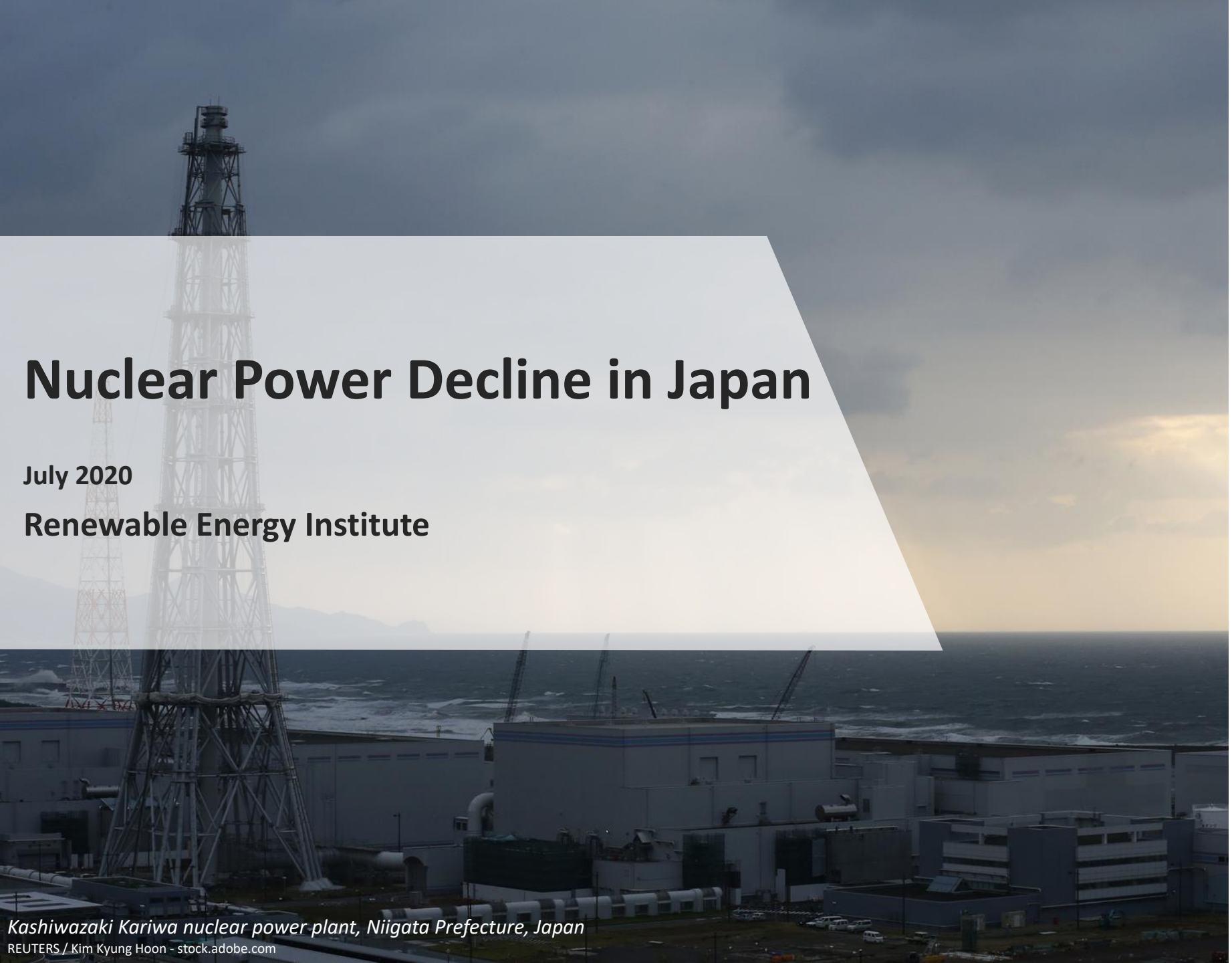
Nuclear Power Decline in Japan

July 2020

Renewable Energy Institute



Kashiwazaki Kariwa nuclear power plant, Niigata Prefecture, Japan
REUTERS / Kim Kyung Hoon - stock.adobe.com

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Executive Summary

Not very performant and reliable before the accident at the Fukushima Daiichi power plant, the Japanese nuclear industry does not manage to get back on its feet since this disaster. Within the past decade, Japan's nuclear reactor fleet has been drastically reduced because of new economic, social and technological realities. Off to a slow restart, nuclear power is not a main electricity generation source in the country anymore. With dark clouds gathering over its future, political support should be reviewed.

Table of Contents

Issue 1: Less reactors and capacity
Issue 2: Slow restart
Issue 3: Small generation
Issue 4: Unachievable FY 2030 target
Issue 5: Minor capacity in FY 2050
Issue 6: Huge restart costs
Issue 7: Uneconomic dispatch
Issue 8: Unreliable supply
Issue 9: Decommissioning, reprocessing, etc.
Appendix: List of reactors

