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Positioning of Nuclear in the Japanese Energy Mix

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Executive Summary

Nuclear fission was discovered in the late 1930s. The first application went towards military use, and gradually expanded to civil use such as power generation. Power generation gained importance in two stages: firstly, to shift away from oil in power generation after the oil shocks in the 1970s, and second, to arrest climate change due to CO_2-free nature of nuclear power more recently. This typically applies to Japan, which has become the world third largest in nuclear power generation. However, nuclear power is violent by nature, and major accidents of nuclear power plants shook the public confidence in nuclear safety. Japan has been put into such situation in a most radical way due to the Fukushima nuclear disaster of March 2011.

This disaster may have its root causes in the history of nuclear development in Japan. Nuclear scientists failed to take the initiative in peaceful use of nuclear and lost the opportunity of making basic researches prior to the commercial introduction of nuclear power generation. Otherwise, safety issues could have been handled with greater care and "nuclear safety myth" could not have prevailed.

Today, the discussion is ongoing on how to position nuclear in the Japanese energy mix. Purely from economic viewpoint, due to the energy reality of Japan, it might be extremely difficult to sustain its economy without nuclear at least in short and medium term. However, the public opinions are divided with the vast majority in favor of zero-nuclear or decreased nuclear dependency.

In this context, employing an energy-economic model, an attempt was made to analyze Japan's power generation mix in 2030 under possible nuclear scenarios and assessed the role of nuclear energy in its energy mix. A technical implication taken form this analysis is that, if intermittent renewables such as solar and wind may largely diffuse in power grid replacing nuclear power, output fluctuation from high penetration level of these energy sources will be comprehensively accommodated by quick load following treatment by natural gas combined cycle, coal-fired power and pumped-storage hydro. Accordingly it will be important to coordinate and optimize multiple measures dynamically, together with technological innovation, for the treatment of the intermittency of renewables.

A newly born "energy democracy" in the post-Fukushima era will have impact on the government's decision on the future energy mix expected early in autumn. Whatever the decision might be, the Japanese energy structure has already started to change towards

further energy saving and efficiency. This will ultimately lead to the development of “a new energy model”, which will benefit all over the world.

Contents

Historical Perspective

This chapter outlines the historical perspective of Japanese nuclear policy and development. When the news ran through the world that Otto Hahn and Fritz Strassmann conducted experiments to discover nuclear fission at the end of 1938, the world military organizations started to develop nuclear weapon almost at once as it was on the eve of World War II. Among those, the Manhattan Project of the USA was most successful resulting in the world's first actual use of nuclear bombs in Hiroshima and Nagasaki in August 1945.

During this period, Japan also started to make research on nuclear weapons like other countries. "Rikagaku Kenkyujo" (The Institute of Physical and Chemical Research) played a key role in the effort to develop nuclear bombs. The Imperial Army strongly backed up this project. However, the research in Japan was no comparison to the Manhattan Project in its size and speed, with no tangible outcomes contributing to actual military application any time soon.

After the unconditional surrender of Japan in August 1945, the General Head Quarters, the Supreme Commander for the Allied Powers, completely forbidden any research related with nuclear in Japan. Accordingly, four cyclotrons held either by Rikagaku Kenkyujo or universities were destroyed. The moratorium was lifted when Japan recovered its independence after the effectuate+on of the San Francisco Peace Treaty in April 1952. The complete absence of nuclear research for this prolonged period might have left invisible but significant impact on the course of nuclear development.

Looking back from now, there were seven groups, among others, influencing the nuclear future of Japan particularly in the early years: scientists, politicians, the government, equipment and engineering industry, utility industry, the general public and the USA.

Scientists

In the early days after the lifting of the moratorium, scientists were largely divided on the way to deal with nuclear. This was typically the

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case when the Science Council of Japan discussed whether or not they should propose the foundation of the Atomic Energy Commission to the government in the second half of 1952. Those who supported this proposal intended to publicly authorize once-forbidden nuclear research under their own initiative. Those who opposed to this initiative worried about the risk of possible involvement with the US military strategy through nuclear research. The US atomic bombing of Hiroshima and Nagasaki followed by an intense nuclear arms race between the USA and the USSR undoubtedly cast shadows over the Japanese nuclear scientists.

Because of such division, scientists were not able to take a leading role in directing the nuclear future of Japan. It was a group of politicians who took the lead by introducing the first budget for nuclear promotion in 1954. Thereafter, scientists generally played an advisory or secondary role until today. If they had taken the initiative and prioritized basic researches, the treatment of nuclear safety could have been different as they were in the best position of knowing the risks involved with nuclear power generation.

Politicians

It was a group of politicians who moved impressively fast to set a clear direction in favor of the use of nuclear, particularly for power generation. In March 1954, barely three months after the Eisenhower's speech on "Atoms for Peace" at the United Nations in December 1953, the first draft budget to promote nuclear research and utilization was proposed by politicians led by Member of Parliament Yasuhiro Nakasone. The budget became effective in April 1954, naturally driving the government to that direction.

Matsutaro Shoriki, President of Yomiuri Newspaper and Nihon TV Group, also acted very powerfully towards introduction of nuclear power. He was appointed as the first Chairman of the Atomic Energy Commission in 1956 soon after being elected as Member of Parliament. He was afraid that the public protest against US nuclear test in the Bikini Atoll in 1954 might lead to the spread of communism in Japan. He worked closely with the Central Intelligence Agency to mitigate anti-nuclear and anti-US sentiment in Japan using every possible means including the media of his own. In a massive campaign launched by his group hailed nuclear energy as "the third fire" in contrast to combustion ("the first fire") and electricity ("the second fire"). He strongly advocated the importation of foreign technology and equipment to short-cut the process of introducing nuclear power generation in Japan.

In 1956, Hideki Yukawa, Nobel laureate in physics, opposed to this short-cut by stressing the importance of the basic research on nuclear reactor in Japan without jumping to established technology abroad. Yukawa's argument was stonewalled by Shoriki, which is symbolic of power imbalance between politicians and scientists mentioned above. His influence was used to form cohesive alliance between politicians and the nuclear-related industry as well.

The government

The government seemed to have been totally unprepared when the first nuclear budget was approved. Its amount was almost nominal, as little as 235 million yen (0.65 million US dollars), however, only 60 million yen were spent. The officials did not know what to do with this new budget, which fell on their shoulders out of blue. The budget increased by over 30 times in four years driving the government further towards nuclear promotion. In 1956, the Atomic Energy Basic Law and related legislations paved the way for several government institutions to promote peaceful use of nuclear: the Agency for Science and Technology, the Japan Atomic Energy Research Institute, and the Nuclear Fuel Corporation.

Nuclear-related government institutions had been expanded and evolved ever since. Local governments became increasingly involved with nuclear issues as the number of nuclear plants increased.

Equipment and engineering industry

The business community quickly responded to the initiative by politicians as commercial opportunity. In March 1956, the Japan Atomic Industry Forum kicked off encompassing a broad range of companies with interest in nuclear business, notably power generation. There also emerged groups of companies such as Mitsubishi, Hitachi, Sumitomo and Mitsui. These groups were normally formed around heavy electric equipment manufactures. The alignment was made with big foreign companies such as General Electric and Westinghouse as discussed in Chapter 2.

However, due to the moratorium on nuclear research for six years (1945-1952), the Japanese companies took many years to establish their own technological build-up. Therefore, in the early phase of the introduction of nuclear power generation, turnkey contracts were applied. Today, Japanese nuclear equipment and engineering companies are leading the international business, but there was a long way for them to reach this stage.

Utility industry

Japan suffered from power shortages in the early 1950s as power supply could not catch up with the speed of economic growth. The rolling blackouts were imposed frequently. Due to the limitation of sites suitable for hydro power generation, the expectation for nuclear option increased as a brand new source of energy. Turnkey contract, largely promoted by General Electric, looked attractive to power utility companies as it offered an access to matured technology and equipment at relatively reasonable costs. In a TV interview broadcasted in September 2011, former vice president of the Tokyo Electric Power Company said that no one cared much about the location of back-up generators for cooling system of Fukushima Daiichi No.1 reactor, which is symbolic of a downside of such contract leaving everything to the hands of the supplier until completion. Here is another episode. The location of the Fukushima Daiichi Plant originally was a terrace 35 meters above the sea level. However, the pumping motors of sea water for cooling allowed to pump up only 10 meters. TEPCO chose to cut the terrace by 25 meters instead of installing more powerful motors as the modification of the turnkey contract meant a huge additional expense for TEPCO (Note: The 3.11 tsunami was 15 meters high). Ever since, utility companies accumulated more knowledge and experience in operating nuclear plants together with the growth of indigenous nuclear equipment manufacturers and engineering companies.

