Outlook for Energy Supply and Demand in FY2040 (reference material)

February 2025

Agency of Natural Resources and Energy

1. Concept

2. Method

① Scenario analysis

② Assumptions of social and economic activity

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3. Outlook for Energy Supply and Demand in FY2040

Basic Concept

- Since the start of Russia's aggression against Ukraine, energy prices have soared, including a significant increase in LNG prices in 2022. In addition, the **supply of fossil fuels is likely to fluctuate significantly both in terms of quantity and price** due to declining investment in fossil fuel development as a result of decarbonization.
- While many countries maintain ambitious goals for climate action, progress has been slow and **the gap between goals and reality tends to widen**. **Global trends regarding decarbonization are changing**, with the Trump administration in the US notifying the UN of its withdrawal from the Paris Agreement in January 2025.
- While global investment toward decarbonization in renewable energy, nuclear power, and hydrogen has increased, **further innovation is essential to achieve carbon neutrality in 2050**, and there are high expectations for future technological development.
- **Uncertainty on the energy demand side is also rising with the progress of DX (digital transformation) and GX (green transformation) in the future**, as noted in the IEA's *World Energy Outlook 2024* published in October 2024: "More than ever, the energy outlook is complex, multifaceted and defies a single view on how the future might unfold."
- Under these circumstances, the Outlook for Energy Supply and Demand in FY2040 (FY2040 energy mix) is presented as a range at the current point in time, based not on a single assumption but rather factoring in the existence of various uncertainties, under the principle of S+3E, toward the goals of a 46% GHG reduction in FY2030 compared to the level of FY2013, and net zero in 2050.
- **Toward 2040, it is first necessary to promote measures aimed at a 46% reduction in FY2030**. On the assumption that various changes will occur, **we will further strengthen and adopt more concrete measures sequentially toward 2040, taking into account technological trends and the status of decarbonization efforts in each sector**.

Multiple Scenario Approach

- In order to achieve carbon neutrality by 2050, **it is essential to expand the utilization of innovative technologies** such as perovskite solar cells, floating offshore wind power, hydrogen and ammonia, and CCUS, **which have not yet been implemented in society**.

- The energy supply and demand structure in FY2040 is on the way to carbon neutrality in 2050, and **will be greatly affected by the trends of innovative technologies**. Future diffusion of innovative technologies will depend largely on factors such as technological maturity, supply availability, and cost reduction, but **at this point, it is extremely difficult to accurately predict technological trends in FY2040**.

- It is important **to utilize a wide range of available measures** based on **a technology-neutral approach** in order to **mitigate national burden and economically rationalize the compatibility of a stable energy supply with decarbonization** even under these uncertain circumstances.

- From this perspective, the following multiple scenarios were set up and analyzed.
  ① A scenario in which innovative renewable energy technologies become widespread and expand
  ② A scenario in which hydrogen, ammonia, e-fuel, e-methane, etc., become more widespread and expand
  ③ A scenario in which the use of CCS expands
  ④ A scenario in which the diffusion and use of innovative technologies as in ① to ③ above expands widely
  ⑤ A scenario in which existing technologies are primarily used, as insufficient reduction of the cost of innovative technologies retards their adoption

Concept of the Technological Progress Scenario

- While further innovation is essential to achieve carbon neutrality by 2050, we must assume the possibility that **the development of decarbonization technologies such as renewable energy, hydrogen and its derivatives, and CCS will not progress as rapidly as expected, and that cost reductions will not be sufficiently advanced in FY2040**.
- **In order to realize economic growth and protect lives from energy constraints** even in such a case, **it is important to take all possible measures to secure a stable energy supply, including securing long-term contracts for LNG**, while taking into account the actions of other countries.
- From this perspective, **we showed the technological progress scenario as a case in which caps are placed on the social costs involved in decarbonization to limit as far as possible differences in international energy prices under the S+3E balance**.
- On the other hand, even if the development of decarbonization technologies such as renewable energy, hydrogen and its derivatives, and CCS does not progress as expected and cost reductions are not sufficiently advanced, **it is possible to achieve the FY2040 NDC if further next-generation innovative technologies** such as next-generation geothermal power, next-generation advanced reactors (i.e., fusion energy), and carbon absorption and removal **are developed to a level beyond expectations**.
- Since energy is an essential foundation for people’s lives and economic activities, **it is important to prepare energy policy instruments while taking into account these uncertainties**.

(Reference) Concepts of the Multiple Scenarios

Scenario	Scenario Overview
① Advanced renewables	Significant cost reductions have been realized in renewable energy technologies including perovskite solar cells and floating offshore wind power, expanding the introduction of renewable energy.
② Advanced hydrogen and new fuels	Significant cost reductions in the production of hydrogen and its derivatives have expanded the utilization of hydrogen and ammonia-fired power generation and the use of hydrogen, ammonia, e-fuel, e-methane in the non-electric power sector.
③ Advanced CCS	Increasing the available CO_2 storage capacity and significantly reducing the cost of CO_2 capture, transport, and storage technologies have expanded the use of CCS in power generation and industry, while fossil fuels remain in use to a certain level.
④ Advanced innovative technologies	Technical constraints on the introduction of a wide range of innovative technologies have been alleviated and the costs involved are being greatly reduced. A balanced use of various innovative technologies related to both energy supply and demand is driving progress in decarbonization.
⑤ Technological progress	Significant cost reductions in innovative technologies have not been fully realized by FY2040. Expansion of technology adoption has mainly progressed with existing technologies.

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Analyses to be Used in the Preparation

- To study the outlook for energy supply and demand in FY2040, we requested six specialized organizations* to analyze scenarios under the same conditions.
- The outlook for energy supply and demand in FY2040 **should be consistent with the basic approach of Japan's GX to simultaneously achieve a stable energy supply, economic growth, and decarbonization**.
- Since **it is essential to minimize cost increases associated with decarbonization**, scenario analyses that cover at least the following elements are adopted as **the basis for the outlook for energy supply and demand**.
  - ① **Analysis based on the concept of cost optimization** covering all sectors of energy supply and demand, considering that costs of GHG emission reduction measures could increase in decarbonizing toward 2040
- To simultaneously achieve a stable energy supply, economic growth, and decarbonization, we must maintain energy costs at a competitive level in addition to maximizing economic activity. To that end, **the analyses should center on scenarios that also allow for the evaluation of the following factors**.
  - ② Assumption to **maximize economic growth** while promoting decarbonization
  - ③ **Analysis based on relative energy price differences with foreign countries**
- Based on the above, **the analysis by Research Institute of Innovative Technology for the Earth (RITE)**, which satisfies all the above elements ① to ③, **is used as the main component of the outlook for energy supply and demand in FY2040**. **The validity of RITE's analysis is verified and supplemented by the results of other scenario analyses** that fulfill the element ① .

※ The government requested analyses from six specialized organizations: the National Institute for Environmental Studies (NIES); the Research Institute of Innovative Technology for the Earth (RITE); Institute for Global Environmental Strategies (IGES); Deloitte Tohmatsu Consulting; the Institute of Energy Economics, Japan (IEEJ); and McKinsey & Company.

(Reference) Requests to Specialized Organizations

- We requested specialized organizations to conduct a scenario analyses.
- In order to make the results of the analyses comparable and verifiable, we requested that the analyses be consistent with at least the following six points.
  ① In order to make the results of each organization comparable, based on the discussions at the joint meetings of the Ministry of the Environment and the Ministry of Economy, Trade and Industry, **a case assuming an extension of the current GHG reduction trend linearly from 46% reduction in FY2030 to net zero in 2050 should be included in the analysis**.
  ② **S+3E should be secured as much as possible** in future energy scenarios.
  ③ Based on Japan's basic philosophy of GX, which is to simultaneously energy security, economic growth, and decarbonization, it should be assumed that **economic activity levels will not decline excessively**.
  ④ **The setting of parameters** as assumptions for scenario analysis should be **consistent with past discussions in government councils mainly of the Agency for Natural Resources and Energy**.
  ⑤ Scenario setting shall **focus on renewable energy, hydrogen and its derivatives, and CCS technologies and costs**, from the perspective of minimizing the overall costs to society associated with decarbonization. In addition, the results of analyses by multiple organizations should be comparable and verifiable. Since **technological development and cost reductions might not progress sufficiently**, a case in which the introduction mainly of existing technologies is expanded should be included in the analysis, **if possible**.
  ⑥ On top of that, the fulfillment of the following points is also desirable.
    - **Analysis covering all GHG emissions** (this does not preclude scenario analysis covering only energy-related CO_2 emissions).
    - **Analysis based on international energy price differences**.

Overview of the Scenario Analyses

Social and economic activity

Population/number of households, industrial production, transportation demand, etc.

Technological trends

Cost reduction, efficiency improvement, etc., by technology

Global Energy and Climate Assessment Model/Economic Model

Estimation of energy systems based on cost optimization
Estimation of the impact on production in each industry
Note that the impact of production decreases due to higher marginal abatement costs is also taken into account.

Results

Energy supply and demand

Final energy consumption
Primary energy supply
Electricity demand, electricity generation, etc.

Costs

Energy system costs
Electricity costs
Marginal abatement costs, etc.

