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Development of Transition Roadmaps for Net-zero Emissions (2025 Edition)

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1. Motivation and Aim of Developing Transition Roadmaps

Motivation and aim of developing transition roadmaps

- ◆ It is necessary to strengthen measures in each sector to achieve the 2°C and 1.5°C long-term targets of the Paris Agreement and carbon neutrality early in the second half of the 21st century.
- ◆ On the other hand, there is a wide range of transitions that can lead to emission reductions. Even if they are consistent with the global CN, the emission reduction pathways for each industrial sector in a specific country like Japan differ from sector to sector in terms of the life span of existing infrastructure and the difficulty level of emission reduction measures. Uniform emission reductions may increase the cost of measures and make emission reductions more difficult to achieve.
- ◆ In general, however, the pathways to consistent emission reductions, including technologies, are not always well understood, and there is a need for quantitative information to make judgments about the appropriateness of investments. Therefore, the NGFS and other organizations are developing emission reduction scenarios using integrated assessment models that allow for quantitative analysis. On the other hand, these models do not provide sufficient information on emission reduction pathways for each sector.
- ◆ The Government of Japan has developed transition roadmaps for FY2021-2022 to provide specific transition directions toward achieving carbon neutrality, with an intention to utilize these for transition financing, and revised them in FY2025. These were developed on a sector-by-sector basis, thus, there is a need to improve the accountability in terms of consistency with the overall 2°C and 1.5°C emission reduction pathways.
- ◆ Therefore, we have developed and made public sectoral transition roadmaps in 2024 using the bottom-up global assessment model for energy and climate change, the DNE21+, that allows for consistent analysis among countries, regions, and sectors. This material is the updated version of the 2024 roadmaps based on the latest trends.

Remarks of existing scenarios/pathways that are widely referenced internationally:

Material for the Study Group to Formulate a Roadmap for Promoting Transition Finance in the Economic and Industrial Sector in FY2021 4

- The ICMA report indicates the issues regarding the consideration of regional and industrial characteristics for the SBTi, TPI, and IEA, which are listed as scientifically based references in the ICMA Basic Guidelines. When formulating the roadmap, it is necessary to select technologies based on the characteristics of Japan, while referring to the above.
- In addition, the NGFS scenarios that have been used in the financial industry have estimated values by country and sector, but it is assumed that they will be adjusted on their own when used.

Remarks of existing scenarios/pathways that are widely referenced internationally: -----

Organizations	Remarks
IEA	• The IEA presents pathways for emissions from energy use by country/region or by energy sector/industry, so regional and industrial characteristics are taken into account, but no pathways are presented that take into account both (country and industry), simultaneously.
SBTi	• The Absolute Contraction Approach requires the same reduction rate for all actors and does not take into account regional and industry characteristics. • The Sectoral Decarbonization Approach (SDA) shows pathways based on the 2DS and B2DS scenarios in the IEA-ETP, but regional characteristics are not taken into account except for current emissions and production.
TPI	• The sectoral approach used by SBTi is utilized by referring to the IEA-ETP, etc., but does not take into account regional characteristics.
NGFS	• The NGFS scenarios are disaggregated by country and industry, but there are issues with the accuracy of industry (final consumption) estimates, and industry-specific data based on regional characteristics need to be adjusted to reflect the characteristics of each country in detail.

The Cabinet of Japanese government approved the 7th Strategic Energy Plan in February 2025, and we updated the model preconditions considering the latest emissions trend, based on the outlook of energy supply and demand in the 7th Strategic Energy Plan. It should be noted that they are not fully consistent with the scenario analysis* we conducted for the development of the 7th Strategic Energy Plan, for the sake of the consistency with the 2023 version of the roadmaps. Also, our analysis is based on modeling scenarios, and the consistency with the corresponding technologies in the government's roadmaps is not considered.

The updates of the model preconditions from the 2023 version are as follows;

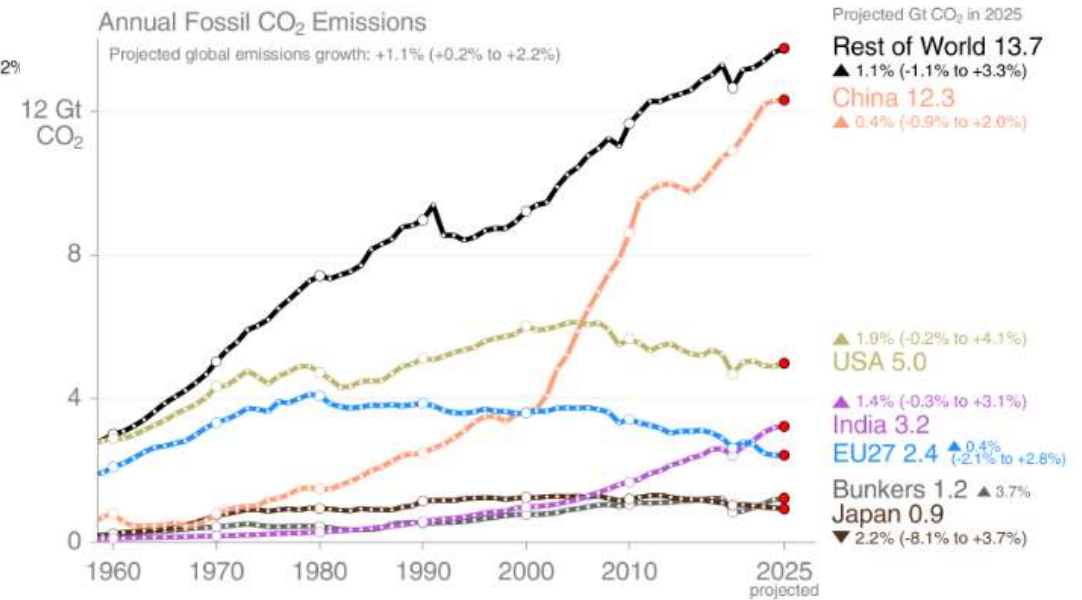
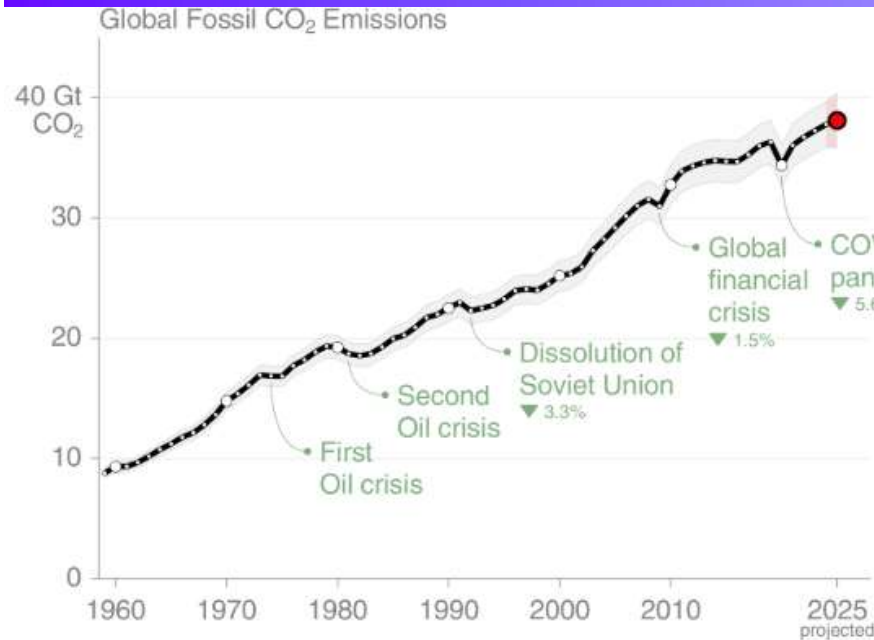
- ◆ Upward revise of the latest actual value of global emission**
- ◆ Downward revise of the latest crude steel production trend in Japan (to be consistent with the assumption in the 7th Strategic Energy Plan)**
- ◆ Revise of costs and potentials of off-shore wind power (revised to the potentials including the usage in EEZ to be consistent with the assumption in the 7th Strategic Energy Plan)**
- ◆ Raising the upper limit of nuclear power relative to total power generation from 10% uniformly to 20% in some scenarios (to be consistent with the assumption in the 7th Strategic Energy Plan)**

* https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2024/068/068_008.pdf

2. Emissions Trend and Reference Scenarios

Current Trend of Global Emissions and Outlook of NDCs

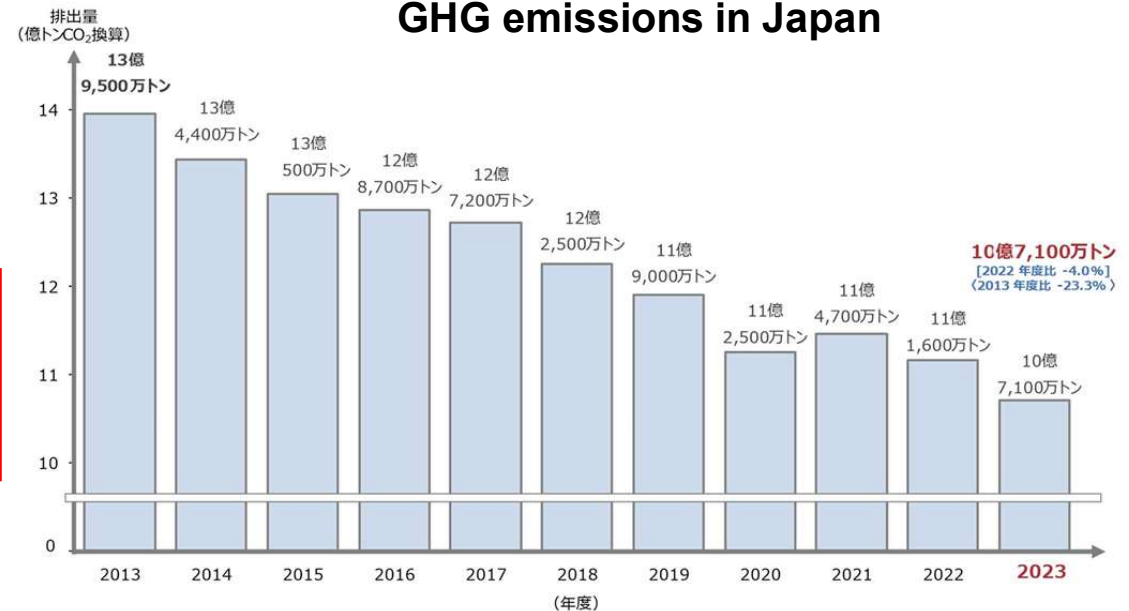
CO₂ emission trajectories in the world and major countries



出典) Global Carbon Project, 2025

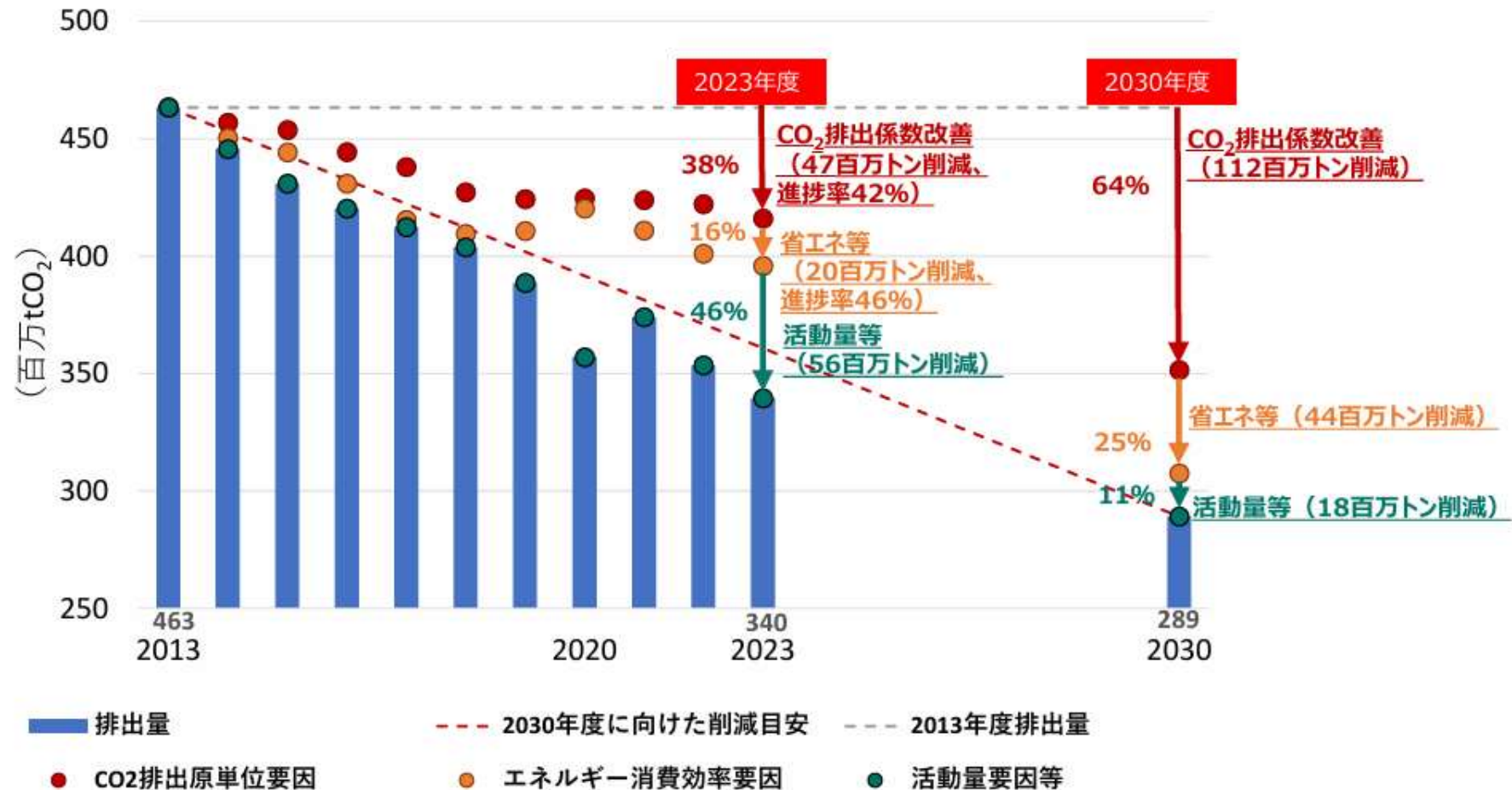
While emissions of Japan, US, and EU are continually decreasing, global emissions keep increasing.

GHG emissions in Japan



Source) The Government of Japan (Ministry of Environment), 2025

Industry sector



※進捗率：2023年度の削減量/2030年度の削減量

※各年度の%：各年度の総削減量に占める各要因の削減量の割合

※各部門でCO₂排出係数改善の進捗率が異なるのは、電力と燃料の比率、電力の自家発電比率等が部門により異なるため。

※要因分解の活動量には製造業は鉱工業生産指数、非製造業は産業別GDPを使用。

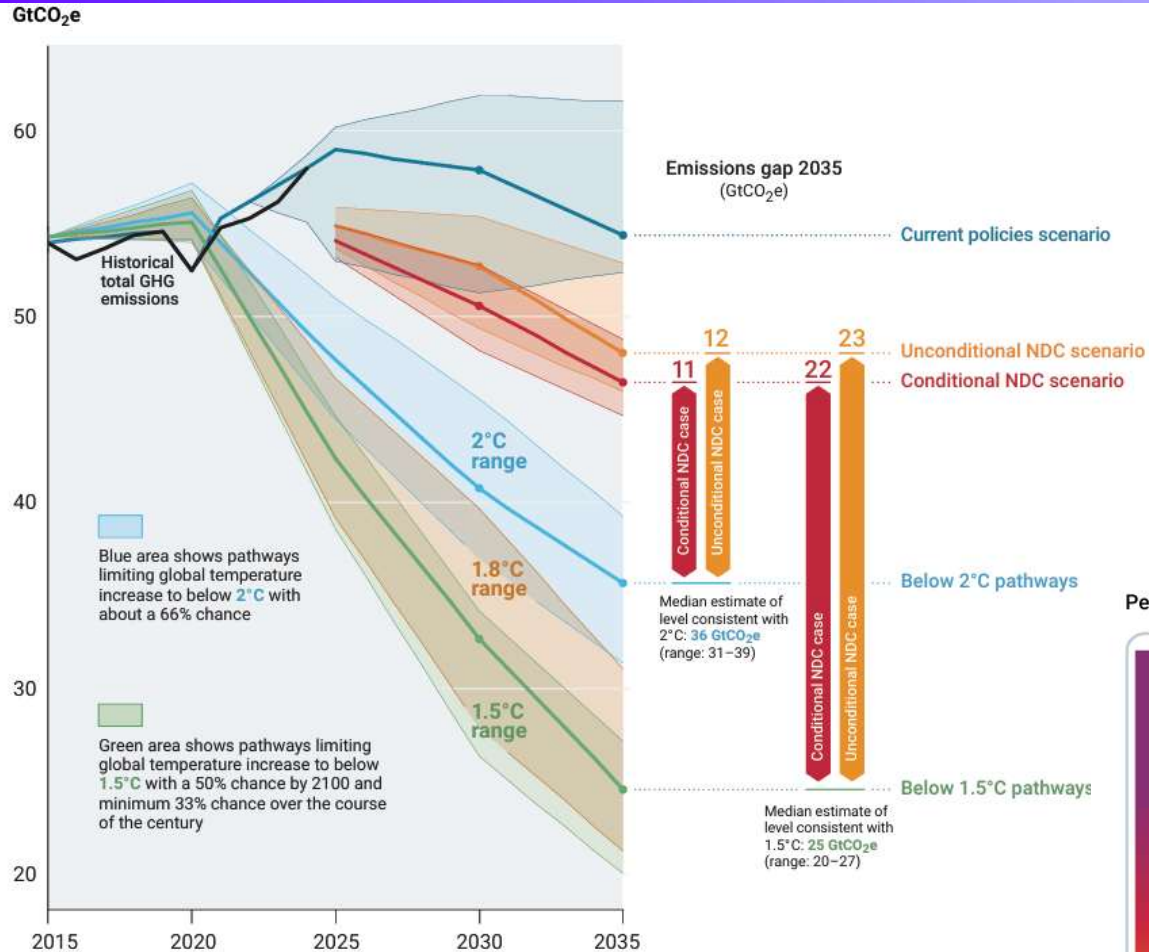
※活動量要因等には要因分解式の構造上、製造業の産業構造の転換等も含む。

＜出典＞ 温室効果ガスインベントリ、地球温暖化対策計画、総合エネルギー統計（資源エネルギー庁）、2030年におけるエネルギー需給の見通し（関連資料）（以上、資源エネルギー庁）、鉱工業生産指数、生産動態統計（以上、経済産業省）、国民経済計算（内閣府）から作成

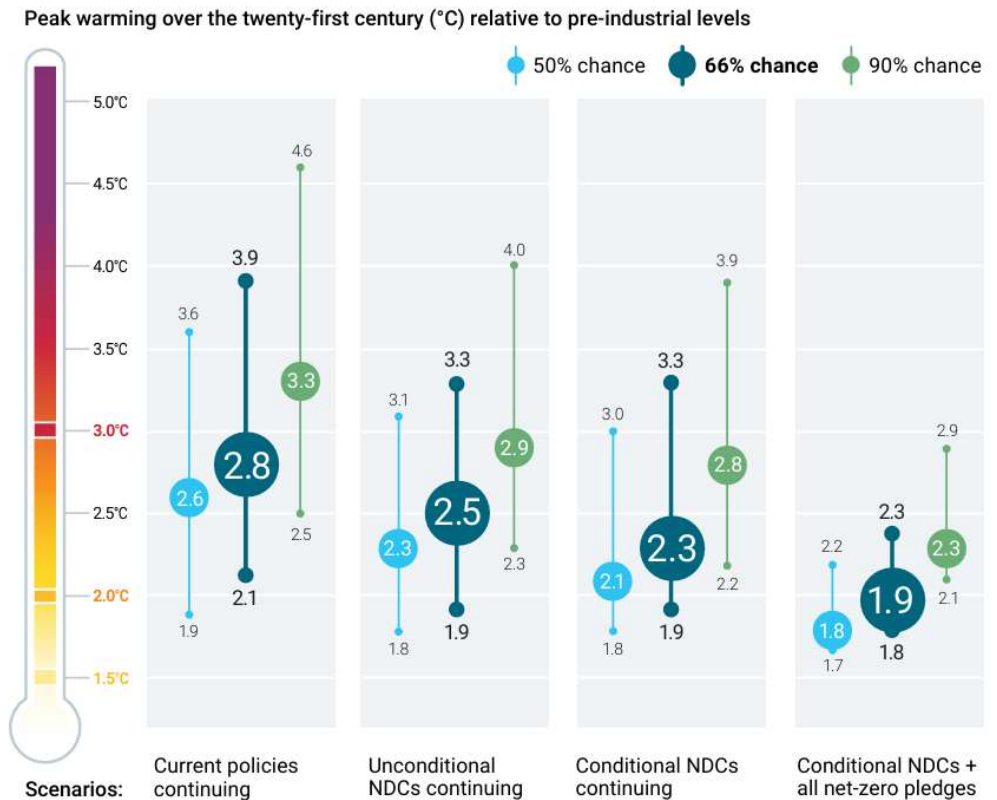
Source) The Government of Japan, 2025

✓ It should be noted that a main factor of emissions reduction is decrease of production activities (e.g. transfer to developing countries).

Emissions gap between 1.5°C/2°C target and current policies

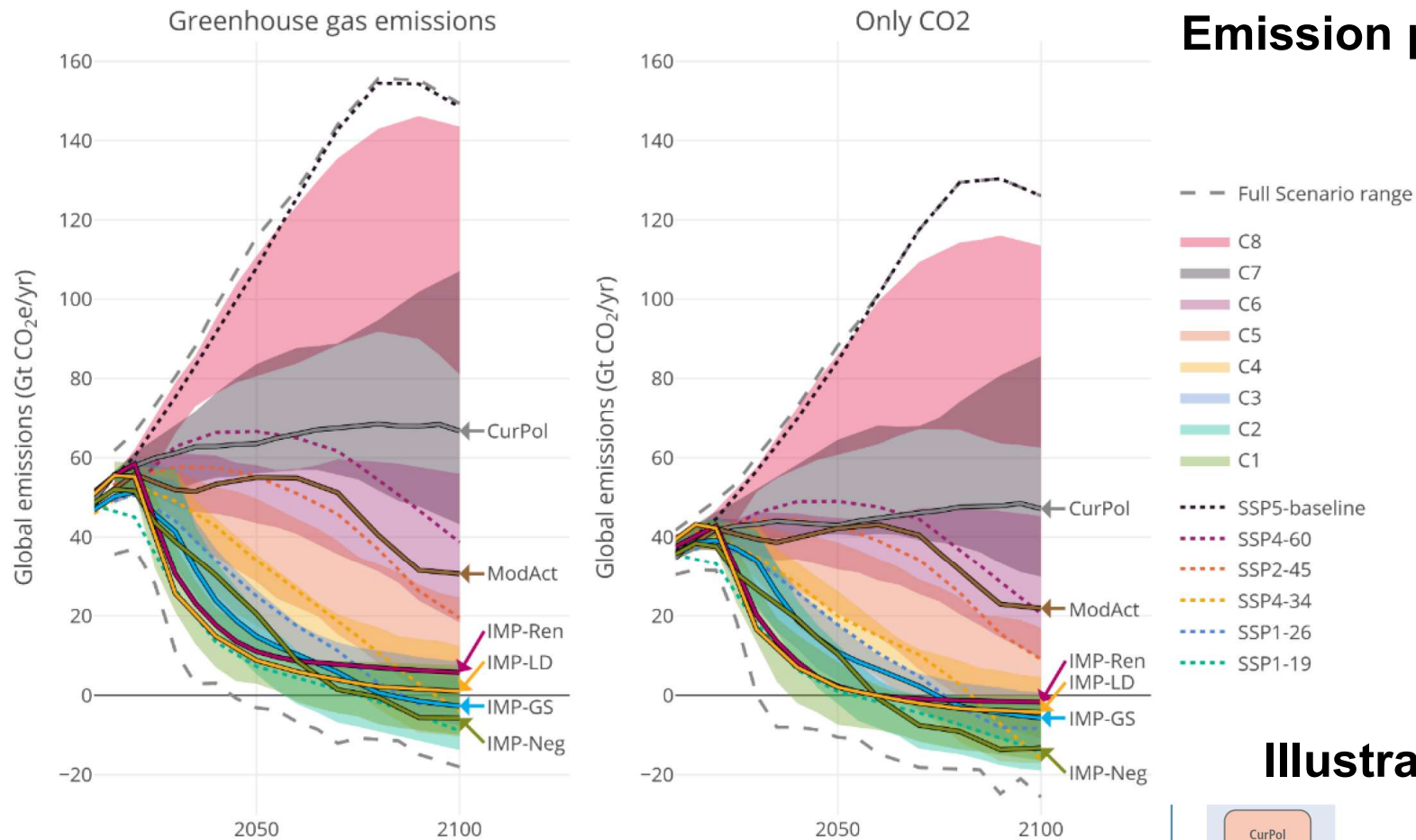


- ✓ There is a significant gap between aggregated emissions of NDCs and the 1.5°C or 2°C target.
- ✓ UNEP EGR(2025) estimates that the global temperature rise will be around 2.6°C in 2100 under the current policies.



IPCC Scenarios

Classification of emissions scenarios and illustrative pathways of the AR6 of IPCC

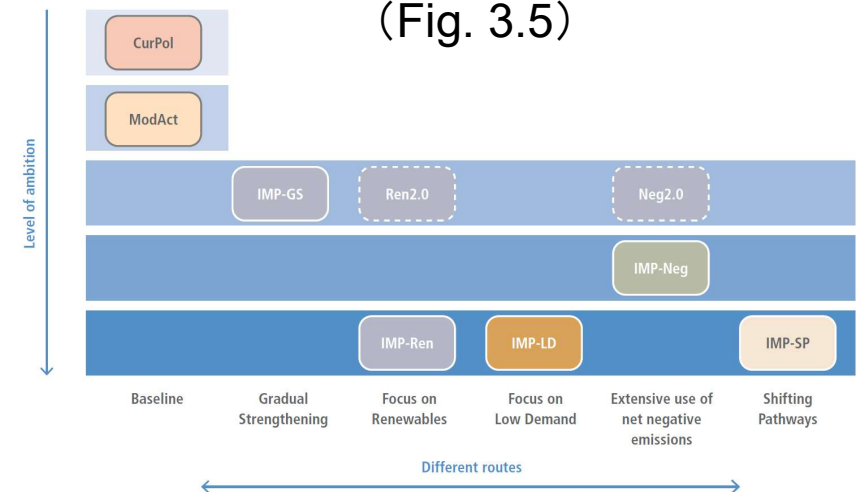


Emission pathways (Fig. 3.10)

C8	>4°C
C7	4°C
C6	3°C
C5	2.5°C
C4	2°C (>50%)
C3	2°C (>67%)
C2	1.5°C-high overshoot
C1	1.5°C-no/limited overshoot

IPs	CurPol	Current Policies	C7
	ModAct	Moderate Actions	C6
The pathways consisting with the long-term goals of Paris Agreement (IMPs)	GS	Gradual strengthening	C3
	Neg	Extensive use of net negative emissions	C2
	Ren	Focus on Renewables	C1
	LD	Focus on Low Demands	C1
	SP	Shifting Pathways	C1

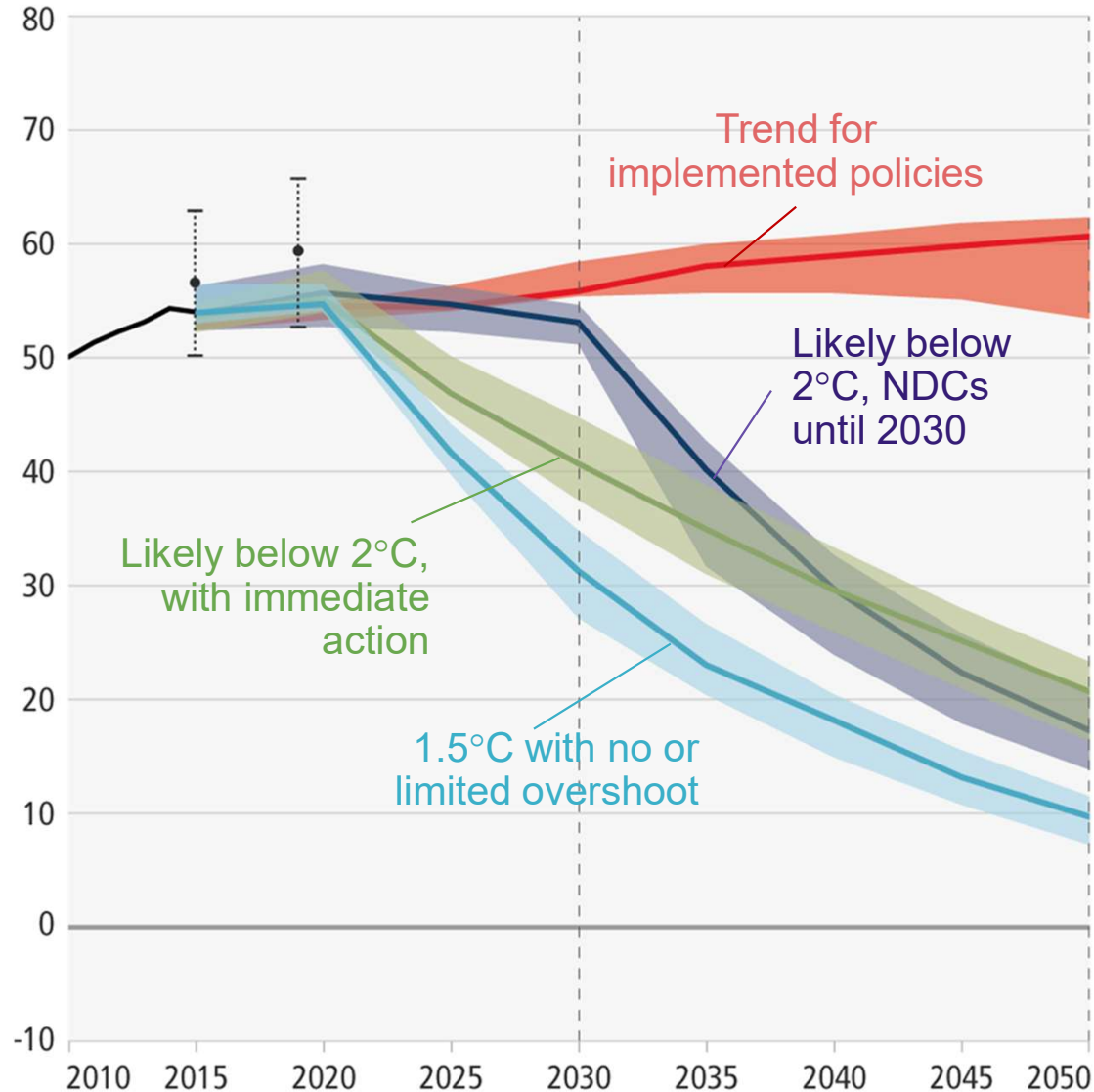
Illustrative Pathways (IPs)
(Fig. 3.5)



NDCs and long-term goals under Paris Agreement

GHG emissions
[GtCO₂eq/yr]

Fig. SPM.4



Note)

NDCs, announced prior to COP26 up to 11 October 2021. (The NDCs announced after this date are not included.)

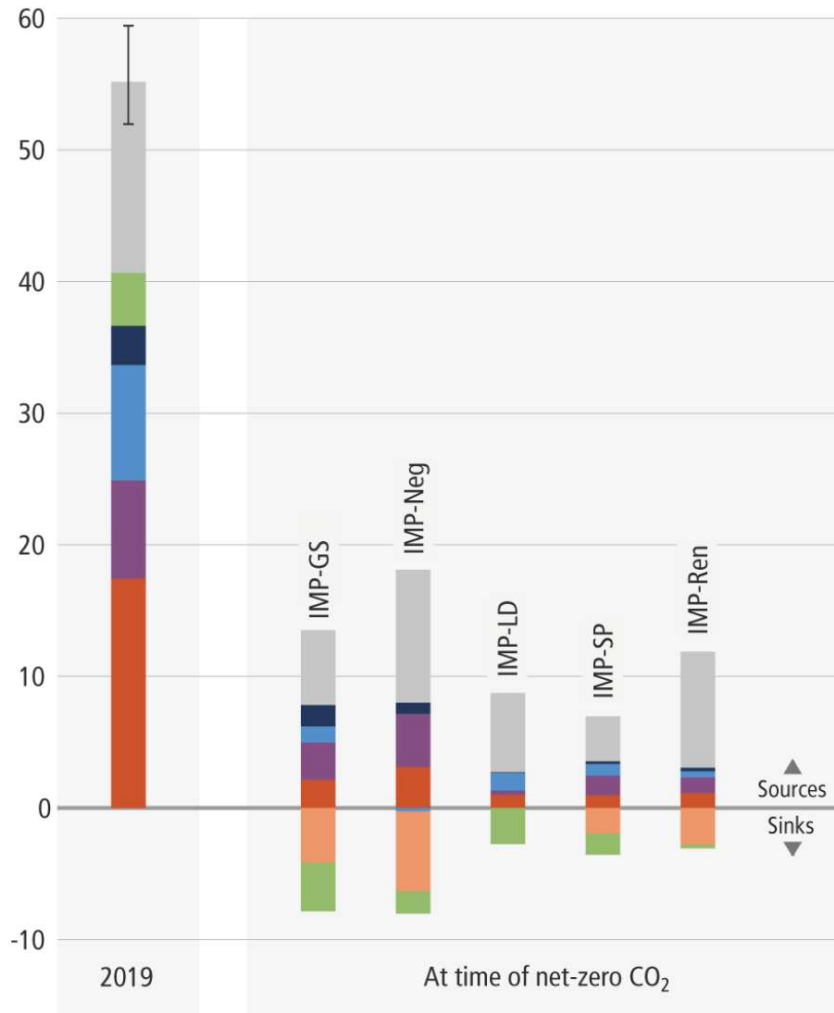
“Unconditional elements: 53 (50–57)

GtCO₂eq/yr, Including conditional elements: 50 (47–55) GtCO₂eq/yr” (SPM, Table SPM 1)

✓ **Sectoral scenarios are analyzed in accordance with three scenarios presented in IPCC Fig. SPM.4, consistent with meeting the long-term “well below 2°C” and 1.5°C goals of the Paris Agreement.**

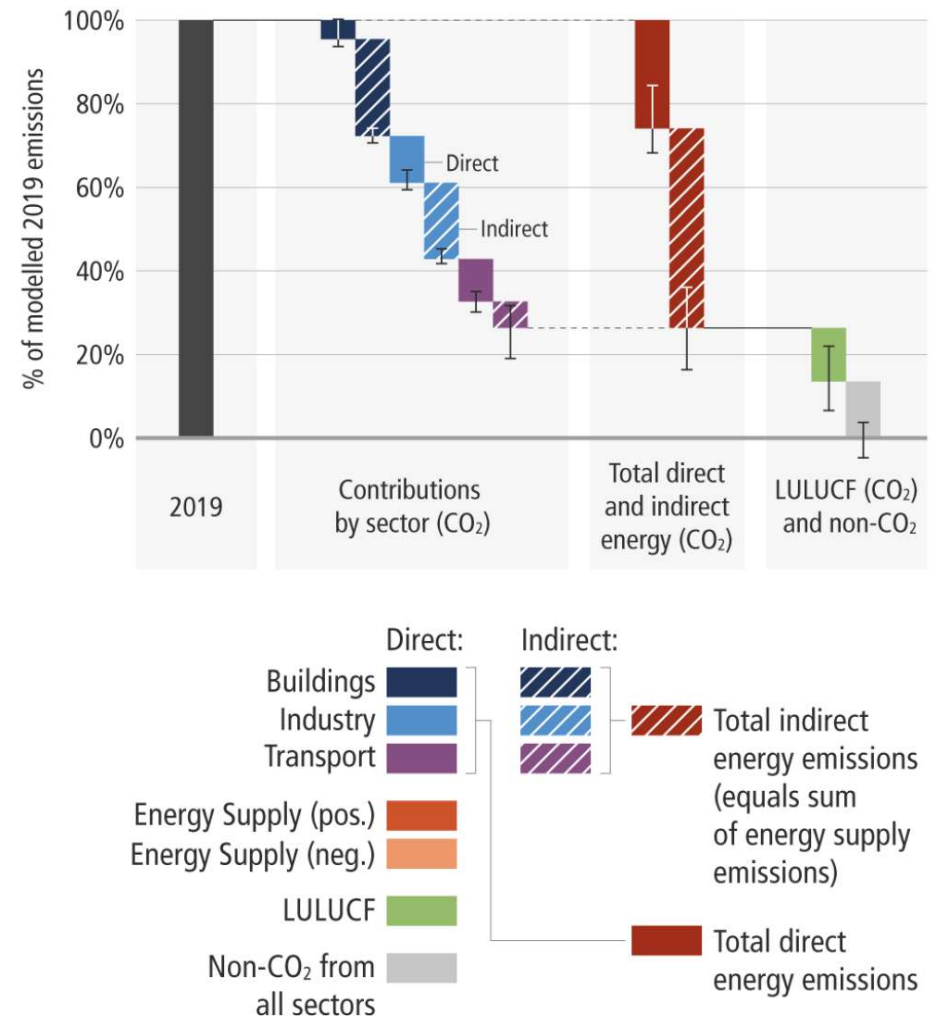
Several opportunities to achieve CN: IPCC AR6

e. Sectoral GHG emissions at the time of net-zero CO₂ emissions (compared to modelled 2019 emissions)



f. Contributions to reaching net zero GHG emissions (for all scenarios reaching net-zero GHGs)

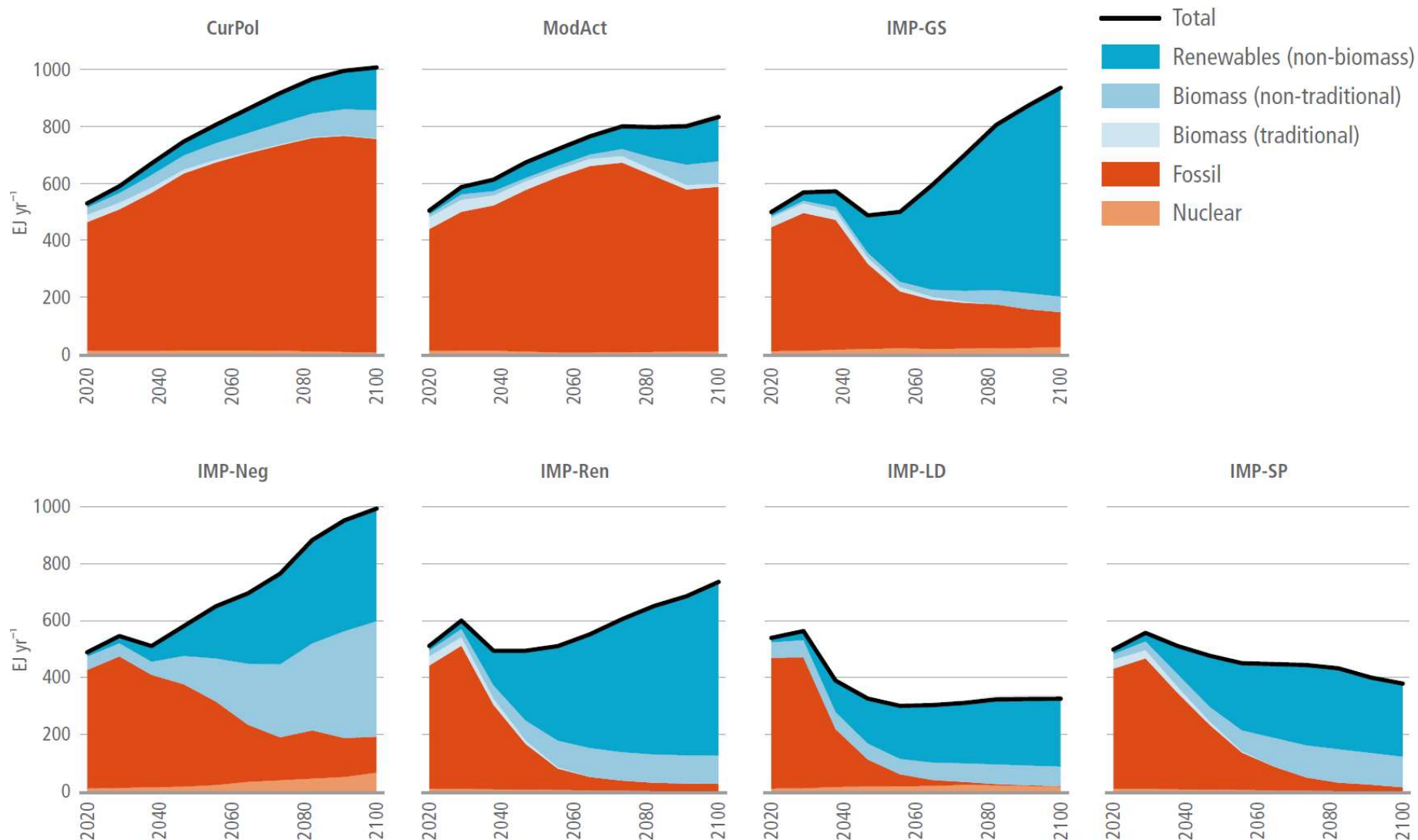
Fig. SPM.5



“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 scenario except Low Demand scenario, CDR options including large-scale afforestation are cost-effective to achieve net zero of CO₂. Furthermore, for net zero GHG emissions, CDR is indispensable.

Global primary energy supply in each of the Illustrative Pathways (IPs)

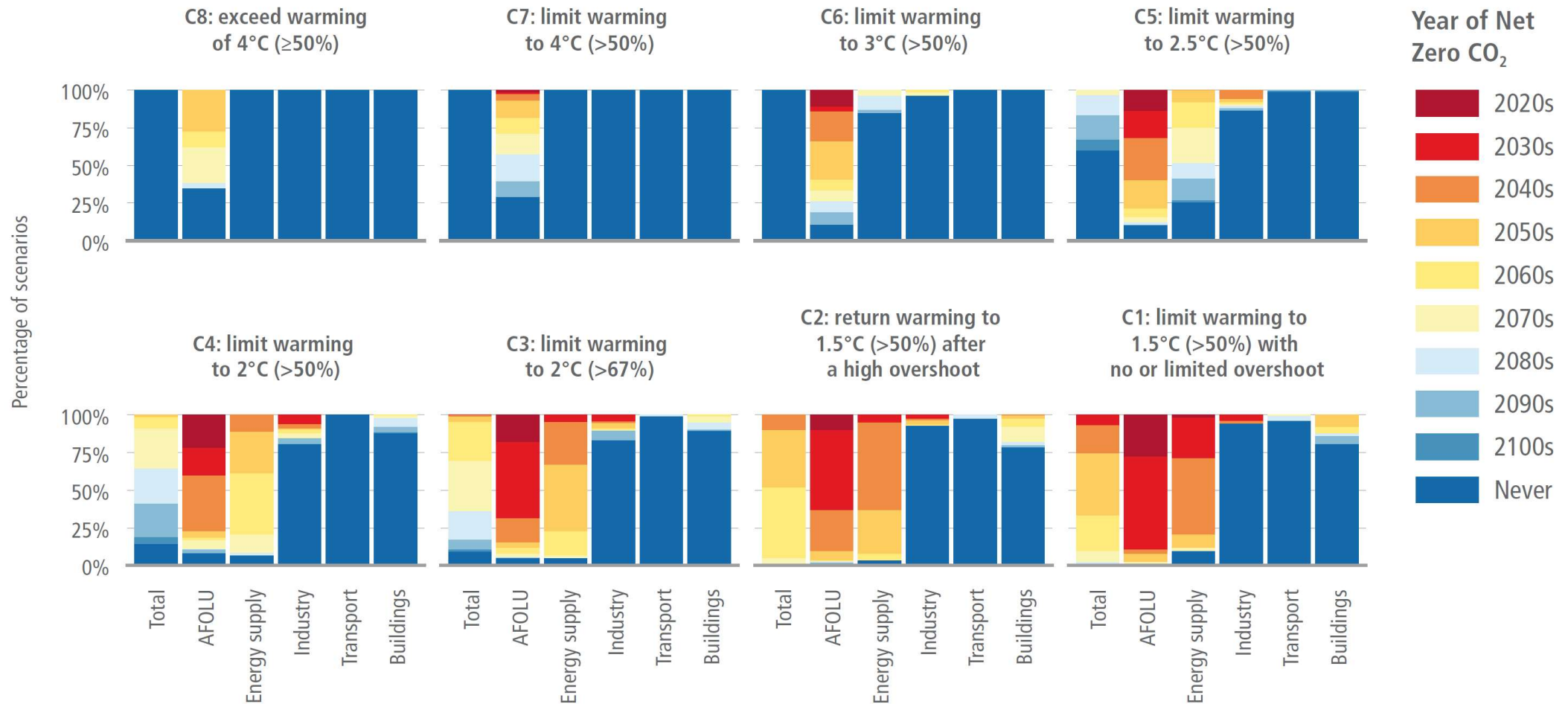


Electricity systems powered predominantly by renewables will be increasingly viable over the coming decades, but it will be challenging to supply the entire energy system with renewable energy. (Chapter 6 ES)

- ✓ Fossil fuels use is likely to increase continually up to 2050 in CurPol and ModAct scenarios.
- ✓ Fossil fuels use would be varied even in 2050 under 2°C, 1.5°C scenarios.

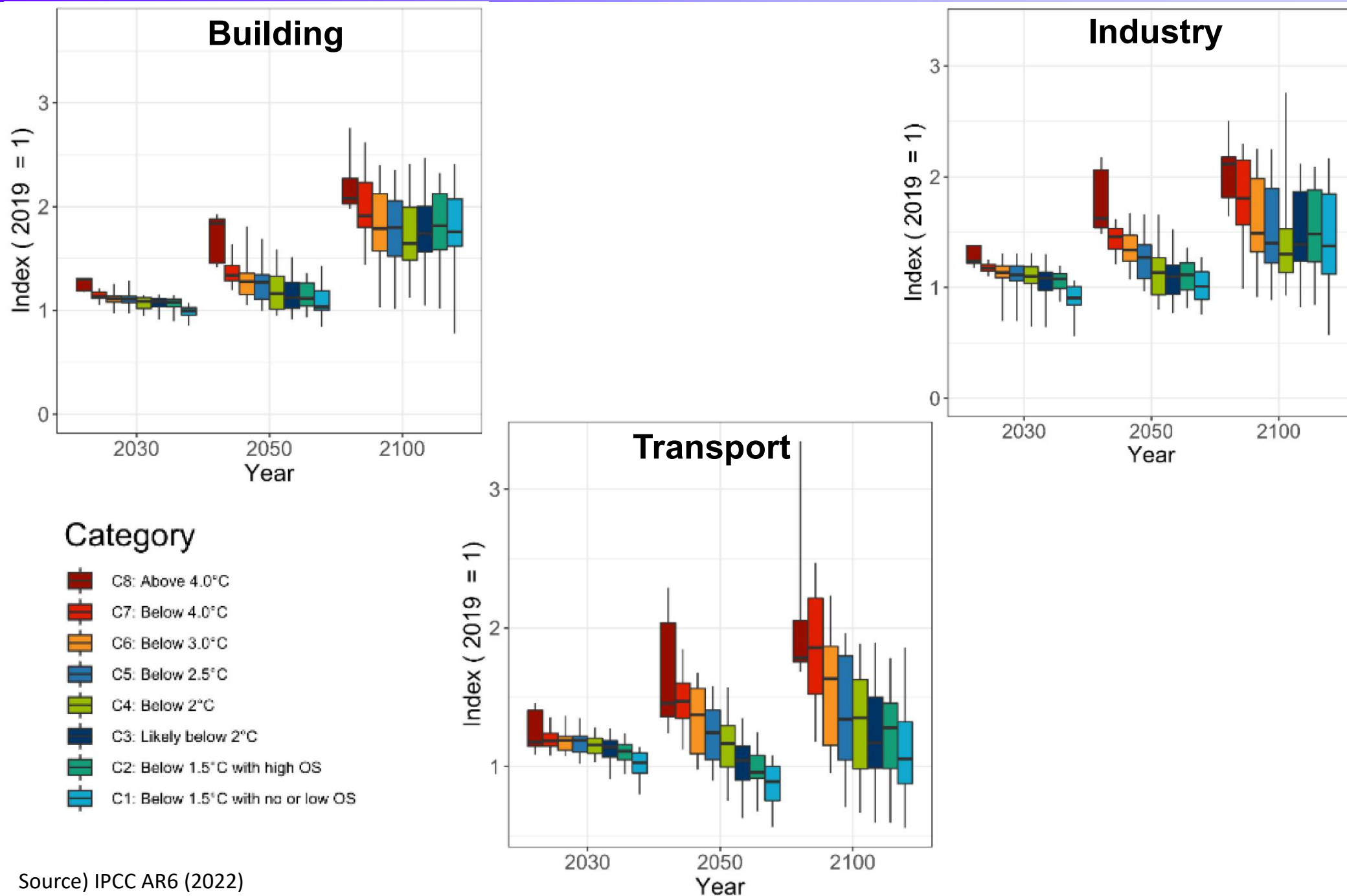
Actualizing CN: Decade in which sectoral CO₂ emissions first reach net negative values

Fig. 3.19

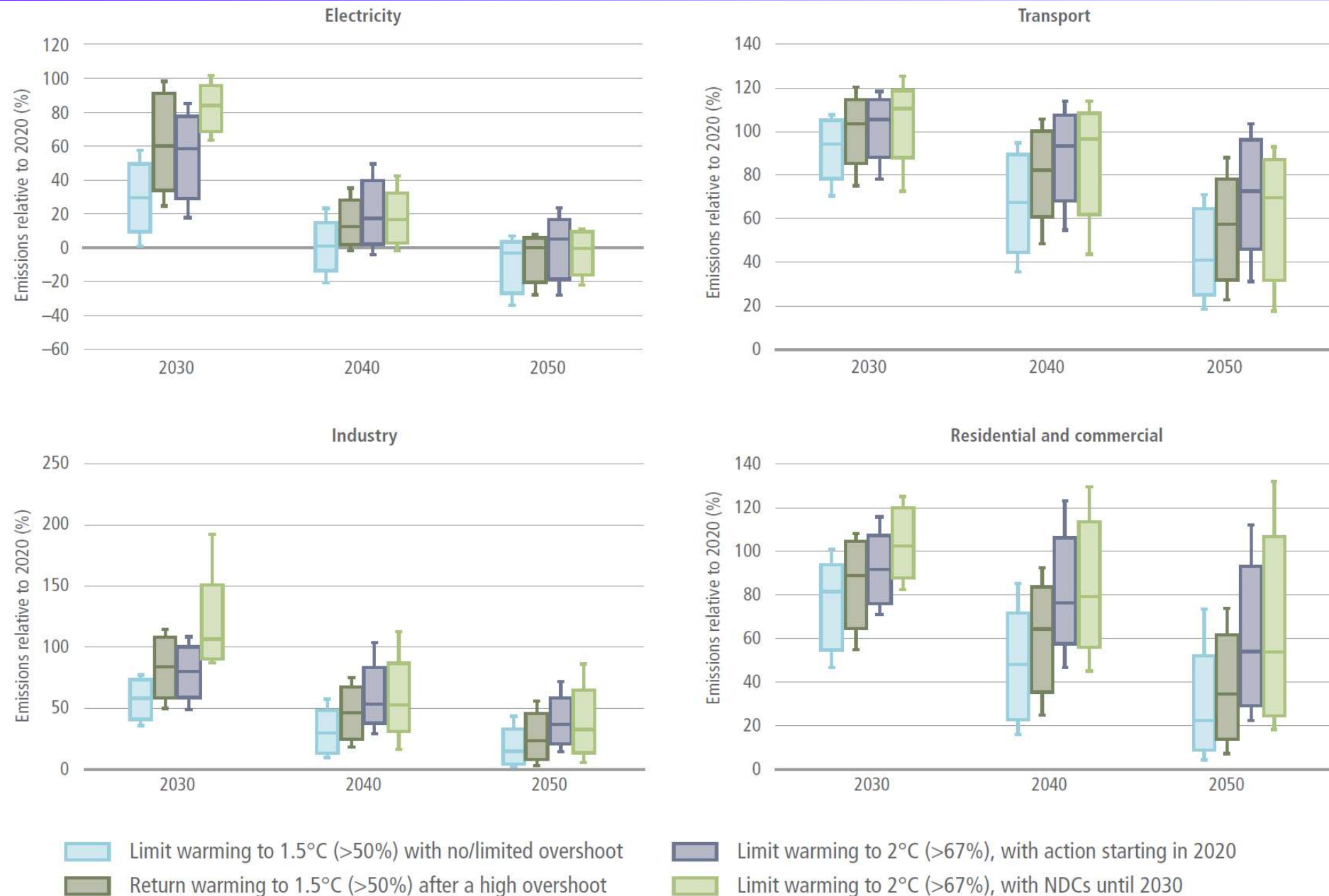


There are few assessments in IAM scenarios which indicate net zero emissions within this century in Industry, Transport, and Buildings sectors under any emission pathways including 1.5°C pathways. => Offsetting with CDR would be cost-effective.

Global final energy consumption by sector



Global CO₂ emissions by sector for the 2 °C and 1.5 °C scenarios (C1, C2, and C3 categories)



Source) IPCC AR6 (2022)

Note) Boxes indicate 25th and 75th percentiles, while whiskers indicate 5th and 95th percentiles.

NGFS Scenarios

Research institutions participating in NGFS scenarios and model overview

Comparison	Climate impacts	Transition pathways	Economic impacts
External research partners	Climate Analytics PIK	PIK UMD IIASA	NIESR
Models	Climate models participating in the ISIMIP project CLIMADA	REMIND-MAGPIE 3.0-4.4 GCAM 5.3+ MESSAGEix-GLOBIOM 1.1-M-R12	NiGEM v1.22 NGFS version IAMs (only GDP provided as an output in the database)
Inputs	Atmospheric concentrations of emissions and associated radiative forcing Economic exposure data for assessment of economic impacts	Constraints from an emissions budget and other climate policies at the global and regional level	Carbon tax prices and revenues, energy consumption, "useful energy", physical risk damage functions
Key assumptions and uncertainties	Physical relationships between various aspects of the climate system Changes in climate at the local scale	Technology costs. Inter-temporal optimisation (for REMIND-MAGPIE and MESSAGEix-GLOBIOM); dynamic recursive (for GCAM). Optimal government policy design and capital reallocation	Econometric relationships between variables hold. Rational expectations and perfect foresight
Outputs	Climate indicators (e.g. temperature, precipitation, river flow, agricultural yields, soil moisture) Economic indicators (e.g. direct losses from flooding and cyclones, area and population exposed to extreme weather)	Energy demand, energy capacity, investment in energy, energy prices, carbon prices, emissions trajectories, temperature trajectories, agricultural variables, water variables, GDP	GDP (and components), unemployment, inflation, productivity, personal disposable income, house prices, interest rates, exchange rates, equity prices, etc.
Time horizon	Time steps of 5 years, up to 2100 in Explorer Up to daily time steps for underlying ISIMIP data	Time steps of 5 years up to 2100 (10 years from 2060 onwards for REMIND-MAGPIE & MESSAGEix-GLOBOM)	Annual steps, up to 2050 (NiGEM)

(Source) NGFS (2022)

RITE's analysis corresponds to this

■ A database of climate scenarios with technical reports is available on the NGFS portal.

<https://www.ngfs.net/ngfs-scenarios-portal/>

Note: In the 5th edition of NGFS, the research paper on which the evaluation of Climate impacts was based received academic criticism and was retracted in December 2025. Therefore, NGFS also advises caution when using Climate impacts.

Overview of the three models employed for the NGFS transition scenarios

Integrated Assessment Model	GCAM 5.3+	MESSAGEix_GLOBIOM 1.1	REMIND-MAgPIE 3.0-4.4
Short name	GCAM	MESSAGEix-GLOBIOM	REMIND-MAgPIE
Solution concept	Partial Equilibrium (price elastic demand)	General Equilibrium (this version has fixed demands for materials)	REMIND: General Equilibrium MAgPIE: Partial Equilibrium model of the agriculture sector
Anticipation	Recursive dynamic (myopic)	Intertemporal (perfect foresight)	REMIND: Intertemporal (perfect foresight) MAgPIE: Recursive dynamic (myopic)
Solution method	Cost minimisation	Welfare maximisation	REMIND: Welfare maximisation MAgPIE: Cost minimisation
Temporal dimension	Base year: 2015 Time steps: 5 years Horizon: 2100	Base year: 1990 Time steps: 5 (2005-2060) and 10 years (2060-2100) Horizon: 2100	Base year: 2005 Time steps: 5 (2005-2060) and 10 years (2060-2100) Horizon: 2100
Spatial dimension	32 world regions	12 world regions	12 world regions
Technological change	Exogenous	Exogenous	Endogenous for Solar, Wind and Batteries
Technology dimension	58 conversion technologies	64 conversion technologies	50 conversion technologies
Demand sectors and subsector detail	Buildings (residential and commercial buildings with heating, cooling, and other services), Industry (Cement, Chemicals,	Buildings, Industry (Cement, Chemicals, Steel, Non-ferrous metals, Other), Transport	Buildings, Industry (Cement, Chemicals, Steel, Other), Transport (various modes and technologies)

NGFS scenarios (Phase V)

Quadrant	Scenario	Physical risk	Transition risk			
		End of century (peak) warming (model averages)	Policy reaction	Technology change	Carbon dioxide removal -	Regional policy variation +
Orderly	Low Demand	1.1 °C (1.6 °C)	Immediate	Fast change	Medium use	Medium variation
	Net Zero 2050	1.4 °C (1.7 °C)	Immediate	Fast change	Medium-high use	Medium variation
	Below 2 °C	1.8 °C (1.8 °C)	Immediate and smooth	Moderate change	Medium use	Low variation
Disorderly	Delayed Transition	1.7 °C (1.8 °C)	Delayed	Slow/Fast change	Medium use	High variation
Hot house world	Nationally Determined Contributions (NDCs)	2.3 °C (2.3 °C)	NDCs	Slow change	Low use	Medium variation
	Current Policies	3.0 °C (3.0 °C)	None – current policies	Slow change	Low use	Low variation
Too-little-too-late	Fragmented World	2.4 °C (2.4 °C)	Delayed and Fragmented	Slow/Fragmented change	Low-medium use	High variation

Colour coding indicates whether the characteristic makes the scenario more or less severe from a macro-financial risk perspective ^

■ Lower risk
■ Moderate risk
■ Higher risk

(Source) NGFS (2024)

Orderly

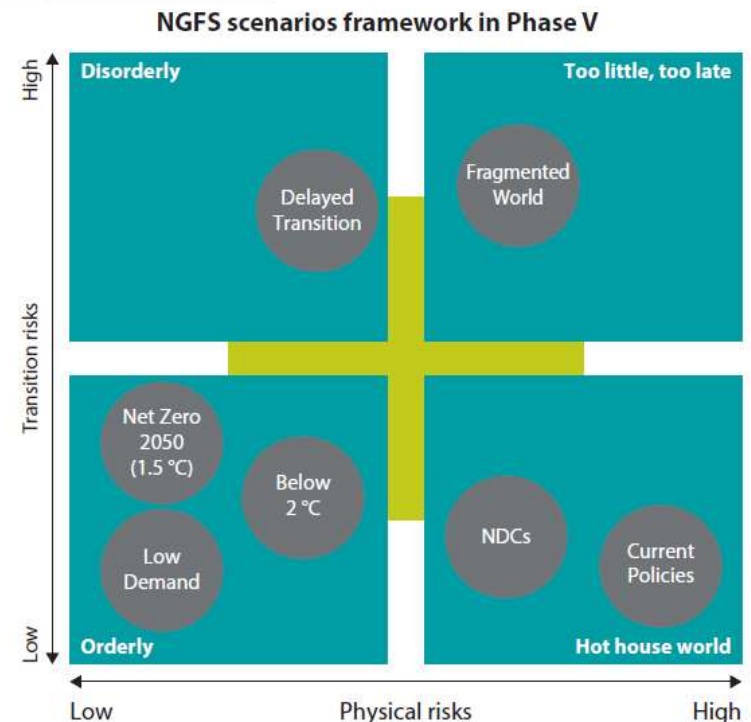
Low Demand: Significant behavioral changes are being triggered globally, while achieving emissions reductions consistent 1.5°C target.