Issue 1: Less reactors and capacity

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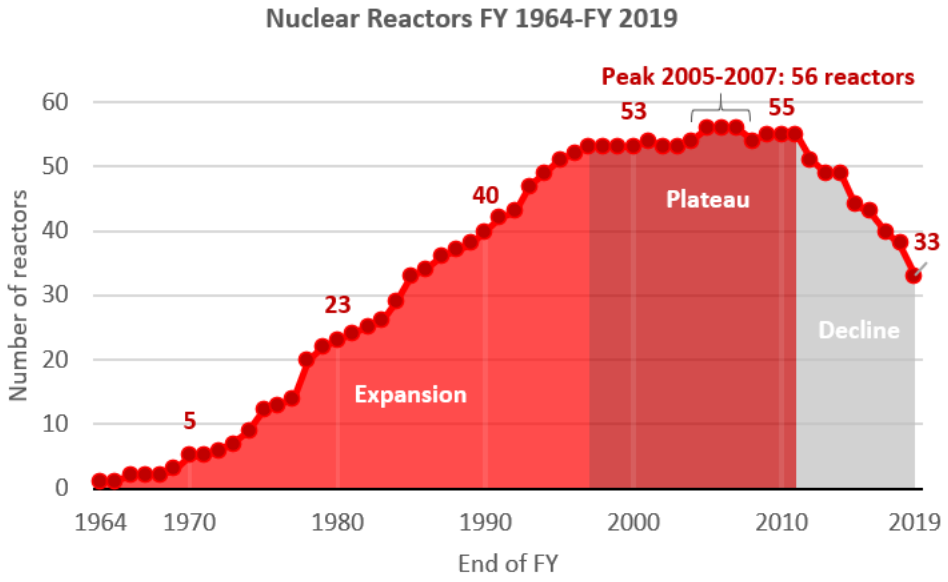
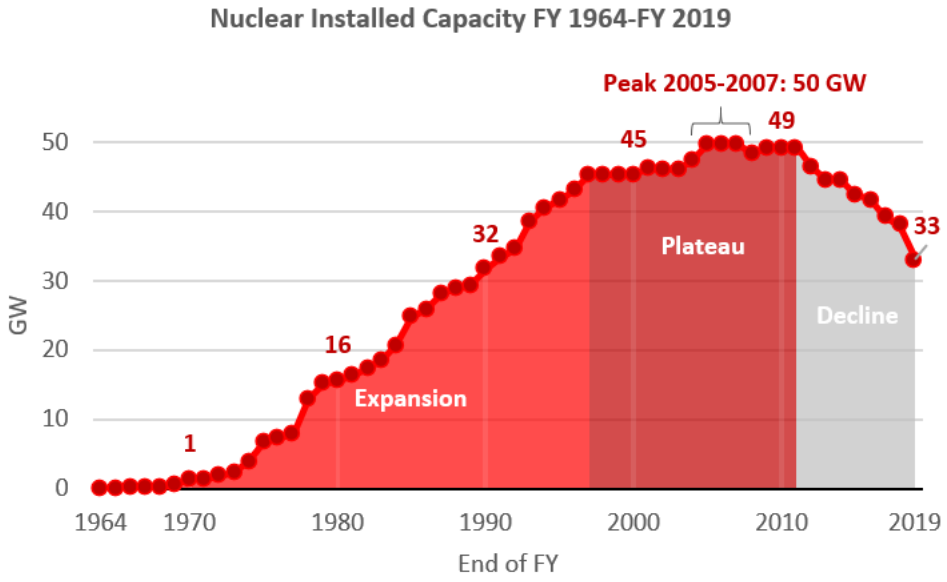


Sources: REI based on JAIF (1) and IAEA (1)



Sources: REI based on JAIF (1) and IAEA (1)

In Japan, a fiscal year (FY) starts on April 1st and finishes on March 31st (e.g. April 2019 to March 2020 for FY 2019), and official statistics are based on FY.

KEY OBSERVATIONS

FY 1964	First reactor, Japan Power Demonstration Reactor (JPDR), commercial operation start.
1970s Oil shocks	Nuclear power program accelerates for energy security purpose.
FY 2005-FY 2007	Peak both in terms of number of reactors; 56 reactors, and installed capacity; 50 gigawatts (GW).
2011	Accident at the Fukushima Daiichi nuclear power plant.
FY 2012-FY 2013	Official permanent shutdown of the damaged Fukushima Daiichi power plant's six reactors.
FY 2013	The Nuclear Regulation Authority (NRA) introduces new more stringent safety standards.
FY 2015-FY 2019	Permanent closures of 16 reactors due to economic and technical difficulties in meeting the new safety standards, and local opposition.

Between FY 2010 (pre-Fukushima level) and FY 2019, Japan's nuclear power fleet has been reduced by 40% in terms of reactors, and 33% in terms of installed capacity.

Issue 2: Slow restart

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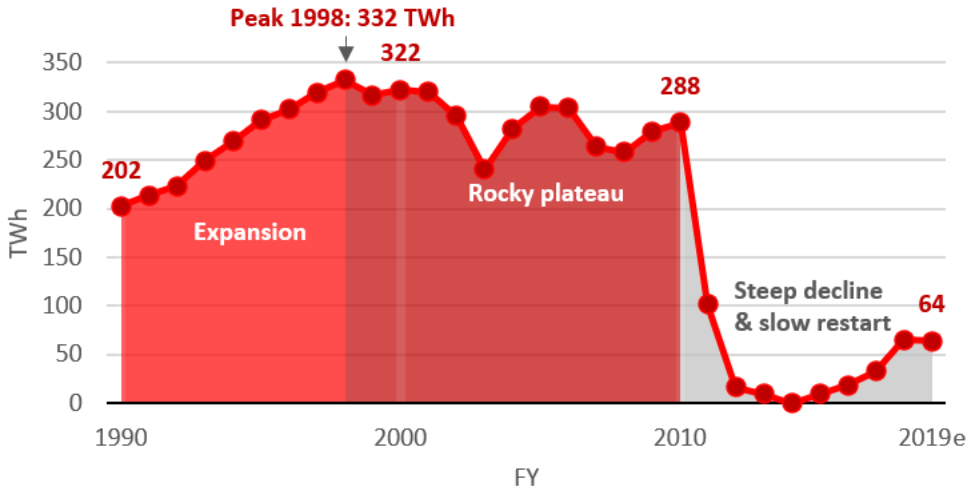
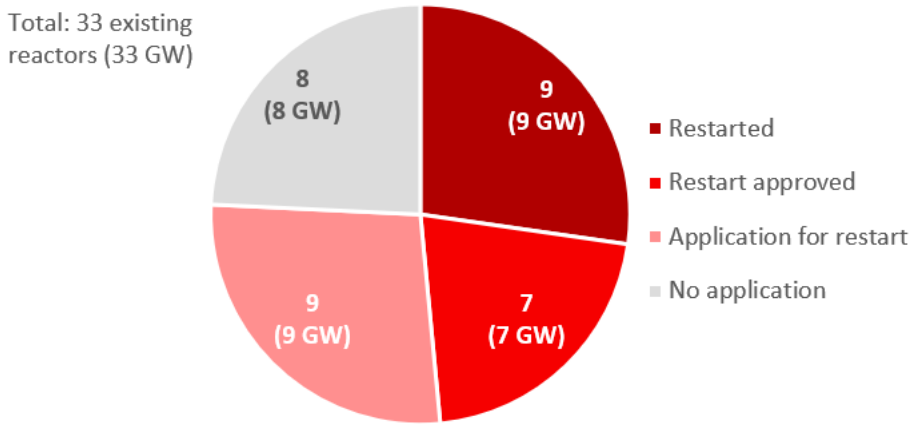
Gross Electricity Generation from Nuclear Power FY 1990-FY 2019e



Source: REI based on IEA (1) for FY 1990-FY 2017 and (2) for FY 2018e and FY 2019e

The FY 2018 and FY 2019 estimates are based on net electricity generation applying a multiplying factor of 1.09.