GHG emissions

Energy-related CO_2
Non-energy related CO_2
GHGs other than CO_2

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Assumptions of Social and Economic Activity (Before Emission Reduction Measures)

- Assumptions of social and economic activity are based on the **GX approach of maximizing economic growth while promoting decarbonization**. The level of industrial production is projected without emission reduction measures and will be smaller than the stated values due to the increase in marginal abatement costs in each scenario.
  - In the analysis by RITE, the baseline economic growth rate without emission reduction measures is set based on the Higher Economic Growth Case of the Cabinet Office projections, and activity indicators of each sector are assumed to be consistent with the economic growth rate. The impact of decreases in domestic production in energy-intensive industries due to the increase in marginal abatement costs is then assessed and reflected in the energy demand-supply analysis.

		Actual	Assumptions for FY2040	Assumptions in analysis by RITE
Population		124 million (2023)	Approx. 110 million	● The future population of each country and region is based on UN population estimates.
Number of households		54.9 million households (2020)	Approx. 52 million households	● Estimated based on the population of each country and region.
Industrial Production	Iron	86.83 million tons (FY2023)	Approx. 89 million tons*	● Industrial production in FY2040 is assumed to be roughly equivalent to the current level as a baseline without emission reduction measures. ● The impact of decreases in domestic production due to higher marginal abatement costs is evaluated with the economic model DEARS and fed back into the energy supply and demand analysis.
	Cement	47.18 million tons (FY2023)	Approx. 47 million tons*	
	Ethylene Propylene	9.58 million tons (FY2023)	Approx. 10 million tons*	
Road Transport	Passengers	826.3 billion person-km (FY2023)	Approx. 740 billion people-km	● Passenger transport demand is assumed to decrease due to population decline, etc. ● Freight transport demand is expected to be roughly on par with the current level.
	Freight	230.7 billion ton-km (FY2023)	Approx. 230 billion ton-km	

Items marked with an asterisk aree assumptions of activity without emission reduction measures.

(Sources) Population Estimates and 2020 Census by Ministry of Internal Affairs and Communications (MIC); Demand Outlook for Steel Products and Current Survey of Production by the Ministry of Economy, Trade and Industry (METI); Cement Supply and Demand by the Japan Cement Association (JCIA); and Annual Report on Automobile Transport Statistics by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT)

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Technology Assumptions for Each Scenario

- Expanding the introduction of innovative technologies is essential to achieve ambitious emission reductions in 2040. In each scenario, expansion of the available amount and cost reductions are assumed in renewable energy, hydrogen and its derivatives, and CCS.

Assumptions of technological trends for each scenario

Scenario		Technology		
		Renewable energy	Hydrogen and its derivatives	CCS
① Advanced renewables		High	Low	Low
② Advanced hydrogen and new fuels		Low	High	Low
③ Advanced CCS		Low	Low	High
④ Advanced innovative technologies		High	High	High
⑤ Technological progress		Low	Low	Low
Technology innovation	Low	**Some progress in cost reduction of renewable energy generation** Cost of generation in FY2040 Solar PV: approx. 12-18 yen/kWh Onshore wind: approx. 12-25 yen/kWh Offshore wind: approx. 18-38 yen/kWh	**Some progress in cost reduction and efficiency improvement for hydrogen production technology** Facility costs in FY2040 Water electrolysis and methanation: approx. 40-70% reduction compared to the current level	**Some progress in increasing CO_2 capture capacity** Available CO_2 storage capacity in FY2040 Domestic storage: approx. 50 million tons Overall including overseas transportation: approx. 60 million tons
	High	**Accelerating cost reduction of renewable energy generation** Cost of generation in FY2040 Solar PV: approx. 7-12 yen/kWh Onshore wind: approx. 11-23 yen/kWh Offshore wind: approx. 12-26 yen/kWh	**Accelerating cost reduction and efficiency improvement in hydrogen production technology** Facility costs in FY2040 Water electrolysis and methanation: approx. 70-90% reduction compared to the current level	**Accelerating increasing CO_2 capture capacity** Available CO_2 storage capacity in FY2040 Domestic storage: approx. 50 million tons Overall, including overseas transportation: approx. 120 million tons

The figures shown are assumed values in RITE's analysis. Costs in the model are assumed to be real prices, at USD 1=110 yen (2000-2010 average).
Each of the above scenarios ①-⑤ correspond to the renewable energy scenario, hydrogen-based fuel scenario, CCS scenario, growth realization scenario, and emissions upside scenario in RITE's analysis, respectively.

Technology Assumptions on the Energy Demand Side

- For each sector on the energy demand side, the introduction of high-efficiency technologies, the shift to non-fossil fuels through electrification and the use of hydrogen and its derivatives, and the utilization of CCS are assumed, with efficiency improvement and cost reduction over time.

Key assumptions of technologies on the energy demand side

Sector		Assumed key technologies
Industry	Iron and steel	● High-efficiency blast furnaces, converter and electric furnaces, hydrogen utilization and CO_2 capture in the blast furnace process (COURSE50, Super COURSE50), direct hydrogen reduction ironmaking, etc.
	Chemical	● High-efficiency equipment for naphtha crackers, ethane crackers, etc.
	Cement	● High-efficiency equipment for clinker production, shifting from coal to gas, hydrogen, and e-methane, CO_2 capture and compression equipment.
Commercial Residential	Space cooling and heating	● High-efficiency equipment for air conditioning, oil heating, etc.
	Hot water	● High-efficiency heat pump water heaters and combustion water heaters (gas, kerosene, etc.)
	Other	● High-efficiency equipment for cooking (gas and induction), lighting, refrigerators, and TVs
Transport	Automobiles	● Disaggregate into passenger cars, buses, and trucks, and assume introduction of conventional internal combustion engine vehicles, hybrid vehicles, plug-in hybrid vehicles, electric vehicles and fuel cell vehicles ● Shift to biofuel and e-fuel
	Aviation Shipping	● Conversion from heavy oil, diesel oil, etc., to biofuel and e-fuel
Others		● The effect of decreasing energy consumption in line with the rise in marginal abatement costs is reflected for both electricity and non-electricity.

Technology Assumptions on the Energy Supply Side

- On the energy supply side, the introduction of decarbonized power sources in the power generation sector and the introduction of non-fossil fuel sources production processes in the energy conversion sector are assumed, with efficiency improvement and cost reduction over time.

Key assumptions of technologies on the energy supply side

Sector		Assumed key technologies
Power generation	Renewable energy	• Solar PV, wind, hydro, geothermal, and biomass power generation • The potential of each power source is estimated based on GIS data related to solar radiation, wind speed, and land use. • Assumes a reduction in facility costs over time and takes into account grid integration costs associated with the introduction of variable renewable energy sources.
	Nuclear	• The amount of electricity generated by nuclear power takes into account social constraints.
	Thermal	• High-efficiency equipment and CO_2 capture equipment of coal thermal, oil thermal, and gas thermal power plants • A reduction in facility costs and improvements in power generation efficiency over time. • Hydrogen and ammonia thermal power generation (biomass/ammonia co-firing for coal thermal power plants, and hydrogen co-firing for gas thermal power plants).
Other Conversions	Hydrogen and its derivatives production	• Hydrogen production through coal gasification, gas reforming, biomass gasification, and water electrolysis (assumes CO_2 capture during production) • E-methane and e-fuel production processes (CO_2 for synthesis to be derived from biomass, DAC, and fossil fuels) • Assumes a reduction in facility costs and an improvement in energy conversion efficiency over time.
	Biofuel production	• Biofuel production process
	CO_2 storage	• Regional CO_2 storage potentials in depleted oil fields, depleted gas fields, deep saline aquifers, and coalbeds, and storage costs based on cumulative CO_2 storage volume; also assumes overseas transport of CO_2.

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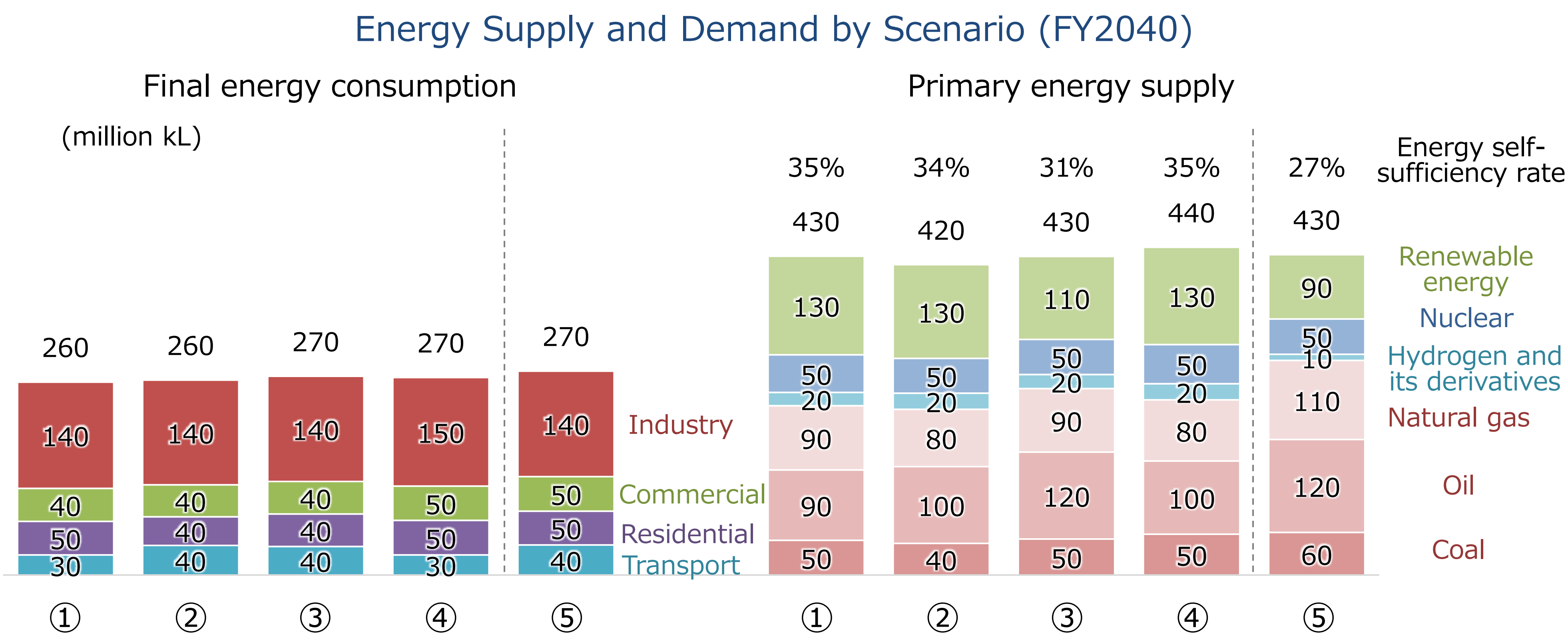
Energy Supply and Demand by Scenario

- Final energy consumption in FY2040 is around 260-270 million kL and primary energy supply is around 420-440 million kL.