Net Zero 2050: Limiting global temperature rise to 1.5°C and achieving net-zero global CO₂ emissions around 2050, through ambitious climate change policies and innovation

Below 2°C: Increasing the stringency of climate change policies in stages, with a 67% probability of limiting global temperature increase to less than 2°C

Disorderly

Delayed transition: Annual emissions will not decrease until 2030, and stringent policies are needed to keep emissions below 2°C. In addition, there are constraints on the removal of CO₂.

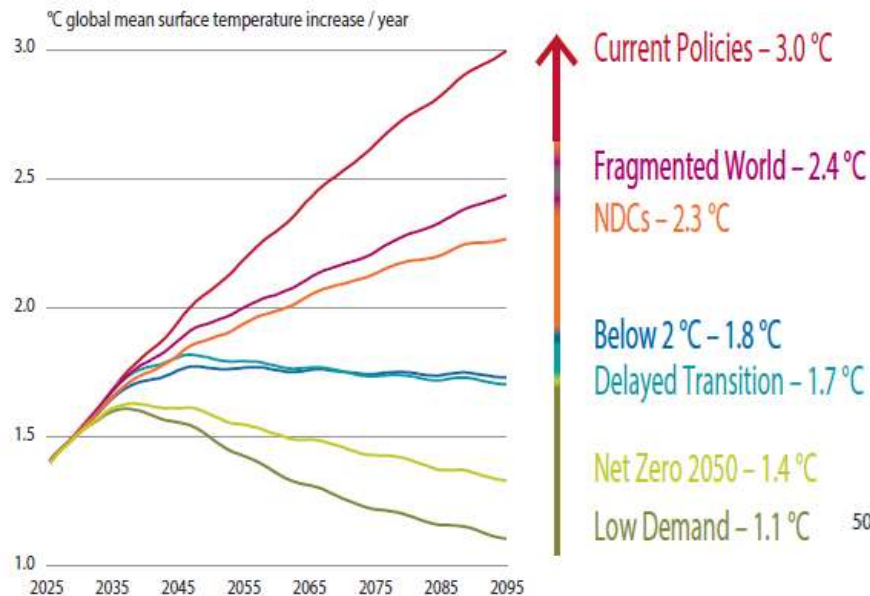


NGFS scenarios' assumptions (Phase V)

Category	Scenario	End of century (peak) warming	Policy reaction	Technology change	Carbon dioxide removal -	Regional policy variation +
Orderly	Low Demand	1.1°C (1.6°C)	Immediate and smooth	Fast change	Medium use	Medium Variation
	Net Zero 2050	1.4°C (1.7°C)	Immediate and smooth	Fast change	Medium-high use	Medium Variation
	Below 2°C	1.8°C (1.8°C)	Immediate and smooth	Moderate change	Medium use	Low variation
Disorderly	Delayed Transition	1.7°C (1.8°C)	Delayed	Slow/ Fast change	Low-medium use	High variation
Hot house world	Nationally Determined Contributions (NDCs)	2.3°C (2.3°C)	NDCs	Slow change	Low-medium use	Medium variation
	Current Policies	3.0°C (3.0°C)	None - current policies	Slow change	Low use	Low variation
Too-little-too-late	Fragmented World	2.4°C (2.4°C)	Delayed and Fragmented	Slow/ Fragmented change	Low-medium use	High variation

(Source) NGFS (2024)

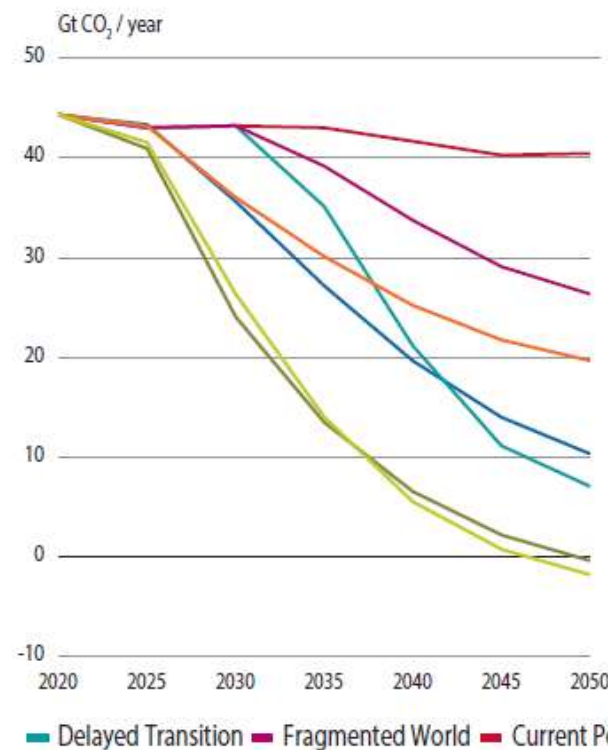
CO2 emissions and carbon prices for each NGFS scenario



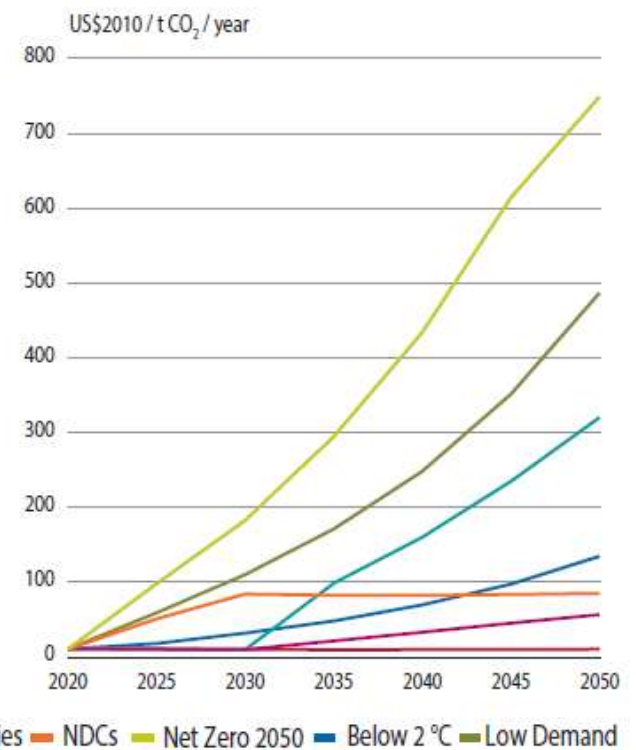
Global temperature increase

Estimates by REMIND model
(Source) NGFS (2024)

CO2 emissions by scenario

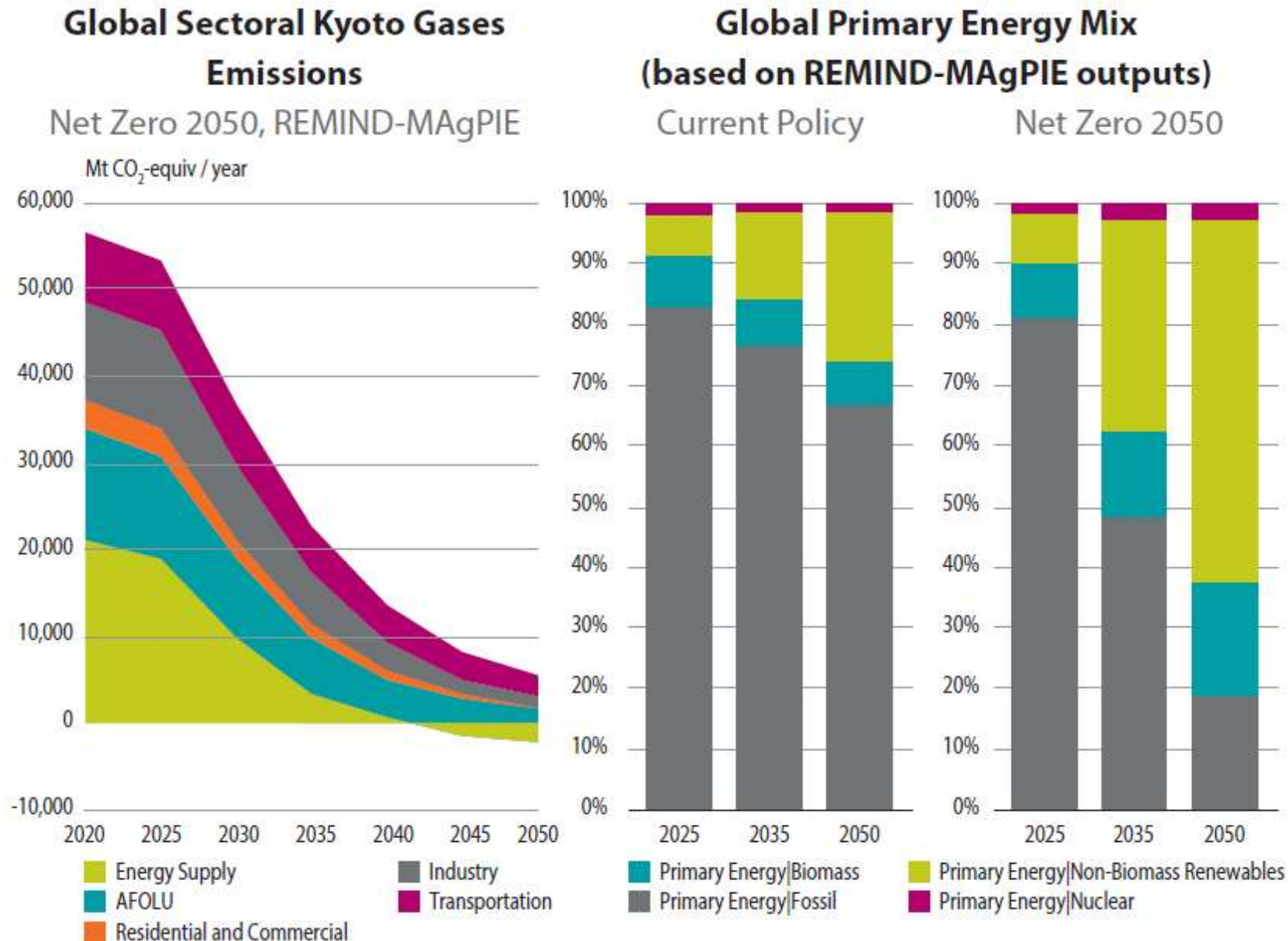


Carbon price development



- The NGFS scenarios are also very similar to IPCC Fig. SPM.4 for the 2°C and 1.5°C equivalent scenarios.

Emissions by sector and primary energy mix in the NGFS Net Zero 2050 scenario



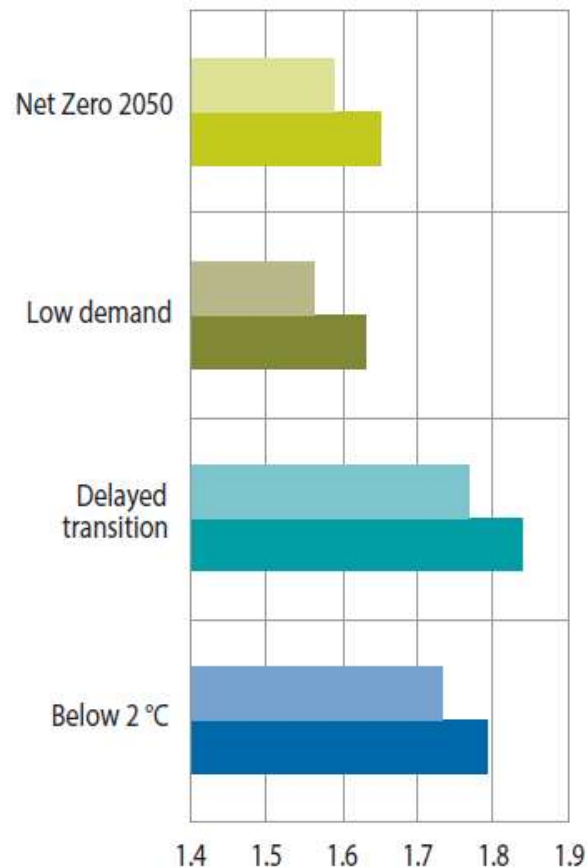
(Source) NGFS (2024)

Comparison of NGFS Scenario Phase IV and Phase V

Peak temperature

REMIND-MAGPIE, World
Phase IV in transparent

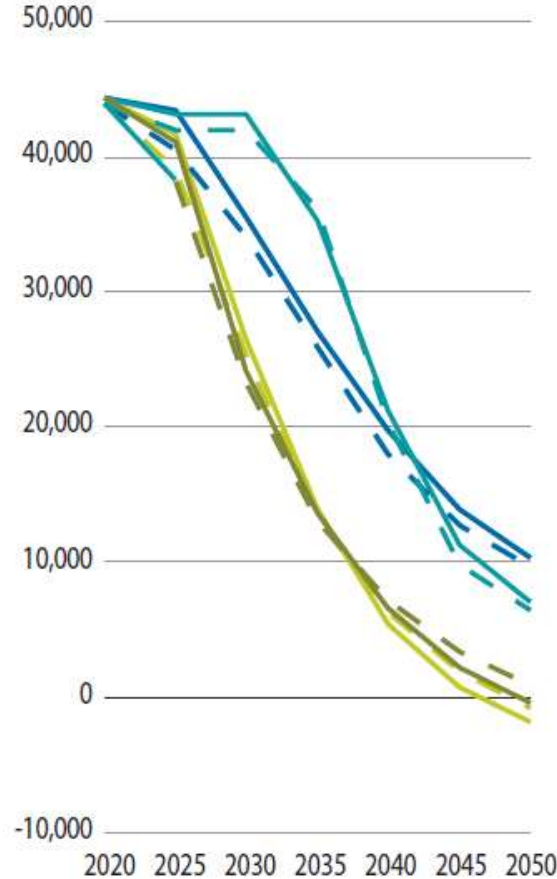
°C



CO₂ Emissions

REMIND-MAGPIE, World
Phase IV in dotted

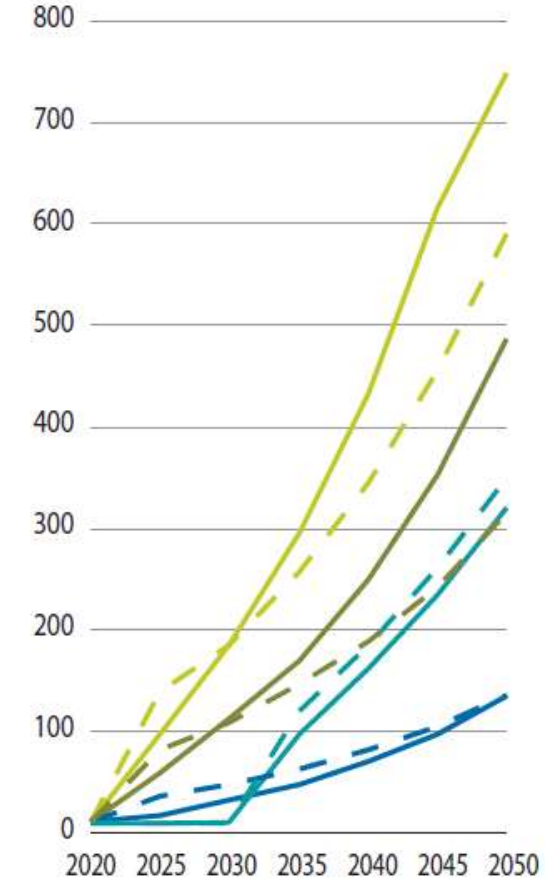
Gt CO₂/year



(Shadow) Carbon Price

REMIND-MAGPIE, World
Phase IV in dotted

US\$2010 / t CO₂eq



(Source) NGFS (2024)

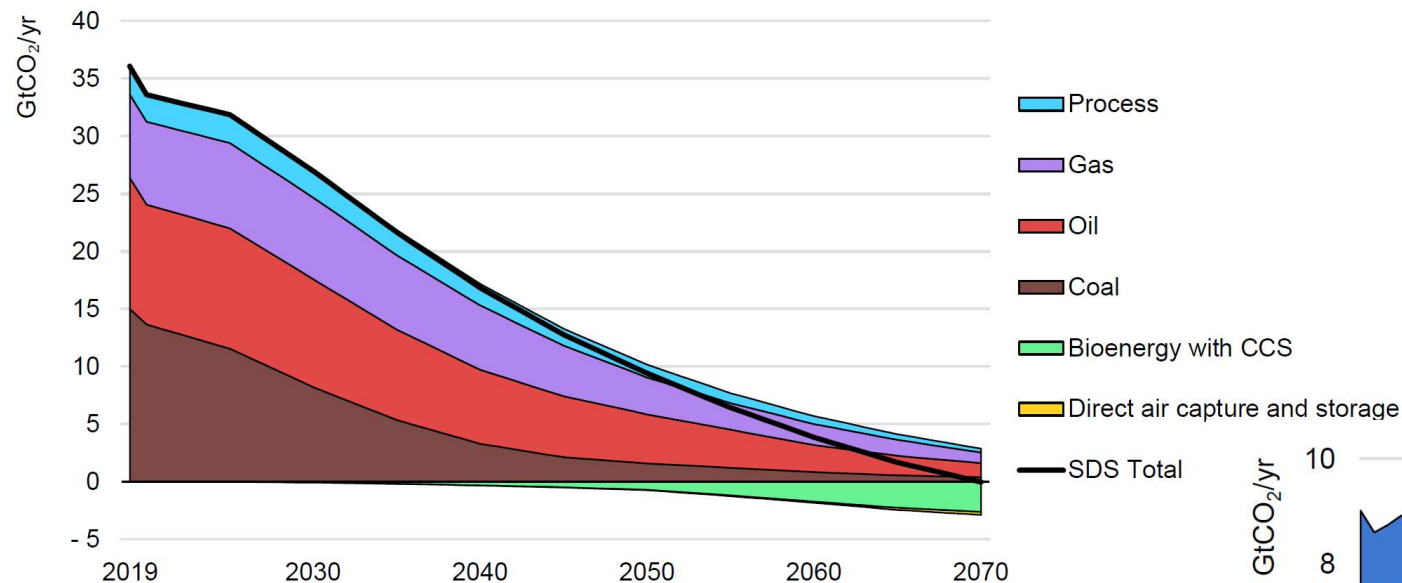
- ✓ In the NGFS Phase V, the IPCC's scenario of no temperature overshoot (<0.1°C) has been eliminated. Based on current emission trends, an overshoot is considered inevitable.

IEA Scenarios

Emissions reduction scenario in SDS in ETP2020

Energy Technology Perspectives (ETP), recently published biannually, is based on analyses using the optimization-type technology assessment model. This document draws figures in the 2020 edition in which technology scenarios are clearly presented.

Figure 2.1 Global energy sector CO₂ emissions by fuel and technology in the Sustainable Development Scenario, 2019-70

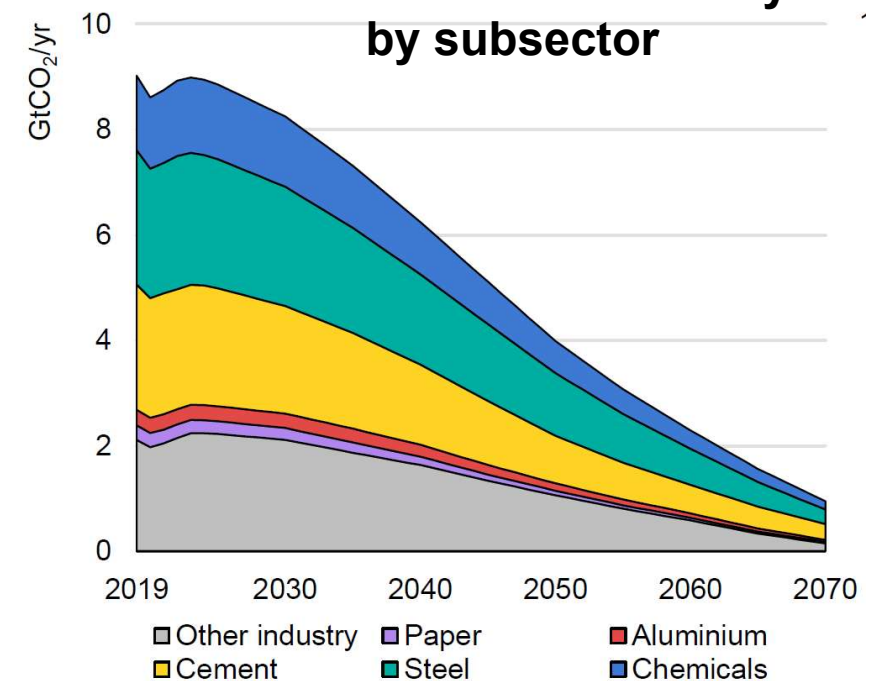


IEA 2020. AI

Notes: CCS = carbon capture and storage. SDS= Sustainable Development Scenario.

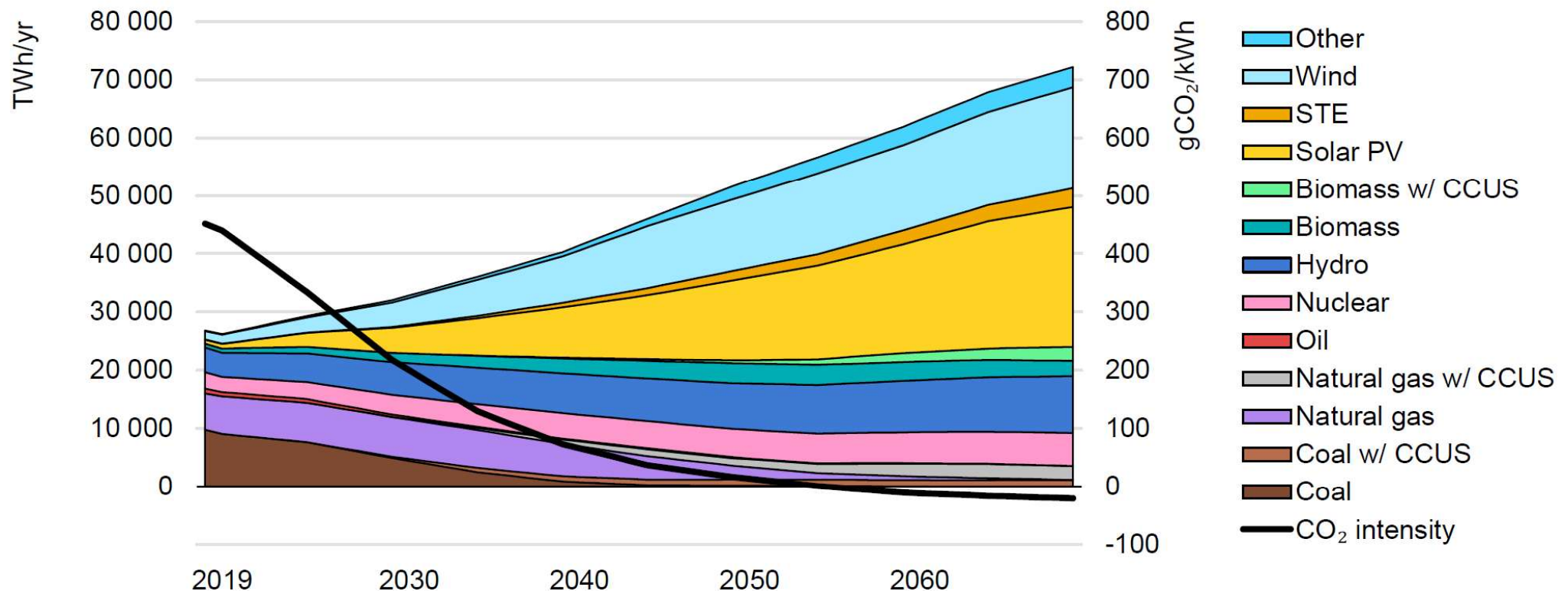
SDS: Sustainable Development Scenario
A scenario with less than 1.8 °C, equivalent to
“well below 2 °C” target under the Paris
agreement

Emissions from Industry by subsector



Electricity generation scenario in SDS in ETP2020

Figure 3.2 Global power generation by fuel/technology in the Sustainable Development Scenario, 2019-70

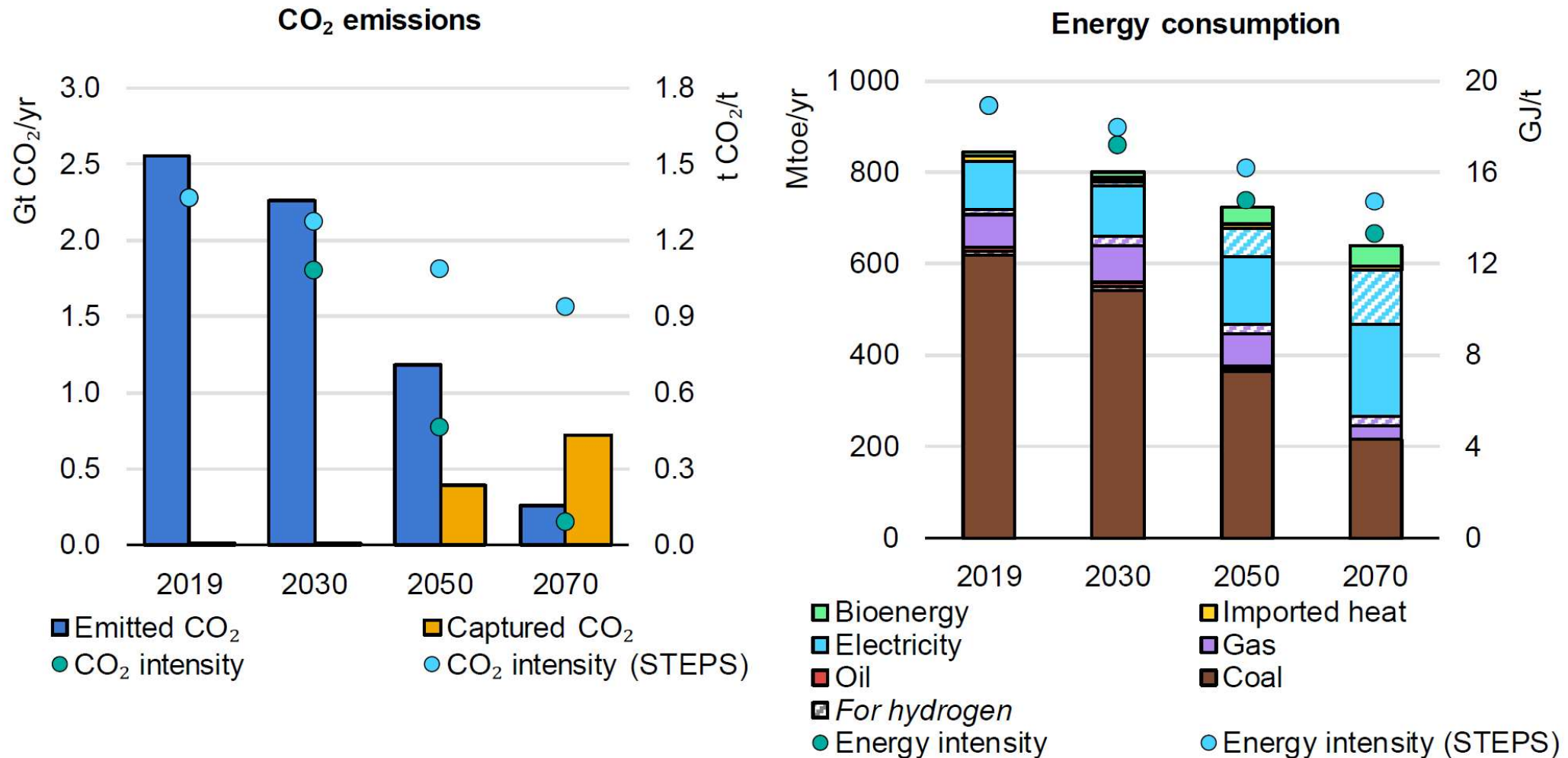


IEA 2020. All rights reserved.

Notes: TWh = terawatt-hours; gCO₂/kWh = grammes of CO₂ per kilowatt-hour; STE = solar thermal electricity; PV = photovoltaic; CCUS = carbon capture, utilisation storage. Other includes geothermal power, ocean energy and hydrogen.

Iron and steel sector emissions and energy consumption in SDS in ETP2020

Figure 4.10 Global iron and steel sector direct CO₂ emissions and energy consumption in the Sustainable Development Scenario, 2019-70

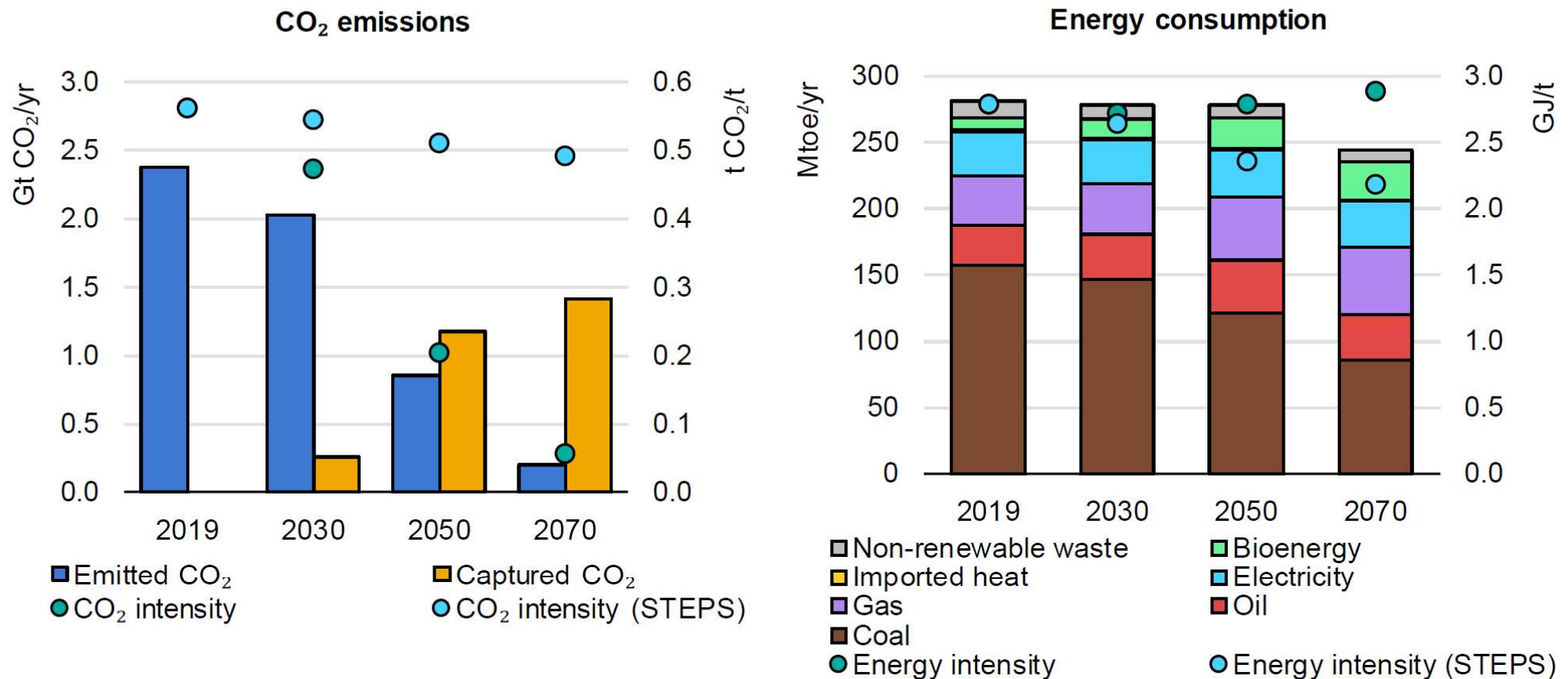


IEA 2020. All rights reserved.

Note: STEPS = Stated Policies Scenario.

Cement sector emissions and energy consumption in SDS in ETP2020

Figure 4.16 Global cement sector direct CO₂ emissions and energy consumption in the Sustainable Development Scenario, 2019-70

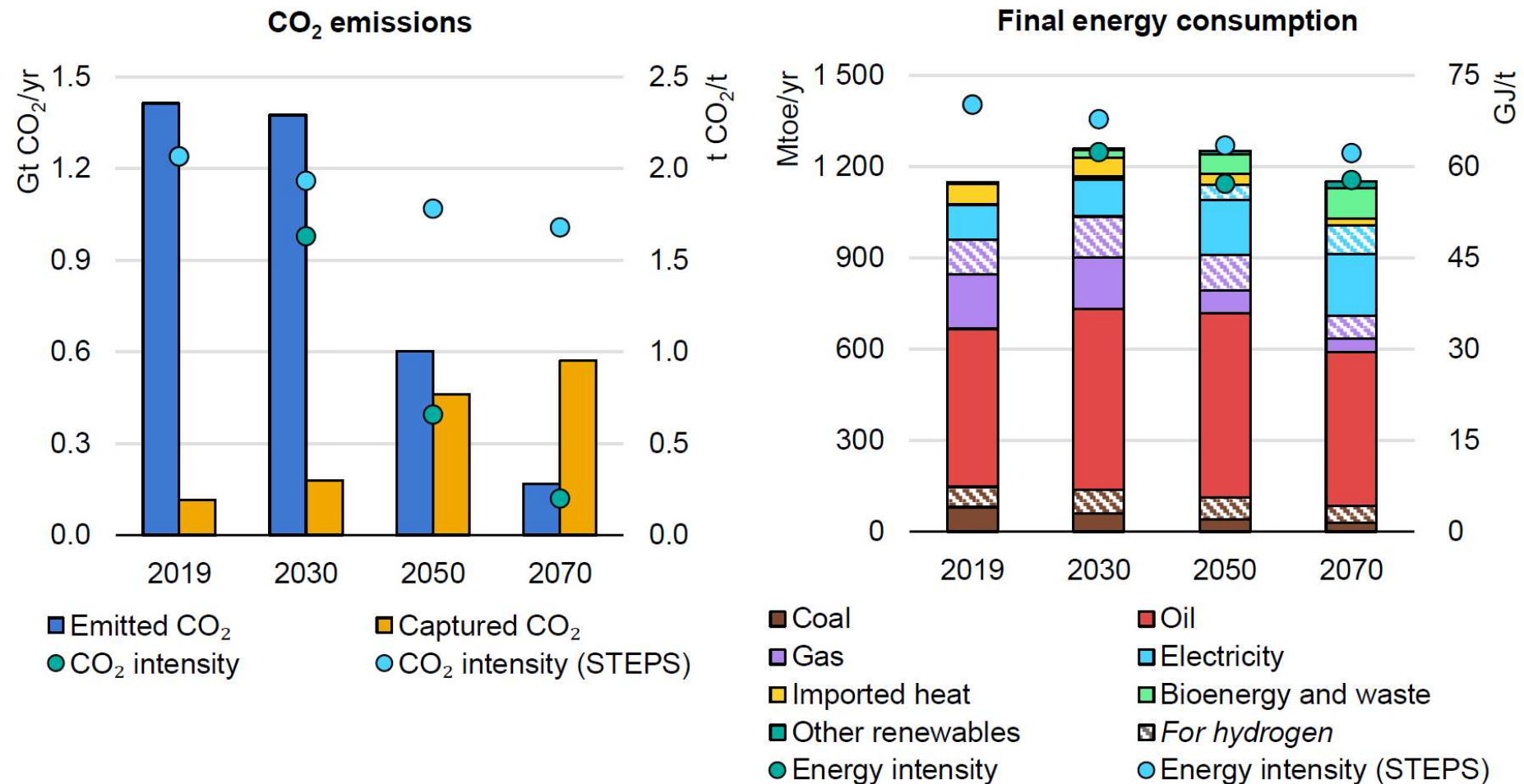


IEA 2020. All rights reserved.

Notes: STEPS = Stated Policies Scenario. Energy intensity here includes all energy used per tonne of cement, including additional energy needs for some strategies deployed in the Sustainable Development Scenario – chemical absorption carbon capture and storage, calcined clay use and alternative fuel use. This explains the increasing overall energy intensity by 2070.

Chemical sector emissions and energy consumption in SDS in ETP2020

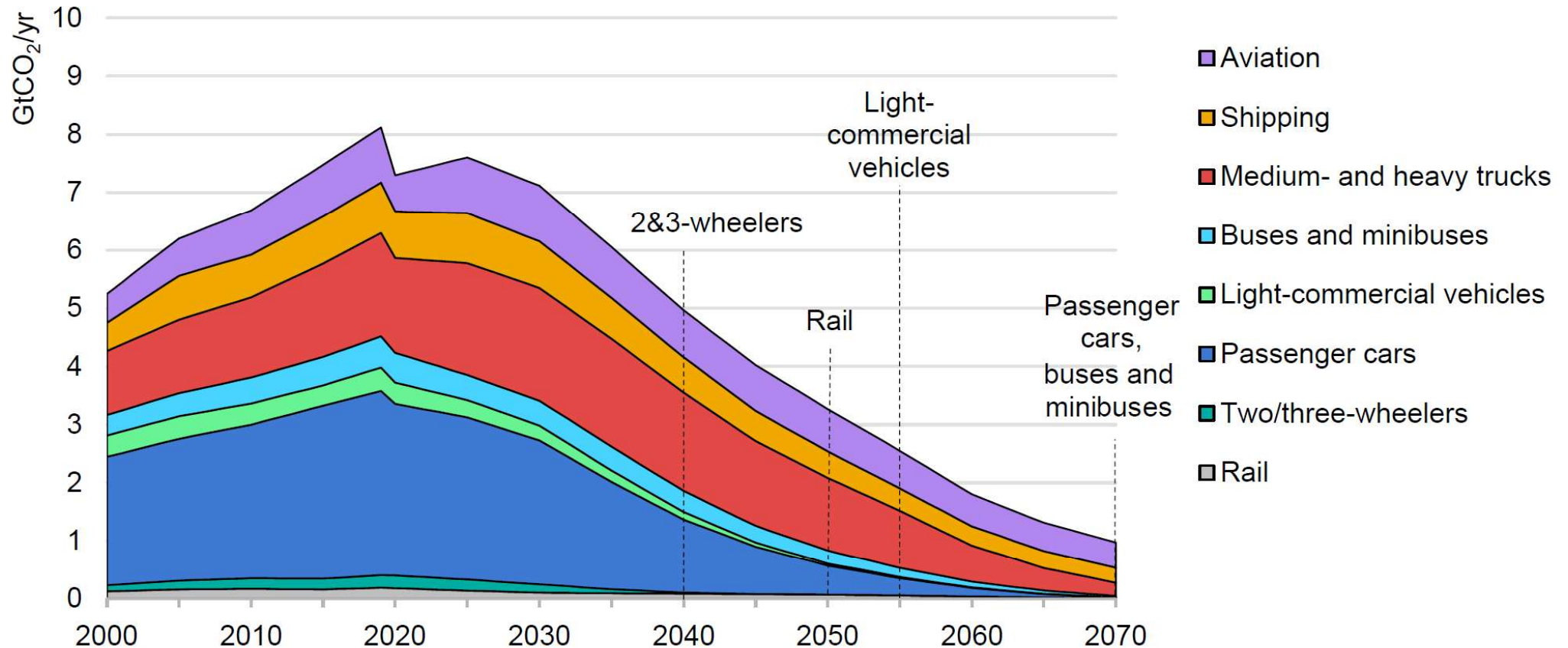
Figure 4.5 Global chemical sector direct CO₂ emissions and energy consumption in the Sustainable Development Scenario, 2019-70



IEA 2020. All rights reserved.

Notes: STEPS = Stated Policies Scenario. Captured CO₂ includes that which is captured then used as feedstock for urea production, as well as that which is captured and stored. Energy consumption includes that used as feedstock. Sectoral energy and CO₂ intensities are calculated based on total primary chemical production and total chemical sector energy consumption.

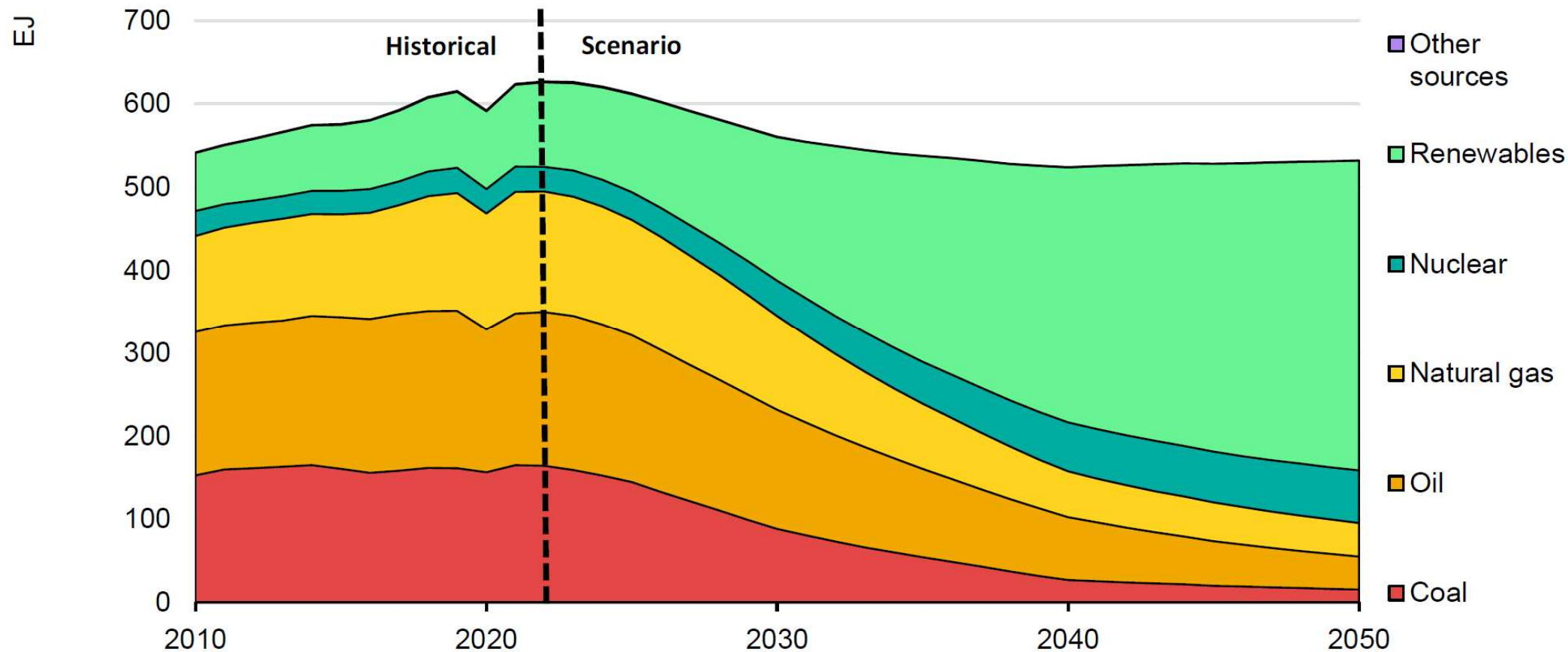
Figure 3.16 Global CO₂ emissions in transport by mode in the Sustainable Development Scenario, 2000-70



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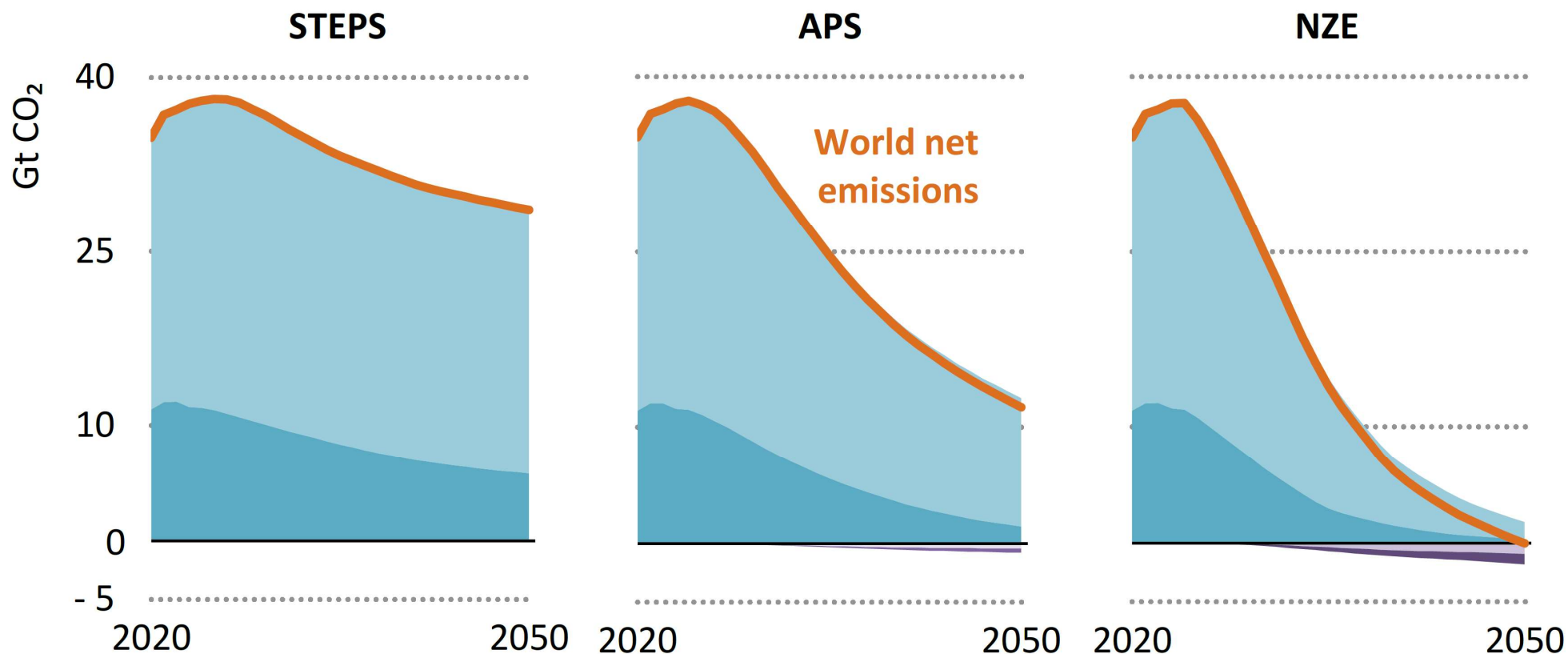
Notes: Dotted lines indicate the year in which various transport modes have largely stopped consuming fossil fuels and hence no longer contribute to direct emissions of CO₂ from fossil fuel combustion. Residual emissions in transport are compensated by negative emissions technologies, such as BECCS and DAC, in the power and other energy transformation sectors.

Global primary energy supply in the NZE scenario in ETP2023



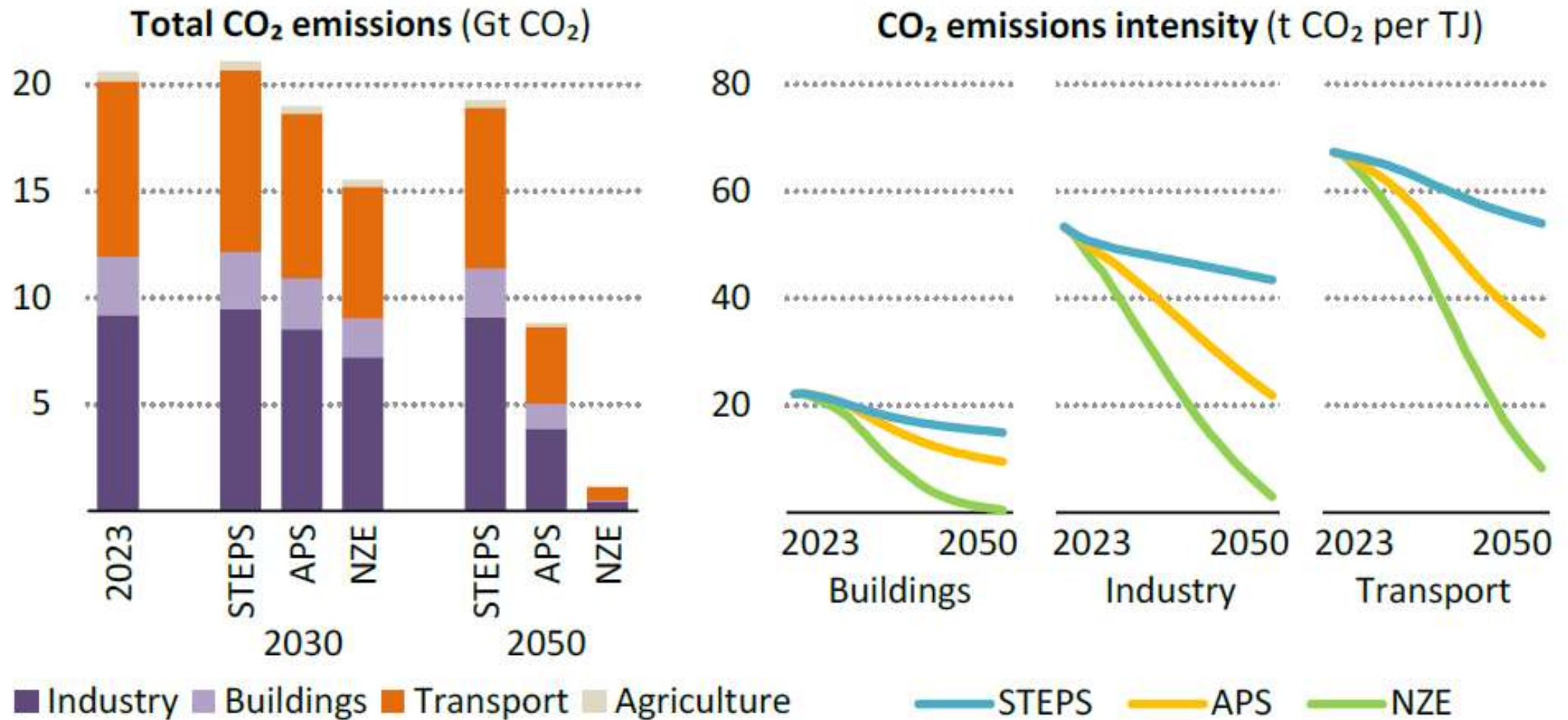
- World Energy Outlook (WEO), a flagship report of IEA published annually, is based on scenario analyses using an econometric model.
- The report depicts future energy landscapes while taking the impacts of various policies, investment trends and technology dynamics into consideration. Regarding the scenarios, **STEPS**, **APS**, and **NZE** are analyzed from the 2022 to 2024 editions; In the 2025 edition, the formerly adopted scenario **CPS** has been brought back, and APS has been eliminated instead.
 - ✓ **CPS (Current Policies Scenario)**: considers energy and climate policies that are already in place
 - ✓ **STEPS (Stated Policies Scenario)**: considers the application of broader range of policies, e.g. those formally stated but not yet adopted, official strategy documents indicating the direction
 - ✓ **APS (Announced Pledges Scenario)**: outlines a trajectory for the energy sector if all national energy and climate pledges(e.g. net-zero, energy access) are met on time and in full, leading to the well below 2°C
 - ✓ **NZE (Net Zero Emissions by 2050) Scenario**: a normative scenario for the energy sector to achieve 1.5°C and major energy-related SDGs

CO₂ emissions in WEO2024

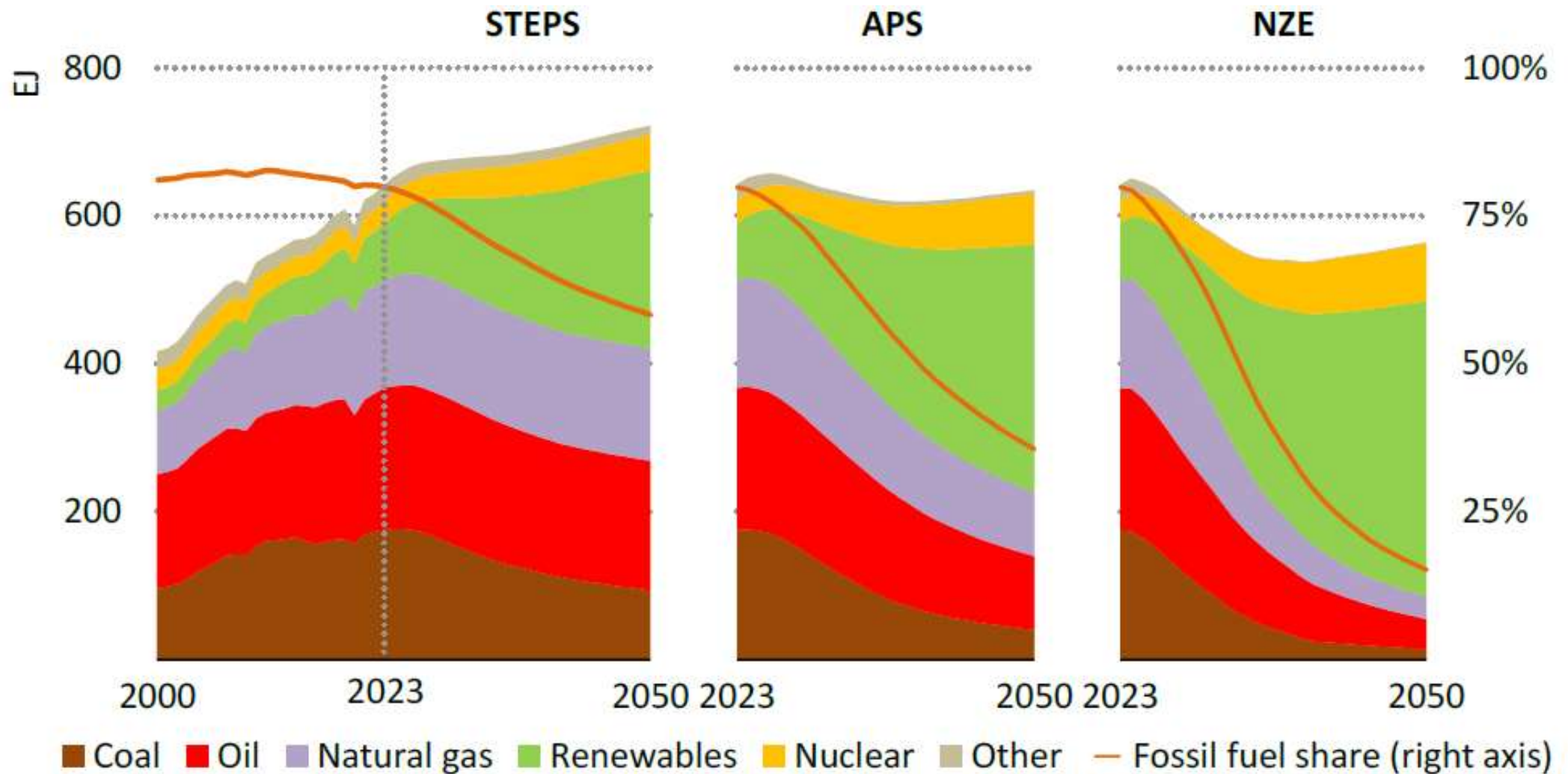


Gross emissions: ■ Advanced economies ■ Emerging market and developing economies
Gross removals: ■ Advanced economies ■ Emerging market and developing economies

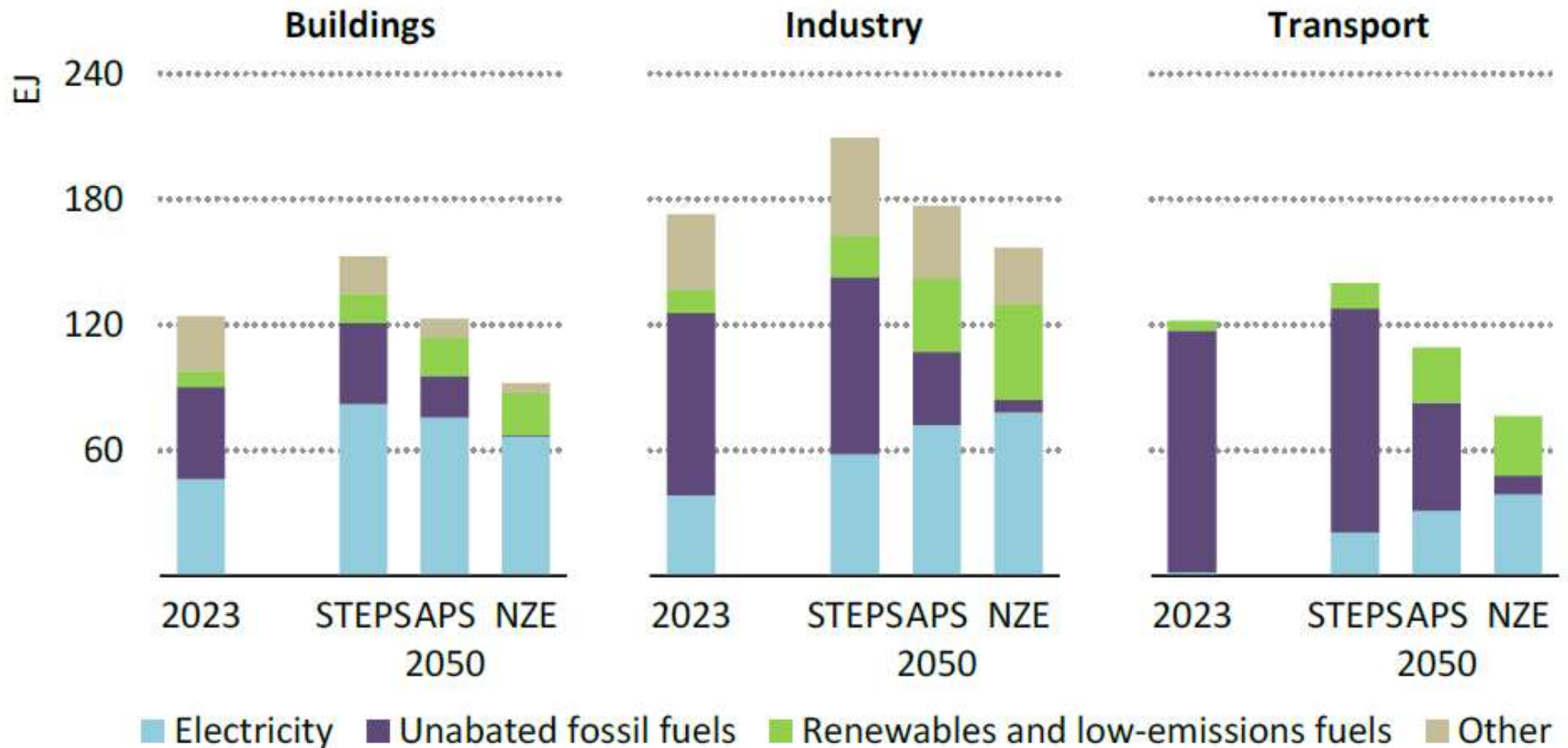
CO₂ emissions and emissions intensity by end-use sector in WEO2024



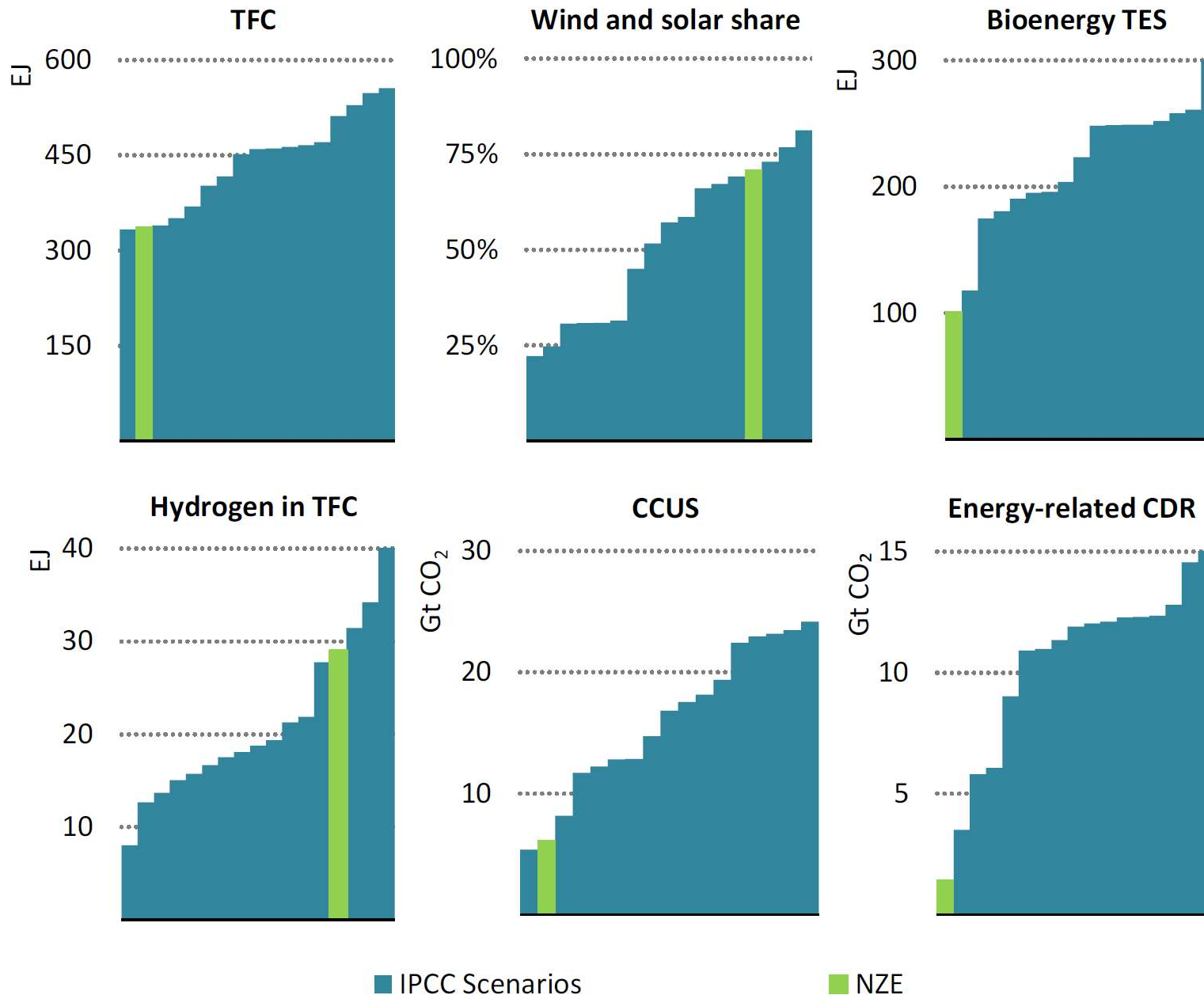
Total energy supply in NZE and other scenarios in WEO2024



Total final consumption in NZE and other scenarios in WEO2024



Features of the NZE scenario and its comparison with IPCC scenarios



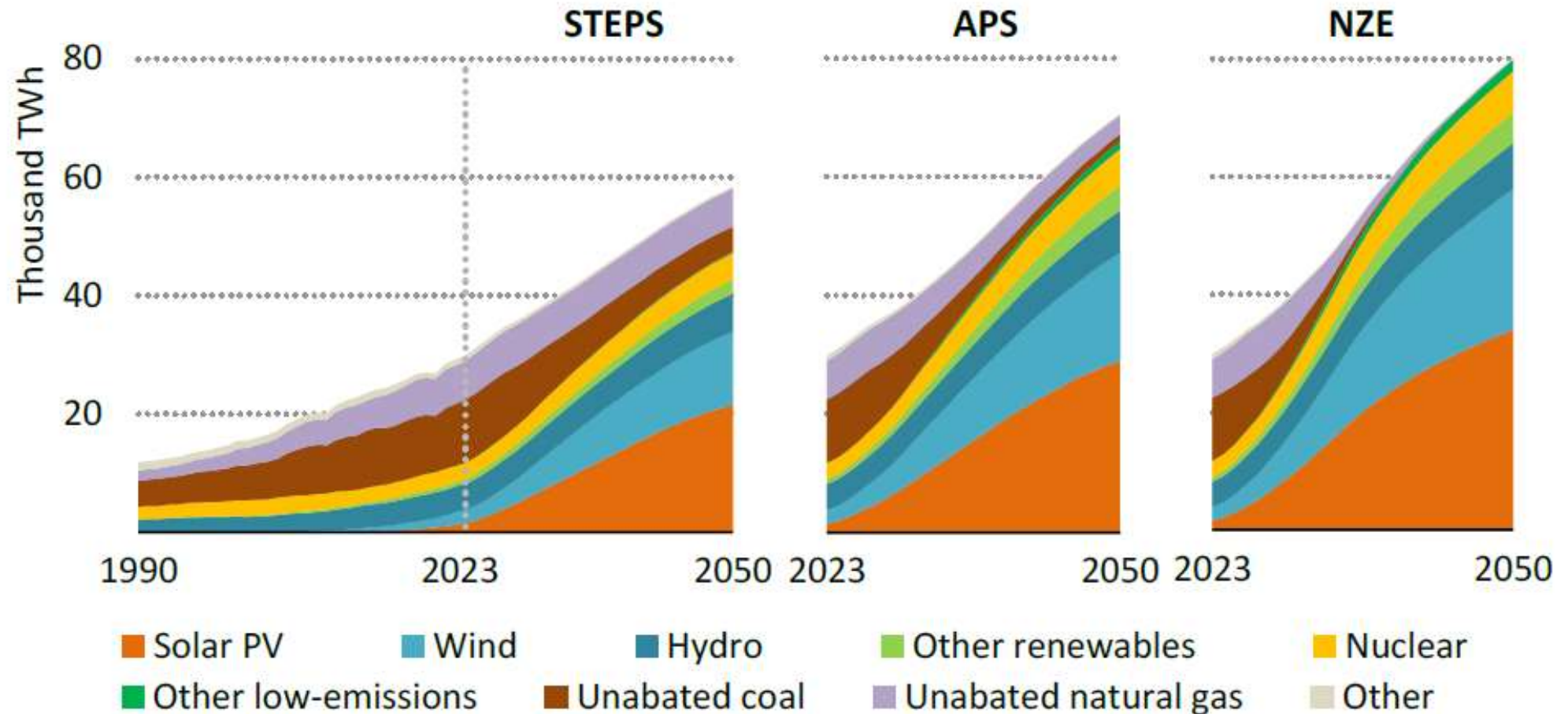
Note) The IPCC scenarios for comparison are only those that reach zero CO₂ emissions from energy by 2050 (16 scenarios). The IPCC 1.5 °C scenarios (C1, C2) have 230 scenarios registered.

