Japan CCS Forum 2022

December 1st, 2022

The role of CCS and the challenges for the large deployments

Keigo Akimoto

Group Leader, Systems Analysis Group

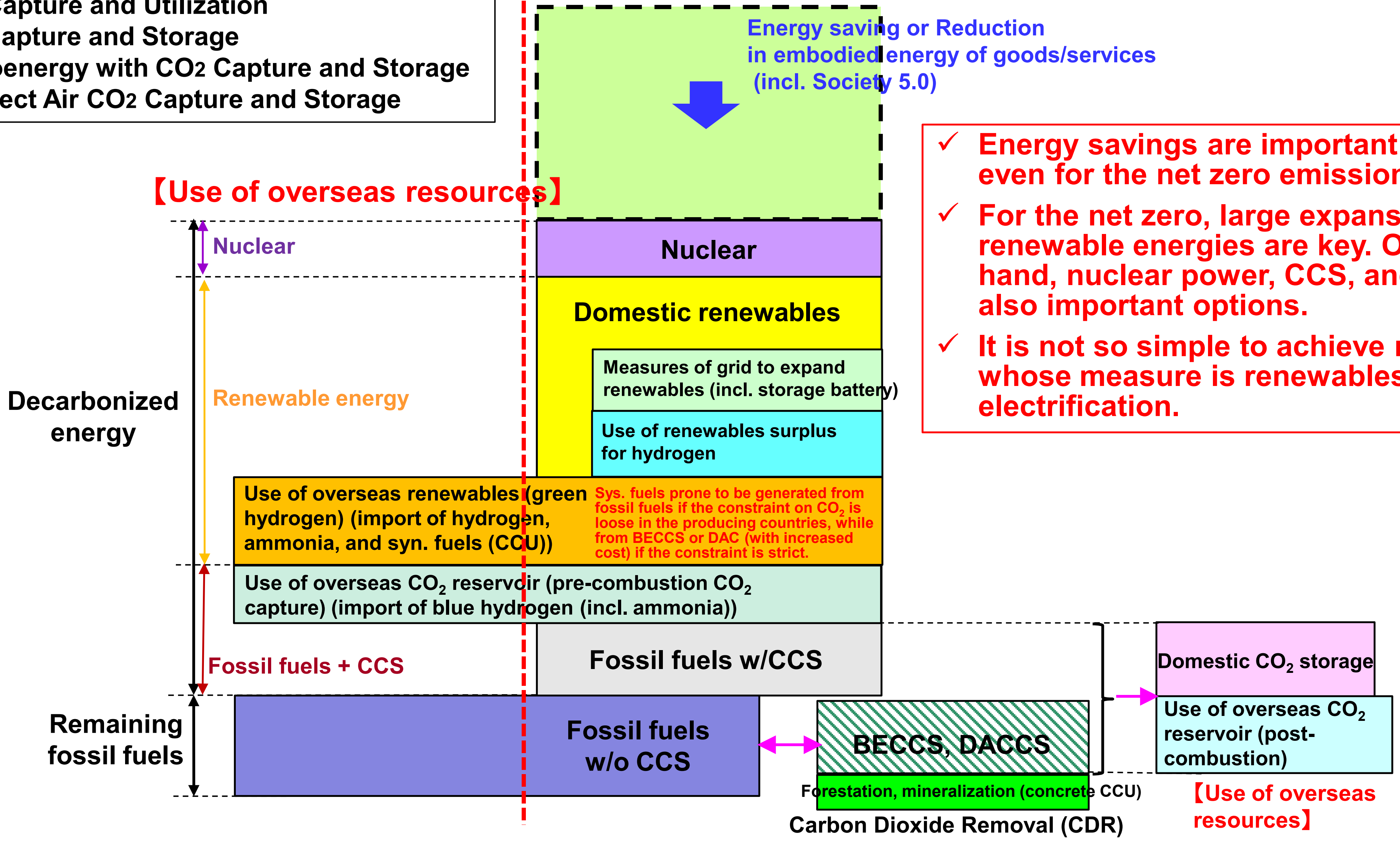
Research Institute of Innovative Technology for the Earth (RITE)

(Project Professor, Tokyo Institute of Technology)

1. Overview of Technological Measures for Carbon Neutrality

Image of Primary Energy for Carbon Neutrality (Net Zero Emissions)

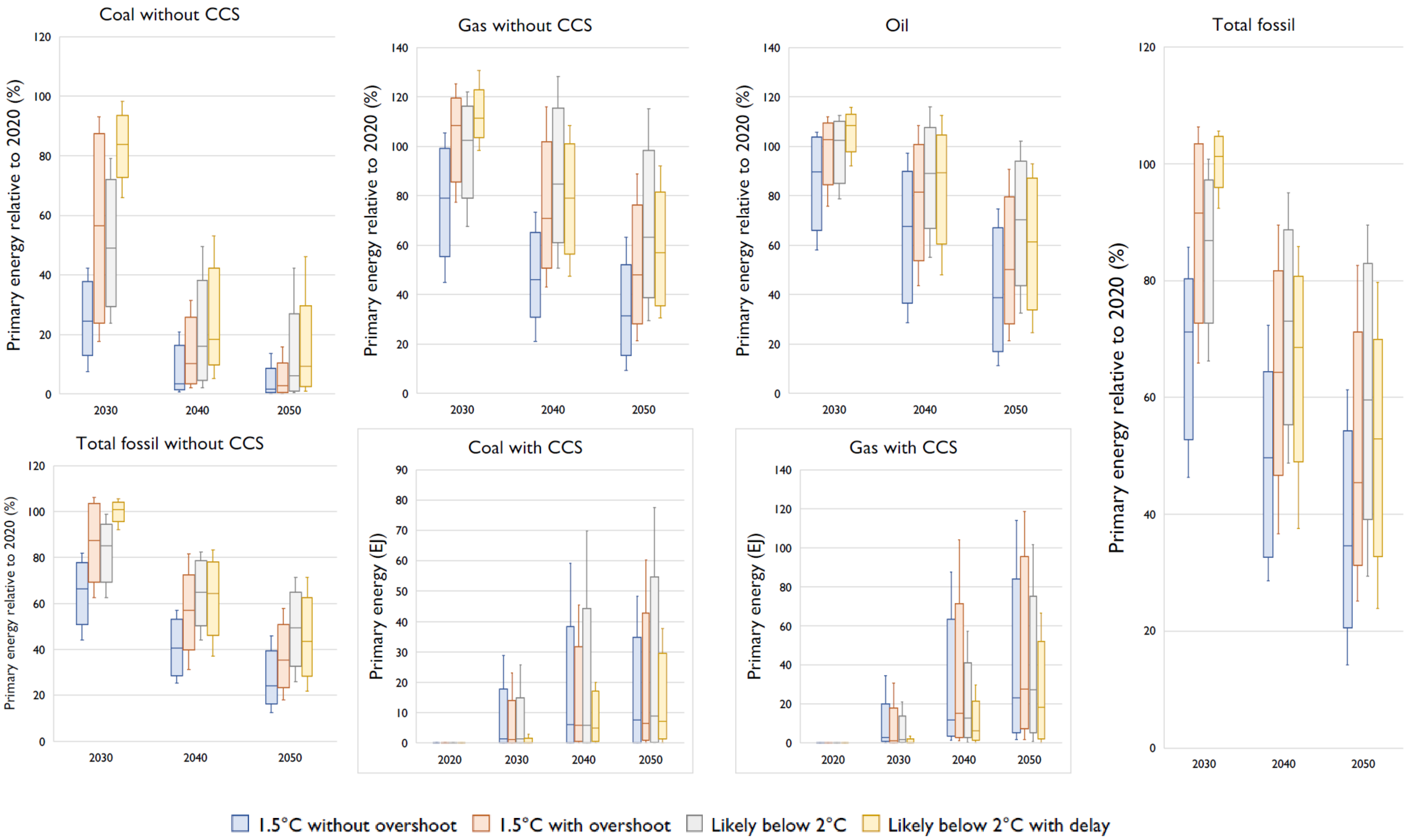
CCU: CO_2 Capture and Utilization
CCS: CO_2 Capture and Storage
BECCS: Bioenergy with CO_2 Capture and Storage
DACCS: Direct Air CO_2 Capture and Storage



- ✓ Energy savings are important options even for the net zero emissions.
- ✓ For the net zero, large expansions of renewable energies are key. On the other hand, nuclear power, CCS, and NETs are also important options.
- ✓ It is not so simple to achieve net zero whose measure is renewables + electrification.

Global CCS Outlook (IPCC AR6) for 2 °C and 1.5 °C

Fig. 6.35



CCS is expected to increase to meet the Paris long-term goals in the world, while wide ranges exist among scenarios.