The general public

The public opinion was generally against, or at best, extremely careful about nuclear for a decade or so after World War II. On top of the disaster in Hiroshima and Nagsaki, the exposure of the Daigo Fukuryu Maru, a Japanese tuna fishing boat, to the nuclear fallouts from the US hydrogen bomb test in the Bikini Atoll (March 1954) fueled the anti-nuclear sentiment in Japan. Under such circumstances, the promotion of nuclear power generation, first, needed the mitigation of the public sentiment against nuclear. Various efforts were made by Mastutaro Shoriki, the government and utility companies. Over time, Japanese public sentiment shifted in favor of nuclear power generation. “Nuclear safety myth” developed by the government and utility companies had gradually been planted in the mind of people.

This is why the public reactions were so acute to the Fukushima nuclear disaster, which has shuttered the belief in almost legendary nuclear safety.

The USA

The US influence was critical on the promotion of nuclear power generation in Japan. Firstly, it was to the direct benefit of the US to export their nuclear technology and equipment to Japan. On top of this, exporting nuclear fuels, namely enriched uranium, offered an important business opportunity to the uranium mining industry there. Second, in the Cold War era, it was imperative for the US to promote the economy of countries in the Western block to demonstrate the excellence of the West vis-a-vis the communist block. To strengthen Japanese economy through introducing nuclear power was in line with such US strategy.

This is why the US government made a continuous and serious effort to alleviate the allergy to nuclear in Japan. There are many evidences that the CIA played an important role in Japan in support of the US strategy as above. Some government officials, who were involved with the promotion of nuclear power in the late 1960s and the early 1970s, hinted that Japan was not in a position to be able to say “No” to the USA on nuclear policy in those days.

Technological Perspective

This chapter mainly reviews the feature of adopted nuclear technology in Japan in contrast to that in the USA and France, which three countries play a leading role in world nuclear industry. A majority of countries already introducing nuclear power plant currently install either pressurized water reactor (PWR) or boiling water reactor (BWR) or both. PWR is originally developed for submarine power generator in the USA. Nowadays in the world nuclear market, PWR is the most common technology and approximately 70% of world nuclear power plant adopts PWR-type, although Japan and the USA use both PWR and BWR technologies. Technological difference between PWR and BWR is that the steam produced by uranium fuel directly or indirectly drives the steam turbine to produce electricity.

Japan

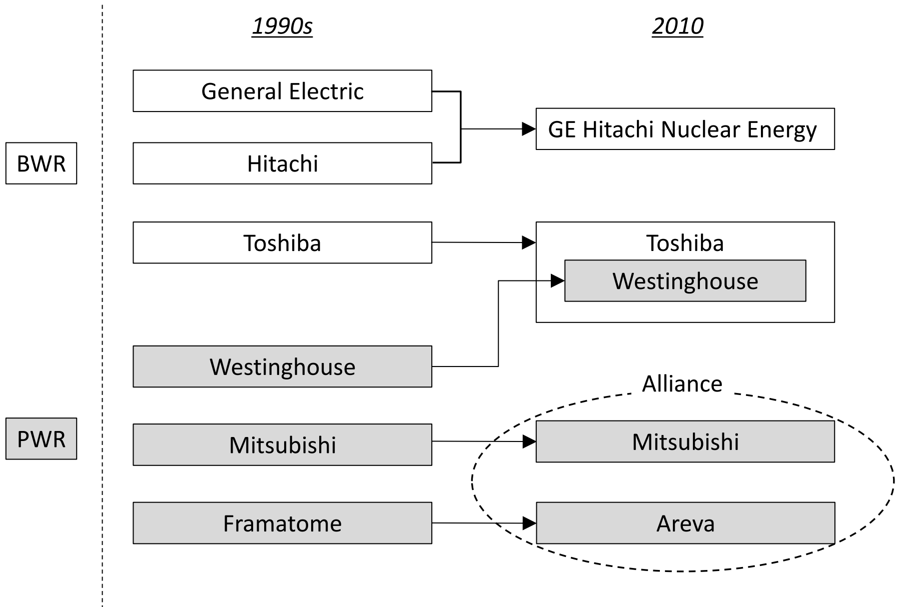
In 1966, Japan began with first operation of commercial nuclear power plant in Ibaraki Prefecture. Just before the Fukushima nuclear disaster, Japan held 54 reactors, explaining around one-third of total electric power generation in Japan. For resource-poor country like Japan, nuclear energy has greatly contributed to energy security by reducing the energy-equivalent of around 440 million barrels of oil per year, which corresponds to about 20 % of total annual crude oil imports. In addition, nuclear has made a significant contribution to climate change issue as well. In 2007, nuclear power generation served as potentially mitigating Japan's total CO_2 emissions by 14%. In this sense, nuclear power has played an important role as a major energy supply source.

Industrial overview

30 BWRs, including 4 ABWRs (advanced BWR), and 24 PWRs have been constructed so far in Japan, backed by political support which promotes nuclear as a national strategic priority since the first oil crisis. Japan is one of a few countries which have a system of full closed nuclear fuel cycle including enrichment and reprocessing of waste fuel for recycle. Japanese nuclear industry is led principally by three companies, Toshiba, Hitachi and Mitsubishi Heavy Industry. In 2006, Toshiba, which is competitive in BWR technology, absorbed Westinghouse with its advanced PWR technology, which enables

Toshiba to deploy both BWR and PWR in the world market. Toshiba and Westinghouse jointly obtained type approval certification of advanced BWR (ABWR) from the US Nuclear Regulatory Commission (NRC) and are aggressively pioneering foreign nuclear market. Hitachi, being strong in BWR, established a joint venture corporation with General Electric (GE) and attempts to do business in global market through selling ABWR with highly-modularized engineering process. Mitsubishi Heavy Industry with advanced PWR technology made alliance with AREVA NP in developing advanced PWR (APWR) so as to compete in the global nuclear market Figure 2-1 illustrates the review of Japanese nuclear industry and the status of the alliance for foreign company.

Figure 2-1. Outline of nuclear industry in the past and the present



(Source: T.Murakami, "World Nuclear Power Generation Markets and Prospects for Nuclear Industry Realignment", IEEJ Energy Journal, vol.33 No.2 (April 2007))

Closed nuclear fuel cycle

Simply for energy security reasons, Japanese nuclear policy has been to maximize the utilization of imported uranium by domestically recycling the unburned portion of uranium and plutonium as mixed-oxide fuel (MOX) in "pluthermal" reactor and in fast breeder reactor (FBR). It is called as a closed nuclear fuel cycle policy, aiming at enhancing the role of nuclear as quasi-indigenous energy sources, as depicted in Figure 2-2. By contrast with the USA, the Japanese Atomic Energy Commission (AEC) prioritized the recycling of spent fuel rather than direct disposal. The implication of the closed fuel cycle is straightforward:

- (a) It conserves imported uranium resources.

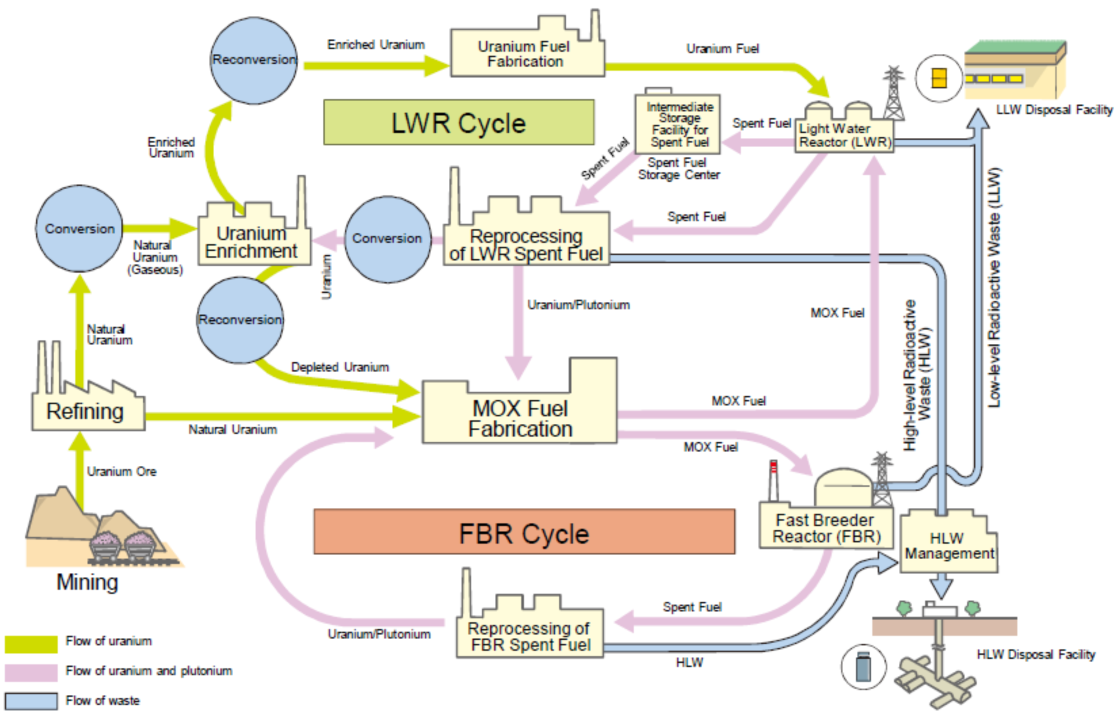
- (b) It reduces the reliance on imported fuels and enhances energy security.