Nuclear Reactors Status, as of June 2020



Source: REI based on JAIF (2)

KEY OBSERVATIONS

FY 1998	Peak of electricity generation from nuclear power; 332 terawatt-hours (TWh). It does not coincide with the peak of nuclear power installations in the 2000s, because of low capacity and operation factors.
FY 2014	Following Fukushima Daiichi accident, all existing reactors are progressively taken offline. Electricity generation from nuclear power bottoms out at 0 TWh.
FY 2019	Nine reactors with a combined capacity of 9 GW have restarted, electricity generation from nuclear power reaches 64 TWh.
2020	COVID-19 lowers electricity consumption and is contracted by employee working at the Kashiwazaki Kariwa nuclear power plant (REI).

Generation peaked in 1998, installed capacity in 2005-2007. After 2011 generation and capacity collapsed, and recovery is unlikely.

Issue 3: Small generation

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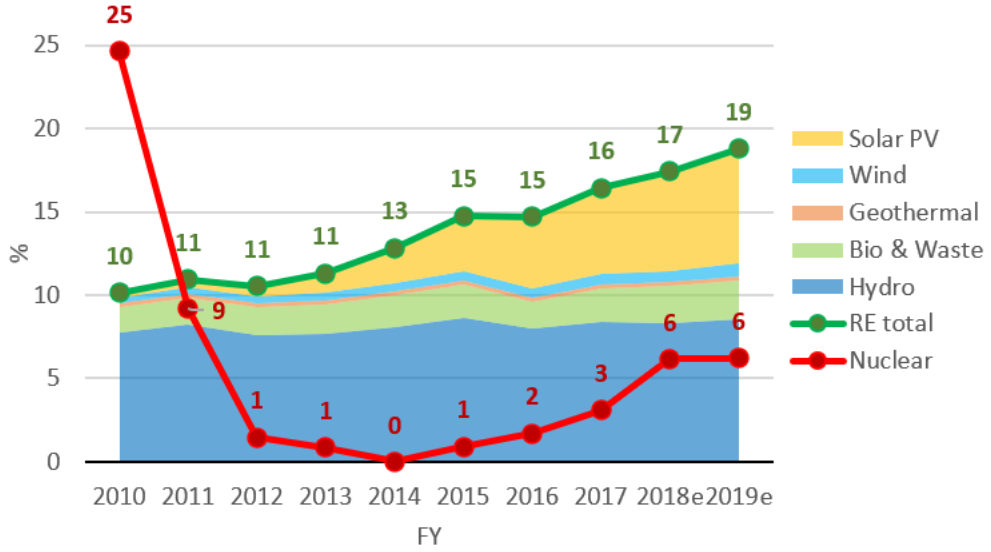
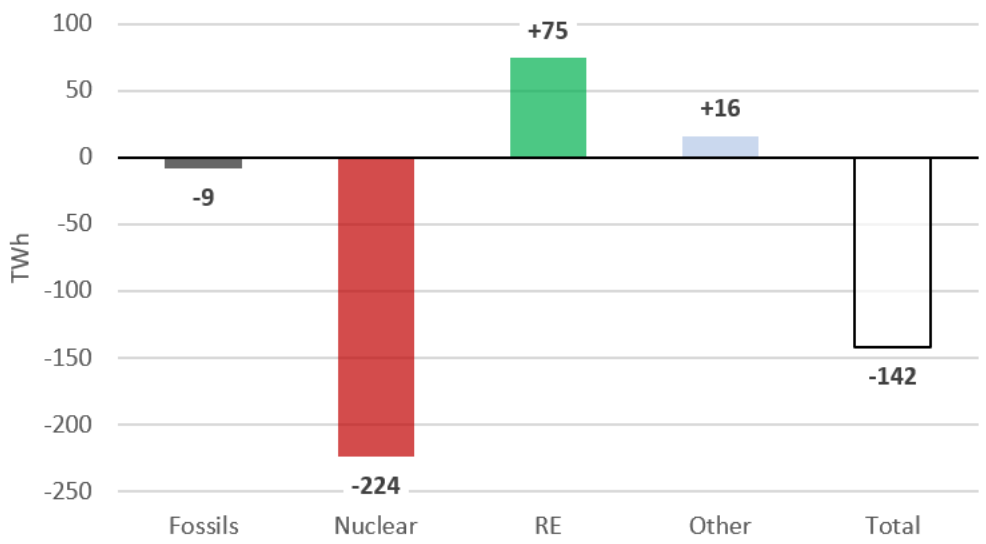
Nuclear and RE Shares in Gross Electricity Generation FY 2010-FY 2019e



Source: REI based on IEA (3 & 4) for FY 2010-FY 2017 and (2) for FY 2018e and FY 2019e

Change in Gross Electricity Generation FY 2019e-FY 2010



Source: REI based on IEA (3 & 4) for FY 2010-FY 2018 and (2) for FY 2019e

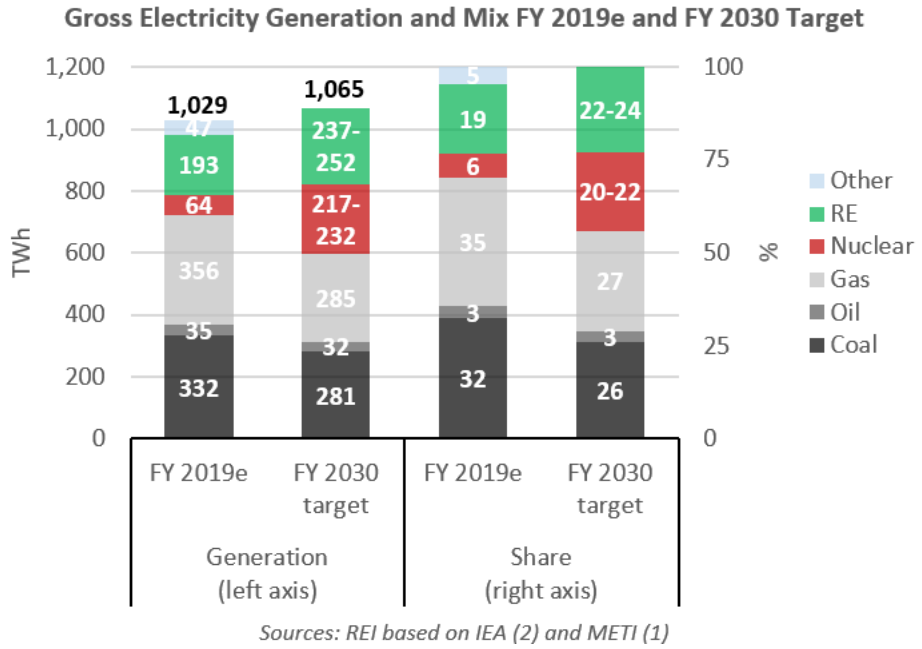
The FY 2018 and FY 2019 estimates are based on net electricity generation applying multiplying factors of: 1.03 to fossil fuels (coal, oil and gas) and other combustibles (bioenergy and waste), 1.09 to nuclear, 1 to RE – except geothermal; 1.11, and 1 to non-specified sources.