Several opportunities to achieve CN: IPCC AR6

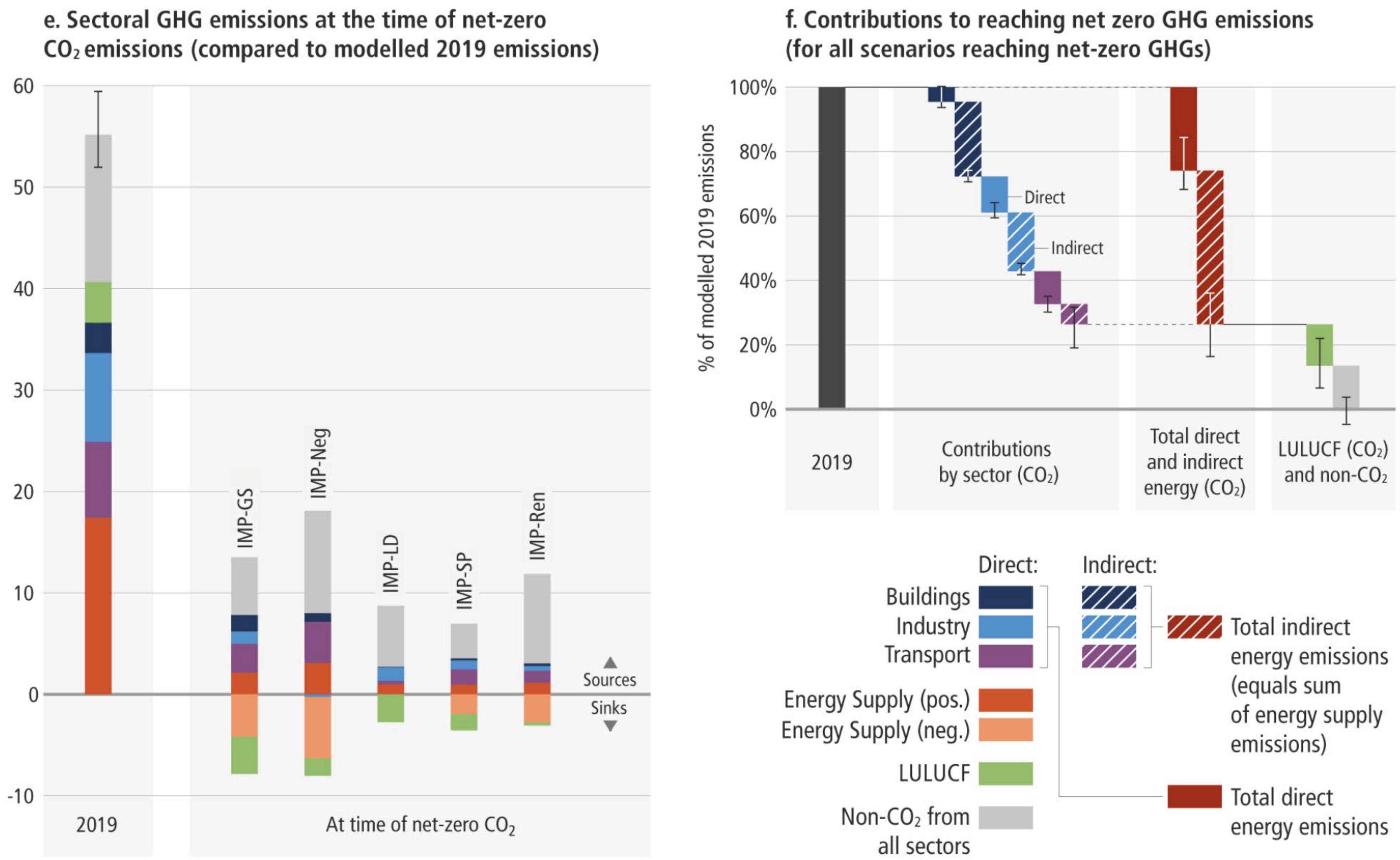


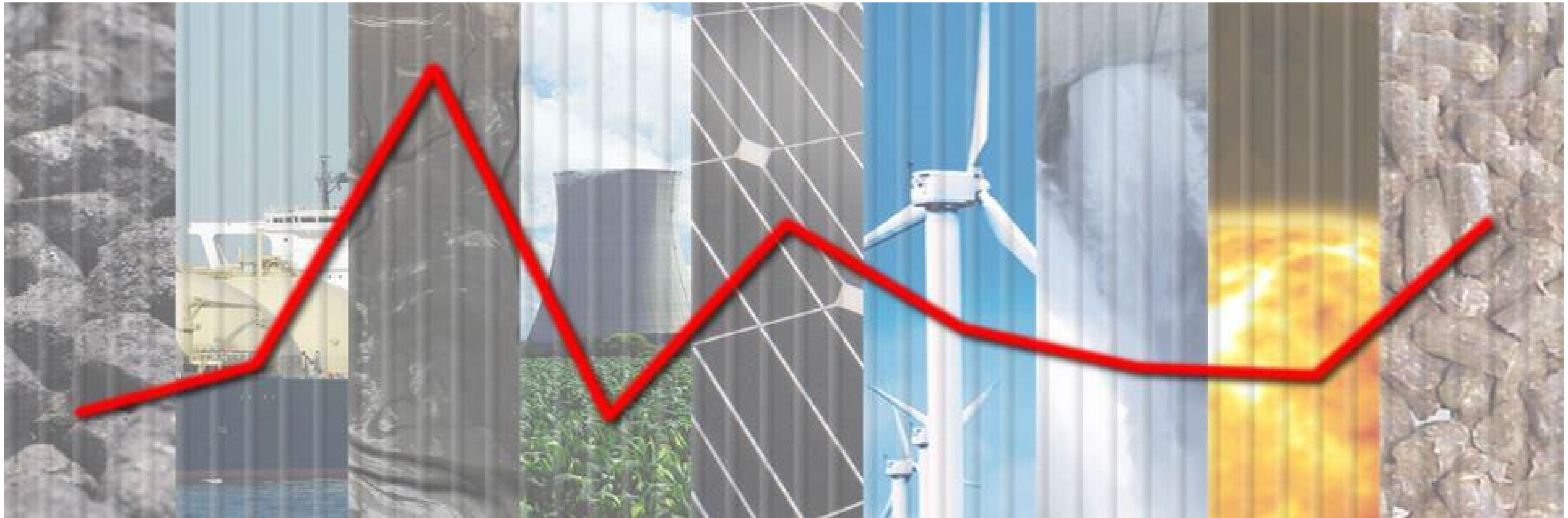
Fig. SPM.5

"The deployment of CDR to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO2 or GHG emissions are to be achieved." (SPM C.11)

In all scenarios except Low Demand scenario, other CDR options as well as large-scale afforestation are also utilized to achieve net zero of CO2. Furthermore, CDR is indispensable for net zero GHG emissions.

2. Comprehensive and Quantitative Scenarios for 2050 Carbon Neutrality in Japan

The scenarios were provided to the Energy Strategy Committee in May 2021.
(Some scenarios had been added.)



Energy Assessment Model: DNE21+ (Dynamic New Earth 21+)

RITE Research Institute of Innovative Technology for the Earth

- Systemic cost evaluation on energy and CO_2 reduction technologies is possible.
- Linear programming model (minimizing world energy system cost; with 10mil. decision variables and 10mil. constrained conditions)
- Evaluation time period: 2000-2100
  Representative time points: 2005, 2010, 2015, 2020, 2025, 2030, 2040, 2050, 2070 and 2100
- World divided into 54 regions
  Large area countries, e.g., US and China, are further disaggregated, totaling 77 world regions.
- Interregional trade: coal, crude oil/oil products, natural gas/syn. methane, electricity, ethanol, hydrogen, CO_2 (provided that external transfer of CO_2 is not assumed in the baseline)
- Bottom-up modeling for technologies on energy supply side (e.g., power sector) and CCUS
- For energy demand side, bottom-up modeling conducted for the industry sector including steel, cement, paper, chemicals and aluminum, the transport sector, and a part of the residential & commercial sector, considering CGS for other industry and residential & commercial sectors.
- Bottom-up modeling for international marine bunker and aviation.
- Around 500 specific technologies are modeled, with lifetime of equipment considered.
- Top-down modeling for others (energy saving effect is estimated using long-term price elasticity).

- **Regional and sectoral technological information provided in detail enough to analyze consistently.**
- **Analyses on non-CO_2 GHG possible with another model RITE has developed based on US EPA's assumptions.**

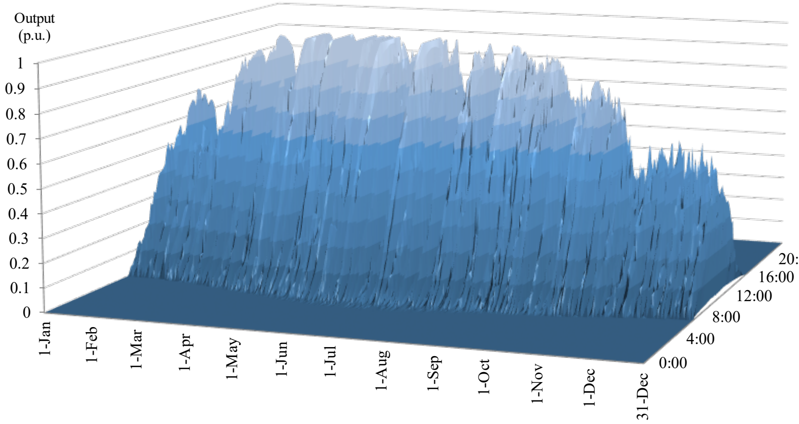
- **Model based analyses and evaluation provide recommendation for major governmental policy making on climate change, e.g., cap-and-trade system and Environmental Energy Technology Innovation Plan, and also contribute to IPCC scenario analysis.**

Integration Cost of VRES: integration with a Power Generation Mix Model by Univ. of Tokyo and IEEJ

- **As DNE21+ is a global model and not suitable for the analysis regarding internal power grid and regional conditions of renewable energy, it applies the results of the study on the assumption of integration cost under high VRE penetration based on an optimal power generation mix model, by Fujii-Komiyama Laboratory, the University of Tokyo and the Institute of Energy Economics, Japan.**
- **Time fluctuation of VRE output is modeled based on nationwide meteorological data, e.g., AMeDAS, to estimate the optimal configuration (power generation and storage system) and the annual operation by linear programming.**
- **Calculated with hourly modeling by 5 divided regions (Hokkaido, Tohoku, Tokyo, Kyushu and others). Prerequisites for power generation cost, resource constraint, etc, are defined in line with DNE21+.**

Considered in modeling･･･ Output control, power storage system (pumped hydro, lithium-ion battery and hydrogen storage), reduction of power generation facility utilization, inter-regional power transmission lines, electricity loss in storage and transmission

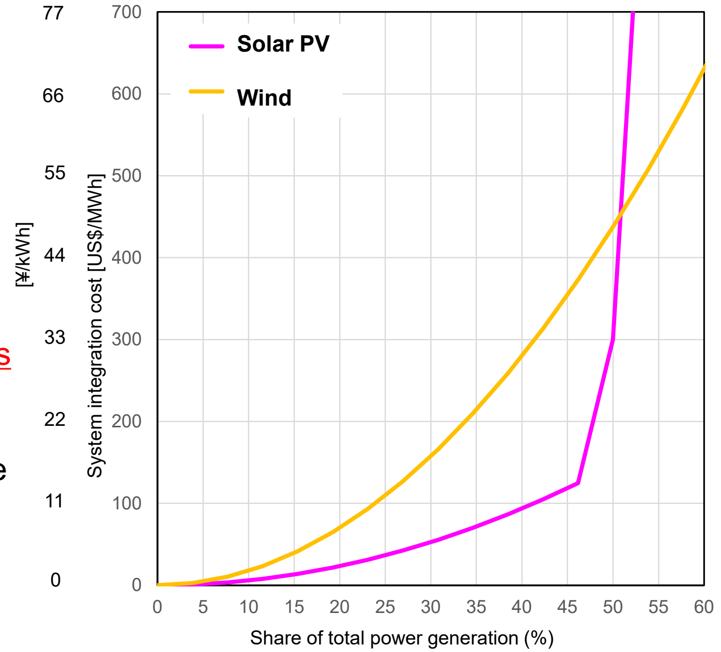
Not considered in modeling･･･ Intra-regional power transmission lines, power grid, influence of decrease of rotational inertia, grid power storage by EV, prediction error of VRE output, supply disruption risk during dark doldrums



Output example of PV

As the VRE ratio increases, marginal integration costs tend to rise relatively rapidly. This is because under the circumstance where a large amount of VRE has already been installed, if it is further installed, it will be required to maintain an infrequently used power storage system or transmission line to deal with the risk that cloudy weather and windless conditions will continue for several days or more.

