Chapter 4
Technology to Support Low-Carbon Society (Utilizing Energy)

4.1 Future Image of Renewable Energy

4.1.1 Rethinking the Value of Renewable Energy

In the previous chapters, we have discussed technologies that increase energy efficiency, while minimizing energy consumption and maximizing the obtainable benefits. However, regardless of how much effort is made to improve efficiency, energy consumption does not become zero, so energy resources with low environmental impact must somehow be secured.

Firstly, energy resources represent an original source of energy that you do not have to get energy from anything else. They must be available from nature, such as buried underground, growing on land, or fallen from the sky.

According to this definition, fossil resources, sunlight, hydropower, wind power, geothermal power, and biomass are all energy resources. However, hydrogen and electricity are not energy resources, since hydrogen and electricity cannot be obtained from nature.

However, hydrogen is often misunderstood. It has been said that "hydrogen will solve the energy problem"; "hydrogen is obtained by electrolyzing inexhaustible water, so if we can obtain energy with hydrogen, energy problems will be solved"; and there has been discussion of a "Hydrogen nation". Certainly, water is inexhaustible and hydrogen can also be used for power generation. Hydrogen can be used for both thermal power generation and fuel cells, and it can be regarded as a resource because it becomes the source of electricity. However, to make hydrogen, we need another resource. Therefore, hydrogen cannot be considered an energy resource of itself.

Looking at the amount of energy resources used, the fossil resource usage rate is still so overwhelmingly large that non-fossil resources account for 24% worldwide and 7% in Japan. However, in order to realize a low-carbon society while maintaining the economy for mankind, we must increase the proportion of non-fossil

H. Komiyama, K. Yamada, *New Vision 2050*, Science for Sustainable Societies,
https://doi.org/10.1007/978-4-431-56623-6_4

resources. To that end, it is necessary to expand the use of renewable energies such as sunlight, wind power, and biomass.

As mentioned in Chap. 2, considering the progress since 1995, "doubling renewable energy" as proposed in Vision 2050 should be revised upward to "half the total energy should come from renewable sources." Let's look at specific strategies to achieve this goal.

4.1.2 The Future Image of Solar Cells and Storage Batteries

In the long run, the main power supply will become renewable energy rather than fossil fuels. There are many types of renewable energy such as hydropower, wind power, geothermal power, and biomass. Among these, solar power has enormous energy availability, and there is also room for cost reduction through future technological development. Thus, expectations are growing for expansion of usage.

However, the amount of power generation varies under the natural cycles of sunlight. In summer and winter, the sunshine hours and sunshine intensity are different, and the weather changes from day to day. In addition, although power generation is limited to daytime but usage takes place in daytime and nighttime and there is thus a gap between the electricity supply and the timing of demand. In order to compensate for this, it is necessary to use a storage battery in combination with the photovoltaic technology. Therefore, not only the photovoltaic power generation system but also the future trends of the storage battery must be clarified in order to study and design the future power supply configuration.

There are various research and reports on cost analysis such as past trend analysis, prospects and scenarios announced by associations and administration, technical roadmaps, market research, and economic analysis. However, these are mainly evaluations of economic efficiency based on experience curves (learning curves). Changes in raw materials, processes, and production scales due to future technological development are not sufficiently discussed, hence it is impossible to project the manufacturing cost.

The method that we applied to make the projections described below puts emphasis on clarifying concrete technical contents to calculate current and future costs. Then we will design the manufacturing process including a detailed equipment list and quantitatively evaluate the economics and environment of products and systems based on the results.

Also, since the influence of the cost of the production scale and the technology level is large, the relationship between these factors will also be clarified. The speed of future technical advancement will be predicted from the progress of related technologies.

This evaluation approach is also useful for planning the investment time and production scale in the product manufacturing plant.

4.1.3 Importance of Balance Between Future Cost and Investment

First of all, let's look at the evaluation result for solar power generation systems.

Table 4.1 shows the prediction of the performances and costs in 2020 and 2030, referring to 2012 as the base year. The current mainstream, single crystal silicon solar cell (single crystal Si), has a module conversion efficiency of 17%, whereas 15% can be achieved with a compound thin film solar cell (CIGS), which has an expanding market. However, it is expected that by 2020, CIGS technology will improve and power generation efficiency will rise to 18%, and annual production volume will increase, while manufacturing cost could be reduced. Furthermore, apart from CIGS, a new type of thin-film solar cell will also be introduced, and conversion efficiency of this is predicted to be about 15%.

The thickness of monocrystalline Si would be suppressed to less than 1/3 of the current level, and power generation efficiency will increase to 25% by 2030. In addition, the tandem CIGS type with the layered structure of multiple CIGSs will expand the market with the high performance of 30% conversion efficiency as a major strength.