KEY OBSERVATIONS

FY 2012	Introduction of feed-in tariffs for RE, a turning point – especially for the expansion of solar photovoltaic (PV).
FY 2015	Nuclear reactors Sendai-1 & -2, and Takahama-3 restarted.
FY 2016	Nuclear reactor Ikata-3 restarted.
FY 2017	Nuclear reactor Takahama-4 restarted.
FY 2018	Nuclear reactors Genkai-3 & -4, and Ohi-3 & -4 restarted
FY 2010-FY 2019	Energy efficiency & energy conservation, and renewable energy (RE) offset the substantial drop in electricity generation from nuclear power.
2020	Temporary closures of five of the nine restarted reactors: (1) four for having failed to meet the new regulatory standard requiring the installation of specialized safety facilities: Sendai-1 & -2 (effective in March and May), and Takahama-3 & -4 (upcoming in August and October), and (2) one, Ikata-3, because of a provisional injunction against its restart in January 2020 (after a shutdown for periodic inspection) (JAIF (2)).

The share of electricity generation from nuclear power is now 3 times smaller than that of renewable energy.

Issue 4: Unachievable FY 2030 target



Sources: REI based on IEA (2) and METI (1)

"Other" includes non-RE waste and non-specified sources.

The FY 2019 estimates are based on net electricity generation applying multiplying factors of: 1.03 to fossil fuels (coal, oil and gas) and other combustibles (bioenergy and waste), 1.09 to nuclear, 1 to RE – except geothermal; 1.11, and 1 to non-specified sources.

FY 2030 PROJECTIONS

Scenario	Description[a]	Result[b]
Low	Only restarted reactors (four of which will be permanently shut down by FY 2030).	**0-3%**
Intermediate	Restarted reactors and those approved for restart.	**7%**
High	Restarted reactors, as well as those approved for restart, and those having applied for restart or start (including the two under construction, i.e. Shimane-3 and Ohma).	**12%**
Highest	All existing reactors and the two under construction.	**15%**

[a] In all scenarios, reactor status is as of June 2020 – see Appendix (pages 11-13), a lifetime of 40 years applies, unless a 60-year operating license has been granted (Mihama-3, Takahama-1 & -2, and Tokai-2), and a capacity factor of 70% is assumed (similar to pre-Fukushima FY (2010)).

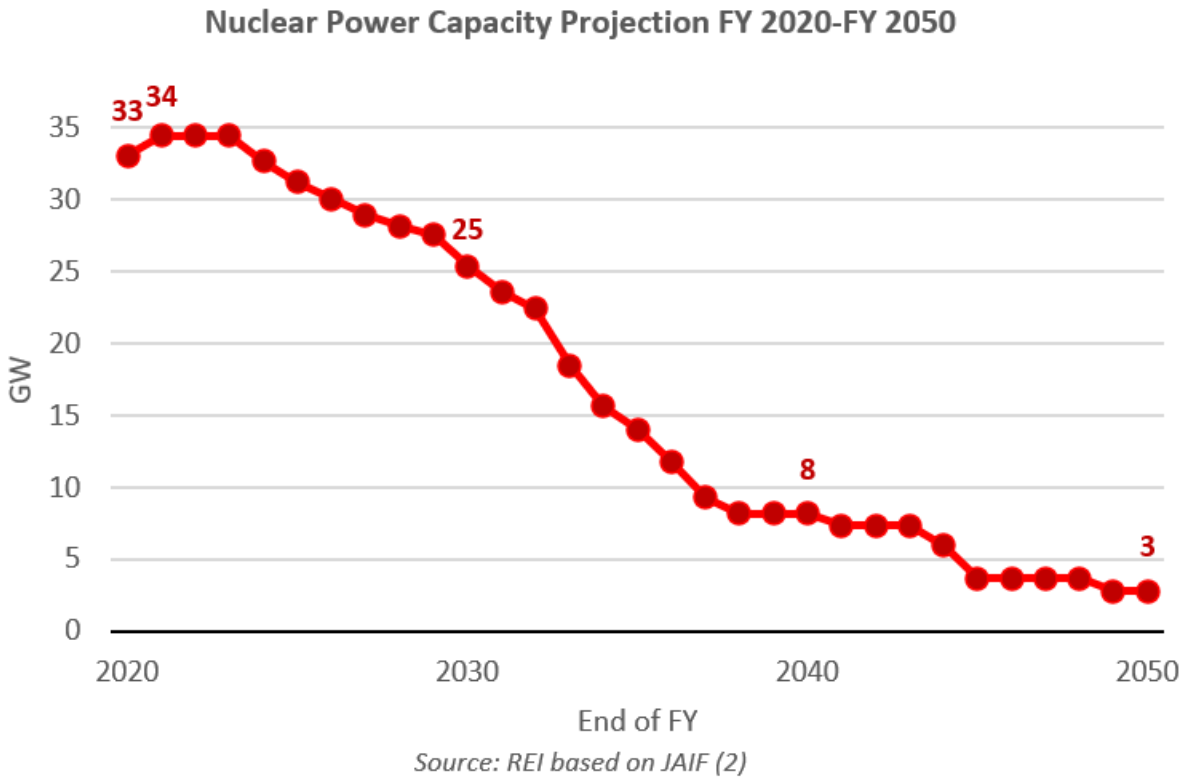
[b] Nuclear power share in total electricity generation. Total electricity generation is targeted to reach 1,065 TWh in FY 2030.