Grid integration costs approximated from the analysis of the Univ. of Tokyo – IEEJ power generation mix model＝Assumption on grid integration costs in DNE21+ (Marginal cost when each implementation share is realized)



Overview of Assumed Scenarios

		GHG emission reduction in 2050	Technology assumption (cost / performance)	Technology deployment scenario
Offset emission credits of overseas (The least-cost measures in the world = Equal marginal abatement costs among nations)		Domestic emission reductions are endogenously determined.	**Standard case** (Note: It is premised that RE is diffused due to suspected inertial force in high share RE scenario.)	**Determined endogenously (cost minimization), with constraints for nuclear power up to 10% and CO_2 storage.**
Reference case		**▲100%** (For other than Japan, ▲100% for each western country, and ▲100% for the others as a whole)		
Assuming high share of RE under Standard case	**1. Renewable Energy 100%**			**Renewable energy nearly 100%** **(Nuclear power 0%)**
Assuming each technology is further accelerated or expanded.	**2. Renewable Energy Innovation**		**Acceleration of RE cost reduction**	**Determined endogenously, with constraints for nuclear power up to 10% and CO_2 storage.**
	3. Nuclear Power Utilization		**Expansion of nuclear power deployment**	**Determined endogenously, with constraints for nuclear power up to 20% and CO_2 storage.**
	4. Hydrogen Innovation		**Acceleration of hydrogen cost reduction**	**Determined endogenously, with constraints for nuclear power up to 10% and CO_2 storage.**
	5. CCS Utilization		**Expansion of CO_2 storage potential**	**Determined endogenously, with constraints for nuclear power up to 10%. Large CCS storage potential assumed.**
	6. Synthetic fuel Utilization		**Acceleration of RE cost red. + Constraints of CO2 intern'l transportation**	**Determined endogenously, with constraints for nuclear power up to 10% and CO_2 storage. No intern'l transportation of CO_2.**
	7. Demand Transformation		**Expansion of car-/ride-sharing**	**Dramatic expansion of car-/ride-sharing due to fully autonomous car implementation assumed. Other assumptions are same as Reference case.**

Scenario Assumption and Share of Renewables in Total Electricity (in 2050)

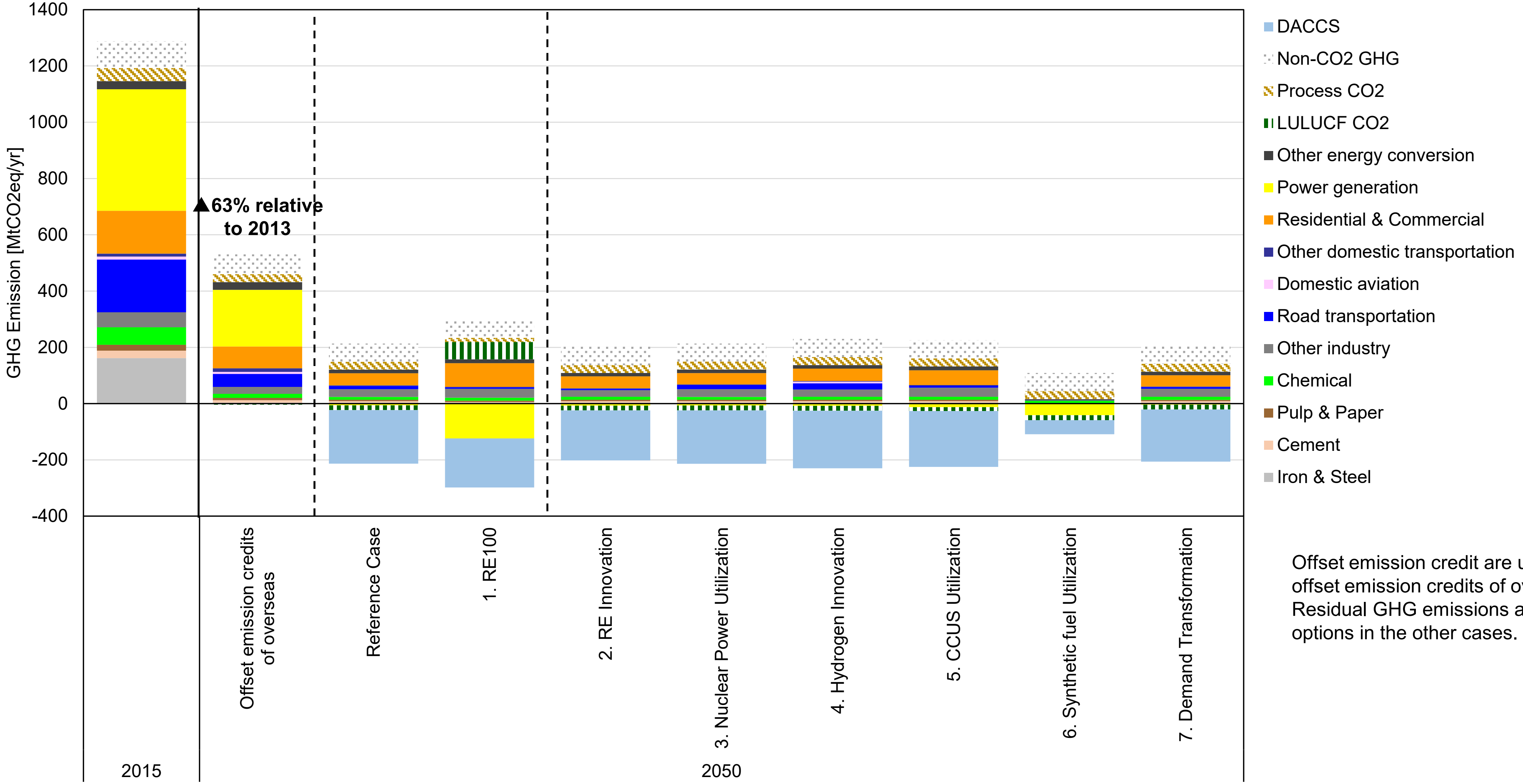
<table>
<tr><th>Scenario</th><th>Cost of renewable energy</th><th>Ratio of nuclear power</th><th>Cost of hydrogen</th><th>CCUS (Storage potential)</th><th>Fully autonomous driving (Car ride sharing)</th></tr>
<tr><td>Reference Case*1</td><td rowspan="2">Standard cost</td><td>Max. 10%</td><td rowspan="4">Standard cost</td><td rowspan="5">Domestic storage: max. 91MtCO_2/yr;
Overseas transportation: max. 235MtCO_2/yr</td><td rowspan="7">Standard assumption
(no fully autonomous cars)</td></tr>
<tr><td>1. Renewable Energy 100%</td><td>0%</td></tr>
<tr><td>2. Renewable Energy Innovation</td><td>Low cost</td><td>Max. 10%</td></tr>
<tr><td>3. Nuclear Power Utilization*2</td><td rowspan="3">Standard cost</td><td>Max. 20%</td></tr>
<tr><td>4. Hydrogen Innovation</td><td rowspan="4">Max. 10%</td><td>Hydrogen production such as water electrolysis, hydrogen liquefaction facility cost: Halved</td></tr>
<tr><td>5. CCS Utilization</td><td>Standard cost</td><td>Domestic: max. 273MtCO_2/yr;
Overseas: max. 282MtCO_2/yr</td></tr>
<tr><td>6. Synthetic fuel utilization</td><td>Low cost</td><td>Hydrogen production, such as water electrolysis, facility cost: Halved;
Innovative methanation</td><td>Domestic: max. 91Mt,
Overseas: 0Mt</td></tr>
<tr><td>7. Demand Transformation</td><td>Standard cost</td><td>Standard cost</td><td>Domestic: max. 91MtCO_2/yr;
Overseas: max. 235MtCO_2/yr</td><td>Realization and diffusion of fully autonomous driving and expansion of car ride sharing after 2030, and decrease in material production due to reduction of the number of automobiles</td></tr>
</table>

* Regarding changes on the demand side, further scenario analysis that takes into account factors other than car sharing will be conducted.

*1: There is no feasible solution without DAC, and DAC is assumed to be available in all scenarios.

*2: Nuclear power utilization scenarios up to a ratio of 50% are separately examined.