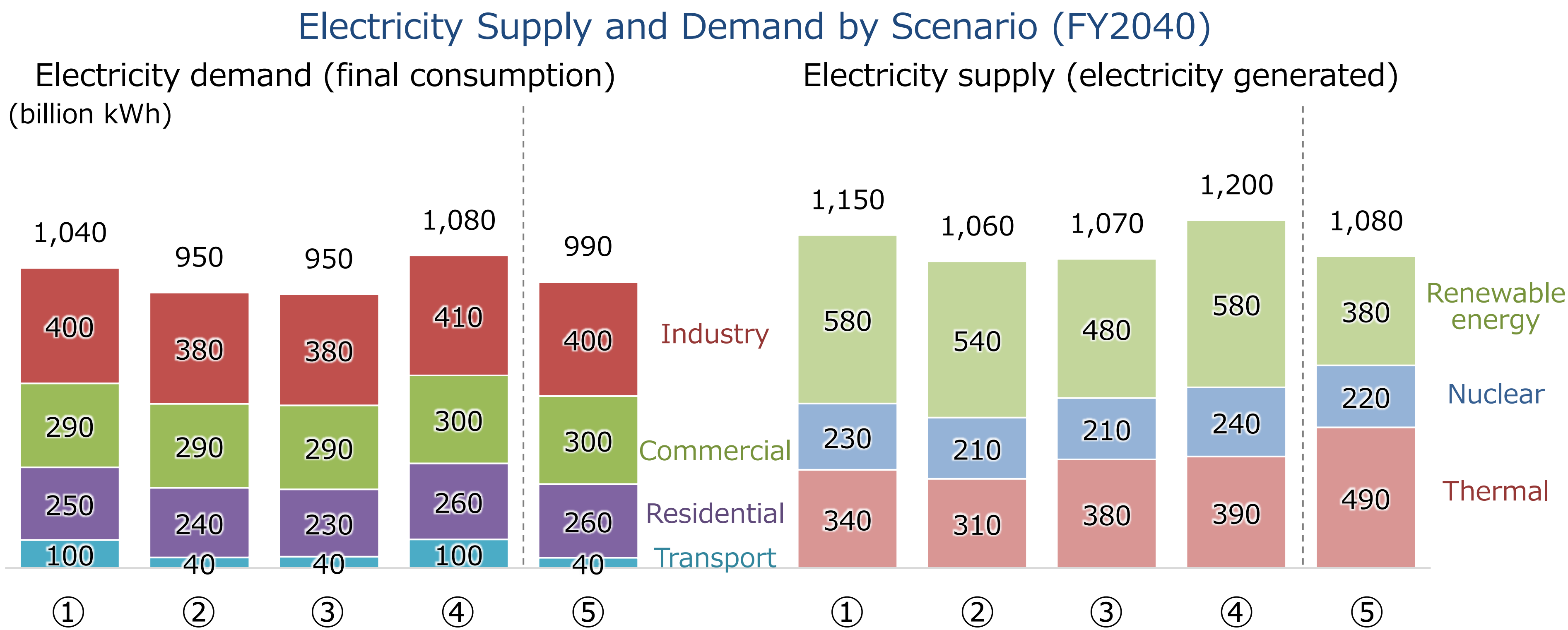


①Advanced renewables, ②Advanced hydrogen and new fuels, ③Advanced CCS, ④Advanced innovative technologies, ⑤Technological progress

Hydrogen and its derivatives include hydrogen, ammonia, e-fuel, and e-methane.
The total may not match due to the rounding of figures.

Electricity Supply and Demand by Scenario

- Electricity demand in FY2040 is about 0.9 to 1.1 trillion kWh, and the amount of electricity generated is about 1.1 to 1.2 trillion kWh.



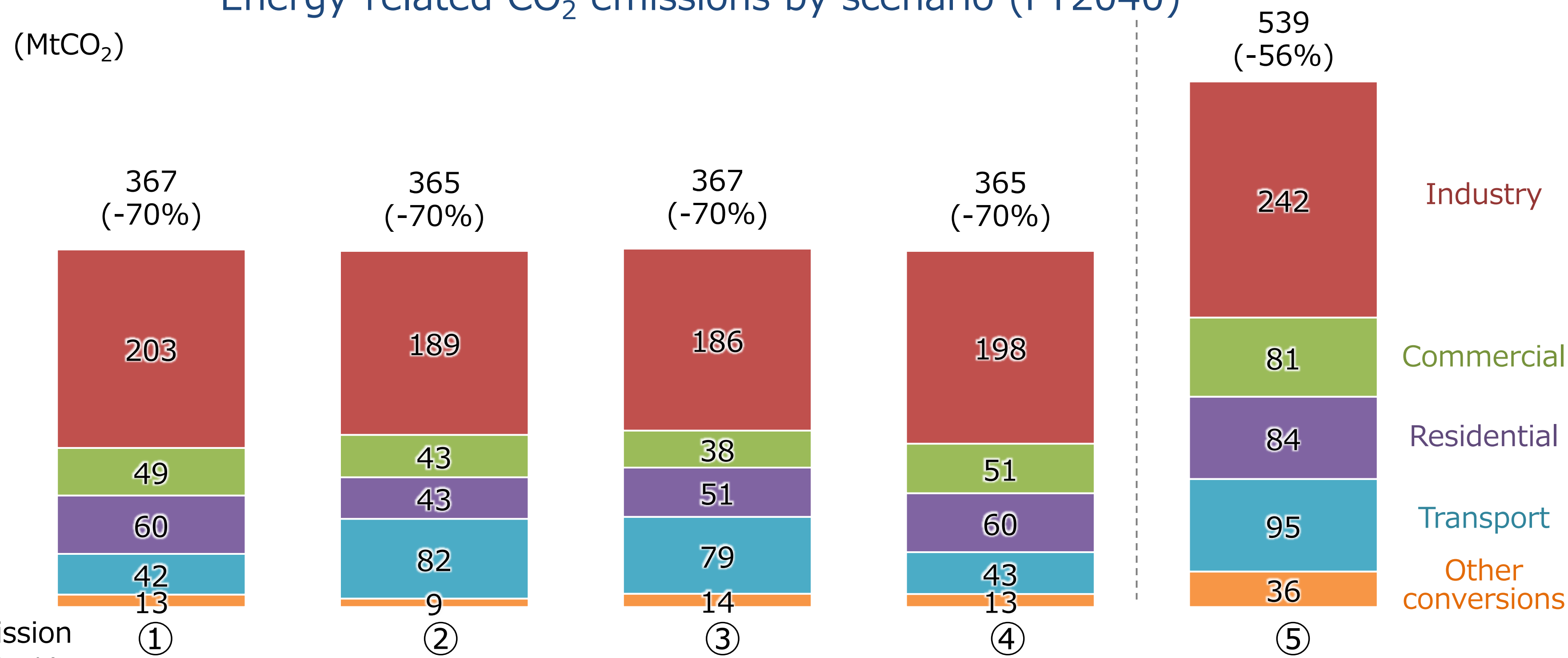
①Advanced renewables, ②Advanced hydrogen and new fuels, ③Advanced CCS,
④Advanced innovative technologies, ⑤Technological progress

The totals may not match due to the rounding of figures.
In the Sixth Strategic Energy Plan, it is assumed that about 50-60% of power generation in 2050 will be from renewable energy sources such as solar PV, wind, hydro, geothermal, and biomass; about 10% from hydrogen and ammonia power generation; and about 30-40% from nuclear power generation and thermal power generation assuming capture of CO_2 emissions. The figures are presented as reference values for the purpose of further discussion.

Energy-related CO_2 Emissions by Scenario

- Under scenarios that achieve linear emission reduction toward net zero in 2050, energy-related CO_2 emissions are about 370 million tons (about 70% reduction compared to the level of FY2013).