Table 4.1 Breakdown of solar power generation system costs

Technological level		Current situation in 2015		2020		2030	
Solar cell		Single-crystal Si 150 μm thickness	CIGS	CIGS	New thin-film	Single-crystal Si 50 μm thickness	New CIGS tandem
Module conversion efficiency		20%	15%	18%	15%	25%	30%
Amount of annual production (GW/Year)		1	1	5	1	5	5
Production cost	Variable costs (raw material costs)	56	51	40	34	35	29
	Variable costs (utilities expenses)	4	2	1	2	1	1
	Fixed costs (equipment costs and personnel expenses)	14	14	9	12	6	7
	Module subtotal (Yen/W)	74	67	50	48	42	37
BOS	Frame (including construction costs)	22	29	27	32	12	10
	Power conditioner	30	30	20	20	10	10
	BOS subtotal (Yen/W)	52	59	47	52	22	20
System (Yen/W)		126	126	97	100	64	57

Source: Created based on materials from the Center for Low-Carbon Society Strategy, Japan Science and Technology Agency

The manufacturing cost of the whole system is expressed by the sum of the manufacturing cost of the module and the balance of system (including peripheral equipment and construction). The manufacturing cost per 1 watt (W) in 2015 was ¥126. It is predicted that it will fall to ¥97–¥100 in 2020, and to ¥57–¥64 in 2030.

Secondly, consider the power generation cost. The production cost of single crystal Si in 2015 was ¥126/W. Assuming that the annual expense rate required to operate this system is 10% of the manufacturing cost, the annual expenses will be ¥12.6/W. Since the annual power generation amount of the 1-W system is 1 W × 1000 hours (h) = 1000 Wh (1 kWh), if the annual sunshine amount is 1000 h, the power generation cost is ¥12.6 per 1 kWh.

Various values have been reported as the power generation cost worldwide, and some are lower than ¥12.6/kWh. For example, there are many reported values such as ¥3 to ¥5/kWh in Dubai and the U.S. where there are good sunshine conditions. In these areas, annual sunshine amounts are large and the amount of electricity generated is more than twice as large as those generated in Japan. Therefore, if the annual expense ratio is set to 7% of the manufacturing cost, the generation cost will be less than ¥5/kWh. Our cost calculation results are in line with the reports from other locations worldwide.

Figure 4.1 shows trends in the cost of solar power generation module and system production along with the sales prices of modules in Japan and China. We produced

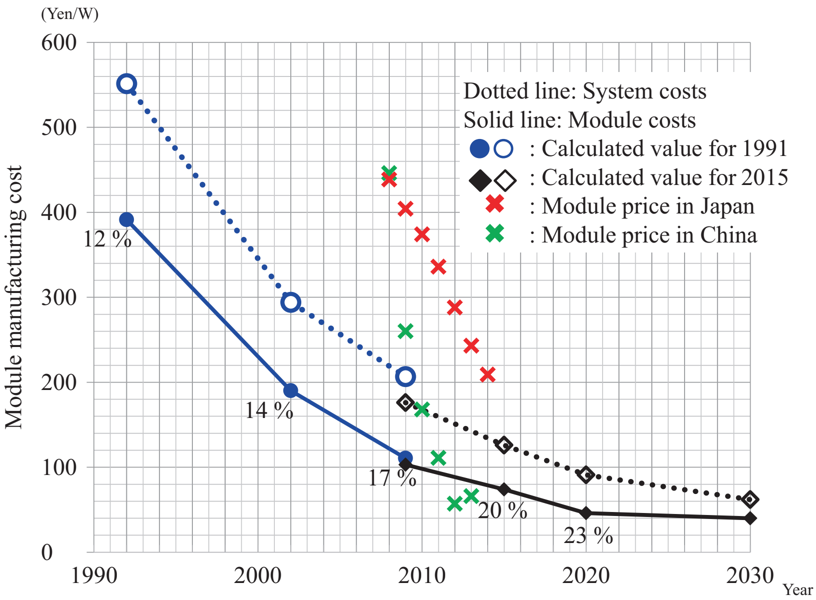

Fig. 4.1 Manufacturing costs of Solar power generation module system. (Source: Created based on materials from the Center for Low-Carbon Society Strategy, Japan Science and Technology Agency)

the cost calculations of the future products in 1991, and values after 2010 were calculated by the Low Carbon Society Strategy Center. From 2010 onwards, due to market expansion and intensified competition, the module price sharply declined and it is now approaching the cost calculation value. In particular, despite the effects of foreign exchange and national policy, the selling price of the modules made in China is lower than the cost. Following the U.S., an anti-dumping and anti-subsidization tax was imposed in Europe in 2012 on solar panels made in China, but it seems there is a logical basis for this based on our cost calculation.

It is quite severe for companies if the selling price drops by this amount. Table 4.2 shows the current profit status of foreign solar cell manufacturing companies. Most companies have fallen into deficit.

From the above discussion, we can see the important considerations needed when companies make investments. As technology advances, the market expands and the production volume increases, while the manufacturing cost decreases. However, this also applies to competitors. If price competition intensifies and the selling price falls below cost, only the deficit will keep accumulating.

That is why it is important to make management decisions by accurately projecting future technological progress, production scale, and future costs. It is meaningless to create a business plan by combining the future market size and the current manufacturing cost. In order to properly determine the technology selection, scale, and timing of a new factory, it is important to determine the future cost. Furthermore, when taking foreign policy such as anti-dumping taxation into consideration, such cost evaluation clearly becomes indispensable.