The NZE scenario by IEA can be argued, when compared with scenario analyses by international IAM, as a scenario with

- ✓ considerably less energy consumption
- ✓ higher wind and solar
- ✓ considerably small biomass
- ✓ considerably less CCS/CDR, thus rather a “deviated” scenario than an average one

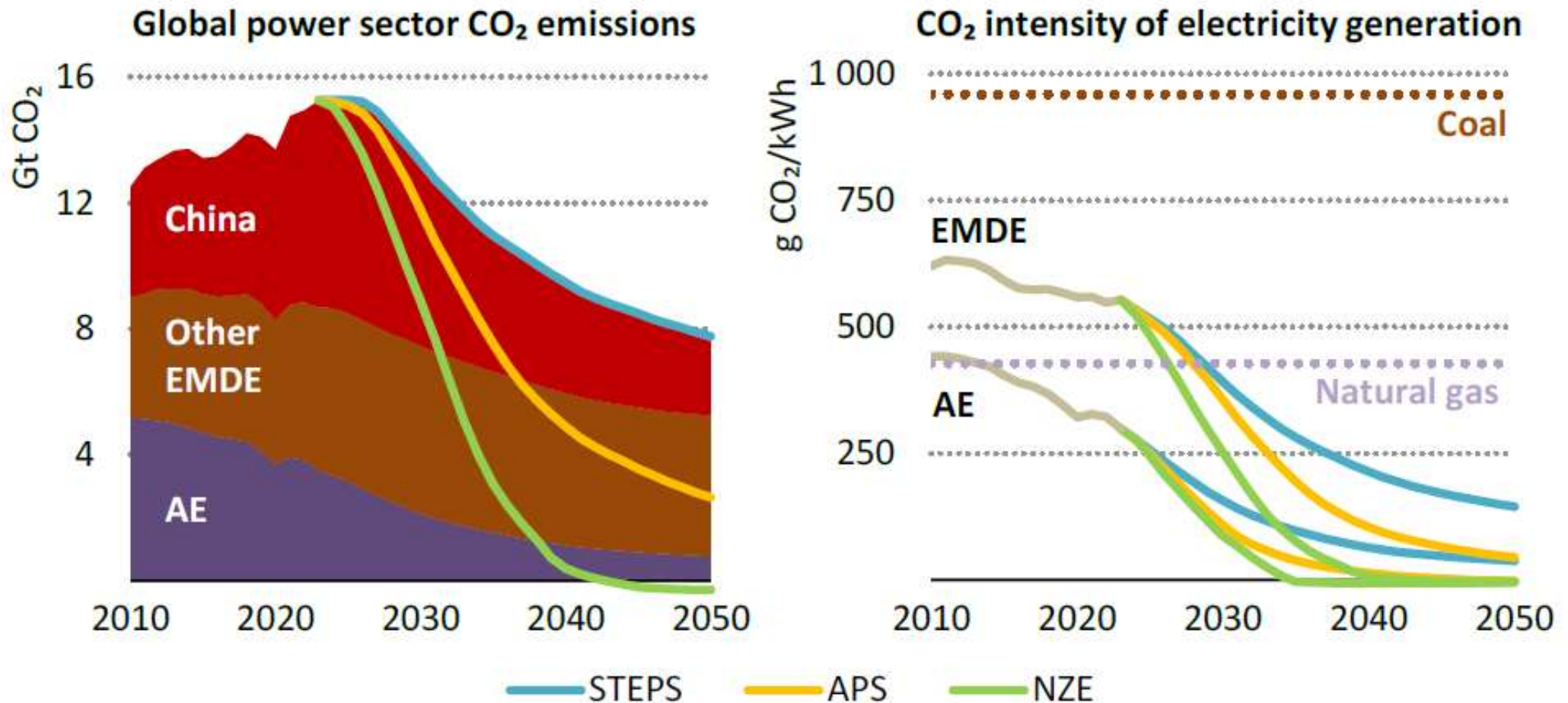
Note) Adopted from IEA WEO2022. No major changes found until WEO2024

Global electricity generation in NZE and other scenarios in WEO2024



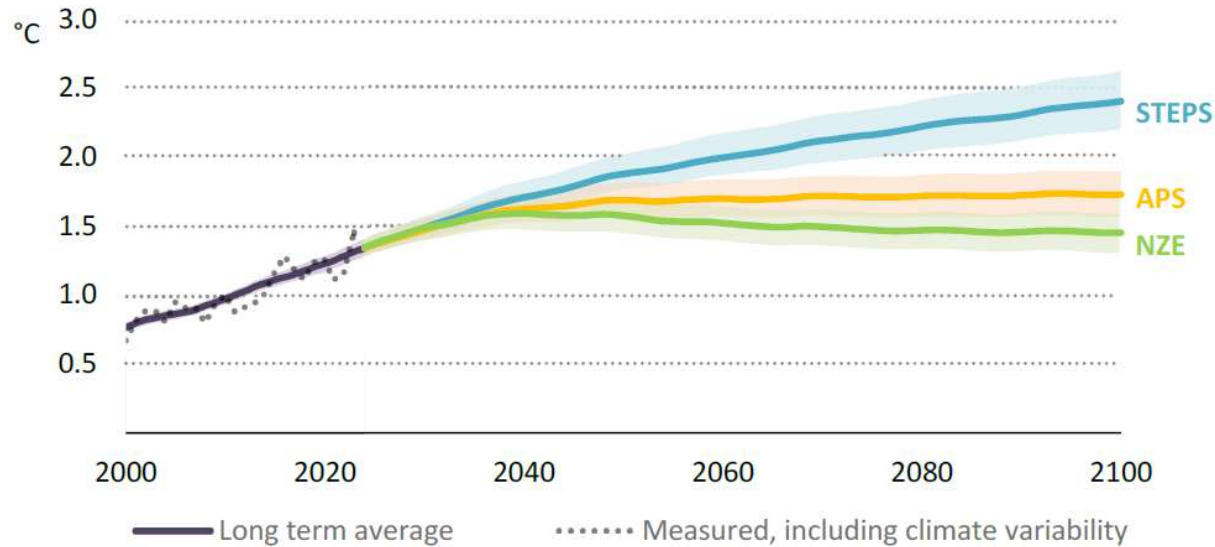
- Electricity generation increases as the emissions reduction target is stringent and more electrification required
- As stated, NZE features larger renewables (especially PV and wind) and smaller CCUS compared to the standard scenarios in the IPCC report. It should be noted that the NZE scenario is somewhat different from the standard global assessments using models

CO₂ emissions and CO₂ intensity of electricity generation in NZE and other scenarios in WEO2024



- CO₂ intensity of electricity generation in advanced economies reaches zero around 2045 in APS, and around 2035 in NZE.

Temperature rise in WEO2025 scenarios(changes from WEO2024)

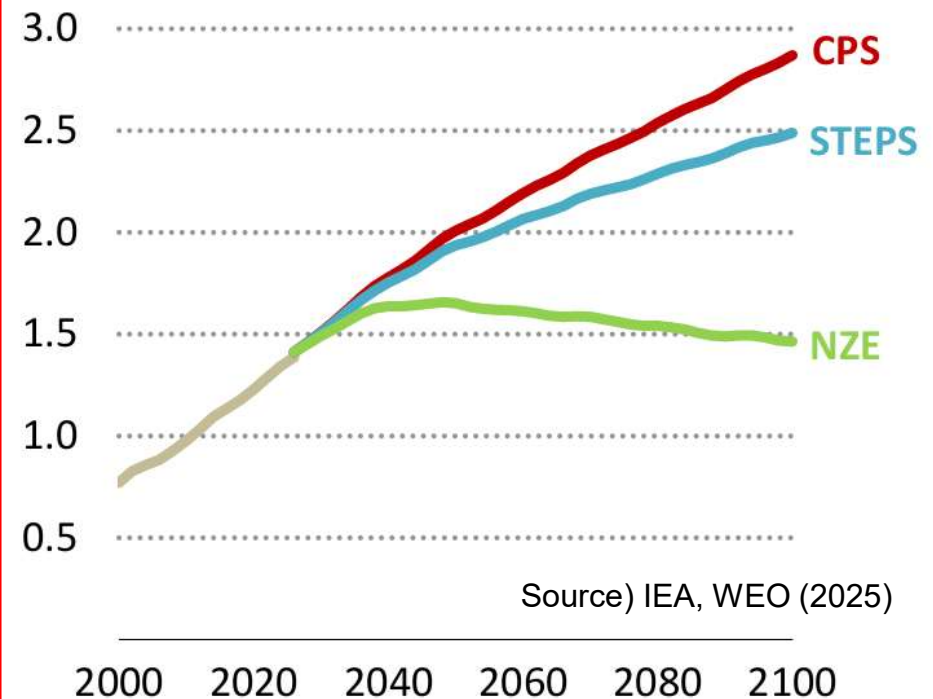


WEO2024

- ✓ Although STEPS, APS, and NZE scenarios were presented until 2024, the CPS scenario has come back and is presented with STEPS and NZE scenarios in the 2025 edition.
- ✓ As a whole, the focus seems to have shifted from climate change to energy access and energy security (CPS and STEPS as main).
- ✓ Although NZE was the scenario without temperature overshooting ($> 0.1^{\circ}\text{C}$) so far, it has changed to the scenario with overshooting (1.7°C at peak), as without overshooting is not realistic anymore.
- ✓ CDR is still conservatively assumed compared to the IPCC scenario analysis.

WEO2025

Temperature rise ($^{\circ}\text{C}$)



Source) IEA, WEO (2025)

3. Development of Quantitative Scenarios and Transition Roadmaps by Using DNE21+ Model

Note) The developed scenarios and roadmaps using the model present average transition pathways for countries and sectors. Decisions about technology choices or investments by individual entities and projects should be made under various circumstances. Individual entities and projects should not treat these roadmaps uniformly as a basis for investment decisions and such, as these could be changed depending on various assumptions.

Energy Assessment Model: DNE21+

(Dynamic New Earth 21+)

- ◆ Systemic cost evaluation on energy and CO₂ reduction technologies is possible.
- ◆ Linear programming model (minimizing world energy system cost; with approx. 10mil. variables and approx. 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, CO₂
- ◆ 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.)

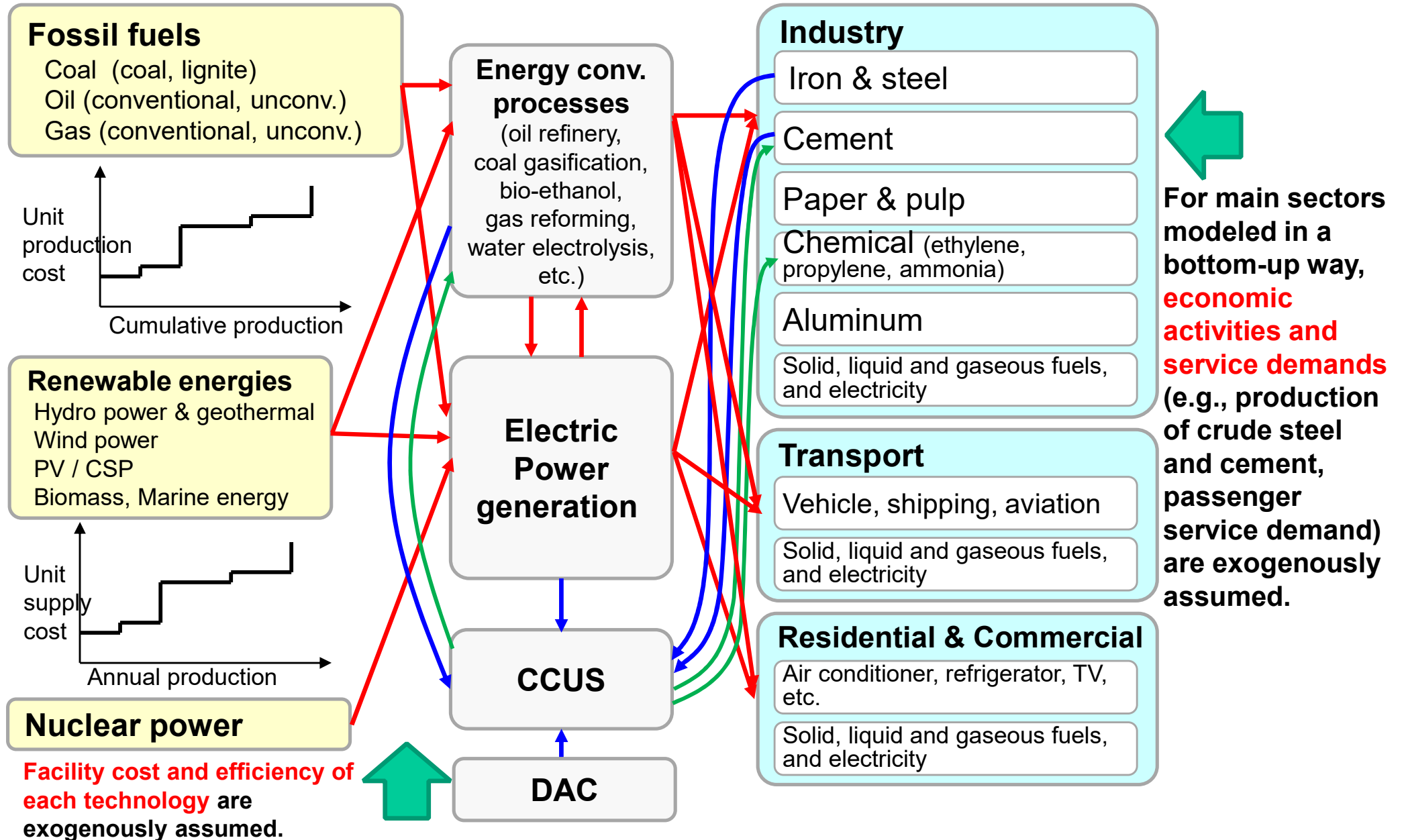
- **Regional and sectoral technological information provided in detail enough to analyze consistently.**
- **Analyses on non-CO₂ GHG possible with another model RITE has developed based on US EPA's assumptions.**

- **Model based analyses and evaluation provide recommendation for discussions on some energy and climate change policy making processes, e.g., cap-and-trade system, Environmental Energy Technology Innovation Plan, 6th Energy Strategic Plan for the Government of Japan, and also contribute to IPCC scenario analyses.**

The structure of DNE21+ model



Oil prices in baseline assuming no climate measures are exogenously assumed, and other price factors, e.g., unit production costs, concession fees, are adjusted. In emission reduction case, prices are endogenously decided accordingly.



- ◆ The DNE21+ model features a capability of global energy system assessment while maintaining consistencies in prices and volumes of energy trade. The model emphasizes worldwide consistency for assumptions. For example, the potentials of solar, wind, or CO2 storage for each country are estimated with the same estimation methodology, based on worldwide GIS data.
- ◆ This feature allows it to easily conduct comparative assessments of technology and economic potentials among countries. On the other hand, each country's situation (e.g. social and physical constraints towards nuclear, renewable energies, or CCS in Japan) is not fully considered.
- ◆ Therefore, a more detailed analysis of Japan requires separate and further consideration of country-specific constraints. For example, power grid configuration in Japan is not considered in the model which makes it difficult to assess differences in grid integration costs of VRE among areas. => The results of the study with the power generation mix model by the University of Tokyo and the IEEJ are employed (see next page).
- ◆ This scenario analysis does not consider energy security issues, although actual policies should take GHG reduction measures while considering energy security.
- ◆ Being a dynamic optimization model, a midpoint (e.g. 2050) assessment can be done while capturing the future outlook towards 2100. It assesses based on cost minimization, and therefore arbitrary scenario settings are excluded to the utmost; however, this may cause extreme changes such as sudden and complete technology replacement once economic rationality is established. Especially, analysis results of transition should be interpreted with caution. (There exist various decision-makers in the real world and technology choices often follow a diffusion curve instead of abrupt change. Compared to econometric models that can represent them well, this optimization model may show abrupt changes.)

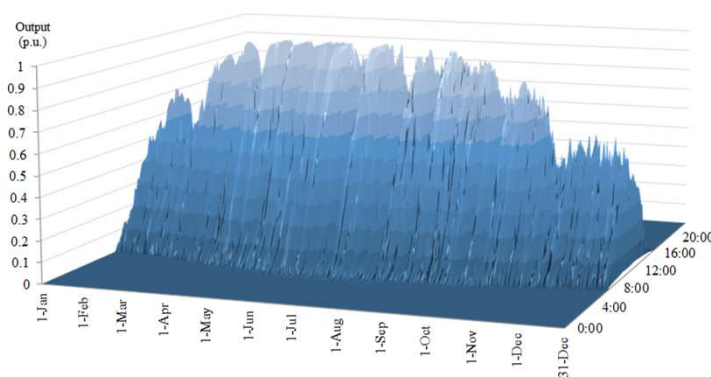
Integration cost of VRES: integration with a power generation mix model by Univ. of Tokyo and IEEJ

- ◆ 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+.

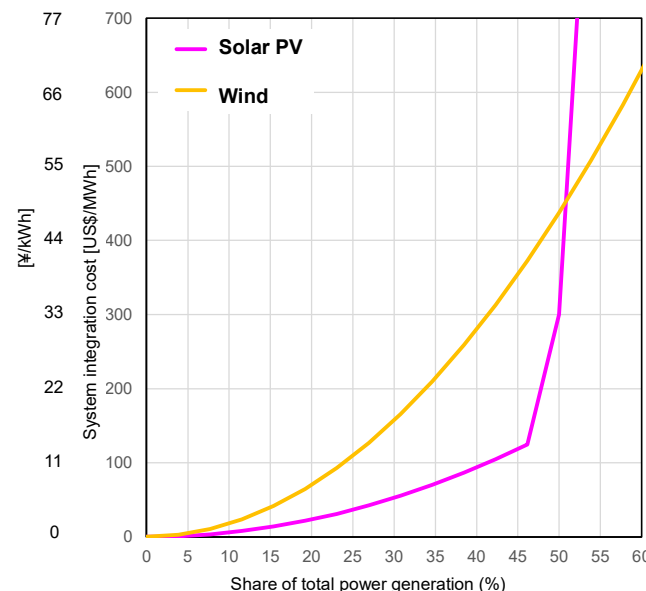
Considered in modeling ··· Output control, power storage system (pumped hydro, lithium-ion battery and hydrogen storage), reduction of power generation facility utilization, inter-regional power transmission lines, electricity loss in storage and transmission

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

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)



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.

Assumed scenarios for the 2 °C and 1.5 °C goals

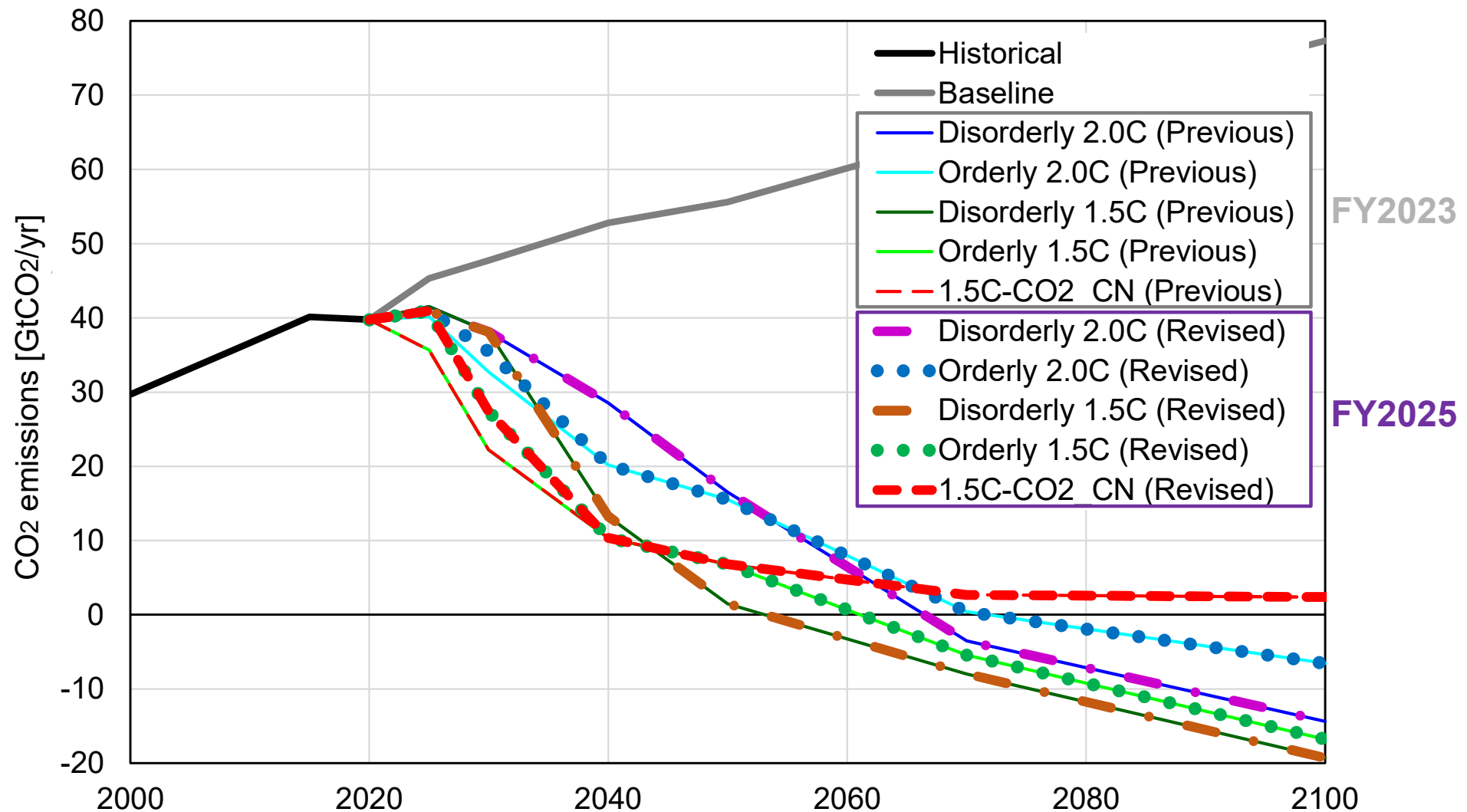
49

Scenarios	Global average temp. increase	Policy speed	CDR contribution	Renewables and BEV	Differences in policy intensity among regions	Relation to other scenarios		
						IPCC AR6 (IPCC 2022)	NGFS (2022/2025)	IEA
Disorderly Below 2 °C	1.7 °C in 2100 (peak:1.8 °C)	Gradual (NDCs in 2030)	medium	Medium cost reductions	Large (major developed countries: CN by 2050)	Likely below 2 C, NDC [C3b]	Disorderly: Delayed Transition	APS (WEO 2024)
Orderly Below 2 °C	1.7 °C	Rapid	Small	High cost reductions	Small (equal MAC among countries)	Likely below 2 C with immediate action [C3a]	Orderly: Below 2C	SDS (WEO 2021)
Disorderly 1.5 °C	1.4 °C in 2100 (peak:1.7 °C)	Gradual (NDCs in 2030)	Large	Medium cost reductions	Large (major developed countries: CN by 2050)	1.5 C with high overshoot (IMP-Neg) [C2]	(Disorderly: Divergent Net Zero)*	
Orderly 1.5 °C	1.4 °C in 2100 (peak:1.6 °C)	Rapid	Medium	High cost reductions	Medium (major developed countries: CN by 2050)	1.5 C with no or limited overshoot [C1]	Orderly: Net Zero2050	
1.5C-CO2_CN	Approx. below 1.5 °C	Rapid	Small (Near-zero of CO2 by sector)	High cost reductions	Large (major developed countries: CN by 2050)	1.5 C with no or limited overshoot [C1]		NZE (WEO 2024)

* The emissions pathway is rather similar to the Orderly 1.5 °C

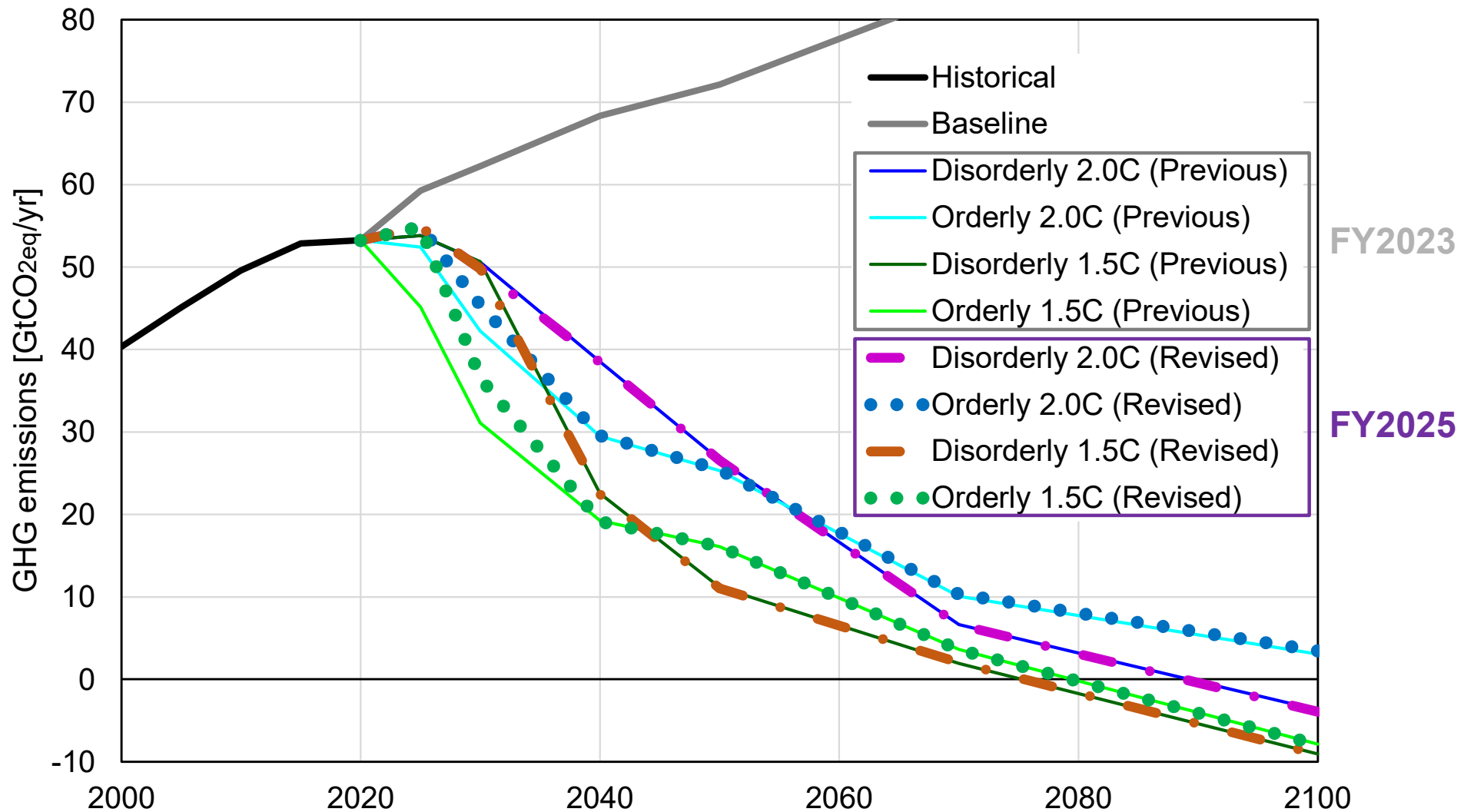
- ✓ The assumed scenarios are consistent with the long-term goals of Paris Agreement, and cover the existing scenarios which are widely referred globally.
- ✓ The scenarios also cover a certain range of uncertainties in technologies and policies.

Global emissions pathways (CO₂)



✓ Based on current emission trends, the emission pathways for 2020-2025 have been revised upward from the 2023 version.

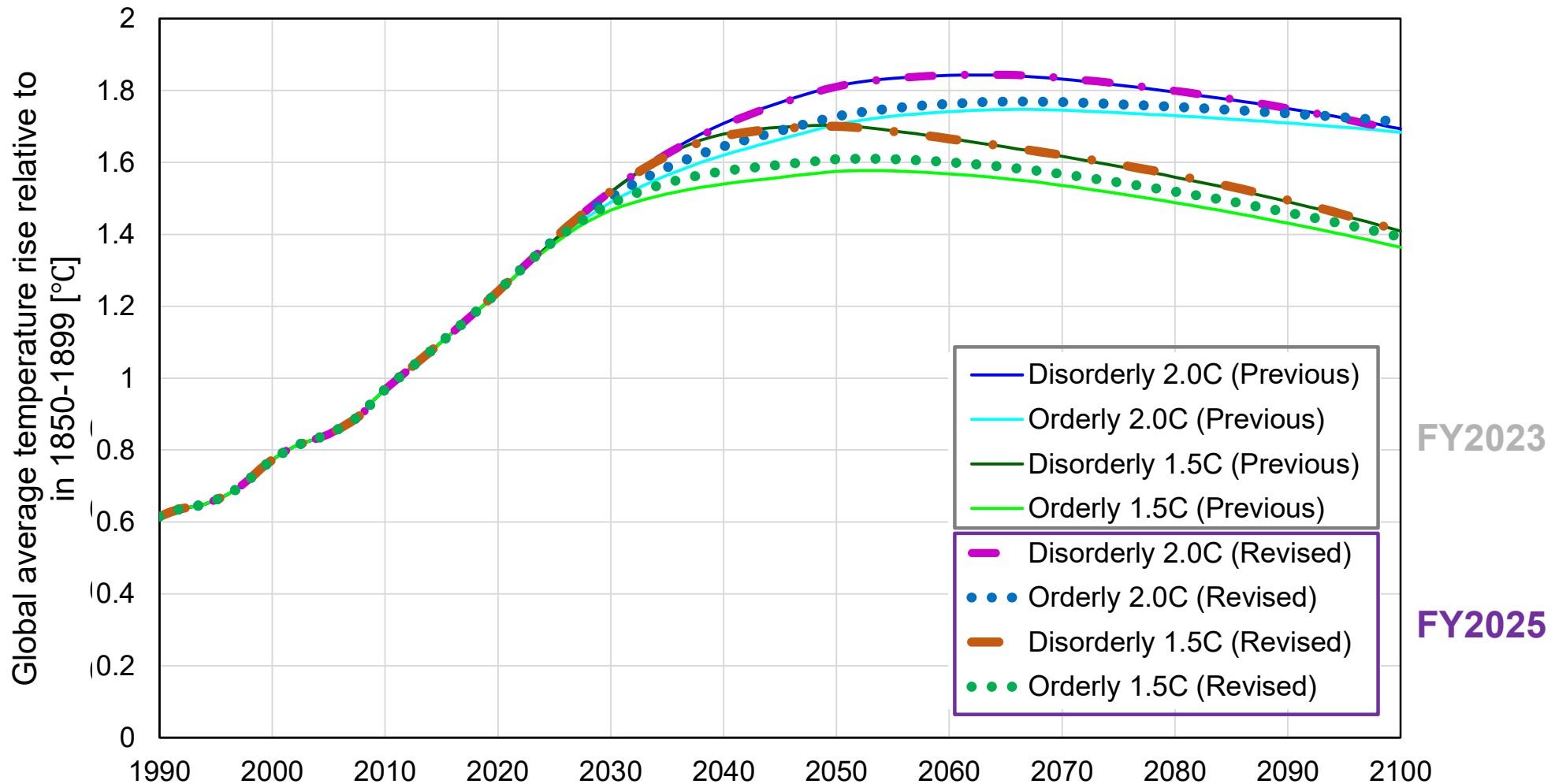
Global emissions pathways (GHG)



Note: The 1.5C_CO2_CN scenario evaluates only CO₂ emissions, in accordance with IEA NZE standards. GHG emission pathways are not considered.

- ✓ **Based on current emission trends, the emission pathways for 2020-2025 have been revised upward from the 2023 version.**

Global average temperature rise for the assumed scenarios



Note: The 1.5C_CO2_CN scenario evaluates only CO2 emissions, in accordance with IEA NZE standards. GHG emission pathways are not considered, nor are temperature pathways identified.

- ✓ In the 2025 version, the upward revision of emissions from the previous point in time has resulted in a slight increase in temperature, particularly in the Orderly scenarios.

(0) World

CO₂ marginal abatement costs for the 2°C scenarios

Disorderly 2.0C

Unit: \$/tCO₂

	2030	2040	2050
Japan	424	306	513
US	221	233	235
EU27	280	199	286
Korea	148	79	121
China	34		
Others	Different among countries due to different NDCs		

Orderly 2.0C

	2030	2040	2050
Japan	57	256	161
US			
EU27			
Korea			
China			
Others			

CO₂ marginal abatement costs for the 1.5°C scenarios

Disorderly 1.5C

Unit: \$/tCO₂

	2030	2040	2050
Japan	427	440	683
US	225	292	275
EU27	278	292	324
Korea	142	292	270
China	41		
Others	Different among countries due to different NDCs		

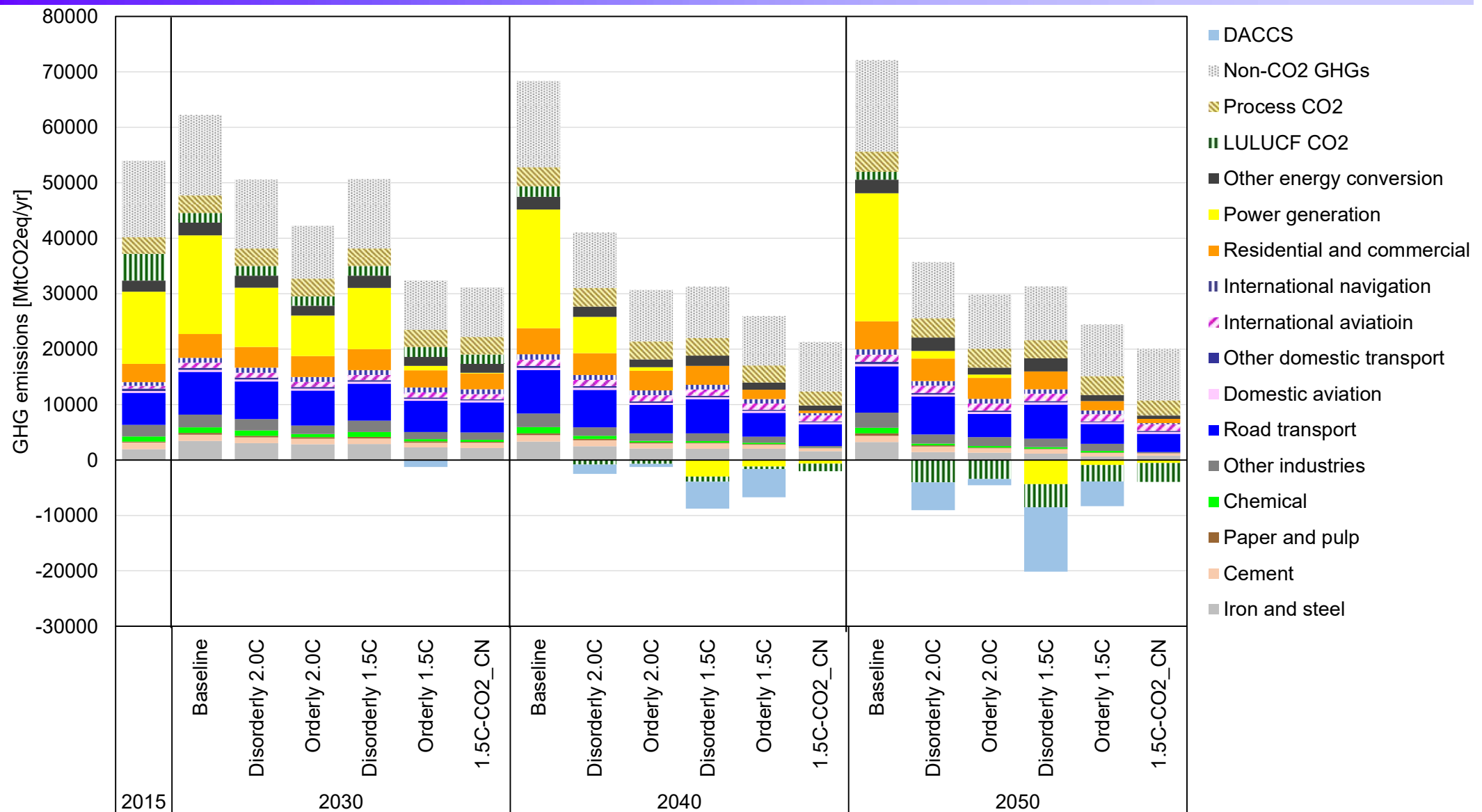
Orderly 1.5C

	2030	2040	2050
Japan	148	547	470
US		497	281
EU27			291
Korea, China and others			262

1.5C-CO₂_CN

	2030	2040	2050
Japan	128	720	338
US			318
EU27			348
Korea, China and others			298

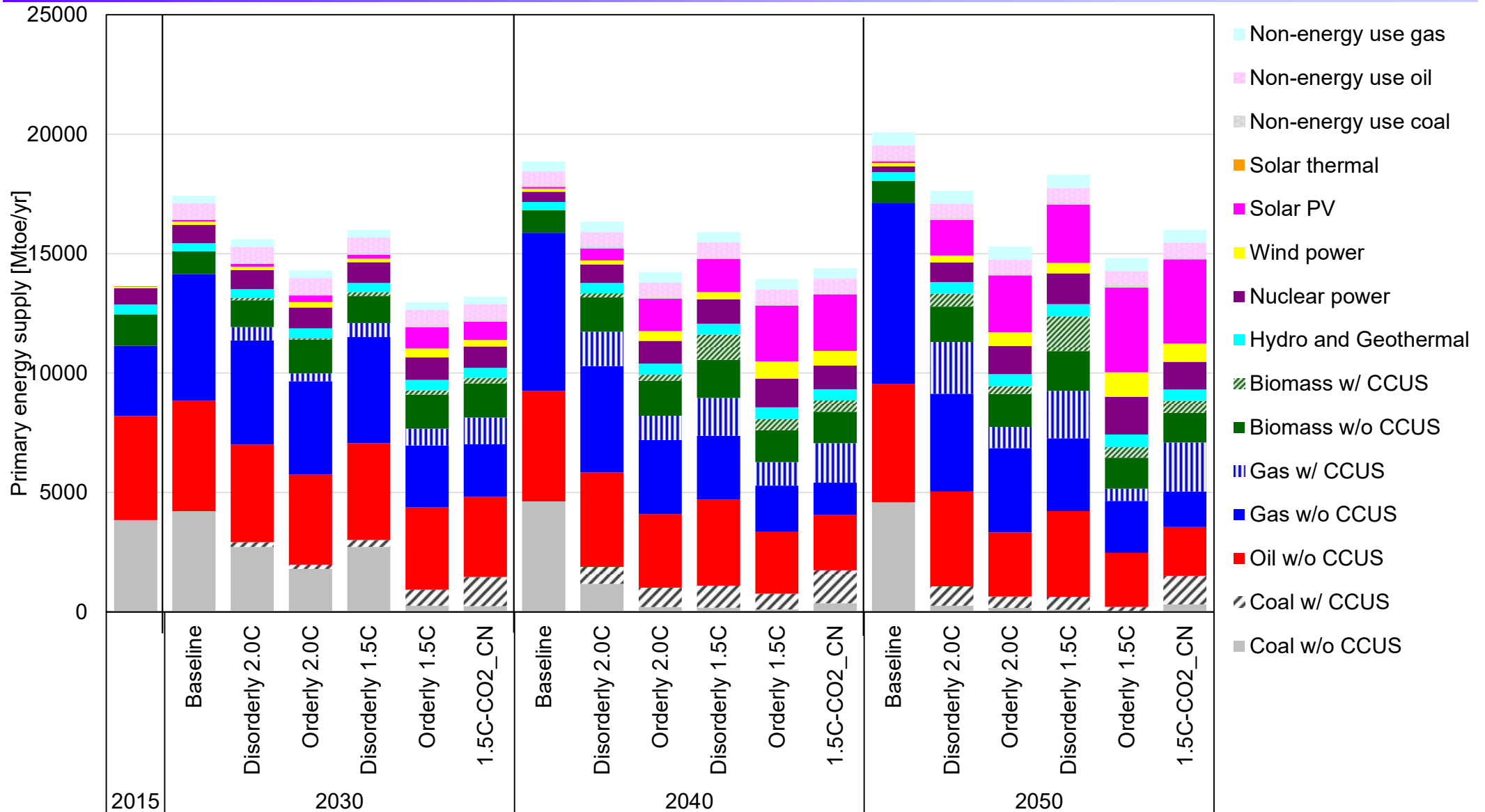
GHG emissions (World)



Note) The 1.5C-CO₂_CN scenario analyzes only on CO₂, but the figure includes non-CO₂ GHG emissions of Orderly 1.5C.

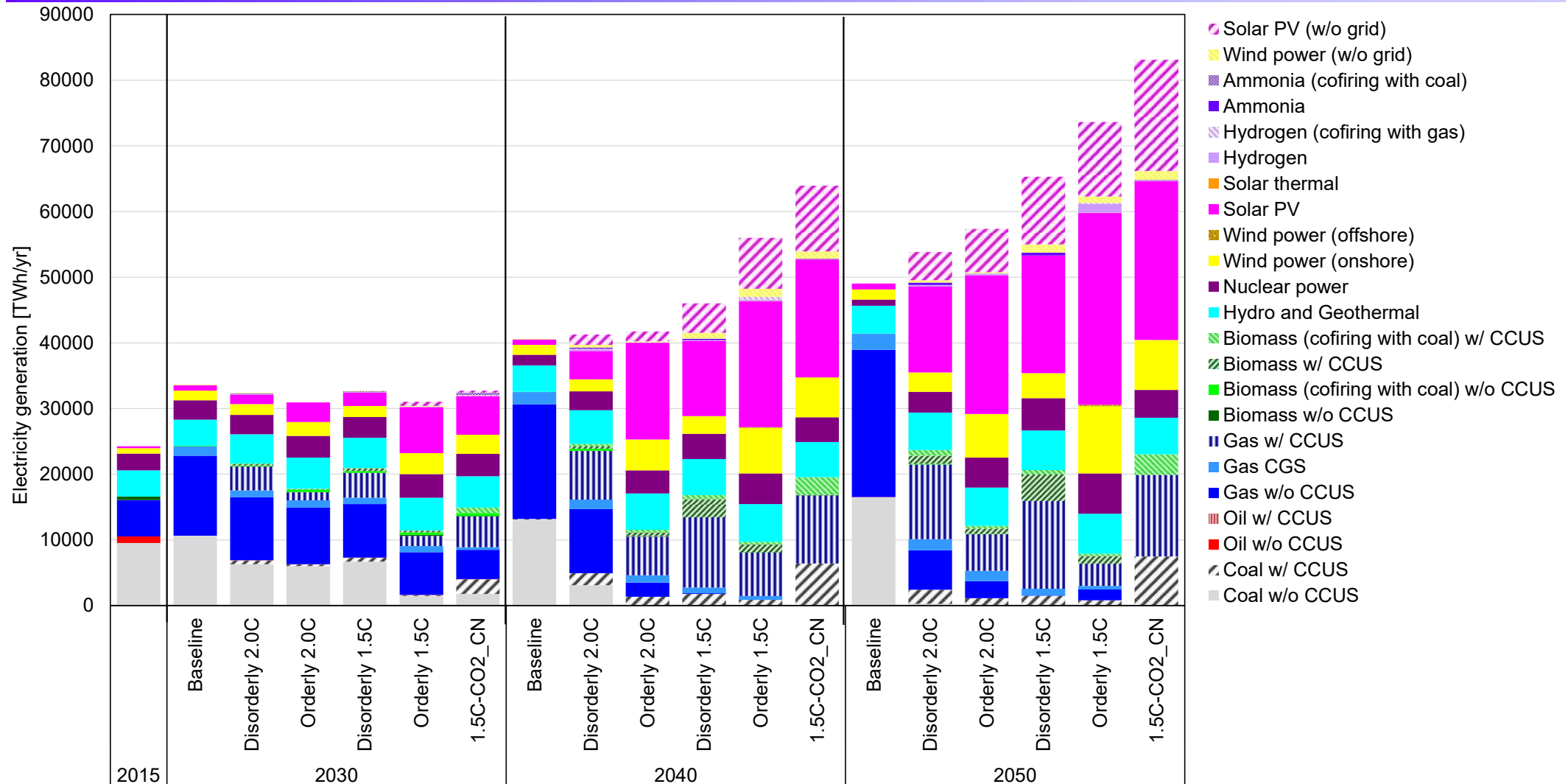
- ✓ The amounts of CO₂ fixations due to CDR is approximately 20GtCO₂eq/yr in 2050 for the Disorderly 1.5°C, and those for other scenarios are below 10 GtCO₂eq/yr.
- ✓ Non-CO₂ GHG emissions of approx. 10 GtCO₂eq/yr remain in 2050 even in both 2°C and 1.5°C scenarios.

Primary energy supply (World)



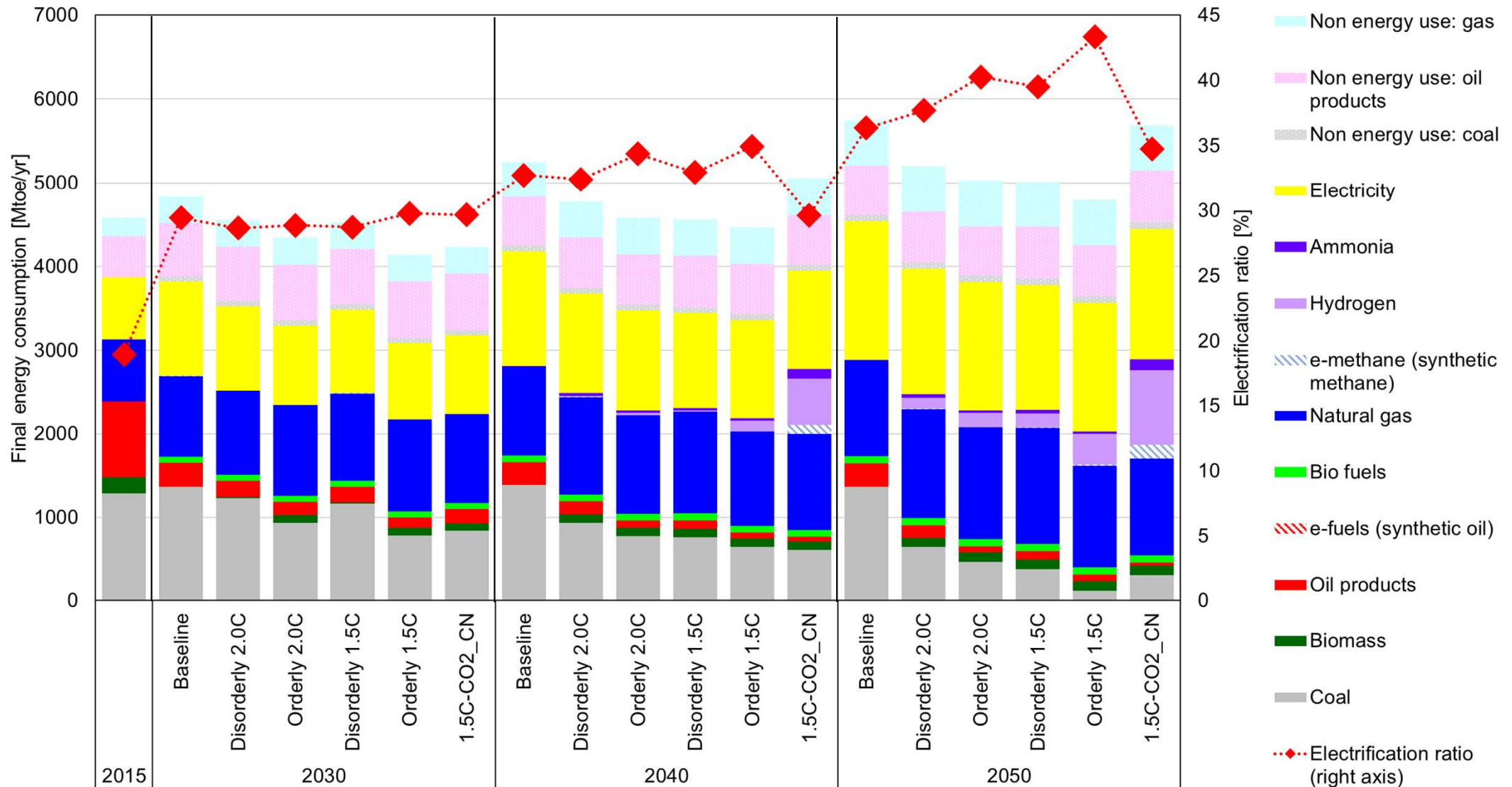
- ✓ Thanks to CDR contributions, fossil fuel uses without CCS still remain in 2050 even for the 1.5°C scenarios.
- ✓ The amount of fossil fuel uses up to 2050 is close to the level in IPCC AR6 IMP-Neg scenario.

Electricity supply (World)



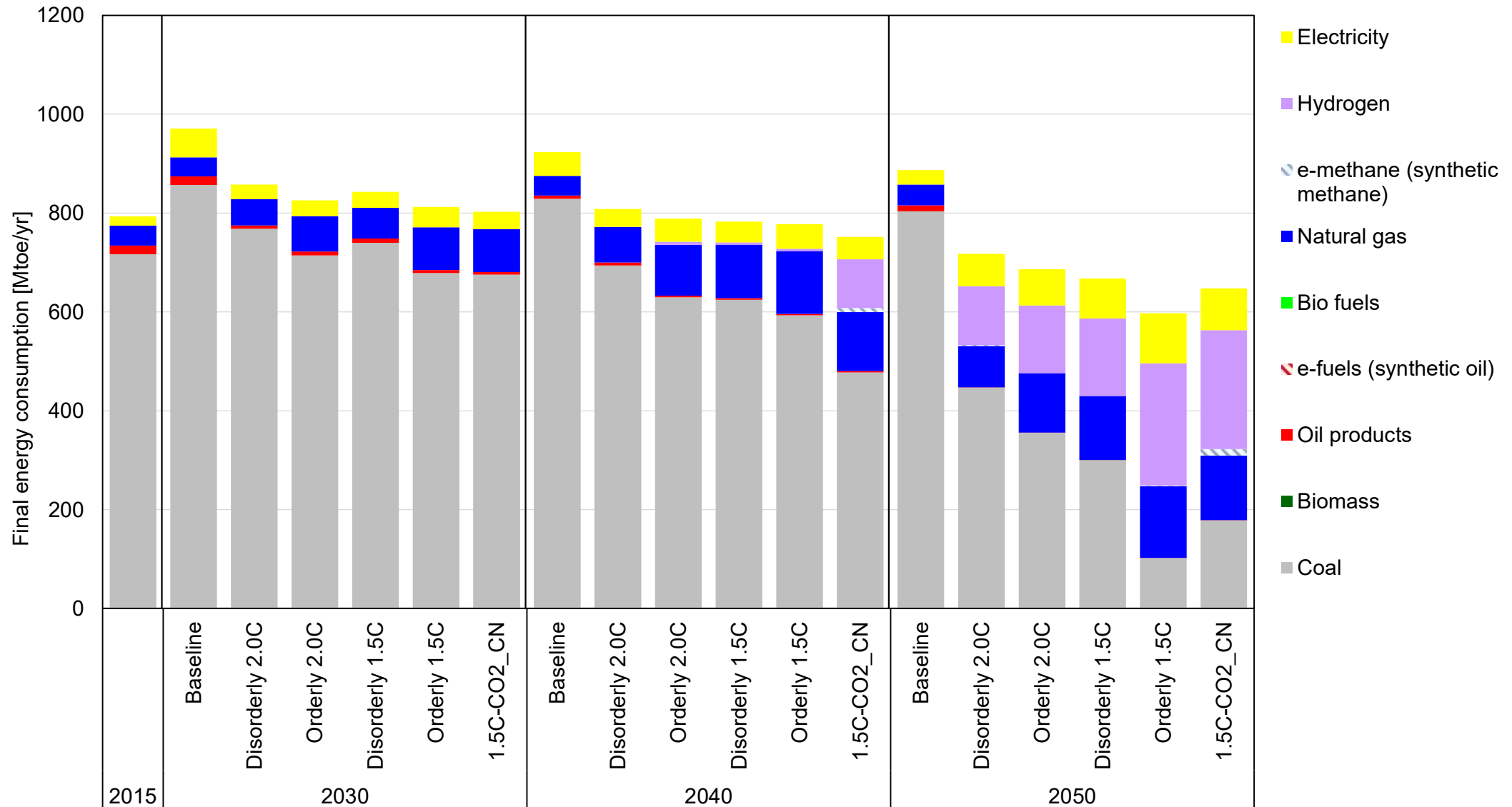
- ✓ Potentials of CO₂ geological storage is large in the world, the shares of gas power with CCS are relatively high compared with those in Japan.
- ✓ In the Orderly 1.5°C/2.0°C scenarios which assume larger constraints of the access of CO₂ geological storage, larger deployments of solar PV and wind power are estimated.
- ✓ Electricity generation in 2050 in IEA ETP2020-SDS is around 52000 TWh/yr, which is the same level in Disorderly 2.0°C, and also in NGFS scenario.