- (c) It reduces the amount of high-level radioactive waste (HLW).

Reprocessing is a technological process that recovers plutonium and reusable uranium from spent fuel mainly from light water reactor and separates radioactive wastes into more manageable forms. The Rokkasho-mura reprocessing plant located in Aomori prefecture, northern part of Japan, was due to begin with commercial operation in November 2008, which reprocessing capacity is designed to 800 ton/year. Also in Rokkasho-mura village, the used fuel storage capacity is arranged at 20,400 ton as well. The starting date of the operation is, however, now postponed to October 2012. This ongoing delay is mainly attributable to accidents in on-site verification process for HLW which is domestically designed.

In addition, Japan Nuclear Fuel Limited (JNFL) is currently engaged in operating both LLW (low level radioactive waste) and HLW storage facilities, and also in doing uranium enrichment. In the past, Japan has relied on countries such as the U.K. and France to reprocess most of the spent fuel generated in Japan.

Figure 2-2. Japan's nuclear fuel cycle

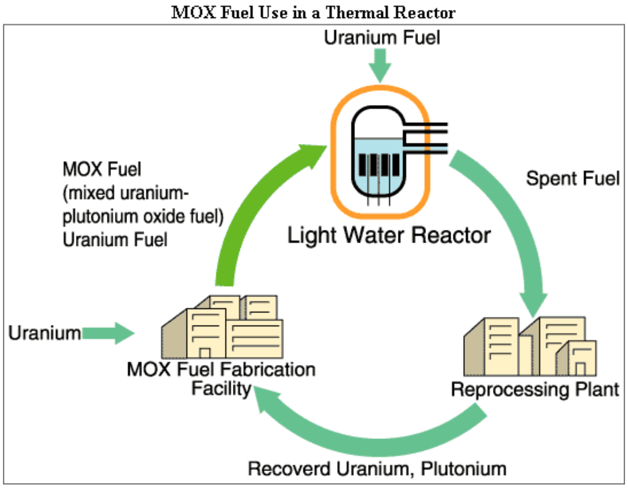


(Source: The Federation of Electric Power companies in Japan)

Pluthermal reactor and Fast breeder reactor (FBR)

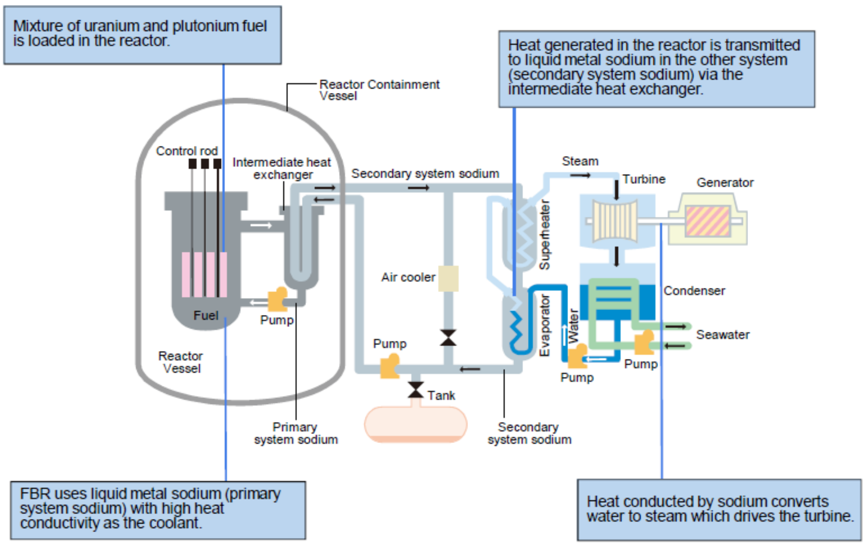
The term "pluthermal" refers to the use of plutonium in thermal reactor, that is, light water reactors as shown in Figure 2-3. The fuel is made from a mixed oxide of plutonium and uranium (MOX), recovered from the abovementioned chemical processing. According to the current plan, pluthermal will be implemented at some 16-18 reactors by 2015 instead of by 2010, and about 6 tons of fissile plutonium per year is expected to be commissioned into light water reactors. After the Fukushima nuclear disaster, however, it is uncertain whether the plan promoting MOX fuel consumption in light water reactor is implemented on schedule or not.

Figure 2-3. MOX fuel usage in pluthermal reactor in Japan



(Source: The federation of electric power companies in Japan)

Figure 2-4. Overview of fast breeder reactor in Japan



(Source: The federation of electric power companies in Japan)

The emphasis of Japanese nuclear policy has been put on developing fast breeder reactor (FBR) in order to effectively consume uranium fuel. FBR is a nuclear reactor which will produce more fissile material than it actually consumes, and the term “breeder” refers to this type of phenomena. The breeding reaction is to produce fissionable plutonium-239 from non-fissionable uranium-238. Non-fissionable uranium-238 is more abundant than fissionable uranium-235 which is consumed in typical light water reactor (LWR). FBR efficiently utilizes uranium resource in terms of converting non-fissionable uranium-238 into fissionable Pu-239 within the reactor. As of 2005, the commercialization of FBR in Japan was envisaged by 2050.

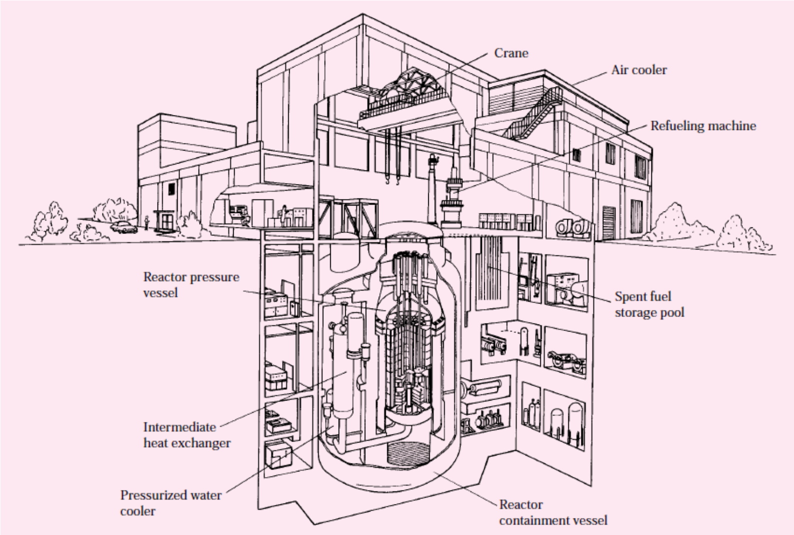
In order to smoothly promote nuclear fuel cycle, Japan has been elaborately engaged in the research of FBR consuming recovered plutonium in the recycling process. At first, Joyo experimental FBR in Tokai has been operating successfully since it reached first criticality in 1977, and has accumulated a lot of technical data so far. After that, 280 MW Monju prototype FBR started operation in 1994, but it was shut down due to a sodium leakage in its cooling system during experimental operation in 1995. In 2010, Monju restarted on trial basis for the first time since the 1995 accident, but it shut down again due to the falling of refueling equipment into the reactor vessel. The collapse of the public confidence in nuclear safety after March 2011 could make FBR future even harder.

Research & Development

Japan plays a leading role in developing high temperature gas-cooled reactor (HTGR) as shown in figure 2-5. JAEA created small prototype gas cooled reactor, the 30 MWt High Temperature Engineering Test Reactor (HTTR) in 1998. This was Japan's first graphite-moderated and helium-cooled reactor. It runs at 850°C and achieved 950°C in 2004. This high level of temperature will allow its application to chemical processes such as thermochemical production of hydrogen. By 2015 an iodine-sulfur plant producing 1000 m3/hour of hydrogen is expected to be installed to ensure the performance of HTTR.

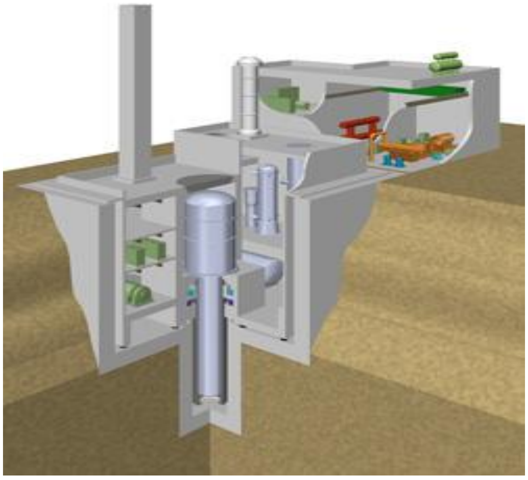
The design of Toshiba 4S (Super Safe, Small and Simple) reactor, illustrated in Figure 2-5, is also developed jointly by Toshiba and the Central Research Institute of Electric Power Industry (CRIEPI) of Japan. The 4S reactor is a fast reactor adopting sodium as coolant and is designed on the basis of passive safety concept. The small-scale modulated unit (10MW～50MW) will be installed in underground level, and will continue to operate without refueling for about three decades.