KEY OBSERVATIONS

FY 2015	The Ministry of Economy, Trade and Industry (METI)'s *Long-term Energy Supply and Demand Outlook* sets a target for electricity generation from nuclear power in FY 2030 of 20-22% (or 217-232 TWh). This objective is adopted in the broader framework of Japan's FY 2030 greenhouse gas reduction goal of 26% (compared to FY 2013)
FY 2018	The METI releases the 5th Strategic Energy Plan – the target remains unchanged (METI (2)).
FY 2020	In the current situation, this target is completely out of reach under all scenarios (see "PROJECTIONS" above).

The nuclear power FY 2030 target should be revised downward in the next Strategic Energy Plan FY 2021-FY 2022.

Issue 5: Minor capacity in FY 2050



Source: REI based on JAIF (2)

KEY OBSERVATIONS

FY 2020	The combined installed capacity of the 33 existing nuclear reactors is 33 GW.
FY 2021	Expected start of operations of Shimane-3 (construction started in FY 2005, was temporarily halted because of Fukushima accident).
FY 2024	Start of a first wave of retirements of reactors having reached the end of their 40-year operating license, the first of which are Sendai-1 and Takahama-3.
FY 2025	Expected start of operations of Ohma (construction started in FY 2008, was temporarily halted because of Fukushima accident).
FY 2034	Start of a second wave of retirements of reactors having reached the end of their 60-year operating license, the first of which is Takahama-1.
FY 2050	Only two reactors, Shimane-3 and Ohma, remain in operation with a combined capacity of about 3 GW.

A lifetime of 40 years applies, unless a 60-year operating license has been granted.

Nuclear power will not be a solution for long-term decarbonization.

Issue 6: Huge restart costs

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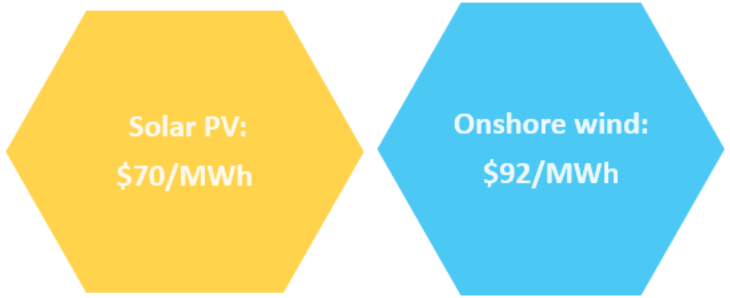
Nuclear Reactors Restart Costs: Examples of Onagawa-2 and Tokai-2

Assumption for each nuclear reactor	Onagawa-2	Tokai-2	*Source*
Safety upgrades	$3.12 bn.	$1.60 bn. – >$2.29 bn.	*Tohoku EPCO / JAPC – General contractors*
Installation of specialized safety facilities	Unknown (assumed same as Tokai-2) $0.56 bn. – <$0.92 bn.	$0.56 bn. – <$0.92 bn.	*JAPC – General contractors*
Total new capital expenditure	$3.68 bn. – $4.04 bn.	$2.16 bn. – $3.21 bn.	*Tohoku EPCO / JAPC – General contractors*
Operating expenditure	$0.06/kWh	$0.06/kWh	*METI (3)*
Remaining lifetime after restart (from FY 2022)	13 years	16 years	*JAIF (2)*
Installed capacity	825 MW	1,100 MW	*JAIF (2)*
Capacity factor	70%	70%	*METI (3)*
Electricity produced over remaining lifetime	65.81 TWh	108.00 TWh	
Total costs until planned permanent shutdown	$7.54 bn. – $7.90 bn.	$8.50 bn. – $9.55 bn.	
Minimum restart costs	**$115/MWh – $120/MWh**	**$79/MWh – $88/MWh**	

Assumes initial capital expenditure fully recovered, no financial cost incurred, and decommissioning, spent fuel & radioactive waste disposal funds sufficiently provisioned so far.
Exchange rate $1 = ¥109.

LCOE of Most Competitive Solar PV and Onshore Wind 2020 H1 (operation year 2022)



Source: REI based on BloombergNEF

KEY OBSERVATIONS

FY 2019 (1)	Tohoku EPCO estimates the costs of the safety upgrades to restart Onagawa-2 at ¥340 bn. ($3.12 bn.). The minimum restart cost for this reactor can be estimated at $115-120/MWh.
FY 2019 (2)	Japan Atomic Power Company (JAPC), estimates the costs of the safety upgrades and of the installation of specialized safety facilities to restart Tokai-2 at ¥235 bn. ($2.16 bn.) According to general contractors, these costs are estimated at ¥350 bn. ($3.21 bn.) (CNIC (1)). The minimum restart cost for this reactor can be estimated at $79-88/MWh.
FY 2019 (3)	The annual average day-ahead spot market price of the Japan Electric Power Exchange (JEPX) is $73/MWh.
2022	With most competitive projects at $70/MWh for solar PV and $92/MWh for onshore wind, renewable energy is poised to economically outcompete nuclear power.

Nuclear economics is quite bleak, and particularly suffers from the comparison with renewable energy.

