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Current Status of Japan's Nuclear Power

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Abstract

The government of Japan published a draft of the 6th Strategic Energy Plan in August 2021 following an interval of three years since the previous plan in 2018. After hearing public comments and carrying out reviews among the relevant ministries, the draft was finally adopted by the Cabinet in October. Based on the plan, this report makes an objective analysis of the current situation of nuclear power in Japan and provides a realistic view of projections towards 2030.

The government assumes that if the existing 27 nuclear power plants are in operation in 2030 with a capacity factor of 70-80%, then it could be possible for nuclear power generation to have a 20-22% share in the energy mix. However, in 2021, there are only 10 nuclear power plants that have been restarted since the Fukushima nuclear accident in 2011. To enable a restart, plants must pass a review by the Nuclear Regulation Authority (NRA) and obtain local consent from host municipalities. This report identified three challenges (low capacity factor, long review period and local opposition) and carried out a scenario analysis. If three of the 27 plants do not restart by 2030, the government assumption of 20% nuclear power will not be possible.

The Institute for Global Environmental Strategies (IGES) takes no position regarding the validity of nuclear power. This report intends to provide information on the current nuclear power policies and relevant data, mainly based on government-produced materials from the Ministry of Economy, Trade and Industry (METI).

Section 1. Current status of Japan’s nuclear power

This section gives an overview of the current status of Japan’s nuclear power. The number of units, installed capacity and operational status are shown on the map in Figure 1. In addition, safety, cost, self-sufficiency & resilience and energy security are analyzed.

1.1. A bird’s-eye view of current nuclear reactors in Japan

As of September 2021, there are 60 units (54.6GW) of nuclear power plants in Japan. The table below shows their current status, the number of units and installed capacity.

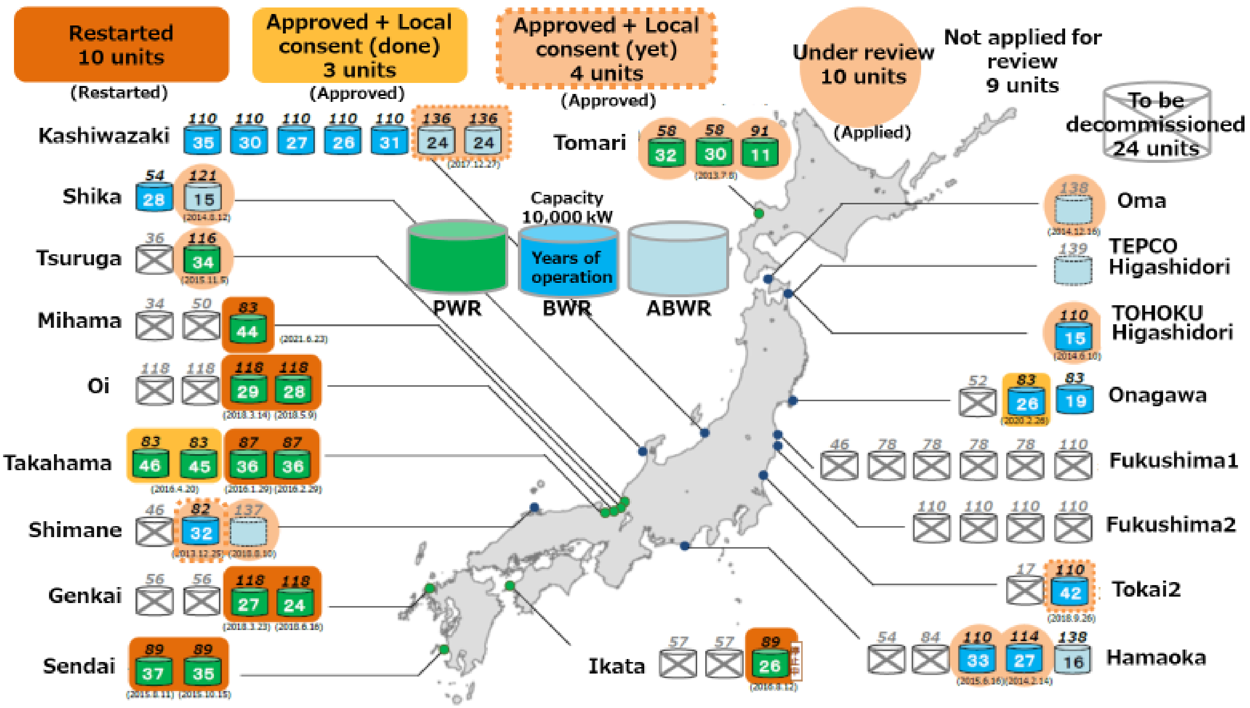
Table 1 Nuclear power plants by status

1.Restarted	10 Units	9,956 MW
2.Approved+Local consent (done)	3 Units	2,477 MW
3.Approved＋Local consent (not yet)	4 Units	4,632 MW
4. Under Review	10 Units	10,529 MW
5. Not applied for review	9 Units	9,630 MW
6. To be decommissioned	24 Units	17,423 MW
Total	60 Units	54,647 MW

Source: Compiled by the author, based on *Long-term Energy Supply and Demand Outlook* in 2030 (Ministry of Economy, Trade and Industry, 2021, p.47)

After the Great East Japan Earthquake in 2011, all the nuclear power plants were shut down. To enhance plant security, new regulatory requirements were enacted in 2013. In order to restart, plants must meet the requirements and receive approval from the Nuclear Regulation Authority (NRA). Local consent is not a legal requirement. However, it is difficult in reality for nuclear power plants to restart without obtaining local consent.

Figure 1 Map of nuclear power plants in Japan



Source: Compiled by the author, based on the *Long-term Energy Supply and Demand Outlook in 2030* (Ministry of Economy, Trade and Industry, 2021, p.47)

The map above shows the state of nuclear power plants in Japan. The 6th Strategic Energy Plan mentions that the government is continuing its efforts to recover from the Fukushima nuclear accident. The main points mentioned in the plan are set out below in Table 2.

Table 2 Reference to the Fukushima nuclear accident in the 6th Strategic Energy Plan

- As of March 2021, 22,000 residents are still under orders to evacuate the affected areas.
- Dependency on nuclear energy should be reduced as much as possible along with the expansion of the use of renewable energy.
- The government takes the lead in decommissioning plants in Fukushima by 2041-2051.
- Advanced Liquid Processing System (ALPS) treated water will be discharged into the sea in about two years.

Source: *Draft of the 6th Strategic Energy Plan* (Ministry of Economy, Trade and Industry, 2021, pp. 166-169)

Table 3 below shows the nuclear power policies described in the *6th Strategic Energy Plan*. This energy plan does not mention additional new nuclear power plants. This indicates that the government is not planning such projects or is refraining from announcing new projects. At the moment, the government’s strategy seems to be to restart existing plants and operate them for as long as possible.

Table 3 Nuclear power policy in the *6th Strategic Energy Plan*

Points	Contents
Energy mix	■ 20-22% in 2030 (6% in 2019) ■ Reduce nuclear dependency as much as possible with expansion of renewable energy
Restart	■ Promote restart of existing plants upon approval from Nuclear Regulation Authority ■ Organize task force to promote restart
Nuclear waste treatment	■ Promote construction of interim storage facilities ■ Develop technologies for volume reduction and detoxification
Nuclear fuel recycling	■ Promote plutonium thermal use and open Rokkasho reprocessing plant (2022) and Mixed Oxide plant (2024)
Final disposal	■ Conduct a survey on final disposal sites in Hokkaido.
Research & development	■ Fast reactors ■ Small module reactors ■ High temperature gas reactors ■ Fusion energy ■ Promote international technology collaboration until 2030

Source: *Draft of the 6th Strategic Energy Plan* (Ministry of Economy, Trade and Industry, 2021, pp.166-169)

1.2. Overview of nuclear power in Japan from four aspects

Draft of the 6th Strategic Energy Plan mentions comprehensive nuclear power strategies. From this section, this report gives an overview of nuclear power in Japan from four aspects, namely safety, cost, self-sufficiency & resilience, and energy security.

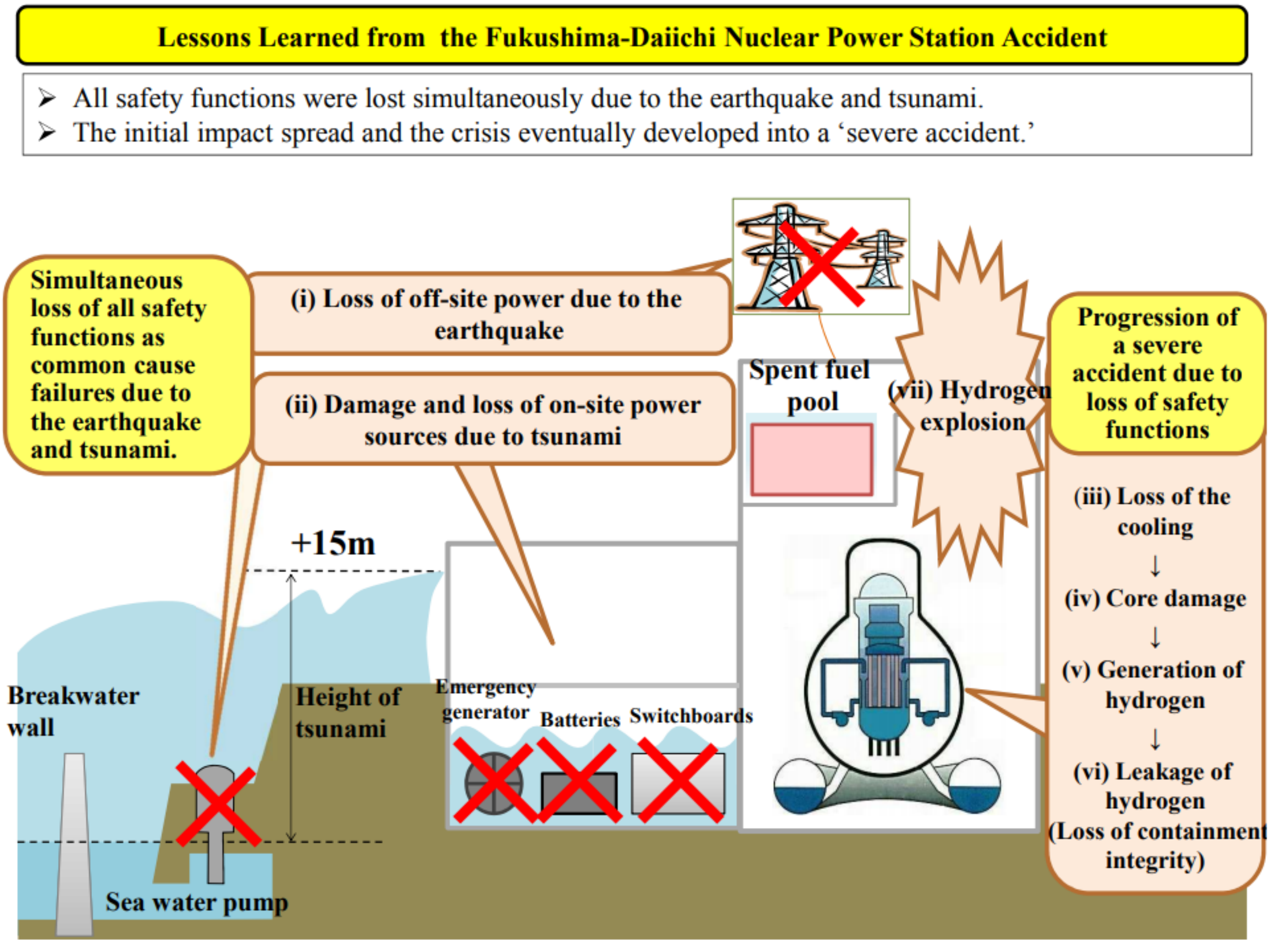
1.2.1. Safety

After the Fukushima nuclear accident, the principle of Japan's energy policy changed from 3E (energy security, economic efficiency and environment) to 3E+S (safety). According to the NRA, if a nuclear accident occurs, there are three major safety measures to be taken:

1) Shut-down
2) Cooling
3) Containment

Before the Fukushima nuclear accident in 2011, the "safety myth" of nuclear power was dominant in Japan. When the Fukushima nuclear accident happened, there was a shut-down, and the reactor was halted. However, due to the massive earthquake, off-site power was lost. In addition, the plant was flooded by tsunami sea water causing an on-site outage. Therefore, the plant could not cool the heated reactor. It caused a melt-down and steam explosion. Figure 2 shows the lessons learned from the 2011 accident.

Figure 2 Lessons learned from the Fukushima nuclear accident



Source: *Enforcement of the New Regulatory Requirements for Commercial Nuclear Power Reactors* (Nuclear Regulation Authority, 2013, pp. 7,11,13)

The NRA recognized the following two major lessons learned from the accident:

Table 4 Major lessons learned from the Fukushima nuclear accident

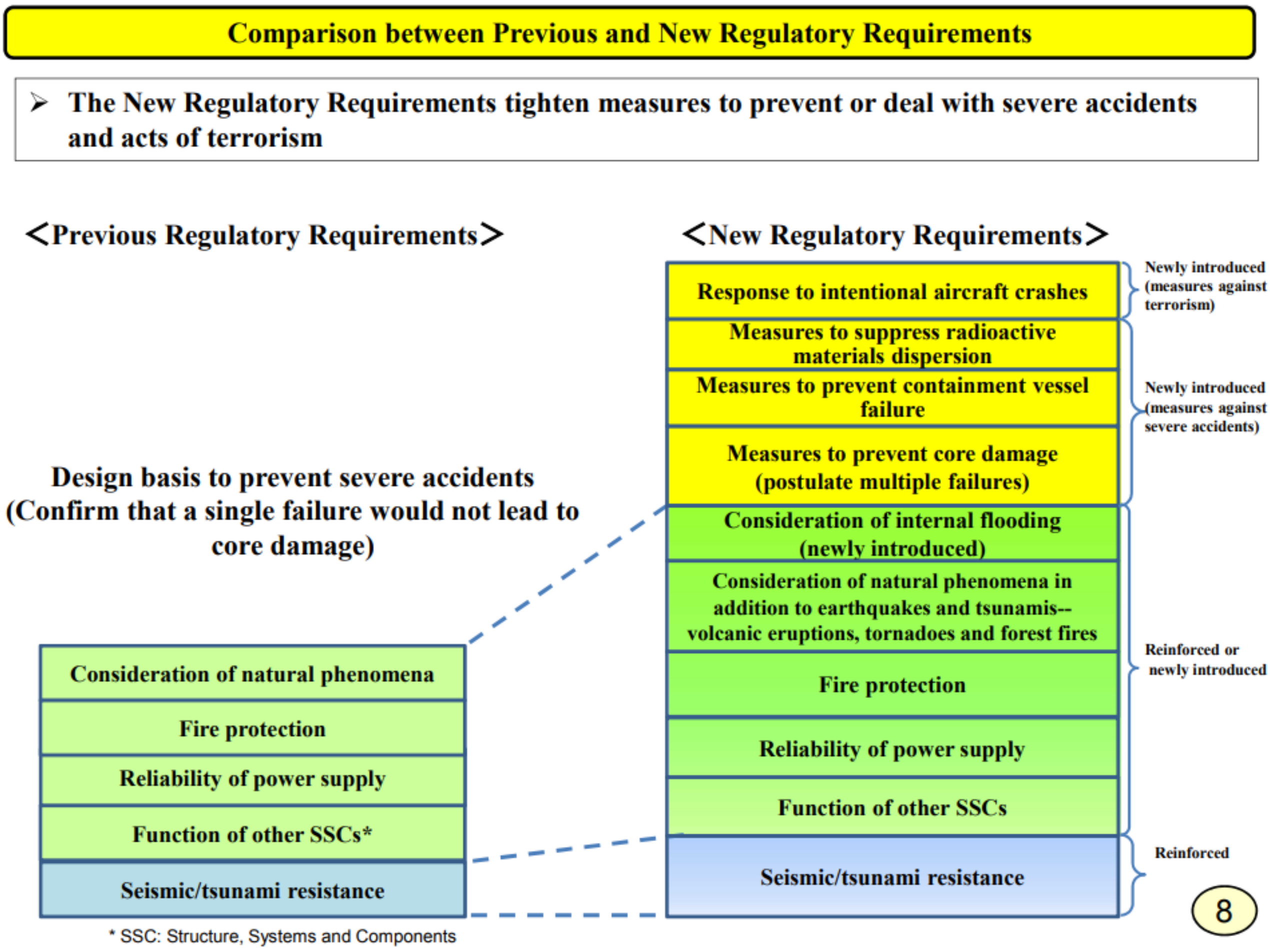
■	Insufficient risk management against large-scale natural disasters such as earthquakes and tsunami
■	Absence of legal requirements for "severe accidents" which exceed the predicted risk at the time of plant design

Source: *Challenges and measures of nuclear power policy* (Ministry of Economy, Trade and Industry, 2017, pp. 14,15,17,36,64,65)

For instance, the Fukushima nuclear power plant was designed to withstand a tsunami with a height of 5.7 meters. However, the actual tsunami was 15 meters in height. These types of risk management were voluntary measures for nuclear power companies. Even if the plant regulations had been tightened, there was no legal framework to enforce and check whether existing plants met the new criteria.

Based on reflection on the Fukushima nuclear accident, new regulatory requirements were enacted in 2013. Figure 3 shows a comparison between previous and new regulatory requirements. The new regulations tightened prevention measures for large-scale natural disasters and added volcano eruptions and hurricanes to the list of natural disasters to be considered. In addition, measures against severe reactor accidents and terror attacks were newly introduced. New and existing nuclear power plants are required to meet the new standards as well as to pass reviews and security checks by the Nuclear Regulation Authority.

Figure 3 Comparison between previous and new regulation requirements



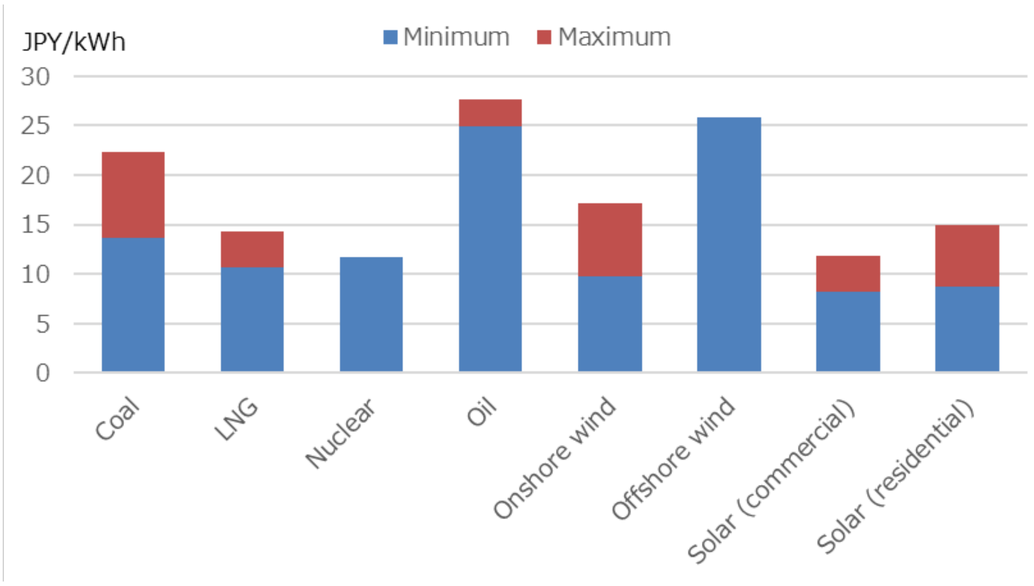
Source: *Enforcement of the New Regulatory Requirements for Commercial Nuclear Power Reactors* (Nuclear Regulation Authority, 2013, pp. 7,11,13)

In the plant review process, attention is focused on geological surveys. Japan is one of the most earthquake-prone countries in the world. “Capable fault” represents an ‘engineering’ hazard that must be considered when designing nuclear installations (IAEA, 2015). The new regulations stipulate that nuclear power plants must be built on ground surfaces without an outcrop of a capable fault. If a capable fault is identified under the plant, the plant cannot pass the review to be restarted.

1.2.2. Cost

Concurrently with the announcement of *6th Strategic Energy Plan*, METI disclosed the estimated power generation costs for 2030 at the Power Generation Cost Analysis Working Group. For the first time, the cost of solar power was estimated to be lower than nuclear. The following graph shows the power generation cost estimates by power source for 2030. The minimum estimated cost of nuclear power is JPY 11.7 per kWh.