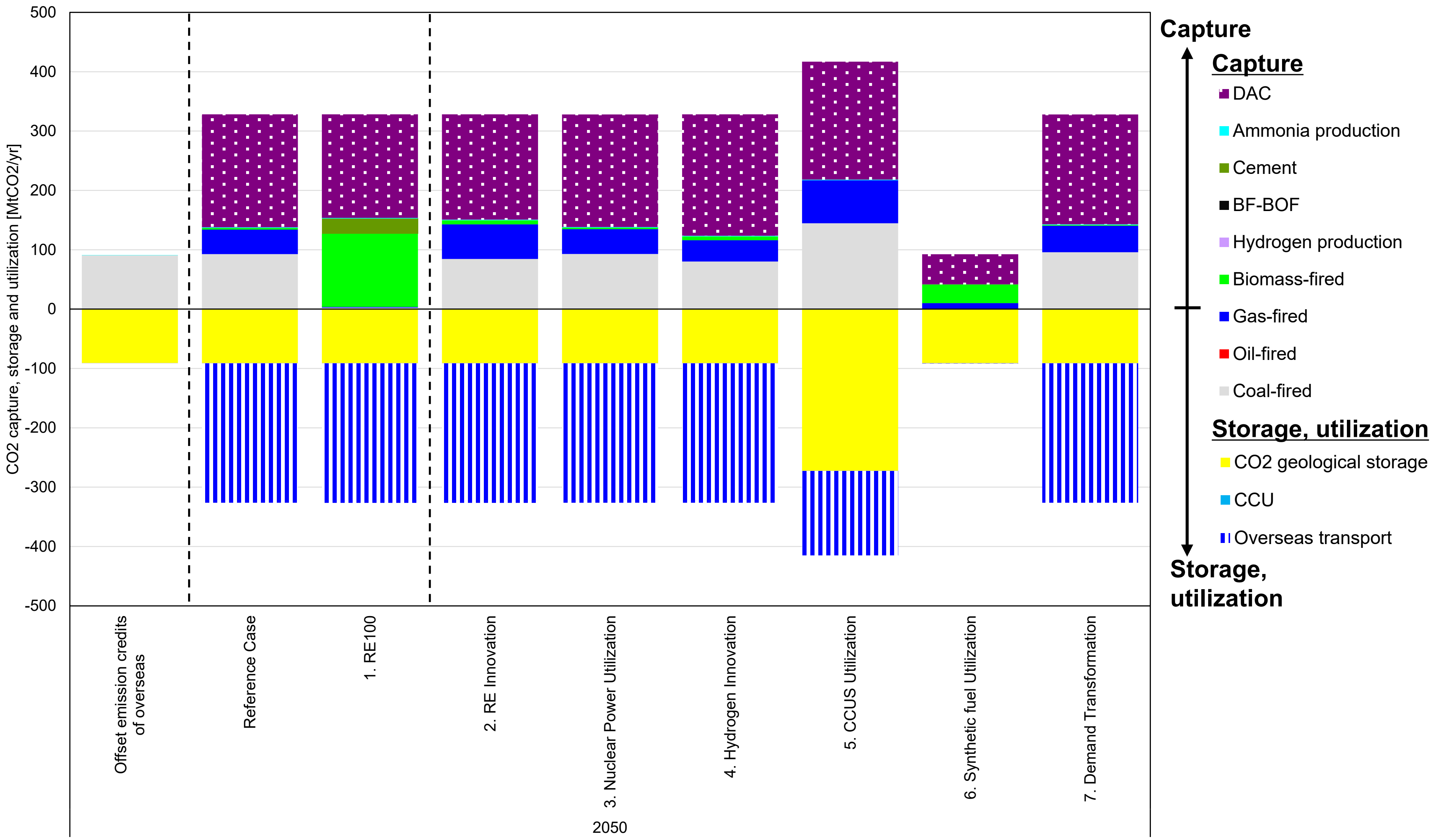
GHG Emissions by Sector in Japan in 2050



Offset emission credit are used in the case of offset emission credits of overseas. Residual GHG emissions are offset by CDR options in the other cases.

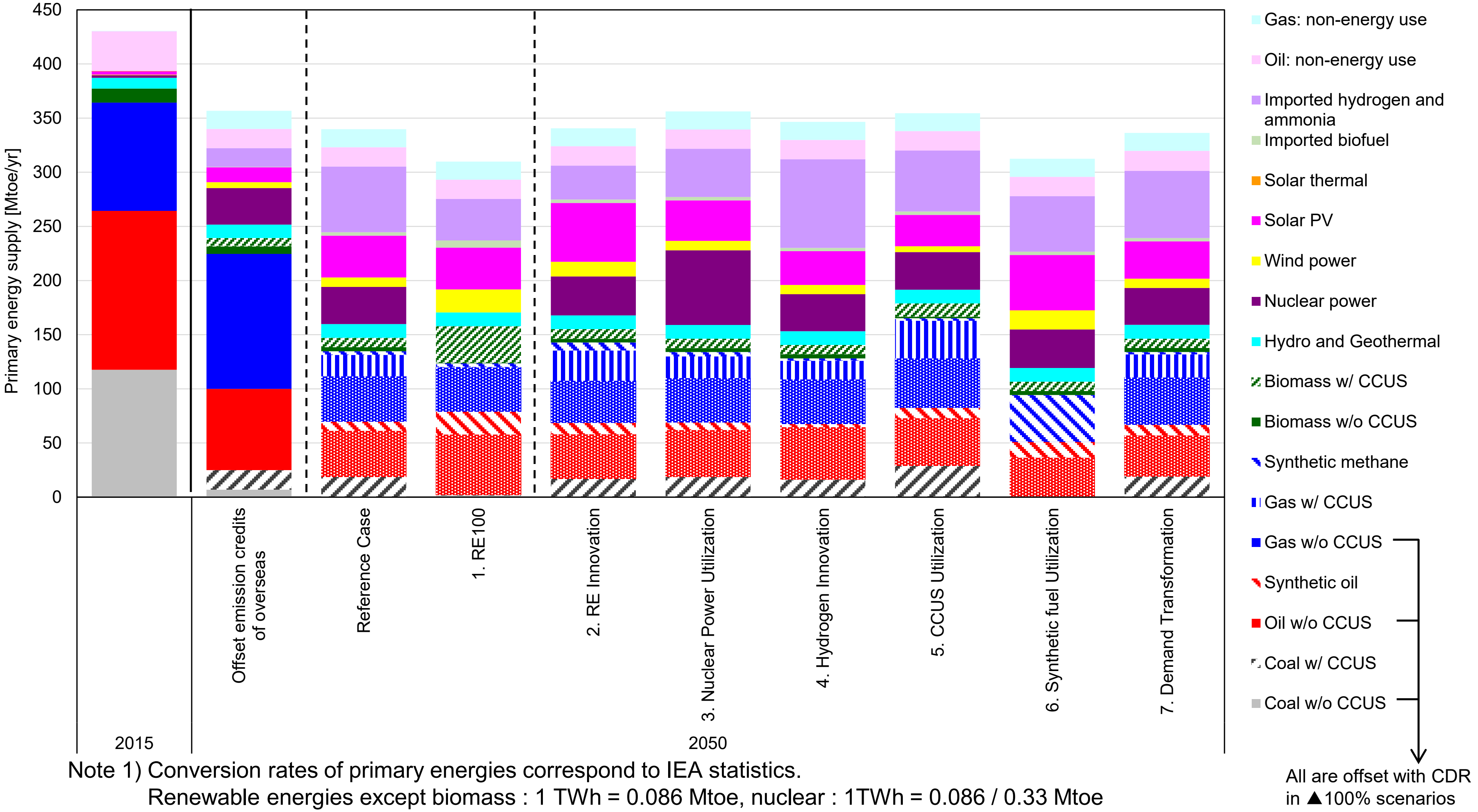
- ✓ **In the case of offset emission credits of overseas, the emission reduction in 2050 is 63% relative to 2013 in Japan, because there are offset emission credit opportunities of cheaper NETs options such as BECCS and DACCS outside of Japan.**
- ✓ **For offset of residual GHG emissions, DACCS plays an important role.**

CO_2 Balances in Japan in 2050



- ✓ **In the RE100 case, fossil fuels + CCS is excluded and BECCS is utilized instead.**
- ✓ **In the case of offset emission credits of overseas, it will be economical that DACCS is implemented outside of Japan.**

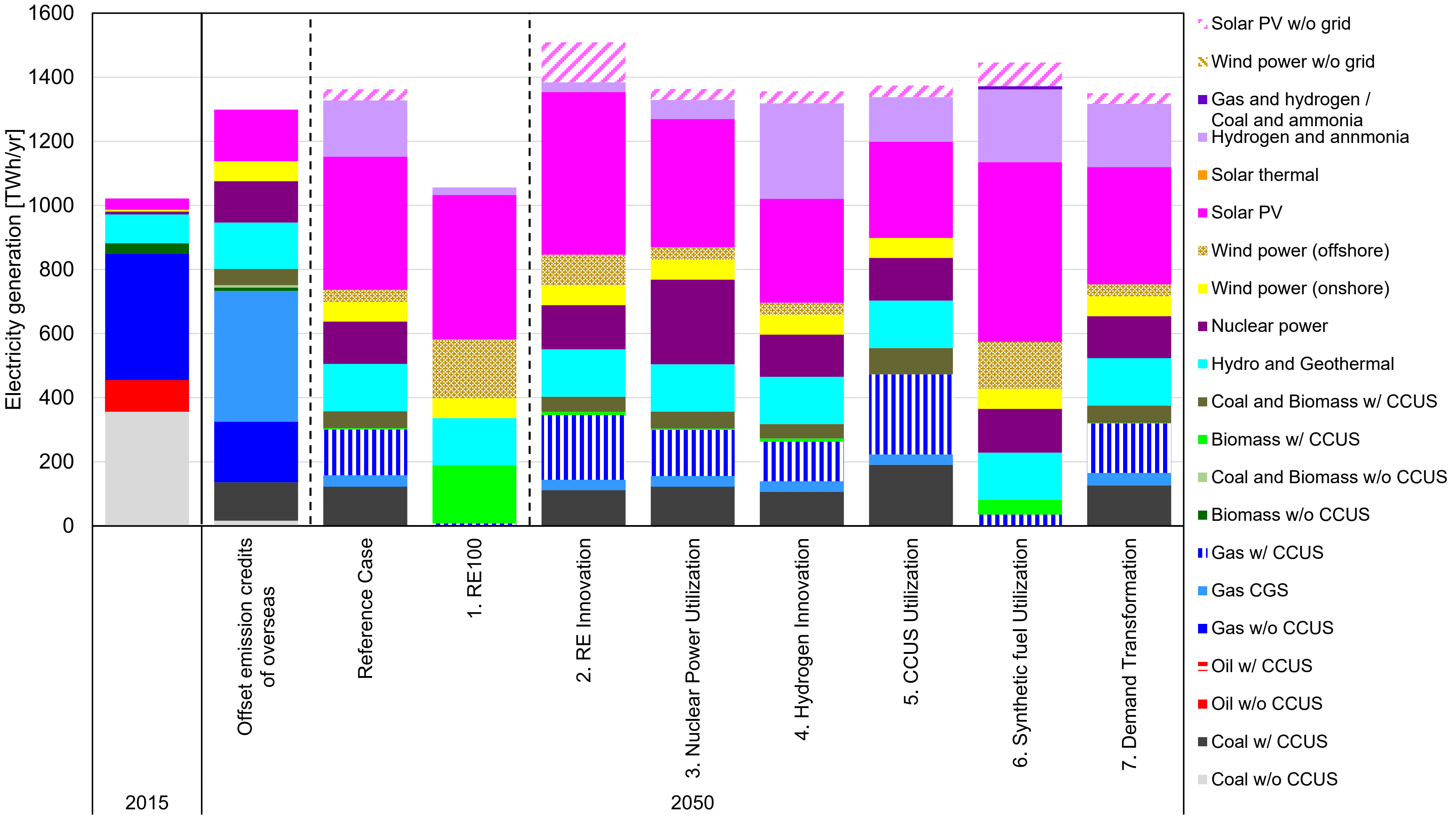
Total Primary Energy Supply in Japan in 2050



Note 1) Conversion rates of primary energies correspond to IEA statistics.
Renewable energies except biomass : 1 TWh = 0.086 Mtoe, nuclear : 1TWh = 0.086 / 0.33 Mtoe
Note 2) Fossil fuels without CCS are offset with CDR, thus serving as carbon-neutral fossil fuels.