Energy-related CO_2 emissions by scenario (FY2040)



Electricity emission factor (kgCO_2/kWh)	①	②	③	④	⑤
Average of all power sources	0.04	0.03	0.00	0.04	0.13
Average of thermal	0.20	0.15	0.08	0.18	0.31

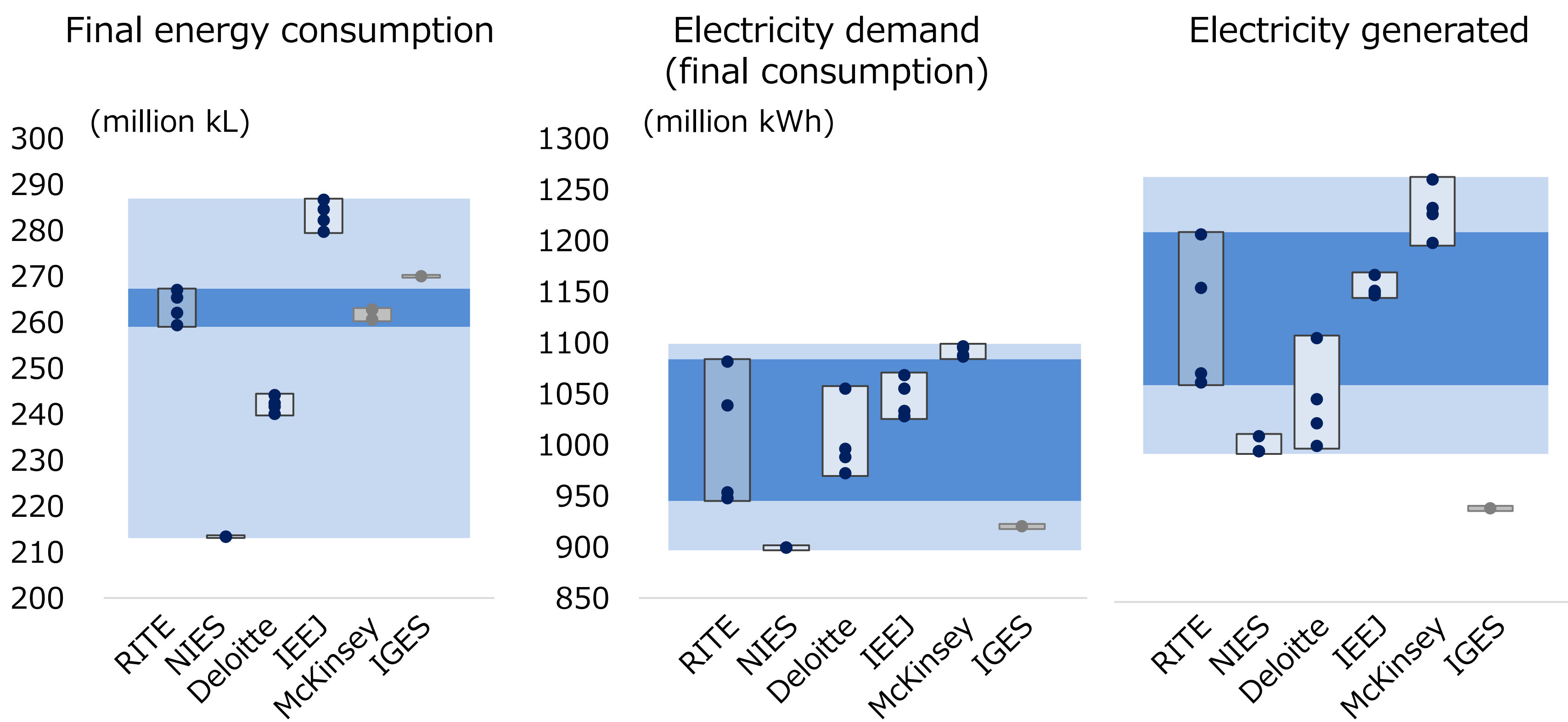
①Advanced renewables, ②Advanced hydrogen and new fuels, ③Advanced CCS, ④Advanced innovative technologies, ⑤Technological progress

CO_2 emissions from electricity generation are allocated to each sector according to the electricity demand of each sector.
Figures in parentheses are reduction rates of energy-related CO_2 emissions compared to the level of FY2013.

(Reference) Comparison with Other Scenario Analyses

- In the scenarios that achieve linear emission reduction toward net zero in 2050, the analyses by other organizations for final energy consumption, electricity demand, and electricity generated in FY2040 are expected to be roughly equivalent to the results of RITE's analysis.

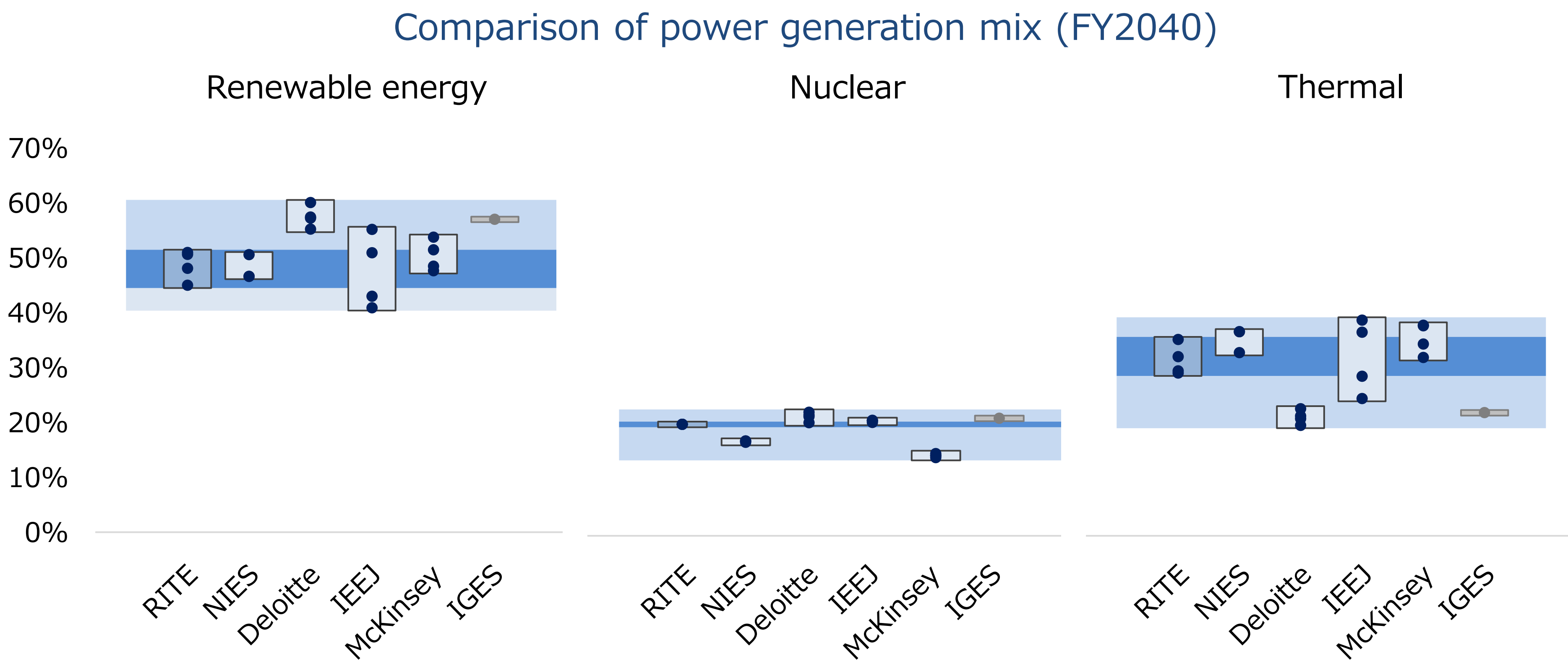
Comparison of final energy consumption and electricity supply and demand (FY2040)



(Source) Prepared based on materials from the 66th and 68th Basic Policy Subcommittee meetings.
(Note) Analyses based on the cost optimization concept are plotted in blue.