Figure 2-5. High Temperature Engineering Test Reactor (HTTR) in Japan



(Source: Japan Atomic Energy Agency)

Figure 2-6. 4S (Super Safe, Small and Simple) reactor



(Source: United States Nuclear Regulatory Commission, http://www.nrc.gov/reactors/advanced/4s.html)

The USA

Due to unfavorable public acceptance, sluggish electricity demand and electricity market deregulation, the opportunity of building new nuclear power plants has significantly decreased in United States. Hence, most of US nuclear companies are affiliated with foreign companies in search for business opportunities in foreign market. General Electric (GE) is an exception taking advantage of its competitiveness in manufacturing BWR (boiling water reactor). As the result of electricity market unbundling which tends to discourage large scale investment like nuclear, enhancing capacity factor of existing nuclear power plants has gained higher priority rather than new construction, which makes it important to ensure enough human resources for maintenance and operation of nuclear power plants. However, nuclear development for military purpose like submarine remains still active supported by the US DOE (Department of Energy) and DOD (Department of Defense).

In the USA, both PWR (pressurized water reactor) and BWR light water reactors have been constructed, and 69 PWRs and 35 BWRs are currently operating. The total capacity of PWR amounts to 67 GW, and that of BWR, 34 GW, which suggests that PWR is the dominant reactor type in the USA. The original design of PWR, which consumes enriched uranium oxide fuel and cooled by light water serving for both coolant and high pressure, is developed by the Argonne National Laboratory (ANL) and Westinghouse (WH). Starting with the original application for submarine, PWR reactors have eventually become most common in the USA. Due to the impact of TMI accident and continuously cheap natural gas price, new nuclear plants have not been constructed since 1977. Reflecting on the Tennessee Valley Authority's (TVA's) decision in 2007, however, the construction process of additional PWR reactors is expected to begin in the upcoming several years.

France

In Europe, due to TMI accident in 1979 as well as Chernobyl nuclear accident in 1986, the construction of new nuclear plants has been stranded. However, France has traditionally maintained extensive nuclear technology and strongly promoted the standardization of nuclear power plant. Before TMI accident, France already introduced a large scale of nuclear power plant and established its competitiveness. In Europe, France currently plays a central role in developing European pressurized reactor (EPR), which received French standard design endorsement in 2004 from the French Nuclear Safety Authority (ASN).

Type of nuclear power plant in France is dominated by PWR, which design is perfectly standardized and is further categorized into following three: Areva NP with combined capacity 900 MW, 1300 MW and 1450 MW. 900 MW type accounts for 34 units, 1300 MW type, 20 units, and 1450 MW type (called N4 type), 4 units. France has previously taken leading initiative in the area of advanced fast breeder reactor as well by commissioning Phénix and Superphénix. However, Mr. Lionel Jospin, French Prime Minister, announced the closure of Superphénix in 1997 due to its excessive costs. Many argued that the closure might have been politically motivated to accommodate with the demand from “Les Vertes (green party)”, one of coalition parties of his government. Even after the closure of

Superphénix in 1997, Phénix continued to operate until 2010 and was mainly dedicated to the research on the transmutation of nuclear waste.

This chapter reviews policy aspect of nuclear energy in Japan's energy mix.

The evolution of energy mix

The tables below show the evolution of Japan's energy mix, where the share of nuclear grew impressively. After commissioning the first commercial nuclear reactor in 1966, the number increased to 55 by the mid-2000s. Considering the following constraints, this growth could be called as "miracle":

- (a) Japan is the only country having suffered from atomic bombing, where the allergy to nuclear was extremely acute.
- (b) It's land is only 378 thousand km^2, the 64^{th} largest in the world, with many islands.
- (c) It is very mountainous and only some 30% of the land is suitable for agricultural, industrial and residential use.
- (d) With population over 127million, the population density is 336 person/km^2, the 34^{th} highest in the world.
- (e) It is well known for frequent earthquakes (occasional tsunamis) with various active fault lines running across the country.

Table 3-1. Japan's Energy Mix (Total Primary Energy Supply)

(%)	1952	1962	1973	1980	1990	2000	2009	2030**
Coal	49	35	18	17	17	18	21	17
Oil	11	47	78	66	57	51	46	31
Natural Gas	-	1	2	6	10	13	18	16
Nuclear	-	-	1	5	10	12	11	24
Hydro	32	13	2	5	4	3	3	13***
Renewables	*							

Note: * wood/ charcoal ** The Basic Energy Plan (June 2010) ***Hydro+Renewables (Source: METI)

Table 3-2. Japan's Energy Mix (Power Generation)

(%)	1952	1962	1973	1980	1990	2000	2009	2030**
Coal	20*	33	8	44	10	18	25	2
Oil		22	73	5	27	9	6	11
Natural Gas		0	2	17	24	27	30	13
Nuclear	0	0	2	17	27	34	29	53
Hydro	80	44	14	17	12	10	8	21***
Renewables	-	-						

Note: *Total share of thermal power **The Basic Energy Plan (June 2010) ***Hydro+Renewables (source: METI)

Expectations for nuclear power

Why the miracle had really taken place? The process of the introduction of nuclear power was not necessarily made in an orderly or rational manner as seen in Chapter 1. Some administrative decisions were made, in somewhat "patch-work manner", to catch up with high expectations for nuclear power. The real driver was perceived merits of nuclear power for a resource-poor but fast-growing economy. Indeed, its GDP growth was extremely fast like China today shown as follows, when Japan was shifting its course towards nuclear.

Annual average GDP growth in Japan

1952–1961 9.7%

1962 – 1972 10.2%

The following reasons were publicly advocated to justify or support nuclear option. Interestingly enough, the emphasis varied reflecting the needs of time.

- (a) Nuclear saves foreign currencies for oil imports(the 1950s ~ the mid 1960s).
- (b) Nuclear is cost effective energy (the 1950s ~ the mid 1990s).

- (c) Nuclear contributes to the energy security (the mid 1960s ~ today).

- (d) Nuclear is "quasi indigenous" energy (the mid 1970s ~ today).

- (e) Nuclear is climate-friendly energy (the 1980s ~ today)

Among those, "quasi indigenous" nature of nuclear power strongly appealed to policymakers. Japan's energy self-sufficiency will go down from 19% to only 4% without counting nuclear power (note: prior to Fukushima). From climate policy perspective, nuclear energy gained renewed importance due to its CO_2-free nature. This is evident from the fact that nuclear power was given extremely high shares for 2030 in the Basic Energy Plan issued by the government in June 2010 as shown in the above two tables.

Post-Fukushima Developments

The impact of the Fukushima nuclear disaster has been far bigger than that of the oil shocks of the 1970s. The latter was due to the actions by the OPEC hitting oil importing countries worldwide and Japan was not alone. The former was considered to be a manmade disaster triggered by the earthquake and tsunami in March 2011, which happened in a country with extremely advanced technology and excellent safety records. The legendary confidence in nuclear safety in Japan has been utterly shattered.

Various developments

Many things took place in parallel after the Fukushima nuclear disaster, which is self-explanatory of the wide-ranging impact of the disaster.

- ① Planned blackouts and rigid power conservation in the Kanto region with over 30 million people, and to a lesser extent nationwide (spring and summer in 2011),
- ② Assistance to the people evacuated from the radioactive contaminated areas,
- ③ Radioactive decontamination of affected areas,
- ④ Compensation for the damages from the nuclear disaster,
- ⑤ Nationalization of TEPCO to avoid bankruptcy (completed in August),
- ⑥ Procurement of LNG and heavy fuel oil for power generation to make up for the loss of nuclear,
- ⑦ Feed-in tariff to promote renewable energy introduction (from July),
- ⑧ New nuclear safety and regulatory regime (from September) ,

- ⑨ New energy and environment strategy (to be decided in September),

- ⑩ Public comments on the power generation energy mix scenarios in 2030 (from July to August),

- ⑪ Restarting of nuclear power plants (first two reactors restarting in July),

- ⑫ Parallel investigations on the causes of the nuclear accident

Parallel Investigations

One of the important initiatives as above is the investigation on the causes of the disaster. It ranged from a private initiative (1) to a parliamentary one (4) as below.