Figure 4 Power generation cost estimates by energy source in 2030

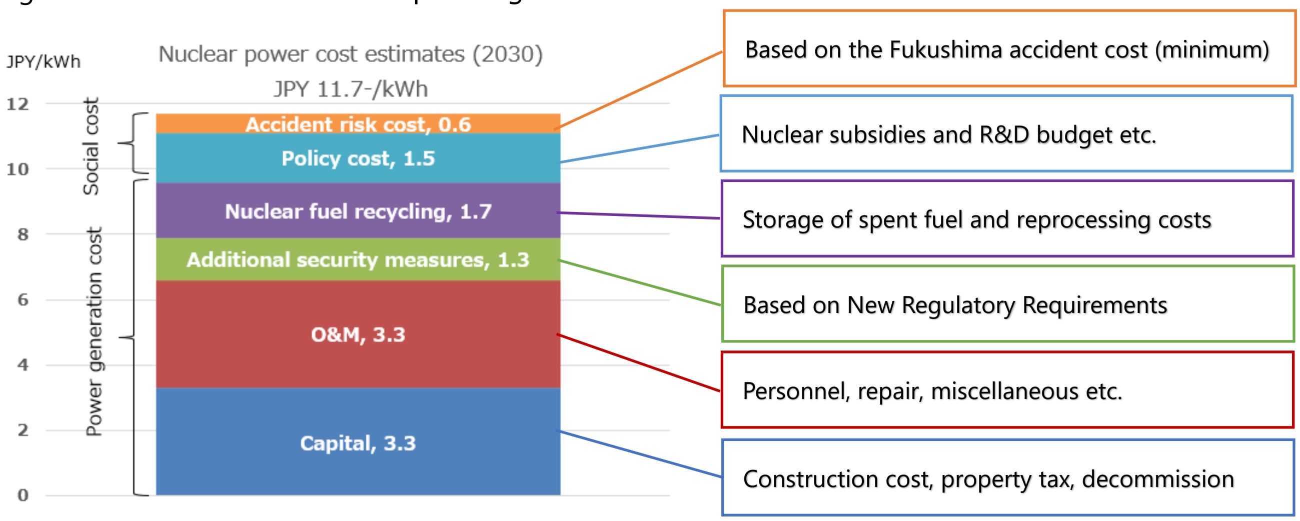


	Coal	LNG	Nuclear	Oil	Onshore wind	Offshore wind	Solar (commercial)	Solar (residential)
JPY/kWh	13.6-22.4	10.7-14.3	11.7	24.9-27.6	9.8-17.2	25.9	8.2-11.8	8.7-14.9
Capacity factor	70%	70%	70%	30%	25%	33%	17%	14%
Operation period	40 years	40 years	40 years	40 years	25 years	25 years	25 years	25 years

Source: *Report on power generation cost analysis for the Basic Policy Subcommittee* (Ministry of Economy, Trade and Industry, 2021, pp. 92-131)

The graph below shows the breakdown of the estimate of JPY 11.7/kWh. The cost estimate is an average cost of sample plants and does not show the actual cost of specific plants.

Figure 5 Breakdown of nuclear power generation cost



Source: *Report on power generation cost analysis for the Basic Policy Subcommittee* (Ministry of Economy, Trade and Industry, 2021, pp. 92-131)

To calculate the cost per kWh, Table 5 below shows the baseline parameters. METI chose four sample nuclear power plants which were commissioned in the past few years, and then took the average cost. Based on the scale of plants, the numerical value is levelized.

Table 5 Baseline Parameters for New Nuclear Power Plant Calculations

Sample plants	Newly commissioned 4 plants: name (capacity, commissioned year)	
	Higashidori 1 (1,100 MW, 2005) / Hamaoka 5 (1,380 MW, 2005)	
	Shiga 2 (1,358 MW, 2006) / Tomari 3 (912 MW, 2009)	
Installed capacity	1,200 MW (average of sample plants)	
Power generation	Generating end 7,358,400,000 kWh/y, Sending end 7,064,064,000 kWh/y	
Capacity factor	70%	
Operation period	40 years	
Capital cost	Construction	JPY 400,000/kW
	Property tax rate	1.4%
	Decommission	JPY 75 billion
Operation & maintenance	Personnel	JPY 2.22 billion/year
	Repairs	1.9% of construction costs
	Miscellaneous	JPY 9.41 billion/year
	Administrative	12.8% of personnel, repairs, and miscellaneous
Fuel	Nuclear fuel recycling	JPY 0.97/kWh (front end), JPY 0.71/kWh (back end)
	Efficiency	35.1%
	Internal plant use	4%

Accident risk cost	JPY 15.7 trillion (decommission, compensation, decontamination etc.)
Accident frequency rate	4,000/reactor-years (50 units x 40 years x 2)
Additional security measures	JPY 136.9 billion
Policy cost	JPY 298.1 billion
Currency rate	JPY 107/USD
Discount rate	3%

Source: Compiled by the author, based on specifications for each power source by the Power Generation Cost Analysis Working Group (Ministry of Economy, Trade and Industry, 2021, pp. 24-25)

There has been criticism of METI'S nuclear power cost calculation, arguing that that the cost is biased to be lower (Citizens' Nuclear Information Center, 2021). Anti-nuclear power and watchdog groups presented counterarguments to METI's Power Generation Cost Analysis Working Group in 2021.

1.2.3. Self-sufficiency and resilience

<Self-sufficiency rate of nuclear power technology>
Japan used to import nuclear power technologies from overseas. However, in many power plants which began operations in the 1970s, the domestic production rate exceeds 90%, and nuclear technologies are integrated into domestic manufacturers. In Japan, there are three manufacturers of nuclear power plants (HITACHI-GE, TOSHIBA and MITSUBISHI Heavy Industries), and more than 400 manufacturers have specialised nuclear power technologies (METI, 2021). The table below shows that the domestic production rate has progressively increased and Japan is self-sufficient in terms of nuclear power technology.

Table 6 Transition of domestic production rate

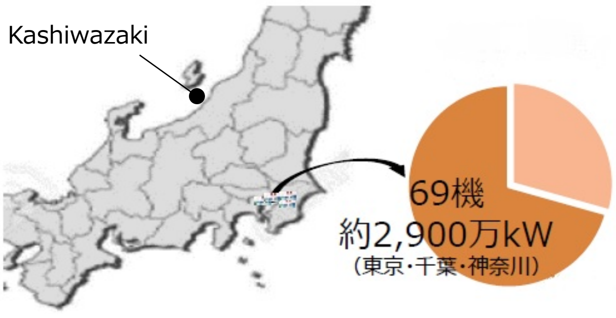
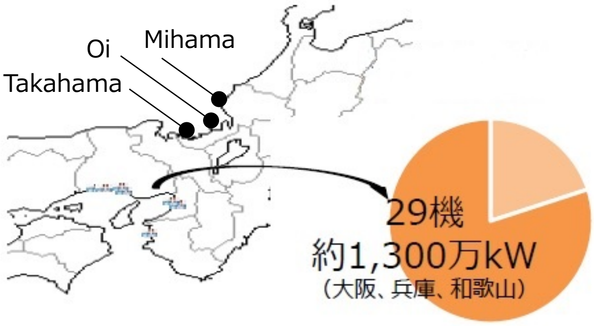
Plant	Tokai (GCR)	Mihama1 (PWR)	Takahama2 (PWR)	Mihama3 (PWR)	Kashiwazaki 5 (BWR)	Kashiwazaki 7 (ABWR)
Year of operation	1966	1970	1975	1976	1990	1997
Domestic production rate	35%	58%	90%	93%	99%	89%

Souce: *Efficiency improvement of nuclear power and industrial policy* (Research Institute of Economy, Trade and Industry, as cited in Ministry of Economy, Trade and Industry, 2021, p.27)

<Resilience of nuclear power>
METI highlights the resilience of nuclear power and its contribution to power supply in times of disaster, and emphasizes the need to increase resilience by decentralizing large-scale power supply throughout Japan in order to prevent major power outages in times of disaster (METI, 2021).

METI introduces two examples of resilience in the Tokyo metropolitan area and the second-largest Kinki area during past major earthquakes. The following figure shows the nuclear power plants located along the Sea of Japan that demonstrated resilience when major earthquakes occurred in 1995 and 2011.

Figure 6 Demonstrated resilience of nuclear power during the great earthquakes

Tokyo capital area	**Kinki area**
	
70% of thermal power (29GW) which JERA provides in the Tokyo area, is concentrated in Tokyo Bay (69 units).	80% of thermal power (13GW) provided by Kansai Power in the Kinki area, is concentrated in Osaka Bay and Seto Inland Sea (29 units).
When the Great East Japan Earthquake hit in 2011, 4 plants in Kashiwazaki (5GW) were in operation.	The Great Hanshin Earthquake hit in 1995, 8 plants in Takahama, Oi and Mihama (7.4GW) were in operation.
Even if a major earthquake hits Tokyo metropolitan area and Kinki area, large power plants located along the Sea of Japan have increased potential to prevent major power outage.	

Source: Compiled by the author, based on *Challenges and measures of nuclear power policy* (Ministry of Economy, Trade and Industry, 2021, pp. 14,15,17,36,64,65)

1.2.4. Energy security

METI considers that nuclear power has an advantage from the viewpoint of energy security compared with other fossil fuels, especially in Japan which has few natural resources (METI, 2021). The table below shows domestic fuel stock levels of nuclear and fossil fuels. Nuclear power could maintain power generation for 2.9 years by using the only the existing domestic fuel stock, assuming that 40 nuclear power plants (39GW) are in operation. Therefore, nuclear power is considered to be advantageous over fossil fuels and is not affected by the volatile global market price of fossil fuels.

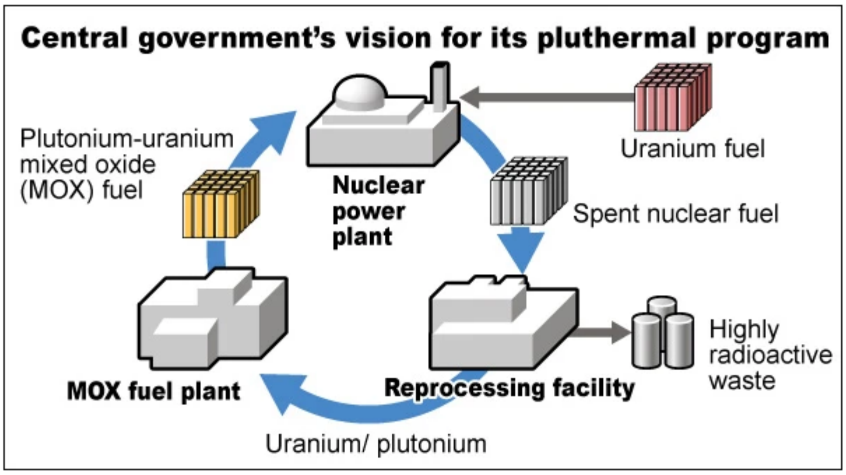
Figure 7 Domestic fuel stockpile levels

Domestic fuel stockpile levels	
Nuclear (uranium)	2.9 years
Natural gas	20 days
Oil	200 days
Coal	29 days

Source: *Potential stockpile effect of nuclear fuel* (Central Research Institute of Electric Power Industry, as cited in Ministry of Economy, Trade and Industry, 2021, p.17)

Spent uranium can be reused. The spent fuel is chemically separated into uranium, plutonium and high-level radioactive waste in a reprocessing plant. The plutonium can be mixed with uranium to manufacture mixed oxide fuel (MOX). MOX can be reused as fuel in pluthermal reactors. METI expects to open the first commercial MOX plant in 2024 and increase pluthermal reactors from the current four plants in operation to 12 plants in 2030 (METI, 2021).