Table 4.2 Profits of the solar cell module manufacturers

	Module shipment volume[a] in 2015	Net interest expenses in 2015[b]	Impact[c] of net interest expenses (net interest expenses ÷ shipment volume)	
Company	GW	M$	¢/W-module	Remarks
SunPower	1.3	**−42**	**−3.2**	US, n-type
JA Solar	3.1	**−39**	**−1.3**	China
Jinko	3.5	**−60**	**−1.7**	China
Trina Solar	4.5	**−49**	**−1.1**	China
Canadian Solar	4.1	**−37**	**−0.9**	Canada
Yingli	3.6	**−155**	**−4.3**	China defaulted
First Solar	2.5	16	0.6	US

Note: Leading-edge factory production cost: About 60¢/W
Source: Created based on materials from the Center for Low-Carbon Society Strategy, Japan Science and Technology Agency
[a]Shipment volume: Fuji Research Institute, [b]Materials presented by First Solar @PVSEC 2016. (Sources are each company's Annual Report)
[c]Since each company also sells cells alone, the figures per watt are reference values

4.1.4 Which Storage Battery Will Be Playing the Leading Role in 2050?

Lithium-ion batteries are used in personal computers and smartphones, and they can be regarded as one of the most familiar storage batteries in our everyday life. The basic structure of a lithium ion battery is a positive electrode composed mainly of lithium metal oxide and a negative electrode typically composed of graphite, which are immersed in an electrolytic solution together with a separator dividing both electrodes. When electricity flows, lithium ions from the positive electrode dissolve into the electrolytic solution, then run through the separator and move to the negative electrode side and remain between the graphite layers. This is a state of electrical charge. When discharging, lithium ions dissolve out from the graphite layer and move to the positive electrode side.

High stability and an economy that can withstand mass introduction are required for the combination of fixed storage batteries with solar power generation. Lithium ion batteries have higher energy density, longer life, and charge–discharge efficiency as high as 90% compared with conventional storage batteries such as lead storage batteries and nickel hydride batteries. It can be said that this is an easy-to-introduce storage battery, as material development and manufacturing technology have improved and prices have also declined in current expanding period.

The prices of current household storage batteries are shown in Table 4.3. The selling price of a Japanese company is about 10 times the manufacturing cost of ¥13.9/Wh shown in Table 4.4, while the selling price of Tesla in the U.S. is about three times this value. Severe price competition will start as the market develops, due to such factors as expansion of production scale, improvement of product yield, and development of new products.

In contrast to lithium ion batteries that have already become widespread, NAS batteries are expected to become popular in the future. This battery was named “NAS” because sodium (Na) is used for the negative electrode and sulfur (S) is used for the positive electrode. A fine ceramic solid electrolyte membrane is used between

Table 4.3 Manufacturer and price of household energy storage systems(Li ion battery) (as of May 2015)

Manufacturer	Product type number	Capacity[kWh]	Price [10,000 Yen]	Unit price [Yen/Wh]	Real price (subsidies included) [Yen/Wh]
Sharp	JH-WBP07A	4.4	107	240	150
Panasonic	PLJ-25522K	5.6	119	210	135
Eliiy Power	EPS-1 1	6.2	131	210	130
NEC	ESS-H-002006B2A	5.53	123	220	140
Tesla	Powerwall	10	41	41	–

LCS cost calculation value of Tesla products: ¥15/Wh (Battery: ¥13, BOS: ¥2)
Source: Created based on materials from the Center for Low-Carbon Society Strategy, Japan Science and Technology Agency

Table 4.4 Current situation of lithium-ion batteries and future scenarios

			Current situation	2020	2030
Battery type			LiNi-C based	LiNi-C based	Li-S based
Production scale [GWh/y]			1(10)	10	10
Yield [%]			66(90)	90	90
Energy density [Wh/kg]			250	340	530
Active substances (positive electrode/negative electrode)			$LiNi_{0.85}Co_{0.12}Al_{0.03}O_2$/graphite	$LiNi_{0.85}Co_{0.12}Al_{0.03}O_2$/graphite	S-C/Li
Positive/negative electrode capacity density [mAh/g]			200/300	270/380	1500/2900
Comparison of actual capacity of positive/negative electrodes and theoretical values			0.71/0.78	0.97/0.99	0.9/0.75
Production costs [Yen/Wh]	Variable costs	Raw material costs	10.2(7.5)	4.8	5.5
		Utilities expenses	0.5(0.4)	0.4	0.1
	Fixed costs		3.2(1.7)	1.4	1.0
	Total		13.9(9.6)	6.6	6.6

Source: Created based on materials from the Center for Low-Carbon Society Strategy, Japan Science and Technology Agency

the positive and negative electrodes. The battery reaction occurs when sodium ions dissolved from the negative electrode combine with sulfur at the positive electrode to produce sodium polysulfide. At the time of charging, the bonds in the sodium polysulfide are broken, and sodium ions move to the positive electrode. The charge–discharge efficiency is about 80%.

The typical characteristic of NAS batteries is that they are high capacity batteries with high energy density. If capacity is the same, the size of an NAS battery can be only about one third the size of a lead storage battery. An NAS battery can handle megawatt-grade electricity storage and it is suitable for large scale solar power systems when arranged in large quantities.

Another potentially appropriate battery is the redox flow battery. This battery contains a tank containing an electrolytic solution with a potential difference between the positive electrode and the negative electrode. There is an electrolysis cell between the two poles, which are connected by a pipe and pump. Historically, there are various active materials used for electrodes, but currently the most promising type uses vanadium for both the positive and negative electrodes.

While other storage batteries exchange different ions at the electrodes to charge and discharge, the redox flow battery charges and discharges by the oxidation reduction reaction of the electrolytic solution, so the battery capacity hardly drops. In other words, long-term use is possible while maintaining the performance. However, the charge–discharge efficiency is only 75% and the energy density is not high. Therefore, although it is not suitable for miniaturization, it has the major advantage that there is no risk of thermal runaway and ignition.