Final energy consumption in industry (World)



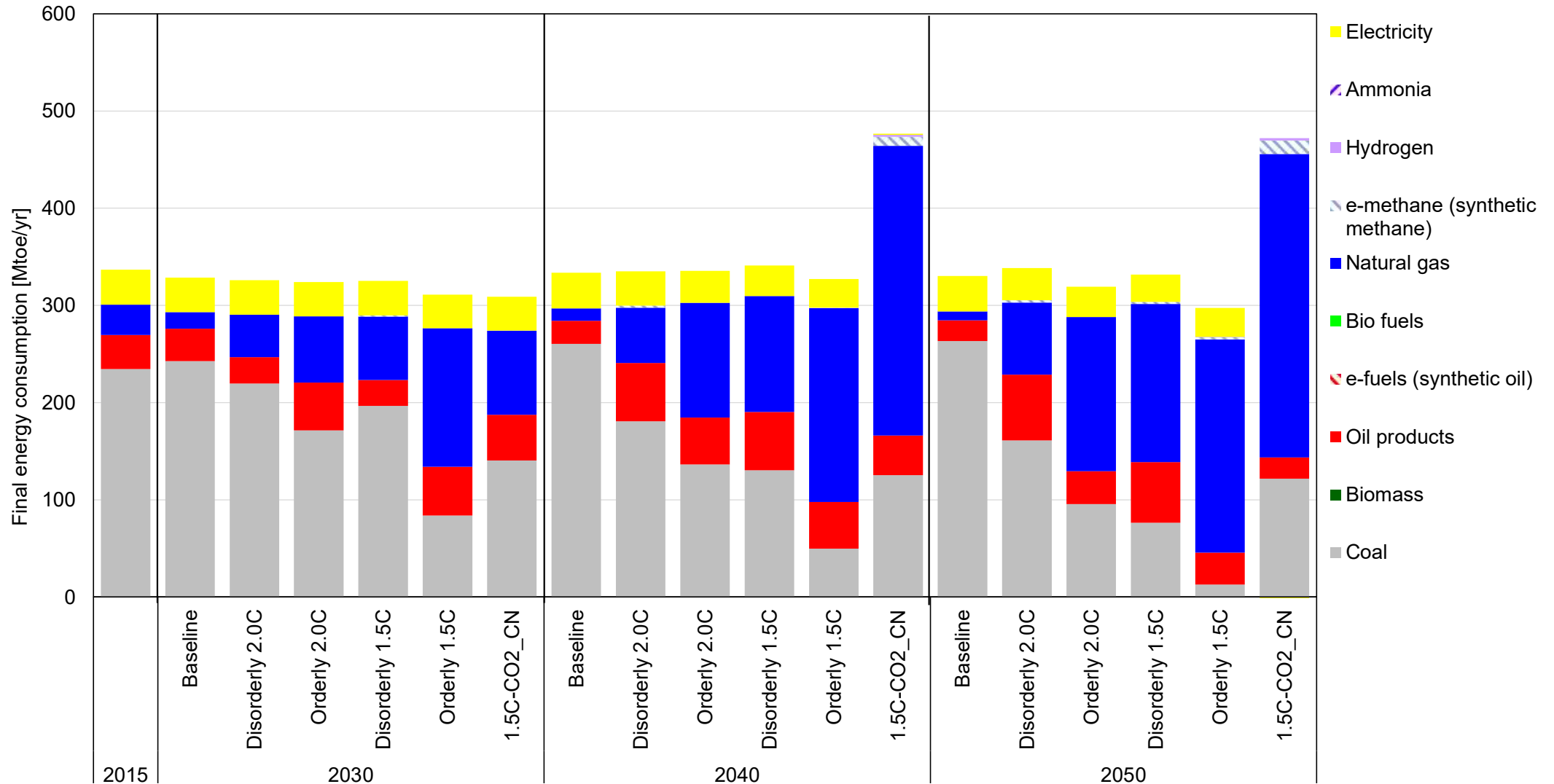
- ✓ Coal uses reduce, and gas and electricity uses increase for the 2°C/1.5°C scenarios in the world.
- ✓ The shares of hydrogen, ammonia, and synthetic methane (e-methane) uses are relatively small compared with those of Japan due to cheaper renewables and CCS, and larger power grid connections.

Final energy consumption in iron & steel (World)



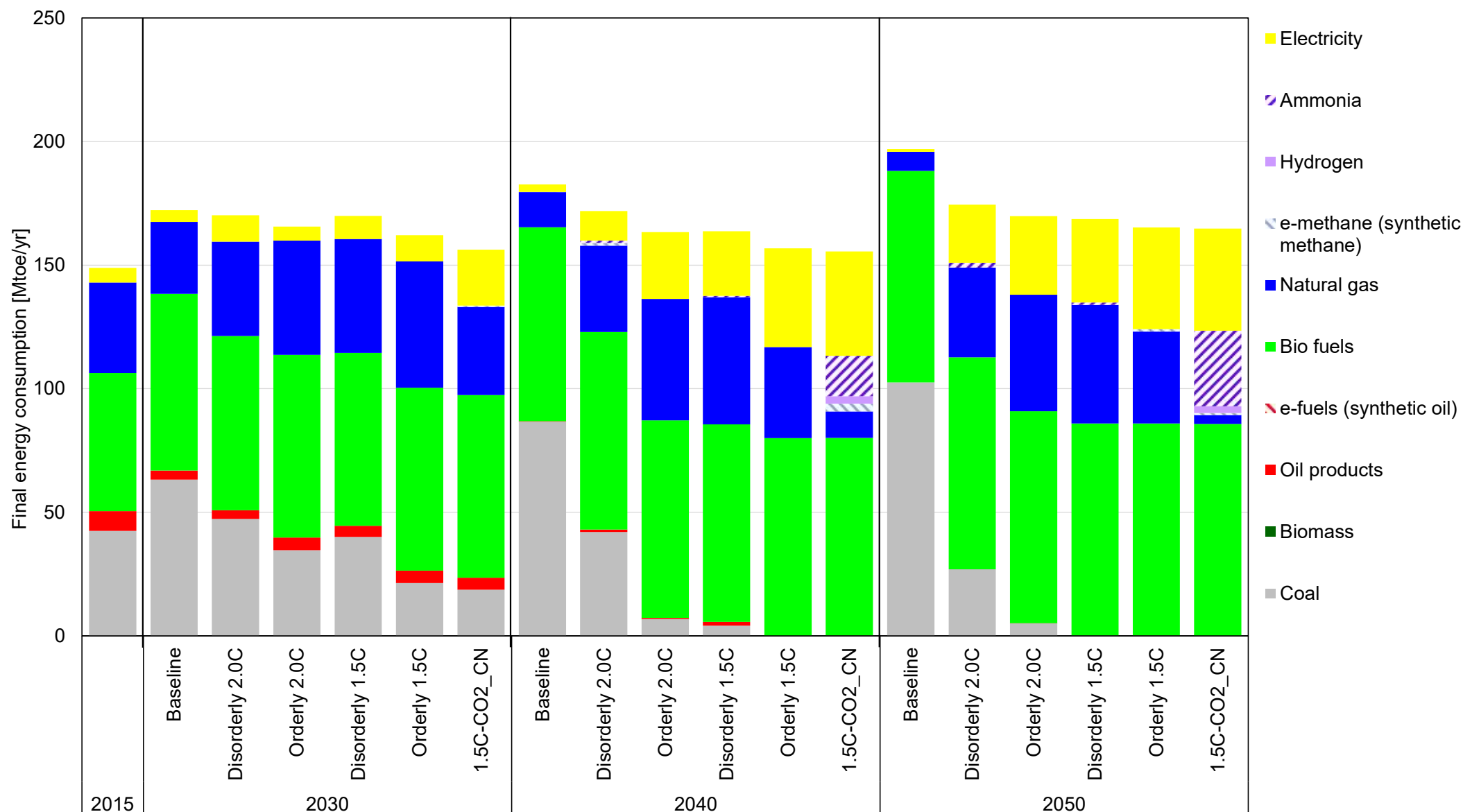
- ✓ Total final energy consumption will decrease due to energy savings and shifts to electric furnace. Meanwhile coal is still major energy sources by around 2040.
- ✓ After 2040, hydrogen from outside of steel making processes (e.g., Super COURSE50) are used, and hydrogen-use DRI are cost-effective options in 2050, and large hydrogen uses are observed.

Final energy consumption in cement (World)



- ✓ A shift from coal to gas is cost-effective under 2°C/1.5°C scenarios.
- ✓ While efficiency continues to improve, there are some cases in which slightly more energy is consumed compared with the Baseline, due to energy use for CO₂ capture, especially in 1.5C-CO₂_CN which assumes a small contribution of CDR.

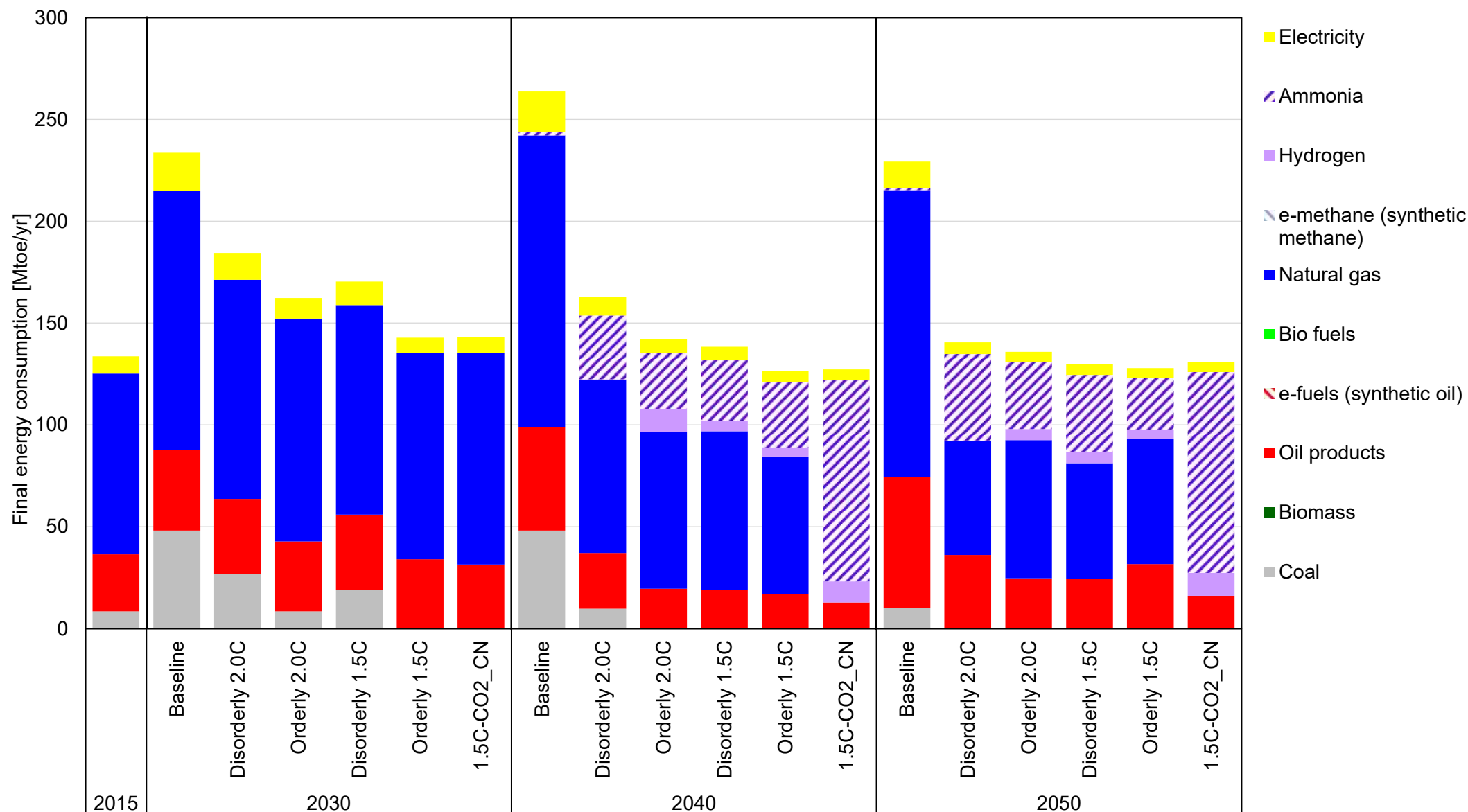
Final energy consumption in paper & pulp (World)



Note) The use of black liquor is included in biofuels consumption.

- ✓ A shift from coal to gas is cost-effective.
- ✓ The uses of ammonia and synthetic methane are observed in the world, even though the amount is small. (There are certain amounts of those uses in 1.5C-CO2_CN, which assumes a small contribution of CDR.)

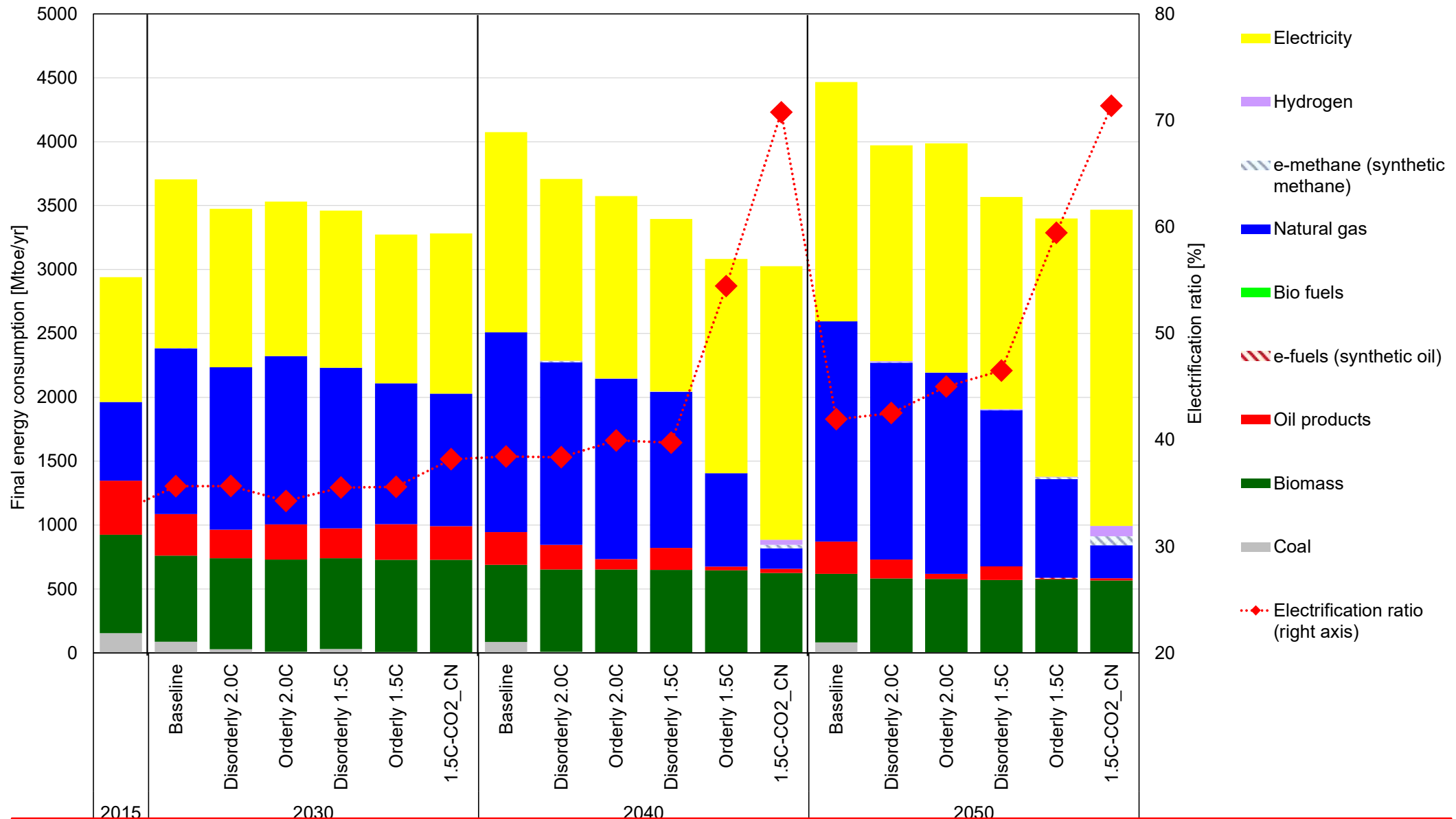
Final energy consumption in petrochemical (ethylene, propylene, and BTX productions) (World)



Note) The graph shows only energy usage consumption, and energy for raw material is not included.

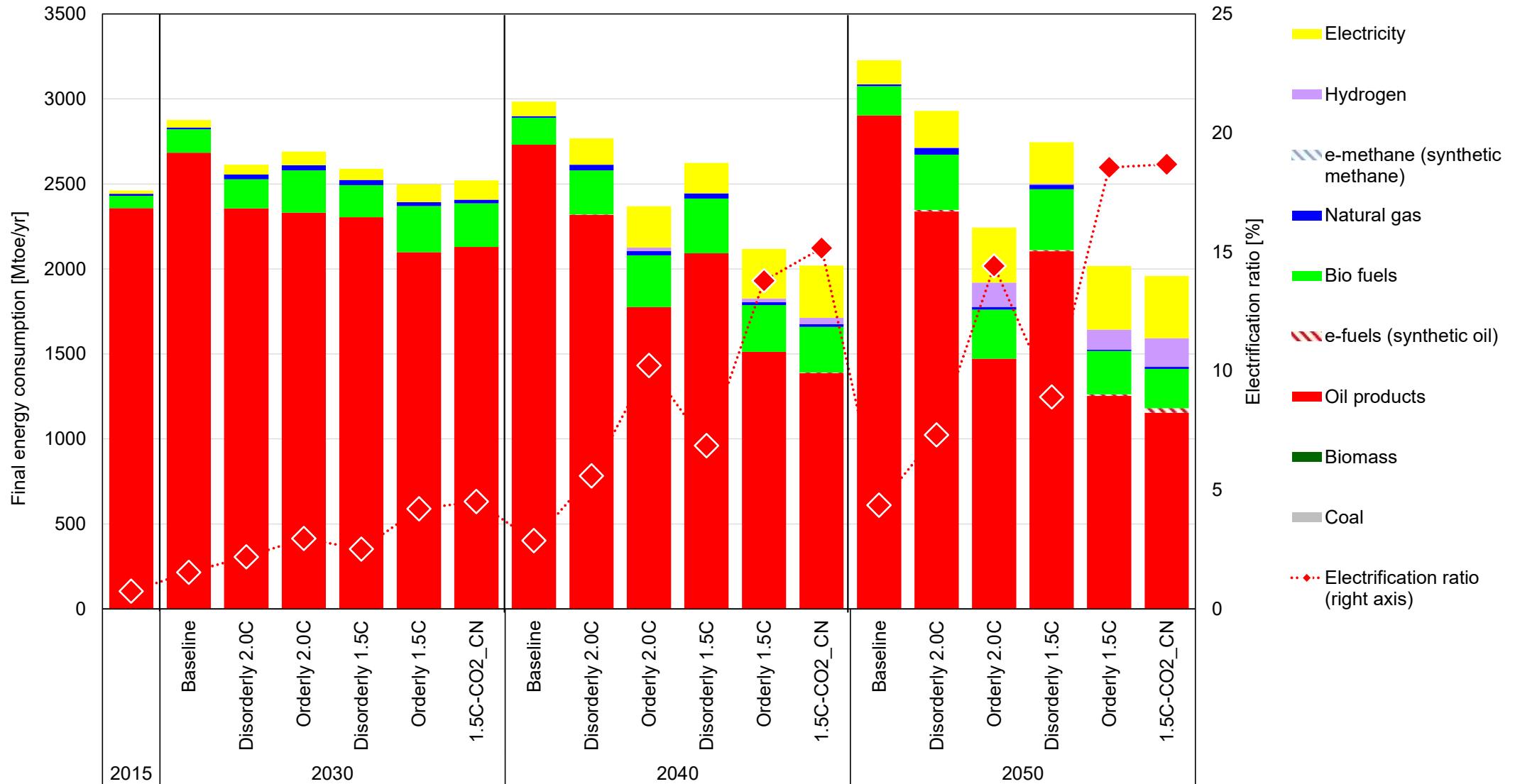
✓ CN fuels, such as ammonia and hydrogen, are used under emissions reduction scenarios, especially in 1.5C-CO2_CN where a small contribution of CDR is assumed.

Final energy consumption in building (World)



- ✓ In building sector, electricity consumptions will increase greatly even for the baseline scenario. Under the 2°C/1.5°C scenarios, larger shares of electricity consumptions will be economical measures.
- ✓ On the other hand, for the 2°C scenarios and Disorderly 1.5°C, a certain amounts of natural gas uses are still economical measures.

Final energy consumption in transport (World)



- ✓ The uses of electricity, bioenergy, hydrogen, and e-fuels will increase, and oil consumptions will decrease.
- ✓ However, a certain amount of oil consumptions will remain by 2050 even under the 2°C /1.5°C scenarios.

(1) Japan

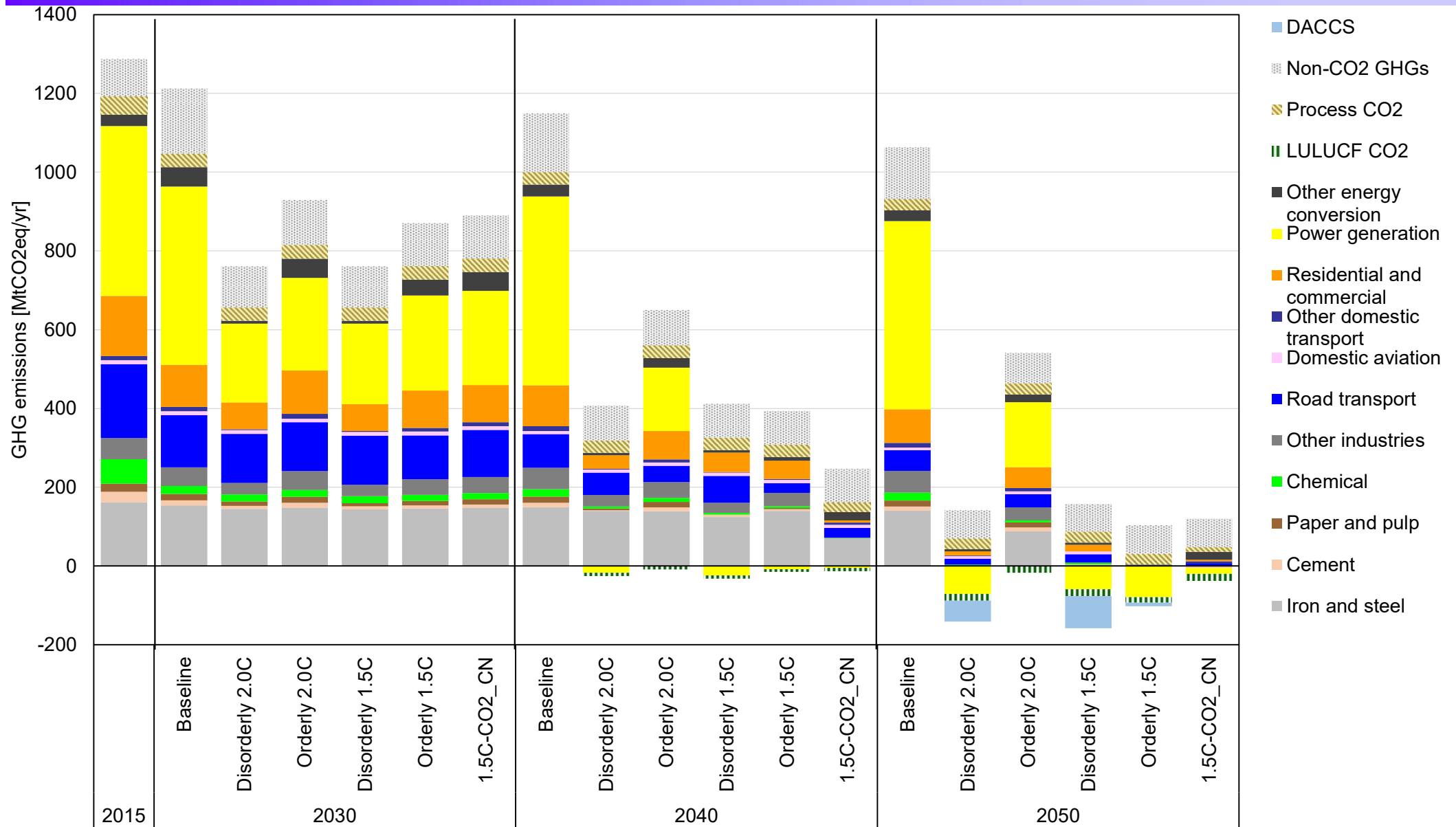
CO₂ emissions reduction cost (Japan)

Unit: billion US\$/yr

	2030	2040	2050
Disorderly 2.0C	64	102	174
Orderly 2.0C	18	21	22
Disorderly 1.5C	60	128	238
Orderly 1.5C	15	99	155
1.5C-CO2_CN	18	174	104

Note) Annual cost increases in energy systems from those of the baseline scenario

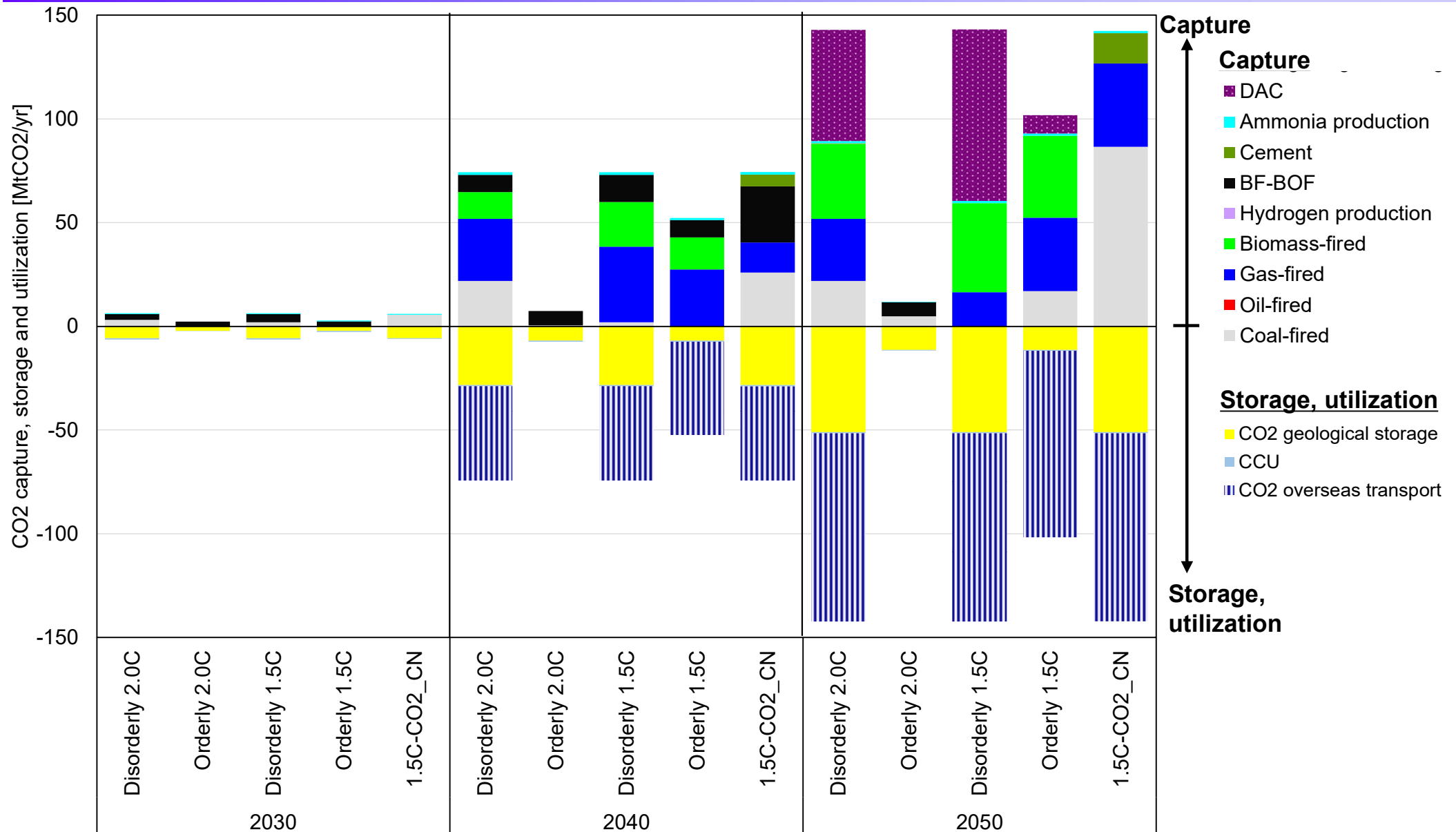
GHG emissions (Japan)



Note) The 1.5C-CO₂_CN scenario analyzes only on CO₂, but the figure includes non-CO₂ GHG emissions of Orderly 1.5C.

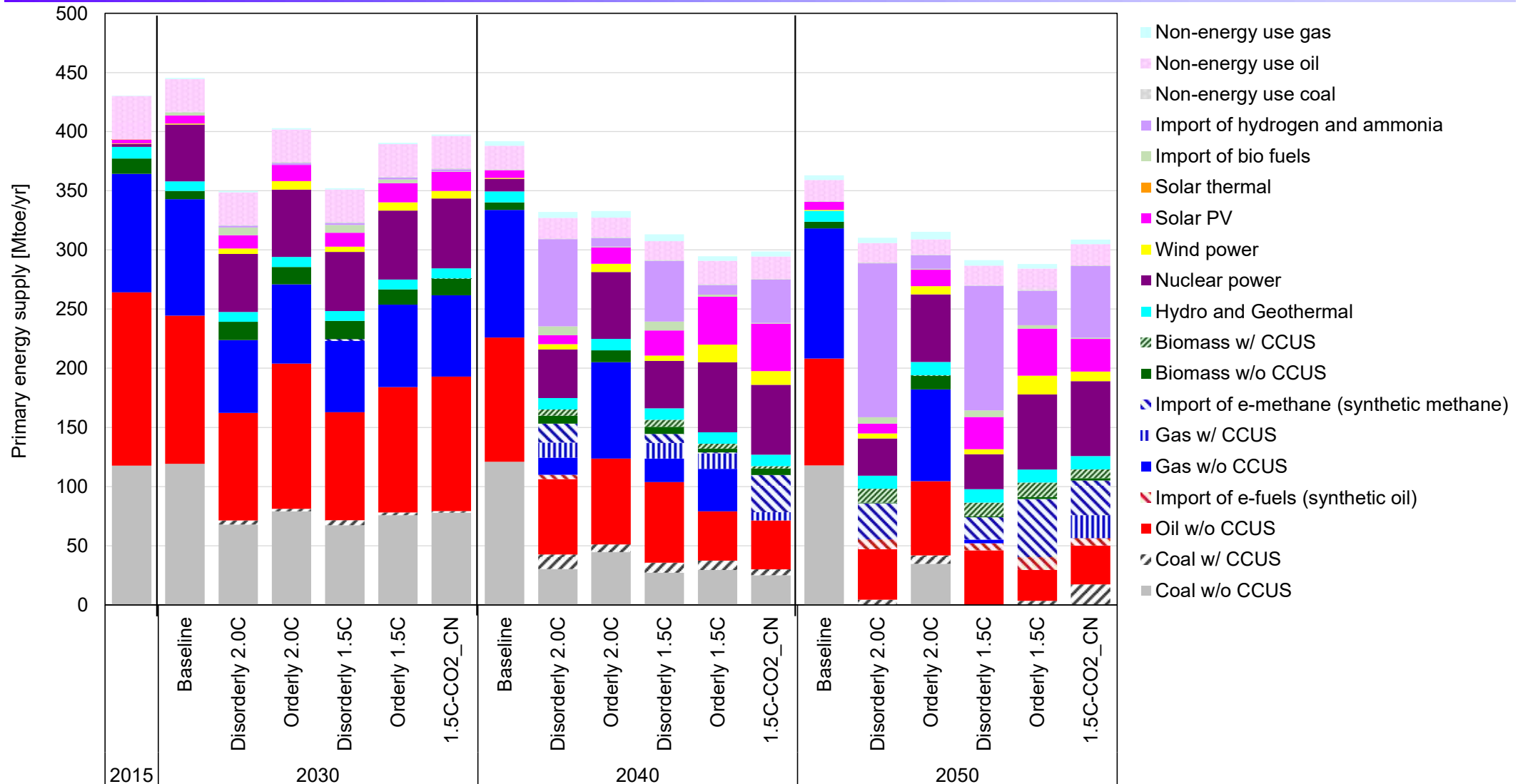
- ✓ To achieve CN in GHG emissions in 2050, DACCS, the use of LULUCF CO₂ (fixation by forestation), and the measures for net negative CO₂ emissions in the Power sector, such as BECCS and synthetic methane+CCS, will be applied.
- ✓ In Orderly 2.0°C where CN in GHG emissions in 2050 is not assumed, the total GHG emissions will be approximately ▲63% relative to 2013, with positive CO₂ emissions from the Power sector and the Iron and steel sector.

CO₂ balance (Japan)



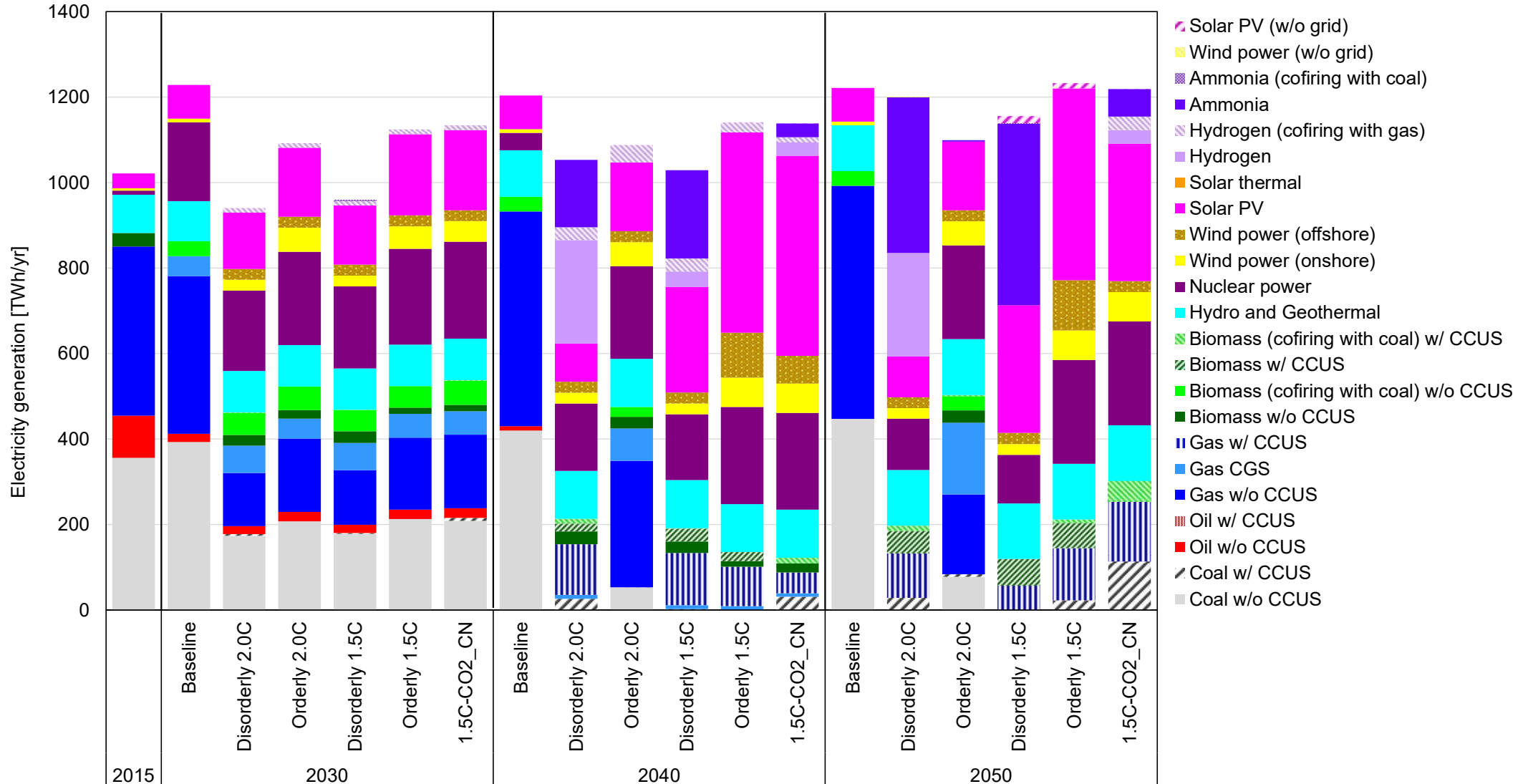
- ✓ CO₂ capture through fossil-fired power generation and BF process (Super COURSE50) are observed in 2040.
- ✓ CO₂ capture through DAC and Biomass processes will be large in 2050.
- ✓ Under 1.5C-CO₂_CN, with limited CDR uses including BECCS and synthetic methane+CCS in the Power sector, CO₂ is captured from coal-fired (incl. Biomass co-firing) and gas-fired, and in the Cement sector in 2050. Captured CO₂ via DAC is used for CCU.

Primary energy supply (Japan)



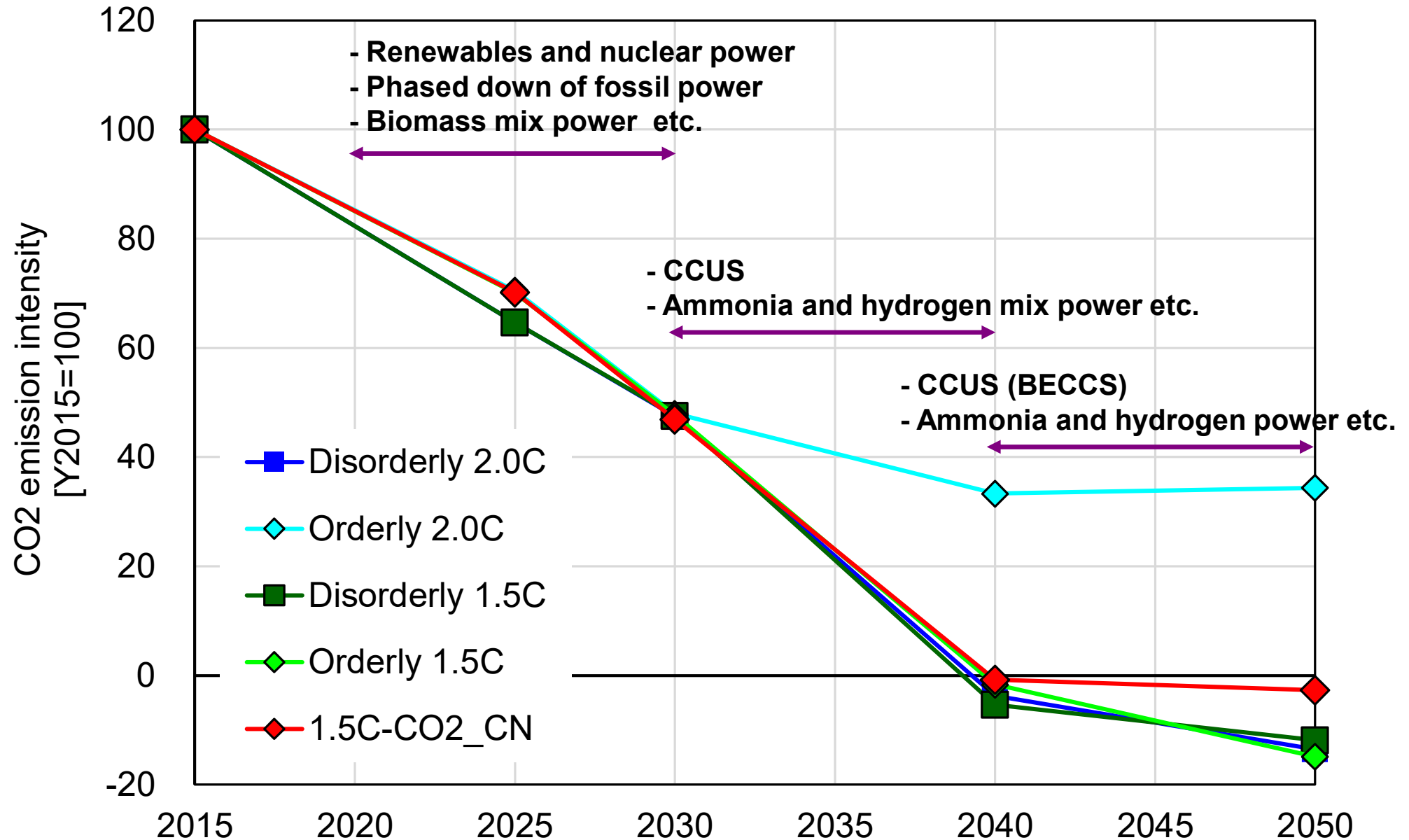
- ✓ Import of hydrogen and ammonia, e-methane, and biofuels would be cost-effective as the MAC of Japan is higher than other countries. However, those amounts in Orderly 2.0°C are relatively small (approx. ▲63% relative to 2013 in 2050).
- ✓ Coal use incl. with CCUS is scarcely observed in the scenarios of GHG CN in 2050. However, in Orderly 2.0°C, some coal w/o CCUS and a reasonable amount of gas w/o CCUS are likely to remain.
- ✓ Import of hydrogen and ammonia, e-methane, and biofuels would be cost-effective as well in 1.5C-CO₂_CN.

Electricity supply (Japan)



- ✓ Electricity supply is in an upward trend, especially in the strict emissions reduction scenarios.
- ✓ The deployment of renewable energy, such as solar PV, the use of CCS, and power generation with imported hydrogen and ammonia are observed. Also, synthetic methane is used for gas power generation in 2050 in the scenarios other than Orderly 2.0°C.
- ✓ Solar PV and wind power are likely to diffuse further due to high cost reduction in Orderly 1.5°C.
- ✓ In 1.5C-CO₂_CN, a portion of coal with CCUS increases due to the constraint of BECCS and synthetic methane+CCS.

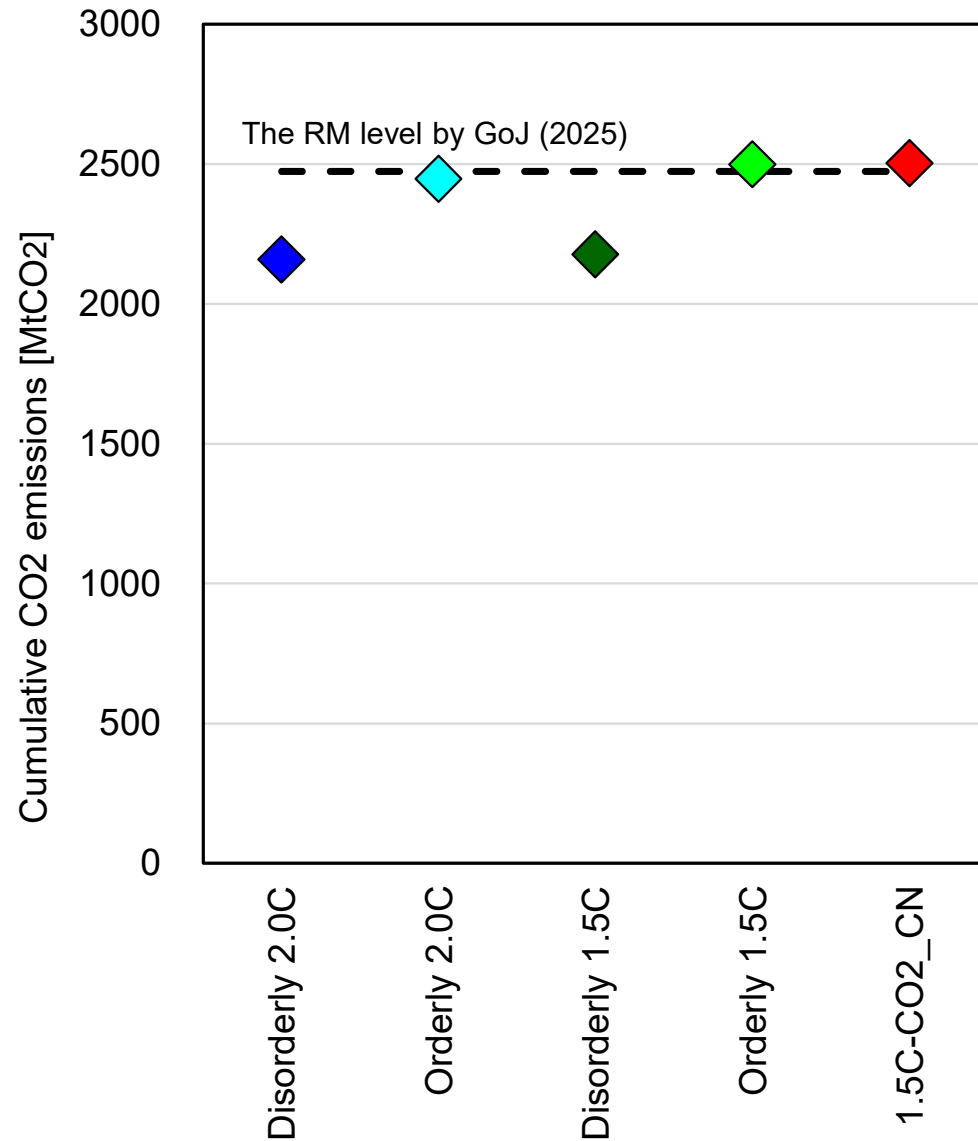
CO₂ intensity of electricity (Japan)



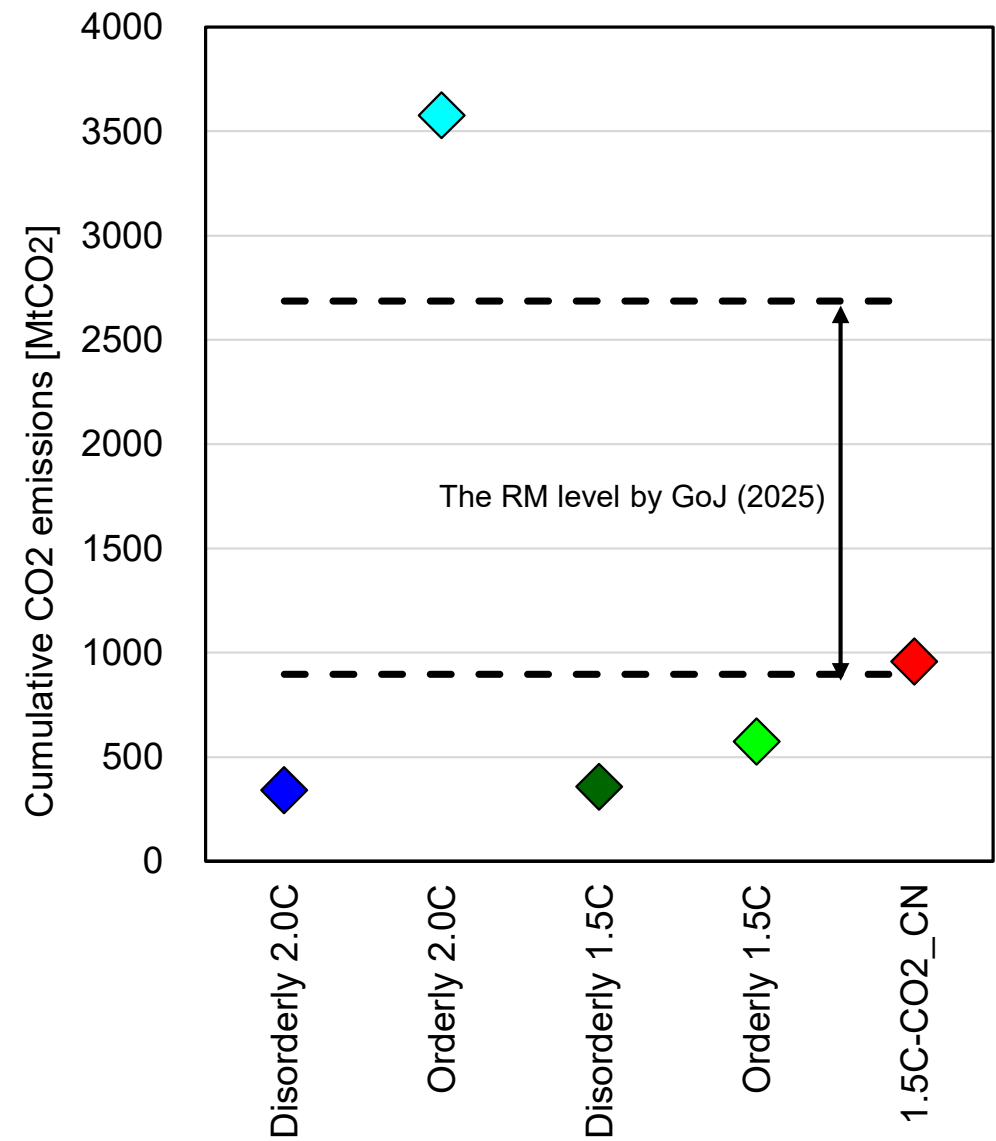
✓ There is no big differences in the trend of CO₂ intensity among Disorderly 1.5°C/2.0°C and Orderly 1.5°C, which assume GHG net zero emissions in 2050, although the power mixes are varied, and achieving CN by around 2040 would be cost-effective as a whole.

CO₂ emissions in power sector (Japan): comparison with the RM by GoJ

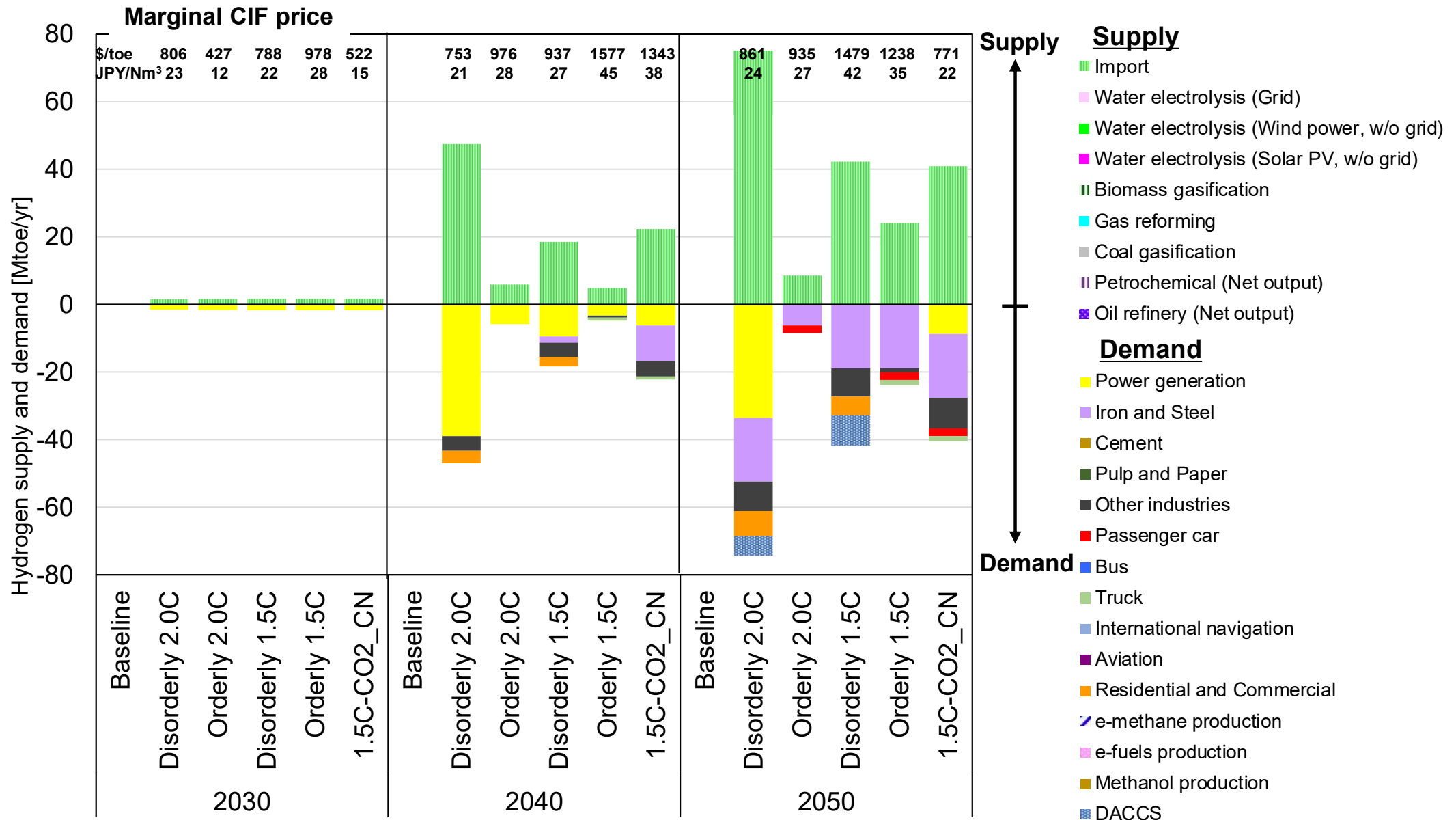
2023-2030



2031-2050

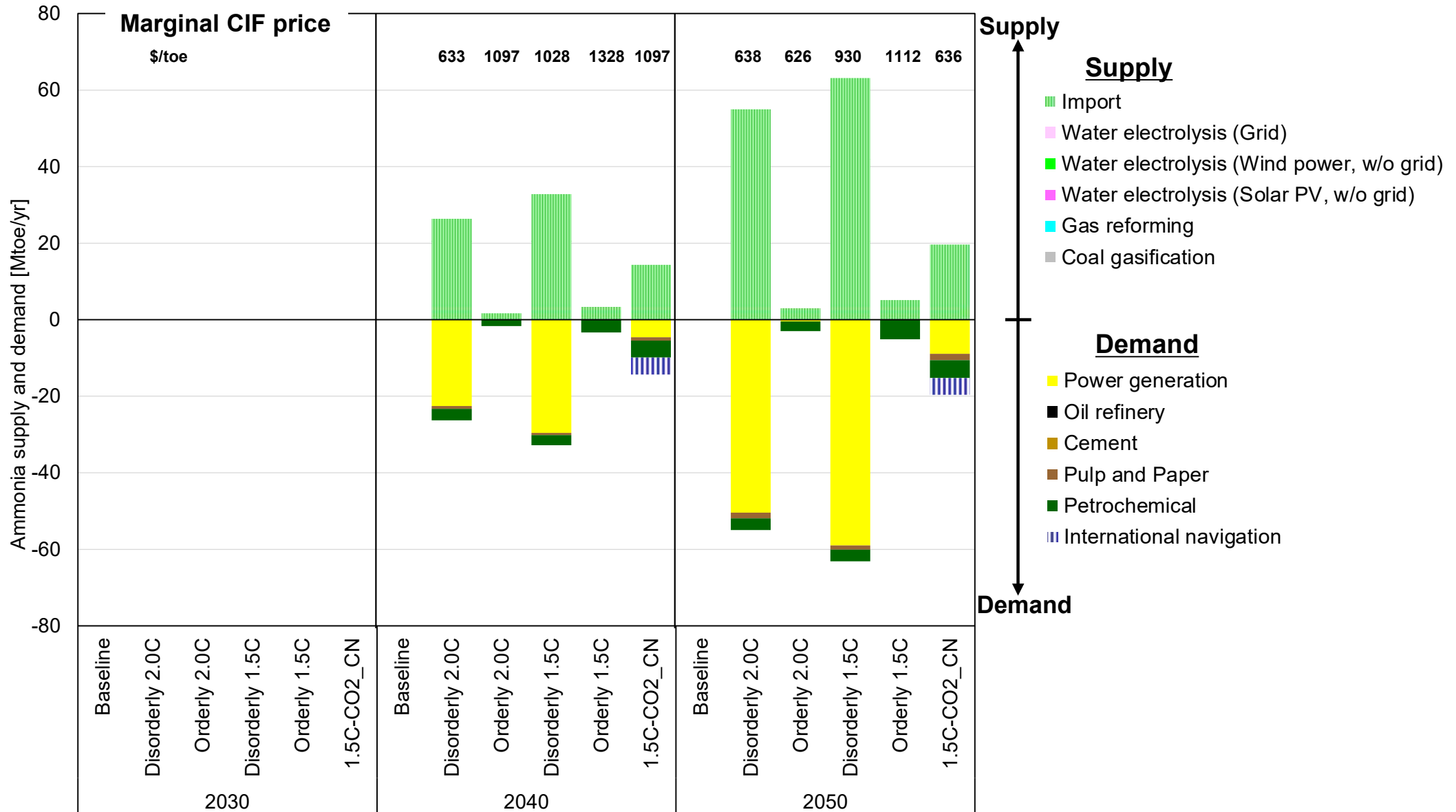


Supply and demand of hydrogen (Japan)



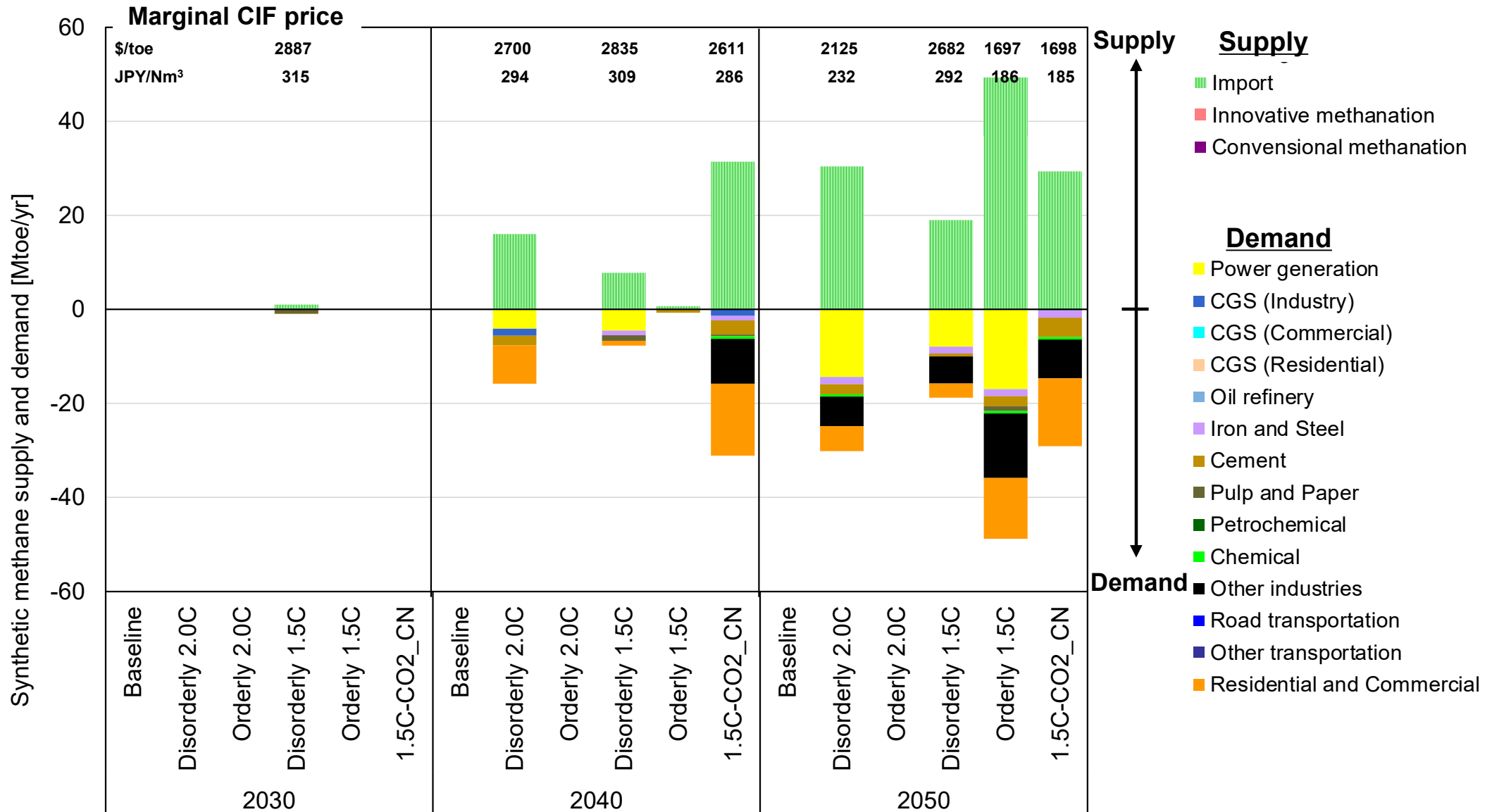
- ✓ Large hydrogen uses for iron and steel sector are estimated in 2050.
- ✓ Domestic hydrogen productions are not observed, and most of hydrogen is imported in all the scenarios.
- ✓ The marginal prices of CIF of the 1.5°C scenarios are high due to competitions among countries.