- ①The Independent Investigation Commission on the Fukushima Daiichi Nuclear Accident (Founded by the Rebuild Japan Initiative Foundation: Report on 28 February 2012),

- ②The Fukushima Nuclear Accidents Investigation Committee (established by TEPCO: Interim Report on 2 December, 2011: Final Report on 20 June 2012),

- ③The Fukushima Nuclear Accident Independent Investigation Committee (established by the Parliament: Report on 5 July 2012),

- ④The Investigation Committee on the Accident at the Fukushima Nuclear Power Station of Tokyo Electric Power Company (established by the Government: Interim Report on 26 December 2011, Final Report on 23 July 2012),

Each of these contributed to unveil the complexity of the situation as well as organizational and managerial problems in multiple ways. The main points of these reports are highlighted in Table 4-1 below. Among these, the following message from the report by the committee established by the parliament run through the world: "It was profoundly manmade disaster－that could and should have been foreseen and prevented." This will be the most fundamental feature of the disaster, which should be fully taken into account in all aspects of energy policymaking and business onwards.

Table 4-1. Main Points of Four Investigation Reports

Report (Release date)	Private Report (28 Feb. 2012)	TEPCO's Report (20 June 2012)	Parliamentary Report (5 July 2012)	Government Report (23 July 2012)
Main message	Nuclear safety myth	Beyond assumptions	Manmade disaster	Disaster preparedness
Main or root causes	-Lack of preparation against tsunami and severe accidents,	-Complete loss of power source functions for cooling due to the flooding,	-Lack of precautionary measures by TEPCO despite many warnings,	-Stoppage in cooling of reactors & spent fuels, due to the flooding,
Government	-Vulnerability in crisis management, -Unprofessional crisis communication,		-Lack of preparation to respond to emergency of this magnitude, -Interventions by Prime Minister to disturb the chain of command,	-Disorder in crisis management, -Delayed declaration of the state of emergency, -Ambiguity in risk communication,
Regulatory body (NISA, NSC)	-Lack of governance on safety regulation, -Fallen under the control of TEPCO,		-"Regulatory captive" to TEPCO, -Failure to function in a mega emergency,	-Insufficient role on prevention measures, -Incompetence in emergency response,
TEPCO	-Organizational negligence in crisis preparation, -Ambiguous behavior during the crisis,	-Taken precautionary measures instructed by the authorities, -Overwhelmed by the magnitude of accident, -Insufficient publicity,	-Lack of preparation to respond to a mega emergency, -Unclear behavior to add confusion to overall crisis management,	-Vulnerability in emergency response capabilities, -Lack of high-level safety culture,
Recommendati-ons & lessons	-New regulatory body with independence and with professionals to cope with severe accidents or terrorism, -Intensification of nuclear security measures,	-Preparation against contingency beyond "assumptions", -Ability to avoid the total loss of power source functions, -Timely & transparent public relations,	-New regulatory body with independence, transparency & professionalism, -Fundamental reexamination of crisis management system, -Dramatic reform of TEPCO, -Monitoring of all operators by the Diet,	-Fundamental disaster prevention measures, -Deficiency analysis from the victims' side, -New regulatory body with independence & transparency, -Further investigation on the whole picture of the accident causes & damage,

The new nuclear regulatory regime

The law to establish the Nuclear Regulatory Commission was enacted on 20 June 2012 enabling to start a new nuclear regulatory regime from September. The Commission, supported by the Nuclear Regulatory Agency as the secretariat, is expected to unify the regulatory process which used to be stretched across several institutions including the Nuclear and Industrial Safety Agency (NISA) under METI. The authorities given to the Commission is far more powerful compared to those under the current regime. The lessons from the disaster and the best practices of foreign countries seem to be duly taken into account in this initiative.

Restarting of nuclear plants

On 5 May 2012, the Tomari nuclear plant (in Hokkaido) stopped for regular maintenance and inspection required by law in every 13 months. Since then, there were no nuclear plant operating in Japan. With the arrival of summer season at hand, there was a strong drive by the government and the business community towards restarting particularly in the service area of the Kansai Electric Power Company (KEPCO), which used to rely on nuclear almost a half of its power supply.

On 8 June, Prime Minister Noda made an exceptional press statement on the need to restart No.3 and 4 reactors at KEPCO's Oi nuclear power plant by saying "The measures and system to secure safety are already in place to prevent nuclear accidents from happening even if hit by Fukushima–scale earthquakes and tsunami.---It is my judgment to restart No. 3 and 4 reactors of the Oi nuclear power plants to protect the life of the people.---". This statement let the prefectural governors agree on restarting, which led to the restart of No.3 unit on 1 July and No.4 on 21 July. Although enthusiastically welcomed by the business community, this decision fueled the ant-nuclear movement in Japan. Reportedly, there are a few more reactors expected to restart in the course of this year.

This decision in itself is very controversial as it was taken before the establishment of new nuclear regulatory regime. Nor this decision did not wait for the release of the reports by the investigation committees established by the parliament and the government.

Energy democracy

The Japanese energy policy had been decided previously by a limited number of people, namely government officials, energy companies, academics and well-informed politicians. It was so far so good until the credibility of nuclear safety collapsed as above. For the first time, "energy democracy" has been brought forth in this country. There is no guarantee that democracy will lead us to better decisions. However, a good thing is that more people pay attention to energy issues.

Taking this newly born democracy into account, the government prepared three options (with nuclear share in power generation varying from 0%, 15% to 20-25%) for public comments and debates in July and August. Implications of each option are analyzed in Chapter 5. Originally, the government planned to take decision on an innovative energy and environment strategy by end August taking these public opinions into account. However, due to wide ranging views expressed through this process with the majority in favor of nuclear phase out, it is likely that the final decision will be deferred till September.

Long-term Energy Scenarios

This chapter reviews energy planning developed by the Japanese government before and after the Fukushima nuclear disaster and analyze Japan's power generation mix for 2030 employing an energy-economic model under possible nuclear energy scenario.

Energy Scenario before the Fukushima nuclear disaster

Essential principles embodied in Japan's policy with respect to energy supply and demand appear in the Basic Act on Energy Policy of 2002. The Act defines the three pillars upon which Japanese energy policy rests: securing a stable energy supply; assuring environmental compatibility; and utilizing market mechanisms.

To formulate concrete political and technological measures for accomplishing the goals described in the Basic Act, the Japanese government developed the Basic Energy Plan fully achieving the provisions of the Act. This Plan developed in 2010 specified and recommended systematic implementation of a broad range of both technologies and policies influencing energy supply and demand. The Plan was completed based on long-term energy demand and supply outlook. The following is the gist of the Basic Energy Plan enacted in 2010, and Figure 5-1 and 5-2 represent energy outlook to 2030 in the Plan developed before Fukushima.

Basic perspective

The Plan has highlighted, as a basis for Japan's energy policy, "realization of steady economic growth", "structural reform of energy market" and "3E's" which are composed of "energy security," "environmental protection" and "economic efficiency".

Energy and environmental goals to 2030

To respond appropriately to anticipated resources and environmental restrictions, which are likely to tighten over the medium and long term, it will be essential to implement reforms targeting not only the energy market but also extending to social systems and lifestyles, taking into account the lead-time in which those reforms actually take effect. The Plan provides specific measures until 2030, while at the same time introducing concrete numerical targets for energy resources supply stability in a following manner.

- Doubling energy self-sufficiency ratio to 70% by 2030 from 38% at present.
- Raising zero-emission power source ratio to 70% by 2030 from 34% at present.
- Halving CO_2 emissions in residential sector.
- Maintaining and further enhancing energy efficiency in industrial sector currently at the highest level in the world.
- Obtaining large-scale shares of global markets for energy-related products.
- Mitigating energy-related CO_2 emissions by 30% until 2030 from the 1990 level.

Figure 5-1. Primary Energy Supply Goals in the Basic Energy Plan in 2010.

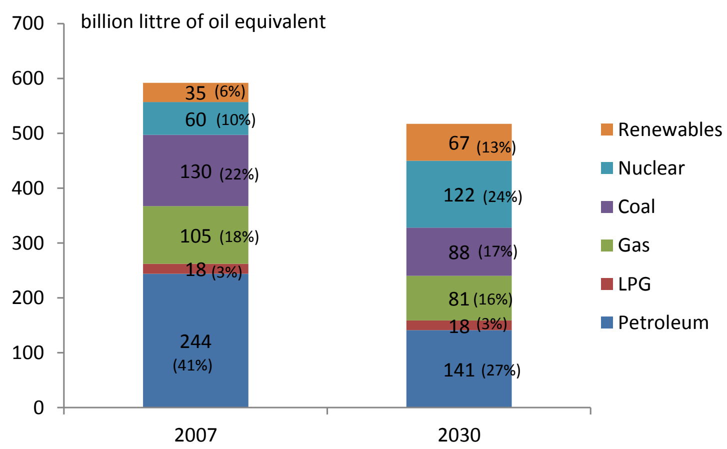
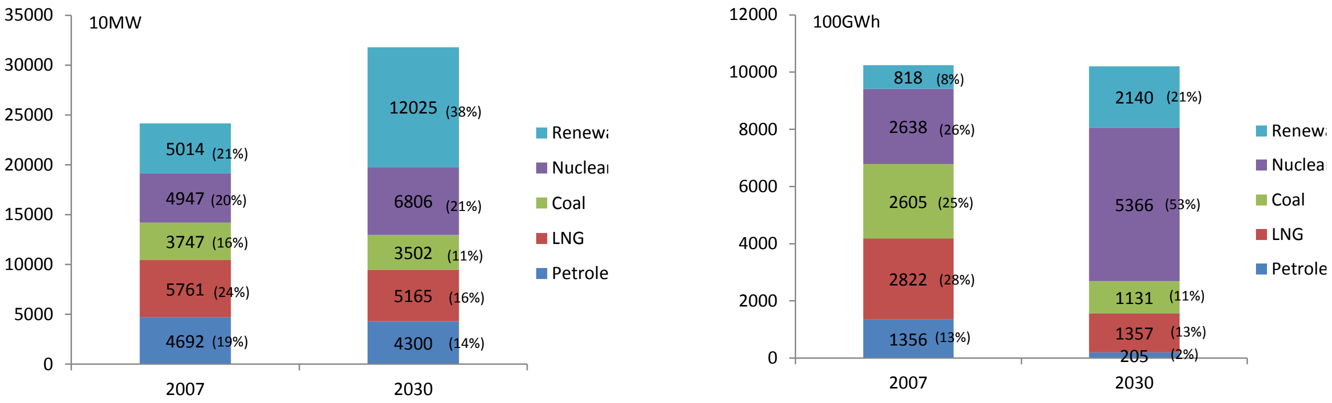