Figure 8 Central government's vision for its pluthermal programme



Source: "Pluthermal reactor dream for Japan still an elusive goal" (*Asahi Shimbun*, 2020)

Regarding its plutonium stockpile, Japan had about 46.1 tonnes of plutonium at the end of 2020. The table below shows the current stockpile in Japan and overseas. Due to the limited reprocessing capabilities at the domestic plant, Japan has outsourced reprocessing to the UK and France. Therefore, most of Japan's reprocessed plutonium is stored outside of Japan and will be transported back to Japan as needed.

Table 7 Japan's current stockpile of plutonium

At the end of 2020

Total			46.1 tons
	In Japan		8.9 tons
	Overseas		37.2 tons
		UK	21.8 tons
		France	15.4tons

Source: *Plutonium management conditions in 2020* (Cabinet Office, Office for Atomic Energy Policy, 2021, p.1)

According to the Federation of Electric Power Companies, the projected annual consumption of plutonium based on the assumption of 12 operational pluthermal plants in 2030, is shown in Table 8. It is clear that Japan has sufficient stock to meet demand until 2030. However, plutonium stock could be diverted to nuclear weapons. Therefore, the Atomic Energy Commission has stated that Japan will reduce its plutonium stockpile and will not exceed the current level (JAEC, 2018).

Table 8 Projection of annual consumption of plutonium

2021	2022	2023	2024	2025	2026-2030
0.2 tons	0.7 tons	1.4 tons	0.7 tons	1.4-2.8 tons	Max 6.6 tons

Source: *Plutonium utilization plan* (Federation of Electric Power Companies, 2021, pp. 1-2)

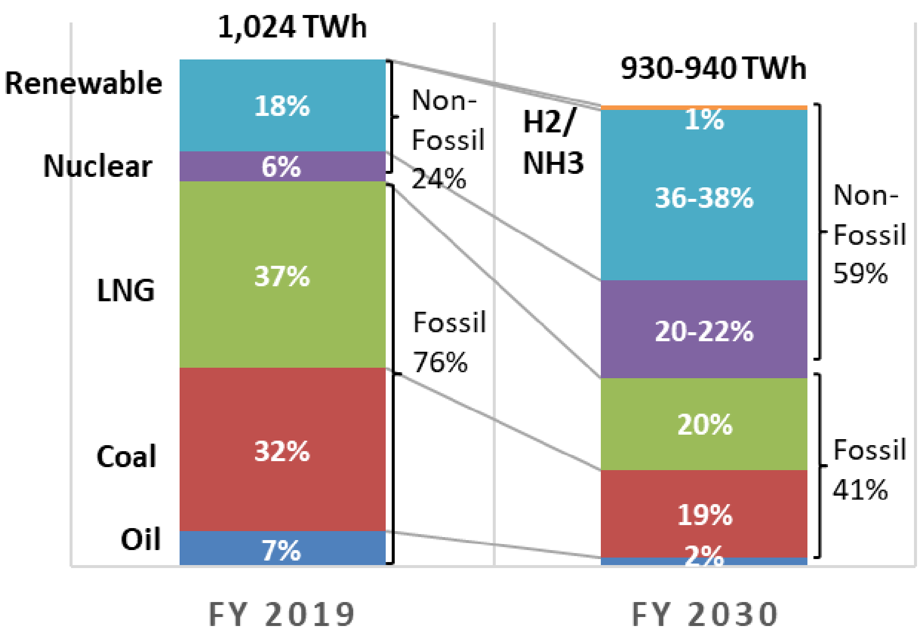
Section 2. Assumption of nuclear power generation in 2030

In this section, the possibility of restarting nuclear power plants and achieving an estimated 20-22% nuclear share of nuclear power in electricity generation by 2030 is analyzed.

2.1. Estimates in the *6th Strategic Energy Plan*

The government disclosed its estimations for electricity demand in 2030. By 2030, economic development and electrification will mean more demand for electricity. However, due to energy efficiency and conservation as well as depopulation, METI estimates that electricity demand in 2030 will decrease to 860-870 TWh, with total power generation at 930-940 TWh. The share of nuclear power generation in the energy mix is estimated at 20-22%.

Figure 9 Energy mix in 2019 and government estimates in 2030



Source: *Draft of the 6th Strategic Energy Plan* (Ministry of Economy, Trade and Industry, 2021, p.8)

This report analyzes whether a 20% share of 930TWh, which is 186 TWh, is realistically achievable or not. As mentioned above, Japan has 60 nuclear power plants. Out of these, 27 existing units (1-4 in the following table) could potentially be restarted to generate power.

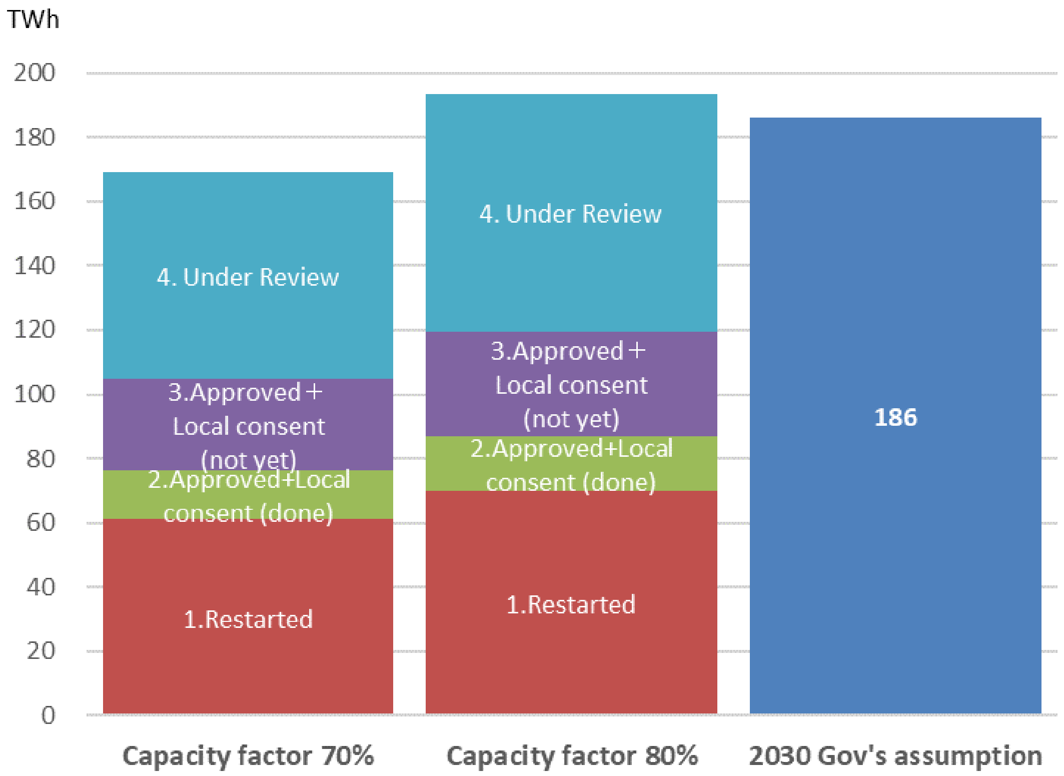
Table 9 Nuclear power plants by status

1.Restarted	10 Units	9,956 MW
2.Approved+Local consent (done)	3 Units	2,477 MW
3.Approved＋Local consent (not yet)	4 Units	4,632 MW
4. Under Review	10 Units	10,529 MW
5. Not applied for review	9 Units	9,630 MW
6. To be decommissioned	24 Units	17,423 MW
Total	60 Units	54,647 MW

Source: Compiled by the author, based on *Long-term Energy Supply and Demand Outlook in 2030* (Ministry of Economy, Trade and Industry, 2021, p.47)

The amount of power generation depends on the capacity of power plants to operate for a year. METI compares two cases with capacity factors[1] of 70% and 80%. Assuming that all 27 plants (categories 1-4 in Table 9) successfully restart, a plant with a capacity factor of 80% applied could generate 193 TWh and achieve 186 TWh of the estimation. For a factor of 70% applied, the amount generated could be 169 TWh, slightly lower than the estimation. METI has given an indication that these scenarios would be possible by 2030.

Figure 10 Government scenario of nuclear power generation in 2030



[1] Capacity factor is the measure of how often a power plant runs for a specific period of time. It is expressed as a percentage and calculated by dividing the actual unit electricity output by the maximum possible output. This ratio is important because it indicates how fully a unit's capacity is used (Duke Energy Nuclear Information Center).

Source: Compiled by the author, based on *Long-term Energy Supply and Demand Outlook in 2030* (Ministry of Economy, Trade and Industry, 2021, p.47)

In order to achieve the government scenario of a 20% share of nuclear in the energy mix by 2030, the following three challenges have been identified:

1) Low capacity factor
2) Long review period for restart
3) Local opposition by residents

2.2. Three Challenges

2.2.1. Low capacity factor

Between fiscal years 2017 and 2019, the capacity factor ranged from 80-84%. However, the capacity factor in FY2020 was only 49% due to tightened security measures, lawsuits against nuclear power plants and technical difficulties. Moreover, a lengthy periodic inspection of a reactor decreases its capacity factor. Nuclear power plants are required to undergo periodic inspection once every 13 months. According to METI, this inspection takes about 90 days on average (METI, 2021), and nuclear power plants must stop all operations during the inspection period. The capacity factor of 49% in 2020 indicates that it would be almost impossible to achieve the estimated 186 TWh by 2030.

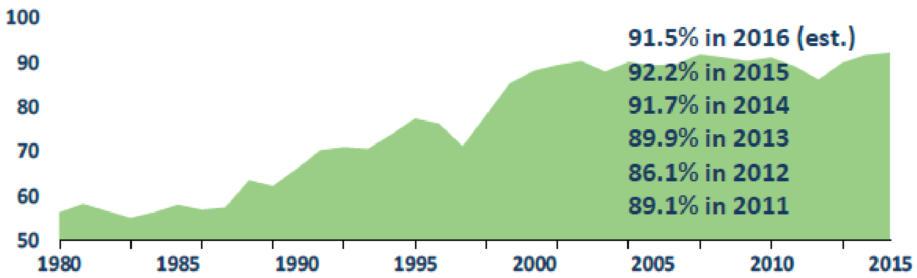
Table 10 Average capacity factor of nuclear power plants in Japan

Year	Capacity factor
FY1981-2010 (before the Fukushima power plant accident)	Approx. 73%
FY2017 (restarted units)	Approx. 84% (5 units)
FY2018 (restarted units)	Approx. 80% (7 units)
FY2019 (restarted units)	Approx. 80% (9 units)
FY2020 (restarted units)	Approx. 49% (9 units)

Source: *Maximum exertion of nuclear power potential and pursuit of safety* (Agency for Natural Resources and Energy, 2021, pp. 2-3)

METI proposes to make the periodic inspection shorter than 90 days by improving efficiency and lengthening the inspection cycle to an interval of more than 13 months so that the capacity factor in Japan could increase and match the US level of 90% (METI, 2021).