4.1.5 Promising Markets Where Various Uses Can Be Considered

We introduced three types of storage batteries, but here we will describe the future prospects for lithium-based storage batteries with the highest charge–discharge efficiency. Table 4.4 shows the current state and future scenario of lithium-ion batteries. Currently, nickel-based (Ni type) batteries with energy density per kilogram of 250 Wh can be manufactured at ¥13.9/Wh. It is forecast that technology will advance by 2020, and energy density will be increased to 340 Wh/kg, while manufacturing cost will be reduced to ¥6.6/Wh. In 2030, the active materials will switch to the Li-S system, the energy density will increase to 530 Wh/kg, but the cost cannot decrease substantially.

Unlike conventional lithium ion batteries, lithium-air batteries do not use metal compounds, but react with metal lithium and oxygen in the air to generate electricity. Because of the high energy density of these batteries, the automobile industry is paying attention to this upcoming technology as it can be made smaller and lighter. Nissan's EV "Leaf" is equipped with a lithium-ion battery weighing about 300 kg

Fig. 4.2 Small hydroelectric power generation using agricultural water. (Courtesy: Imagineer Co., Ltd.)

or 20% of the car's weight, which is inefficient in terms of weight and cost. An EV requires a battery with three times the current energy density. As shown in Table 4.4, it will be closer to this target in 2030, and may be beyond it in 2050. In 2050, if 10 million EVs are running in Japan, there will be a large storage battery market of about 500 GWh just for the EVs.

Meanwhile, the requirement for the physical properties of household storage batteries and power storage batteries is not as stringent as that for automobiles. The size of the storage battery market for power supply is about the same as that for EVs. Furthermore, many other applications such as for use in robots can be considered, so it can be said that the battery market is a particularly promising field.

As such, I have described the quantitative calculation results including the current state and future prospects of solar cells and storage batteries. Economy is necessary for expanding the market, and for that purpose, high efficiency and high performance are indispensable. The research and development issues are clear, and a large number of researchers and engineers are working on this issue worldwide. Although competition between companies will intensify, it is a market that will continue to grow for decades (Fig. 4.2).

I now introduce an interesting corporate strategy for commodities. The Dow Chemical Company, a huge petrochemical company, has been successful in the commodities field. The outline of its strategy is as follows:

1. Keep the top share, or continue securing the share within the top three;
2. Maintain superiority, even if differences with other companies in terms of quality and manufacturing cost are actually small;
3. To achieve the above, continue investing no matter how bad the economic environment is;
4. On top of that, it is important to make a society that is not afraid of failure.

In this way, Dow started to dominate the commodity field. In the past, both solar cells and storage batteries may have been classified as high-performance products, but in the future, they will be commodities. Technological development is indispensable, but a management strategy like that of Dow is also essential. We expect that some Japanese companies will succeed in this field. Furthermore, We hope that new technologies to enhance energy efficiency of new product and to reduce manufacturing costs of them beyond what we forecast in this book will emerge.

4.1.6 Dissemination of Hydropower Generation by Region

Although Japan is said to be a country with limited resources, water resources are abundant enough to allow self-sufficiency. Hydropower is renewable energy that does not use fossil fuels, but it is difficult to build any new hydropower facility that is currently accompanied by large-scale development that is typical in Japan.

However, small hydropower generation has considerable potential for development. Even hydropower plants with an output of 10,000 kW or less are estimated to have a potential of about 10 million kW in the whole country. This is equivalent to about 4% of the total electricity generation capacity of 243.6 million kW (2010) of the general electric utilities, about 80% of the amount of power generated by large scale hydroelectric power plants, or 10 nuclear power plants.

Small hydropower plants have a propeller installed where there is a difference in water level and generate electricity using the thrust generated by the propeller. Places in which electricity can be generated include water supply and drainage pipes, rivers, and agricultural canals where water flows beyond a certain flow rate. Small hydropower generation has not become thoroughly widespread because of the high cost, even though the potential has been pointed out in the past. The ability to generate power in various places is an advantage of small hydropower generation, but it is also a disadvantage at the same time. Since conditions such as water flow rate, flow path, and the surrounding environment change according to the location, it is necessary to amend the dimensions of the propeller to suit each case. It would not be profitable if you were to build various types of equipment for a hydropower plant that generates about 10 kW. Conversely, it could be profitable to position a general-purpose propeller in a place where the installation environment is similar.

There are already moves to increase the number and capacity of hydropower projects in Japan. Imagineer Co., Ltd., known for the development of game content, is working on a plan to expand small hydropower generation to agricultural canals in collaboration with a land improvement district. According to Mr. Takayuki Kamikura, CEO of the company, demonstration experiments are being conducted in Miyagi Prefecture, and introduction of small hydropower plants with power generation capacity of 500 to 1000 kW are planned in Toyama Prefecture.

Since agricultural canals are generally similar in shape, if three or four propellers are made, they can be installed in many places. However, there are some technical hurdles, for example, the AC power generated by the propeller must be converted to DC, re-converted to AC, and then linked to the grid. Collaborative research between Yaskawa Electric Corporation and Japanese universities is being conducted to improve efficiency.