- ✓ **For all of the scenarios, CCS is a cost-effective measure. Particularly in 6) syn. fuel case, large amounts of synthetic fuel supplies can be observed.**
- ✓ **A substantial amount of imports of hydrogen, ammonia and synthetic fuels are observed.**

Electricity Supply in Japan in 2050



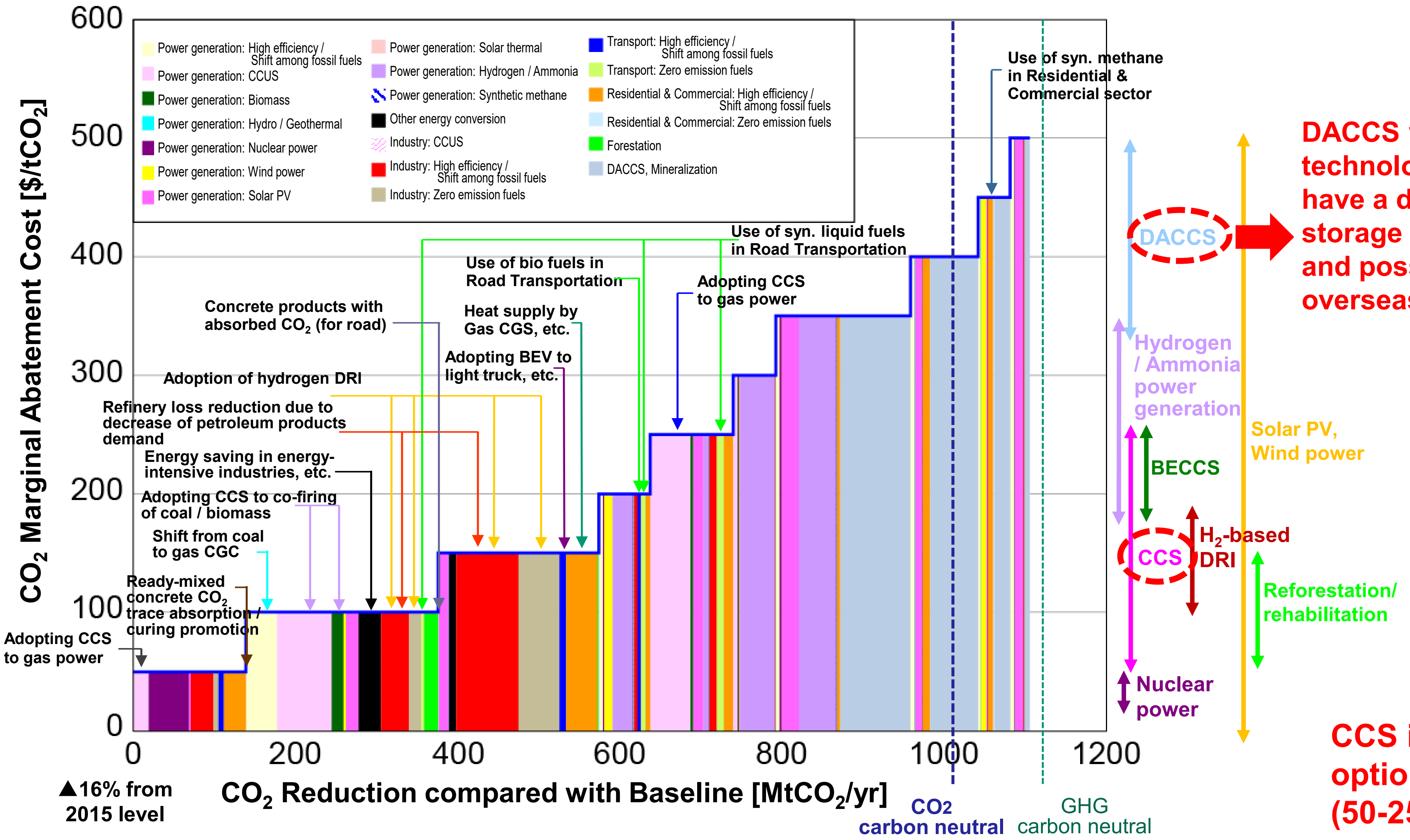
- ✓ In the case of offset emission credits of overseas, relatively large share of gas without CCS including CGS can be seen in Japan.
- ✓ Especially for the RE100 case, a surge in integration costs significantly raises marginal cost of electricity supply, causing considerable decrease in electricity demand. CCS is important.

CO_2 marginal abatement cost, energy system cost, and marginal cost electricity in 2050: Japan

	CO_2 marginal abatement cost [$/t$CO_2$]	Energy system cost[*1] [billion US$/yr]		Marginal cost of electricity [US$/MWh][*2]
Baseline (No climate policy scenario)	—	986	—	121
Emission credit of overseas	168	1044	[+58]	184
Reference case	525	1179	[+193]	221
1.Renewable Energy 100%	545	1284	[+299]	485
2.Renewable Energy Innovation	469	1142	(-37)	198
3.Nuclear Power Utilization[*3]	523～503	1166～1133	(-13～-45)	215～177
4.Hydrogen Innovation	466	1160	(-19)	213
5.CCS Utilization	405	1150	(-29)	207
6.Synthetic fuel Utilization	507	1175	(-4)	190
7.Demand Transformation	509	909	(-270)	221

*1 Numbers in **blue parentheses** are changes from baseline; Numbers in **red parentheses** are changes from the reference.
*2 The marginal costs include grid integration costs. The electricity marginal cost from model estimation in 2020 is 123 US$/ MWh.
*3 Nuclear utilization scenarios assume a nuclear power ratio from 20% to 50%.

Emission reduction potentials and costs in 2050 by sector and technology: Japan



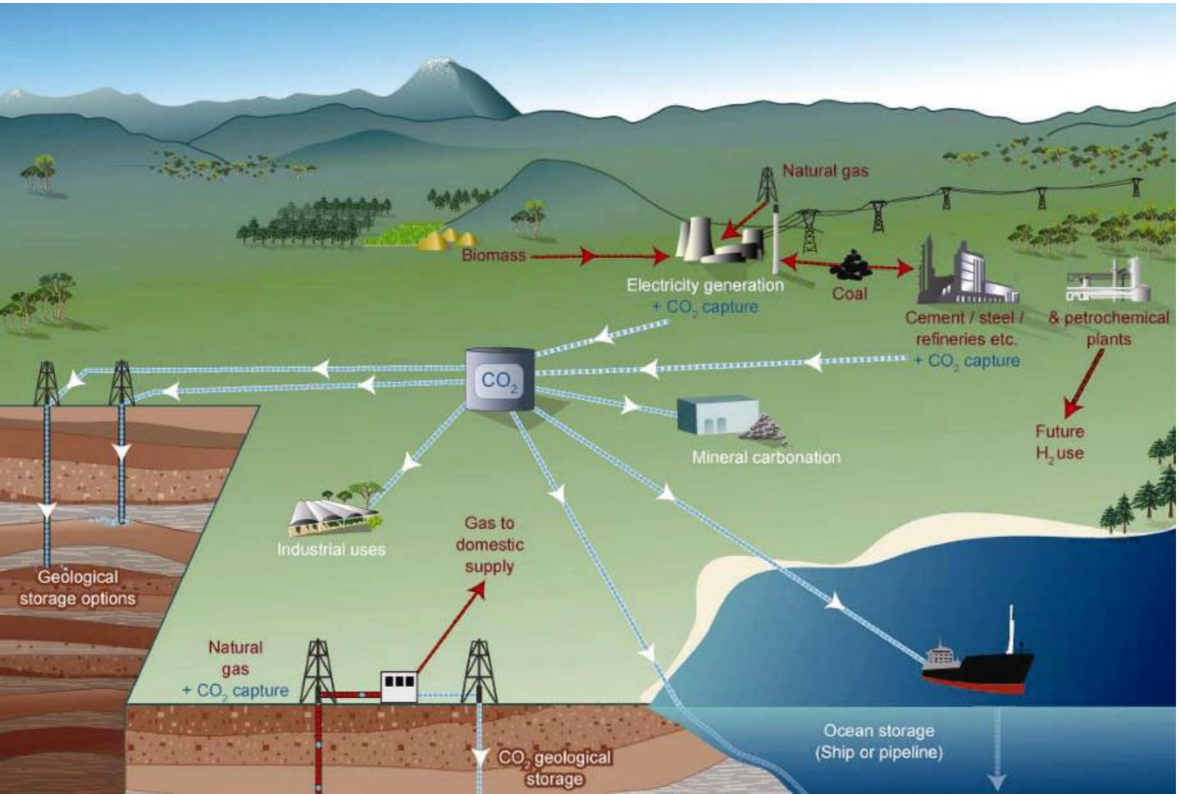
DACCS will serve as a "backstop" technology even in Japan, but will have a dependency on CO2 storage potentials domestically and possibilities of transport to overseas.

CCS is relatively cheap options also in Japan (50-250 USD/tCO2 in 2050).

Note 1) This analysis shows the result of the estimation under the technology assumption in the "Reference case".

Note 2) The emission reduction potentials in this analysis should be referenced as a rough guide, as the emission reduction effects by sector / technology will vary depending on the definition of the variables for sectors, countermeasures, and technologies, etc.