(Reference) Comparison with Other Scenario Analyses

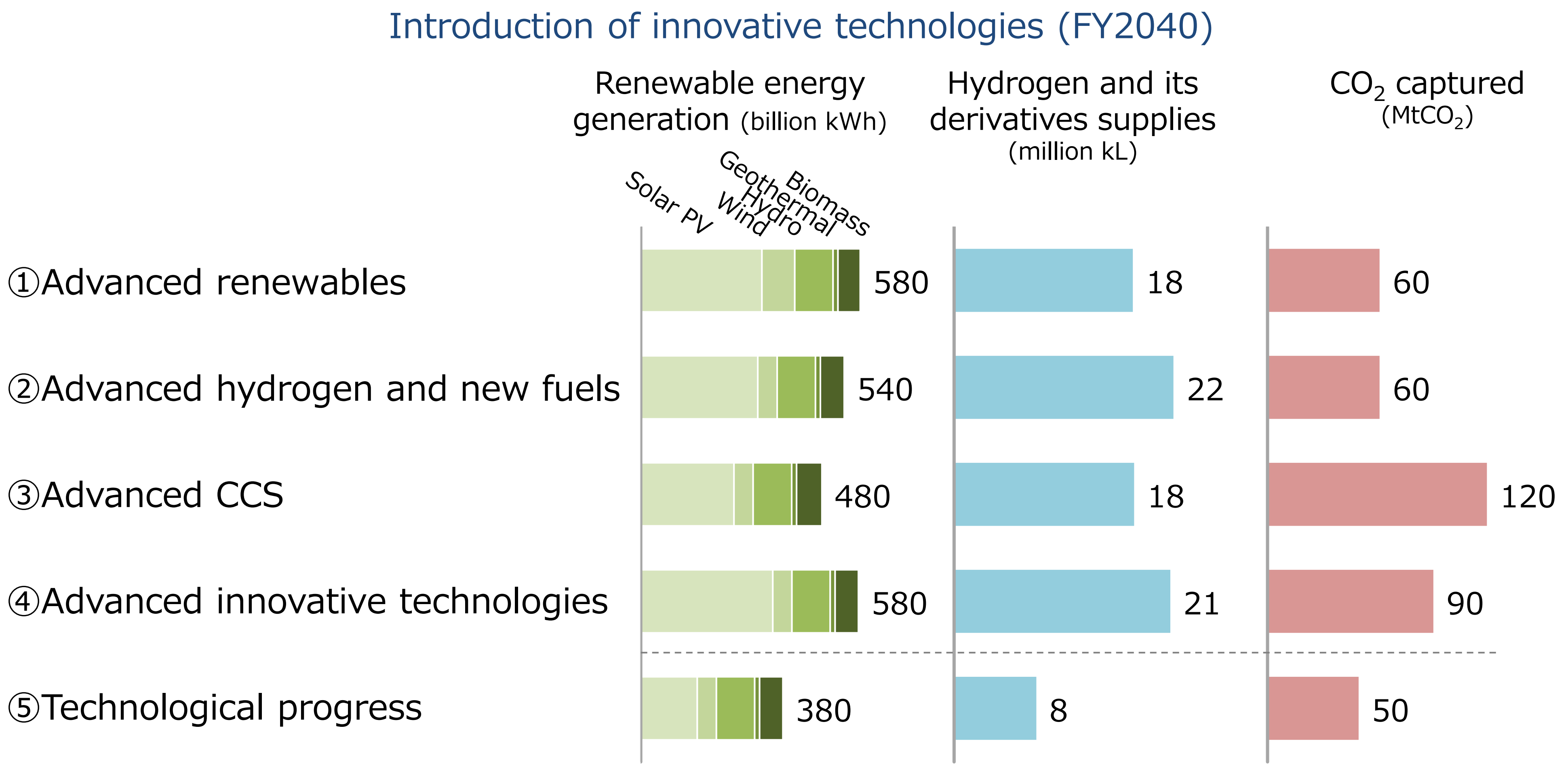
- In the scenarios that achieve linear emission reductions toward net zero emissions in 2050, the analyses by other organizations for the power generation mix in FY2040 are expected to be roughly equivalent to the results of RITE's analysis.



(Source) Prepared based on materials from the 66th and 68th Basic Policy Subcommittee meetings.
(Note) Analyses based on the cost optimization concept are plotted in blue.

Innovative Technology Deployment by Scenario

- Renewable energy, hydrogen and its derivatives, and CCS are all expected to play important roles in decarbonization, but the combination of economically rational technology deployment for ambitious emission reductions in FY2040 varies depending on costs and other technology trends.

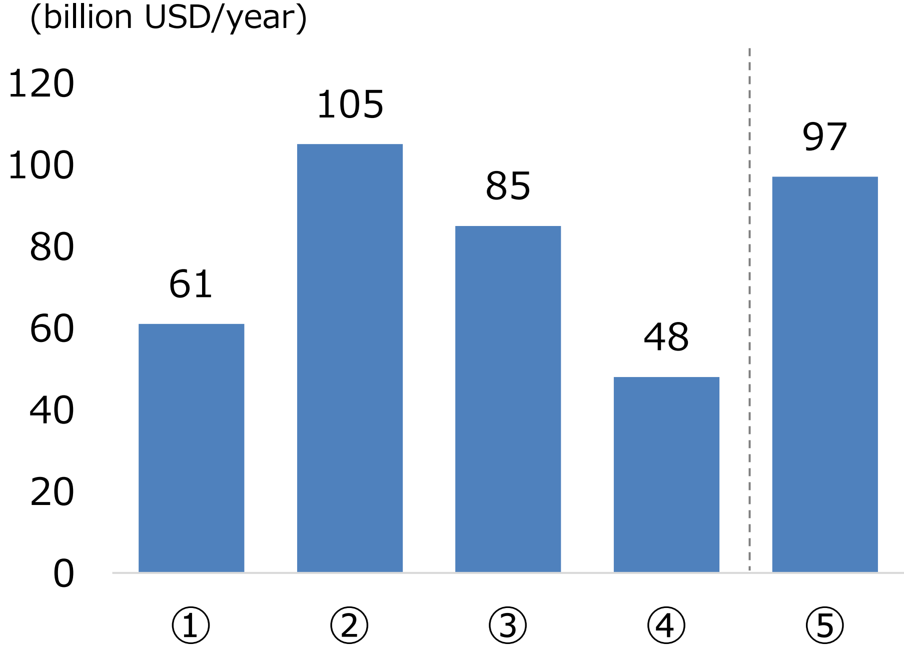


※ Hydrogen and its derivatives include hydrogen, ammonia, e-fuel, and e-methane.

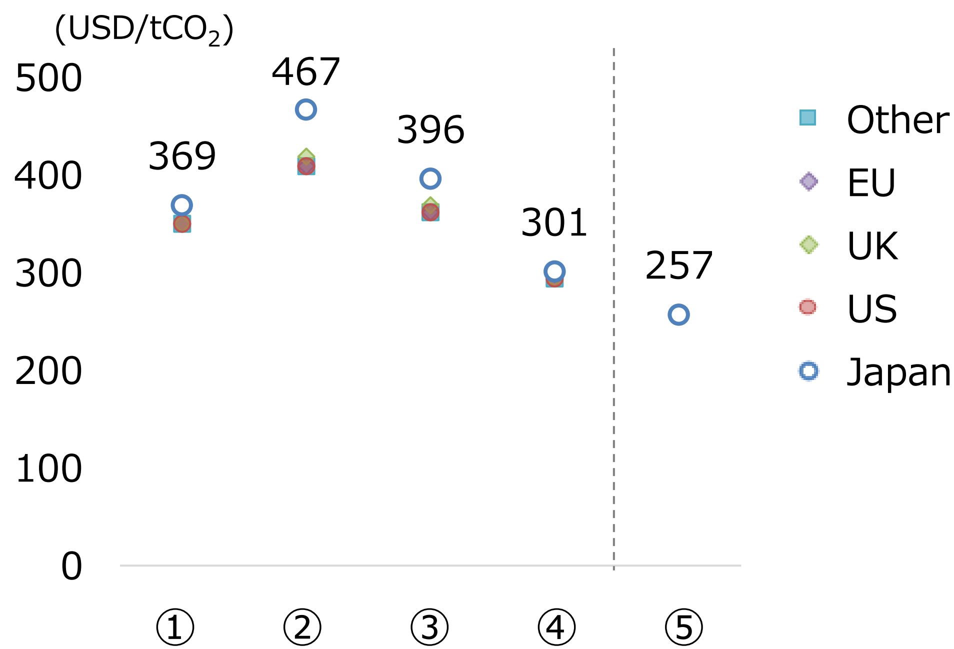
Emission Reduction Costs

- Costs are expected to rise from the present level toward ambitious emission reductions in 2040. Cost reductions in a wide range of innovative technologies are needed to limit the widening cost gap relative to foreign countries.

Emission Reduction Costs by Scenario (FY2040)



International comparison of marginal abatement costs (FY2040)



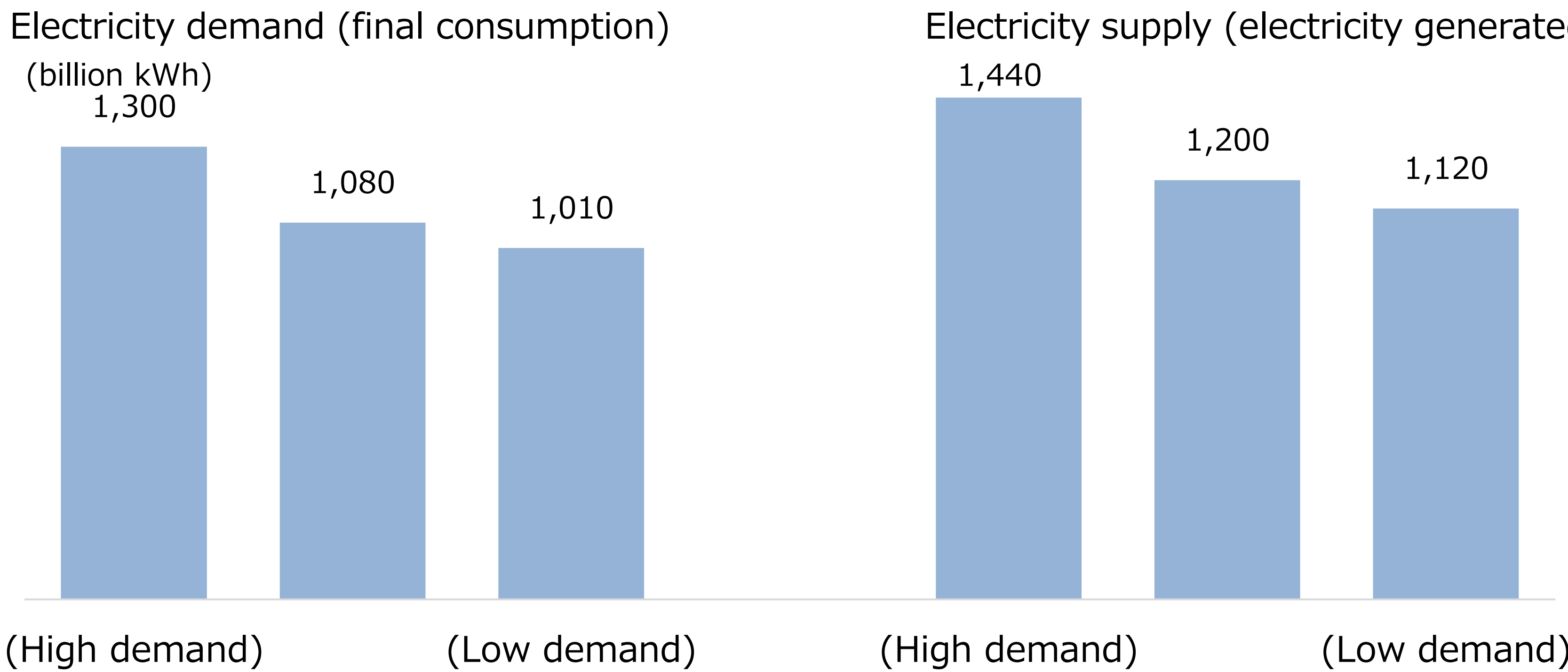
①Advanced renewables, ②Advanced hydrogen and new fuels, ③Advanced CCS,
④Advanced innovative technologies, ⑤Technological progress

※ Results are shown in 2000 prices.

