complicated way that, with the best of intentions, decision-makers often choose suboptimal solutions. We must look at each problem from a variety of vantage points and make decisions that take into account all the related aspects – from the big picture down to the fine details. And to do this, we must set up a social infrastructure for forming consensus based on discussions that involve as many stakeholders as possible.

Structuring of Knowledge and a Place for Debate

To make Vision 2050 a reality, it is essential to develop and introduce new technologies. It is no overstatement to say that only when there is a good relationship between society and technology will the sustainability of the earth become possible. But recently some people have come to see technologies as the contents of a

Pandora's Box opened by science and released upon humanity, causing misery and destruction. When we remember that science gave birth to the atomic bomb, has contributed to the destruction of ecosystems, and has given us the power to manipulate human life, it is understandable why some people may hold this perception.

Therefore, to pave the road to Vision 2050, scientists and engineers must take the initiative in starting a dialogue with society about technology. In this dialogue, we must guarantee a high level of transparency about scientific findings and must fully disclose to the public the known results of research and the likely consequences of development of different technologies for a sustainable earth.

I would like to tell you about an incident of public disclosure about technology, an incident I was involved in several years ago. In the early 1990's, the Japanese government funded a project to develop a computer program for calculating the cost and energy payback times for solar cells. One of the preconditions of the project was the public disclosure of all the findings together with the methods by which the findings were made. Over the course of a year, discussions were conducted in the public venue of a research panel at the Society for Chemical Engineering of Japan. Based on those discussions, a method for obtaining the payback time of solar cells was developed, and all of the assumptions and calculation methods were made public. Anyone who had a question about the assumptions or numbers used in the calculations could change the corresponding values and recalculate the payback time. In fact, one expert, who had originally reported that the energy payback time was five years, used a computer program produced by the project to conduct a verification of his numbers and ended up agreeing that two years was almost right. This example shows how the program acted as a platform for establishing a consensus regarding the highly complex problem of calculating cost and energy payback times for solar cells.

The Internet is sure to play an important role in facilitating public disclosure of research and development. Already, it has become common for research institutes and even private companies to publish information on the web about research activities and product development. Although it takes significant effort to maintain a website with this information, experience has shown that the advantages in terms of a company's image outweigh the costs. As another example, a group of researchers at the University of Tokyo have used advanced artificial intelligence and web technologies to develop a web-based platform that lets scientists add specially formatted descriptors to their scientific publications that can be read by a computer search engine. These special computer-interpretable descriptors function like "barcodes" that help search engines and other knowledge retrieval systems on the Internet more effectively match knowledge needs with knowledge seeds. Although the platform is still at an experimental stage, the hope is that this work will lead to publishing results of scientific research in a way that is more immediately accessible to stakeholders in society. For example, a non-expert interested in learning more about state-of-the-art research on solar cells could draw on the computer interpretation capabilities to "translate" expert scientific expressions into language that person understands.

Another example of how to bridge the gaps between researchers and stakeholders can be seen in the Tokyo Greenhouse Gas Half Project (THP). This project was initiated in 1996 with the goal of drawing up a plan for reducing by one half the emission of greenhouse gases in the city of Tokyo. The core members of THP were researchers and professors from the Faculty of Engineering at the University of Tokyo, who worked in collaboration with researchers from the Massachusetts Institute of Technology and the Swiss Federate Institutes of Technology as well as other universities and research institutes in Japan and around the world. The primary objective of the project was to evaluate the potential for combinations of technologies and policies to reduce the amount of greenhouse gases generated by a range of factors, including cars, trains, homes, offices, garbage incinerators, construction sites, and manufacturing plants, focusing on the impact of interaction effects between those different technologies and policies.

This project has had one other important aim: the development and implementation of methods for effectively communicating the information necessary for a research study on the complex systems of a city the size of Tokyo. As is shown on the project web site (http://www.thp.t.u-tokyo.ac.jp/thp_en), in addition to coming up with a comprehensive plan for reducing CO_2 emissions in Tokyo, researchers in THP also considered how current methods for enabling effective information exchange between engineers and experts from different disciplines of science and technology could be extended to make possible a discussion between all kinds of people who are interested in the object of the study, including ordinary citizens, policy-makers, and experts.

In recent years, it has become evident that we need a new academic discipline – sustainability science – to address the issues above in a more structured way. An on-going example of this science at work exists in the collaborative research and education undertaken by the University of Tokyo, the Massachusetts Institute of Technology, the Swiss Federal Institute of Technology, and Chalmers University of Technology under the Alliance for Global Sustainability. In 2005, with the support of the Japanese government, the Integrated Research System for Sustainability Science (IR3S) was created at universities and research institutes throughout Japan, including the University of Tokyo. The IR3S aims to form a network in Japan for coordinating sustainability science research and education. IR3S has begun a program addressing sustainability issues led by three flagship projects: “sustainable countermeasures for global warming,” “development of an Asian recycling-oriented society,” and “conceptualization and development of global sustainability focusing on reform of the socioeconomic system and the role of science and technology.” The University of Tokyo has also started a new graduate program in sustainability science emphasizing exercises and projects that help students master the diverse set of academic skills and practical knowledge required to become leaders in the effort to establish a sustainable global society.