To disseminate small hydropower generation, we must also overcome the hurdles of institutions and regulations. Agricultural canals were originally built for agricultural use, and there are many water rights stakeholders. If these agricultural canals were to be used for power generation, some people may disagree saying that their agricultural applications would be affected.

To overcome these issues, Mr. Kamikura's project is taking place in collaboration with a land improvement district. His company works to maintain a relationship with the local people, municipal governments, and agricultural affiliated organizations, so it is easy to gain the understanding of the local community. Moreover, the maintenance and management of the power generation equipment is entrusted to the land improvement district. Power generation facilities are normally managed wirelessly, but staff members of the land improvement district will rush to the scene if an error occurs.

Small hydroelectric power generation can be realized through improvement of technology and the system, and can contribute to local production and consumption of energy. Even if the steps are small, accumulating achievements will lead to low carbon society.

4.1.7 The Potential of Biomass

Biomass has the potential to enable Japan to achieve a high energy self-sufficiency rate as in the case of water resources.

In 1999, when I proposed Vision 2050, biomass plantations were drawing attention in the world. However, in recent years, biomass has rarely been addressed in the public sphere. The cause of this decline in interest in biomass is economic rationality. Wood for construction is worth ¥50,000 per cubic meter, whereas wood for fuel is worth about ¥5000 per cubic meter, which is the same level as coal. That is about one tenth. Even if you were to operate a large-scale farm for biomass only, it would not be economically viable.

Fig. 4.3 Large-scale forestry in Sweden
A harvester in the process of bucking trees; it can perform felling and bucking of a single tree in about 40 s.

Therefore, when I proposed Vision 2050, I thought that we cannot expect much from biomass, but recently new possibilities have emerged. This is because many people have come to understand that expanding domestically produced wood consumption leads to healthy forests.

Currently, Japanese forestry has weakened as a result of losing in price competition with foreign countries. In Japan, 55% of timber products are used for construction and 40% for pulp and chips, among which only 30% of domestic resources are used. This amount represents only around 20–30% of Japanese forest resources. It is an important task to keep Japanese forest healthy and to reform forestry into a form that is economically feasible even with a self-sufficiency rate of 100% (Fig. 4.3).

Regarding forestry as a whole, we can learn from success stories such as supply chain building in Sweden or Austria. In the Platinum Society Network, a Smart Forestry Working Group has been established to discuss forestry revitalization, such as building a supply chain using wood. Forestry is an extremely important industry from the standpoint of building national resilience and existing in harmony with nature, as described in Chap. 6. It is not easy to regenerate a completely weakened industry, the whole country should tackle the problem of forestry revitalization as an approach to simultaneously solving both resource and environmental problems.

4.1.8 Hydrogen as a Partner of Renewable Energy

Renewable energy sources such as sunlight, hydropower, and biomass are mostly converted into electricity and used for daily living and monozukuri. Although electricity is not an energy resource, it is a form of energy that is easy for human beings to use and will become increasingly important in the future.

Hydrogen is not an energy resource just as electricity, but it can be used as a CO_2-free energy medium. For example, picture the following image: in combination with a power generation method that has fluctuations in the amount of power generated such as solar power, hydrogen is produced by electrolysis when the amount of power generated is large (i.e., in bright conditions) then electrical energy is stored in the form of hydrogen like a storage battery.

Gas cylinders containing hydrogen are not as heavy as storage batteries, and can be transported and stored. Therefore, it does not matter if the place where electricity is generated (the place where hydrogen is produced) and the place where it is used are separated. Hydrogen can be used directly as a CO_2-free energy medium for fuel cells and thermal power generation. Attempts have recently been made to reform lignite, which is an unused fossil fuel resource, into hydrogen. Lignite is carbonized plants from tens of millions to 100 million years ago. Because coal is formed from plants from 300 million years ago, lignite can be considered as young coal. However, lignite is not as user-friendly as coal, it is heavy and has high moisture content, so it is not suitable for shipping because of the high cost. Moreover, its physical properties are unstable, and it will ignite spontaneously when dried (Fig. 4.4).

Therefore, a method has been devised in which hydrogen can be extracted from lignite using a chemical reaction (gasification process) near the mining site. Since gas containing CO_2 is generated in this process, it is collected and combined with CO_2 Capture and Storage (CCS) for underground storage. Kawasaki Heavy Industries is promoting a project to transport lignite-derived hydrogen from Latrobe Valley, Victoria, Australia. There is a withering gas field in the vicinity of the mining site, which can be used for CCS. The concept is that hydrogen can be obtained from low grade coal without CO_2 emissions.

At the same time as this project, Kawasaki Heavy Industries is also working on the development of hydrogen-dedicated gas turbine thermal power generation facilities. Since only water is generated by burning hydrogen, zero emissions can be practically achieved through a series of supply chains, beginning with lignite.

Fig. 4.4 Lignite mine in Australia and lignite, which is a young coal. (Courtesy: Kawasaki Heavy Industries)

4.2 Innovations Emerging from Theory and IT

4.2.1 Pursuing Efficiency to the Utmost Limit

Overall, we are moving in the direction indicated by the three goals in Vision 2050. Innovations are necessary to achieve the three goals of tripling the energy efficiency, doubling the share of renewable energy, and establishing a material circulation system. However, innovation cannot occur by just waiting. As both scientists and engineers conduct research seriously and engage in technological development, they often say, "We cannot increase efficiency any further," or "We are doing our best." However, pioneers have opened up a new world by developing ways to overcome that wall.