Supply and demand of ammonia (Japan)



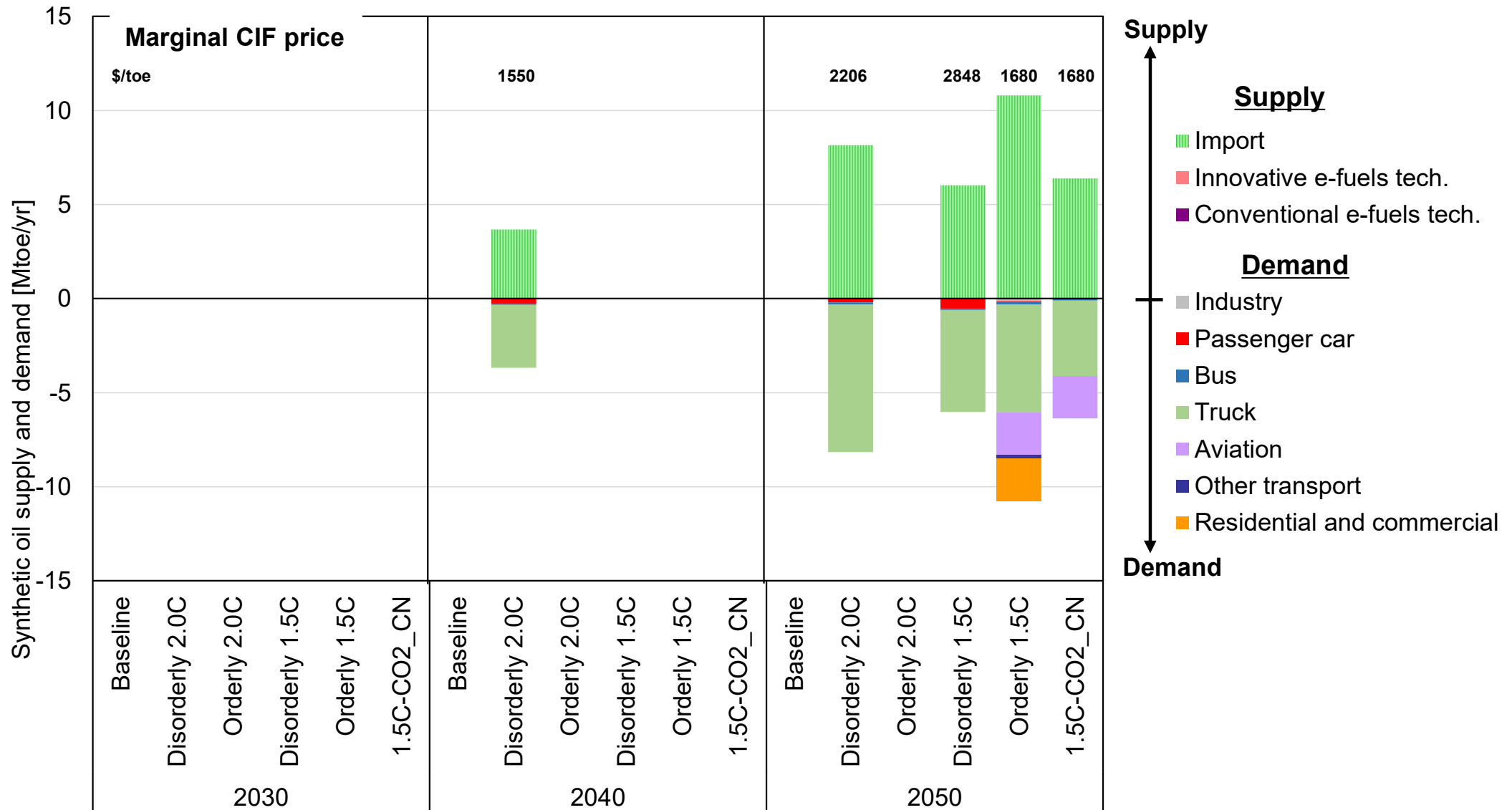
- ✓ In the Disorderly 1.5°C/2.0°C scenarios, the cost reductions of VRE are gradual, and blue ammonia from overseas plays an important role in the power sector.
- ✓ Ammonia uses for industrial sectors are also economical options in Japan.

Supply and demand of e-methane (synthetic methane) (Japan)



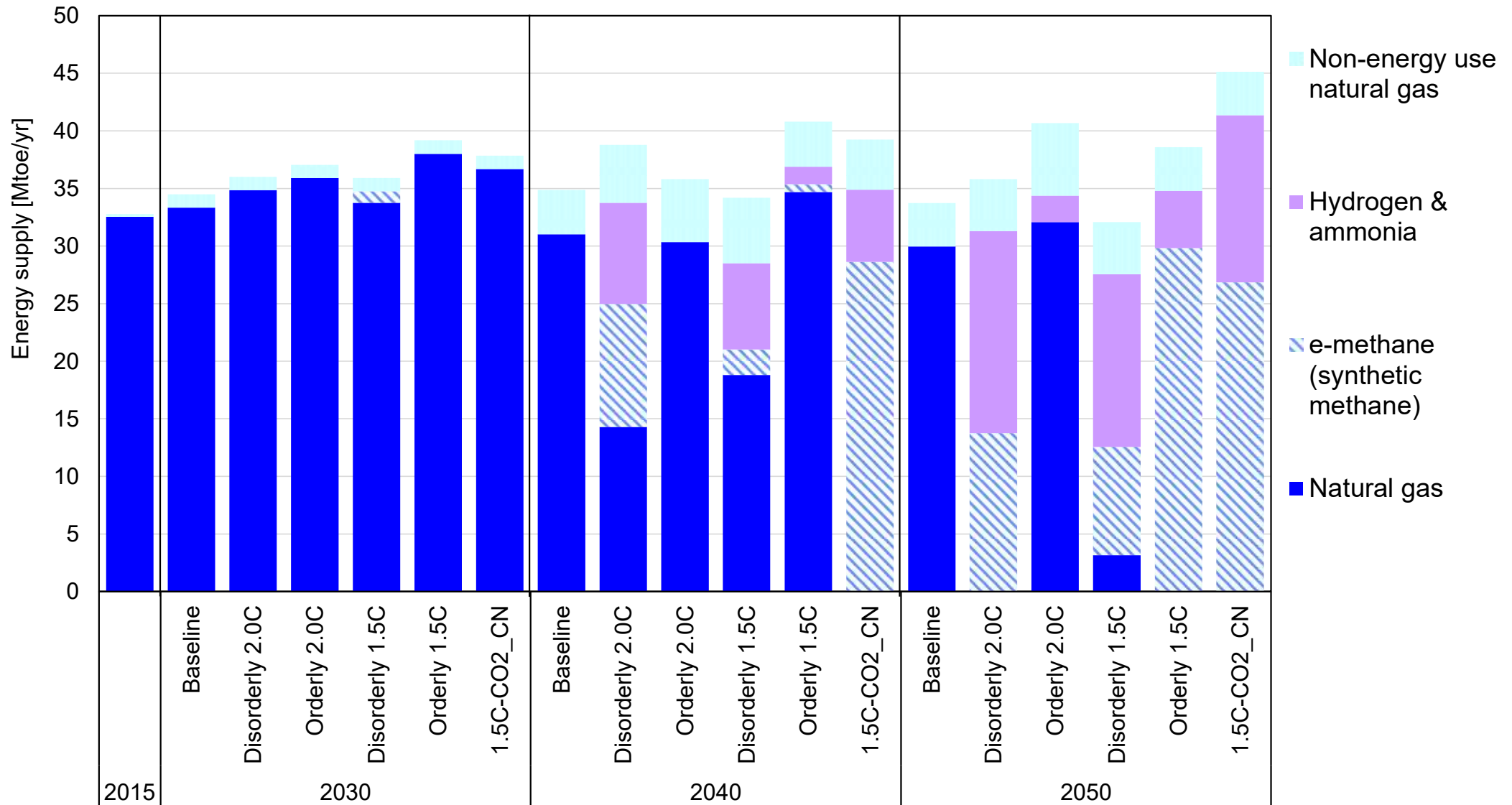
- ✓ e-methane will contribute to power sector as well as building and industrial sectors.
- ✓ Productions of synthetic methane overseas are dominant due to differences in renewable energy costs.

Supply and demand of e-fuels (synthetic oil) (Japan)



- ✓ Uses of passenger car is observed, but relatively large uses are for truck and aviation due to their limited alternatives.
- ✓ Synthetic oil is produced overseas, where the costs of renewables are cheaper.

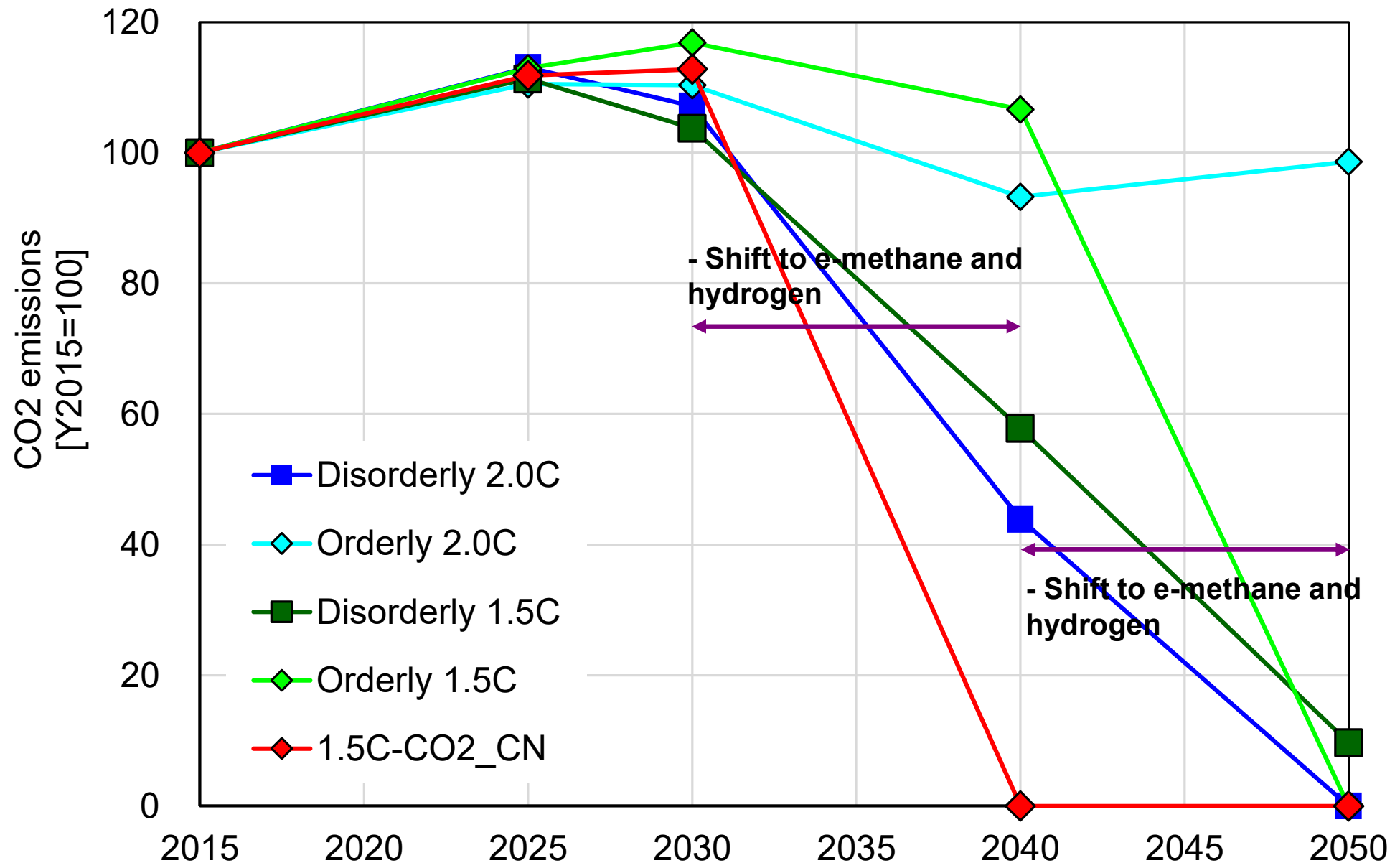
Gas supply (Japan)



Note) The uses in power, iron & steel, and petrochemical sectors are not included here and described in each sectoral analysis.

- ✓ In Orderly 2.0°C, natural gas supply would keep the current level or slightly decrease by 2050. Other scenarios predict greater uses of hydrogen or synthetic methane after 2040.
- ✓ The choice between hydrogen and synthetic methane is sensitive depending on preconditions, such as the assumption of cost reduction timing.

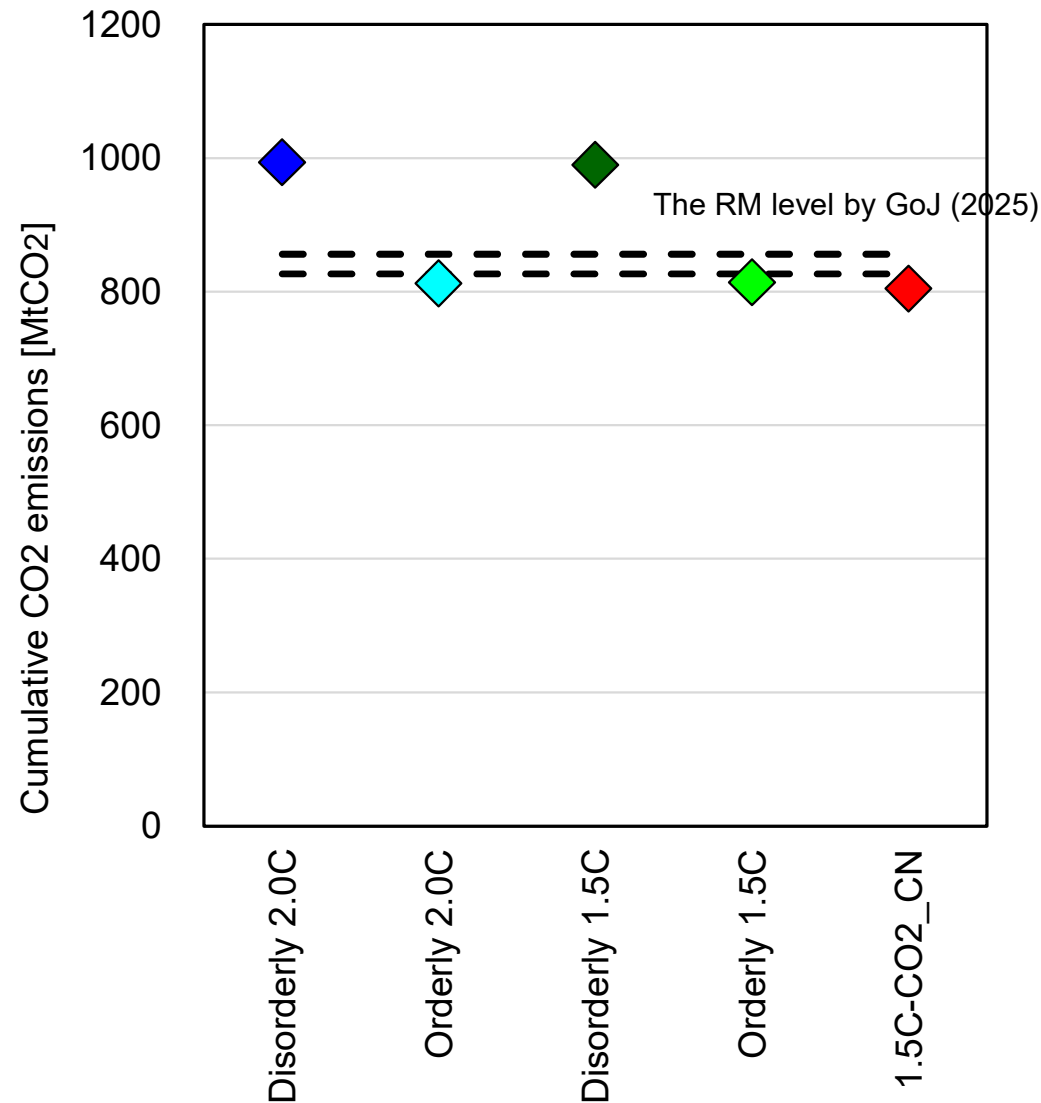
CO₂ emissions from gas (Japan)



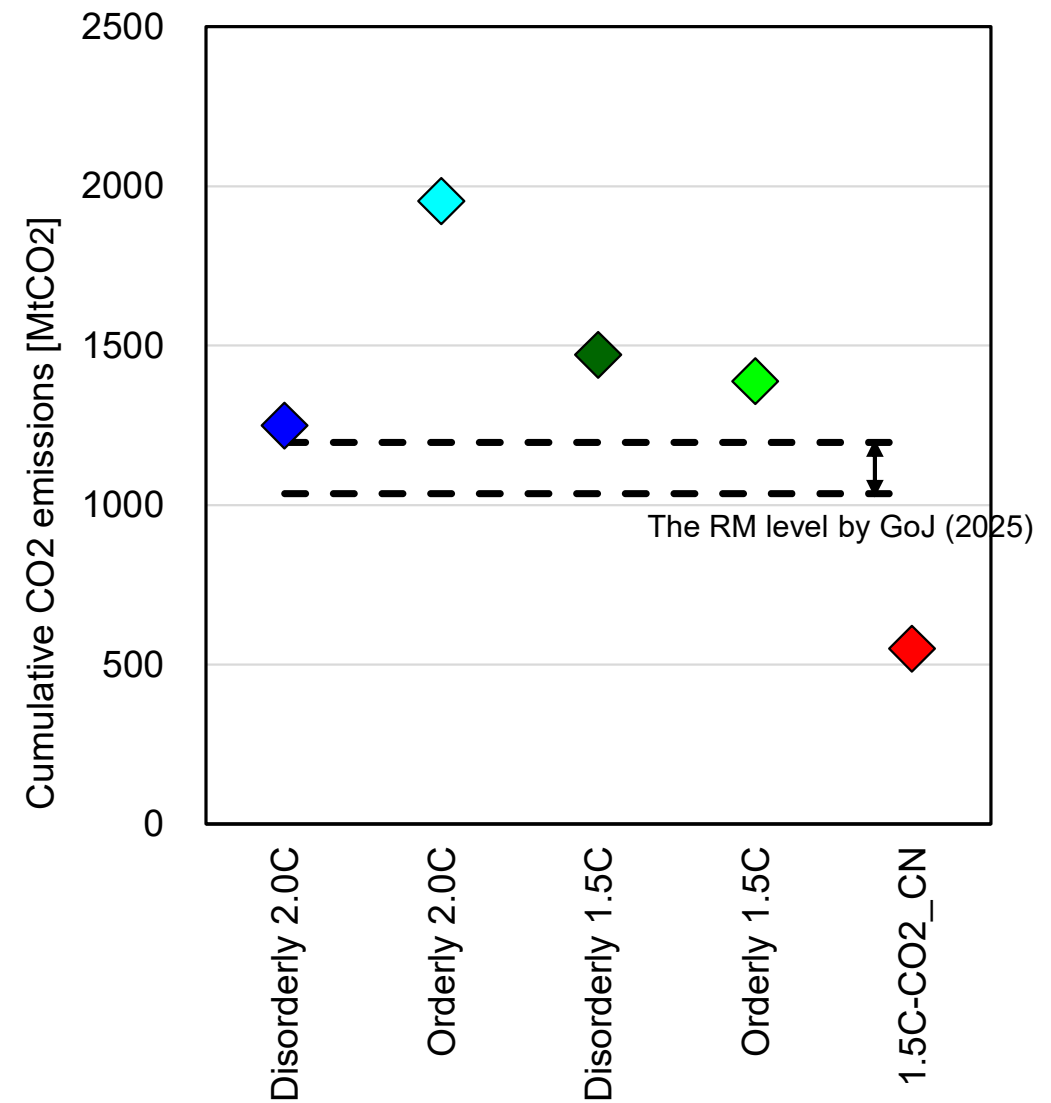
✓ As for Orderly 1.5°C, it can be interpreted that the MAC would be close to those of other countries in 2040, causing competition in importing synthetic fuels and hydrogen (the marginal CIF price is also high), and the CO₂ emissions in 2040 is relatively large.

CO₂ emissions in gas sector (Japan): comparison with the RM by GoJ

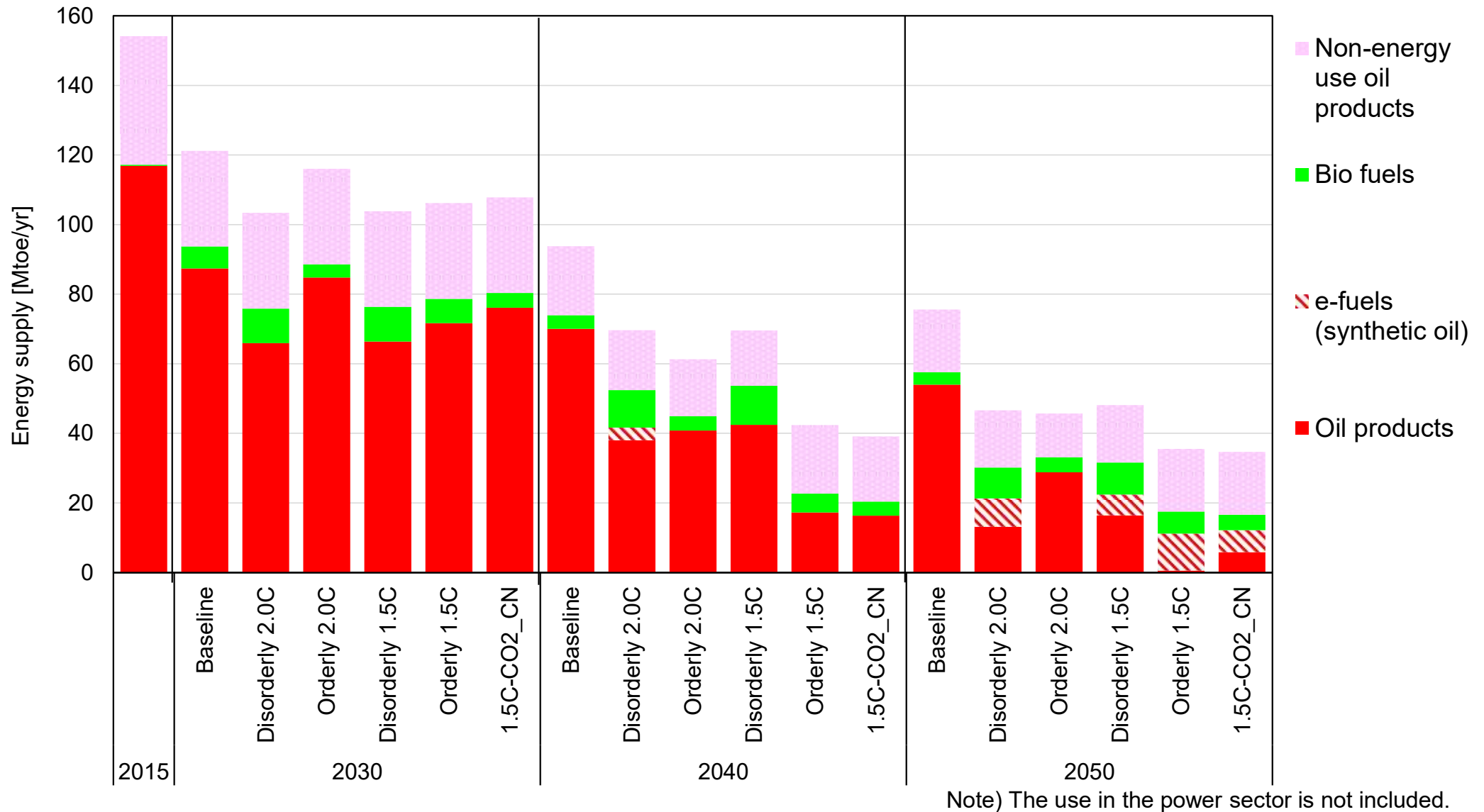
2023-2030



2031-2050

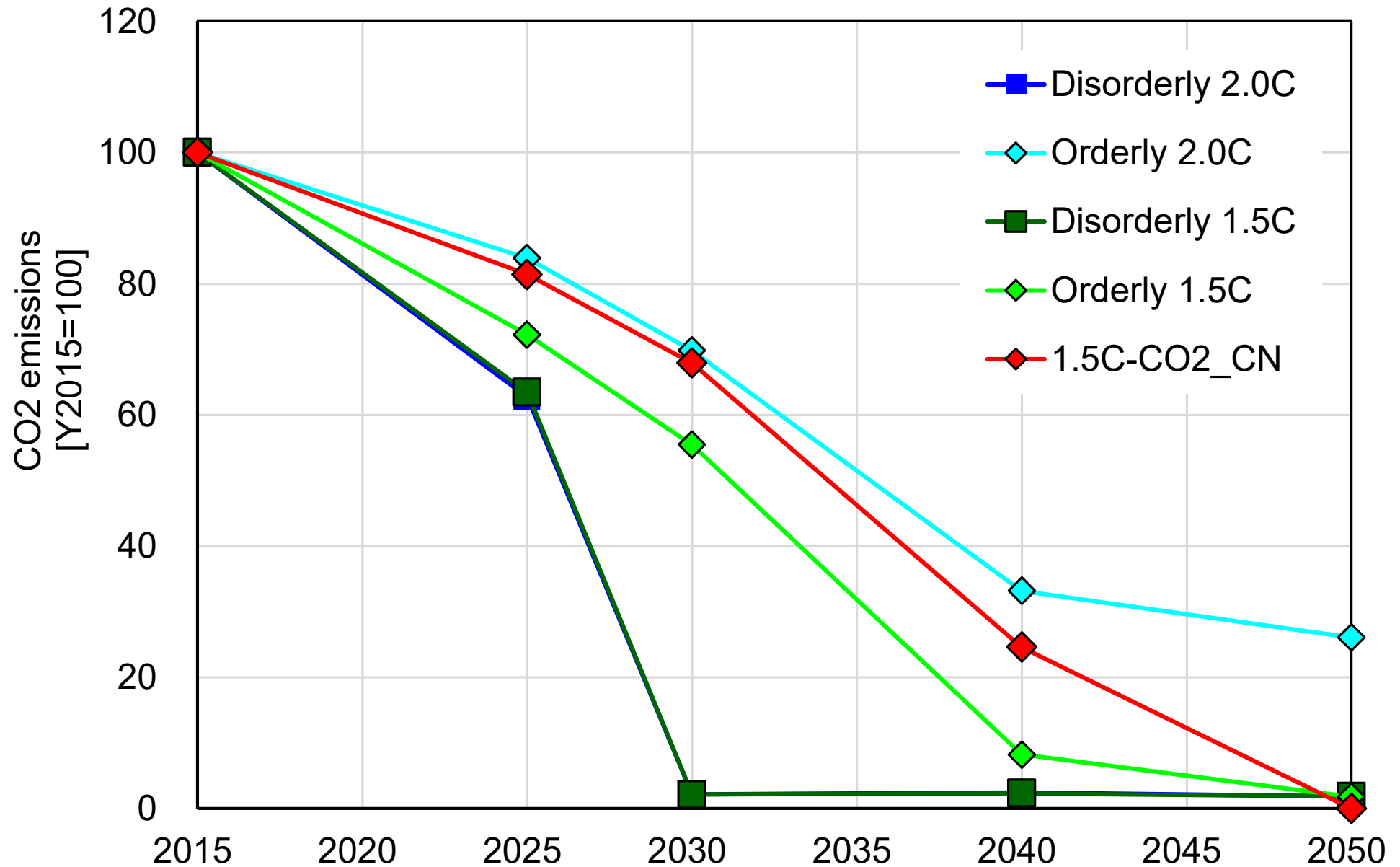


Oil (liquid fuels) supply (Japan)



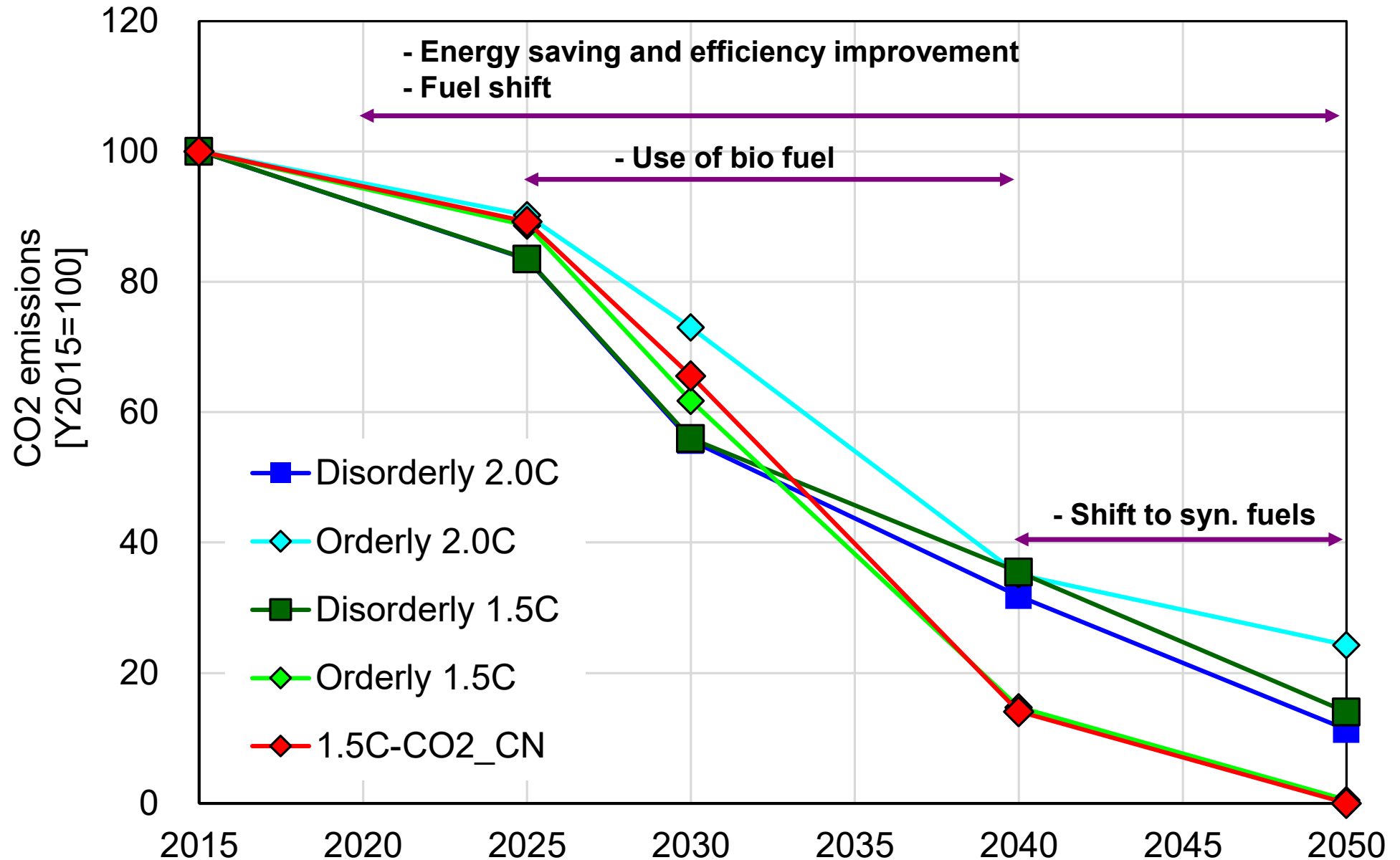
- ✓ Oil use is considerably decreasing due to efficiency improvement of automobiles, EV diffusion, and so on, in any scenarios. This trend is notable especially in Orderly 1.5°C, which assumes high cost reduction of renewable energy and EV. (Please refer to the results of the transport sector.)
- ✓ The use of e-fuels is observed in 2050. In particular, oil would be replaced with e-fuels in Orderly 1.5°C, in which emission offset is limited due to strict constraints on CCS, and the price of e-fuels decreases because of a decline of renewables costs.

CO₂ emissions in oil refinery: Scope 1 (Japan)



✓ Scope1 emissions are decreasing as oil refining volume decreases. This trend is particularly strong in Disorderly scenarios, where there are large differences in CO₂ MAC with other countries.

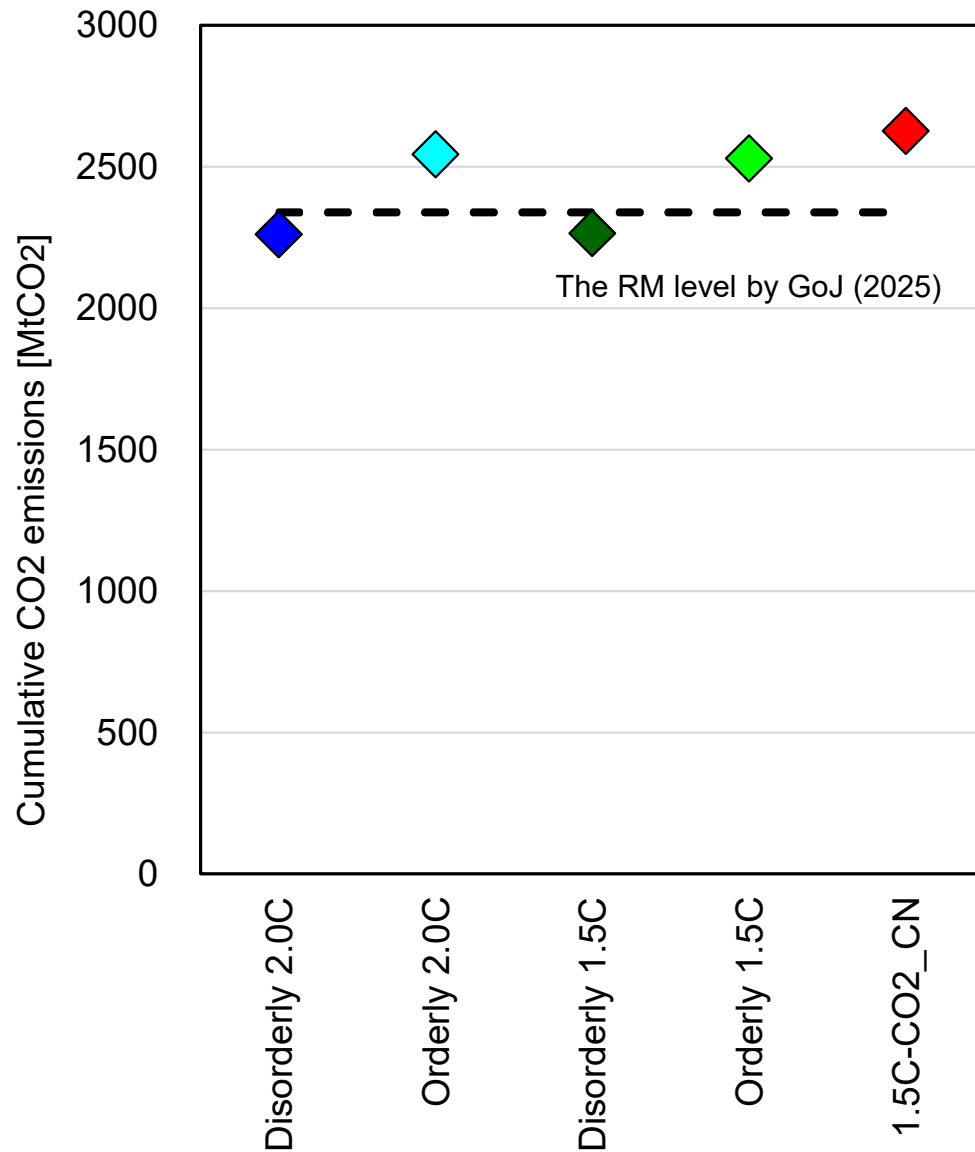
CO₂ emissions from oil (Japan)



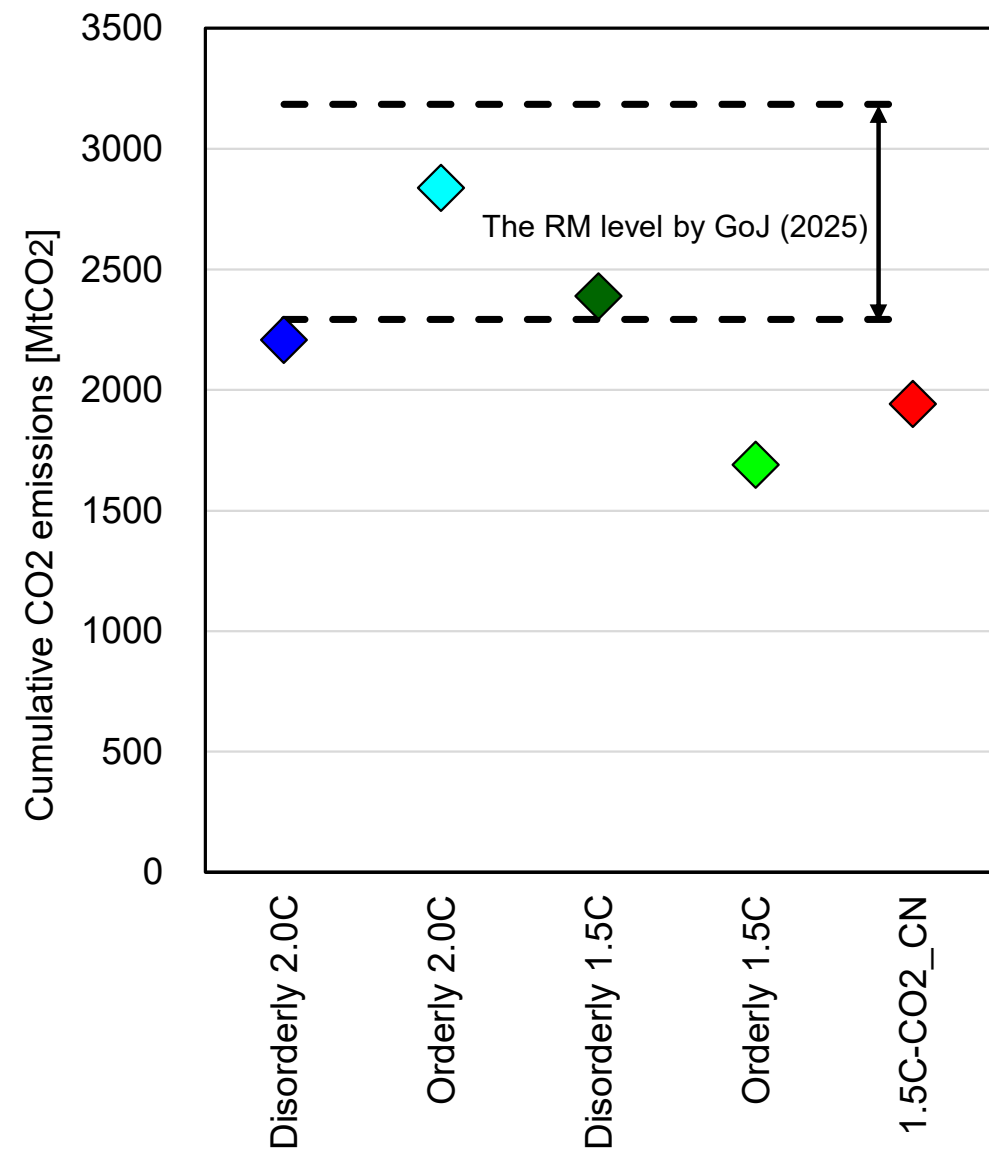
✓ In Orderly 1.5°C, which assumes strict constraints on CCS, CO₂ emissions in 2050 would be reduced to almost zero because there is a small room for offsetting emissions through DACCS, etc.

CO₂ emissions in oil sector (Japan): comparison with the RM by GoJ

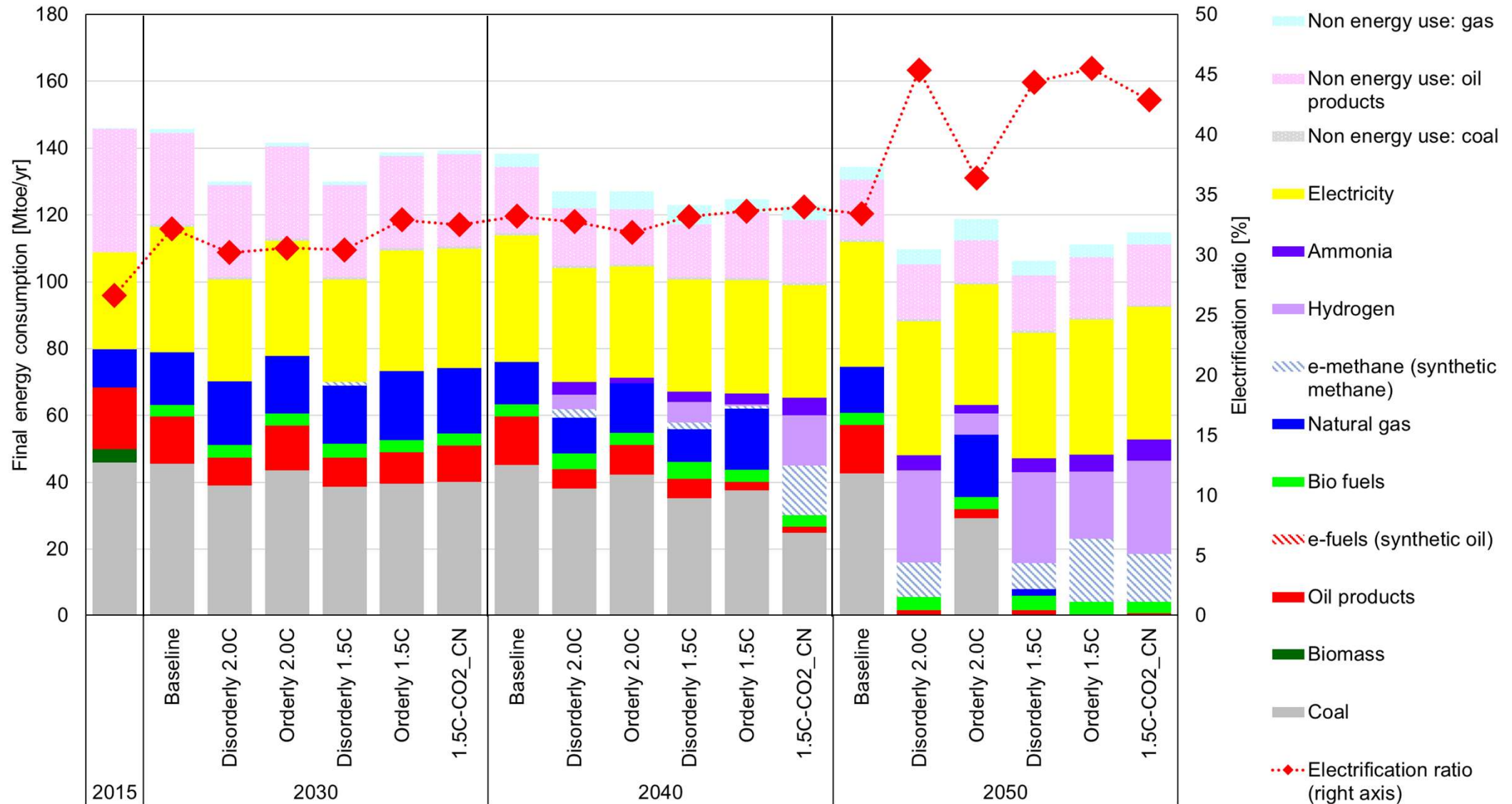
2023-2030



2031-2050

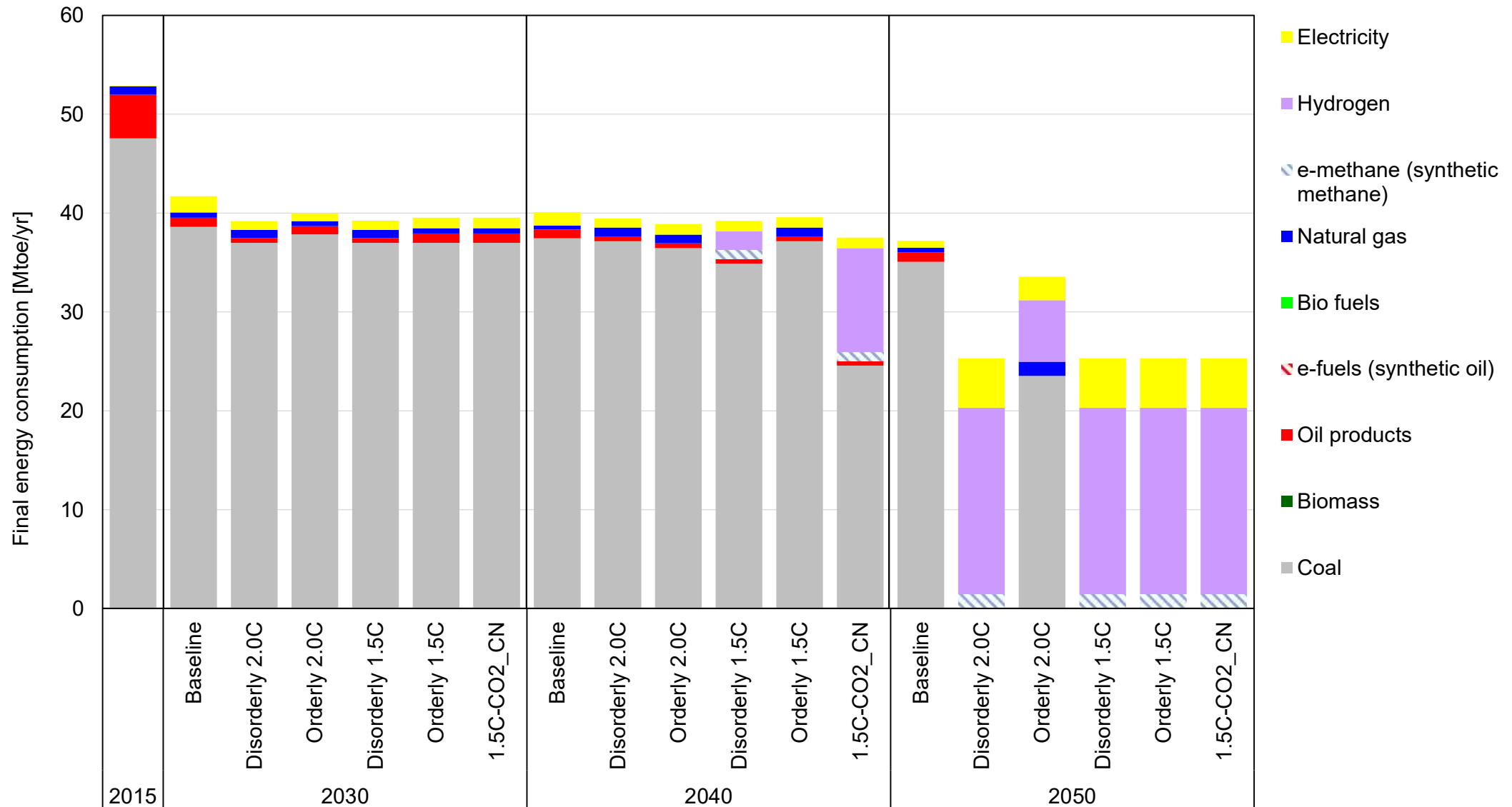


Final energy consumption in industry (Japan)



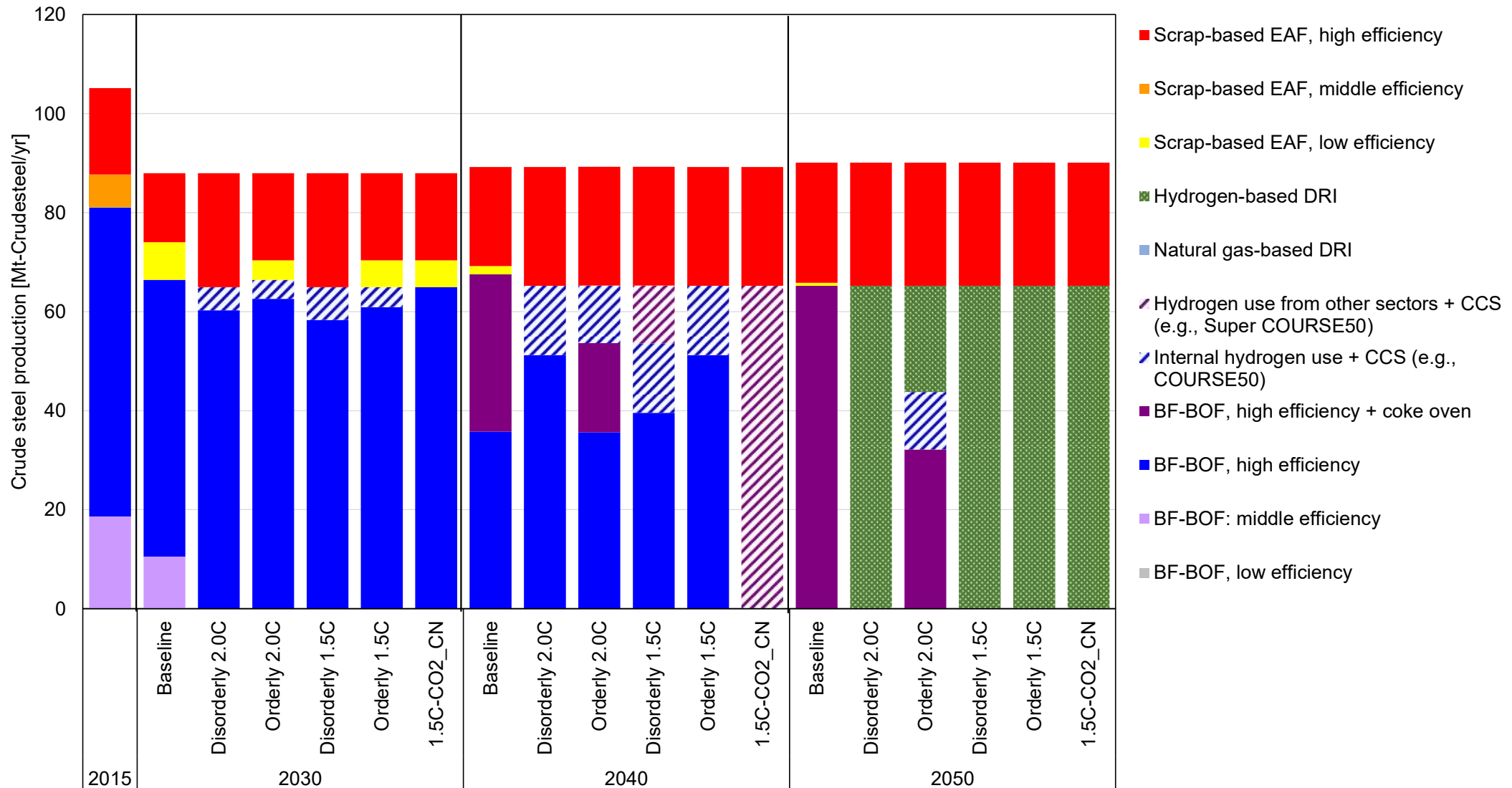
- ✓ Coal uses remain for BF-BOF in the iron and steel sector in 2040.
- ✓ In 2050, coal is not used, and the uses of hydrogen, ammonia, and synthetic methane are observed in the scenarios other than Orderly 2.0°C.

Final energy consumption in iron & steel (Japan)



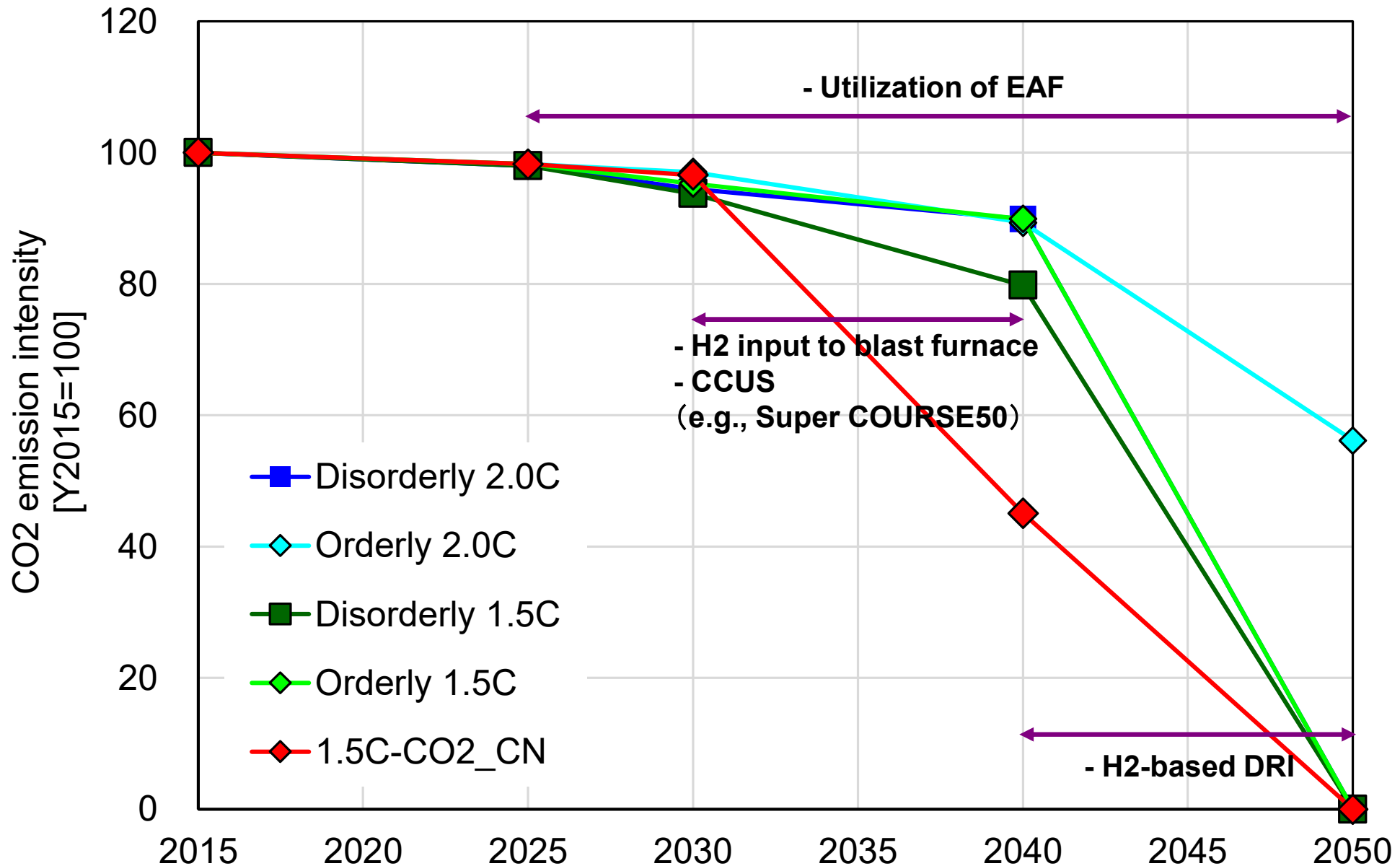
- ✓ Coal is used in BF-BOF in 2040. Hydrogen use from other sectors (Super COURSE50) is also observed.
- ✓ In 2050, coal is not used and replaced with hydrogen-based DRI in other scenarios than Orderly 2.0°C, in which total emission is predicted to be ▲63% relative to 2013. Synthetic methane is used in scrap-based EAF.

Steel production by technology (Japan)



- ✓ Up to 2040, CCS will play an important role.
- ✓ In 2050, hydrogen-based DRI will play a main role in iron and steel production processes.
- ✓ Under the 1.5C-CO₂_CN scenario, hydrogen use from other sectors in BF (e.g., Super COURSE50 like technologies) will be large.

