Future Energy System and Executive Summaries of the Parts

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Abstract This book aims to foster visualization of bright future energy societies by describing energy technology options. An exteriorized vision for future energy systems in Japan beyond 2030 based on feasible technologies discussed in each chapter is presented in a figure. The system consists of domestic primary, secondary, and ternary industrial sectors plus energy supply infrastructures, electric power generation, and transportation, with consideration of international relationships. Parts II–VIII of this book cover these categories. Executive summaries for the parts that contain chapters for technological terms described in the figure are introduced in this chapter.

Keywords Future energy system • Energy technology option • Japan

1 Energy System Beyond 2030

This book aims to provide a basis for envisioning a bright future society that uses energy sustainably, by providing future perspectives on major technology options. Figure 1 illustrates an exteriorized vision of a future energy system in Japan beyond 2030, based on feasible technologies discussed in the chapters of this book. Japan's energy system will be developed in consonance with its unique geopolitical, economic, and social structures. The figure consists of categories of domestic primary, secondary, and ternary industrial sectors, together with the residential and transportation sectors and energy supply infrastructures such as large-scale electric power generation systems. Parts II–VIII cover topics in each of those

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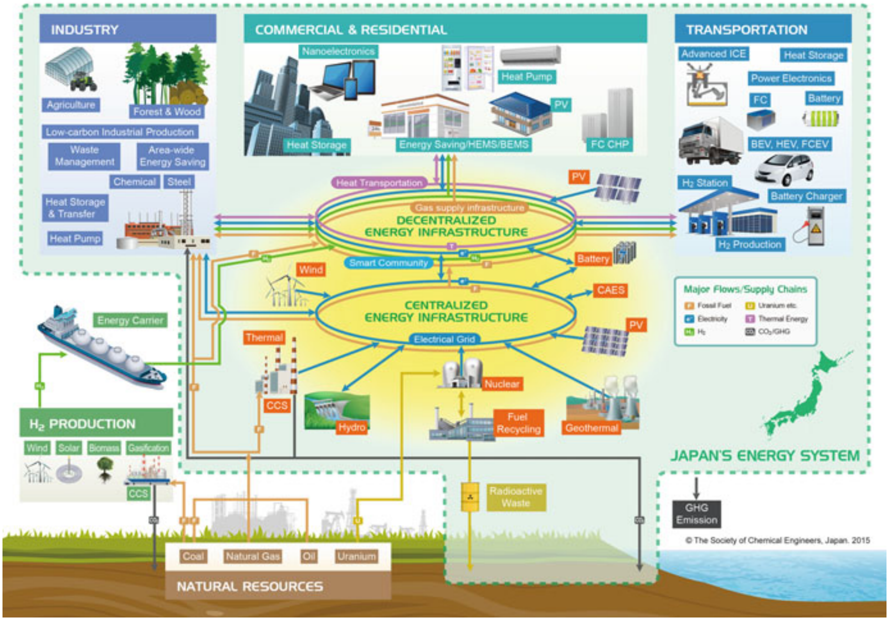

Fig. 1 Future energy system in Japan beyond 2030 based on feasible technologies (*BEMS* building energy management system, *BEV* battery electric vehicle, *CAES* compressed air energy storage, *CCS* carbon dioxide capture and storage, *CO_2* carbon dioxide, *FC* fuel cell, *FC CHP* FC combined heat and power, *FCEV* FC electric vehicle, *GHG* greenhouse gas, *HEMS* home energy management system, *HEV* hybrid electric vehicle, *ICE* internal combustion engine, *PV* photovoltaic solar cell) (Published with kind permission of © the Society of Chemical Engineers, Japan, 2015. All Rights Reserved)

categories. Technological terms in the figure are representative of the chapters. There are many items not shown in the figure that are important in the future energy system. Therefore, we recommend that readers first review the figure to grasp the big picture of future energy systems and the relationships of each technology option and then read chapters of interest to discover detailed perspectives in the field.