One good example is pollution control in Japan and Germany. Due to the spread of pollution accompanying economic development since the 1950s, strict environmental regulations have been laid in Japan and Germany. Some believed that the regulations would cause a decline in the productivity of factories and would not be economically feasible. It certainly must have been difficult to overcome the situation by relying on the existing technology at the time.

However, as a result of working on research and development by back-casting toward the vision of halting pollution, a number of innovative ideas were born. Thanks to those ideas, Japan and Germany not only met the targets of the environmental regulations but also succeeded in increasing productivity to higher levels than before. The success led to the competitiveness of companies in Japan and Germany.

In 1978, as the air pollution caused by automobile exhaust gas became serious, the Japanese version of the Muskie Law to reduce NOx emissions by 90% was enforced. At that time, it was also said that it would be impossible to achieve such a decrease because of the extremely high target value, but Japanese manufacturers worked diligently to realize this. Later, as environmental regulations around the world became stricter, Japanese technology had a major advantage.

Innovations often happen when seeking to achieve a high target that initially seems impossible. The important thing is setting a target that seems impossible at first sight, but not reckless.

The authors' research team made technical predictions concerning air conditioners in 1990 based on the thermodynamic theory and also the heat balance. Air conditioners use heat pump technology for absorbing and releasing heat against the temperature difference between indoors and outdoors. The energy efficiency is represented by the numerical value of the coefficient of performance. Before 1990, the coefficient of performance was 3 because air conditioners could heat up or cool down 3 kW with 1 kW of electricity.

The theoretical limit of the coefficient of performance is calculated as the indoor temperature divided by the temperature difference. The temperature here is absolute temperature in which 273 is added to the temperature in Celsius (°C). Assuming that the room temperature is 28 °C and the outside air is 35 °C, the coefficient of performance will be (273 + 28) / (35–28) = 43. In other words, 43 times the heat of the consumed electric energy can be pumped out of the room by the heat pump. This number represents is the theoretical value, which is large compared with the value of 3 before 1990. Thus, there is considerable room for innovation here.

In 1990, our team predicted the coefficient of performance in 2050 to be 12. A quadrupling of the coefficient of performance means that the efficiency will be quadrupled. Manufacturers' technicians strongly objected, saying that it was impossible to achieve the coefficient of 12, and it was completely ignored by the former Ministry of International Trade and Industry (currently the Ministry of Economy, Trade, and Industry). However, we had confidence in achieving the coefficient of 12. For the prediction, we even considered improving the efficiency of magnets of motors used in compressors of air conditioners. Since the compressors at that time were consuming twice the amount of electricity as the theoretical value, we thought that we could solve it by using a more efficient magnet. In addition, we examined detailed elemental technologies such as fluid dynamics technology and lubricant technology, and judged that 12 was an appropriate level of possible achievement rather than the theoretical value of 43.

The prediction was largely accurate. As of 1990, when the coefficient of performance was 3, the value of 12 in Vision 2050 seemed to be an extremely high target, but it increased to 7 in 2010, and has steadily evolved thereafter. In response to this trend, the Ministry of Economy, Trade, and Industry also raised the target value for 2050 to 12. Looking at the circumstances, the importance of applying theory and comprehensive and realistic technological forecasts is obvious, rather than merely being a prediction based on the past. In order to induce innovation, high but reasonable target setting is necessary.

4.2.2 Enhance Efficiency with an Energy Management System

In spring of 2016, full liberalization of electricity retailing began in Japan. In order to switch electric power companies, it is necessary to introduce a smart meter equipped with a communication function, and exchange of conventional electric power meters with the smart meter has been progressing. Since the Ministry of Economy, Trade, and Industry has launched a policy to introduce this meter to all households in the 2020s, its uptake will continue to spread in the future.

The smart meter measures the amount of electricity used every 30 min and can transmit data using the communication function. Electric power companies will not only need to conduct meter reading work, but also utilize big data to develop diversified fee structures and adjust supply and demand by pricing.

The advantage for the customer is to be able to view energy consumption trends in real time. Information on smart meters can be linked with the Home Energy Management System (HEMS). The HEMS is a mechanism to optimize energy consumption by connecting all equipment related to electricity in the home such as lighting equipment, air conditioning equipment, photovoltaic power generation systems, household fuel cells, water heaters, and electric cars. By visualizing this information, customers will be able to view whether their electricity consumption is high compared with other households or whether the amount of consumption at this time is larger than expected. As a result, it is expected that the energy conservation awareness will increase in each household. This information is also useful when the customer selects a price plan.

The HEMS also has a great feature in that it can be used to control the connected equipment. It is possible to optimize the whole by balancing the lighting and air conditioning so that a comfortable environment can be maintained or by switching the household electric appliances that consume a large amount of electric power to eco operation according to the remaining amount of power. It is also possible to operate “EcoCute” with solar power to acquire hot water and electricity at the same time, as well as to manage energy consumption and conserve energy.

Similar to HEMS, there are BEMS (Building Energy Management System) for buildings and FEMS (Factory Energy Management System) for factories as systems that optimize energy use in the system. Furthermore, CEMS (Cluster/Community Energy Management System) can also be established in areas where HEMS, BEMS, and FEMS are gathered.

There are several problems to overcome to make these systems popular. Among these, the biggest problem is price.