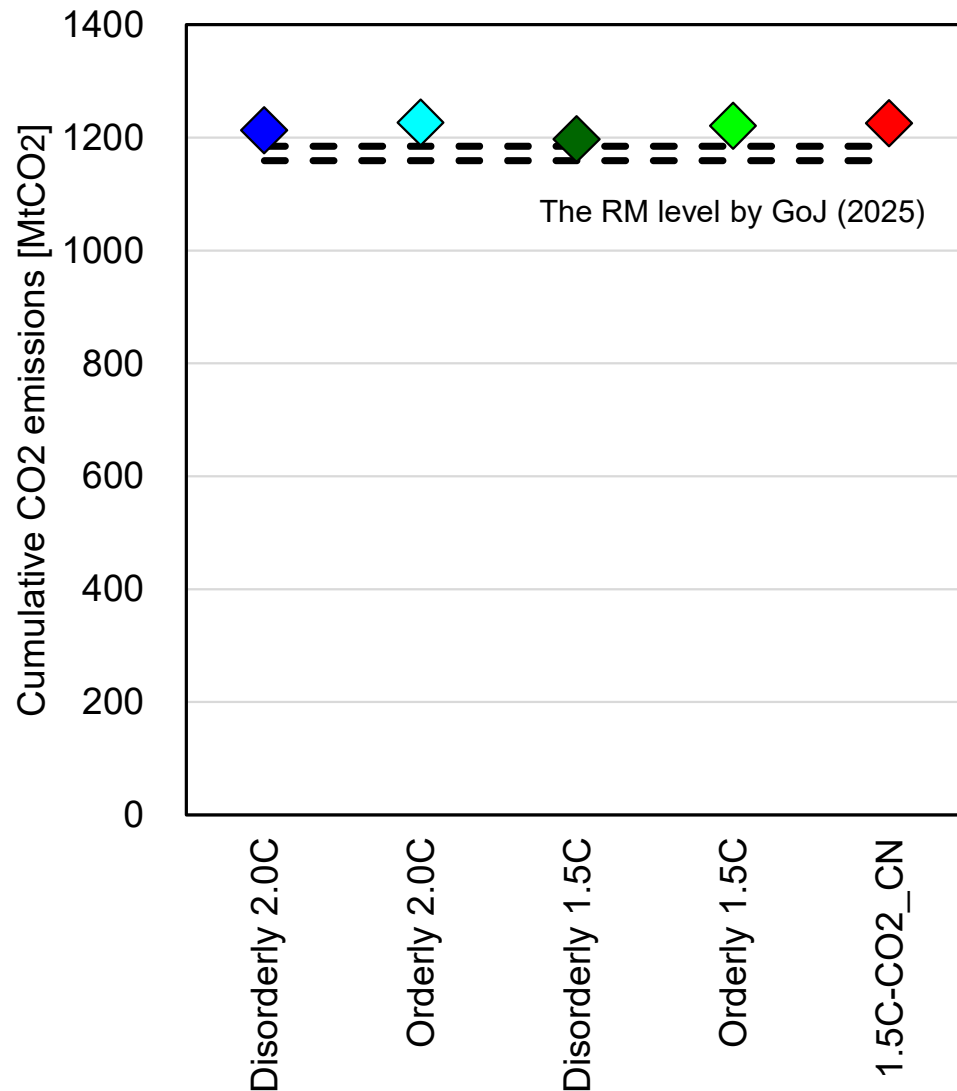
CO₂ intensity of iron and steel sector (Japan)



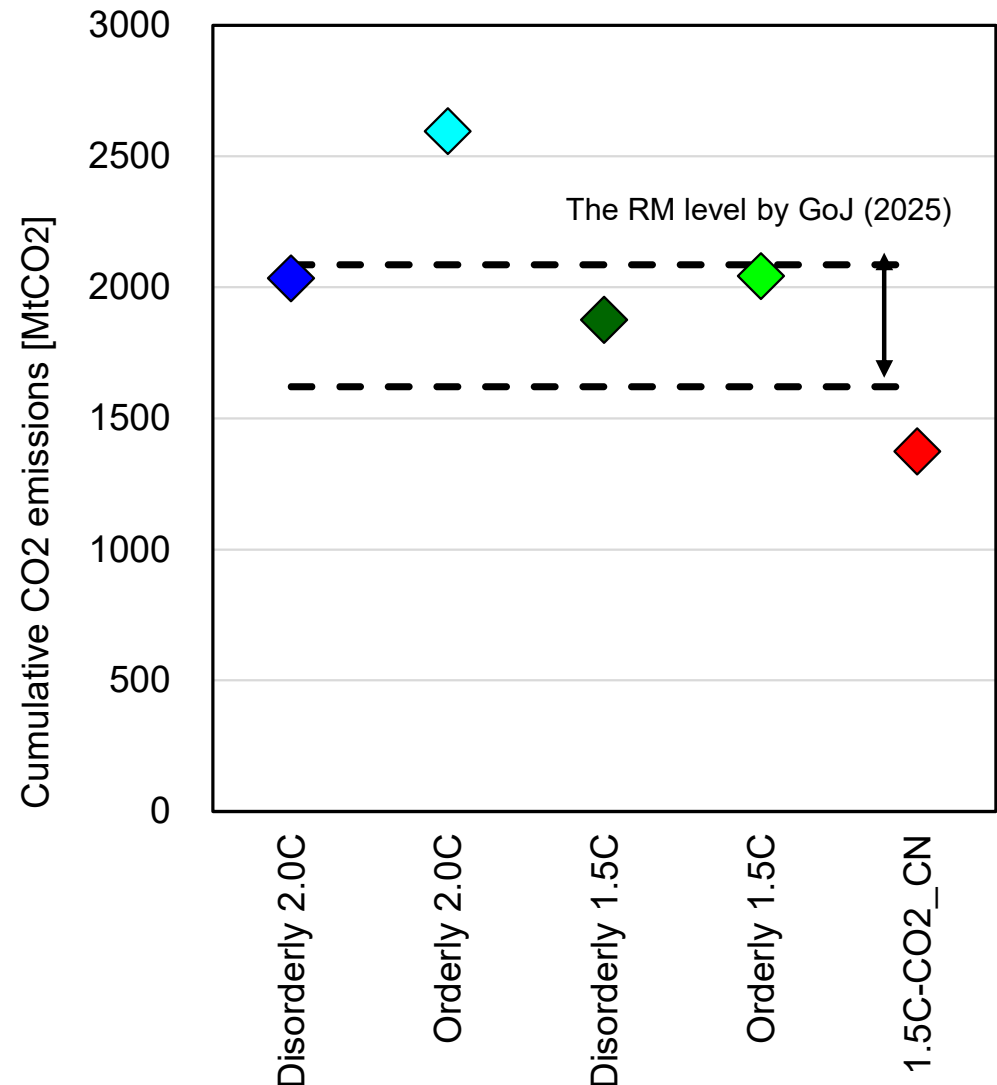
✓ In any scenarios, nearly zero emissions would be achieved in 2050 by CCUS and hydrogen input to BF after 2030, and by a shift to hydrogen-based DRI after 2040. However, a part of emissions remains in 2050 in Orderly 2.0°C.

CO2 emissions in iron & steel sector (Japan): comparison with the RM by GoJ

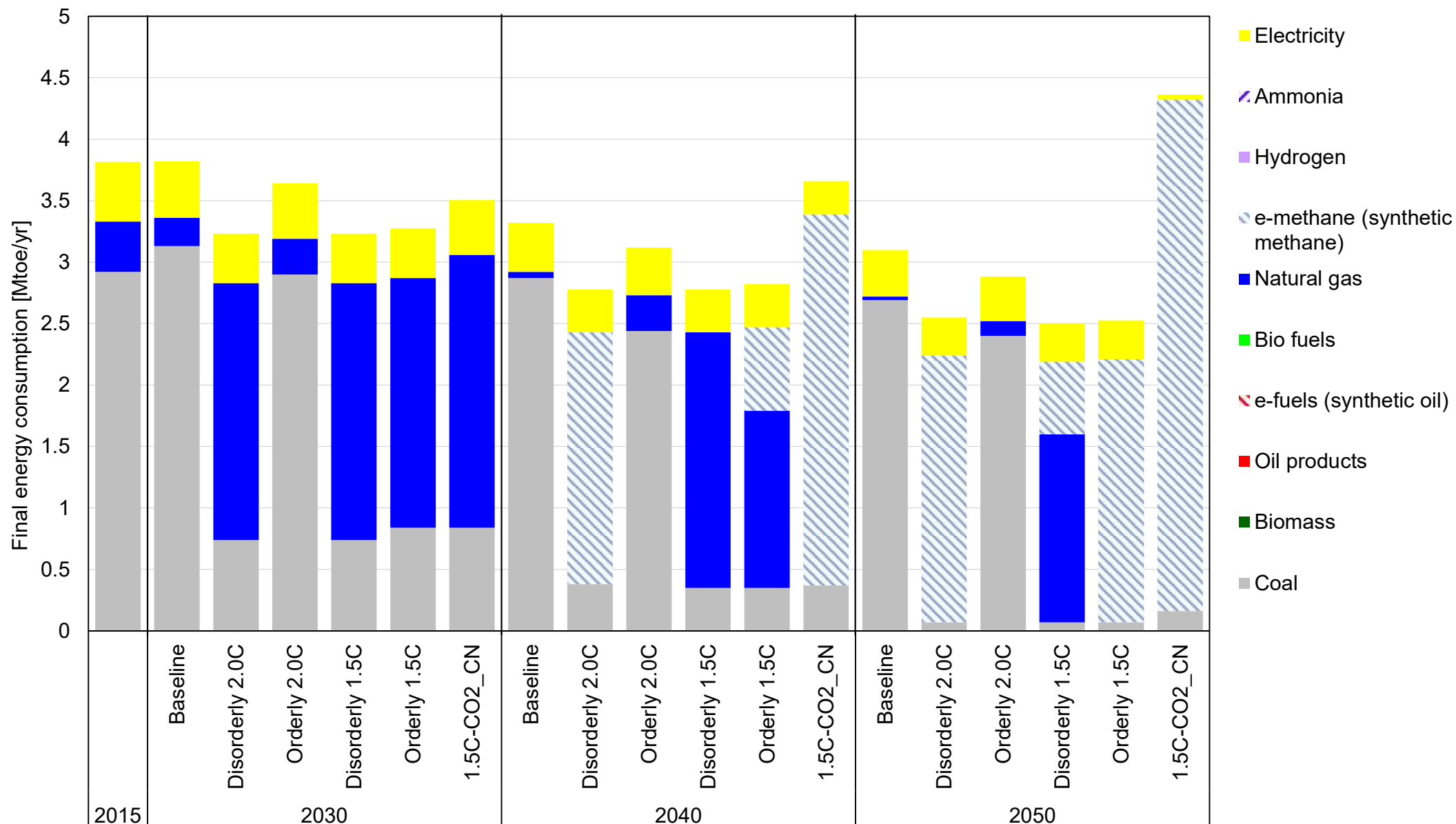
2023-2030



2031-2050

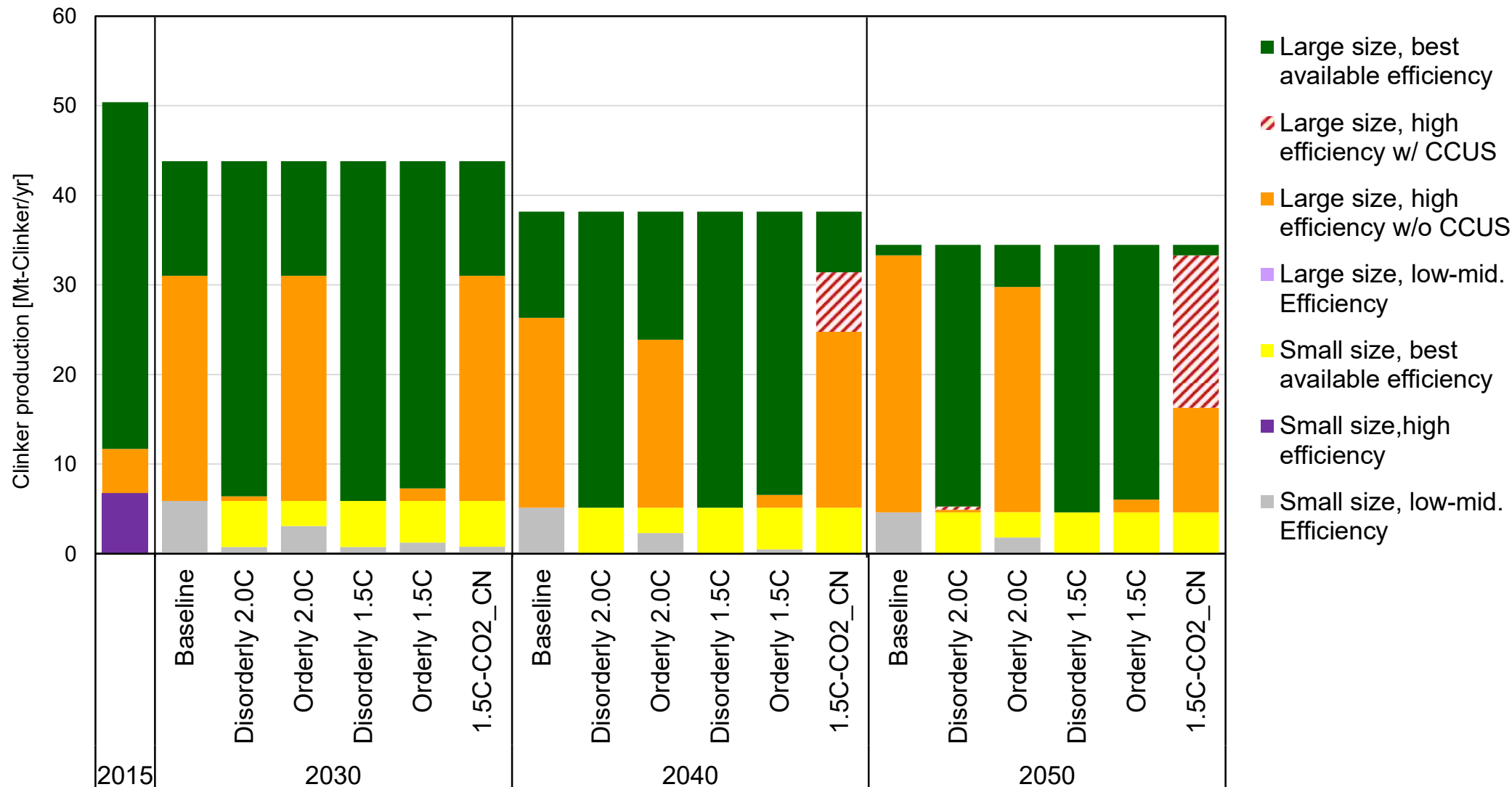


Final energy consumption in cement (Japan)



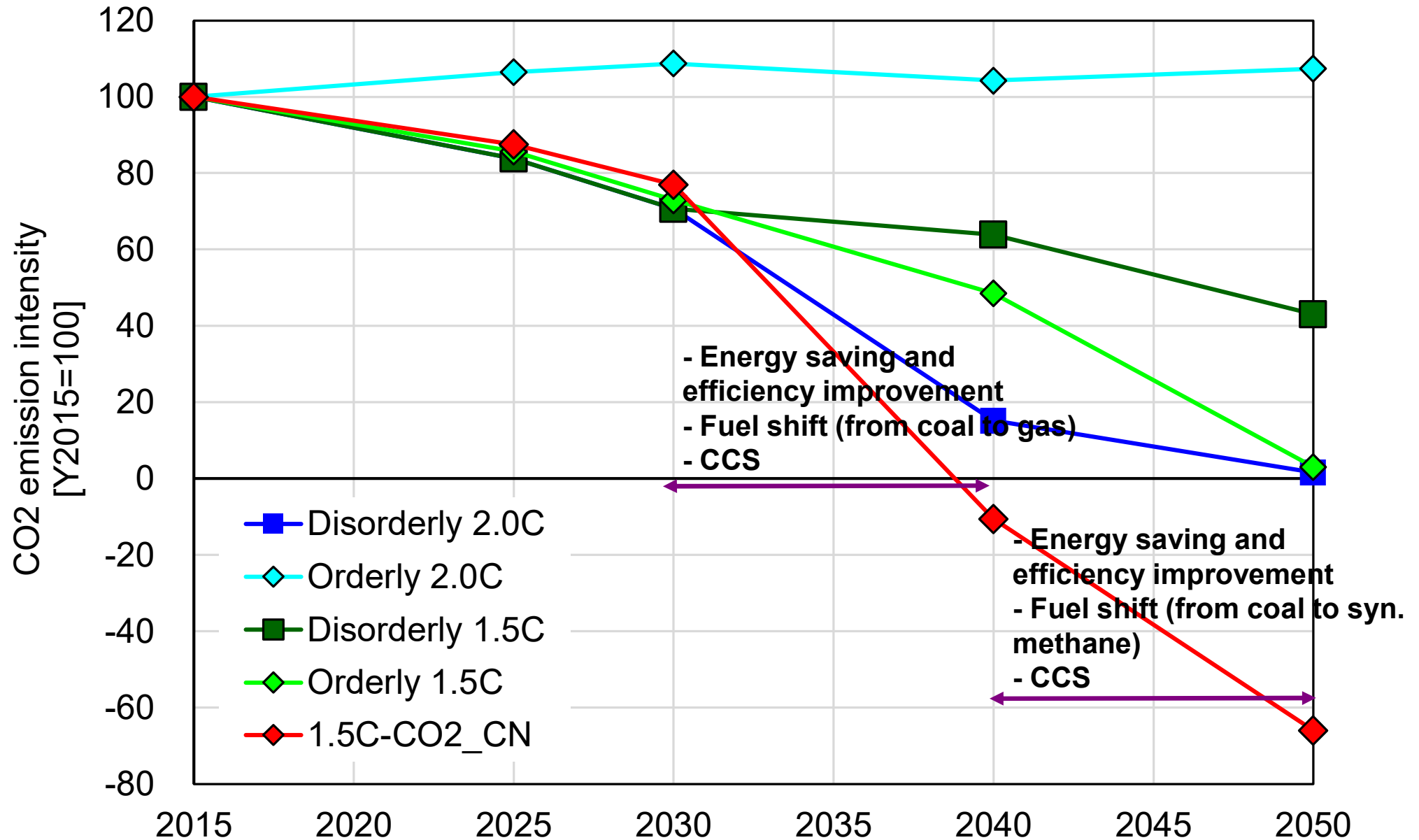
- ✓ A shift from coal to gas is cost-effective in 2030 except Orderly 2.0°C.
- ✓ A further shift to gas is promoted toward 2040, and synthetic methane is evaluated to be cost-effective around 2050 in the scenarios which assume CN in Japan.

Clinker production by technology in cement sector (Japan)

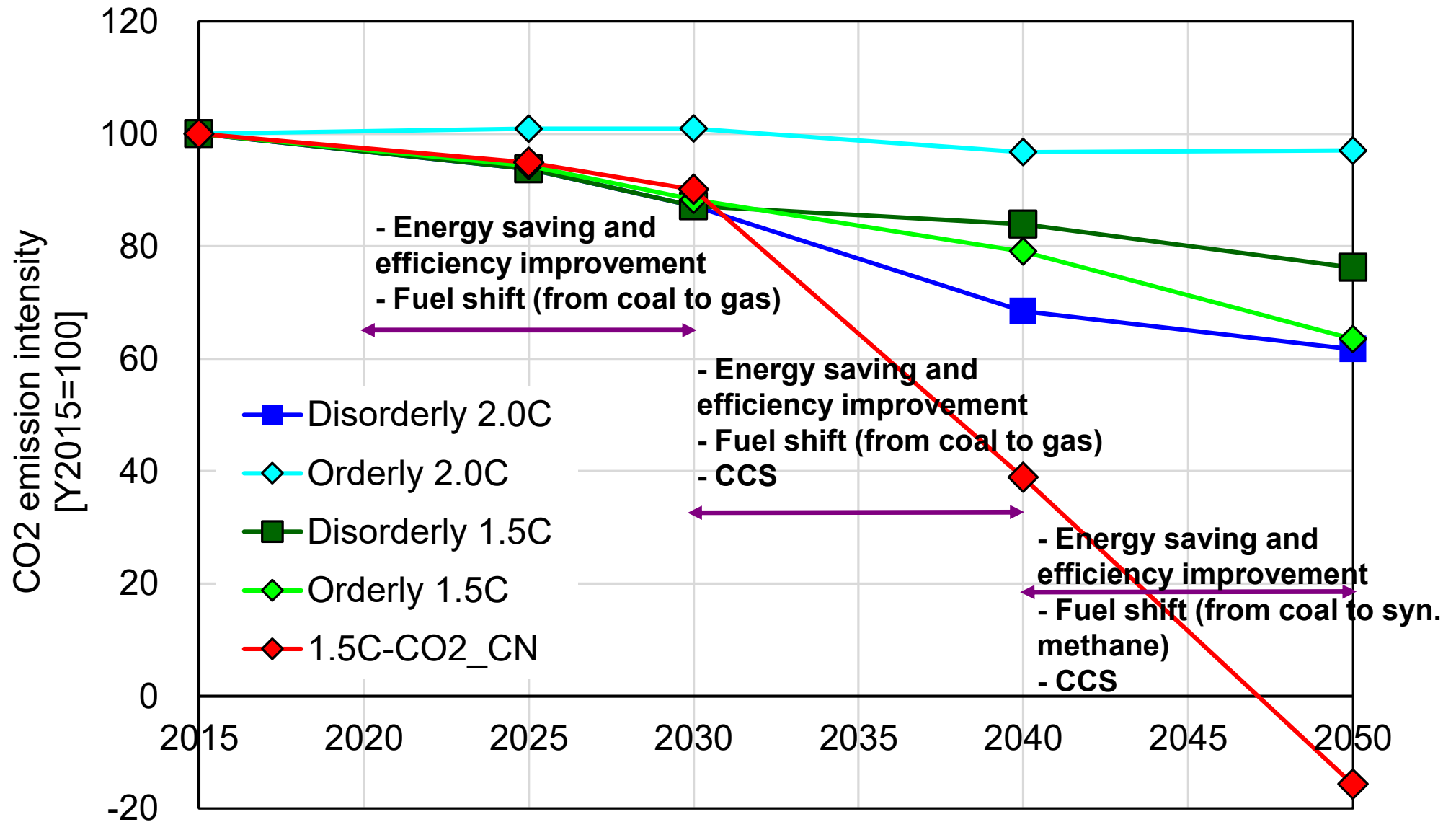


- ✓ CO₂ capture in clinker production is not selected as a cost-effective measure in Japan in other scenarios than 1.5C-CO₂_CN. Some possible reasons are that CCS cost is relatively high in the cement sector and that negative emission measures, such as DACCS, are prioritized due to the constraint on overall CO₂ storage potential.
- ✓ On the other hand, CO₂ capture is also introduced in large size production facility in 1.5C-CO₂_CN.

Energy-related CO₂ intensity of cement sector (Japan)



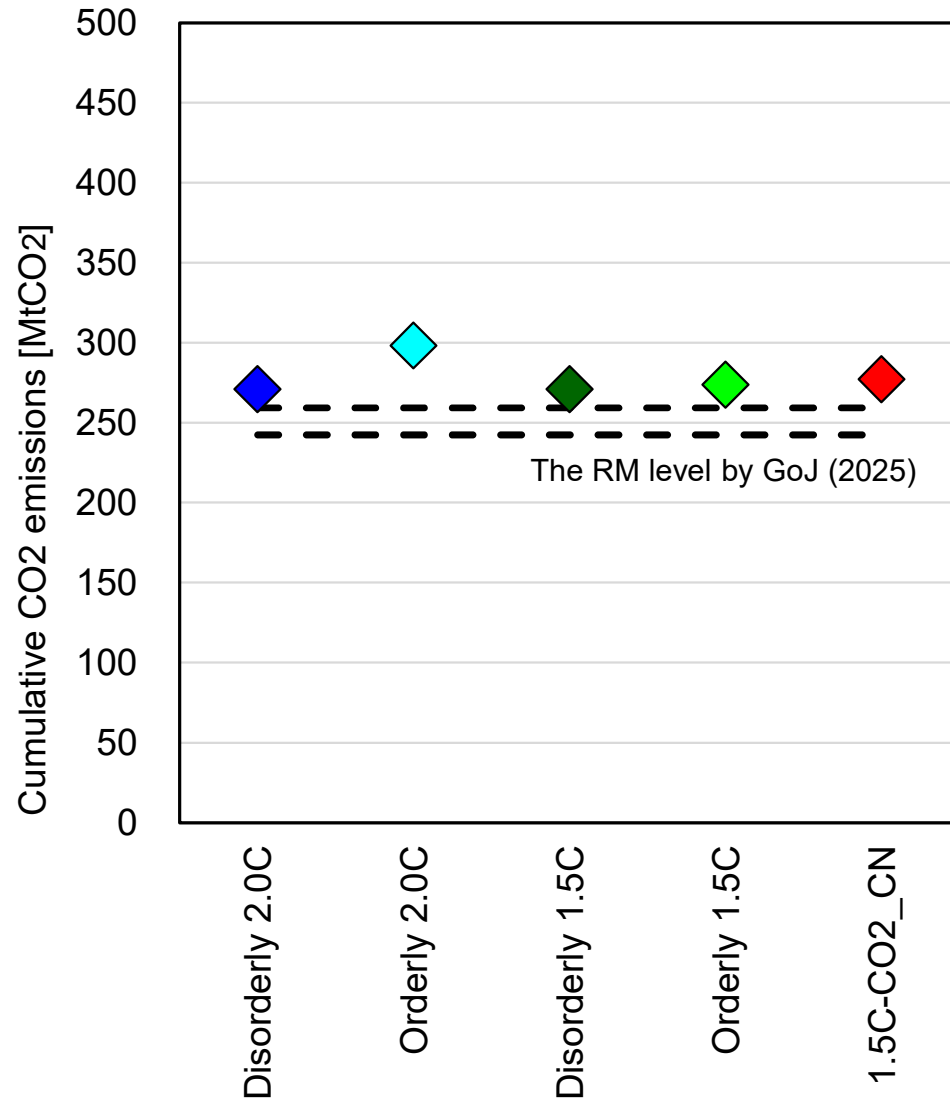
CO₂ intensity of cement sector (Japan)



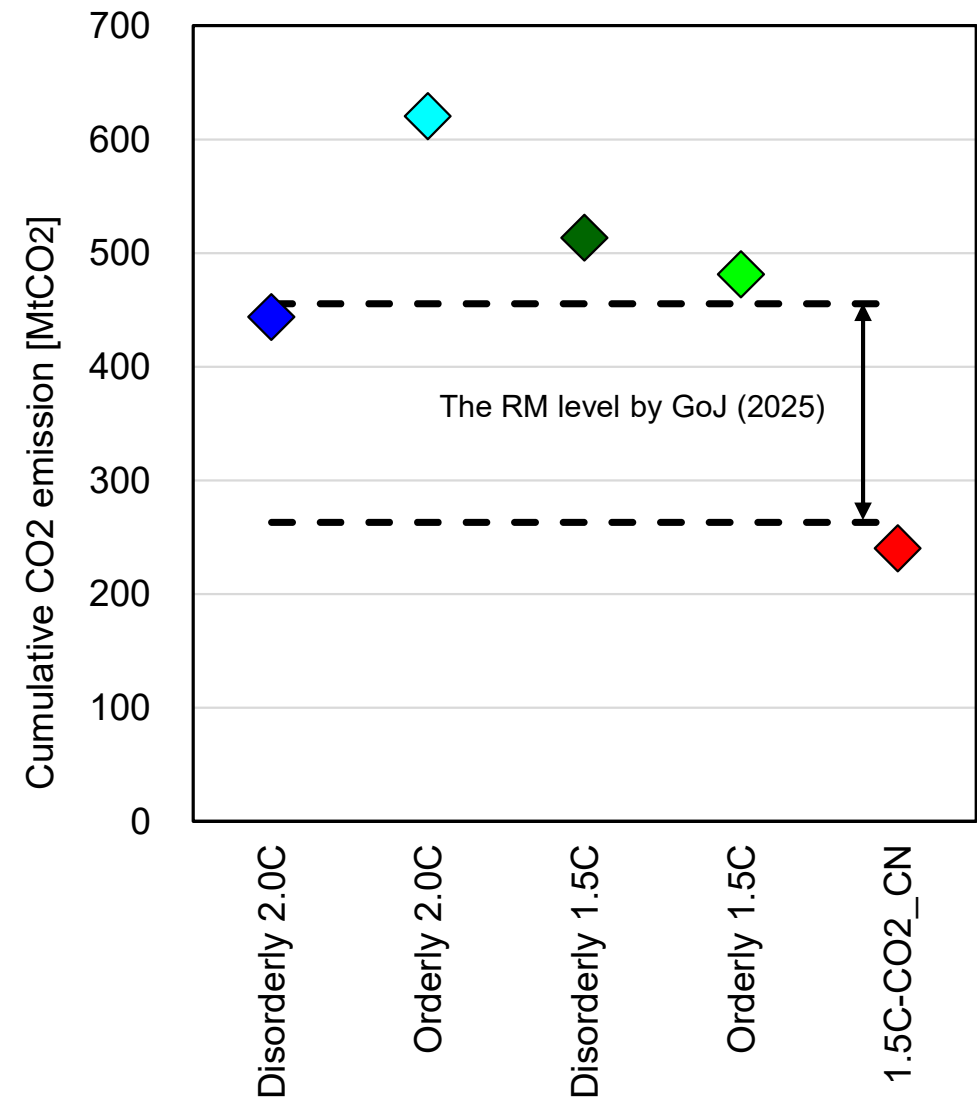
- ✓ In other scenarios than 1.5C-CO₂_CN, emissions from processes still remain in 2050 as there is no CCS deployment.
- ✓ In 1.5C-CO₂_CN, CN is achieved by the introduction of synthetic methane+CCS.

CO₂ emissions in cement sector (Japan): comparison with the RM by GoJ

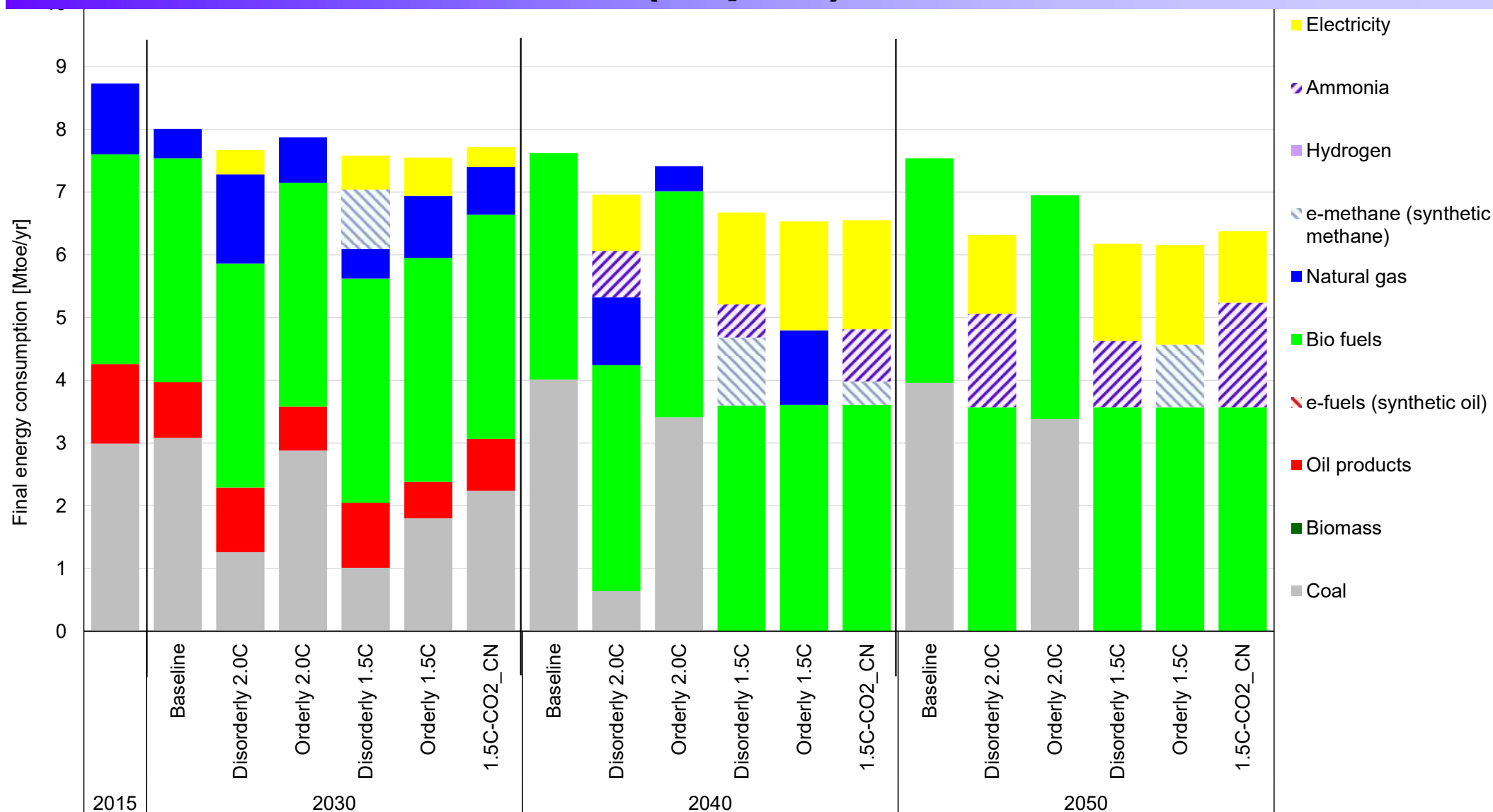
2023-2030



2031-2050



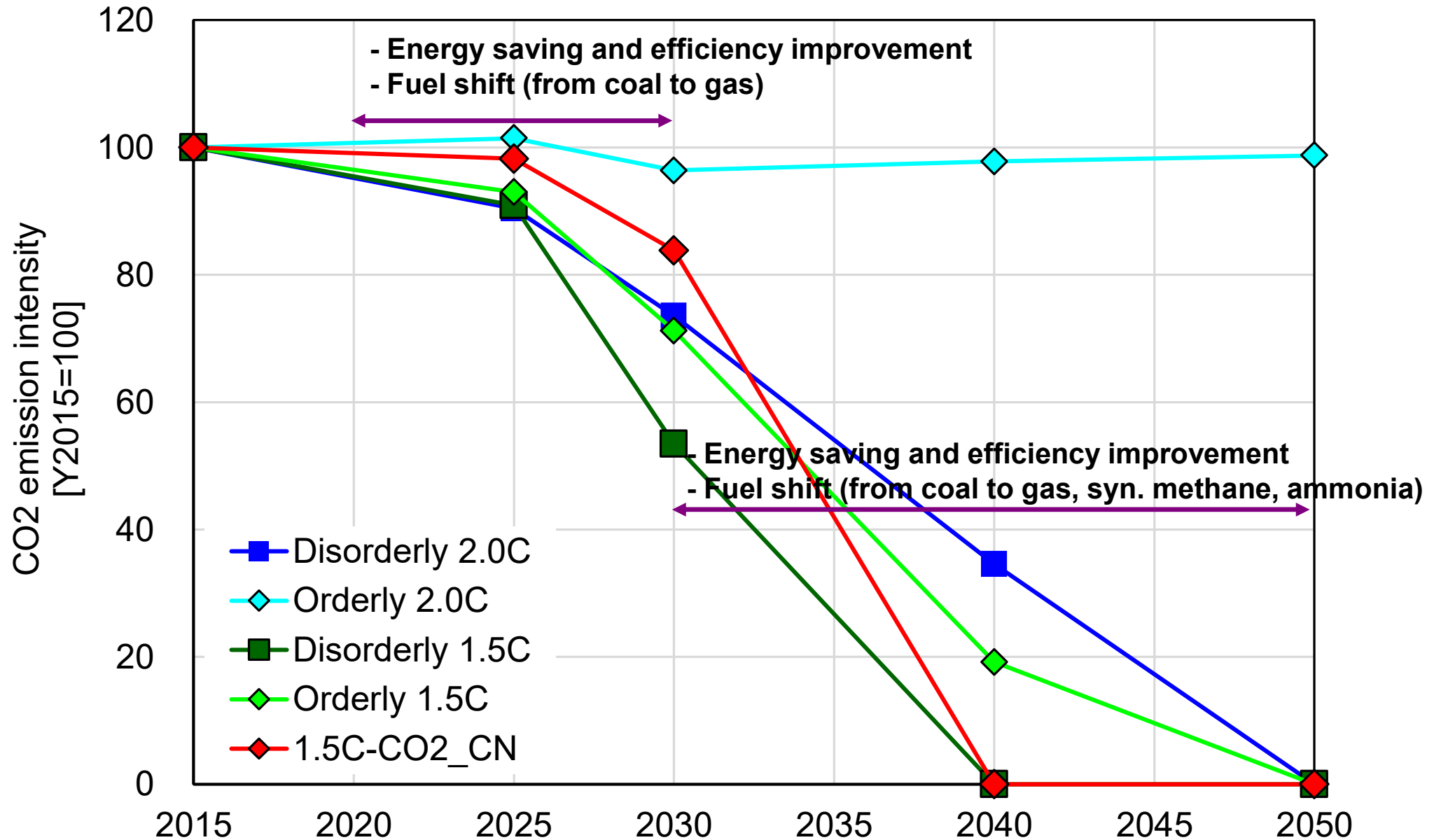
Final energy consumption in paper & pulp (Japan)



Note) Black liquor use is included in biofuels consumption.

- ✓ A Shift from coal to gas, biomass and electricity are observed in 2030.
- ✓ After 2040, a shift to blue ammonia produced overseas in Disorderly 2.0°C/1.5°C, which assumes relatively modest constraints on CCS, and a shift to synthetic methane in Orderly 1.5°C, in which ammonia production is difficult due to relatively strict constraints on CCS, are observed.

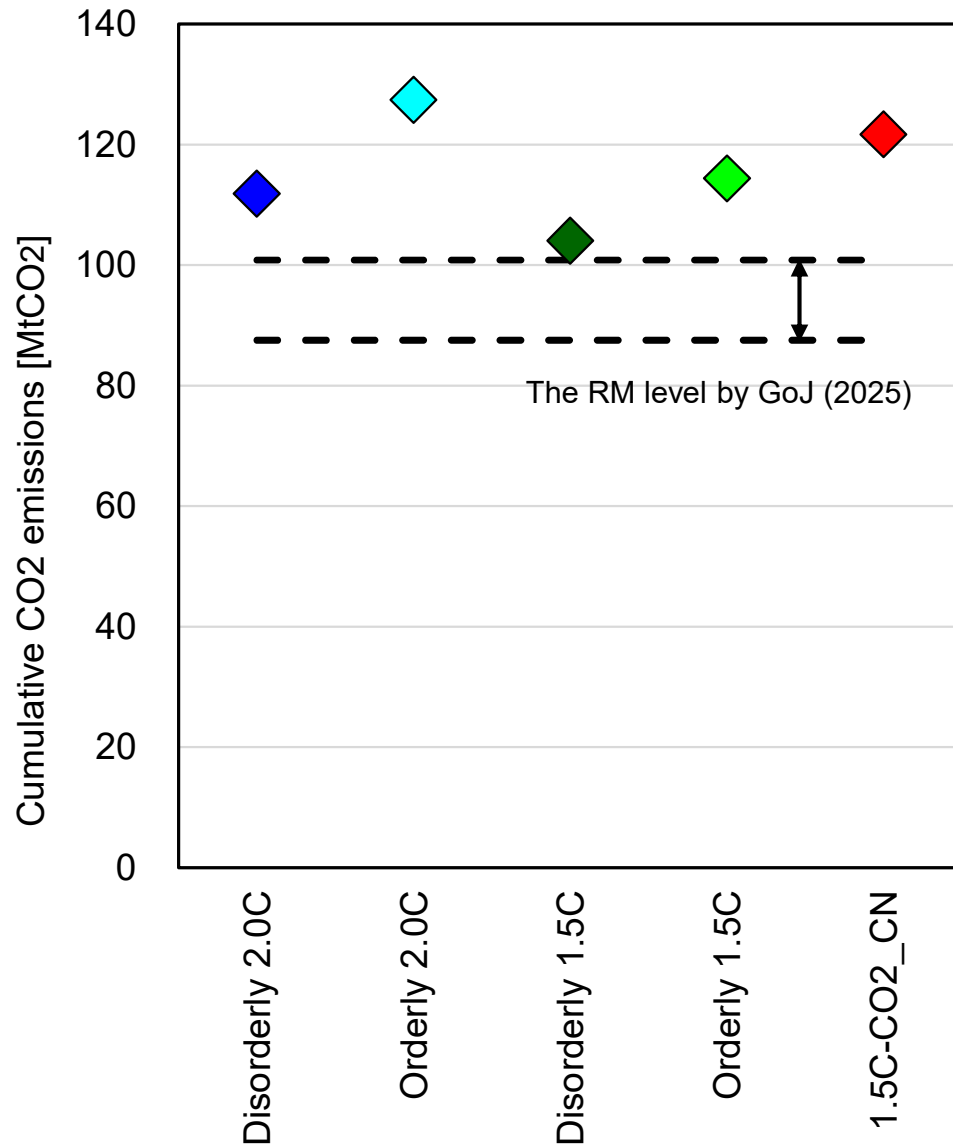
CO₂ intensity of paper & pulp sector (Japan)



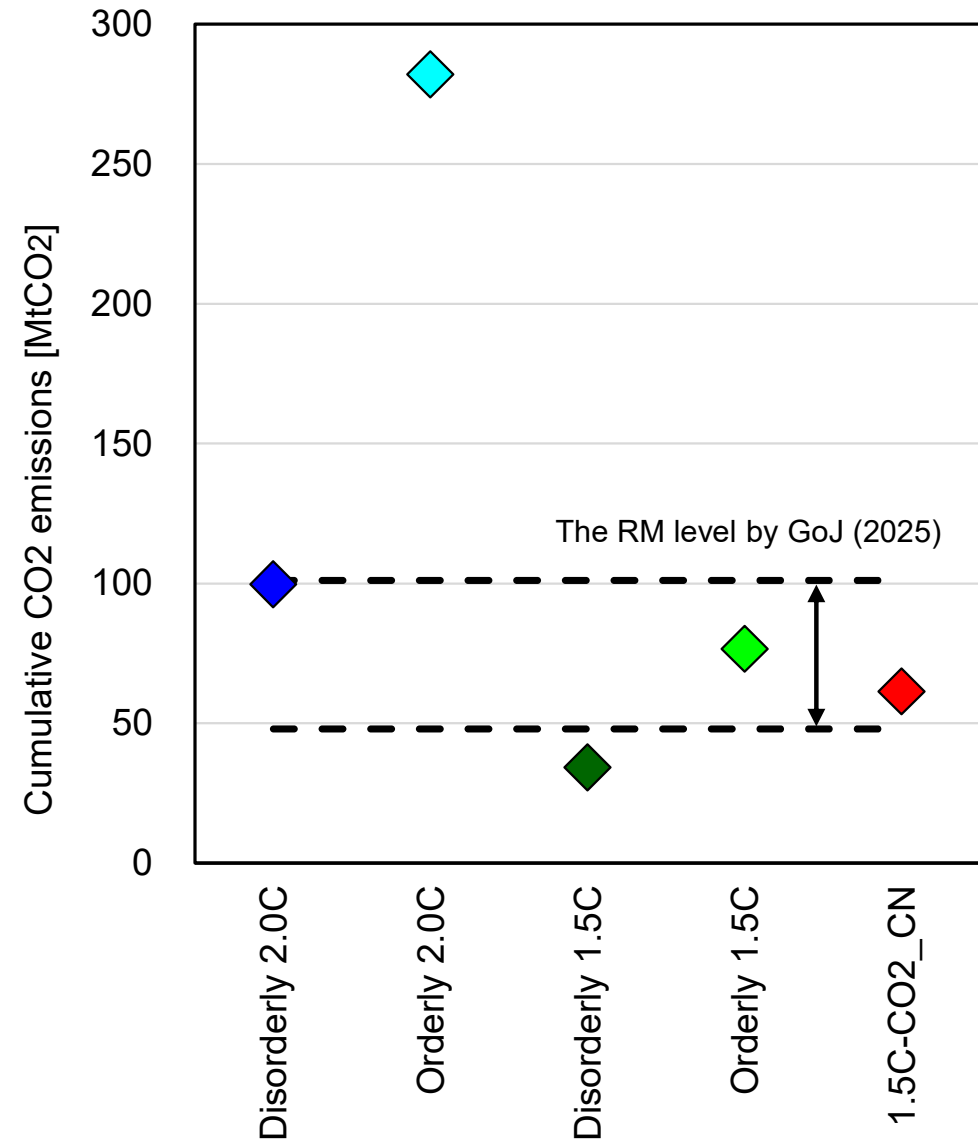
- ✓ A certain amount of emissions remains in Orderly 2.0°C, where emissions reduction is modest.
- ✓ In other scenarios, zero emission is achieved in 2050 by the introduction of synthetic methane or ammonia.

CO₂ emissions in paper & pulp sector (Japan): comparison with the RM by GoJ

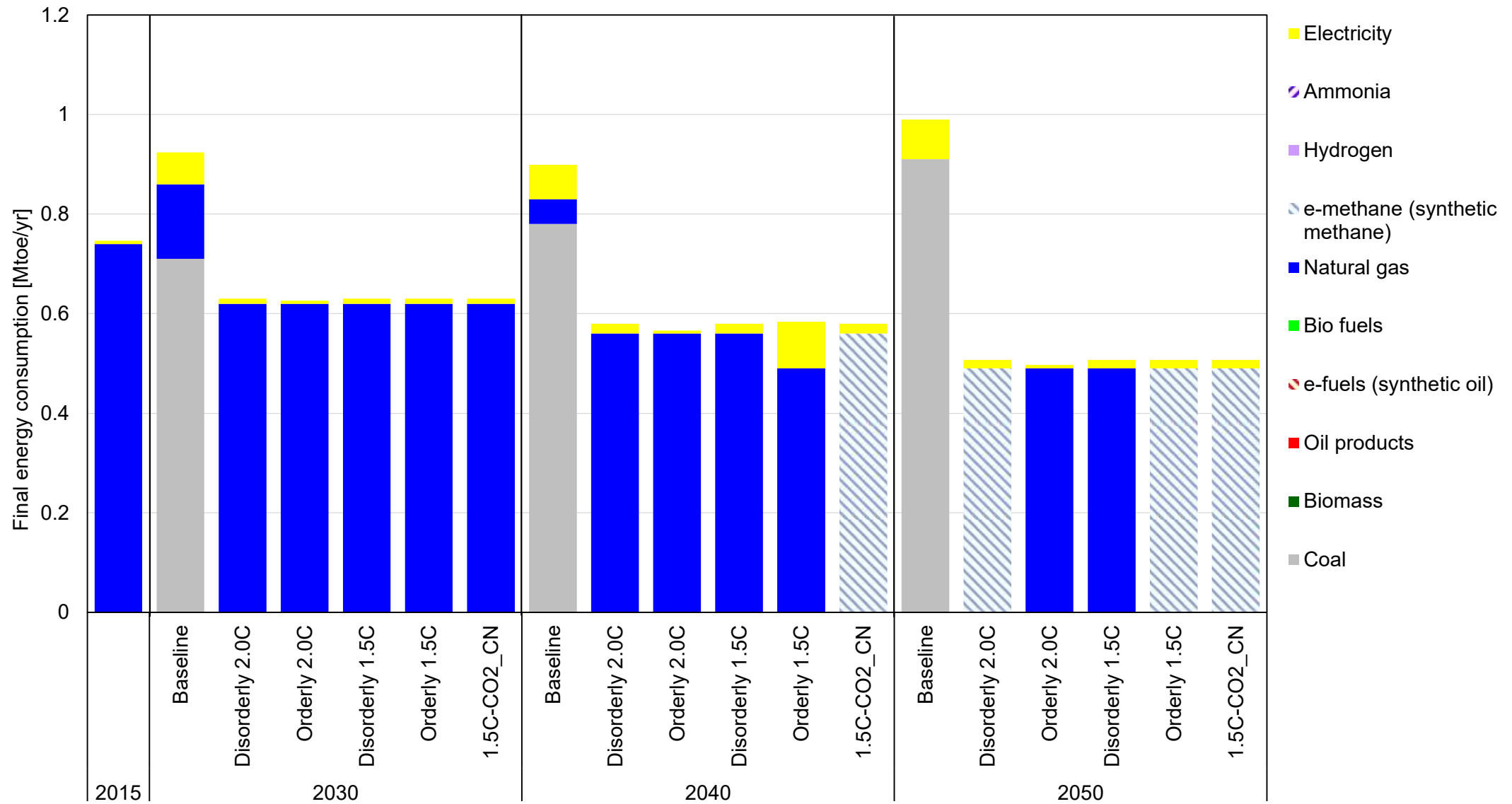
2023-2030



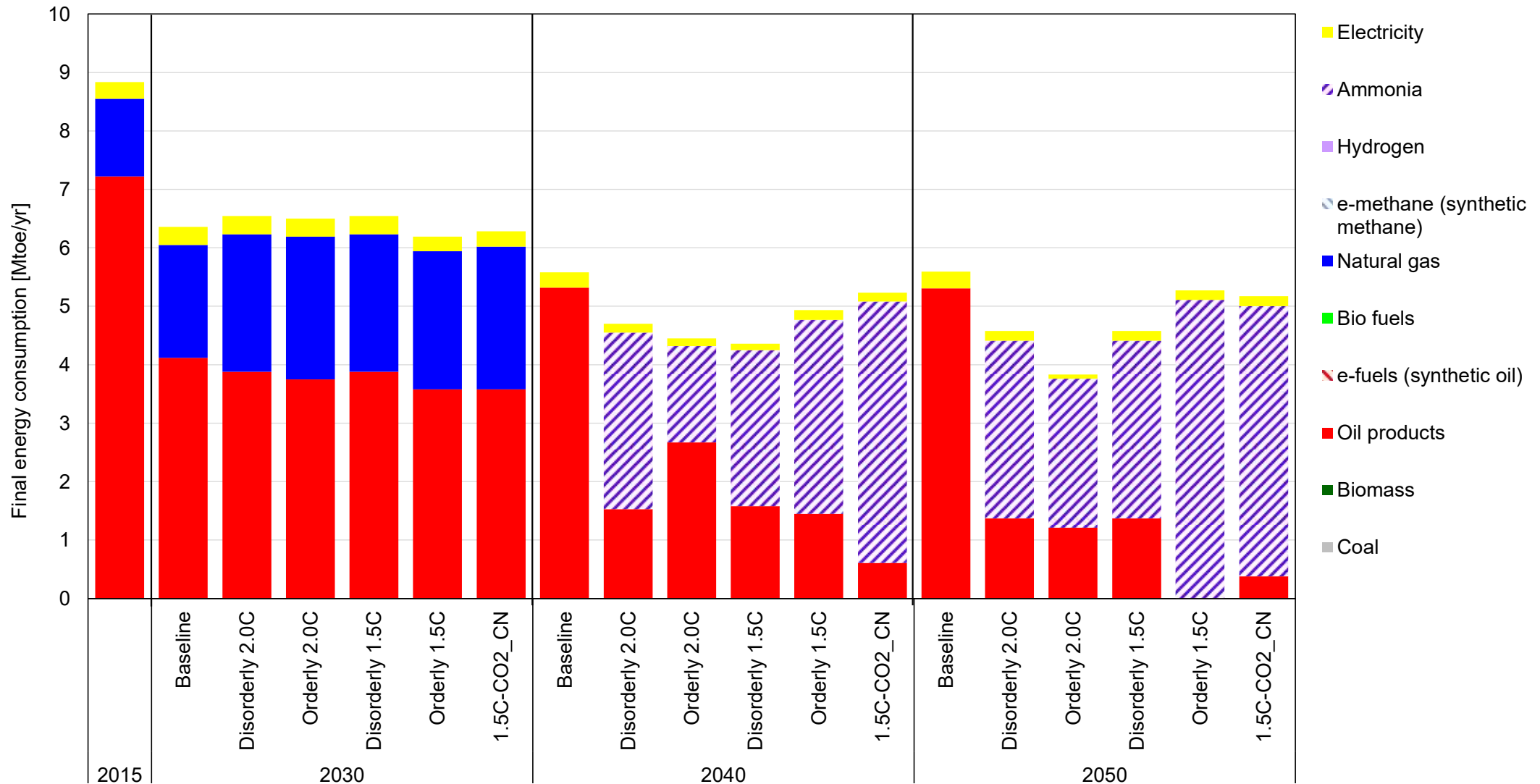
2031-2050



Final energy consumption in ammonia productions of chemical sector (Japan)



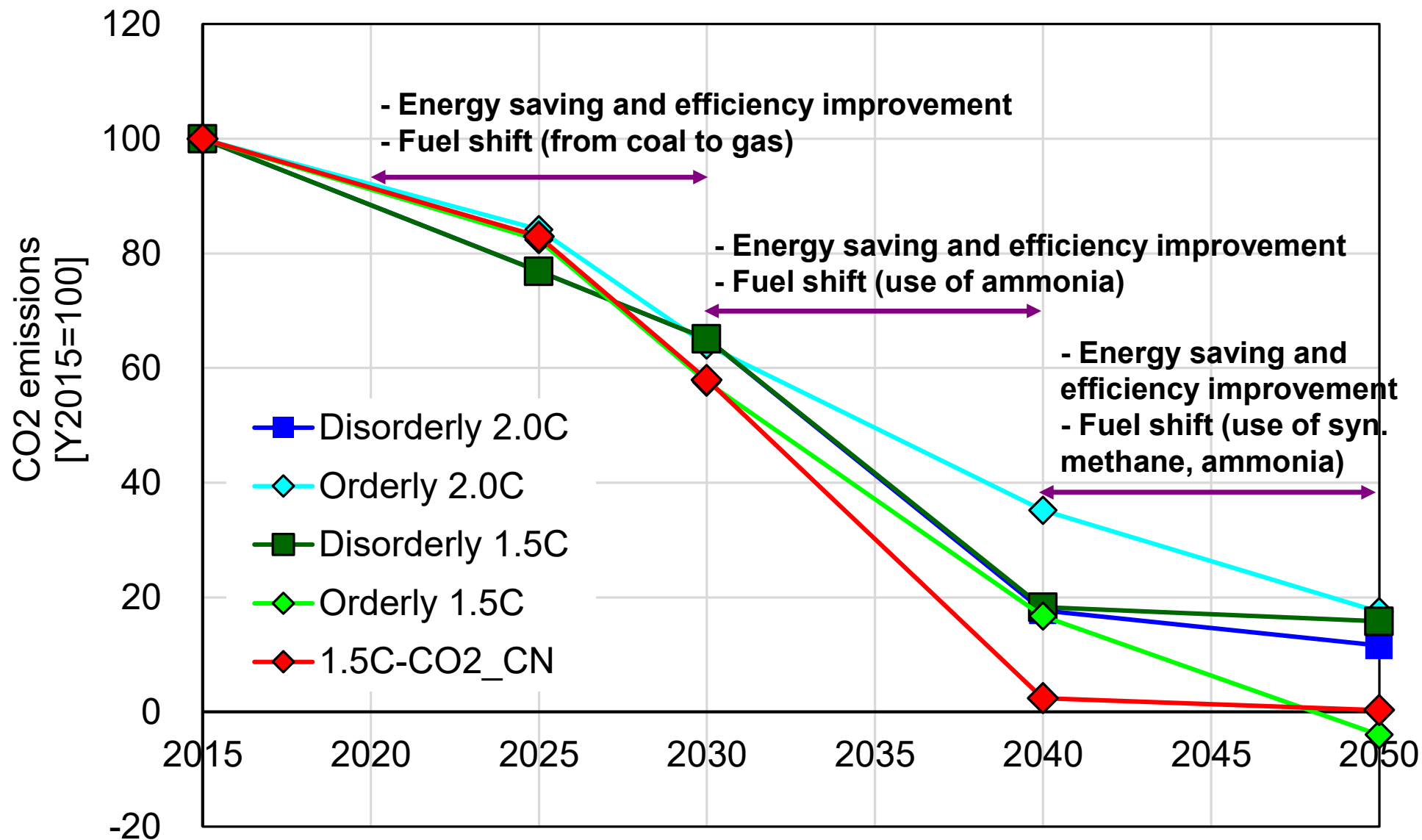
Final energy consumption in ethylene, propylene, and BTX productions of chemical sector (Japan)



Note) The graph shows only energy usage consumption, and energy for raw material is not included.

✓ The use of ammonia expands in 2040 and 2050.

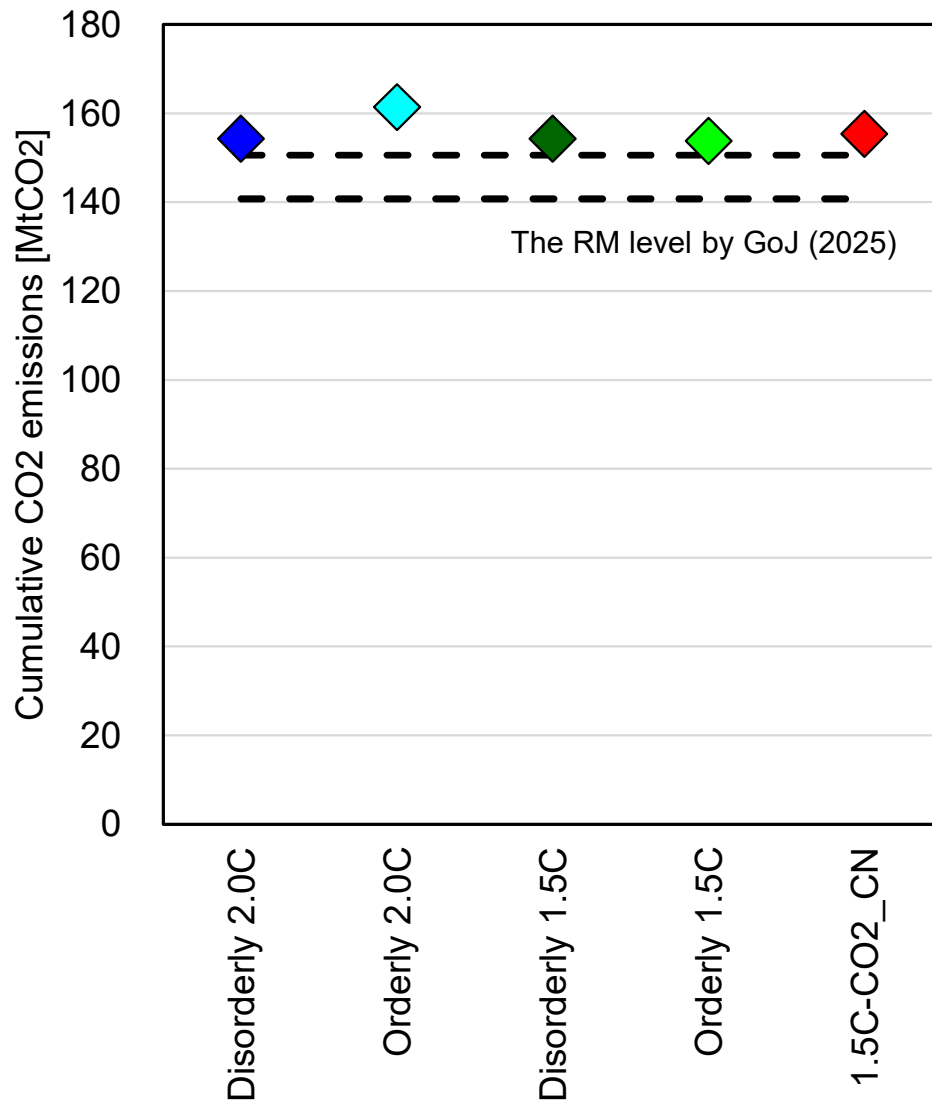
CO₂ emissions in chemical sector (Japan)



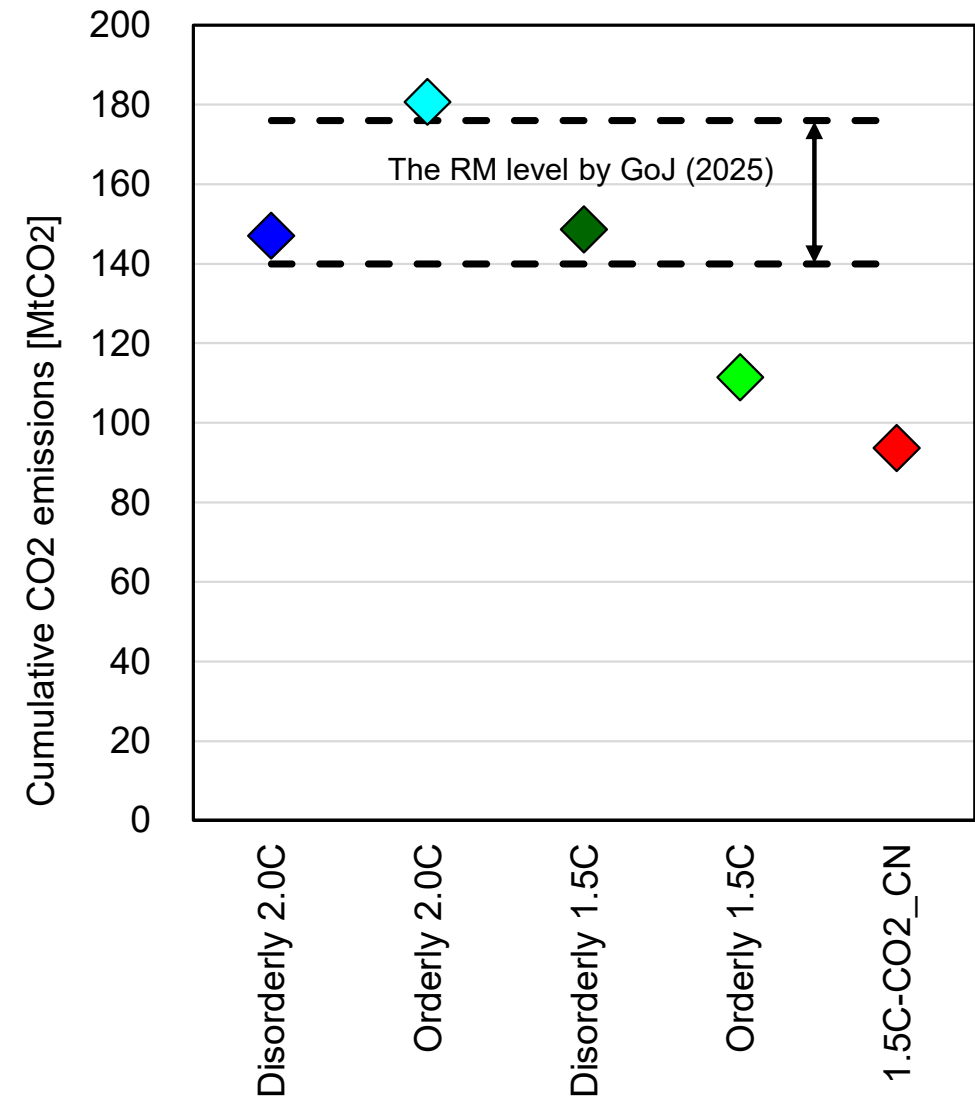
✓ Emissions reduction is progressed by use of ammonia and synthetic methane and electrification.