As a consequence of the specialization of knowledge, even for a single field of science or technology, each expert’s breadth of understanding has become extremely narrow. It is worth taking a moment to think about why this has happened. We hear about the great Renaissance Men (invariably, the people with the time and resources to become great thinkers during the Renaissance were almost all men), such as Leonardo da Vinci, Galileo Galilei and Benjamin Franklin, all masters of a wide range of disciplines both in science and the arts. Some people may say that we have become less intellectually agile in modern times. However, it is not that the modern individual's capacity for processing information has decreased in comparison to that of the Greek philosophers or the Renaissance Men. Rather, the huge increase in the amount of accumulated knowledge, which has expanded at an accelerating rate due in part to the trend in science of splitting disciplines into narrower fields since the days of Isaac Newton, is enough to overwhelm even the greatest modern geniuses. Today, even the most devoted intellectuals can hope to sample only a small fraction of the vast accumulation of human knowledge within their lifetimes. If Aristotle or Su Song were alive today, even they would find the breadth and depth of current human knowledge overwhelming.

Here is just one example. You probably remember the "Y2K problem," the fear that some erroneous computer operations would occur when the clocks built into older computers changed from December 31, 1999 to January 1, 2000. Now we may look back at the confusion and consternation during the final months of 1999 with some embarrassment, but at the time the concern was quite real. Danny Hillis, an American inventor, entrepreneur, and author, made the following thought-provoking comment regarding the real nature of the problem:

> *I have come to believe that the Y2K apocalypse is, in the truest sense of the word, a myth. It is a shared falsehood that carries within it a profound truth. ... There are no real experts, only people with partial knowledge who understand their own little pieces of the puzzle. The big picture is a mystery to us, and the big news is that nobody knows.*

This comment exemplifies the present difficulty of "increasing complexity of social problems and increasing subdivision of fields of knowledge." We must work out a method for understanding the big picture behind the problems that we face today.

So what is required in order to do this? The first step is to carry out a widespread structuring of knowledge. One problem adding to the difficulty of accessing specialized knowledge is the cryptic way in which knowledge is expressed in each specific field. As human knowledge has expanded, members of each discipline have developed their own specialized vocabularies to communicate the results of their scientific research. At the same time, scientific publications expect their readers to be familiar with an increasingly large set of specialized terms and tacit assumptions.

"Structuring knowledge" means making the specialized knowledge in specific fields clear to people outside those fields by establishing the connection of the ideas in that field with the whole of human knowledge. When scholars report knowledge that they hope to be helpful in achieving a sustainable earth or addressing some other social need, they must prune the jargon from their prose. Only then will actors in society be able to understand that knowledge and translate it into actions. The responsibility for doing this must lie with the members of each field. But even between related fields in the sciences, the same words may be used to express very different concepts, so an electrical engineer, for example, may interpret a paper written by a physicist in a completely different way from what was intended. To make their knowledge more structured and accessible, specialists need to establish clear definitions in everyday language for the terminology they have developed in their specific fields. This must be done in parallel to the process of publishing specific research findings. Most scientific disciplines have one or more representative societies, where members of the discipline gather to share ideas related to their field. These academic societies might be good places for scientists and other specialists to establish how their work is related to other fields of knowledge. To clearly describe the way knowledge in each field is connected with that of other fields, the specialists must focus on the meaning of the entire field rather than getting mired in specific details.

Computers may facilitate the difficult task of structuring knowledge. In the same way computer algorithms have been developed to translate text between languages as different as Japanese and English, it may be possible to develop computer-based techniques for translating the materials written by experts to describe their knowledge, such as papers in professional journals, from one field, such as chemical engineering, to another, such as economics. But if computers are to play the role of interpreters, the specialists must prepare descriptors of the knowledge they are sharing in ways a computer can understand most easily and most accurately. Just as we do not burden a human translator with jargon and expressions unfamiliar to the translator, these descriptors must avoid ambiguous human expressions that would baffle a computer translation program.

Another step in making accessible the “big picture” behind the large-scale and complex problems of society is finding a way to store the structured knowledge in a form people can easily tap into. Suppose that we wanted to present the latest expert knowledge on the current state of global warming, on the role played by solar cells, and on the time it takes solar cells to pay for themselves. And suppose that we wanted to present this knowledge in a way that could be accessed easily by people deciding whether to invest in a solar cell system. This knowledge should be presented in such a way that each area of related knowledge is integrated seamlessly with the overall topic: how investing in solar cell systems can help mitigate global warming. By presenting this knowledge on a web site in a way that allows feedback and dynamic interaction, the person accessing the knowledge on the web site, who may have a question about what he/she is reading, can pursue that question by interacting directly with the web site. Already several interesting web sites are providing access to expert knowledge in this way. We must continue developing the computer infrastructures and software tools that allow experts to share their specialized knowledge themselves in integrated, easily accessible formats with minimal effort.

The analysis and vision presented in this book represent an attempt to articulate an overview of the entire system of human activities within the earth’s biosphere, and to use that overview as a framework for planning how by wise use of technology we human beings can assure the sustainability of the earth. Certainly this book has not included all of the specifics related to every human activity and every technology that could be included in a plan to realize a sustainable earth. To give but a single example, there is no question that experts on transportation and automobile engineering know the details regarding the design and implementation of energy efficient automobiles far better than the authors of this book. To build a sustainable future for the earth, detailed knowledge of technologies, human activities, and the workings of natural systems will certainly be necessary. But it is our belief that what we need right now is a clear and comprehensive vision of how our activities and the technologies determining how those activities are performed relate to the earth as a whole. Once we have a shared vision of the whole, we can focus on the specifics, always with an eye on how those specifics affect the entire system of human activities and what implications those specifics have on the sustainability of human life on the earth.