The future energy system shown in Fig. 1 is based on two main networks, i.e., centralized and decentralized energy infrastructures. Presently, Japan mostly depends on imported resources of coal, natural gas, crude oil, and uranium. Depending on the period of focus, these will remain major resources, but drastic increases in domestic energy production will raise the self-sufficiency ratio, so the contribution of such conventional resources could become minor. As a possible energy resource shift, overseas hydrogen (H_2) produced from wind, solar, and biomass energies, plus coal gasification implemented with carbon capture and storage, is illustrated in the figure. Establishing feasible H_2 carrier systems is necessary to support the transport of H_2 from overseas production sites to domestic consumption sites. The centralized energy supply system will maintain its present role, with both conventional and nontraditional technologies. In addition to the efficient use of fossil fuels or the increased role of renewable energy sources, backend measures such as carbon capture and storage and radioactive waste treatment should be considered for mitigating environmental loads. Decentralized energy infrastructures will be developed for electricity, H_2, fossil fuels, and thermal energy, with integration with the smart community. Advancement of electricity and gas supply infrastructure as well as heat transportation systems is inevitable. In the industrial sector, energy-consuming industries such as chemical and steelmaking are targeting drastic reductions of carbon dioxide emissions by introducing innovative processes or radical reformation of current processes. Another important approach is integration, such as area-wide energy saving. In addition to energy consumption, one must consider waste management measures. Also, primary industry such as agriculture, forest, and wood should be maintained sustainably, considering their various aspects or roles in the local community. Many advanced technologies such as highly efficient fuel cells, heat pumps, and ultralow energy-consuming electric appliances will be implemented in the commercial and residential sectors. Their integration with energy management systems in a smart community will be key to strong penetration of intermittent renewable energy systems such as photovoltaic cells and wind power. In the transportation sector, dramatic advancement of the power train is expected together with the progress of electronic devices and heat management systems. For nonconventional power train systems, there will be establishment of infrastructure such as battery chargers and H_2 refueling stations.

We expect a low-carbon, sustainable, and bright future for society as a result of harmonized contributions of advanced technologies and concepts described in this book.

2 Executive Summaries of Book Parts

This book consists of eight parts. Parts II–VIII contain chapters describing the details of items shown in Fig. 1. Executive summaries for the parts are provided in the following.

2.1 Part II: Multiple Aspects of Energy Systems in Japan: Present and Future Perspectives

This part addresses the background, present status, and future directions of Japan's energy system.

Energy systems and policy are influenced by geopolitical, economic, social, and technological factors and regimes. Because Japan has few fossil fuel resources, its energy system is heavily dependent on imports. Thus, it is considered important to diversify energy resources, replacing fossil fuel with other energy resources such as nuclear power generation and renewable energy technologies. It is also important to increase efficiency of energy use in electricity generation and the industrial, transportation, commercial, and residential sectors.

The accident at Fukushima Daiichi Nuclear Power Plant caused by the earthquake and tsunami of 2011 changed public attitudes toward nuclear power. The short-term challenge in supplying peak demand during the summer was overcome by collective measures, including urgent enhancement of power supplies, reduction of peak demand through lifestyle and behavioral changes, and others. However, the future energy system is uncertain and under debate.

The design of future energy systems and energy policy involves diverse stakeholders with varying priorities toward energy security, the environment, economic efficiency, safety, and industrial and economic development. Alternative guiding principles for the energy system and policy design are necessary and discussed in this part.

2.2 Part III: Advanced Use of Secondary Energy Media

This part discusses advanced use of secondary energy media. Large-scale electrical energy storage systems with electrochemical batteries offer the promise of better utilization of electricity, with load leveling and massive introduction of solar and wind power renewable energies. Sodium-sulfur and redox-flow batteries are candidate technologies. Greater energy efficiency and cost reduction are technical challenges.