3. Policy Schemes to Mobilize to Investments



Basic Guidelines on Climate Transition Finance

- **As a response to the EU taxonomy, which is organized by the dualism of whether it is green or not, we will focus on the transition such as energy saving and energy conversion toward decarbonization and promote "transition finance" to promote funding there.**
- **In May this year, the Financial Services Agency, the Ministry of the Environment, and the Ministry of Economy, Trade and Industry formulated "Basic Guidelines" for labeling transition bonds and transition loans based on the international principles published in December last year.**

Development of sectoral roadmaps for high-emission industries to pave the way for decarbonization

Published in May in 2021

Basic Guidelines on
Climate Transition Finance

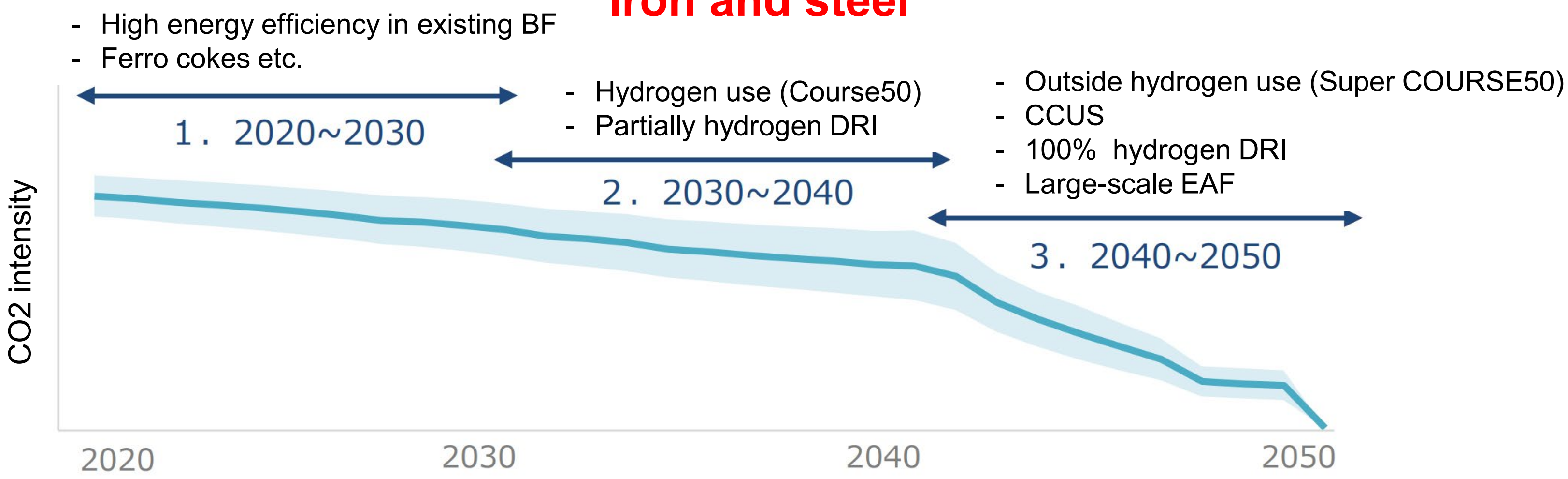
May 2021
Financial Services Agency;
Ministry of Economy,Trade and Industry;
and Ministry of the Environment, Japan

Source) Japanese government document

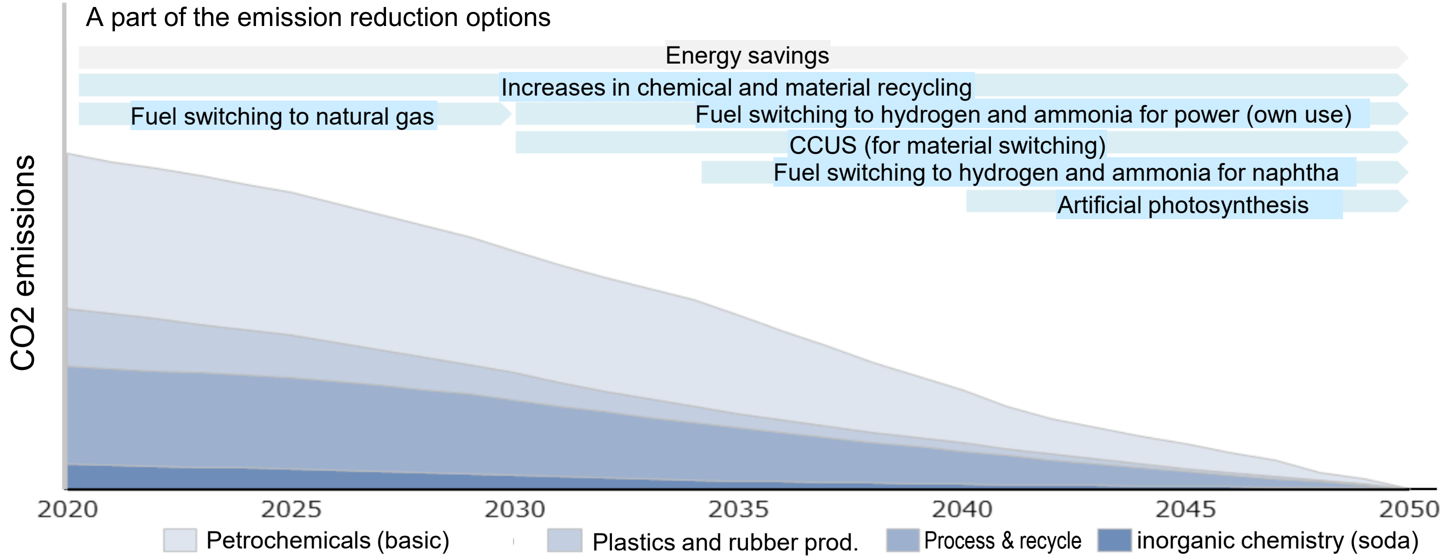
Development of transition roadmaps by sector (1/2)

- METI is developing climate transition roadmaps by sector to support the transition finance.
- Those for iron & steel, chemical, electric power, gas, and oil refinery sectors had been developed, and those for cement and paper & pulp sectors are being developed.

Iron and steel

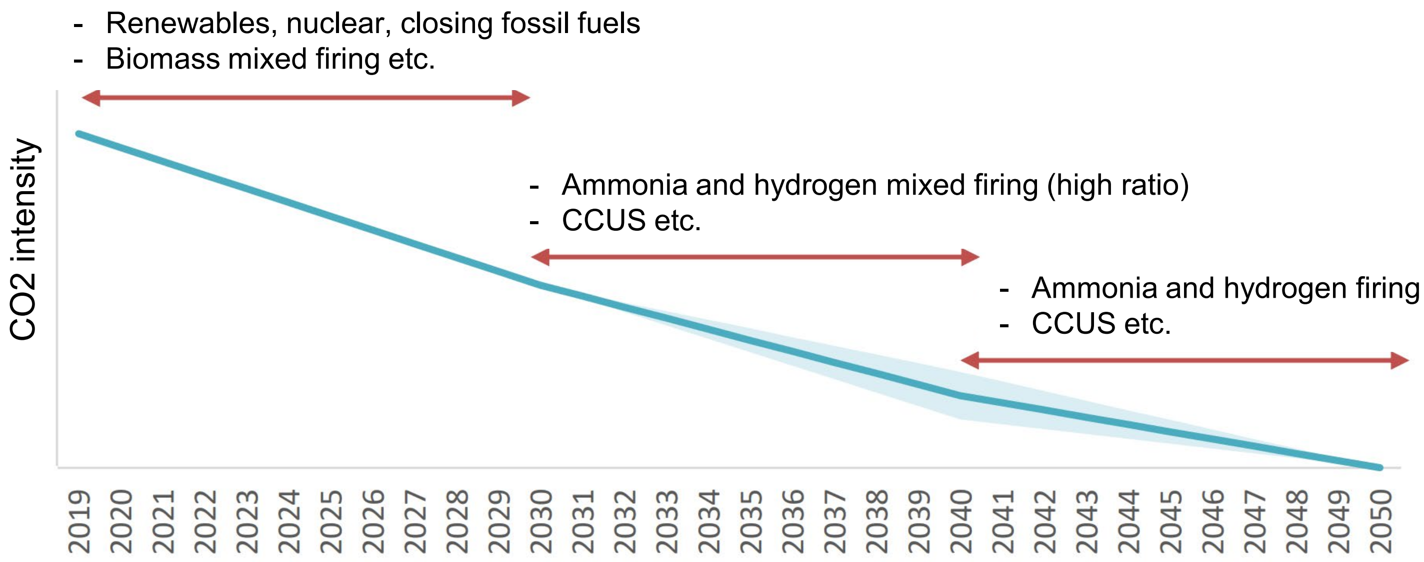


Chemical

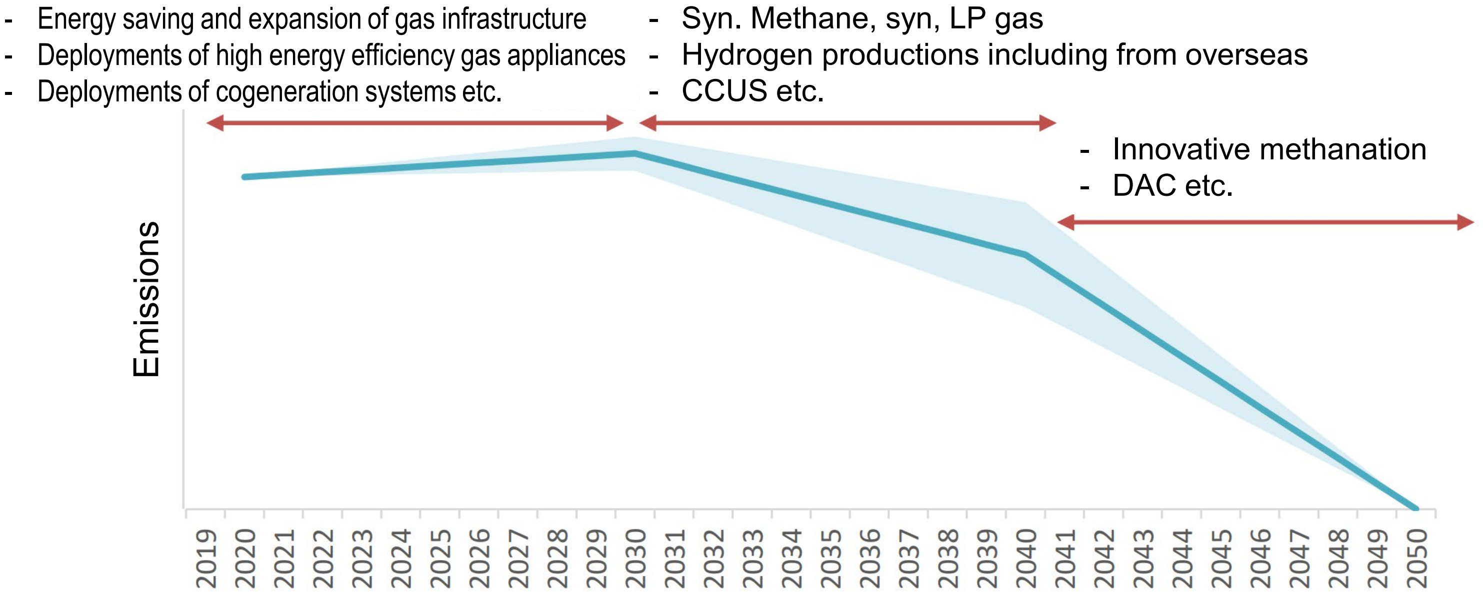


Development of transition roadmaps by sector (2/2)