Figure 5-2. Goals of power generation mix in the Basic Energy Plan in 2010



(a) Power generation capacity (b) Power generation

And the following technological and institutional measures are envisaged in the Plan in order to achieve the abovementioned goals.

Expanding renewable energy

- ・Expanding the feed-in tariff system in PV, wind, small-size hydro, geothermal, and biomass.
- ・Strengthening a broad range of support for deployment through R&D support, initial cost support, tax reduction etc.
- ・Controlling Power grid stabilization and relevant deregulation.

Promoting nuclear power generation

- ・Building 9 additional nuclear plants with achieving capacity factor at 85% by 2020 and more than 14 with further enhancing the factor at 90% by 2030.
- ・Achieving long-term plant operations and shortening the maintenance period for regular inspections.
- ・Completing the nuclear fuel cycle establishment including the development of "plutonium-thermal" and fast breeder reactors.
- ・Encouraging international cooperation for nonproliferation and nuclear safety.

Advanced utilization of fossil fuels

- · Mandating in principle to reduce CO_2 emissions of newly-constructing coal-fired plants to IGCC plant levels in principle by early 2020s.

- · Accelerating CCS (carbon capture and storage) technology development aiming at an early commercialization around 2020, requiring by 2030 new coal-fired plants to be equipped with CCS technology.

- · Spreading overseas these advanced clean coal technologies (CCT) and promoting domestically further technology development and demonstration.

Enhancing electricity and gas supply systems

Realizing the world's leading advanced smart grid network in early 2020s.

In terms of achieving the abovementioned energy security and environmental goals, nuclear development, depicted as building more than 14 plants by 2030, was supposed to play an indispensable role. However, this became quite uncertain after Fukushima for obvious reasons. Therefore, the next section investigates Japan's energy outlook considering possible future nuclear energy scenario employing energy-economic model.

Possible Power Generation Mix Scenario after the Fukushima nuclear disaster

After the Fukushima nuclear disaster, the Japanese government has been planning to rewrite an existing basic energy plan and find out a best energy mix to 2030.

Currently, an advisory panel in METI (Ministry of Economy, Trade and Industry) compiled three options and several references for possible power generation mix in 2030, as shown in Table 5-1, which could potentially work as a basis for Japanese government to finalize the best energy mix: (Option 1) the share of nuclear in Japan's total power generation in 2030 to be reduced to zero; (Option 2) the ratio of nuclear to be reduced to 15 percent; (Option 3) the share of nuclear to be maintained somewhere between 20 and 25 percent.

Table 5-1. Three options of power generation mix in 2030.

	Nuclear	Renewables	Thermal Power	Energy saving + cogeneration
Option 1	0%	35%	50%	15%
Option 2	15%	30%	40%	15%
Option 3	20-25%	25-30%	35%	15%
Reference 1	35%	25%	25%	15%
Reference 2	Market mechanism determines optimal energy mix			
Basic Plan (Before Fukushima)	45%	20%	23%	12%
FY 2010	29%	10%	61%	-

During the discussion associated with the proposed three options, the target of stabilizing the Japan's dependence on nuclear to 35 percent was set aside as a "Reference" and excluded from the list of the options, reflecting on the opposition from some members of the panel. An idea of setting no quantitative goals and letting the market mechanism to decide the power generation mix was dropped off as well. Among those options, a majority of business community tends to oppose lower nuclear options such as Option1, because they have a concern that a radical reduction in dependence on nuclear energy from current levels (29 percent of total power generation in FY 2010) may cause a sharp increase in reliance on thermal and renewable power leading to increase in electricity costs. By stark contrast, a wide-ranging people seriously concerned with nuclear safety after Fukushima seem to strongly favor a zero-nuclear option or reduced nuclear dependence at best.

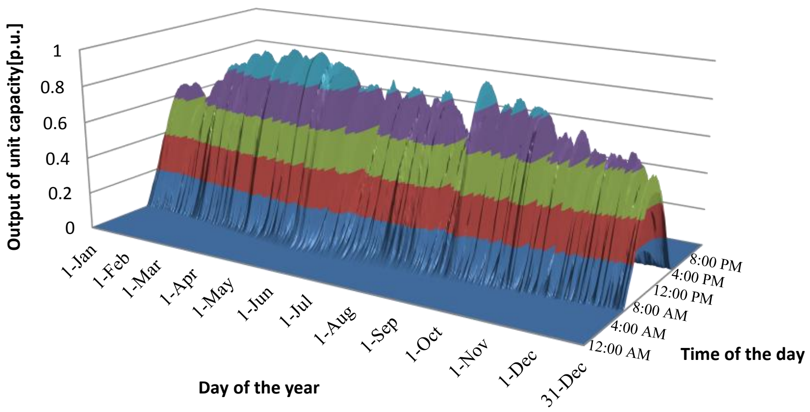
The Japanese government is planning to hold the meeting of the Energy and Environment Council sometimes in September in order to determine one optimum energy mix in 2030, not necessarily limited to those three in the list, which will be taken into consideration in determining Japan's next basic energy plan.

Power generation mix scenario after the Fukushima nuclear disaster

The compiled three options for possible power generation mix, as illustrated in Table 5-1, tend to show a high ratio of renewable energy in total power generation in 2030. All three options assume massive deployment of solar power to 53 GW and Option1 envisages wind power installation to 60 GW, 35GW for Option2 and 15GW for Option3. Solar and wind power output, however, will largely fluctuate depending on weather condition and is considered to be difficult to harmonize with existing power grid mainly comprised of thermal, nuclear and hydro power. Therefore, it is important to analyze the technological feasibility for such a large-scale deployment of variable renewable energy in power generation mix as indicated in Table 5-1.

Considering the energy mix in the proposed three options, this section simulates Japan's optimal power generation mix and investigates the technological viability of progressive introduction of renewables, employing optimal power generation mix model.

Figure 5-3. PV output pattern of Japan in 365 days at ten-minutes' interval (2007)



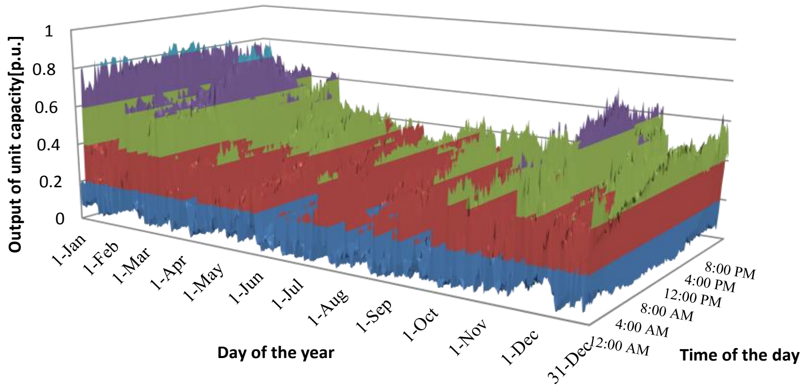
Solar and wind power generation in Japan

AMeDAS (Automated Meteorological Data Acquisition System) is a weather observation system that covers the Japanese archipelago. The system encompasses about 1,300 places, and measures precipitation, wind direction, wind velocity, temperature and duration of sunshine by automatic operation at ten-minutes' interval. The yearly time profile of the regional average outputs of PV power generation at ten-minutes' interval on 686 observation sites in Japan is estimated by using the numerical solar irradiance model with AMeDAS observation data on sunshine duration, precipitation and ambient temperature.

The estimated PV output in Japan at ten-minutes' interval in 365 days during the year 2007 is shown in Figure 5-3, which indicates that PV output tends to be larger in summer and smaller in winter.