Figure 11 Average capacity factor of nuclear power plants in the U.S.

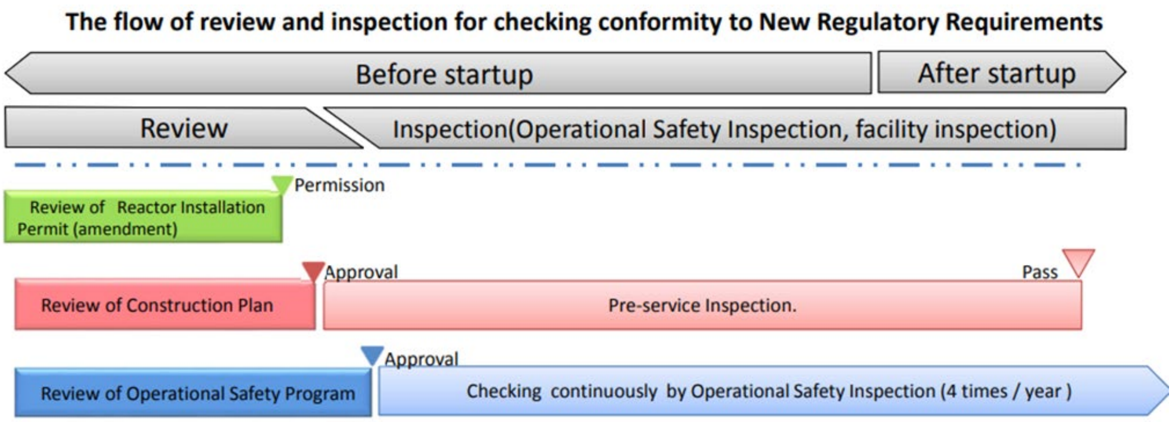


Source: *Challenges and measures of nuclear power policy* (Ministry of Economy, Trade and Industry, 2021, pp. 14,15,17,36,64,65)

2.2.2. Long review period for restarting reactors

Another concern is the long review period for restarting reactors. In order to restart, plants must meet new regulatory requirements and undergo a review. They must then receive permission and approval from the NRA. Figure 12 below shows the flow of the review and inspection processes. Review processes are carried out in parallel. The licensee of power reactor operation must not operate the facilities before they pass the pre-service inspection.

Figure 12 Flow of review and inspection process of new regulation requirements



Review	
Reactor installation permit (amendment)	Review changes in reactor installation, location, structure and equipment of reactor facilities and nuclear power operators.
Construction plan	Review detailed design of nuclear power facilities and methods of quality management for design and construction.
Operational safety program	Review operation & maintenance, prevention of accidents by nuclear fuel material, contaminated material or damaged power reactors.
Inspection	
Pre-service inspection	Examine the conformity to the construction plan and technical standards.
Operational safety inspections	Review the compliance with the operational safety programme prescribing the necessary operational safety measures.

Source: *The flow of review and inspection for checking conformity to new regulatory requirements* (Nuclear Regulation Authority, Retrieved in 2021)

The longer the review and inspection period, the longer it takes to restart. It is not unusual for a plant to take more than five years to restart. The following table shows the time periods spent by the restarted plants from the submission of an application for review to approval as well as receiving local consent. These restarted plants took less time than the other plants which are still under review.

Table 11 Review period time before restarting

	Restarted	Review period time
1	Takahama 3	2 years 7 months
2	Takahama 4	3 years 11 months
3	Oi 3	4 years 9 months
4	Oi 4	4 years 10 months
5	Mihama 3	6 years 3 months
6	Ikata 3	3 years 1 month
7	Genkai 3	4 years 10 months
8	Genkai 4	5 years 0 months
9	Sendai 1	2 years 2 months
10	Sendai 2	2 years 4 months

Source: Compiled by the author, based on *Review and inspection for checking conformity to new regulatory requirements* (Nuclear Regulation Authority, 2021)

On the other hand, the following table shows the time period spent by plants under review. As of September 2021, 10 units were undergoing review by the NRA. In case of Tomari units 1 and 2, the review has taken more than eight years, and was still ongoing.

Table 12 Review period time of plants still under review

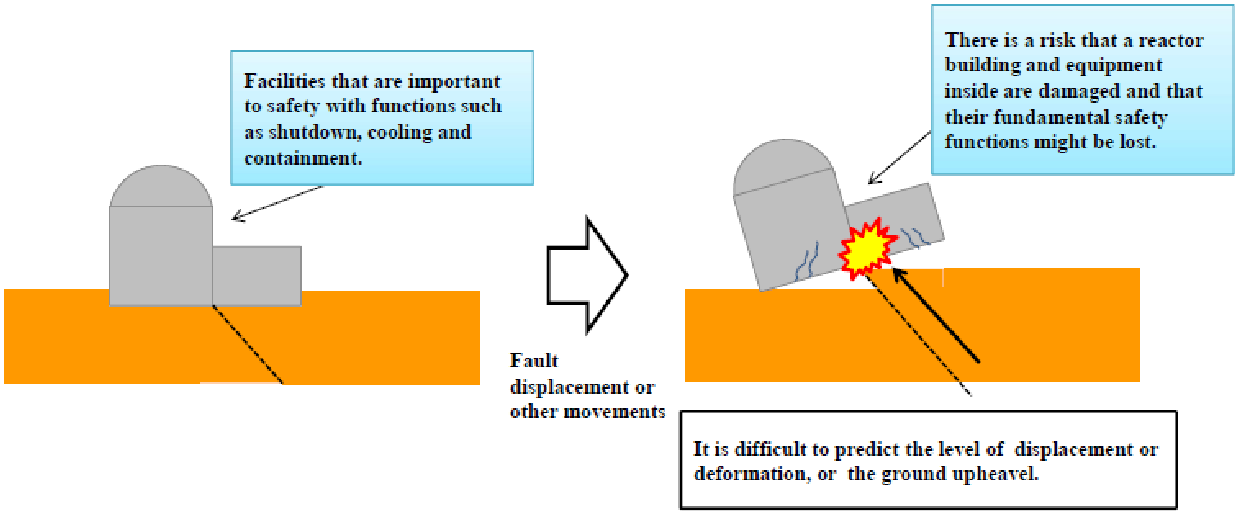
	Under review	Review period as of Sep 2021
1	Tomari 1	8 years 2 months
2	Tomari 2	
3	Tomari 3	5 years 9 months
4	Tsuruga 2	5 years 10 months
5	Hamaoka 4	7 years 6 months
6	Hamaoka 3	6 years 2 months
7	Higashidori 1	7 years 3 months
8	Shika 2	7 years 0 months

9	Shimane 3	3 years 1 month
10	Oma	6 years 9 months

Source: Compiled by the author, based on *Review and inspection for checking conformity to new regulatory requirements* (Nuclear Regulation Authority, 2021)

The review period differs from place to place depending on geographical characteristics. One particuarly critical point is identifying potential earthquake sources, known as "capable faults". Once a capable fault is identified, the NRA will not approve a restart. It is hard to predict how much more time is needed for these plants to get approval from the NRA.

Figure 13 Clarification of standards of displacement and ground deformation



Source: *Enforcement of the New Regulatory Requirements for Commercial Nuclear Power Reactors* (Nuclear Regulation Authority, 2013, pp. 7,11,13)

Specifically, an expert mission by the NRA suspected that the following three plants are located on capable faults based on a field survey (NRA, 2015). If the suspected plants cannot provide counter-evidence and clear the suspicion, they have no hope to restart.

1) Tsuruga 2
2) Higashidori 1
3) Shika 2

In order to expedite restarts, the Federation of Electric Power Companies announced this year that it will form a taskforce to enable accelerated restarts. The taskforce intends to assist plants to gain approval at each step of the process prior to restart. The assistance consists of workforce support and technical support for reviews etc. (FEPC, 2021).

2.2.3. Local opposition by residents

Local consent is not a legal requirement. However, as described in the strategic energy plan, the government will make every effort to obtain the understanding and cooperation of relevant parties including host municipalities. In practice, nuclear power companies do not restart their plants without obtaining local consent. Obtaining local consent from the host municipalities is the next big obstacle.

A host municipality is narrowly defined as the municipality where the plant is located. Furthermore, other municipalities within the urgent protective action planning zone (30 km radius), also claim the right to prior understanding. This makes restart difficult and time-consuming. Local residents tend to ask for a guarantee that the nuclear power plant will be 100% safe. Local opposition to a nuclear power plant is seen at many plant sites. The table below shows those plants which have been contested by lawsuits that have been brought before a court by local residents. If the court orders a mandatory injunction, the process to gain local consent and restart the plant becomes even longer.

Table 13 Lawsuits against nuclear power plants

Status	Plant	Date of filing	Situation	Court level
Approved + Local consent (not yet)	Kashiwazaki 6,7	2012/4/23	Pending in court	District court
	Tokai 2	2012/7/31	Pending in court	High court
	Shimane 2	1999/4/8	Pending in court	High court
Under review	Tomari 1,2,3	2011/11/11	Pending in court	District court
	Higashidori 1	N/A	N/A	N/A
	Hamaoka 3,4	2011/7/1	Pending in court	High court
	Shika 2	2012/6/26	Pending in court	District court
	Tsuruga 2	2011/11/8	Discontinuance	District court
	Oma	2010/7/28	Pending in court	High court
	Shimane 3	2013/4/24	Pending in court	District court

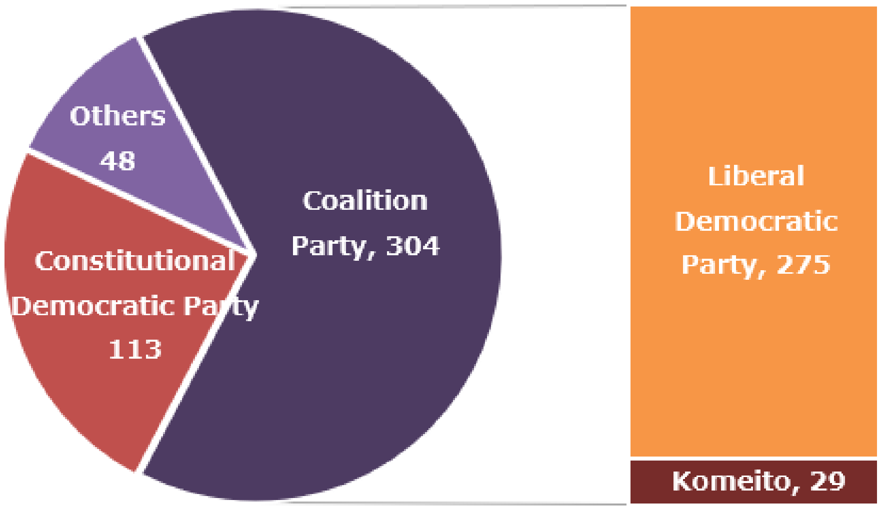
Source: (National Anti-nuclear Defense Counsels, 2021)

2.3. Political issues

In Japan, nuclear power is a political issue. Japan is the only country to have suffered an atomic bombing. Furthermore, a certain segment of the public is still traumatized by the Fukushima nuclear accident and also associates nuclear power with the atomic bomb.