Electric power



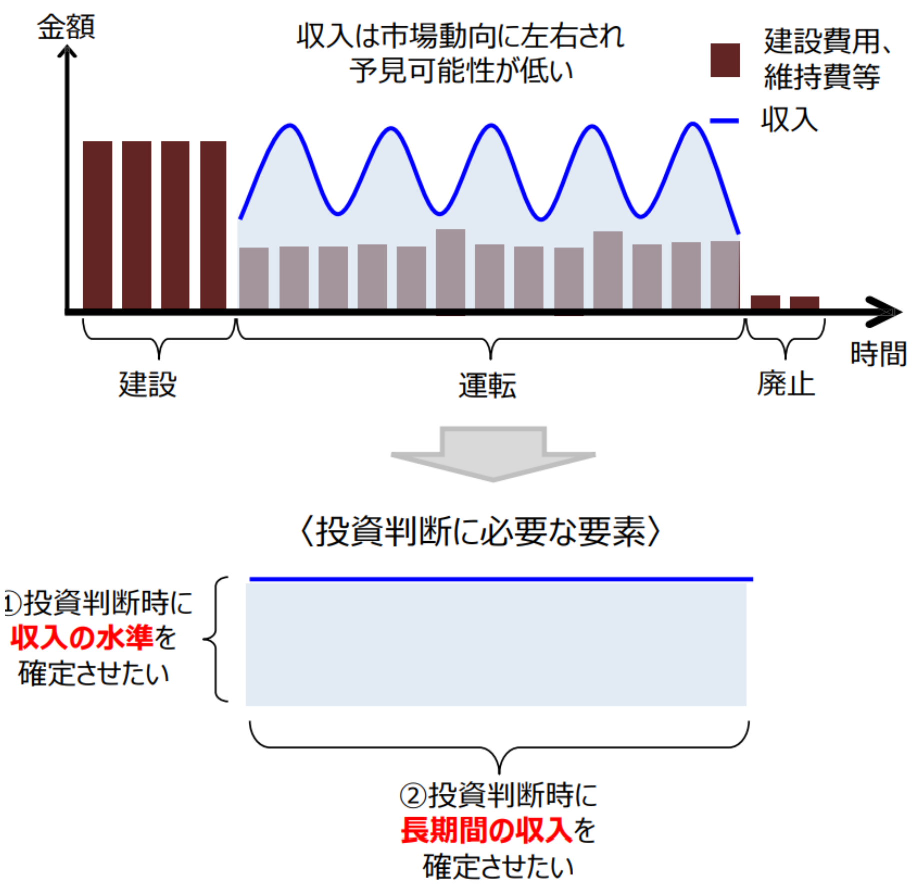
Gas



Long-term commitment to revenues for newly decarbonized power through capacity market in power sector (1/2)

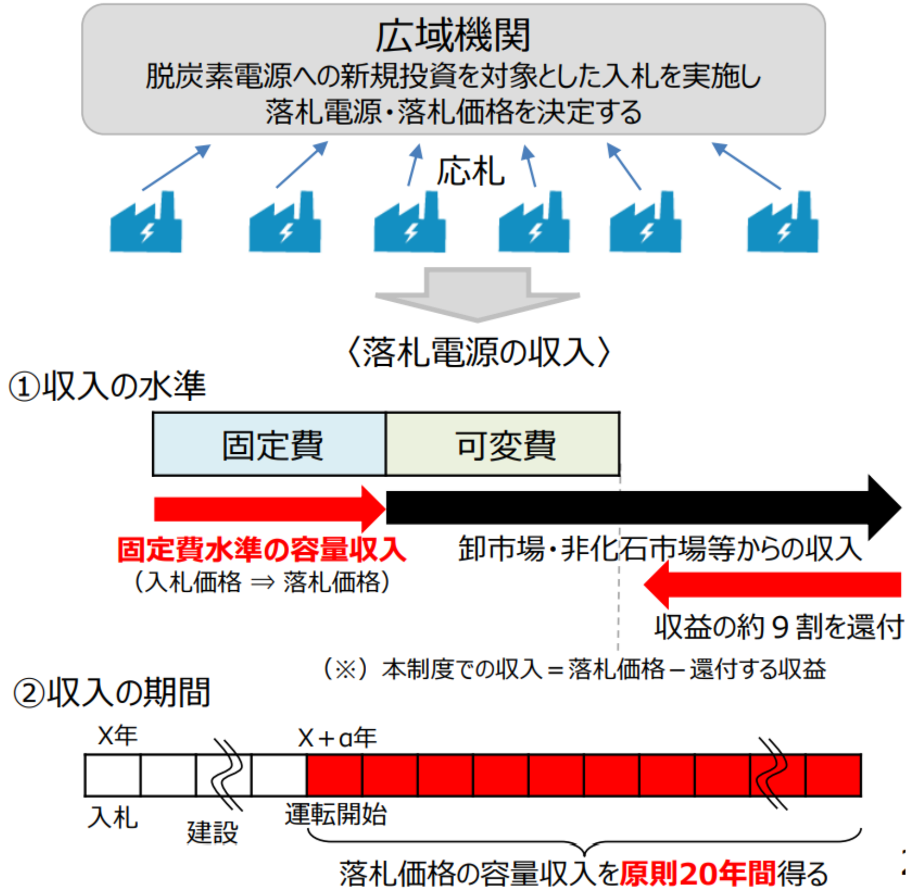
Issues for investment

〈電源投資の課題〉



New scheme

〈新制度のイメージ〉



- ✓ **In the capacity market, the revenues for providing kW are uncertain in the future, and there can be large risks of investing in decarbonized power plants (including CCS) which are higher unit costs of kW in general.**
- ✓ **A new scheme for newly decarbonized power which commit the revenues for 20 years will provide from FY2023. Then, a certain part of the investment risks will be reduced.**

Long-term commitment to revenues for newly decarbonized power through capacity market in power sector (2/2)

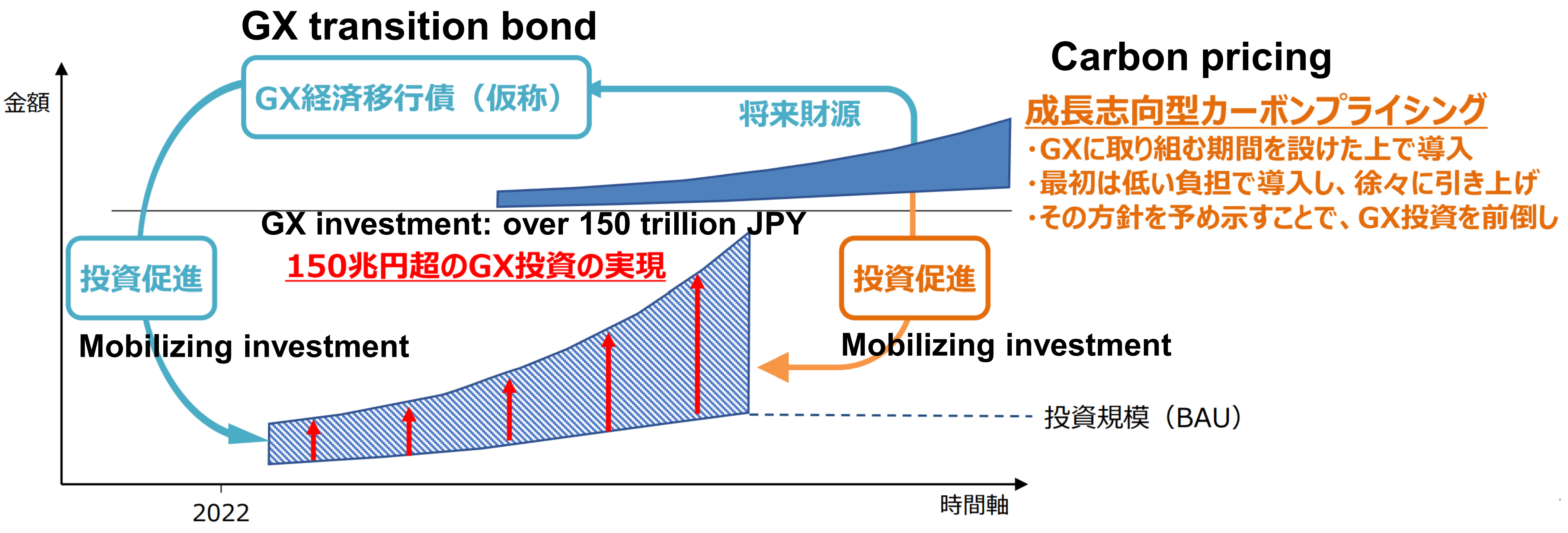
Consideration in different lead time

Deadline for power supply

電源種		供給力提供開始期限（案）
太陽光	Solar PV	5年（法・条例アセス済の場合：3年）
風力、地熱	Wind, geothermal	8年（法・条例アセス済の場合：4年）
水力	Hydro power	12年（法・条例アセス済の場合：8年） （多目的ダム併設型についてはダム建設の遅れを考慮）
水素・アンモニア（専焼）、バイオマス 水素・アンモニア混焼のLNG、CCS火力 既設火力の改修（水素・アンモニア混焼、バイオマス専焼）	Hydrogen, ammonia, biomass, LNG with hydrogen/ammonia, CCS	11年（法・条例アセス済・不要の場合：7年）
原子力	Nuclear	17年（法・条例アセス済の場合：12年）
蓄電池	Battery	4年
LNG（時限的に対象）	LNG (only for limited years)	6年 ※21頁のとおり、早期に供給力を提供開始できる新設・リプレース案件のみを対象とするため、供給力提供開始期限を短く設定