Issue 7: Uneconomic dispatch

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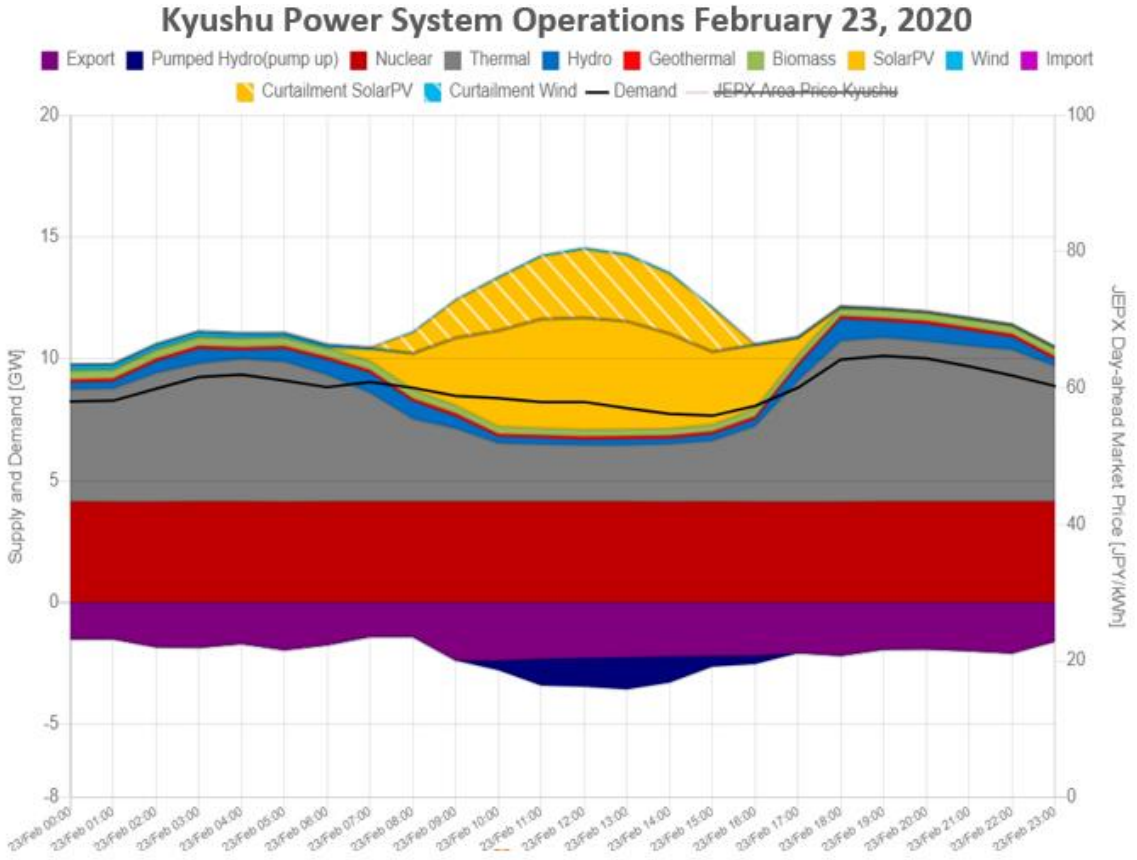
Simplified Presentation of Curtailment Rule of Power Plants

1. • Fossils; coal, oil, and gas, adjustments
   • Pumped storage hydro adjustment
2. • Use of interregional interconnections
3. • Biomass adjustment
4. • Solar PV and wind curtailments
5. • Nuclear, hydro, and geothermal adjustments

Source: REI based on METI (4)

KEY OBSERVATIONS

FY 2015	In Kyushu, nuclear reactors Sendai-1 & -2 restart commercial operation in September and November, respectively.
FY 2016	Establishment of the curtailment rule of power plants prioritizing nuclear power over lower marginal costs renewable energy solar PV and wind (METI (4)).
FY 2018 (1)	In Kyushu, nuclear reactors Genkai-3 & -4 restart commercial operation in May and July, respectively.
FY 2018 (2)	In Kyushu, on October 13, 2018, first curtailment of renewable energy (solar PV).
FY 2019	In Kyushu, on February 23, 2020, a record renewable energy output of almost 3,000 megawatts (MW) is curtailed as the nuclear reactors Genkai-3 & -4 and Sendai-1 & -2 (combined capacity of more than 4,000 MW) did not ramp down as they should have under a normal economic dispatch approach.
2020	In Kyushu, since the first curtailment event and up to the end of April 2020, solar PV and wind combined curtailment amounted to 0.7 TWh, or 4% of their production, and took place in more than 1,300 hours, or about 10% of the time. Because of COVID this issue was exacerbated both in terms of intensity and frequency.

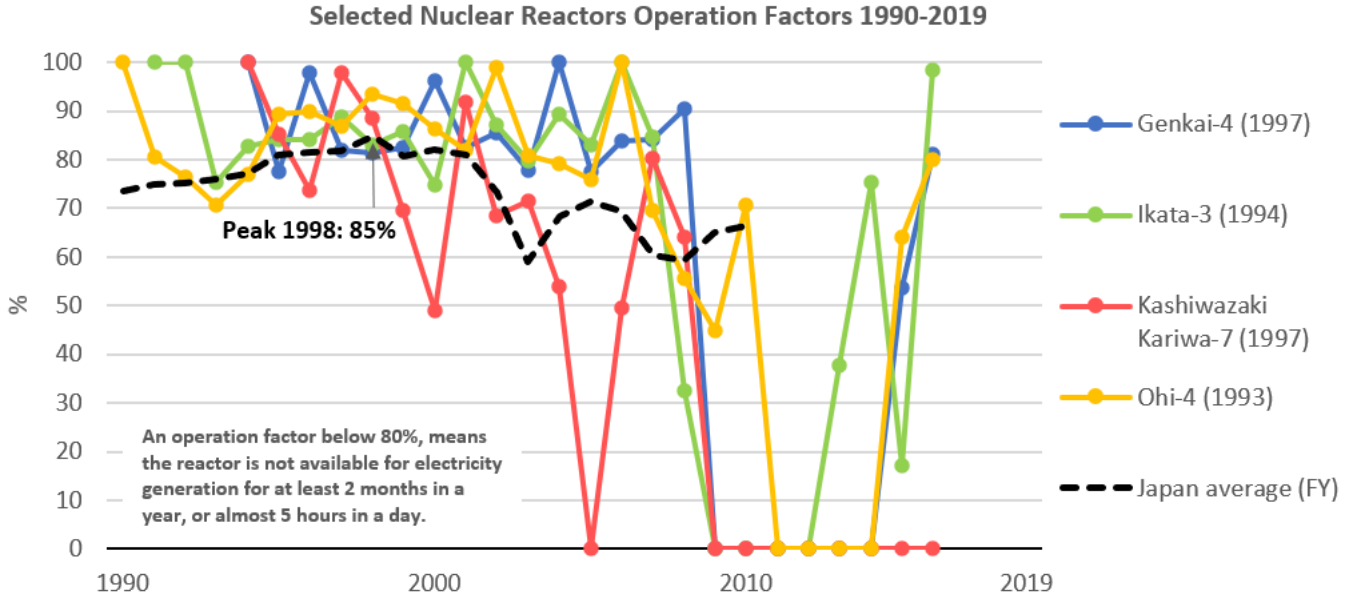


Source: REI Power Supply & Demand Chart

https://www.renewable-ei.org/en/statistics/electricity/#demand

Japan has been wasting economic and environmentally-friendly renewable energy in favor of nuclear power.