(Reference) Sensitivity analysis of electricity demand

- The expansion of electricity demand due to DX development and so forth is highly uncertain in the future, and the need to significantly increase the amount of electricity generated may arise as the demand for electricity in data centers and other facilities grows significantly.
  - For the sensitivity analysis, we applied a high-level case that assumes a more significant increase in electricity demand for data centers and network centers compared to the assumptions in the Advanced innovative technologies scenario, and a low-level case that assumes about the same growth rate as in the past.

Sensitivity Analysis of Electricity Demand Expansion (Advanced innovative technologies Scenario, FY2040)



In the RITE analysis, the growth rate of the innovative technology expansion scenario is assumed to be about the same as that of the all-combination scenario (*Applied Energy*, 2021) in Koot et al. In the low demand case, the growth rate is assumed to be about the same as in Masanet et al. (*Science*, 2020) and the base scenario in Koot et al. These assumptions are potential demand assumptions before emission reduction measures, and electricity demand will decrease as electricity prices rise due to CO_2 emission reductions.

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Views on the Outlook Based on the Scenario Analysis

- The Outlook for Energy Supply and Demand in FY2040 is created with **the analysis by RITE as the main component**, and **the validity of RITE's analysis results is verified and supplemented by the results of analyses by other organizations using cost optimization modelling**.

- Specifically, the outlook for energy supply and demand in FY2040 is organized as follows.
  - **The outlook** was established from RITE's analysis **with ranges for the key indicators related to energy supply and demand in FY2040, focusing on the range of values among the scenarios that achieve linear emission reductions toward net zero in 2050**. A clear distinction must be made between the results of the scenario analysis and the outlook for energy supply and demand in FY2040.
  - Since the results of scenario analysis heavily depend on assumptions of technologies and costs, and the characteristics of the model, **the ranges of each indicator of the RITE's scenario analysis are compared with the ranges indicated by the results of other scenario analyses in setting the outlook for each indicator**.

- With the great uncertainty toward the achievement of carbon neutrality by 2050, the target of 73% GHG reduction by FY2040 has been set as an ambitious goal to promote initiatives to achieve both economic growth and emissions reductions while maintaining predictability. **The Outlook for Energy Supply and Demand in FY2040 adopts a back-casting approach** based on this ambitious target. Therefore, the Outlook for Energy Supply and Demand in FY2040 **indicates the direction of Japan's energy policy**, taking into account the fact that **it depends on assumptions**, and that **it requires certain technological progress**.

- Therefore, the levels shown in the outlook (e.g., the FY2040 power generation mix) **do not represent upper limits or caps on the adoption of technology**, and **technological innovations and other factors might lead to such adoption going beyond the indicated levels**. In addition, if the energy situation surrounding Japan changes significantly, such as future trends in technological innovation or progress in GX and DX, it will be reviewed as necessary, taking such changes into account.

Final energy consumption and primary energy supply

		FY2013 (Actual)	FY2022 (Actual)	FY2040 (Forecast)
Final energy consumption		**360 million kL**	**310 million kL**	**Approx. 260-270 million kL**
	Industry	170 million kL	140 million kL	Approx. 140-150 million kL
	Commercial	60 million kL	50 million kL	Approx. 40-50 million kL
	Residential	50 million kL	50 million kL	Approx. 40-50 million kL
	Transport	80 million kL	70 million kL	Approx. 30-40 million kL
Primary energy supply		**540 million kL**	**470 million kL**	**Approx. 420-440 million kL**
	Renewable energy	50 million kL	70 million kL	Approx. 110-130 million kL
	Nuclear	2 million kL	10 million kL	Approx. 50 million kL
	Hydrogen and its derivatives	–	–	Approx. 20 million kL
	Natural gas	130 million kL	100 million kL	Approx. 80-90 million kL
	Oil	230 million kL	170 million kL	Approx. 90-120 million kL
	Coal	140 million kL	120 million kL	Approx. 40-50 million kL
Energy self-sufficiency rate		6.5%	12.6%	Approx. 30-40%

※ Hydrogen and its derivatives include hydrogen, ammonia, e-fuel, and e-methane.

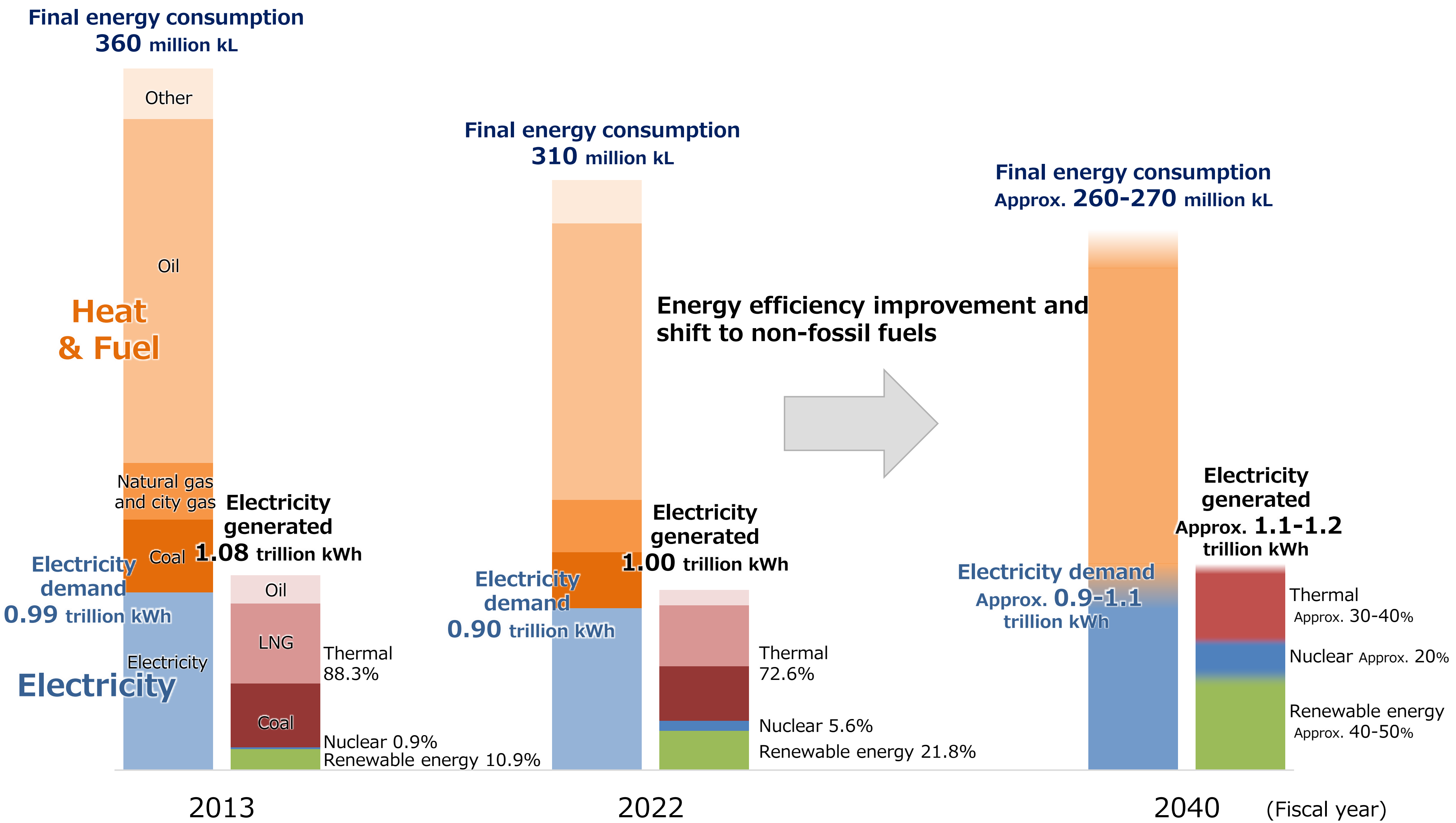
Electricity demand and power generation mix