Japan's total output of wind power generation at ten minutes' interval is estimated by employing the AMeDAS metrological observation data as well. In Japan, the majority of onshore wind resources concentrate in Hokkaido and Tohoku regions (Northern part of Japan). Therefore, the whole patterns of wind output in Japan are calculated using a weighted average of the derived regional wind power output in the amount of regional wind resources. Figure 5-4 illustrates wind power generation pattern in the resolution of ten minutes in 365 days a year.

Figure 5-4. Wind output pattern of Japan in 365 days at ten-minutes' interval (2007)



Simulation result

Figure 5-5 and Figure 5-6 show the configuration of power generation mix in the proposed options in terms of power generation and capacity respectively considering the potential of renewables. These results are consistently calculated with optimal power generation mix model, which is capable of analyzing optimal power dispatch in time resolution of ten minutes on 365 days a year under various technical constraints using linear programming technique. Detailed information of the model is available in a following paper: R.Komiyama, S.Shibata, Y.Fujii" Simulation Analysis for Massive Deployment of Variable Renewables employing an Optimal Power Generation Mix Model" Proceedings of 35th IAEE International Conference (2012). In Option1, nuclear zero scenario, at Figure 5-5, the ratio of wind power accounts for 10% of total power generation and the share of intermittent renewables including solar and wind adds up to 18%. It is, hence, necessary to simulate and ensure the technological feasibility of accommodating large-scale variable renewables in power generation mix.

Figure 5-5. Power generation mix (electric power generation)

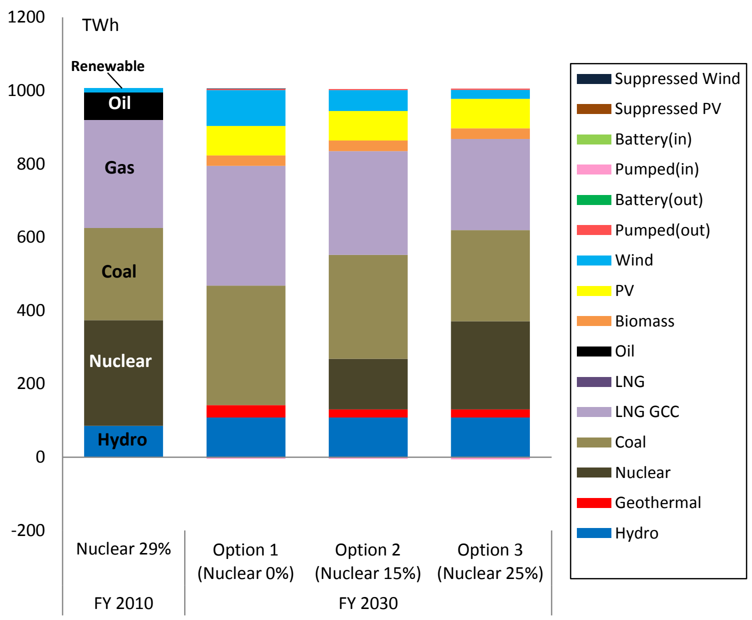


Figure 5-6. Power generation mix (capacity)

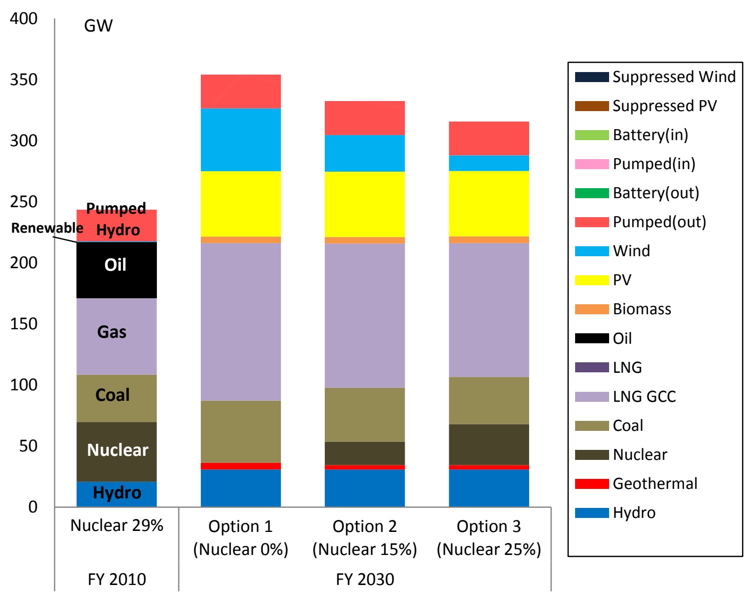
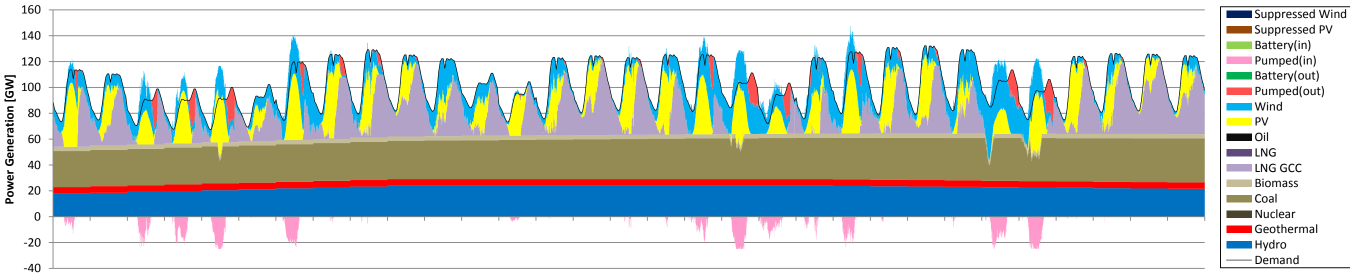
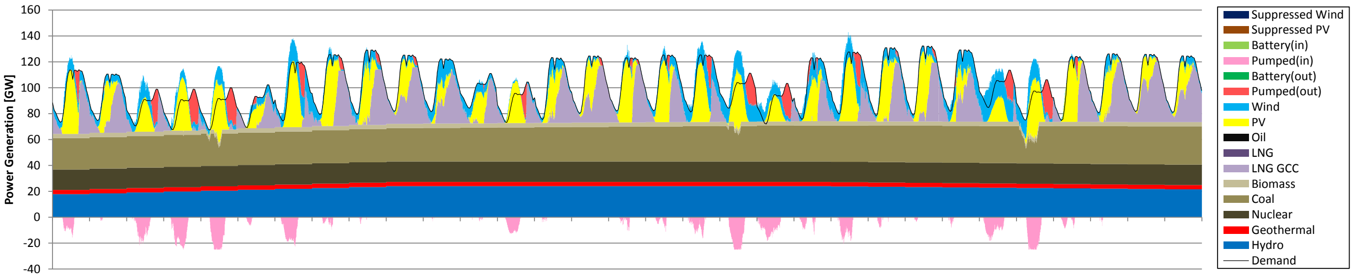


Figure 5-7 and Figure 5-8 show monthly optimal operation of individual power generation in May and October of 2030 respectively. During weekends in May and October, when electricity demand becomes lower than weekdays, the power output of coal-fired, gas combined cycle and pumped-storage hydro largely changes to accommodate intermittency of renewable energy. Thus, it turns out that renewable intermittency is technically compensated by power charge/discharge cycle of pumped-storage hydro, and load following operation by natural gas combined cycle and coal-fired power generation. This implies that a variety of measures will function as a whole to accommodate the output fluctuation of variable renewables.

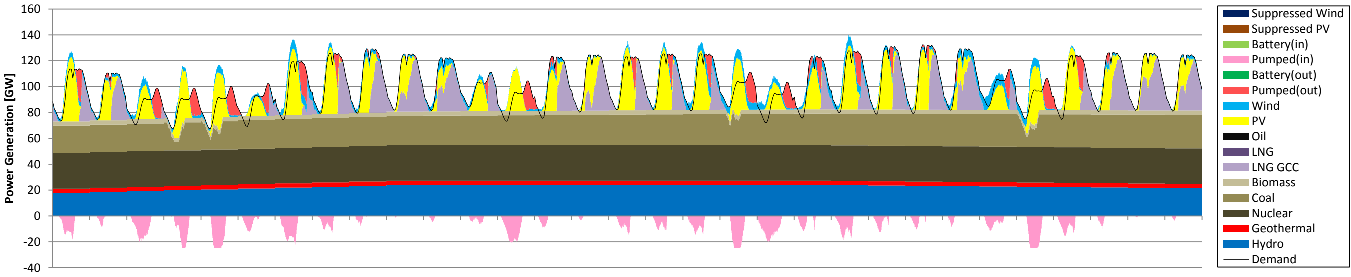
Figure 5-7. Monthly power generation profile of Japan in May 2030 at ten-minutes' interval



(a) Option 1 (Nuclear 0%)