At present, Japan is under a coalition government between the Liberal Democratic Party and Komeito. The following graph shows the number of seats in the House of Representatives.

Figure 14 Number of seats in the House of Representatives



Source: (The House of Representatives, as of September 2021)

Komeito insists on a nuclear-free society, and their policy opposes any addition of new nuclear plants or extending their operation for more than 40 years (Komeito, 2021). The biggest opposition party is the Constitutional Democratic Party. Its nuclear power policy is a nuclear-free society, and it advocates the adoption of a nuclear-free basic law (CDP, 2021). The next general election of the House of Representatives is scheduled at the end of October 2021. If the Liberal Democratic Party loses its seats, and Komeito and the Constitutional Democratic Party gain momentum, the government would have to make a policy adjustment to go no-nuclear.

The administration of Prime Minister Kishida Fumio began in October 2021. At the time of preparation of this report, Kishida was discreet and does not mention additional nuclear power plants. But he insisted on the necessity of restarting nuclear plants and reprocessing nuclear fuel, and he is in favor of small modular reactors and fusion energy. It is still premature to evaluate his nuclear power policy. Compared with the previous administration, the Kishida administration includes many pro-nuclear power government officials.

Table 14 Pro-nuclear power government officials in the Kishida administration

Name	Position	Background
Shimada Takashi	First Secretary of Prime Minister	Former Administrative Vice Minister of Economy, Trade and Industry
Hagiuda Koichi	Minister of Economiy Trande and Industry	Close aid of Former PM Abe Shinzo
Kishi Nobuo	Minister of Defense	Younger brother of Former PM Abe Shinzo
Yamagiwa Daishiro	Minister for Economic Revitalisation	Close aid of Amari Akira
Amari Akira	Secretary General of Liberal Democratic Party	Former Minister of Economy, Trade and Industry
Takaichi Sanae	Policy Chairperson of Liberal Democratic Party	Parliamentary group menber of underground nuclear power plant

Source: Compiled by the author, based on public documents

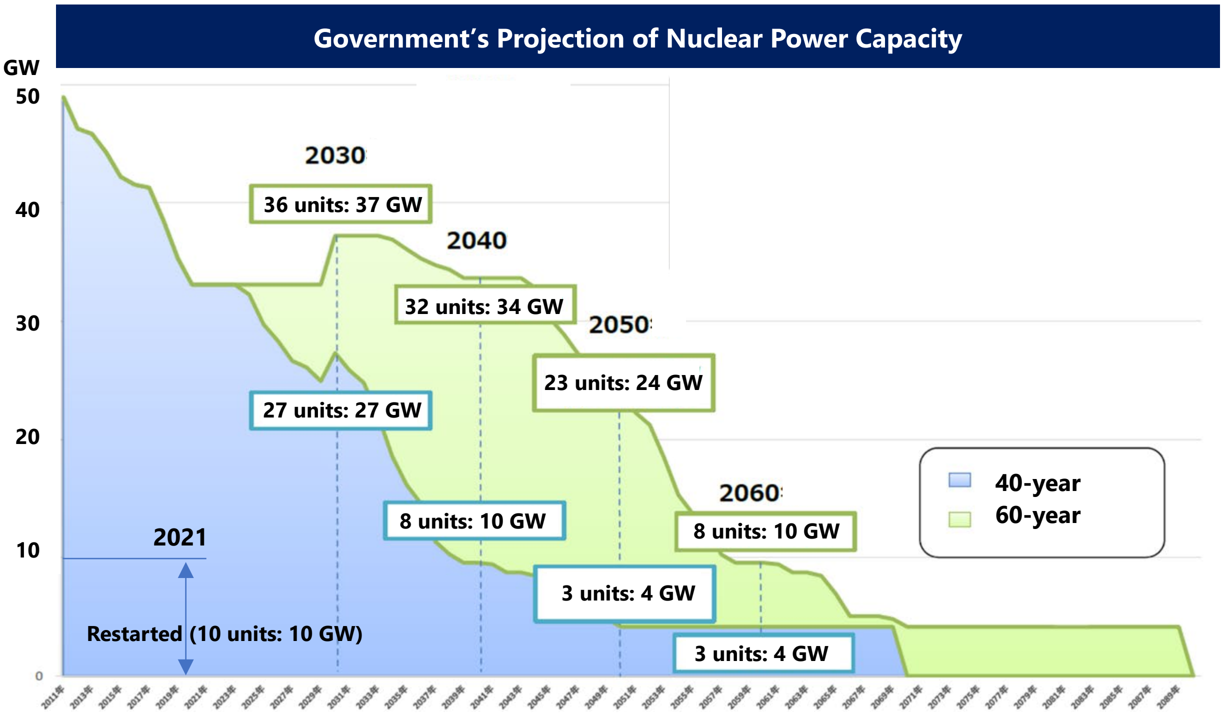
Section 3.Scenario analysis towards 2030 and 2050

This section shows a scenario analysis using the government's projection of nuclear power capacity in 2030 and 2050, and also analyses the possibility of achieving the estimation of 20-22% nuclear power generation in the energy mix by 2030.

3.1. Government scenarios of plant operation periods (40-year and 60-year)

After the Fukushima nuclear accident in 2011, the Nuclear Reactor Regulation Act limits operation up to 40 years. But if approval is gained from the NRA, a one-time extension of up to another 20 years is possible. So far, four nuclear power plants have received approval. Figure 15 below shows the government's projection for nuclear power capacity. The blue part represents a 40-year operation scenario, and the green part represents a 60-year operation scenario.

Figure 15 Government's projection of nuclear power capacity



Source: Expanded version of *Challenges and measures of nuclear power policy* (Ministry of Economy, Trade and Industry, 2021, pp. 14,15,17,36,64,65)

The government aims to extend the operating period of existing plants as long as possible rather than carry out new construction or retrofitting. The government shows some cases from the US of plants with operating periods up to a maximum of 80 years as examples to justify its position (METI, 2021). In order to achieve the government's estimated 20% share for nuclear energy in

2030, operational nuclear power capacity must increase to 27 units (27 GW) from the current 10 units (10 GW). The oldest nuclear power plant in the world is Beznau plant in Switzerland, built in 1969, with an operating period of 52 years.

Table 15 Overseas power with long operating periods

US	47 units in operation for more than 40 years among the 94 operating units 60-year operation: 86 units approved, 4 units to apply 80-year operation: 4 units approved, 6 units under review, 12 units to apply
France	14 units in operation for more than 40 years among the 56 operating units
UK	4 units in operation for more than 40 years among the 15 operating units

Source: *Maximum exertion of nuclear power potential and pursuit of safety* (Agency for Natural Resources and Energy, 2021, pp. 2-3)

3.2. Case study of a realistic nuclear power generation scenario in 2030

According to the METI scenario, if all 27 units (27GW) are operational in 2030 at a capacity factor of 80%, the total nuclear power generation will reach 186 TWh. This could achieve the estimated 20% energy mix. However, there are many obstacles to restarting the plants, such as the low capacity factor, long review period and local opposition. In this study, a realistic scenario assumes that three plants (Tsuruga 2, Higashidori 1 and Shika 2) would not pass the review due to the existence of capable faults. If these three plants are excluded from the government scenario, the realistic scenario becomes 23 of 27 units (24GW) in operation. Assuming that these 23 plants are operational in 2030, the total nuclear power generation is estimated using both higher capacity factor of 80% and a lower capacity factor of 60%.

Table 16 Comparison between the government scenario and a realistic scenario

<Government scenario>

1.Restarted	10 Units	9,956 MW
2.Approved+Local consent (done)	3 Units	2,477 MW
3.Approved+Local consent (yet)	4 Units	4,632 MW
4. Under Review	10 Units	10,529 MW

27 units, 27,594 MW

3 plants may not restart due to capable fault

Tsuruga 2 (1,160 MW)
Higashidori 1 (1,100 MW),
Shika 2 (1,206 MW)

<Realistic scenario>

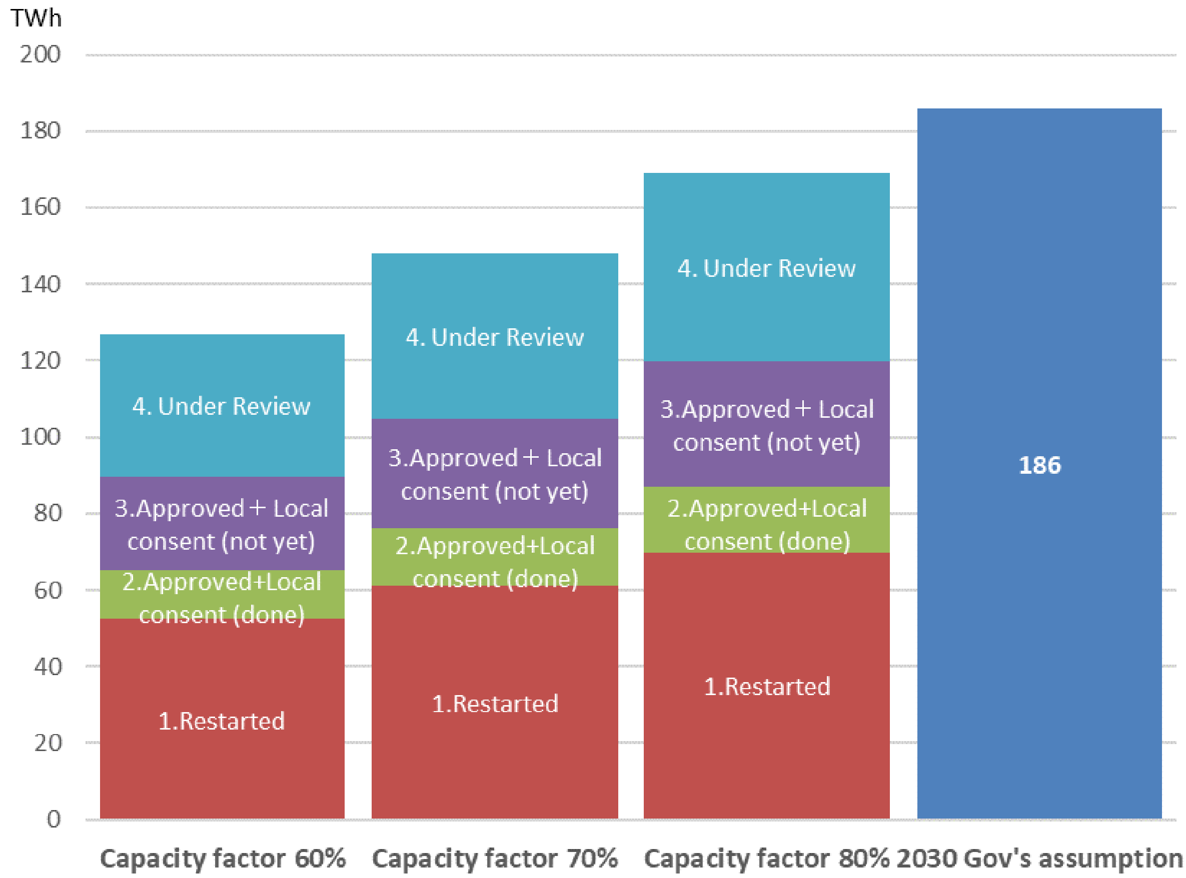
1.Restarted	10 Units	9,956 MW
2.Approved+Local consent (done)	3 Units	2,477 MW
3.Approved+Local consent (yet)	4 Units	4,632 MW
4. Under Review	7 Units	7,063 MW