CO₂ emissions in chemical sector (Japan): comparison with the RM by GoJ

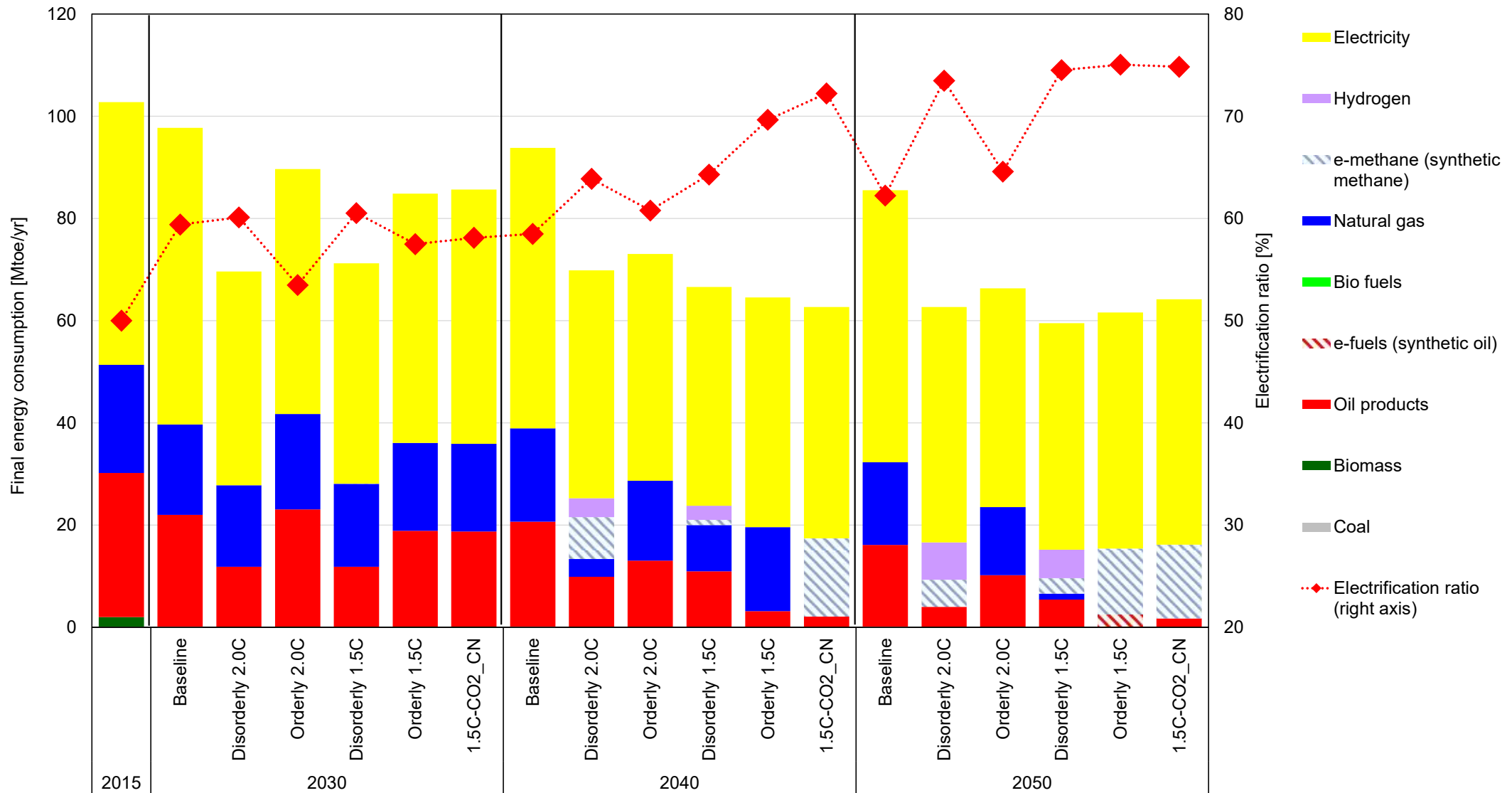
2023-2030



2031-2050

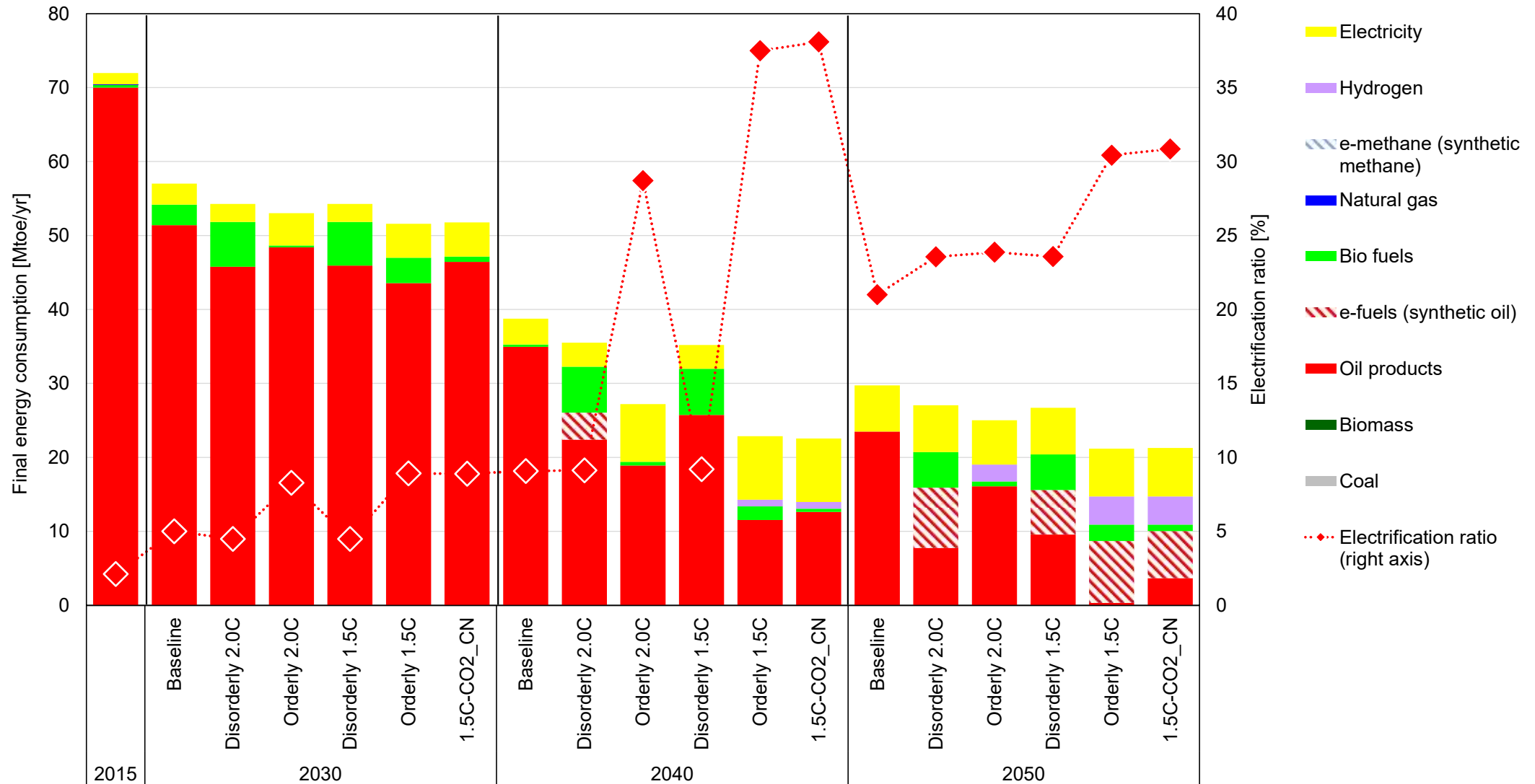


Final energy consumption in building (Japan)



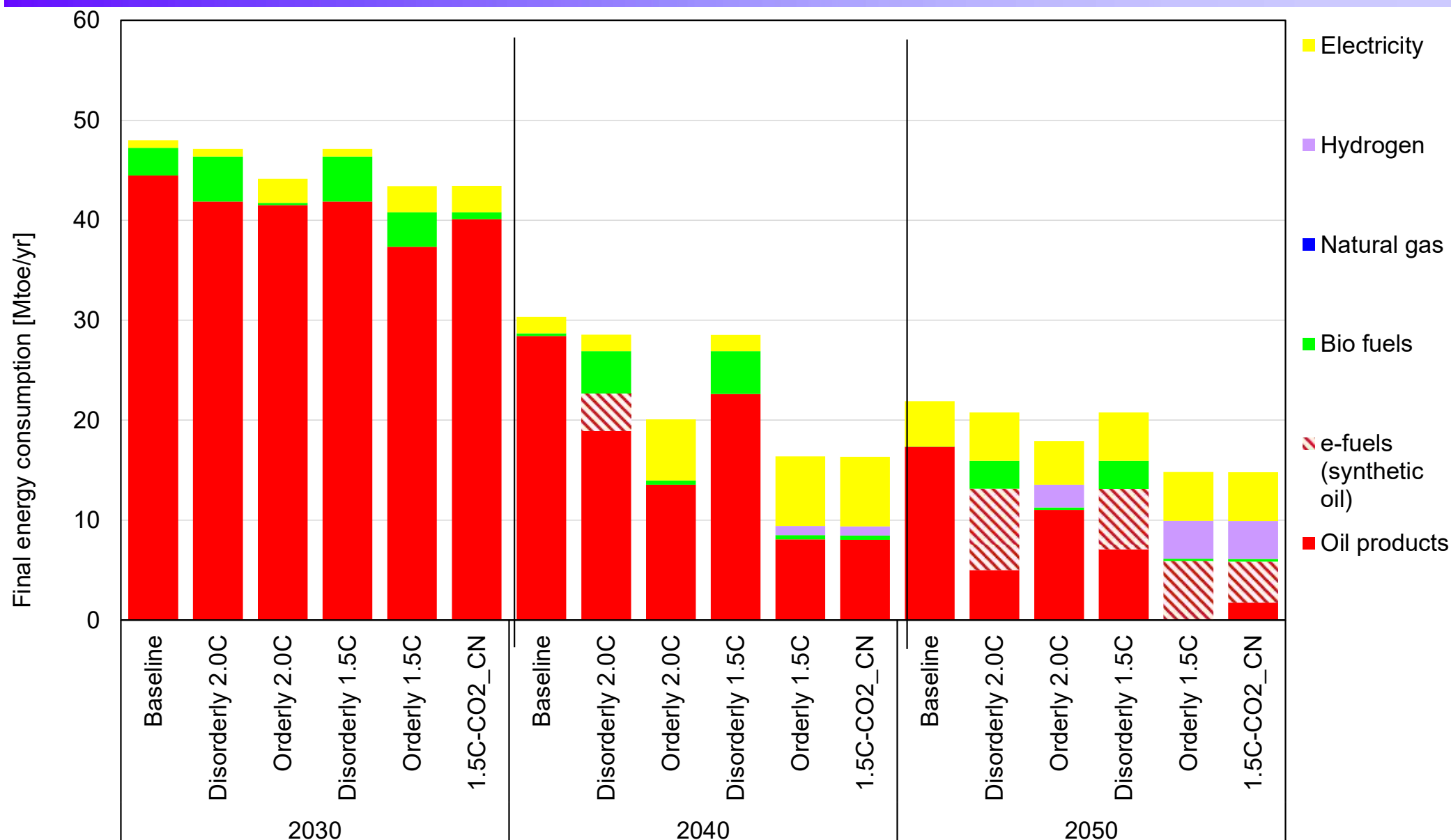
- ✓ The improvement of electrification ratio is cost-effective as emissions reduction is stricter.
- ✓ In Orderly 2.0°C, natural gas remains even in 2050. It is replaced with synthetic methane in other scenarios.

Final energy consumption in transport (Japan)



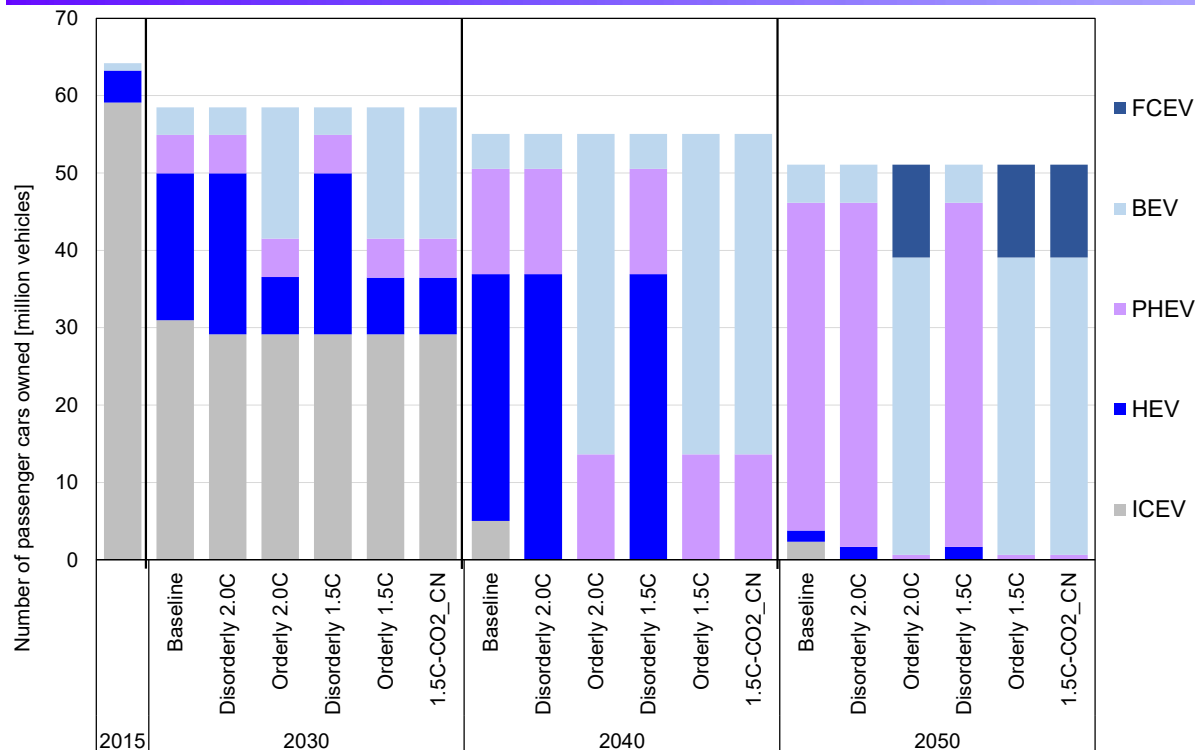
- ✓ Oil remains to some extent even in 2050 in the scenarios other than Orderly 1.5°C.
- ✓ The uses of hydrogen and synthetic fuels, etc. are observed after around 2040 toward 2050.

Final energy consumption in road transport (Japan)



- ✓ Electricity notably increases from around 2040 in Orderly scenarios, which assume significant cost reduction in renewables and EV.
- ✓ Synthetic fuels are also used in 2050. Almost all passenger cars would be BEV, and synthetic fuels are used mainly for trucks in Orderly 1.5°C.

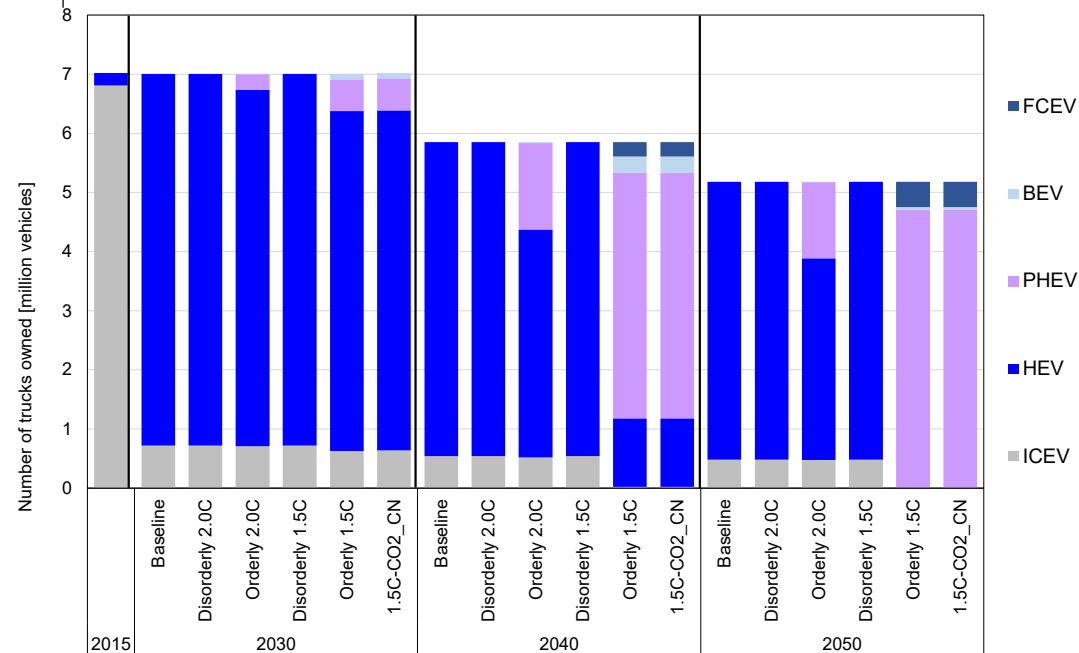
Number of vehicles owned (Japan)



Passenger cars

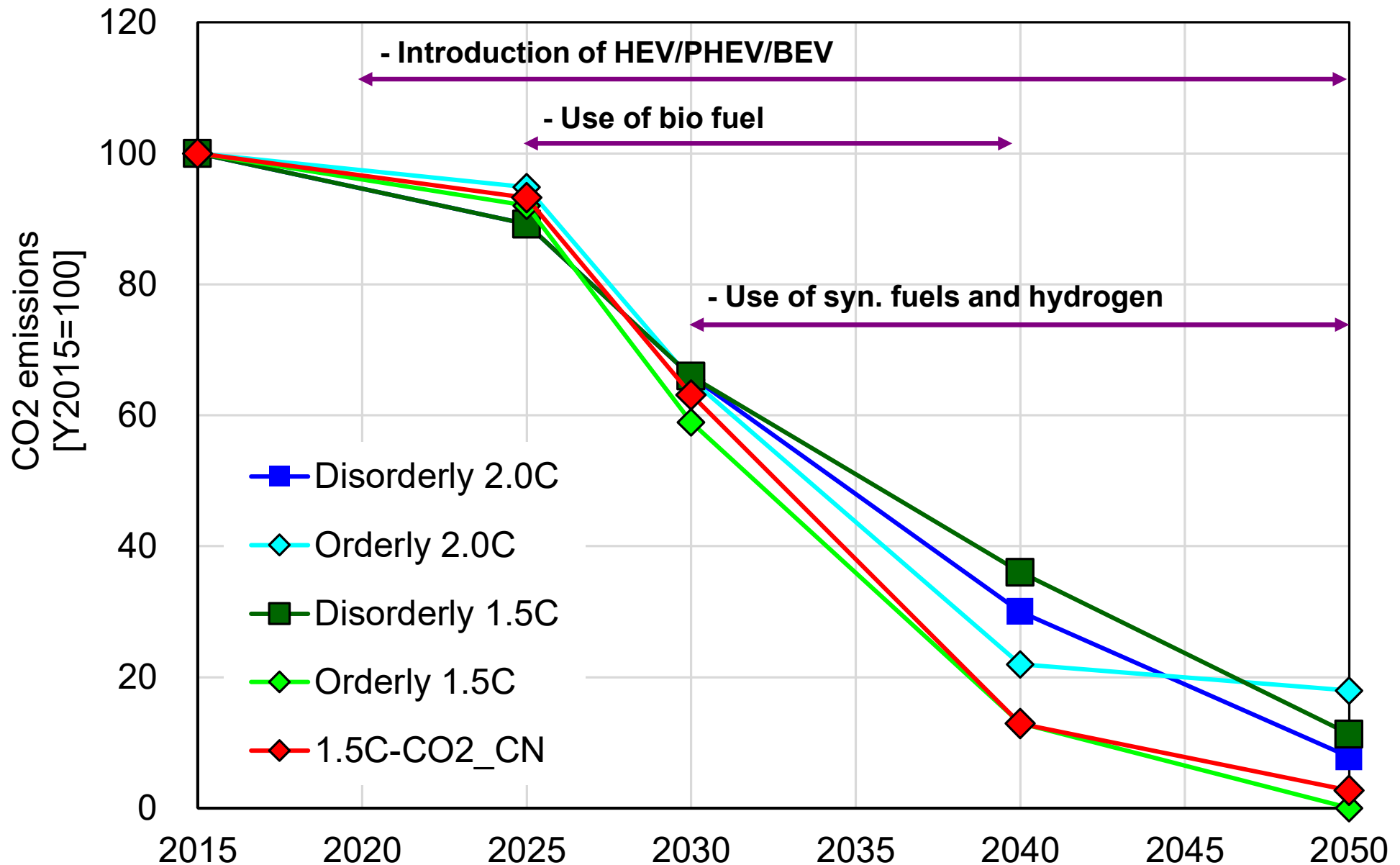
- ✓ In Disorderly scenarios, PHEV is cost-effective.
- ✓ In Orderly scenarios, BEV becomes cost-effective from around 2040, an FCEV can be observed around in 2050.

Trucks



- ✓ For trucks, in Orderly scenarios, most of them are internal combustion trucks, while BEV and FCEV are partly observed.

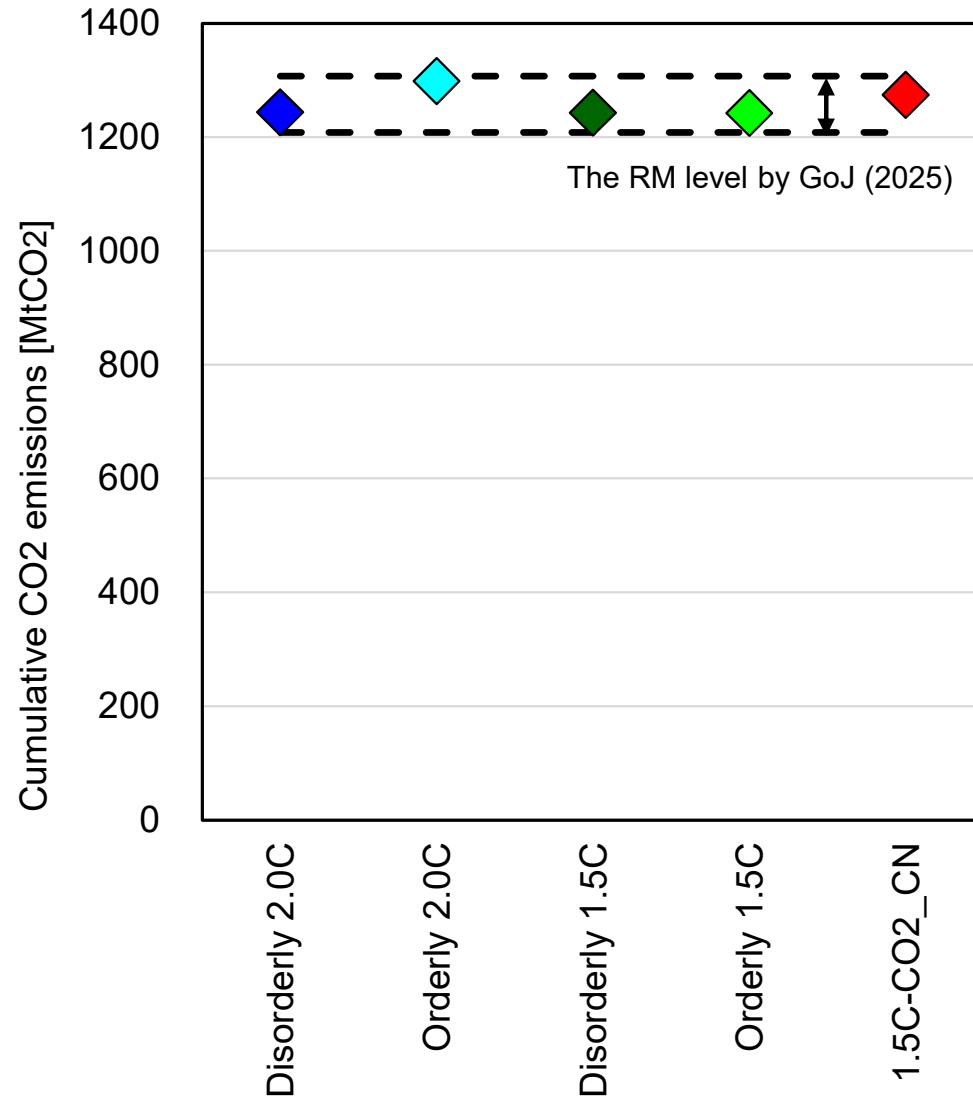
CO₂ emissions in road transport (Japan)



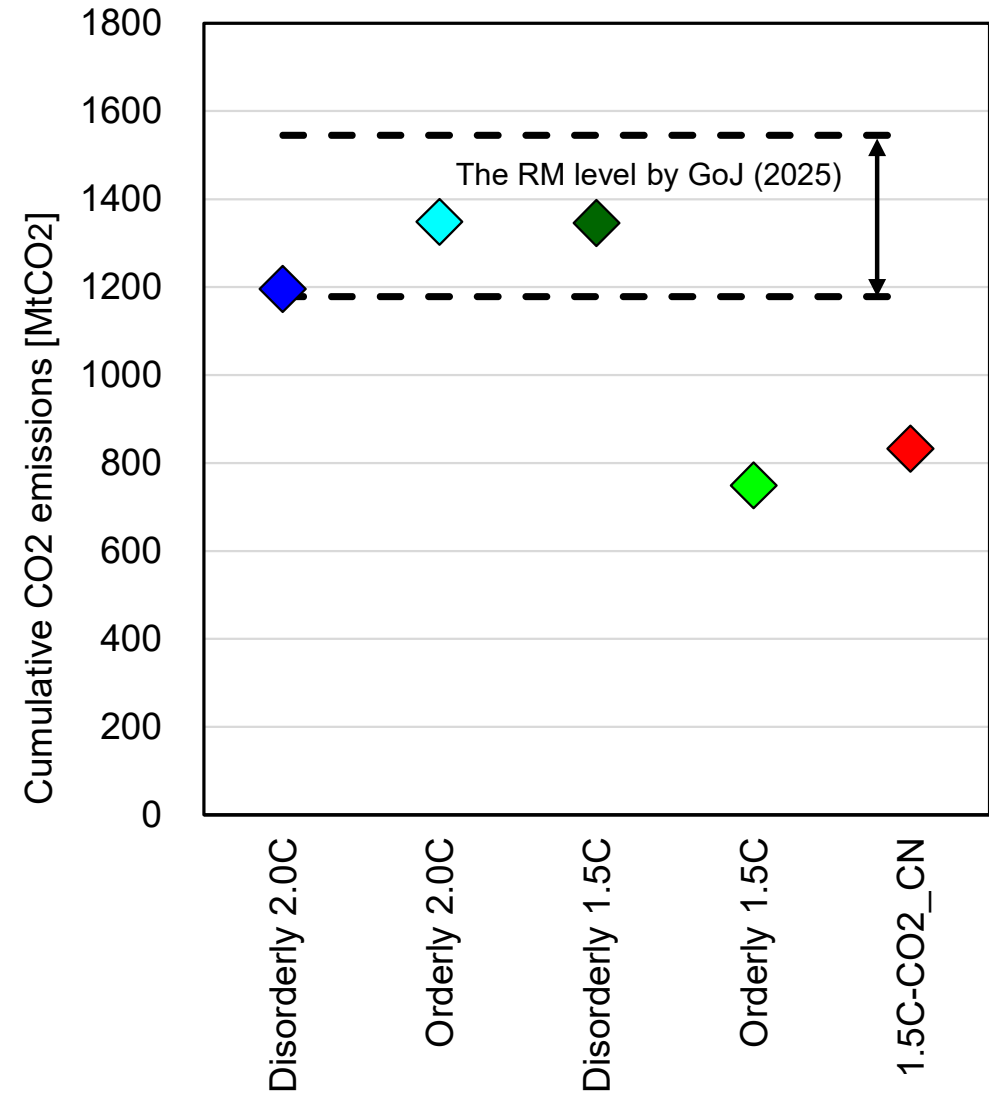
- ✓ Continuous CO₂ emissions reduction is expected due to the enlarged introduction of HEV/PHEV/BEV.
- ✓ The use of hydrogen and synthetic fuels is expected from around 2040.

CO₂ emissions in road transport sector (Japan): comparison with the RM by GoJ

2023-2030

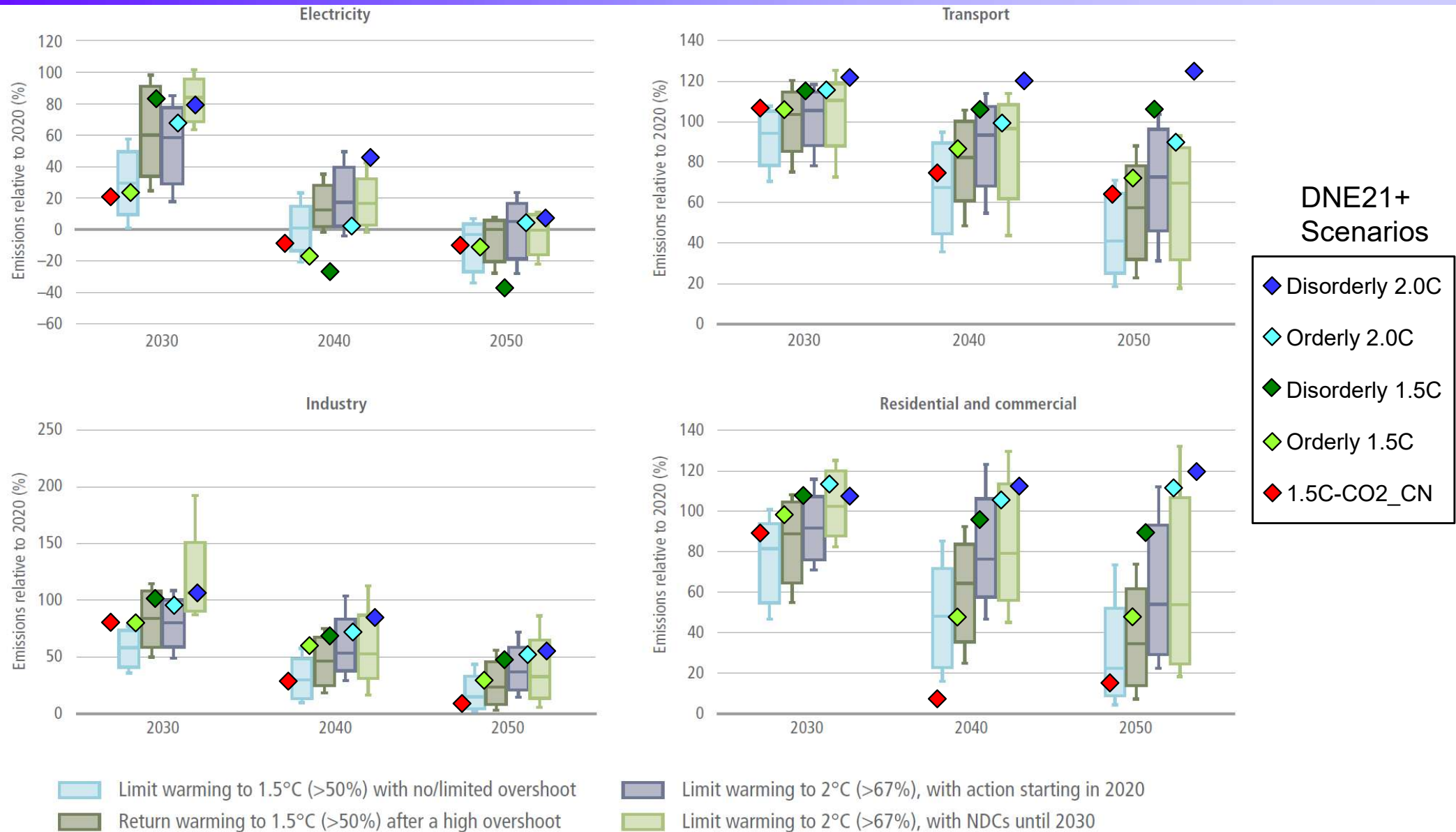


2031-2050



4. The Scenarios Developed by Using DNE21+ Model and the Comparison with Other Scenarios

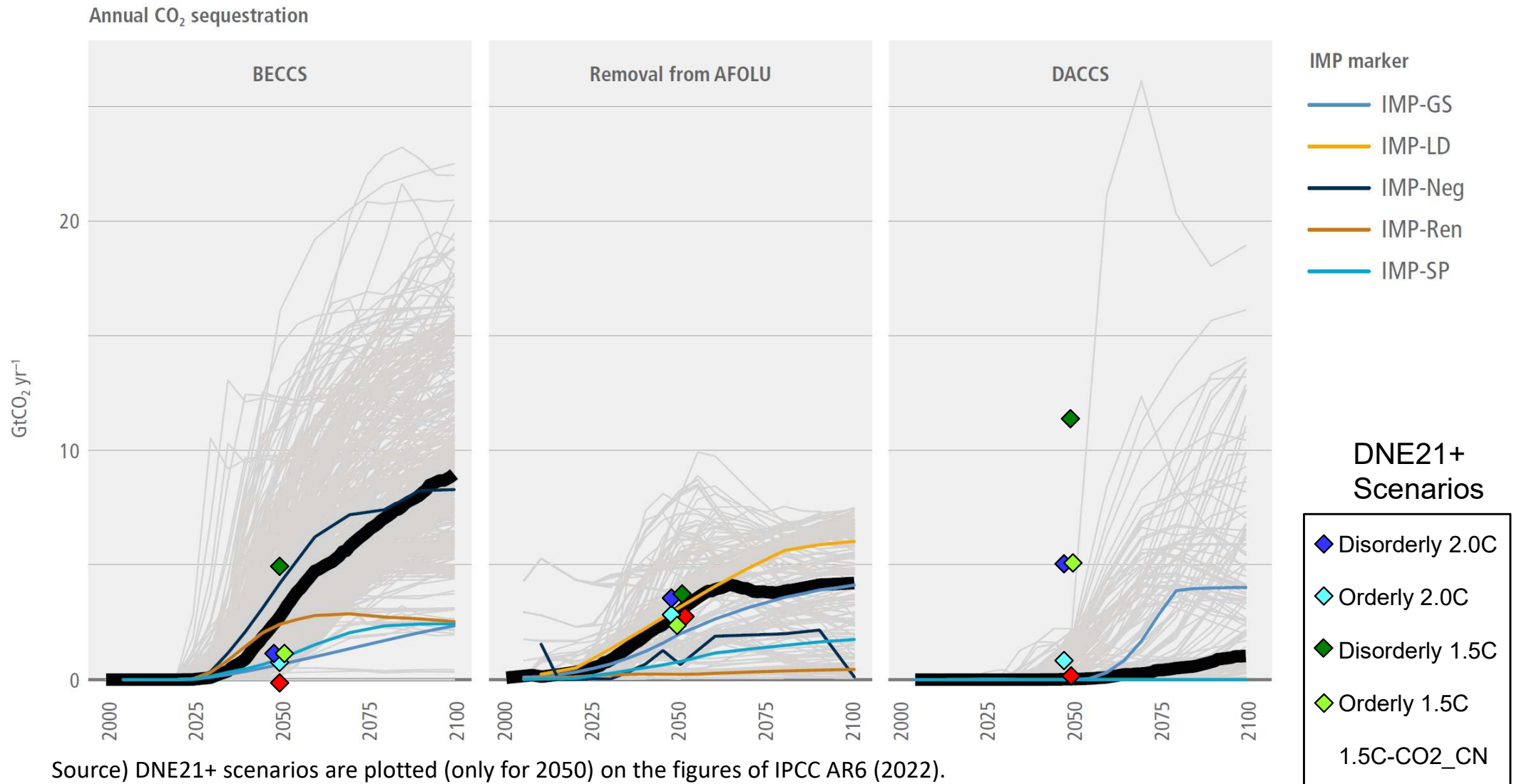
Comparison with global CO₂ emission scenarios of IPCC



Source) DNE21+ scenarios are plotted on the figures of IPCC AR6 (2022).
Note) Boxes indicate 25th and 75th percentiles, while whiskers indicate 5th and 95th percentiles in IPCC scenarios.

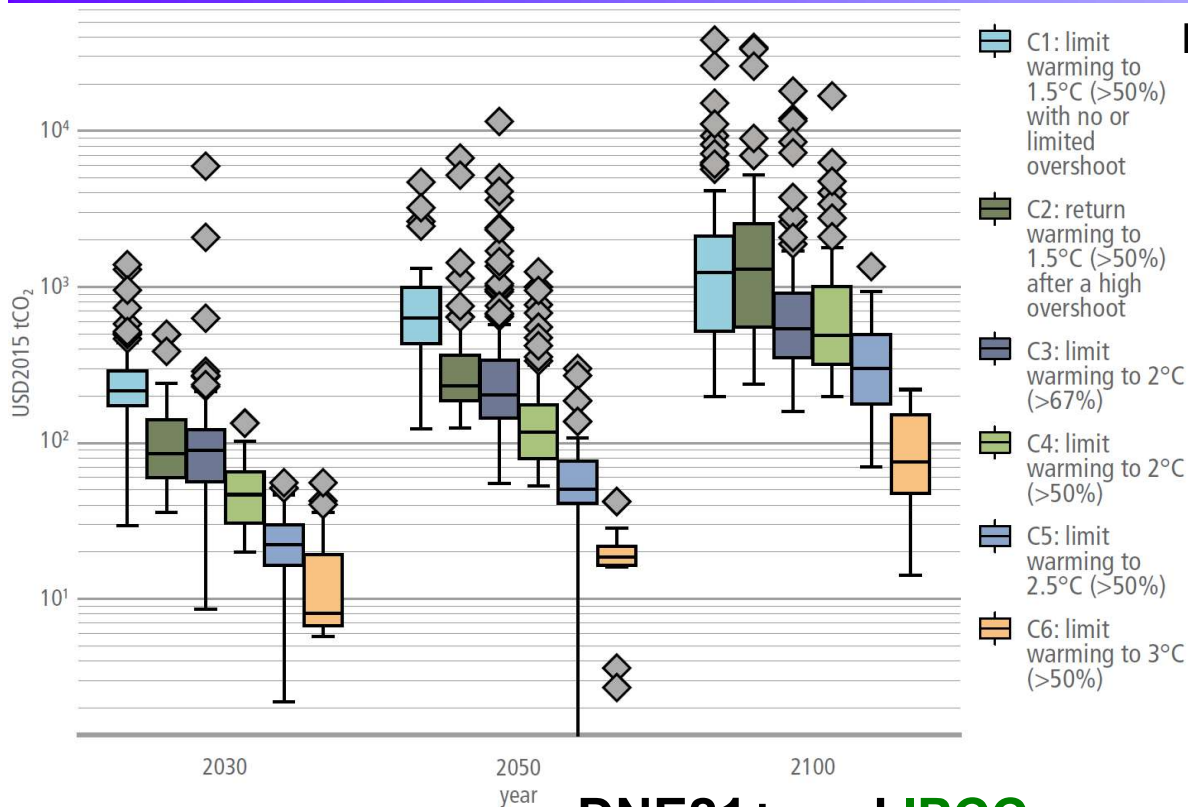
The DNE21+ scenarios are almost consistent with those of IPCC, covering their ranges of upper and lower limits. Some parts are slightly out of the range, probably due to the assumption of DACCS.

Comparison with global CDR scenarios of IPCC



The CO₂ amounts for DACCS in Disorderly 1.5°C are around at the upper most level of those in IPCC scenarios, and the amounts for DACCS in other scenarios and for BECCS and Removal from AFOLU are around at the middle of those in IPCC scenarios. (Slightly higher in DACCS while slightly lower in BECCS.) It can be said that RITE scenarios are quite reasonable considering that not many models explicitly evaluate DACCS in IPCC AR6.

CO₂ marginal abatement costs: compared with IPCC and IEA



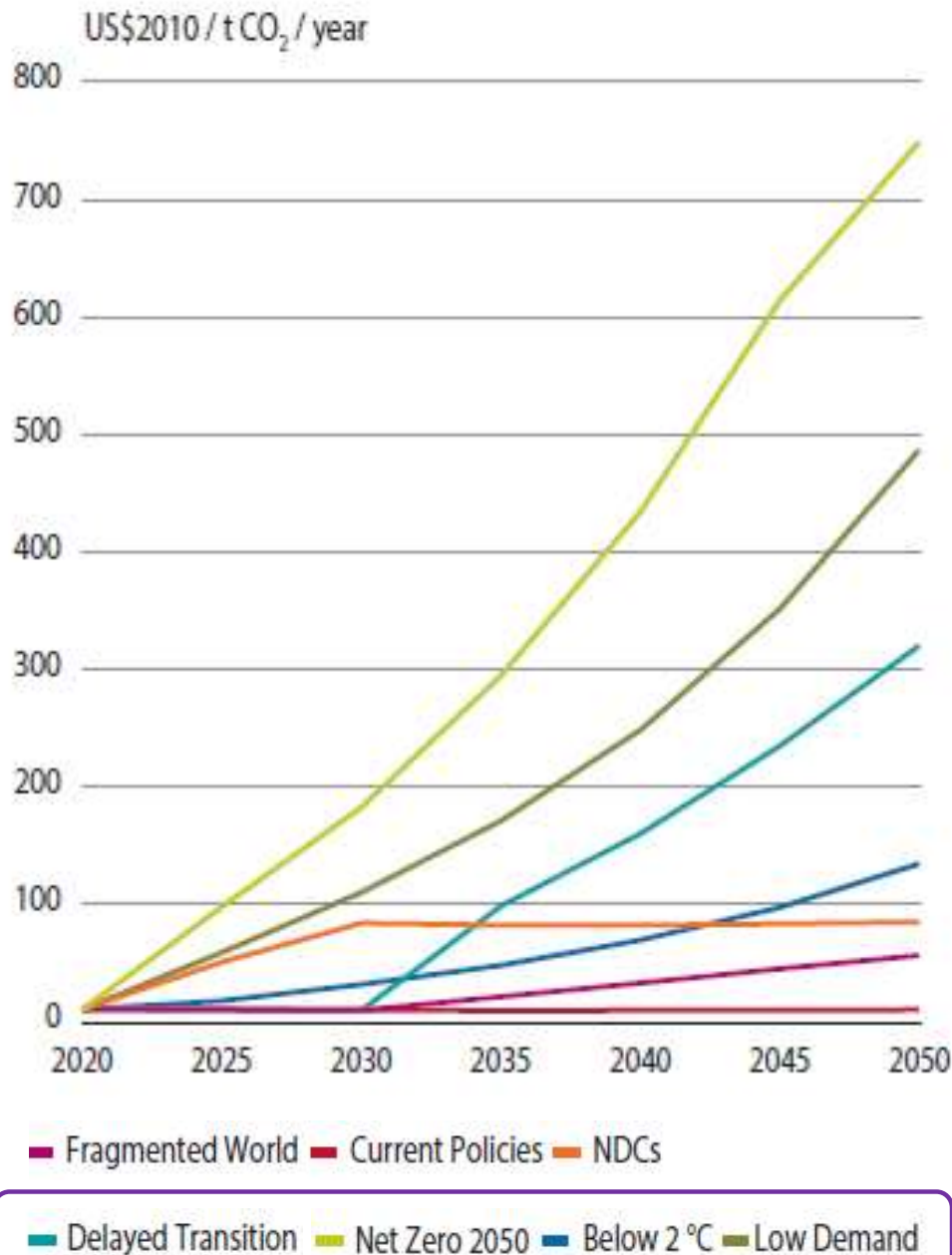
IPCC AR6, Fig. 3.33

- Most of the carbon prices in the IPCC reports had been estimated under the equal MAC across countries. The prices of DNE21+ scenarios are consistent with those of the IPCC report.
- Most of the IPCC scenarios had not considered DACCS explicitly, while DNE21+ considers. Thanks to DACCS, the carbon prices of DNE21+ for the C1 categories are slightly lower than those of the IPCC.

DNE21+ and IPCC scenarios and IEA WEO2022 \$/tCO₂eq.

	DNE21+	IPCC (25-75 percentile, approx.)		IEA WEO2022 NZE
Disorderly 2.0C	121~513	C3	150~350	—
Orderly 2.0C	161	C3		
Disorderly 1.5C	270~683	C2	200~350	
Orderly 1.5C	262~470	C1	450~1000	
1.5C-CO2_CN	298~348	C1		180~250

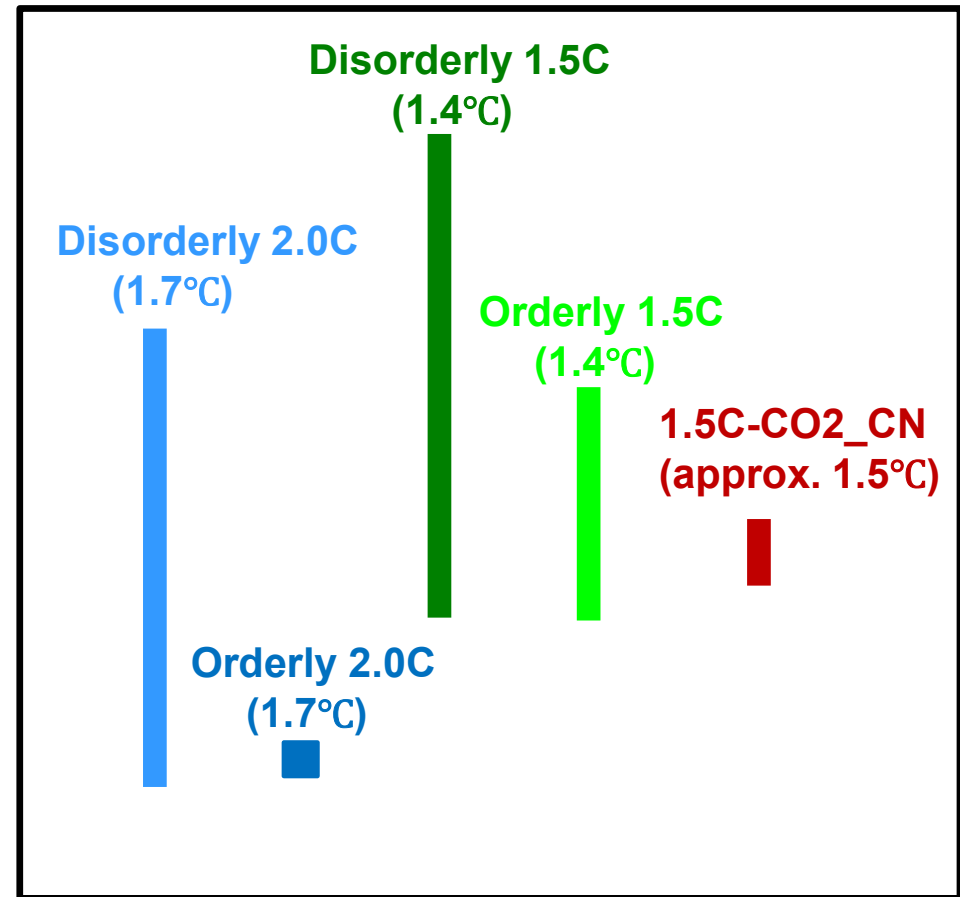
CO₂ marginal abatement costs: compared with NGFS



NGFS (2025)

Scenarios consistent with the 2°C and 1.5°C targets

DNE21+ scenarios in 2050



Note) the parentheses numbers are temperature rise in 2100

- ✓ Thanks to DACCS, the carbon prices of DNE21+ for the 1.5°C scenarios are slightly lower than those of NGFS scenarios.
- ✓ Generally, the carbon prices (MAC) are consistent with the NGFS's.

5. Summary and Future Challenges

[Summary]

- ◆ The transition roadmap (RM) analysis published by RITE in January 2024 as the FY2023 edition has been updated based on the latest global emissions data and the contents of Japan's 7th Strategic Energy Plan.
- ◆ Five scenarios consistent with the 2°C and 1.5°C targets, as well as aligned with NGFS and IEA scenarios, were developed. Using the DNE21+ model, which enables quantitative and consistent analysis, sector-specific mitigation pathways including the transition toward carbon neutrality were derived.
- ◆ Emissions pathways differ significantly across sectors, and the range also varies substantially depending on the assumed scenario. In particular, differences in CDR (Carbon Dioxide Removal) assumptions can lead to large divergences in outcomes.
- ◆ Relatively early reductions in the CO₂ intensity of the power generation sector are required. (This is consistent with IPCC and IEA scenarios.)
- ◆ Although Japan's sectoral roadmaps differ depending on the scenario, they are generally consistent with the sector-specific roadmaps prepared by the Japanese government in FY2025. In other words, the government roadmaps are aligned not only with the 2°C target but also with the 1.5°C target.
- ◆ Expanding the range of mitigation options and adopting cost-effective measures as broadly as possible is considered the most effective pathway toward earlier achievement of carbon neutrality. In this regard, this scenario analysis and roadmap are expected to provide useful strategic guidance.

[Future challenges]

- ◆ We will continue to closely monitor technological developments and update the analysis.
- ◆ We will also continue considering the development of roadmaps for individual countries and regions beyond Japan, with the aim of promoting broader international use.

Appendix 1:

The Model Assumptions

[Peer-reviewed papers]

- K. Akimoto, F. Sano, T. Homma, J. Oda, M. Nagashima, M. Kii, Estimates of GHG emission reduction potential by country, sector, and cost, *Energy Policy*, 38-7 (2010) 3384–3393.
- K. Akimoto, T. Homma, F. Sano, M. Nagashima, K. Tokushige, T. Tomoda, Assessment of the emission reduction target of halving CO₂ emissions by 2050: macro-factors analysis and model analysis under newly developed socio-economic scenarios, *Energy Strategy Reviews*, 2(3-4) (2014) 246-256.
- T. Nagata, F. Sano, K. Akimoto, Analyses on the Contribution of Natural Gas in the World and Japan as Medium- and Long-term Global Warming Countermeasures, *Journal of Japan Society of Energy and Resources* 41-5 (2020).
- F. Sano, T. Nagata, K. Akimoto, Role of Hydrogen and Synthetic Methane under Long-term Scenarios toward Carbon Neutrality, *Journal of Japan Society of Energy and Resources* 42-1 (2021).
- K. Akimoto, F. Sano, J. Oda, H. Kanaboshi, Y. Nakano, Climate change mitigation measures for global net-zero emissions and the roles of CO₂ capture and utilization and direct air capture, *Energy and Climate Change*, 2, 100057 (2021).
- K. Akimoto, F. Sano, Y. Nakano, Assessment of comprehensive energy systems for achieving carbon neutrality in road transport, *Transportation Research Part D: Transport and Environment*, 112, 103487 (2022).
- K. Akimoto, F. Sano, T. Homma, M. Nagashima, N. Onishi, Analysis of the 2030 emissions reduction targets of the previous and current nationally determined contributions of Japan, and a comparison between countries using energy-technology and energy-economic models, *Asia-Pacific Sustainable Development Journal*, 30-1 (2023).
- K. Akimoto, M. Nagashima, F. Sano, T. Ando, Gaps between costs and potentials estimated by bottom-up assessments versus integrated assessment models, *Energy Strategy Reviews*, 55, 101521 (2024).
- K. Akimoto, F. Sano, D. Kang, M. Nagashima, Analyses on transitions to net-zero emissions in Asian countries, *International Energy Journal*, 25(2), 301–314 (2025).
- K. Akimoto, F. Sano, T. Homma, Scenario analyses of Japan's energy systems toward net-zero emissions by 2050 and the Japanese Government's 7th Strategic Energy Plan, *Energy Strategy Reviews*, 62, 101917 (2025).

[Others]

- K. Akimoto, F. Sano, "Scenario analysis towards achieving carbon neutrality in 2050 (interim report)", Agency for Natural Resources and Energy, Strategic Policy Committee, May 13, 2021
https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2021/043/043_005.pdf
- K. Akimoto, F. Sano, T. Homma, "Energy demand in Japan towards achieving carbon neutrality in 2050 ", Agency for Natural Resources and Energy, Strategic Policy Committee, December 25, 2024
https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2024/068/068_008.pdf

Assumed socioeconomic scenarios (Overview)

Shared Socioeconomic Pathways, SSP1 to 5, are developed in response to a call from IPCC. Among the quantitative scenarios developed by RITE in line with these SSPs storylines, this study assumes **SSP2 “middle of the road” scenario** to deliver the analyses.

【World】

	2030	2050	2100
Population (billion people)	8.36 (8.14-8.59)	9.21 (8.61-10.05)	9.31 (7.00-12.73)
GDP (%/year)	2.7 (2.4-3.1) [2010-]	2.2 (1.3-2.8) [2030-]	1.4 (0.6-2.2) [2050-]
Crude steel production (billion ton)	1.90 (1.88-2.00)	2.07 (1.93-2.27)	2.27 (1.47-2.65)
Cement production (billion ton)	4.10 (3.90-4.30)	4.34 (3.85-4.66)	4.41 (2.94-5.91)
Passenger transport demand in road sector (trillion p-km)	30.2 (31.2-37.3)	60.0 (56.8-74.2)	83.3 (66.8-88.8)

【Japan】

	2030	2050	2100
Population (billion people)	0.118 (0.116-0.126)	0.102 (0.096-0.122)	0.084 (0.047-0.105)
GDP (%/year)	1.6 (1.3-1.9) [2010-]	0.4 (-0.1-1.2) [2030-]	0.4 (-0.9-1.5) [2050-]
Crude steel production (billion ton)	0.09 (0.081-0.097)	0.090 (0.073-0.111)	0.085 (0.045-0.090)
Cement production (billion ton)	0.053 (0.050-0.068)	0.043 (0.031-0.075)	0.039 (0.023-0.065)
Passenger transport demand in road sector (trillion p-km)	0.77 (0.69-0.85)	0.64 (0.61-0.82)	0.51 (0.51-0.70)

Note: The values in parentheses show the scenario ranges among SSP1-SSP5. Energy demands and electricity generation are endogenously calculated in the model.

Assumptions on facility costs of power generation

Note 1) The DNE21 + employs the 2000 price, which is the initial year of the model. The 2018 price shown is converted using the US GDP deflator.

Note 2) Facility costs are assumed to decrease over time within the range shown in the table.

Note 3) This figure is an assumed value for the United States, and is multiplied by the location factor depending on the country/region, and there is a slight difference (up to + 3% in Japan). The assumptions on renewable energy are shown in other slides.

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Note 1) The DNE21+ employs the 2000 price, which is the initial year of the model. The 2018 price shown is converted using the US GDP deflator.			Capital costs in 2000 [US\$/kW]	Capital costs in 2018 [US\$/kW]
Note 2) Facility costs are assumed to decrease over time within the range shown in the table.				
Note 3) This figure is an assumed value for the United States, and is multiplied by the location factor depending on the country/region, and there is a slight difference (up to + 3% in Japan). The assumptions on renewable energy are shown in other slides.				
Coal power	Low efficiency (e.g., Conventional (sub-critical), currently used in developing countries)		1000	1458
	Middle efficiency (e.g., mainly used in developed countries (super-critical) – Combined power generation including Integrated Coal Gasification (IGCC) in the future)		1500	2187
	High efficiency (e.g., mainly used in developed countries (super-critical) – Combined power generation including IGCC and Integrated Coal Gasification Fuel cell Combined Cycle (IGFC) in the future)		1700	2479
Co-firing of biomass in coal power	(Additional cost to medium and high efficiency coal power generation)	Co-firing ratio: up to 5%	+85	+124
		Co-firing ratio: up to 30%	+680	+992
Co-firing of ammonia in coal power	(Additional cost to medium and high efficiency coal power generation)	Co-firing ratio: up to 20%	+264-+132	+385-+193
		Co-firing ratio: up to 60%	+271-+135	+395-+197
Oil power	Low efficiency (e.g., diesel)		250	365
	Middle efficiency (sub-critical)		650	948
	High efficiency (super-critical)		1100	1604
	CHP		700	1021
Gas power	Low efficiency (steam turbine)		300	437
	Middle efficiency (combined cycle)		650	948
	High efficiency (combined cycle with high temperature)		1100	1604
	CHP		700	1021
Co-firing of Natural gas / hydrogen	(Additional cost to medium and high efficiency natural gas power generation)	Co-firing ratio: up to 20%	+55	+80
Biomass power	Low efficiency (steam turbine)		2720–2400	3967–3500
	High efficiency (combined cycle)		3740–3030	5454–4419
Nuclear power			2743	4000
IGCC/IGFC with CO ₂ Capture			2800–2050	4083–2989
Natural gas oxy-fuel power			1900–1400	2771–2042
Hydrogen power(FC/GT)			1160	1692
Ammonia power generation (single fuel firing)			3040-1444	4433-2106
Electricity storage (e.g., pumping-up)			1000	1458

Assumptions on conversion efficiency for thermal power

Generating efficiency (%LHV)

		2010	2020	2030	2050
Coal power	Low efficiency (e.g., Conventional (sub-critical), currently used in developing countries)	23.0	24.0	25.0	27.0
	Middle efficiency (e.g., mainly used in developed countries (super-critical) – Combined power generation including Integrated Coal Gasification (IGCC) in the future)	37.8	39.6	41.4	45.0
	High efficiency (e.g., mainly used in developed countries (super-critical) – Combined power generation including IGCC and Integrated Coal Gasification Fuel cell Combined Cycle (IGFC) in the future)	44.0	46.0	48.0	58.0
	IGCC/IGFC with CO ₂ Capture	34.0	35.5	38.5	50.3
Oil power	Low efficiency (e.g., diesel)	23.0	24.0	25.0	27.0
	Middle efficiency (sub-critical)	38.6	40.2	41.8	45.0
	High efficiency (super-critical)	52.0	54.0	56.0	60.0
	CHP*1	39.0	41.0	43.0	47.0
Gas power	Low efficiency (steam turbine)	27.2	28.4	29.6	32.0
	Middle efficiency (combined cycle)	39.8	41.6	43.4	47.0
	High efficiency (combined cycle with high temperature)	54.0	56.0	58.0	62.0
	CHP*1	40.0	42.0	44.0	48.0
	Natural gas oxy-fuel power	40.7	41.7	43.7	48.7
Biomass power	Low efficiency (steam turbine)	22.0	22.5	23.5	25.5
	High efficiency (combined cycle)	38.0	40.0	42.0	46.0
Hydrogen power (GT/FC)		54.0	56.0	58.0	62.0

*1 Exhaust heat recovery efficiency is assumed to be 5 to 20% that varies by region, considering supply and demand balance.

Assumptions on nuclear power generation cost

Year	Facility cost (\$/kW)		Unit price of electricity (\$/MWh)	
	2000 price	2018 price	2000 price	2018 price
2020	2763	4029	75	110
2030	2779	4053	76	111
2050	2794	4075	78	114
2100	2824	4117	79	115

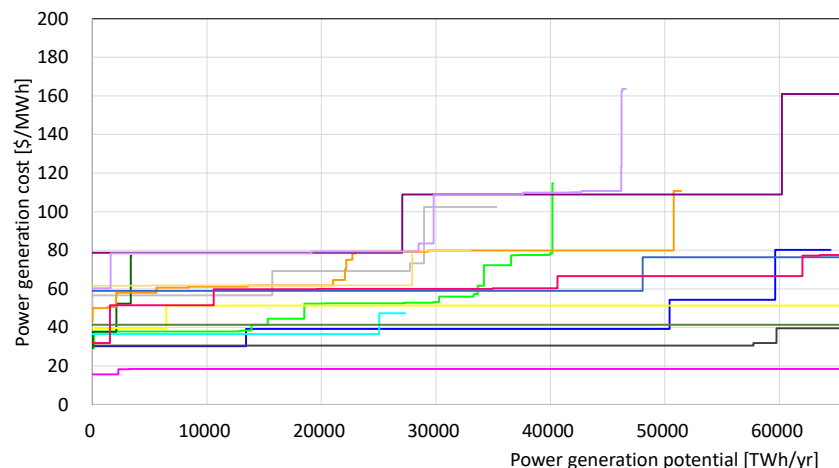
*1 The figures in the table are assumed values for Japan. For the rest of the world, location factors are multiplied, resulting in slightly different assumptions.