	FY2013 (Actual)	FY2022 (Actual)	FY2040 (Forecast)
Electricity demand	**0.99 trillion kWh**	**0.90 trillion kWh**	**Approx. 0.9-1.1 trillion kWh**
Industry	0.36 trillion kWh	0.32 trillion kWh	Approx. 0.38-0.41 trillion kWh
Commercial	0.32 trillion kWh	0.31 trillion kWh	Approx. 0.29-0.30 trillion kWh
Residential	0.29 trillion kWh	0.26 trillion kWh	Approx. 0.23-0.26 trillion kWh
Transport	0.02 trillion kWh	0.02 trillion kWh	Approx. 0.04-0.10 trillion kWh
Electricity generated	**1.08 trillion kWh**	**1.00 trillion kWh**	**Approx. 1.1-1.2 trillion kWh**
Renewable energy	10.9%	21.8%	Approx. 40-50%
Solar PV	1.2%	9.2%	Approx. 23-29%
Wind	0.5%	0.9%	Approx. 4-8%
Hydro	7.3%	7.7%	Approx. 8-10%
Geothermal	0.2%	0.3%	Approx. 1-2%
Biomass	1.6%	3.7%	Approx. 5-6%
Nuclear	0.9%	5.6%	Approx. 20%
Thermal	88.3%	72.6%	Approx. 30-40%

Energy-related CO_2 emission

	FY2013 (Actual)	FY2022 (Actual)	FY2040 (Forecast)
Energy-related CO_2 emission	**1,240 $MtCO_2$**	**960 $MtCO_2$** (-22% compared to FY2013)	**Approx. 360-370 $MtCO_2$** (Approx. -70% compared to FY2013)
Industry	460 $MtCO_2$	350 $MtCO_2$	Approx. 180-200 $MtCO_2$
Commercial	230 $MtCO_2$	180 $MtCO_2$	Approx. 40-50 $MtCO_2$
Residential	200 $MtCO_2$	160 $MtCO_2$	Approx. 40-60 $MtCO_2$
Transport	220 $MtCO_2$	190 $MtCO_2$	Approx. 40-80 $MtCO_2$
Other conversions	100 $MtCO_2$	100 $MtCO_2$	Approx. 10-20 $MtCO_2$
CO_2 captured	–	–	Approx. 60-120 $MtCO_2$

(Reference) Outlook for Energy Supply and Demand (Image)



The left graph shows the final energy consumption, and the right graph shows the electricity generated. Electricity demand is the amount of electricity generated minus the amount of transmission and distribution losses and the amount of on-site electricity consumption.

(Reference) Overview of technological progress scenario

- Assumptions include a situation in which the development of renewable energy, hydrogen and its derivatives, CCS, and other decarbonization technologies does not progress as much as expected in FY2040, and significant cost reductions and other measures do not go far enough. In this case, the primary energy supply of natural gas would be 74 million tons.

	FY2040 (Technological progress scenario)
Final energy consumption	**Approx. 270 million kL**
Primary energy supply	**Approx. 430 million kL**
Renewable energy	Approx. 90 million kL
Nuclear	Approx. 50 million kL
Hydrogen and its derivatives	Approx. 10 million kL
Natural gas	Approx. 110 million kL
Oil	Approx. 120 million kL
Coal	Approx. 60 million kL
Electricity demand	**Approx. 1.0 trillion kWh**
Electricity generated	**Approx. 1.1 trillion kWh**
Energy-related CO_2 emission	**Approx. 540 $MtCO_2$** (-56% compared to FY2013)
CO_2 captured	Approx. 50 $MtCO_2$

※ Hydrogen and its derivatives include hydrogen, ammonia, e-fuel, and e-methane.

Reference data

Summary of the Verification results of the cost of power generation in 2023

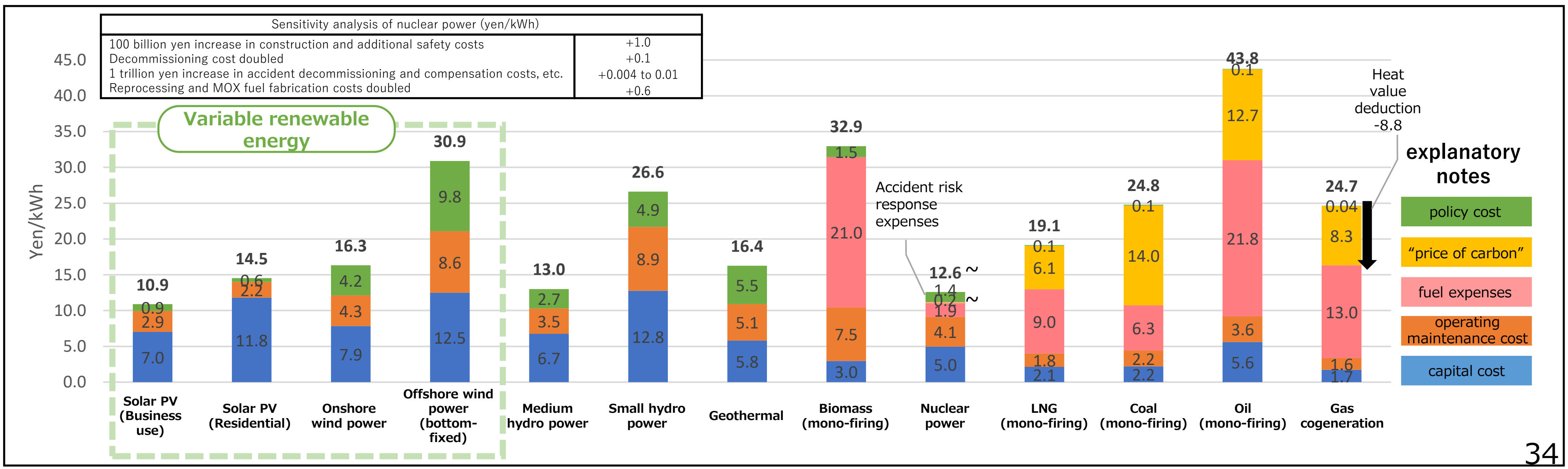
The verification results are estimates of the “total cost of power generation” if a standard power plant is newly constructed and operated for a predetermined period of time without taking into account the location conditions, etc. They are not consistent with the performance and price targets that should be achieved based on policy support.

1. These estimates are to **serve as reference material for discussions on energy policy toward 2040**, including which power sources to direct policy efforts toward, considering the cost characteristics of each power source.
2. **This result is a mechanical estimate of the cost per kWh of a standard power plant which is newly constructed and operated in 2023, based on certain assumptions**, which is **not equivalent to the cost of operating existing facilities**.
3. When a company **actually constructs a power generation facility, various conditions (location constraints, fuel supply constraints, etc.) are taken into account in addition to the cost of power generation as** described below, and a comprehensive decision is made.

		Variable renewable energy				Hydro power		Geothermal	Biomass	Nuclear power	Thermal			Cogeneration
Power source		Solar PV (Business use)	Solar PV (Residential)	Onshore wind power	Offshore wind power (bottom-fixed)	Medium hydro power	Small hydro power	Geothermal	Biomass (mono-firing)	Nuclear power	LNG (mono-firing)	Coal (mono-firing)	Oil (mono-firing)	Gas Cogenera-tion
LCOE (yen /kWh)	With policy cost	10.9	14.5	16.3	30.9	13.0	26.6	16.1 – 16.8	32.9	12.6~	19.1	24.8	43.8	15.8 – 16.9
	Without policy cost	10.0	14.0	12.1	21.1	10.3	21.7	10.9	31.4	11.2~	19.1	24.7	43.8	15.8 – 16.9
Facility Utilization Ratio		18.3%	15.8%	29.6%	30%	54.7%	54.4%	83%	87%	70%	70%	70%	30%	72.3%
Number of years in operation		25 years	25 years	25 years	25 years	40 years	40 years	40 years	40 years	40 years	40 years	40 years	40 years	30 years

(Note 1) Values in the graph are based on the Stated Policies Scenario (STEPS) case from the IEA’s World Energy Outlook 2024, with “price of carbon” calculated using the EU-ETS average price in 2023 and cogeneration costs calculated using CIF prices.
(Note 2) As it is generally the case that policy costs taken into account by the Power Generation Cost Verification WG are not included in internationally established methods, we have also included cases where policy costs are not included.
(Note 3) Totals may not match due to rounding.
(Note 4) In this case, the carbon price indicated in the WEO is considered as the "price of carbon," which is a part of the external environmental cost.

Sensitivity analysis of nuclear power (yen/kWh)	
100 billion yen increase in construction and additional safety costs	+1.0
Decommissioning cost doubled	+0.1
1 trillion yen increase in accident decommissioning and compensation costs, etc.	+0.004 to 0.01
Reprocessing and MOX fuel fabrication costs doubled	+0.6



Summary of the Verification results of the cost of power generation in 2040

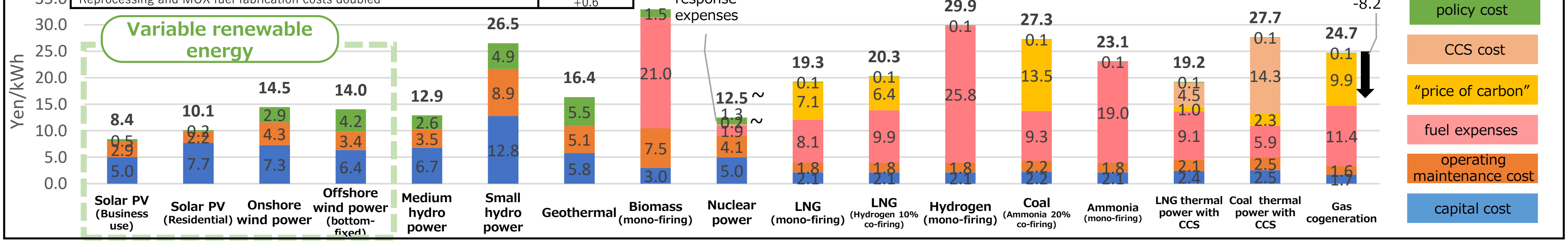
The verification results are estimates of the "total cost of power generation" if a standard power plant is newly constructed and operated for a predetermined period of time without taking into account the location conditions, etc. They are not consistent with the performance and price targets that should be achieved based on policy support.