✓ **Construction times are different among power sources. Different lead times among power sources are considered in the new capacity market for long-term decarbonized power.**

GX transition bond and carbon price (under discussions)



13	CCS	約4兆円～	**CCS事業法の整備** • 2030年までのCCS事業開始に向けた事業環境を整備するため、模範となる先進性のあるプロジェクトの開発及び操業を支援するとともに、早急にCCS事業法（仮称）を整備する。

✓ **Introduction of emissions trading schemes in the future (for just image, ETS with free allocation from around 2025, and with auction from around 2028), and subsidy schemes through “GX transition bond” of over 150 trillion JPY based on the auction revenues in the future.**

4. Conclusion

Conclusion

- The Government of Japan decided the 6th Energy Strategic Plan, new Global warming countermeasure plan in October 2021: carbon neutrality (CN) by 2050, and -46% in 2030.
- To achieve carbon neutrality, in principle, primary energy should consist of renewable energy, nuclear energy, and fossil fuels with CCS. The combination of an increase in electrification ratio and low- and de-carbonized power supply plays a vital role in achieving net-zero emissions.
- CCS will play a certain role toward CN in Japan as well as the importance of global strategy including the utilization of overseas-made renewable energy and CCS through hydrogen, ammonia, e-methane (synthetic gas), and e-fuels (synthetic oil).
- Negative emission measures such as DACCS will also play an important role in achieving net-zero emissions including the opportunities in the implementations overseas with emission credit transfer.
- The transition measures and policies will be also very important. The Government of Japan is developing the transition roadmaps for supporting the transition finance.
- The policy schemes to mobilize large amounts of investment in decarbonized energy sources (e.g., nuclear power, CCS) with high risks for investments are important.
- Some policy schemes are under development, and will help to reduce the investment risks also for CCS. But CCS uses geological formations and they accompany with relatively high uncertainties in actual amounts of CO_2 storage, CO_2 injection rate. The needs for the additional policy schemes (or not) should be discussed.
- Not only financial schemes but also developments of several business environment for CCS will also reduce investment risks.

Appendix

[Supplementary slide]

Concept of Innovation in Power Supply Ref. Value

- **Each power source must overcome a large hurdle to achieve the reference values for power sources in 2050 as presented at the Strategic Policy Committee.**
- **Under these conditions, for the 30 to 40% of nuclear power and fossil+CCUS, in case the upper limit of nuclear power is 10%, it is necessary to cover 20-30% with fossill+CCUS, thus it is assumed a considerable amount of CO2 is stored at home/abroad including CCUS required amount other than the electric power sector. For hydrogen/ ammonia and carbon recycled fuel, it is assumed that infrastructure development, etc. is expected to execute large-scale transportation without setting the upper limit of supply on the model.**
- **It should be noted that in this analysis, the conditions were set by mechanically assuming such CCS storage amount based on the above reference values.**

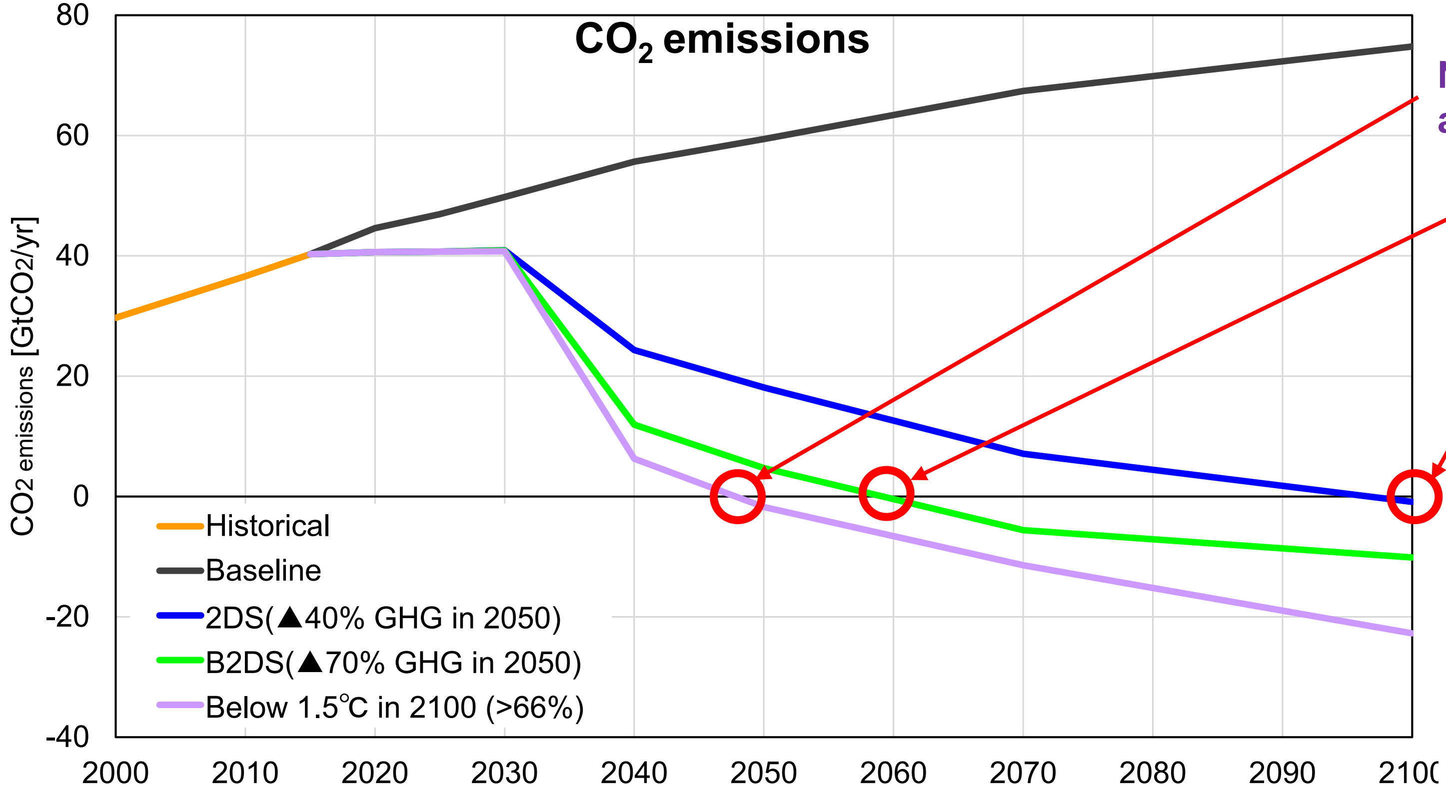
2020/12/21 Strategic Policy Committee Material

In order to aim for carbon neutrality in 2050, stable power supply from decarbonized power sources is indispensable. From the perspective of 3E+S, multiple scenarios will be analyzed without limiting to the following. In deepening the discussion, the positioning of each power source is suggested as follows.

Established decarbonized power source	Renewable Energy		・Continue to aim for maximum introduction as the main power source in 2050. ・Immediately work on issues to promote the maximum introduction such as adjustment amount, transmission capacity, ensuring inertial force, responding to natural conditions and social constraints, maximizing cost control, and increasing social transformation to cost increases. ・How about deepening discussions on covering 50-60%(approx.) of the generated power (* 1) with renewable energy in 2050 as a reference value (* 2)?
	Nuclear power		･As an established decarbonized power source, aim for a certain scale of utilization on the premise of safety. ・In order to restore public trust, make an increased effort to improve safety, gain understanding and cooperation of the location area, solve back-end problems, secure business feasibility, maintain human resources and technical capabilities, etc. How about deepening discussion on covering 30-40% (approx.) with nuclear power which is a carbon-free power source other than renewable energy and hydrogen/ammonia, along with fossil+CCUS/carbon cycle in 2050 as a reference value (* 2)?
Power sources required innovation	Thermal power	Fossil + CCUS	・While having the advantages of supply capacity, adjustment power, and inertial force, decarbonization of fossil-fired power is the disadvantage. ･Aim to utilize on a certain scale iimmediately by developing technology and suitable sites, expanding applications and reducing cost, etc., toward the implementation of CCUS / carbon recycling. How about deepening discussion on covering 30-40% (approx.) together with nuclear power which is a carbon-free power source other than renewable energy and hydrogen/ammonia in 2050 as a reference value (* 2)?
		Hydrogen, Ammonia	･While having the advantages of adjusting power and inertial force without emitting carbon during combustion, the challenges are establishing technology for large-scale power generation, reducing costs, and securing supply. Aim to build a stable supply chain immediately by promoting co-firing of gas-/coal-fired power, increasing supply and demand. ･Aim for a certain scale of utilization as a carbon-free power source, taking into account competition with industrial and transportation demand. Based on the fact that procurement required for future power generation is estimated to be 5-10-million ton as basic hydrogen strategy, how about deepening discussion on covering 10% (approx.) of generated power with hydrogen/ammonia in 2050 as a reference value (* 2)?

1: The amount of power generated in 2050 will be about 1.3-1.5 trillion kwh as a reference value (2) based on the power generation estimation by RITE presented at "the 33rd Strategic Policy Committee".
*2: This is not as a government goal, this is one guideline / option for future discussions. This will be the one of options to deliberate in considering multiple scenarios in the future.

Global Baseline Emissions and Assumed Emissions Scenarios under 2°C and 1.5°C



Note) Emissions for baseline shows model estimates results under SSP2, not assumed scenario

※ 2DS, B2DS, Below 1.5 °C scenarios assume emission constraints equivalent to NDCs of each nation up to 2030.

In the scenario analyses of Japan's 2050 carbon neutrality, 1.5°C global scenarios are assumed in addition to Japan's emissions reduction scenarios, for the global competition for carbon neutral resources to be considered.