In a project that was carried out by Toyota City in Aichi Prefecture upon the city’s receiving designation from the Ministry of Economy, Trade, and Industry as a Next-Generation Energy and Social System Demonstration Area, remarkable results have emerged with regard to energy self-sufficiency.

As a result of the distribution of smart houses with energy creation (3.6 kW solar power generation), energy saving, equipment for energy storage equipment (including EV) and control by HEMS in the residential area of the city, energy consump-

Table 4.5 Reducing heating energy to 1/12

Coefficient of performance of air conditioners						
Before 1990	1997	2004	2006	2010	Vision 2050	Theoretical value
3	4	5	6	7	12	43

Source: "The Revitalization for Japan"

tion at home and EV 70% of the respondents became energy self-sufficient. In other words, the possibility of self-sufficiency of household and transport energy has come into perspective.

The market price of HEMS is around ¥200,000. Although there are some differences depending on the accompanying function, even the inexpensive systems exceed ¥100,000. Considering that personal computers and tablet devices can be purchased even at around tens of thousands of yen, the current cost of HEMS is too expensive. This is largely because companies try to recover development costs in the early stages of dissemination.

However, there are also successful product examples such as heat-tech products by UNIQLO and Toray's partnership which realized a speedup of product dissemination by pricing based on mass dissemination to the market from the beginning. This was made possible by collaboration between a large-scale production process that realizes low cost and a large-scale sales network that sells at a low price (Table 4.5).

The dissemination of HEMS is one of the keys to creating a low-carbon society. Companies should have the courage to consider the supply system and develop pricing based on the premise that they will be mass disseminated from the beginning.

4.2.3 *Japan Should Compete with High-Added-Value Items*

Let's think about the costs that are the key to the dissemination of products and services from another angle.

Table 4.6 shows the selling price and the partial cost per weight of the products that are used daily. Most of the weight of products is made up of basic materials such as steel, aluminum, glass, and plastic. The cost of the materials is about ¥0.1 to ¥0.2 per gram. The selling price of mass-produced home appliances such as electric fans, washing machines, and refrigerators is about 5 to 10 times the cost of the materials. The price of light cars and trucks is only five times to ten times as much as the cost of the materials.

The closer the material cost and the selling price, the lower the added value. From this point of view, solar cell modules are becoming commodity products like fans and trucks, and it is clear that price competition is intense.

Li-ion batteries are also considered to be more expensive than other storage batteries, but in terms of weight unit price, there is no major difference from dry batteries. Therefore, Sony and Nissan decided to withdraw from the Li-ion battery

Table 4.6 Selling price of products by weight

Product	Selling price (Yen/g)
Mobile phone	100 ~ 600
Jet aircraft (B787)	100
Watch	50 ~ 3,000 ~
Large gas turbine	15 ~ 30
Personal computer	10 ~ 30
Lithium-ion battery	6
Television	4 ~ 10
Passenger car	1 (light vehicle) ~ 6 (Lexus)
Refrigerator	1
Truck	0.8 ~ 2
Washing machine	0.8
Dry battery	0.7 ~ 4
Electric fan	0.7 ~ 3
Solar cell module	0.7 ~ 2

Source: Created based on materials from the Center for Low-Carbon Society Strategy, Japan Science and Technology Agency

business. It was judged that it is no longer necessary for companies to invest in research and development of their own exclusive products, and all they have to do is to procure general purpose goods from the market. However, the battery market still has plenty of room for technical development. For those who understand this market and technology situation and make appropriate business decisions, it would be possible to expand the industry.

Meanwhile, large-sized gas turbines represent an example of a high value-added product whose selling price per product weight is much larger than the cost. Gas turbines have advanced product design, material development, manufacturing technology, and their price is more than 100 times the price of the materials. The price of an aircraft with a more complicated system than a simple product such as a battery has an additional digit.

In the future low-carbon society, along with the hardware product industry that creates products such as robots, sensors, computers, and medical equipment, progress can be expected in the services industry for freely utilizing these hardware products. We believe that Japan should compete in such high-added-value areas.

In terms of improving the dissemination of HEMS, we should apply a model in which the basic system sets the price assuming mass dissemination and each company competes with high-added-value services that make use of HEMS data. For example, the early mobile phone market had a model for popularizing products by lowering hardware prices and raising revenues from fees. The HEMS data provide the user with the time they get up or sleep, and also actions related to the use of electricity, such as cooking, bathing, and hobbies. Handling of personal information is difficult, but if settled, a high value-added service will be built.

4.2.4 Increased Sophistication of Demand Forecasting by Utilizing Big Data

Approximately 300 million tons of fossil resources are imported to Japan. Roughly, 60% go to oil refineries, 25% to power plants, 5% to gas companies, and the remainder represents coal for iron making. Of these, oil refineries, power plants, and gas companies do not aim to consume energy themselves. It is the daily life (transportation, households, and businesses) and monozukuri sectors mentioned earlier that actually consume energy. Oil refineries, power plants, and gas companies convert energy into different forms so that consumers can use it easily, so they are called the energy conversion sector.

It is preferable to convert fossil resources without loss in the energy conversion sector, but some energy is consumed here. In the case of thermal power generation, the turbine is rotated by the power of steam generated by burning fuel, but since steam does not flow unless one direction is of lower pressure, there is a step in which steam is liquefied in a condenser. About 60% of the total energy from fuel burning is released to the sea and the atmosphere here. Japan's thermal power boasts the world's top efficiency, but the loss is still not small. Loss occurs other than in thermal power generation. Power generation loss, daily life, and monozukuri each account for about one third of the total energy consumption.