1. These estimates are to **serve as reference material for discussions on energy policy toward 2040**, including which power sources to direct policy efforts toward, considering the cost characteristics of each power source.
2. **This result is a mechanical estimate of the cost per kWh of a standard power plant which is newly constructed and operated in 2040, based on certain assumptions**, which is **not equivalent to the cost of operating existing facilities**.
3. **The results of the cost in 2040 will change if the assumptions used in the estimation are changed**, such as the outlook for fuel costs, facility operating years and facility utilization rates, the amount of natural variable power sources installed, and weather conditions. It is also necessary to keep in mind the possibility of further technological innovations, etc., that have not been assumed at this time.
4. When a company **actually constructs a power generation facility, various conditions (location constraints, fuel supply constraints, etc.) are taken into account in addition to the cost of power generation as described below and a comprehensive decision is made.**

		Variable renewable energy				Hydro power		Geothermal	Biomass	Nuclear power	LNG	Decarbonized thermal power						Cogeneration
Power source		Solar PV (Business use)	Solar PV (Residential)	Onshore wind power	Offshore wind power (bottom-fixed)	Medium hydro power	Small hydro power	Geothermal	Biomass (mono-firing)	Nuclear power	LNG (mono-firing)	LNG (Hydrogen 10% co-firing)	Hydrogen (mono-firing)	Coal (Ammonia 20%. co-firing)	Ammonia (mono-firing)	LNG thermal power with CCS	Coal thermal power with CCS	Gas cogeneration
LCOE (yen /kWh)	With policy cost	6.9 - 8.8	7.8 - 10.6	12.6 - 14.5	13.5 - 14.3	12.9	26.5	16.1 - 16.8	32.9	12.5~	16.0 - 21.0	16.9 - 22.3	24.4 - 33.1	21.1 - 32.0	21.0 - 27.9	17.1 - 21.1	26.6 - 32.3	16.5 - 17.5
	Without policy cost	6.6 - 8.4	7.6 - 10.4	10.1 - 11.6	9.5 - 10.1	10.3	21.7	10.9	31.4	11.2~	15.9 - 20.9	16.8 - 22.2	24.3 - 33.0	21.0 - 31.9	20.9 - 27.8	17.0 - 21.0	26.5 - 32.2	16.4 - 17.4
Facility Utilization Ratio		18.3%	15.8%	29.6%	40.2%	54.7%	54.4%	83%	87%	70%	70%	70%	70%	70%	70%	70%	70%	72.3%
Number of years in operation		25 years	25 years	25 years	25 years	40 years	40 years	40 years	40 years	40 years	40 years	40 years	40 years	40 years	40 years	40 years	40 years	30 years

(Note 1) The values in the table are estimates with a wide range depending on how future fuel prices, "price of carbon", and equipment price reductions associated with the expansion of Solar PV and wind power installations are anticipated. For example, the range of "price of carbon" exists based on Korea's stated policy scenario (STEPS) and the EU's Announced Pledges scenario (APS) in the IEA's "World Energy Outlook 2024" (WEO2024).
(Note 2) Values in the graph are based on the WEO2024 STEPS case; "price of carbon" are based on the WEO2024 EU STEPS case; hydrogen and ammonia are based on the case where blue hydrogen and blue ammonia are imported from overseas; CCS is based on the pipeline transportation case; cogeneration is calculated using CIF prices.
(Note 3) As it is generally the case that policy costs taken into account by the Power Generation Cost Verification WG are not included in internationally established methods, we have also included cases where policy costs are not included.
(Note 4) Totals may not match due to rounding. (Note 5) Hydrogen and ammonia co-firing rate are expressed based on calorific value. (Note 6) In this case, the carbon price indicated in the WEO is considered as the "price of carbon," which is a part of the external environmental cost.

Sensitivity analysis of nuclear power (yen/kWh)	
100 billion yen increase in construction and additional safety costs	+1.0
Decommissioning cost doubled	+0.1
1 trillion yen increase in accident decommissioning and compensation costs, etc.	+0.004 to 0.01
Reprocessing and MOX fuel fabrication costs doubled	+0.6

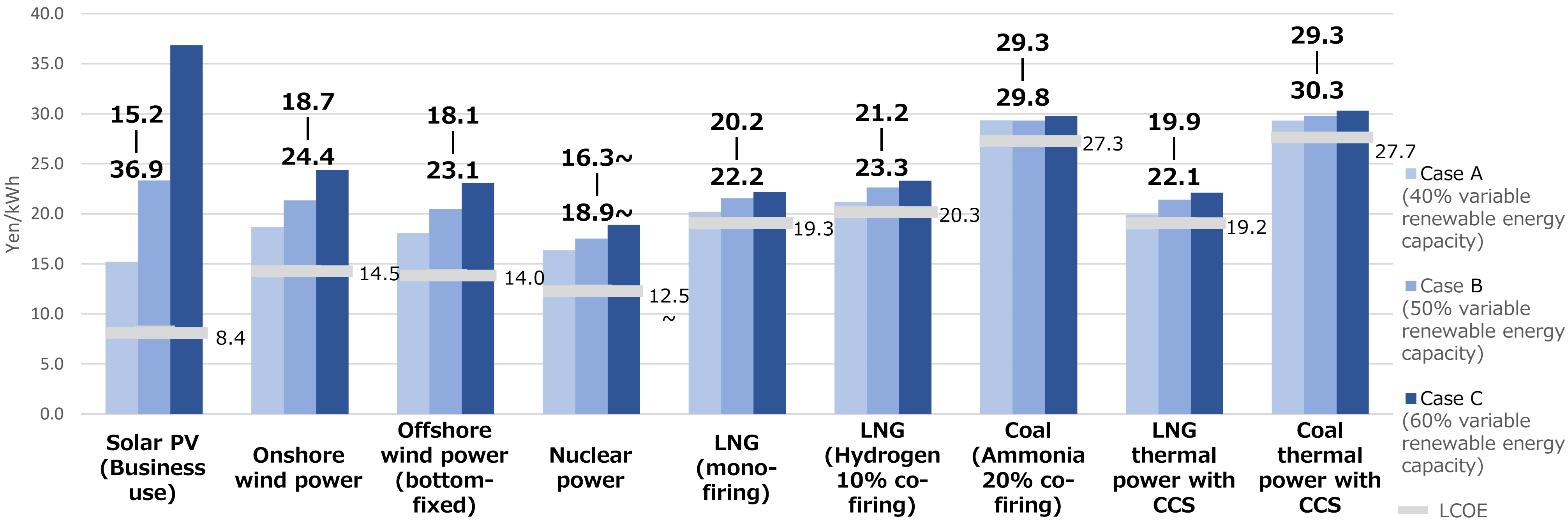


※ At present, the technologies for perovskite solar cells and floating offshore wind turbines are still in the process of technological development, and cost is not always predictable. Using cost calculation models based on cost data from other countries and estimates from operators, we made some assumptions and estimated the cost of power generation. The results were 16.4 yen/kWh with policy costs and 15.3 yen/kWh without policy costs for perovskite solar cells, and 21.6~21.7 yen/kWh with policy costs and 14.9 yen/kWh without policy costs for floating offshore wind power generation. (Reference values)

Summary of the Verification results of the cost of power generation in 2040

Verification results based on committee member estimates. They are not consistent with the performance and price targets that should be achieved assuming policy support.

1. As the ratio of power sources such as solar PV and wind power, which are difficult to supply stably, increases, the overall cost of the power system necessary to stabilize the entire power system will also increase. In comparing power generation costs by power source, we calculated not only (1), which has been conventionally calculated, but also (2), based on certain assumptions.
   (1) A mechanical estimate of the cost per kWh of constructing and operating a new power generation facility, based on certain assumptions (▬ LCOE)
   (2) The cost that takes into account the **additional cost to the entire power system when** a certain power source is added (e.g., the cost of storage batteries and adjustments to other power sources). (■ The cost of power generation taking into account some of the integration costs)
2. The cost taking into account some of the integration costs calculates the **additional cost to the power system when a particular power source is added while the existing generation facilities are still in operation**. In particular, costs are taken into account related to adjustments by other power sources such as LNG mono-firing, storage and discharge losses due to pumping and storage batteries for the grid, and output control of renewable energy.
3. The **results will change if the assumptions used in the estimation are changed,** such as the outlook for fuel costs, facility operating life and facility utilization, and the power source that is assumed to be substituted in the power system when a particular power source is added (in this case, coal mono-firing, the highest cost, was used). At this time, calculations were made for three cases. The possibility of further technological innovation should also be taken into account.



※ The power supply system in 2040 is assumed to have a certain level of inter-regional interconnection lines reinforcement and storage batteries installed. The effect of lowering integration costs due to these measures is included in the above results. In addition, when demand response is taken into account to a certain extent, the generation cost, which takes into account a portion of the integration cost, will be lower than the above.
※ The costs of reinforcing inter-regional interconnection lines and installing storage batteries are not included in the calculations, as they are not additional costs incurred by the entire power system "when a particular power source is added".
※ Hydrogen and ammonia co-firing rate are expressed based on calorific value.