Hydrogen production involves the consideration of energy conversion efficiency, carbon dioxide (CO_2) emission, and cost. Even when hydrogen is produced conventionally from fossil fuel, a fuel-cell vehicle's well-to-wheel CO_2 emission can be less than that of conventional gasoline engine vehicles. Hydrogen production methods using biomass, renewable energy-based electrolysis, thermochemical methods, and photoelectrochemical water splitting are important to reduce CO_2 emission.

The importance of the energy carrier for hydrogen produced by renewable energy use has been recognized. Long-term and stable storage of hydrogen becomes subject to the complete hydrogen supply chain in the form of liquid hydrogen or chemical hydride, such as ammonia or organic hydride.

Waste heat recovery has great potential in Japan. Efficient heat use requires optimized technologies, with a combination of heat storage, transportation, and transfer. Thermochemical energy storage has potential for high-temperature storage at temperatures $>200\ ^\circ\mathrm{C}$. Heat transportation at $<200\ ^\circ\mathrm{C}$ by latent heat storage has practical possibilities for waste heat utilization. Technology for heat exchange in the gas phase will become increasingly important. Consistent design of material, reactor, heat exchanger, and heat utilization systems at low cost is an ideal technology goal for heat recovery.

2.3 Part IV: Energy Supply Infrastructure

Part IV discusses the infrastructure of energy supply for people and economic activities in Japan, focusing on the infrastructures for gas, electricity, and automobiles. After imported natural resources such as primary energy, heat amount, component, and quality adjustments are made at refineries and power plants, those energy media supply consumers. Pipelines are used for gas and transmission grids for electricity. Those infrastructures must change per current trends of electricity and gas market reformation, discussions of infrastructure robustness after the Great East Japan Earthquake, and requirements of low-carbon energy use.

For gas supply infrastructure, stable and effective energy supply is expected through diversification of resources and extensive geographical and smart gas transmission networks. In city gas production, the calorific value of liquefied natural gas is likely to be less by using unconventional sources such as shale gas and coalbed methane, which have not yet been used extensively. Facilities and equipment must respond to this change, and a robust energy supply with the use of such diversified sources is expected. In gas transmission, it is also expected that wide-area gas pipelines will be constructed through cooperation of the government and gas companies. New technologies including underwater gas pipelines are also anticipated. The introduction of smart gas meters has progressed for consumer convenience, followed by comprehensive energy supply services using telecommunication networks. Challenges in gas supply businesses include energy infrastructure replacement needed for electricity and gas market reformation, transportation, and mixing of hydrogen for current city gas, plus more complex fuel adjustment owing to the use of hydrogen. Although there are some technical issues, gas supply infrastructure is likely to have a central role in Japan's future energy supply.

In the electricity infrastructure, it is anticipated that nationwide power interchange will increase and regional-level demand-side management (DSM) will expand in the long term. This trend is expected to be strengthened with nationwide and regional efforts. A robust supply chain and reductions in energy consumption and CO_2 emissions will be realized by the expansion of power interchange over wide areas, demand response, and smart grids in micro areas, plus increased use of renewable energy. Power generation efficiency improvement, the introduction of CCS technology, and expansion of renewable energy are likely after the 2030s, in response to greater demand for CO_2 emission reductions. Japan is tackling issues such as uncertainties of fluctuating energy prices and nuclear power plant rebuilding or replacement. However, the aim for its electricity infrastructure remains a resilient power supply and greater reduction of CO_2 emissions.

In the automobile fuel supply infrastructure, the number of gasoline refueling stations for internal combustion engine vehicles (ICEVs) and hybrid electric vehicles (HEVs) will continue to decline in the long term, while deployment of electric car charging and hydrogen refueling stations will progress with active government support to increase battery electric vehicles (BEVs), plug-in hybrid electric vehicles