24 units, 24,128 MW

Source: Compiled by the author

The figure below compares the government's assumption with the estimated nuclear power generation. Even in the case of a higher capacity factor of 80%, the government's estimation cannot be achieved. Considering the level of 49% in 2020, 80% is an ambitious assumption. Unless the government successfully makes the periodic inspection shorter and lengthens the inspection cycle, the capacity factor is not likely to increase to the level of more than 80% as seen in the US.

Figure 16 Nuclear power generation estimates in 2030 according to the realistic scenario



Source: Compiled by the author

There could be a more pessimistic scenario, whereby more than three plants were not able to pass NRS's review and/or could not obtain local consent, and in that case, nuclear power generation in 2030 would be far below the government's assumption of 186 TWh.

Section 4. Technology development and international cooperation

This section outlines Japan's nuclear power technology development and international collaboration.

4.1. Technology development

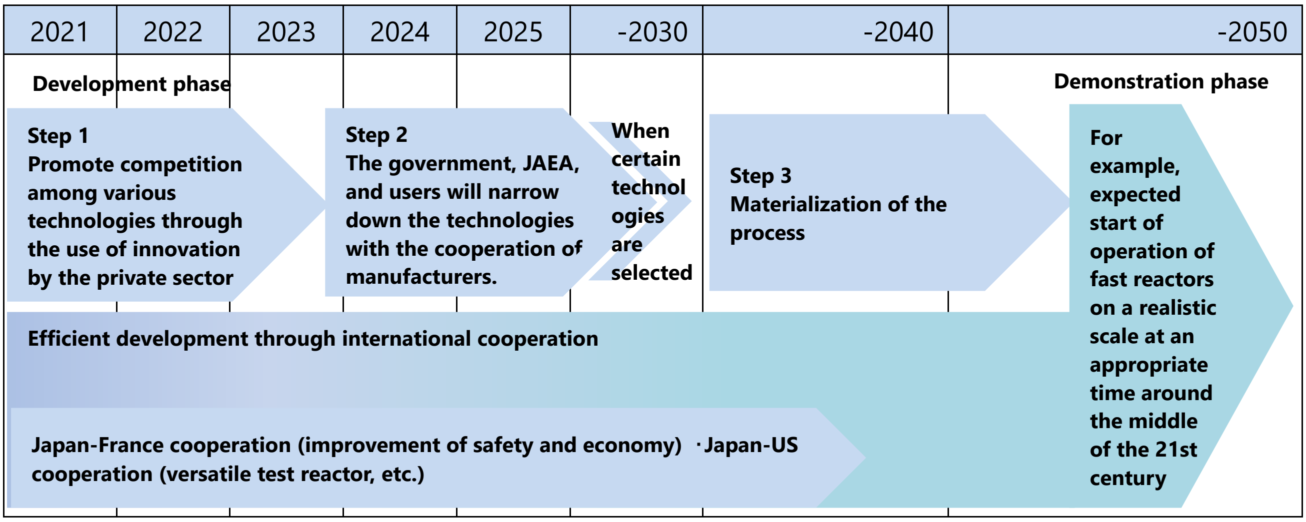
According to the Green Growth Strategy in 2050, the government aims for technology development of nuclear power in four fields — fast reactor, small modular reactor (SMR), high temperature gas reactor (HTGR) and fusion energy. The following section summarises the development plan and roadmap for each of these fields.

4.1.1. Fast reactor

Figure 17 Fast reactor development plan

Current status	Future efforts
Develop fast reactor based on the strategic roadmap formulated in 2018. From step 1 to step 3, encourage competition among technologies and narrow down to materialization of the process. Use the test plant of Joyo.	In the mid-21st century, expect operation of real-scale fast reactor in terms of technological maturity, finance and operational experience.

Roadmap



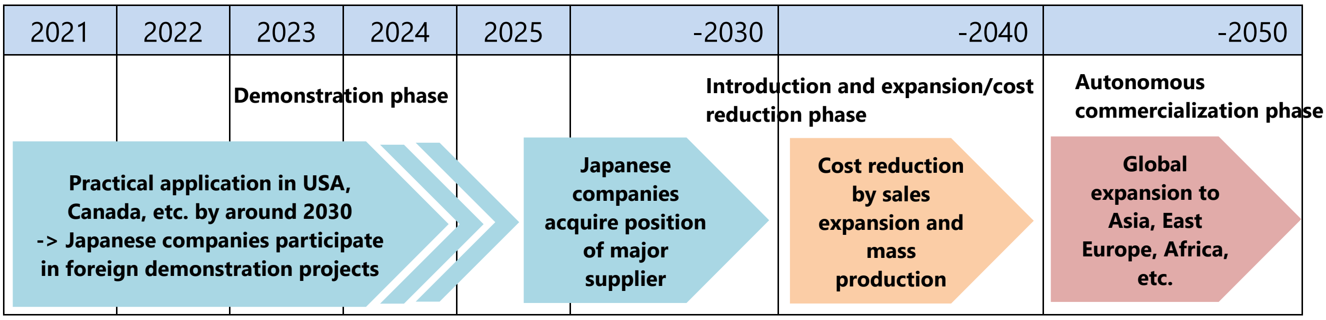
Source: *Green Growth Strategy Through Achieving Carbon Neutrality in 2050* (Ministry of Economy, Trade and Industry, 2021, pp. 185,186,188)

4.1.2. Small Modular Reactor (SMR)

Figure 18 Small modular reactor development plan

Current status	Future efforts
Japanese companies are conducting development using original designs and considering diverse needs. Continuous R&D support is essential.	The government will actively support efforts by Japanese companies in cooperation with international demonstration projects by USA, UK, Canada and other countries, aiming for commercial operation by the end of 2020s.

Roadmap



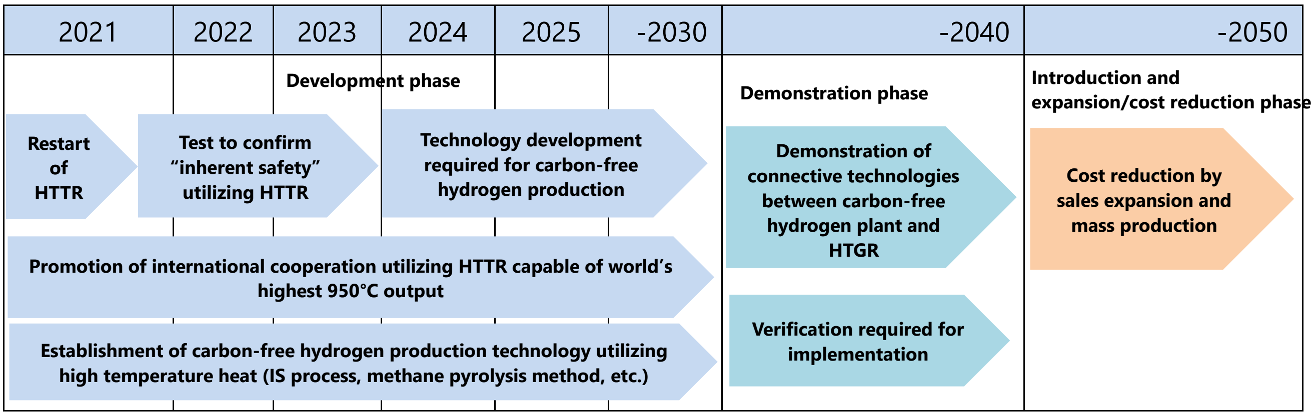
Source: *Green Growth Strategy Through Achieving Carbon Neutrality in 2050* (Ministry of Economy, Trade and Industry, 2021, pp. 185,186,188)

4.1.3. High Temperature Gas Reactor (HTGR)

Figure 19 High temperature gas reactor development plan

Current status	Future efforts
In Japan, JAEA possesses the High Temperature Engineering Test Reactor (HTTR). The HTTR has achieved a high-temperature continuous operation at the world's highest temperature of 950°C for 50 days.	The government will support necessary technology development for massive and low-cost carbon-free hydrogen production by 2030. Cost target of hydrogen in2050: JPY 12 /Nm3

Roadmap



Source: *Green Growth Strategy Through Achieving Carbon Neutrality in 2050* (Ministry of Economy, Trade and