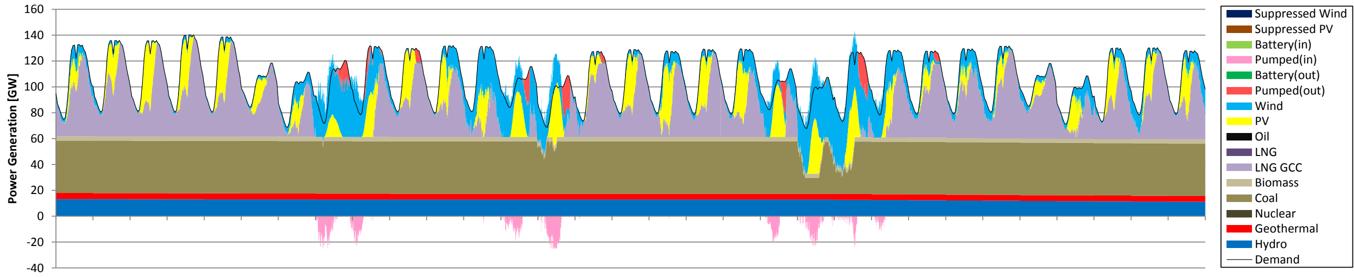


(b) Option 2 (Nuclear 15%)

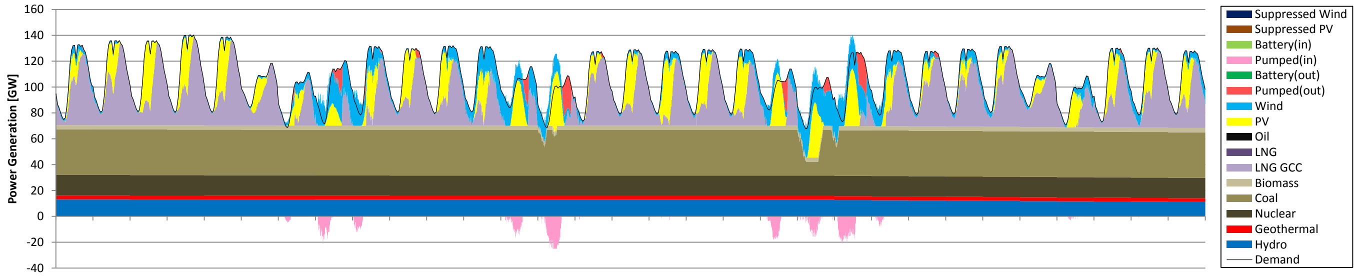


(c) Option 3 (Nuclear 25%)

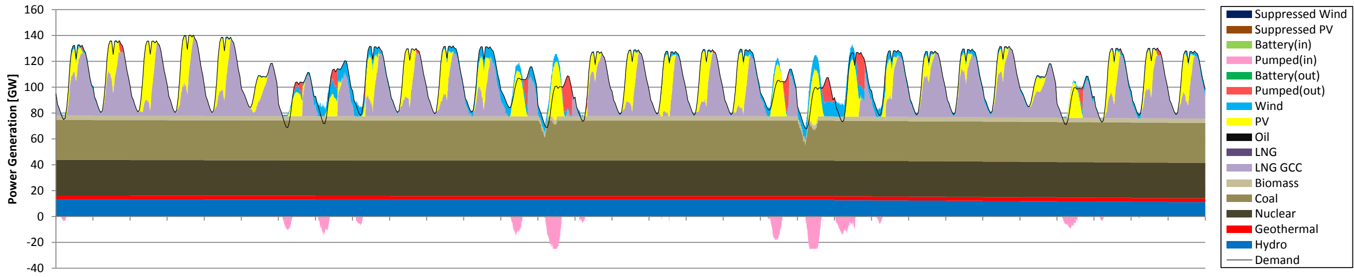
Figure 5-8. Monthly power generation profile of Japan in October 2030 at ten-minutes' interval



(a) Option 1 (Nuclear 0%)



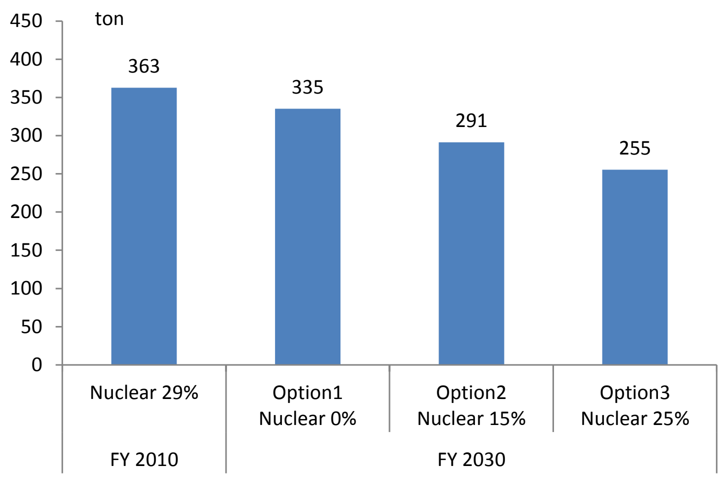
(b) Option 2 (Nuclear 15%)



(c) Option 3 (Nuclear 25%)

Figure 5-9 shows CO_2 emissions from power generation sector in each option. In Option1 where nuclear is reduced to zero and the dependency on renewable energy rises to 35%, CO_2 emissions are mitigated by 8% from the emissions level in 2010 when the reliance on nuclear power in power sector was 29%. CO_2 emissions in Option3, when nuclear dependence is maintained at 2010 level, are cut by 30% compared with 2010.

Figure 5-9. CO_2 emissions



Implications of the Fukushima nuclear disaster on Japan's energy policy

In this chapter, an optimal power generation mix is analyzed in the time resolution of 10 minutes through 365 days a year in 2030, considering output variability of PV and wind, reflecting on the proposed three options for possible power generation mix by the Japanese government.

A technical implication taken form this analysis is that intermittent fluctuation from high penetration level of variable renewables will be comprehensively accommodated by quick load following treatment by natural gas combined cycle, coal-fired power and pumped-storage hydro. Accordingly it will be important to coordinate and optimize multiple measures dynamically for the control of intermittent resources and to realize technical innovation enabling that treatment for variable renewable. CO_2 emissions will be reduced to the level below 2010 due to the assumed large-scale diffusion of renewable energy in all three options.

Observation

Nuclear power had established a solid position in the Japanese energy mix. In view of various constraints on the introduction of nuclear power as discussed in Chapter 3, this achievement is worthwhile being called as a miracle. Foreign observers might argue this as the result of the following;

- (a) Farsighted and thoughtful policymaking,
- (b) Powerful administration to implement policies,
- (c) High level of technology and manufacturing/engineering skills,
- (d) Allocation of affluent financial and human resources both in public and private sectors as national priority,
- (e) Harmonious collaboration between politicians, the government and the industry,
- (f) Public support to nuclear option in general,
- (g) Hard working of the Japanese people whoever involved.

Among these, (c), (d) and (g) will undoubtedly be the case. As discussed in "Technological perspective", Japan is one of the top runners in nuclear power technology and by far the forerunner in the quest for full nuclear fuel cycle. However, others including (e) and (f) should be treated with some reservations. The government officials were unprepared when they were thrown into the world of nuclear in the mid 1950s, and this rather disorganized start had a lingering effect on nuclear administration afterwards. What is regrettable is somewhat passive role played by scientists. If they took a strong initiative in the 1950s and onwards, they would have secured more time for basic research by themselves. Most probably, they would have shed light more on safety as discussed in Chapter 1, giving no room for "nuclear safety myth" developed by the government and utility companies. This safety myth worked to constantly down play the risks, which must have influenced the public perception on nuclear safety. Utility companies, the government as well as the regulators had been obsessed with this myth, which made them hesitate to aggressively review existing safety measures and regulations from time to time.

Collaboration among key players was not always in place. Even within the government, the Agency for Science and Technology (nuclear development for improving the level of science and technology) and the Ministry of Economy, Trade and Industry (nuclear policies for power generation as well as nuclear safety regulation) were often struggling for power over nuclear administration. Such power struggles within the administration, although this may not be limited to Japan, must have alleviated the efficiency and effectiveness of their performance and diverted their attention form more important tasks on national level. It is strongly hoped that the Nuclear Regulatory Commission will do the right job taking lessons from the disaster.

The Japanese energy system, which was considered to be one of the best models in the world, is under tight scrutiny. Diversified views on the options laid out in Chapter 5 may suggest difficult choices for Japan as the public confidence in nuclear safety will not recover any time soon. Literally, the entire country is struggling to find out an optimal energy mix for the future. From a slightly longer term perspective, this is an unprecedented opportunity for Japan to develop “a new energy model”, which should be full of wisdom and new thinking to benefit all over the world. Already, various efforts are under way towards further energy saving, efficiency and renewable energy introduction involving multiple stakeholders. No country but Japan can do this by taking stocks from its successes as well as failures.

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