(PHEVs), and fuel-cell electric vehicles (FCEVs). To realize a new low-carbon energy supply chain, it is anticipated that charging and hydrogen refueling stations will have more attractive features. Examples include a demand response system for BEV and PHEV chargers that works as energy storage by absorbing fluctuating supply energy from renewables. Furthermore, stable power supply is expected by integrating these into smart grid networks. In addition to their role as fuel supply facilities for vehicles, hydrogen refueling stations are also anticipated to have different functions, e.g., as energy storage and conversion stations from electricity to hydrogen. As part of energy storage and supply networks, they supply natural gas-reforming hydrogen to local areas similar to community gas businesses. It may take a while for hydrogen to become widespread, because it is currently controlled under the High Pressure Gas Safety Act, which has strict regulations. Regarding negative aspects of BEVs and PHEVs, if such vehicles expand, power demand is likely to rapidly increase. However, successful charging infrastructure deployment for BEVs, PHEVs, and FCEVs will boost market penetration of these vehicles, and consequently they are anticipated to contribute to greater CO_2 emission reductions.

2.4 Part V: Electric Power Generation and Its Backend Technologies

Part V deals with electric power generation and its backend technologies. Electricity is the most important secondary energy in the modern world. It is converted from various primary energy sources, such as fossil fuels, uranium, and renewable sources. This part covers principal technologies for large-scale electric power generation systems connected directly to power grid systems, including the back end of the nuclear fuel cycle. Reviewing Japan's energy flow, 7.44 EJ primary energy from several primary energy sources was fed into the electric power generation system and converted into 3.97 EJ of electricity and nearly the same amount of rejected energy in FY 2010. In particular, the share of nuclear power generation was ~30 % before the Great East Japan Earthquake, contributing to securing a stable supply of energy and low CO_2 emission. Thermal power generation, which evenly consumes coal, natural gas, and petroleum as fuel because of energy supply security, has been the main electric power source since the 1960s (the strong growth period of the Japanese economy). These increased in importance after the earthquake. Owing to the country's mountainous land and warm oceanic climate, hydropower can generate electricity year round. In recent decades, pumped storage hydropower has increased for load leveling, especially in the summer peak season.

The share of solar, wind, and geothermal power generation is <1 %, whereas solar power generation has been greatly increasing after enforcement of the Japanese "feed-in tariff." The main renewable source is still hydropower. From the viewpoint of industrial structure, the country is unique in that many heavy industry companies, including contractors for nuclear power plants, compete with each other and thereby produce the most efficient electric power in the world.

In the fourth strategic energy plan, the national government described in their policy that "nuclear power is an important baseload power source." However, no disposal site for high-level radioactive nuclear waste has been identified. Also, Japan had ~47 tons of plutonium within and outside the country at the end of 2013. In this difficult situation, reprocessing technologies of used nuclear fuel for recycling fast breeder reactors may be a solution, in addition to recycling back into metal oxide nuclear fuel for thermal reactors. To avoid CO_2 emission in tail gas, imported hydrogen is expected in the future, even for large-scale power generation and carbon capture and storage technology.

2.5 Part VI: Primary and Secondary Sectors of Industry

Part VI describes primary and secondary sectors of industry. There are three major dimensions that each industry can explore to plan their contribution toward a sustainable society: (1) enhancement of efficiency, (2) increasing availability and the use of renewable raw materials and energy, and (3) cascade utilization of materials and energy beyond the borders of business entities, sectors, and locations. It is generally said that for (1), Japan is already a top performer in the world in many of its industries. For (2) and (3), there remains much room for exploration. In reality, the situation varies by industry. Therefore, which of the three dimensions should have more emphasis will vary by sector.

Chapters in this part describe road maps to transform current industrial sectors other than electricity (Part V) and residential and commercial (Part VII), toward a sustainable future. Among industries in the primary sectors, the focus is on forestry, wood, and agriculture. Historical, cultural, and technological aspects are explained, to better guide readers through issues confronting Japan within these industries. From the secondary sector, chemical industries are discussed, with various emphases on the aforementioned dimensions. Finally, because energy recovery from waste has emerged as an increasingly important topic in the coming decades, a chapter is devoted to this topic. The authors share their vision on how different sectors in Japan may engage in endeavors toward the formation of sustainable industrial systems through management of technologies and resources. Sustainable systems in primary and secondary industrial sectors based on renewable resources require coprosperity of urban and rural communities. The chapters also highlight how new technologies can help in this regard and where the opportunities lie in the envisioned societal circumstances. In addition, many interesting individual projects are presented to deepen understanding, based on actual examples.