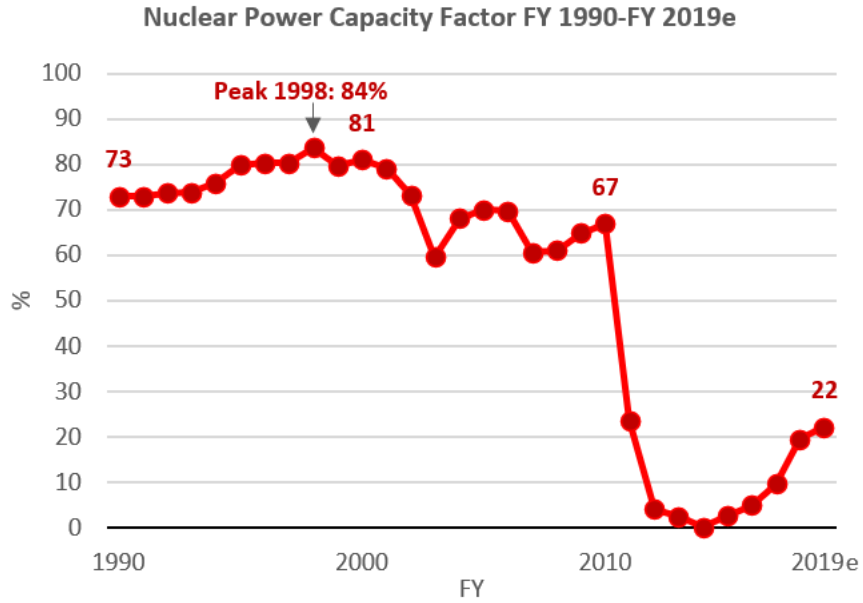
Issue 8: Unreliable supply



Sources: REI based on IAEA (1) (selected reactors) and JNES (Japan average)

Operation factor: an availability indicator defined as the ratio of the number of hours a unit is online to the total number of hours in a reference period.

These reactors are the most recent ones commissioned by the electric power companies of Kansai (Ohi-4), Kyushu (Genkai-4), Shikoku (Ikata-3), and Tokyo (Kashiwazaki Kariwa-7).



Sources: REI based on IEA (1) for FY 1990-FY 2017 and (2) for FY 2018 and FY 2019e, JAIF (1) and IAEA (1)

Capacity factor: a performance indicator dividing the actual energy output of an electricity-generating device by the energy output that would be produced if it operated at its rated power output for the entire year.

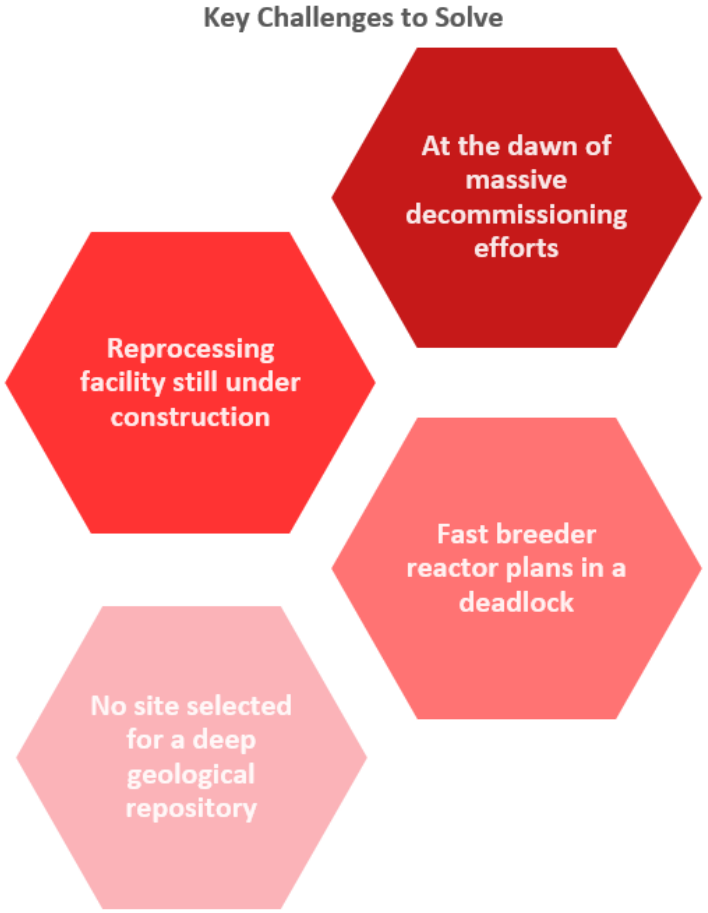
The FY 2018 and FY 2019 estimates are based on net electricity generation applying a multiplying factor of 1.09.

KEY OBSERVATIONS

FY 1998	Peaks for operation factor and capacity factor; 85% and 84%, respectively.
FY 2002- FY 2010	Low operation factors negatively impact capacity factors; both always below 75% in this period.
2008	Kashiwazaki Kariwa-7 reactor offline for a whole year following an earthquake in 2007.
2015-	After nuclear reactor restarts, operation factors are rarely significantly over 80%, one of these few examples is Ikata-3 in 2019 (temporarily offline since the end of December 2019).

Sometimes offline for long periods of time, nuclear power cannot be qualified of reliable energy source.

Issue 9: Decommissioning, reprocessing, etc.



Source: created by REI

KEY OBSERVATIONS

Decommissioning	Only 1 of the 27 nuclear reactors permanently shut down has been decommissioned; JPDR a small (12 MW) experimental boiling water reactor. The decommissioning of Tokai (166 MW) – gas cooled reactor type, Japan's first commercial reactor, permanently shut down in FY 1997, is delayed by more than ten years and now expected to be completed in FY 2030 at a cost over $0.8 bn. (IAEA 2 & 3). The typically planned period for reactor decommissioning is 30-40 years (JAIF (2)). Decommissioning costs of the main commercial nuclear power related facilities (power plants and fuel cycle facilities) are estimated at $120 bn., out of which $73 bn. for the Fukushima Daiichi reactors 1-4 (CNIC (2)).
Reprocessing	Rokkasho facility under construction since 1993 is expected to be completed in FY 2021 after a series of postponements (JNFL). The entire project is estimated to cost nearly $130 bn. (NURO).
Fast breeder reactor	Monju has been permanently shut down in FY 2017 following decades of extremely poor performances despite investments of at least $10 bn. (JAEA).
Spent fuel & waste disposal	No site for a deep geological repository has been selected yet. The expected project cost is about $35 bn., less than $10 bn. had been provisioned as of FY 2019 (NUMO).