Besides improving power generation efficiency, power consumption prediction is also important to reduce power generation losses. Electric power companies adjust the amount of electricity to be shipped by predicting the power consumption based on past power consumption conditions and weather forecasts (temperature predictions). If the amount of electricity generated is larger than the amount consumed, we will discard unused electricity wastefully, but if the electricity generation is less than the amount consumed we will face supply shortage, and society will fall into turmoil. Therefore, electric power companies must constantly generate electricity to a level higher than the predicted power consumption. It is troublesome not to be able to store the electricity once generated.

A research team of Center for Low Carbon Society Strategy (LCS) investigated the power consumption prediction in areas served by TEPCO and the weather forecast data of the meteorological observatory and found that there is an error of several percent. In order to eliminate this error, the accuracy of both the weather forecast model and the power consumption prediction model must be increased. If the weather forecast model improves, it will be easier to set up the power generation plan, and if the accuracy of the demand forecast increases, it will be easier to control power transmission. If prediction accuracy improves, it is expected to reduce energy loss and reduce cost in hundreds of billions of yen, so we should develop highly accurate prediction models using artificial intelligence (AI) and big data (Fig. 4.5).

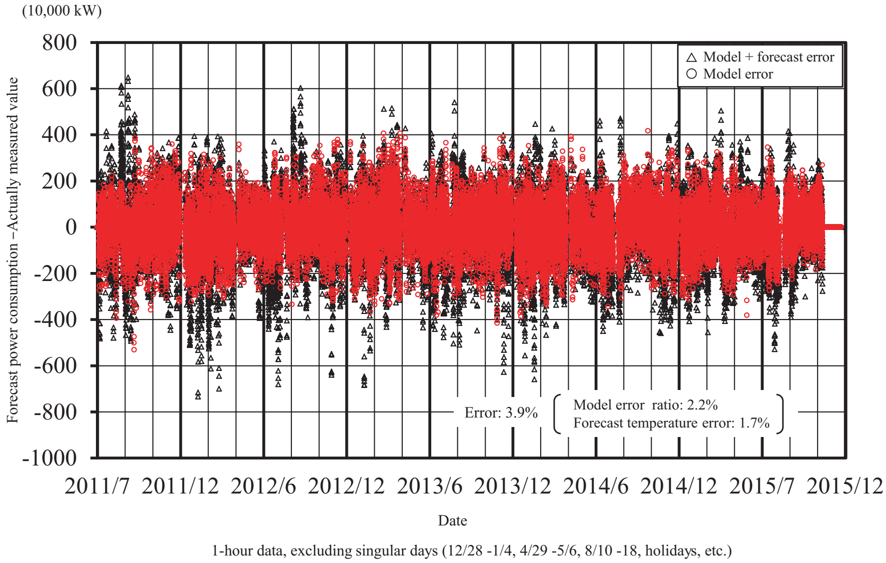

Fig. 4.5 Forecast power consumption error in grid area of Tokyo Electric Power Company. (Source: Created based on materials from the Center for Low-Carbon Society Strategy, Japan Science and Technology Agency)

4.2.5 The Possibility of Carbon Pricing

A "stranded asset" is an asset whose value decreases as the social environment changes. In 2013, the concept of a stranded asset was announced by the Carbon Tracker Initiative, a non-profit think tank, and the London School of Economics, and fossil fuel resources were considered stranded assets.

For the development of coal, petroleum, and natural gas, companies invest $674 billion a year, spending more than $6 trillion over a period of 10 years. In order to keep the rise in average global temperature within 2 °C before the industrial revolution, we cannot utilize 60 to 80% of the recoverable reserves of these fossil fuel resources, and most of the investment in these resources will become useless. In other words, they would be considered stranded assets.

In 2015, Oxford University showed the possibility that many of the domestic coal-fired power plants in Japan will become stranded assets. This is because there are plans to build an excessive number of power plants, considering the competition with other power sources and the renewal cost of existing coal-fired power. The value of the power plants is ¥7 trillion to ¥9 trillion. If a coal-fired power plant becomes a stranded asset, it means that the electric companies made a major mistake in management decision-making.

The problem lies in the cost of CO_2 emissions not being taken into account in companies' decision-making. Decisions on the kind of power station to build should be made after carbon pricing (i.e., after determining the cost of CO_2 that would be discharged by the development).

The setting of an appropriate CO_2 price is difficult to do immediately. However, it is an important viewpoint with regard to realizing a low-carbon society.

Vision 2050 assumes that progress in low carbonization naturally progresses as technology advances, but if there is a mechanism under which low carbonization takes on value, the speed of change can be increased. Hybrid cars are a typical example of products with value in terms of low carbonization. Despite the high price of the car itself, the purchaser judges that it is more profitable in total, if fuel costs are also taken into consideration.

With regard to the carbon tax (taxation on CO_2 emissions), it is better to tax at the stage when resources are shipped, as far as possible. This is because it is easier to set a tax rate according to the amount of CO_2 emissions, such as 3 times of the shipping cost for coal, 2 times for petroleum, or 1.2 times for gas. Alternatively, there is a way to change the tax rate according to the contribution of each resource to GDP. To date, 38 countries have introduced some type of carbon pricing and Japan can learn from many case examples.

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