Although greenhouse gas emission from Japanese industries currently contributes substantially to the global total, its quantitative importance will decline because of slowing population growth. Projects of the country's industrial systems can play key roles in creating and innovating advanced technologies that can first be applied in Japan and then in other parts of the world that are rapidly developing. Because Japan is facing sustainability challenges in advance of most countries and regions in Asia, its vision for adaptation to changing socioeconomic and environmental circumstances will provide a reference to many regions that will face similar challenges in the near future.

2.6 Part VII: Commercial and Residential Energy Utilization

Part VII addresses technologies for commercial and residential energy use. It deals with energy technology road maps in commercial and residential sectors. These sectors, which include homes and buildings, account for about a third of primary energy consumption in Japan, and their energy consumption has been continuously increasing in recent decades; this consumption in 2012 was 2.4 times greater than that in 1973. Hence, there is a great demand for reduction of energy consumption in the two sectors. As shown in the chapter by Kikuchi et al. in Part II, the residential sector consumes electricity (46 %), natural gas (26 %), and oil (27 %). Electricity, natural gas, oil, and coal account for 44 %, 27 %, 28 %, and 1 % of energy consumption in the commercial sector, respectively. In the residential sector, electricity is used for lighting, power supply, space cooling, and others. However, ~6 % of electricity use is dissipated by standby power; this energy loss should be reduced by a novel device using nanoelectronics technology.

Fossil fuels such as natural gas and oil are converted into heat for space heating, hot water supply, and cooking. Consequently, nearly half of consumed energy in both sectors is supplied as electricity, and the other half used as heat. Therefore, it is important to use electricity and heat efficiently and reduce losses of both energies in the commercial and residential sectors. From this point of view, combined heat and power (CHP) systems with fuel cells (FCs) were introduced in the residential market in 2009. At the end of 2014, a FCEV was launched in the Japanese market. As a result, the establishment of a hydrogen economy has been pursued in Japan. Moreover, after the Great East Japan Earthquake in 2011, distributed power generation such as gas-fueled CHP systems has gained attention for reinforcing energy resiliency and for improving energy utilization efficiency. These systems can supply electricity via islanded operation, even during outages. Therefore, introduction of CHP systems in Japan will be further promoted. In addition to improvement of energy efficiency of facilities, smart energy systems, in which distributed generators are connected to form a network with user equipment and power storage as nodes, have also attracted attention in the country. Examples are smart houses, smart communities, and smart cities. With this background, this part contains five chapters and two topics on energy technologies using electricity.

2.7 Part VIII: Transportation

Part VIII portrays technologies for the transportation sector. As next-generation automobiles, BEVs and FCEVs have been developed because they have high energy efficiency and low CO_2 emissions. However, as alternatives to gasoline cars, they have major problems such as mileage, price, and infrastructure.

Thermal management of automobiles improves their total energy efficiency, not only for internal combustion engines but also for BEVs and HEVs. Chemical heat pump systems can be driven by both engine waste heat and various waste heats in HEVs or electric power from charging equipment, saving on energy use with expensive batteries for heating and cooling.

Power electronics that facilitate DC-AC or AC-DC conversion of electric power are a critical technology for energy saving. Electrification of vehicles contributes to CO_2 emission reduction. Wide-bandgap semiconductors such as SiC or GaN, which can be driven at high frequency and high temperature with downsized converters, will be important in future power electronics.

The transportation section must achieve further reductions in fossil oil consumption and CO_2 emissions. ICEVs (including HEVs) are expected to remain dominant in 2050. The thermal efficiency of HEVs with next-generation ICEs will reach 50 % in the future, via ICE technology developments for high compression/expansion ratios, super lean combustion, and higher boost pressure.