All these key challenges represent major economic and technical challenges for which almost everything remains to be done.

Appendix

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Current Status of Nuclear Reactors in Japan, as of June 2020 (unit: specified for each item).

EXISTING

Status	Reactor	Commercial operation start date	Operational lifetime (year)	Gross electrical capacity (MW)
Restarted commercial operation	Genkai-3	March 18, 1994	40	1,180
	Genkai-4	July 25, 1997	40	1,180
	Ikata-3	December 15, 1994	40	890
	Ohi-3	December 18, 1991	40	1,180
	Ohi-4	February 2, 1993	40	1,180
	Sendai-1	July 4, 1984	40	890
	Sendai-2	November 28, 1985	40	890
	Takahama-3	January 17, 1985	40	870
	Takahama-4	June 5, 1985	40	870
Sub-total	9 reactors			9,130
NRA's official approval received	Kashiwazaki Kariwa-6	November 7, 1996	40	1,356
	Kashiwazaki Kariwa-7	July 2, 1997	40	1,356
	Mihama-3	December 1, 1976	60	826
	Onagawa-2	July 28, 1995	40	825
	Takahama-1	November 14, 1974	60	826
	Takahama-2	November 14, 1975	60	826
	Tokai-2	November 28, 1978	60	1,100
Sub-total	7 reactors			7,115
Application submitted to NRA	Hamaoka-3	August 28, 1987	40	1,100
	Hamaoka-4	September 3, 1993	40	1,137
	Higashidori-1	December 8, 2005	40	1,100
	Shika-2	March 15, 2006	40	1,206
	Shimane-2	February 10, 1989	40	820
	Tomari-1	June 22, 1989	40	579
	Tomari-2	April 12, 1991	40	579

Appendix (continued 1)

	Tomari-3	December 22, 2009	40	912
	Tsuruga-2	February 17, 1987	40	1,160
Sub-total	9 reactors			8,593
No application submitted to NRA	Hamaoka-5	January 18, 2005	40	1,380
	Kashiwazaki Kariwa-1	September 18, 1985	40	1,100
	Kashiwazaki Kariwa-2	September 28, 1990	40	1,100
	Kashiwazaki Kariwa-3	August 11, 1993	40	1,100
	Kashiwazaki Kariwa-4	August 11, 1994	40	1,100
	Kashiwazaki Kariwa-5	April 10, 1990	40	1,100
	Onagawa-3	January 30, 2002	40	825
	Shika-1	July 30, 1993	40	540
Sub-total	8 reactors			8,245
Total	**33 reactors**			**33,083**

UNDER CONSTRUCTION

Status	Reactor	Commercial operation start date	Operational lifetime (year)	Gross electrical capacity (MW)
Application submitted to NRA	Shimane-3	FY 2021	40	1,373
	Ohma	FY 2025	40	1,383
Total	**2 reactors**			**2,756**

Appendix (continued 2)

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PERMANENTLY SHUT DOWN

Decommissioning status	Reactor	Commercial operation start date	Operation ended or permanent shut down date	Gross electrical capacity (MW)
Completed April 3?, 1996	JPDR	March 15, 1965	March 18, 1976	12
To be completed FY 2033	Fugen	March 20, 1979	March 29, 2003	165
To be completed FY 2030	Tokai	July 25, 1966	March 31, 1998	166
To be completed FY 2036	Hamaoka-1	March 17, 1976	January 30, 2009	540
To be completed FY 2036	Hamaoka-2	November 29, 1978	January 30, 2009	840
To be completed FY 2039	Tsuruga-1	March 14, 1970	April 27, 2015	357
To be completed FY 2045	Mihama-1	November 28, 1970	April 27, 2015	340
To be completed FY 2045	Mihama-2	July 25, 1972	April 27, 2015	500
To be completed FY 2054	Genkai-1	October 15, 1975	April 27, 2015	559
To be completed FY 2045	Shimane-1	March 29, 1974	April 30, 2015	460
To be completed FY 2056	Ikata-1	September 30, 1977	May 10, 2016	566
To be completed FY 2047	Monju	August 29, 1995 (first grid connection)	December 6, 2017	280
To be completed FY 2048	Ohi-1	March 27, 1979	March 1, 2018	1,175
To be completed FY 2048	Ohi-2	December 5, 1979	March 1, 2018	1,175
To be completed FY 2058	Ikata-2	March 19, 1982	May 23, 2018	566
To be completed FY 2053	Onagawa-1	June 1, 1984	December 21, 2018	524
To be completed FY 2054	Genkai-2	March 30, 1981	April 9, 2019	559
To be completed in 30-40 years later	Fukushima Daiichi-1	March 26, 1971	April 19, 2012	460
To be completed in 30-40 years later	Fukushima Daiichi-2	July 18, 1974	April 19, 2012	784
To be completed in 30-40 years later	Fukushima Daiichi-3	March 27, 1976	April 19, 2012	784
To be completed in 30-40 years later	Fukushima Daiichi-4	October 12, 1978	April 19, 2012	784
Utilized to decommission units 1-4	Fukushima Daiichi-5	April 18, 1978	January 31, 2014	784
Utilized to decommission units 1-4	Fukushima Daiichi-6	October 24, 1979	January 31, 2014	1,100
To be completed FY 2064	Fukushima Daini-1	April 20, 1982	September 30, 2019	1,100
To be completed FY 2064	Fukushima Daini-2	February 3, 1984	September 30, 2019	1,100
To be completed FY 2064	Fukushima Daini-3	June 21, 1985	September 30, 2019	1,100
To be completed FY 2064	Fukushima Daini-4	August 25, 1987	September 30, 2019	1,100
Total	**27 reactors**			**17,880**

Sources: REI based on JAIF (2) and IAEA (1)

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Nuclear Power Decline in Japan
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