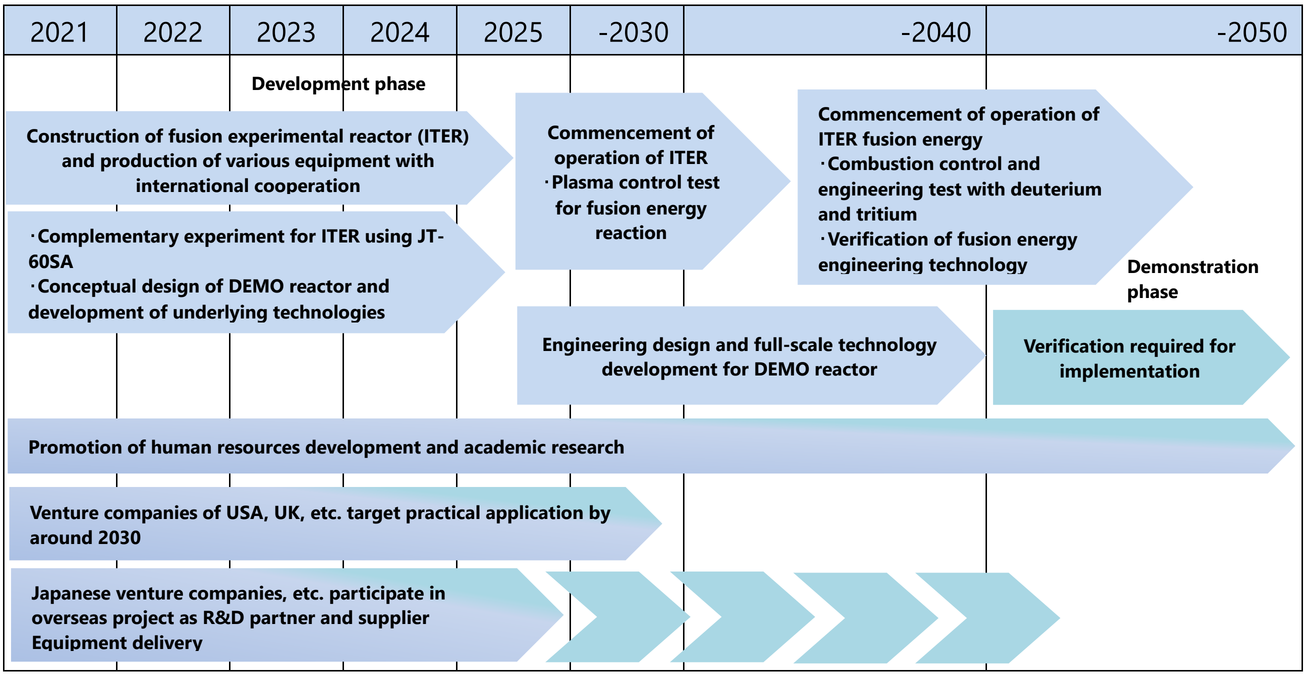
Industry, 2021, pp. 185,186,188)

4.1.4. Fusion energy

Figure 20 Fusion energy development plan

Current status	Future efforts
Test implementation for advanced plasma control technology utilizing a large Tokamak device (JT-60SA) which is under construction in Japan (starting operation from spring 2021).	Various design and technology development activities for the fusion DEMO reactor construction project in Japan will be implemented to promote R&D to have a prospect of practical application of fusion energy by the mid-21st century.

Roadmap



Source: *Green Growth Strategy Through Achieving Carbon Neutrality in 2050* (Ministry of Economy, Trade and Industry, 2021, pp. 185,186,188)

4.2. Technology cooperation with other countries

The government promotes bilateral and multilateral cooperation for the peaceful use of nuclear energy. As of March 2021, Japan has bilateral nuclear cooperation agreements with 15 countries.

Table 17 Countries with bilateral nuclear cooperation agreements with Japan

Canada, Australia, China, US, France, UK, EURATOM, Kazakhstan, Korea, Viet Nam, Jordan, Russia, Turkey, UAE and India

Source: *White Paper on Nuclear Energy 2020* (Japan Atomic Energy Commission, 2021, pp. 122-126)

Out of those 15 countries, Japan maintains policy dialogues with the US, France and UK (JAEC, 2021).

The US-Japan Bilateral Commission on Civil Nuclear Cooperation was established in 2012. The Commission has five working groups — nuclear security, civil nuclear energy research and development, safety and regulatory issues, emergency management, and decommissioning and environmental management.

The 10th meeting of the Japan-France Nuclear Cooperation Committee was held in January 2021 and views were exchanged on nuclear safety, emergency preparedness, fuel cycle, radioactive waste and decommissioning of the Fukushima nuclear power plant.

The 9th Annual Japan-UK Nuclear Dialogue was held in December 2020 and discussions featured various topics including decommissioning, environmental remediation, and research and development.

Nuclear technology development mentioned above can only proceed with international collaboration. The table below shows Japan’s collaboration with specific countries.

Table 18 Bilateral nuclear technology cooperation

Technology	Country	Cooperation technology
Fast reactor	France	Improvement of safety and economics, e.g. natural circulation cooling system and automatic insertion of control rods in case of high temperature
	US	Development of Versatile Test Reactor (VTR), the Memorandum of Cooperation was signed in 2019
Small Modular Reactor	US	Development of maintenance instruments (between US NuScale Power and Japanese JGC)
		Development of SMR called BWRX-300 (between US GE Hitachi and Japanese Hitachi-GE)
High Temperature Gas Reactor	UK	Safety of HTGR (between JAEA and UK’s National Nuclear Laboratory)
	Poland	Design, coated particle fuel and safety analysis (between JAEA and Poland’s NCBJ)
Fusion energy	ITER	Joint development with ITER member states (China, EU, India, Russia, Republic of Korea and US)
Decommission	US	Regulation and industry collaboration at the Japan-US Bilateral Decommissioning Workshop
		Sharing experience on decommissioning (between US AECOM and Japanese Toshiba ESS)

Source: Compiled by the author, based on *Green Growth Strategy Through Achieving Carbon Neutrality in 2050* (Ministry of Economy, Trade and Industry, 2021 and public documents)

Appendix

A1. List of commercial nuclear power plants in Japan

Status	No.	Power Company	Plant	Reactor	MW	Date of Commission	Operating years
1.Restarted	1	Kansai	Takahama 3	PWR	870	1985.01.17	36
	2	Kansai	Takahama 4	PWR	870	1985.06.05	36
	3	Kansai	Oi 3	PWR	1,180	1991.12.18	30
	4	Kansai	Oi 4	PWR	1,180	1993.02.02	28
	5	Kansai	Mihama 3	PWR	826	1976.12.01	45
	6	Shikoku	Ikata 3	PWR	890	1994.12.15	27
	7	Kyushu	Genkai 3	PWR	1,180	1994.03.18	27
	8	Kyushu	Genkai 4	PWR	1,180	1997.07.25	24
	9	Kyushu	Sendai 1	PWR	890	1984.07.04	37
	10	Kyushu	Sendai 2	PWR	890	1985.11.28	36
2.Approved+Local consent (done)	1	Kansai	Takahama 1	PWR	826	1974.11.14	47
	2	Kansai	Takahama 2	PWR	826	1975.11.14	46
	3	Tohoku	Onagawa 2	BWR	825	1995.07.28	26
3.Approved＋Local consent (not yet)	1	Tokyo	Kashiwazaki-kariwa 6	ABWR	1,356	1996.11.07	25
	2	Tokyo	Kashiwazaki-kariwa 7	ABWR	1,356	1997.07.02	24
	3	Japan Atomic Power	Tokai 2	BWR	1,100	1978.11.28	43
	4	Chugoku	Shimane 2	BWR	820	1989.02.10	32
4. Under Review	1	Hokkaido	Tomari 1	PWR	579	1989.06.22	32
	2	Hokkaido	Tomari 2	PWR	579	1991.04.12	30
	3	Hokkaido	Tomari 3	PWR	912	2009.12.22	12
	4	Tohoku	Higashidori 1	BWR	1,100	2005.12.08	16
	5	Chubu	Hamaoka 3	BWR	1,100	1987.08.28	34
	6	Chubu	Hamaoka 4	BWR	1,137	1993.09.03	28
	7	Hokuriku	Shika 2	ABWR	1,206	2006.03.15	15
	8	Japan Atomic Power	Tsuruga 2	PWR	1,160	1987.02.17	34
	9	J-Power	Oma	ABWR	1,383	2008.05 began construction	-
	10	Chugoku	Shimane 3	ABWR	1,373	2005.12 began construction	-

5. Not applied for review	1	Tohoku	Onagawa 3	BWR	825	2002.01.30	19
	2	Tokyo	Kashiwazaki-kariwa 1	BWR	1,100	1985.09.18	36
	3	Tokyo	Kashiwazaki-kariwa 2	BWR	1,100	1990.09.28	31
	4	Tokyo	Kashiwazaki-kariwa 3	BWR	1,100	1993.08.11	28
	5	Tokyo	Kashiwazaki-kariwa 4	BWR	1,100	1994.08.11	27
	6	Tokyo	Kashiwazaki-kariwa 5	BWR	1,100	1990.04.10	31
	7	Chubu	Hamaoka 5	ABWR	1,380	2005.01.18	16
	8	Hokuriku	Shika 1	BWR	540	1993.07.30	28
	9	Tokyo	Higashidori 1	ABWR	1,385	2011.01 began construction	-
6. To be decommissioned	1	Tohoku	Onagawa1	BWR	524	1984.06.01	37
	2	Tokyo	Fukushima Daiichi 1	BWR	460	1971.03.26	50
	3	Tokyo	Fukushima Daiichi 2	BWR	784	1974.07.18	47
	4	Tokyo	Fukushima Daiichi 3	BWR	784	1976.03.27	45
	5	Tokyo	Fukushima Daiichi 4	BWR	784	1978.10.12	43
	6	Tokyo	Fukushima Daiichi 5	BWR	784	1978.04.18	43
	7	Tokyo	Fukushima Daiichi 6	BWR	1,100	1979.10.24	42
	8	Tokyo	Fukushima Danini 1	BWR	1,100	1982.04.20	39
	9	Tokyo	Fukushima Danini 2	BWR	1,100	1984.02.03	37
	10	Tokyo	Fukushima Danini 3	BWR	1,100	1985.06.21	36
	11	Tokyo	Fukushima Danini 4	BWR	1,100	1987.08.25	34
	12	Japan Atomic Power	Tokai 1	GCR	166	1966.07.25	55
	13	Japan Atomic Power	Tsuruga 1	BWR	357	1970.03.14	51
	14	Chubu	Hamaoka 1	BWR	540	1976.03.27	45
	15	Chubu	Hamaoka 2	BWR	840	1978.11.29	43
	16	Kansai	Mihama 1	PWR	340	1970.11.28	51
	17	Kansai	Mihama 2	PWR	500	1972.07.25	49
	18	Kansai	Oi 1	PWR	1,175	1979.03.27	42
	19	Kansai	Oi 2	PWR	1,175	1979.12.05	42
	20	Chugoku	Shimane 1	BWR	460	1974.03.29	47
	21	Shikoku	Ikata 1	PWR	566	1977.09.30	44
	22	Shikoku	Ikata 2	PWR	566	1982.03.19	39
	23	Kyushu	Genkai 1	PWR	559	1975.10.15	46
	24	Kyushu	Genkai 2	PWR	559	1981.03.30	40

Source: Compiled by the author, based on Japanese nuclear power reactors (operational, under construction and planning etc.) (Japan Atomic Industrial Forum, 2021)

A2. List of new plants described in the power companies' business plans

Years of planned commencement of construction and commissioning are not announced.

	Power Company	Plant	Reactor	MW
1	Japan Atomic Power	Tsuruga 3	APWR	1,538
2	Japan Atomic Power	Tsuruga 4	APWR	1,538
3	Tohoku	Higashidori 2	ABWR	1,385
4	Chugoku	Kaminoseki 1	ABWR	1,373
5	Chugoku	Kaminoseki 2	ABWR	1,373
6	Kyushu	Sendai 3	APWR	1,590
	Total			8,797

Source: *Japanese nuclear power reactors (operational, under construction and planning etc.)* (Japan Atomic Industrial Forum, 2021)

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