*2 Since the base year of the model is 2000, the 2000 price is also shown; the conversion from the 2000 price to the 2018 price is multiplied by 1.46 (based on CPI of U.S.).

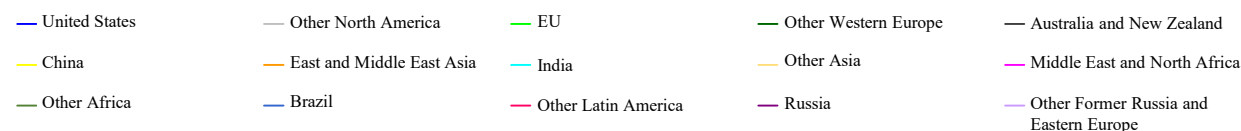
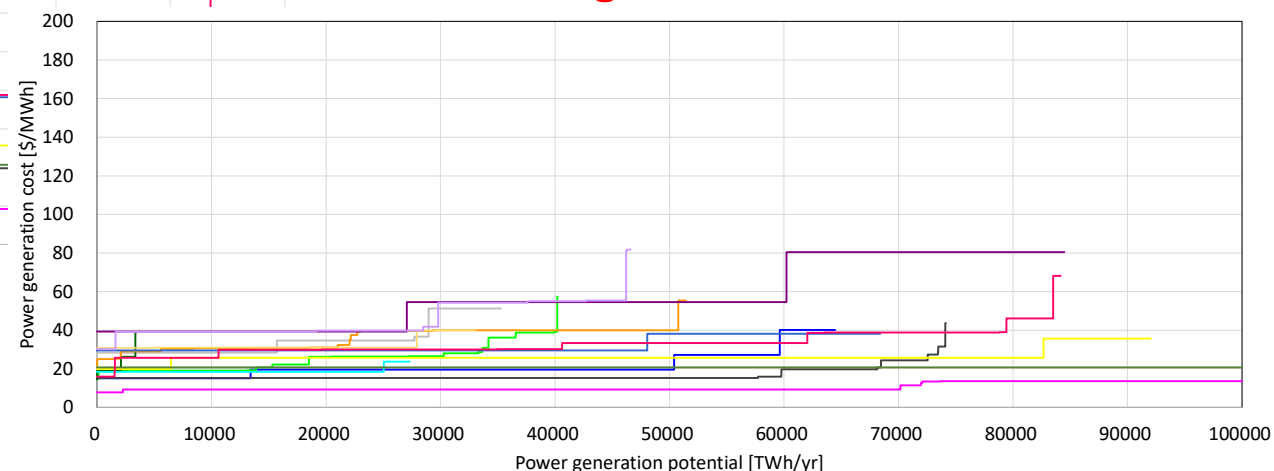
*3 The unit prices of electricity shown in the table are converted using a capacity factor of 85%.

Assumptions on the costs and potentials of solar PV and wind power

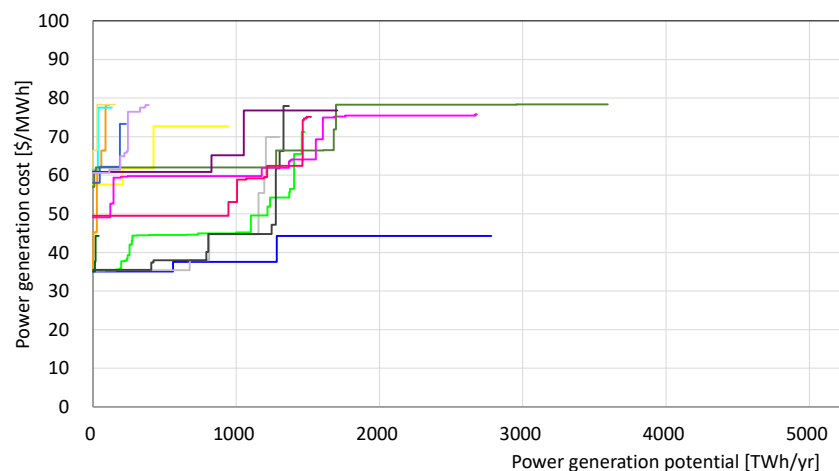
Solar PV: middle cost reduction



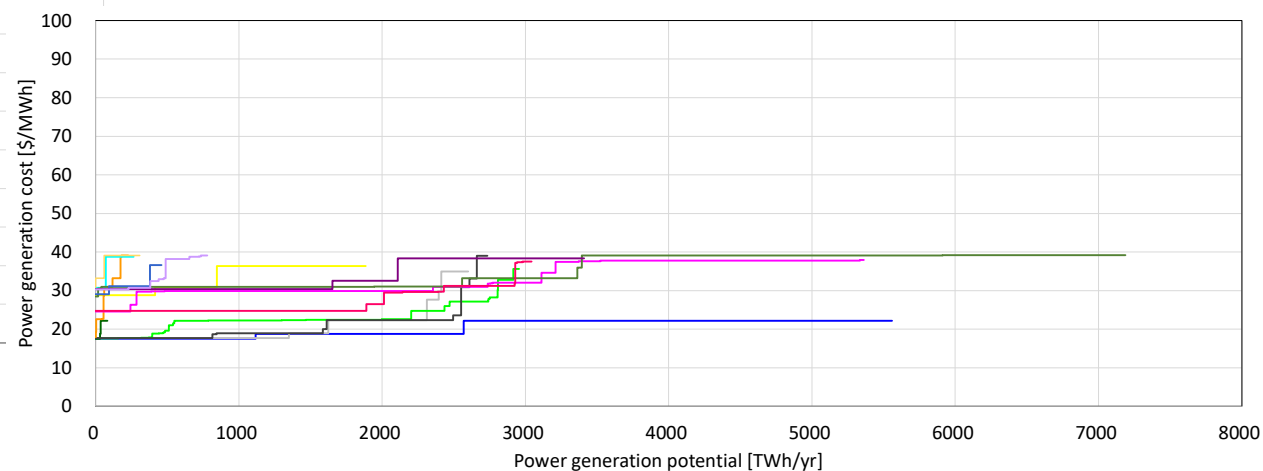
Solar PV: high cost reduction



Onshore wind power: middle cost reduction



Onshore wind power: high cost reduction



Assumptions on co-generation system (CGS)

Facility Cost (\$/kW, Price in 2000)

	2015	2030	2050
Industry (equivalent to 5 MW)	1250		
Business 1 (1-2 MW)	1875		
Business 2 (0.5MW)	2500		
Household (PEFC/SOFC)	15167	3575	3575

Note) The listed price is the price in 2000. The US consumer price index is 1.46 in 2015 if year 2000 is 1.

Efficiency Assumption (LHV%)

		2015	2030	2050
Industry (equivalent to 5 MW)	PGE	49.0	51.0	54.5
	HRE	36.2	34.8	31.2
Business 1 (1-2 MW)	PGE	42.3	47.5	50.7
	HRE	36.2	31.0	27.8
Business 2 (0.5MW)	PGE	41.0	44.0	47.0
	HRE	34.0	31.0	28.0
Household (PEFC/SOFC)	PGE	39.7	47.8	55.0
	HRE	55.3	45.0	37.8

Note) PGE = Power Generation Efficiency, HRE=Heat Recovery Efficiency

Assumptions on CO₂ capture technology

	Capital costs (price in 2000) (\$/kW)	Generating efficiency (LHV%)	CO ₂ capture ratio (%)
IGCC/IGFC with CO ₂ Capture* ¹	2800 – 2050	34.0 – 58.2	90 – 99
Natural gas oxy-fuel power* ¹	1900 – 1400	40.7 – 53.3	90 – 99
	Capital costs (price in 2000) (1000\$/ (tCO ₂ /hr))	Required electricity (MWh/tCO ₂)	CO ₂ capture ratio (%)
Post-combustion CO ₂ capture from coal-fired power plants* ¹	851 – 749	0.308 – 0.154	90
Post-combustion CO ₂ capture from natural gas-fired power plants* ¹	1309 – 1164	0.396 – 0.333	90
Post-combustion CO ₂ capture from biomass-fired power plant* ¹	1964 – 1728	0.809 – 0.415	90
CO ₂ capture from gasification* ¹	62	0.218	90 – 95
CO ₂ capture from steelworks blast furnace gas* ¹	386 - 319	0.171 – 0.150	90
	Capital costs (price in 2000) (1000\$/ (tCO ₂ /hr))	Required fuels (GJ/tCO ₂) Recovered electricity (MWh/tCO ₂)	CO ₂ capture ratio (%)
CO ₂ capture from clinker manufacturing* ²	2485 - 2246	4.87 – 3.66 0.199 – 0.150	90

*1 The range of values in the table indicates improvement from 2015 to 2100.

*2 It is assumed that the assumed values have a range shown in the table depending on the fuel type used in the kiln body, CO₂ capture, and compression equipment.

Note) It is 2000 price. The US consumer price index (CPI) in 2018 is 1.46 when the CPI in 2000 is 1.

Not only the CO₂ capture technologies in the power sector, but also CO₂ capture from fossil fuel gasification (in hydrogen production processes), from blast furnace gas in steel making processes, and in clinker production processes, are explicitly modeled.

The assumptions on the costs and potentials of CO₂ geological storage

	CO ₂ storage potentials (GtCO ₂)		【References】 IPCC SRCSS (2005) (GtCO ₂)	Storage costs (\$/tCO ₂)* ¹
	Japan	World		
Depl. oil well (EOR)	0.0	112.4	675–900	92 – 227* ²
Depl. gas well	0.0	147.3 – 241.5		10 – 32
Deep saline aquifer	11.3	3140.1	10 ³ –10 ⁴	5 – 85
Coalbed (ECBMR)	0.0	148.2	3–200	47 – 274* ²

Note 1: It is assumed that the CO₂ storage potentials of depl. gas well could be expanded to the upper limit in the table with the increase of future mining volume.

Note 2: It is assumed that the storage costs could rise within the range in the table with the increase of accumulated storage amount.

*1 The costs for CO₂ capture are not included. They are assumed separately.

*2 Oil and gas profits from enhanced oil recovery and enhanced methane recovery are not included in this figure, but they are assumed separately.

The constraint on CO₂ storage expansion is assumed considering the difficulties such as limited number of available drilling rigs, i.e., **in Orderly scenario**, the CCS is assumed available since 2026 onwards and CO₂ storage **growth is based on 0.004%/yr** to gross domestic/regional CCS implementation(**maximum storage potential in 2050 in Japan's case is 11MtCO₂/yr**). CCS is assumed available since 2026 onwards for **Disorderly and 1.5C-CO₂-CN scenarios** as well however, **the storage amount is assumed to grow by 0.01%/yr until 2030 and by 0.02%/yr onwards(maximum storage potential in 2050 is 51Mt CO₂ /yr in Japan's case)**.

【CO₂ transportation cost】

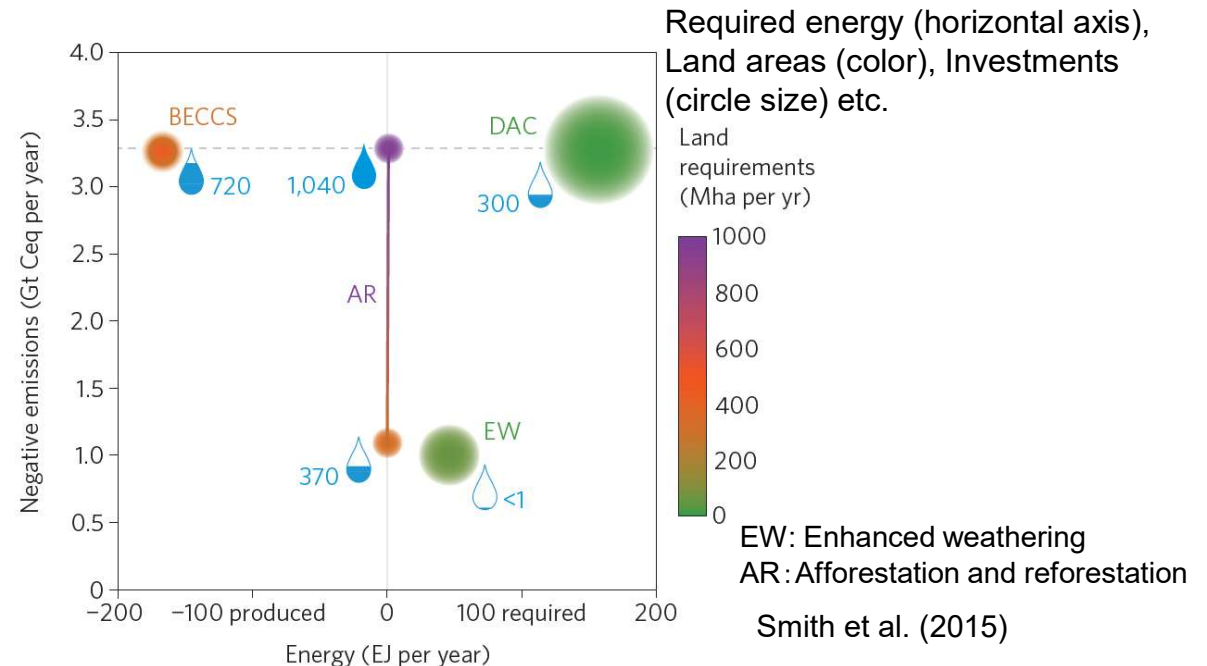
- The CO₂ transportation costs from the sources to the reservoirs are assumed separately as 1.36\$/tCO₂ (per 100km) and 300km for average transport distance in Japan's case.
- For large area countries which are disaggregated in the models (US, Russia, China and Australia), the interregional CO₂ transportation costs are estimated according to the transportation distance.
- Cross-border CO₂ transport is also assumed. **Annual export ceiling of 91 Mt CO₂ is set for Japan.**

Assumption for Direct Air Capture (DAC)

- DAC is a technology to capture atmospheric CO₂ at low level of about 400ppm, requiring more amounts of energy than capturing exhaust gas emissions from fossil fuels combustion.
- On the other hand, DACCS (including CO₂ storage) can achieve negative emissions.
- It is economical to deploy in area close to CO₂ storage and where energy supply is available at low cost such as low cost PV.



Climeworks



Assumed energy consumption and facility costs of DAC in 2020 based on M. Fasihi et al., (2019):

This analyses adopt “Conservative” among 2 scenarios, “Base” and “Conservative”, by Fasihi et al.

		Energy consumption (/tCO ₂)		Facility costs (Euro/(tCO ₂ /yr))	
		2020	2050	2020	2050
High temperature (electrification) system (HT DAC)	Elec. (kWh)	1535	1316	815	222
	Heat (GJ)	6.3 (=1750 kWh)	4.0	730	199
Low temperature systems (LT DAC): use of hydrogen or gas for heat	Elec. (kWh)	250	182		

Assumption: Negative Emission Technologies (NETs) - Carbon Dioxide Removal (CDR) Technology

- ◆ The implementation of BECCS and DACCS will be at a low level in the Orderly scenario because imposing constraints on the expansion rate of CO₂ storage (refer to page 124) is used.
- ◆ The maximum supply of commercial biomass is assumed to be 50EJ/yr in the Orderly scenario and the 1.5C-CO2-CN scenario, considering the impact on food prices and biodiversity. BECCS implementation will be low in these scenarios due to biomass utilization constraints.
- ◆ Since reproducing a scenario close to the IEA NZE scenario in 1.5C-CO2_CN, significant constraints are imposed on negative emission technologies (NETs). It is assumed there will be no use of DACCS, biomass-only power generation + CCS, and e-methane + CCS power generation, which is one of the NETs, in 1.5C-CO2_CN. (Coal co-firing biomass power generation + CCS is possible if there is a condition for establishing economic efficiency as a transition.).

Assumption for hydrogen production and energy transport technologies

Hydrogen production technologies

	Facility cost (US\$/(toe/yr))	Conversion efficiency (%)
Coal gasification	1188 - 752	60%
Gas reforming	963 - 733	70%
Biomass gasification	1188 - 752	60%
Water electrolysis	2050 - 667	64 - 84%

Liquefaction technology

	Facility cost (US\$/(toe/yr))	Electricity consumption (MWh/toe)
Natural gas/Synthetic methane	226	0.36
Hydrogen	1563	1.98

Transport cost

		Facility cost	Variable cost*1
		Electricity: \$/kW Other energy: US\$/(toe/yr) CO ₂ : US\$/(tCO ₂ /yr)	Energy: US\$/toe CO ₂ : US\$/tCO ₂
Electricity*2		283.3+1066.7L	-
Hydrogen	Pipeline*3	210.0L	5.0L
	Tanker	69.5L	7.26+0.60L
CO ₂	Pipeline*3	99.4L	2.35L
	Tanker	47.5L	1.77L
Natural gas (The same applies to synthetic methane.)	Pipeline*2	128.3L	3.5L
	Tanker	35.1L	8.09+0.39L

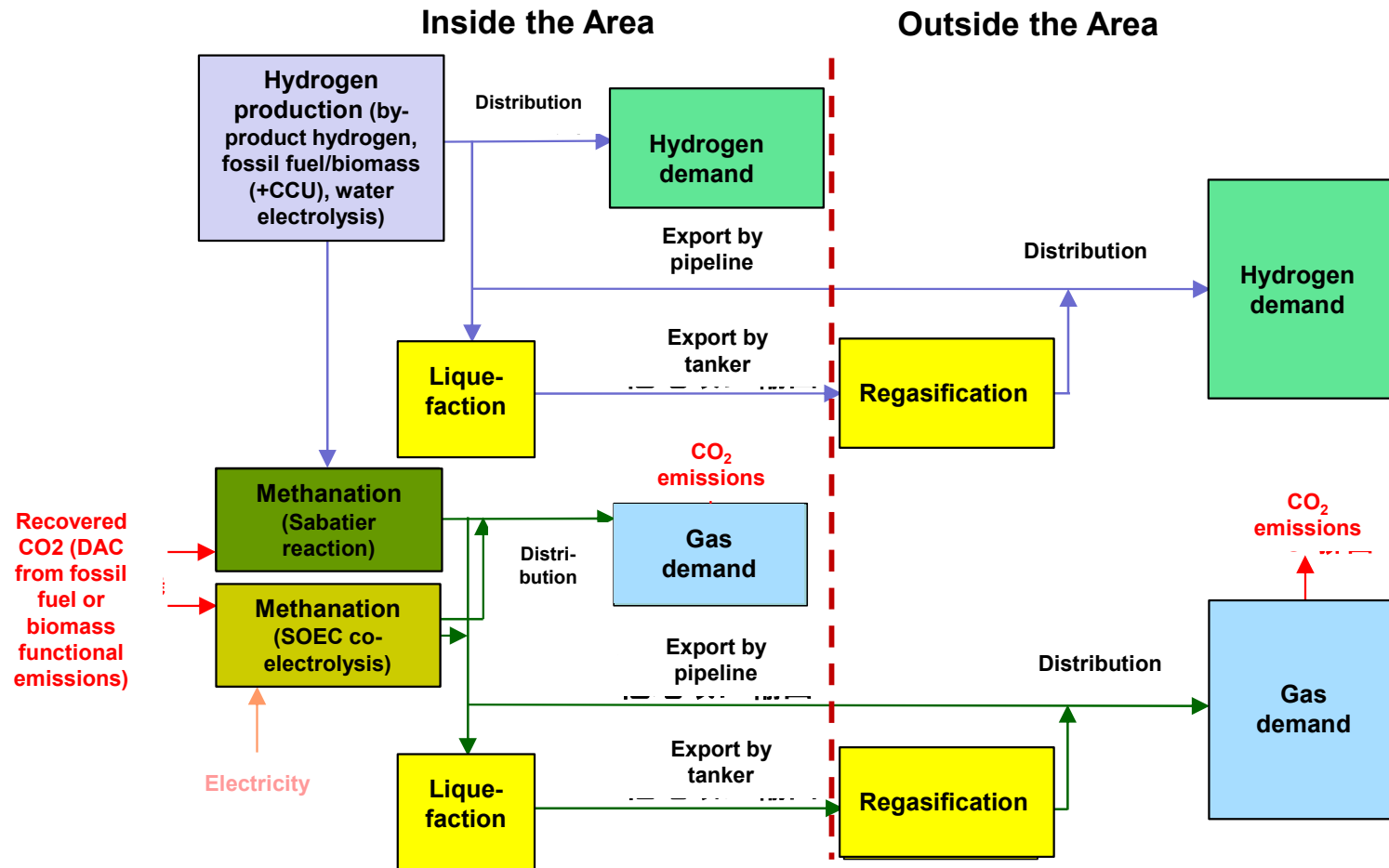
L: Distance between regions (1000km)

*1 For ships, the distance-independent term assumes fuel costs. For pipelines, the distance-dependent terms assume fuel costs and compression power costs, respectively.

*2 For submarine transmission lines, fixed costs are assumed to be 10 times higher than the above.

*3 For submarine pipelines, fixed costs are assumed to be three times higher than above.

Modeling of e-methane (methanation)



✓ Hydrogen is not limited to renewable-based hydrogen (green hydrogen). The most economical one is selected according to the assumed scenarios.

✓ Recovered CO₂ can be obtained from fossil fuel / biomass combustion emissions or by DAC. The most economical one is selected according the assumed scenarios.

Note) In this analysis in order to provide incentives to use of synthetic fuels for the countries that use the fuels, CO₂ emissions are not recorded in the countries that use them, but in the countries that produce them.

Balance in Methanation (Assumption in 2050)

Sabatier reaction	Hydrogen	1.22 toe	⇒	Methane	1 toe
	CO ₂	2.33 tCO2			
SOEC co-electrolysis	Electricity	15.7 MWh (=1.35 toe)	⇒		
	CO ₂	2.33 tCO2			

Modeling of e-fuels (synthetic oil)

- ✓ Hydrogen is not limited to renewable-based hydrogen (green hydrogen). The most economical one is selected according to the assumed scenarios.
- ✓ Recovered CO₂ can be obtained from fossil fuel / biomass combustion emissions or by DAC. The most economical one is selected according to the assumed scenarios.

1. Renewable electricity

Renewable energy obtained from hydropower.

2. Electrolysis

Electrolysis splits water into hydrogen and oxygen. Oxygen dissipates into the surrounding air.

Chemical synthesis

In the first step, hydrogen and CO₂ are converted to synthesis gas in the reverse water-gas shift reactor.

The Fischer-Tropsch reactor then uses this to build hydrocarbon chains.

3. Conversion

A two-step process turns CO₂ and hydrogen into hydrocarbon chains.

Heat for use in residential areas or in industry.

Renewable waxes for cosmetics, foodstuffs and chemical industries.

Infrastructure compatibility

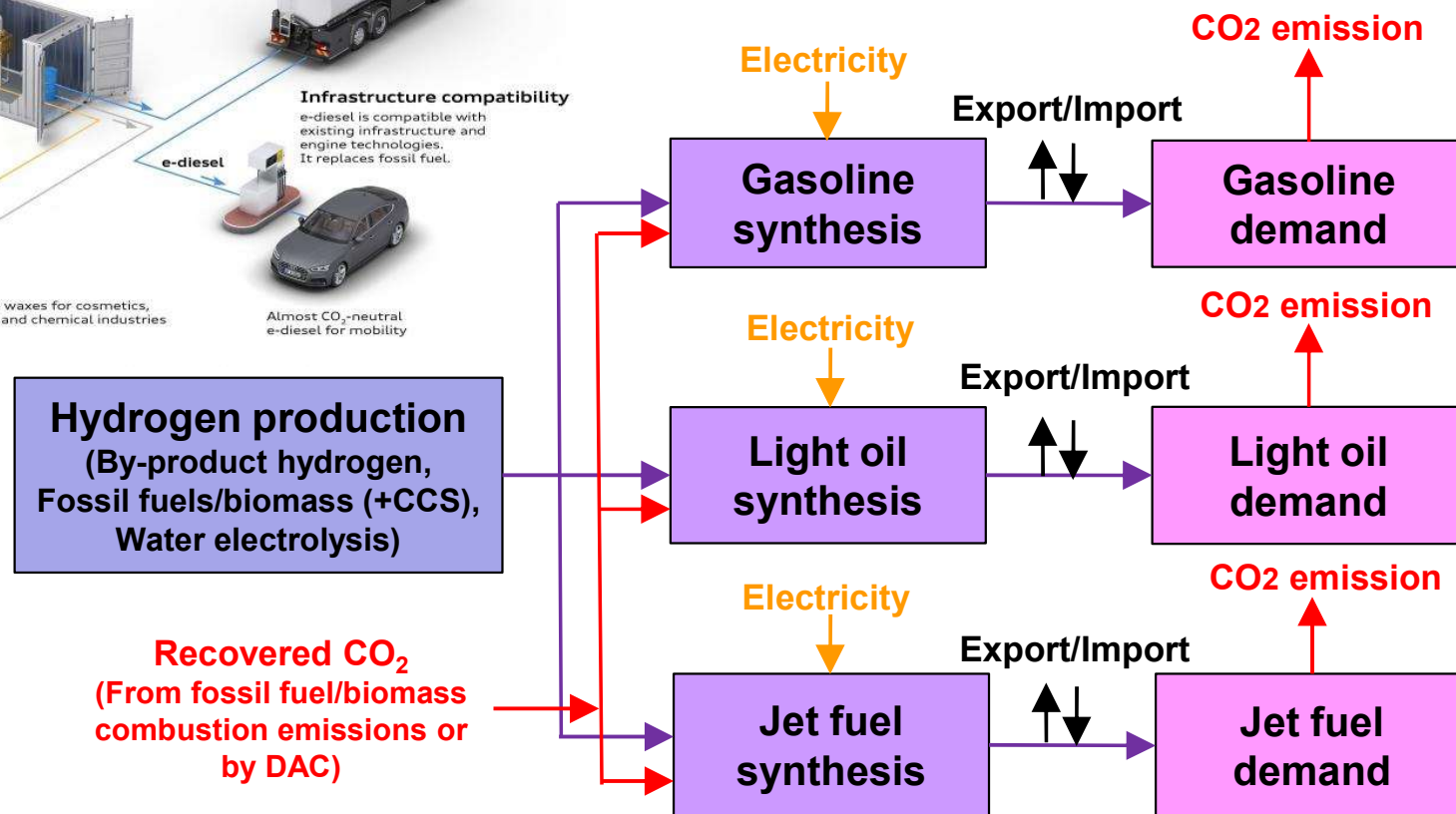
e-diesel is compatible with existing infrastructure and engine technologies. It replaces fossil fuel.

Almost CO₂-neutral e-diesel for mobility

Audi e-diesel

Balance in synthetic oil generation in 2050

Hydrogen	1.25 toe	⇒	Synthetic oil	1 toe (Available energy: 0.71 toe)
CO ₂	3.02 tCO ₂			
Electricity	0.02 toe			

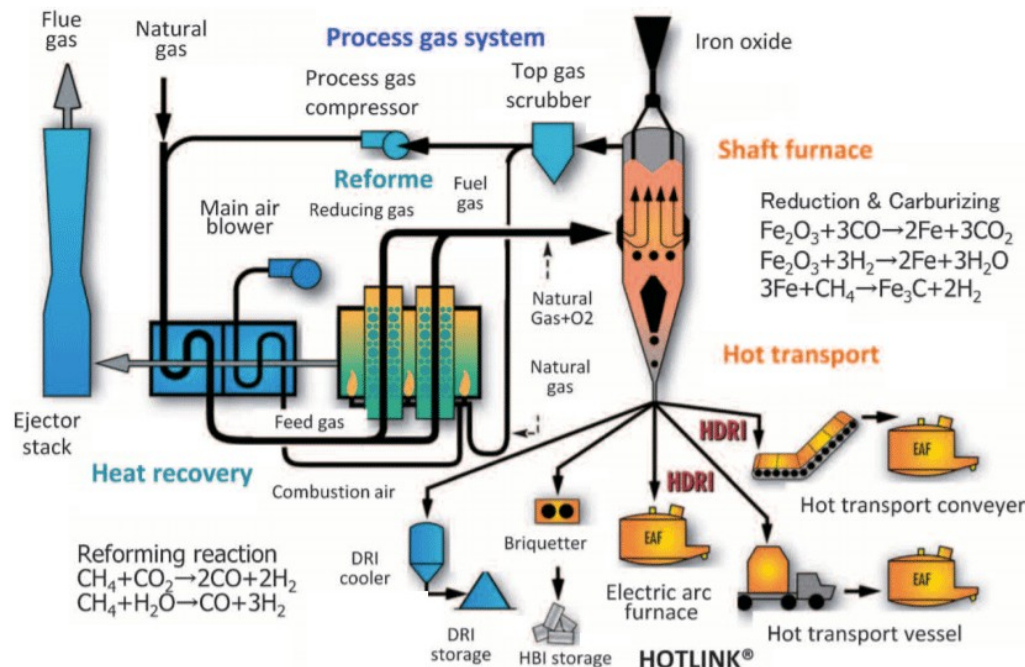


Note) In this analysis in order to provide incentives to use of synthetic fuels for the countries that use the fuels, CO₂ emissions are not recorded in the countries that use them, but in the countries that produce them.

Modeling and assumption of H₂-based DRI process

- ✓ The fuel used for existing direct reduced iron (DRI) production is natural gas, etc. (see left Fig).
- ✓ H₂-based DRI is a process that replaces fuel with hydrogen (see right Fig).
- ✓ DNE21+ assumes a set of integrated processes up to EAF and hot rolling in addition to the H₂-based DRI process [capital cost: 438.1\$/t-cs/yr, H₂ consumption: 12.1GJ/t-cs, power consumption: 695kWh/t-cs]
- ✓ In the H₂-based DRI acceleration scenario, it is assumed that new construction will be possible from 2041.

Example of gas-based DRI making process



Demonstration plant for H₂-based DRI



<https://www.midrex.com/>

https://www.kobelco.co.jp/releases/1201993_15541.html

Assumptions for vehicle: compact cars

【Standard technology scenarios】

(EV battery costs : 10,000 JPY/kWh in 2050)

	2015	2020	2030	2050
Conventional internal combustion engine	1700	1700	1800	1850
Hybrid (gasoline)	2100	2090	2020	2010
Plug-in hybrid (gasoline)	2700	2480	2190	2100
Pure electric (BEV)	3110	3050	2650	2250
Fuel cell (FCEV)	5980	5140	3880	2440

Unit: thousand JPY per vehicle

【High cost reduction in EVs (rapid cost reductions in BEV and FCEV)】

(EV battery costs: 6,000 JPY/kWh in 2030, 5,000 JPY/kWh in 2050)

	2015	2020	2030	2050
Conventional internal combustion engine	1700	1700	1800	1850
Hybrid (gasoline)	2100	2080	2010	2010
Plug-in hybrid (gasoline)	2700	2440	2100	2050
Pure electric (BEV)	3110	2850	2100	2050
Fuel cell (FCEV)	5980	4120	2440	2050

Unit: thousand JPY per vehicle

Assumptions for vehicle: large cars

【Standard technology scenarios】

(EV battery costs : 10,000 JPY/kWh in 2050)

	2015	2020	2030	2050
Conventional internal combustion engine	3700	3700	3800	3850
Hybrid (gasoline)	4180	4150	4040	4020
Plug-in hybrid (gasoline)	5210	4820	4290	4140
Pure electric (BEV)	6220	5500	4900	4300
Fuel cell (FCEV)	10460	9020	6820	4670

Unit: thousand JPY per vehicle

【High cost reduction in EVs (rapid cost reductions in BEV and FCEV)】

(EV battery costs: 6,000 JPY/kWh in 2030, 5,000 JPY/kWh in 2050)

	2015	2020	2030	2050
Conventional internal combustion engine	3700	3700	3800	3850
Hybrid (gasoline)	4180	4150	3920	3910
Plug-in hybrid (gasoline)	5210	4710	4040	3970
Pure electric (BEV)	6220	5200	4070	4000
Fuel cell (FCEV)	10460	7480	4670	4020

Unit: thousand JPY per vehicle

Appendix 2:
Transition roadmap by sector
provided by the Government of
Japan (FY 2025)
[In Japanese]

- 本技術ロードマップは、2050年カーボンニュートラルの実現を目的とした我が国の各政策や国際的なシナリオ等を参照して策定しており、パリ協定と整合する。
- 地域と共生した再エネ・安全性の確保と地域の理解を大前提とした原子力の最大限活用に加え、火力発電の休廃止、アンモニア・水素混焼・専焼技術、CCUSの導入拡大等により2050年のカーボンニュートラルを実現する。

CO₂削減イメージの概要・根拠等

概要・策定根拠

- 右図は、p 29～31に記載の技術を含め、発電分野の排出削減に向けた技術が広く普及することを前提に、日本の発電分野全体での排出削減経路のイメージを示したもの。
- 削減イメージの作成にあたっての各種想定は、「2040年度におけるエネルギー需給の見通し」等、2050年カーボンニュートラルの実現を見据えた我が国の各種政府施策や、パリ協定整合のシナリオ等を踏まえ設定している。

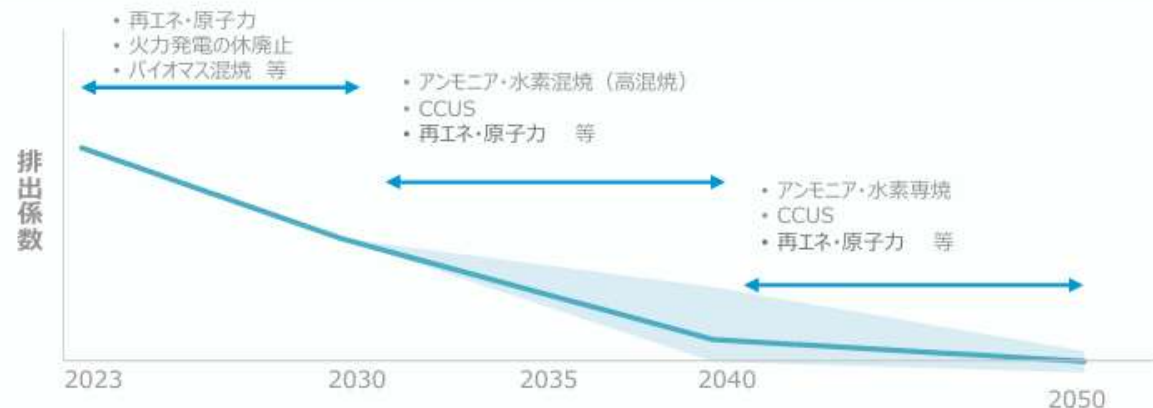
経路に大きな影響を与える主要要素

- 次世代型太陽光・洋上風力等の再エネ拡大
- CCS等による火力発電の低・脱炭素化
- 再エネ・原子力の最大限活用等

パリ協定整合性の確認

- 削減イメージは、「経済産業分野におけるトランジション・ファイナンス推進のためのロードマップ策定検討会」において、日本の地域・産業特性を踏まえつつ、NDCやパリ協定整合のシナリオ等との整合を検証し、科学的根拠／パリ協定整合性を確認している。

CO₂排出削減イメージ※



- 1 2020～2030**
地域と共生した再エネ・安全性の確保と地域の理解を大前提とした原子力の利用拡大に加え、火力発電へのバイオマス混焼や休廃止により低炭素化を進めていく。並行して、アンモニア・水素混焼技術やCCUSの技術開発・実証に取り組む。
- 2 2030～2040**
アンモニア・水素混焼の導入拡大、混焼比率拡大による高混焼化等に取り組む。
- 3 2040～2050**
アンモニア・水素専焼の実用化、導入拡大等により大幅な排出削減を行い、カーボンニュートラルを実現。

※：我が国における電力産業のうち本ロードマップの対象分野としての削減イメージであり、実際には電力各社は各々の長期的な戦略の下でカーボンニュートラルの実現を目指していくことになるため、各社に上記経路イメージとの一致を求めるものではない。

The roadmap by GoJ (2025 edition): Gas

- 本技術ロードマップは、2050年カーボンニュートラルの実現を目的とした我が国の各政策や国際的なシナリオ等を参照したもので、パリ協定と整合する。
- 天然ガス、LPガスへの燃料転換で熱需要の低炭素化を図りつつ、省エネやガスの高度利用、供給網整備等に加え、合成メタン/バイオガス/グリーンLPガスや水素等への転換、CCUS、DAC等の革新的技術の導入により、2050年のカーボンニュートラルを実現する。

CO₂削減イメージの参照先・策定根拠等

概要・策定根拠

- ・ 右図は、前頁の「技術リスト」に記載の技術による排出削減経路をイメージとして示したものの。
- ・ 主な参照先は、「第7次エネルギー基本計画」、「2040年度におけるエネルギー需給の見通し」等、2050年カーボンニュートラルの実現を目的とした我が国の各種政府施策等としている。

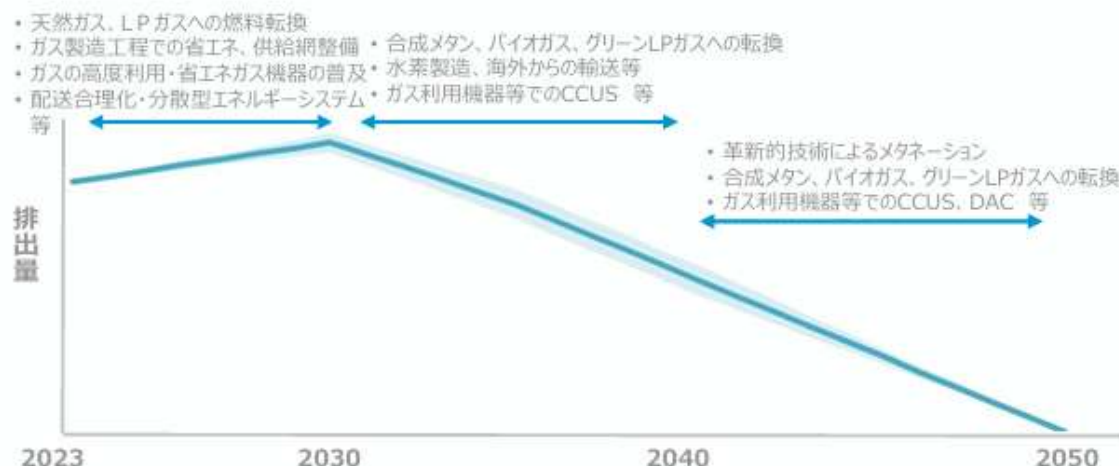
経路に大きな影響を与える主要要素

- ・ ガス需要量
- ・ 合成メタン、バイオガス、グリーンLPガス等への転換
- ・ 需要側におけるCCUSの活用

パリ協定整合性の確認

- ・ 削減イメージの試算結果は、「経済産業分野におけるトランジション・ファイナンス推進のためのロードマップ策定検討会」において、日本の地域・産業特性を踏まえつつ、NDCや国際的に認知されたシナリオとの整合を検証し、パリ協定整合であることを確認している。

CO₂排出の削減イメージ※



主要な削減方法

1. 2023~2030

- ・ ガス製造工程での省エネによる低炭素化に加え、ガス供給網の整備やガスの高度利用等を通じて、トランジション期における重要な燃料であるガスへの燃料転換を進める
- ・ 合成メタン、バイオガス、グリーンLPガスの製造技術を確認し、化石燃料由来のガスからカーボンニュートラルなガスへの転換を進めることで、脱炭素化を進める。水素サプライチェーンやCCUS等の実用化・普及拡大にも取り組む。

2. 2030~2040

- ・ 合成メタン、バイオガス、グリーンLPガスへの転換をさらに進めるとともに、DAC等の革新的技術の実用化を通じて、カーボンニュートラルを実現する。

3. 2040~2050

※ 我が国におけるガス分野としての削減イメージであり、実際にはガス事業各社は各々の長期的な戦略の下でカーボンニュートラルの実現を目指していくことになるため、各社に上記経路イメージとの一致を求めるものではない。

- 本技術ロードマップは、2050年カーボンニュートラルの実現を目的とした我が国の各政策や国際的なシナリオ等を参照したもので、パリ協定と整合する。
- 原油処理に関しては、各種省エネや燃料転換推進等による着実な低炭素化に加え、精製プロセスの変革やCCUSなどの革新的技術の導入による脱炭素化を図る。さらに、合成燃料をはじめとする脱炭素燃料の供給体制へのシフトなどにより、2050年カーボンニュートラルを実現していく。

CO₂削減イメージの参照先・策定根拠等

概要・策定根拠

- ・ 右図は、p27～29に記載の技術による、日本の石油産業全体での排出削減経路のイメージを示したもの。
- ・ 削減イメージの作成にあたっての各種想定は、「2040年度におけるエネルギー需給の見通し」等、2050年カーボンニュートラルの実現を見据えた我が国の各種政府施策や、パリ協定整合のシナリオ等を踏まえ設定している。

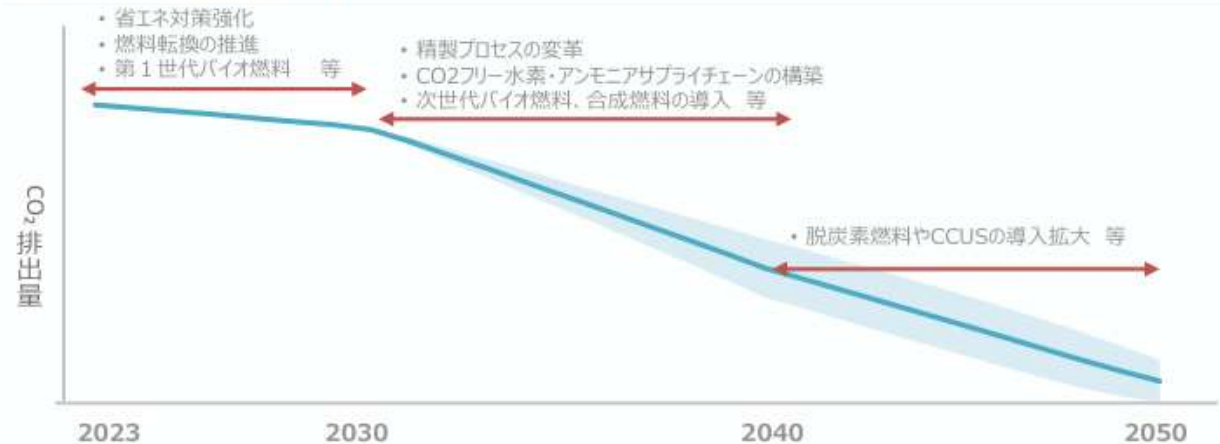
経路に大きな影響を与える主要要素

- ・ 石油製品需要
- ・ 脱炭素燃料の導入
- ・ 製油所の脱炭素化

パリ協定整合性の確認

- ・ 削減イメージの試算結果は、「経済産業分野におけるトランジション・ファイナンス推進のためのロードマップ策定検討会」において、日本の地域・産業特性を踏まえつつ、NDCや国際的に認知されたシナリオとの整合を検証し、パリ協定整合であることを確認している。

CO₂排出の削減イメージ※



- 2020～2030**
石油精製における省エネ対策の強化や燃料転換の推進により、着実な低炭素化を図っていく。また、既に実用段階にある第1世代バイオ燃料等の脱炭素燃料の活用拡大に取り組む。
- 2030～2040**
石油精製プロセスの変革やCO₂フリー水素、アンモニア、次世代バイオ燃料、合成燃料等の脱炭素燃料関連技術を確立し、カーボンニュートラルに向けた取組を加速する。
- 2040～2050**
脱炭素燃料やCCUSの導入拡大により大幅な排出削減を行い、カーボンニュートラルを実現。

※1 我が国における石油産業のうち本ロードマップの対象分野としての削減イメージであり、2050年に石油需要がゼロになることを示すものではない。
また、実際には石油各社は各々の長期的な戦略の下でカーボンニュートラルの実現を目指していくことになるため、各社に上記経路イメージとの一致を求めるものではない。
※2 2050年カーボンニュートラルの達成は他産業との連携によるDAC等を含めたCCUSやその関連のインフラ等が整備されていることを前提としている。

- 本技術ロードマップは、2050年カーボンニュートラルの実現を目的とした我が国の各政策や国際的なシナリオ等を参照したもので、パリ協定と整合する。
- 我が国鉄鋼業の競争力を維持・強化しつつ、着実な低炭素化と革新技术の実現・導入により、2050年のカーボンニュートラルを実現する。

CO₂削減イメージの参照先・策定根拠等

概要・策定根拠

- ・ 右図は、p28～29に記載の技術による、日本の鉄鋼産業全体での排出削減経路のイメージを示したもの。
- ・ 削減イメージの作成にあたっての各種想定は、「2040年度におけるエネルギー需給の見通し」等、2050年カーボンニュートラルの実現を見据えた我が国の各種政府施策や、パリ協定整合のシナリオ等を踏まえ設定している。

経路に大きな影響を与える主要要素

- ・ 電炉比率、電力排出係数
- ・ 高炉の低・脱炭素化技術の導入
- ・ 水素直接還元製鉄技術等の導入

パリ協定整合性の確認

- ・ 削減イメージの試算結果は、「経済産業分野におけるトランジション・ファイナンス推進のためのロードマップ策定検討会」において、日本の地域・産業特性を踏まえつつ、NDCや国際的に認知されたシナリオとの整合を検証し、パリ協定整合であることを確認している。

CO₂排出の削減イメージ※



主要な削減方法

	概要
1. 2023~2030	・ 既に我が国鉄鋼業は世界最高水準のエネルギー効率を達成しているが、引き続き、高炉法の省エネ等による着実な低炭素化を図る。また、需要が見込まれるエコプロダクツ等、競争力の源泉である高級鋼を生産。その収益をもとに、将来的な脱炭素技術の研究開発・実証に取り組む。
2. 2030~2040	・ 更なる省エネ・高効率化に加え、所内水素の活用(既存高炉)等の新技术を導入。 ・ また、十分なGX製品市場の成熟を前提に研究開発・実証を継続し、脱炭素に向けた革新技术の確立を目指す。
3. 2040~2050	・ 水素供給インフラやCCUS等が整備されることを前提に、水素還元製鉄等の革新技术の導入により、2050年に向けたCO ₂ の大幅な削減により、カーボンニュートラルを実現。

※ 我が国における鉄鋼業全体としての削減イメージであり、実際には鉄鋼各社は各々の長期的な戦略の下でカーボンニュートラルの実現を目指していくことになるため、各社に上記経路イメージとの一致を求めるものではない。

※ 再エネ・水素等の安定・安価な供給、CCUSやその関連のインフラ、サーキュラーエコノミーなど新たな社会システムの構築などが整備されていることが前提。

- 本技術ロードマップは、2050年カーボンニュートラルの実現を目的とした我が国の各政策や国際的なシナリオ等を参照して策定しており、パリ協定と整合する。
- 具体的には、各種省エネ・効率化や燃料転換などによる着実な低炭素化に加え、CCUSなどの革新的技術を積極的に導入することで、2050年のカーボンニュートラルを実現していくものである。

CO₂削減イメージの試算概要・根拠等

概要・策定根拠

- 右図は、p35~36に記載の技術による排出削減経路を試算のうえ、その結果をイメージとして示したもの。
- 試算にあたっての各種想定は、「第7次エネルギー基本計画」における「2040年度におけるエネルギー需給の見通し」等、2050年カーボンニュートラルの実現を目的とした我が国の各種政府施策や、国際的に認知されたパリ協定整合のシナリオ等を踏まえ設定している。

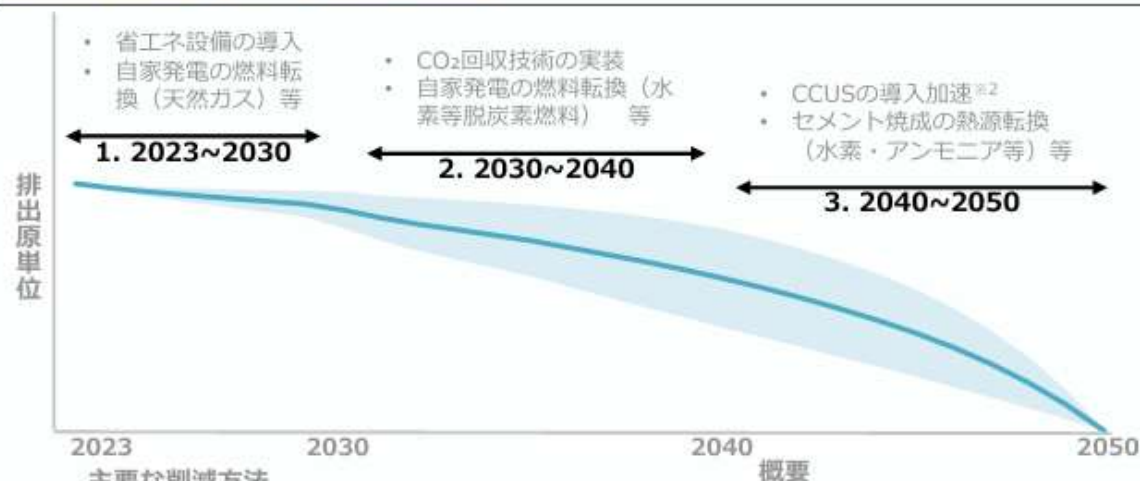
経路に大きな影響を与える主要要素

- CCUSの導入状況
- 自家発・焼成工程における燃料転換の進展
- クリンカ比率

パリ協定整合性の確認

- 削減イメージの試算結果は、「経済産業分野におけるトランジション・ファイナンス推進のためのロードマップ策定検討会」において、日本の地域・産業特性を踏まえつつ、NDCや国際的に認知されたシナリオとの整合を検証し、パリ協定整合であることを確認している。

CO₂排出削減イメージの試算結果※1、2、3



主要な削減方法

1. 2023~2030

- 省エネ設備の導入や、バイオマス・廃棄物等への燃料転換を進める。
- CO₂回収等の技術開発、クリンカ比率の低減、廃棄物の原料利用等を進める。

2. 2030~2040

- 2020年代の取組に加え、CO₂回収等技術の実装を進める。
- 自家用電力や焼成用キルンについて、水素等の脱炭素燃料への転換を進める。

3. 2040~2050

- CO₂回収等技術の実装を加速させるとともに、自家発電・キルンの脱炭素燃料への転換を進め、脱炭素を目指す。

※1 我が国におけるセメント産業全体としての削減イメージであり、実際にはセメント各社は各々の長期的な戦略の下でカーボンニュートラルの実現を目指していくことになるため、各社に上記経路イメージとの一致を求めるものではない。

※2 2050年カーボンニュートラルの実現には、CCUSや水素・アンモニア等の導入拡大も非常に重要。省エネ技術の進展や水素・アンモニアなどの新燃料の安定・安価な供給、その関連のインフラ、サプライチェーンを通じた連携によるCCUSやサーキュラーエコノミーなど、新たな社会システムの整備が前提。

The roadmap by GoJ (2025 edition): Paper & Pulp

- 本技術ロードマップは、2050年カーボンニュートラルの実現を目的とした我が国の各政策や国際的なシナリオ等を参照して策定しており、パリ協定と整合する。
- 具体的には、各種省エネ・効率化や燃料転換などによる着実な低炭素化に加え、CCUSなどの革新的技術を積極的に導入することで、2050年のカーボンニュートラルを実現していくものである。

CO₂削減イメージの試算概要・根拠等

概要・策定根拠

- 右図は、p28~31に記載の技術による排出削減経路を試算のうえ、その結果をイメージとして示したもの。
- 試算にあたっての各種想定は、「第7次エネルギー基本計画」における、「2040年度におけるエネルギー需給の見通し」等、2050年カーボンニュートラルの実現を目的とした我が国の各種政府施策や、国際的に認知されたパリ協定整合のシナリオ等を踏まえ設定している。

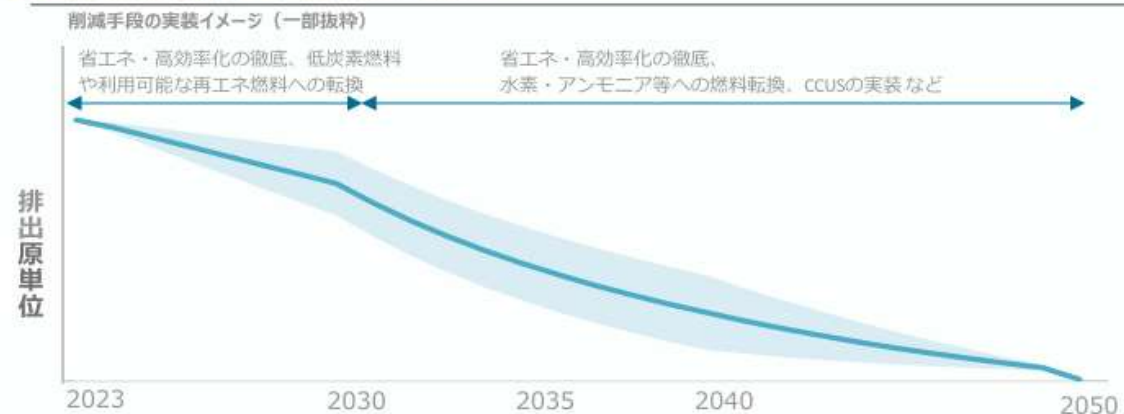
経路に大きな影響を与える主要要素

- 自家発電・自家用蒸気等の燃料転換
- 省エネ・高効率化の進展

パリ協定整合性の確認

- 削減イメージの試算結果は、「経済産業分野におけるトランジション・ファイナンス推進のためのロードマップ策定検討会」において、日本の地域・産業特性を踏まえつつ、NDCや国際的に認知されたシナリオとの整合を検証し、パリ協定整合であることを確認している。

CO₂排出削減イメージの試算結果※1、2、3



2020年代

- 省エネ・高効率化を進めつつ、石炭・石油から天然ガス・バイオマス等へ燃料を転換する

2030年代

- 省エネ・高効率化を進めつつ、石炭・石油・天然ガスから水素・アンモニア・バイオマス等の脱炭素燃料に転換する。CCUS技術の導入も進める。

2040年代

※1 我が国における紙・パルプ産業のうち本ロードマップの対象分野としての削減イメージであり、実際には製紙各社は各々の長期的な戦略の下でカーボンニュートラルの実現を目指していくことになるため、各社に上記経路イメージとの一致を求めるものではない。

※2 省エネ技術の進展や水素・アンモニアなどの新燃料の安定・安価な供給、他産業との連携によるDAC等を含めたCCUSやその関連のインフラ、サーキュラーエコノミーなど新たな社会システムの構築などが整備されていることが前提。なお、植林等によるCO₂吸収分は上記イメージには含まれていないが、森林経営を行う製紙企業が実際に2050年ネットゼロを目指すうえで、p23にあるように、吸収分を含め検討することも考えられる。

- 本技術ロードマップは、2050年カーボンニュートラルの実現を目的とした我が国の各政策や国際的なシナリオ等を参照して策定しており、パリ協定と整合する。
- 具体的には、各種省エネ・効率化や燃料転換などによる着実な低炭素化に加え、CCUSなどの革新的技術を積極的に導入することで、2050年のカーボンニュートラルを実現していくものである。

CO₂排出削減イメージの試算結果※1、2、3

CO₂削減イメージの試算概要・根拠等

概要・策定根拠

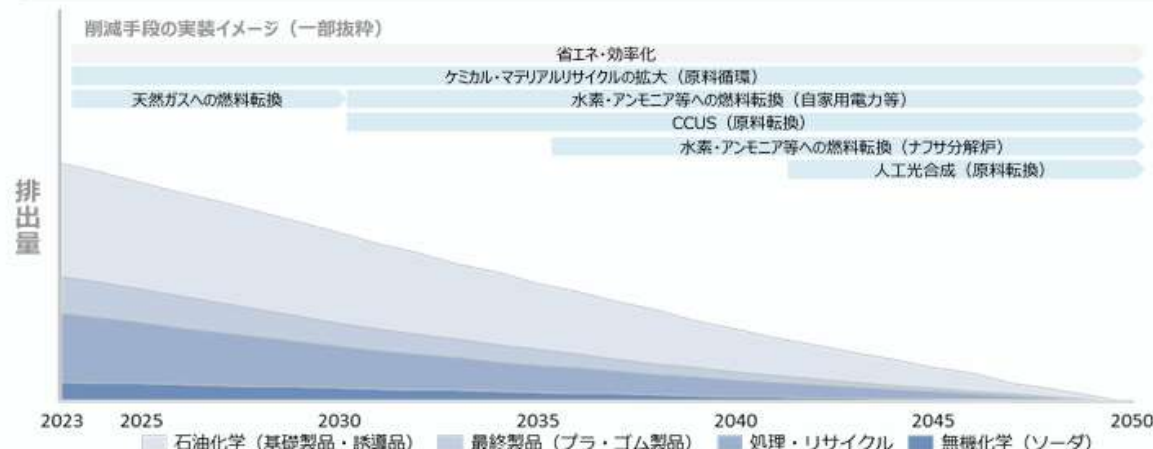
- 右図は、p33~36に記載の技術による排出削減経路を試算のうえ、その結果をイメージとして示したもの。
- 試算にあたっての各種想定は、「第7次エネルギー基本計画」における、「2040年度におけるエネルギー需給の見通し」等、2050年カーボンニュートラルの実現を目的とした我が国の各種政府施策や、国際的に認知されたパリ協定整合のシナリオ等を踏まえ設定している。

経路に大きな影響を与える主要要素

- 各種化学品の需要・生産量
- 自家発電・自家用蒸気等の燃料転換
- 原料転換・リサイクル
- ナフサ分解炉の燃料転換

パリ協定整合性の確認

- 削減イメージの試算結果は、「経済産業分野におけるトランジション・ファイナンス推進のためのロードマップ策定検討会」において、日本の地域・産業特性を踏まえつつ、NDCや国際的に認知されたシナリオとの整合を検証し、パリ協定整合であることを確認している。



主要な削減方法	対象	概要
(1) 燃料転換	全部門	ナフサ分解炉や自家発電等について、短期的にはBPTや天然ガス、中長期的には水素・アンモニア等に燃料を転換する。
(2) 原料転換	処理・リサイクル、石化	廃プラ・廃ゴム・廃タイヤの焼却・サーマルリサイクルを減らし、ケミカル・マテリアルリサイクルを拡大する。
	石化、最終製品	バイオマスやCO ₂ 由来の原料を利用した化学品・製品に転換する。人工光合成技術も活用する。

※1 我が国における化学産業のうち本ロードマップの対象分野としての削減イメージであり、実際には化学各社は各々の長期的な戦略の下でカーボンニュートラルの実現を目指していくことになるため、各社に上記経路イメージとの一致を求めるものではない。

※2 省エネ技術の進展や水素・アンモニアなどの新燃料の安定・安価な供給、他産業との連携によるDAC等を含めたCCUSやその関連のインフラ、サーキュラーエコノミーなど新たな社会システムの構築などが整備されていることが前提。

The roadmap by GoJ (2025 edition): Automobile

- 本技術ロードマップは、2050年カーボンニュートラルの実現を目的とした我が国の各政策や国際的なシナリオ等を参照したもので、パリ協定と整合する。
- 製造時の各種省エネ・効率化や燃料転換に加え、電動車の導入と脱炭素燃料の導入拡大により、2050年カーボンニュートラルを実現していく。

※なお、本技術ロードマップの策定にあたっては、日本自動車工業会2050年カーボンニュートラルシナリオの中の一つのシナリオ（CNFシナリオ）におけるパワートレインや燃料の構成を参照した。

(参照) https://www.jama.or.jp/operation/ecology/carbon_neutral_scenario/PDF/Transitioning_to_CN_by_2050A_Scenario-Based_Analysis_JP.pdf

CO₂削減イメージの試算概要・根拠等

概要・策定根拠

- 右図は、p 31～33に記載の技術による排出削減経路を試算のうえ、その結果をイメージとして示したものの。
- 試算にあたっての各種想定は、「第7次エネルギー基本計画」における「2040年度におけるエネルギー需給の見通し」等、2050年カーボンニュートラルの実現を目的とした我が国の各種政府施策や、国際的に認知されたパリ協定整合のシナリオ等を踏まえ設定している。

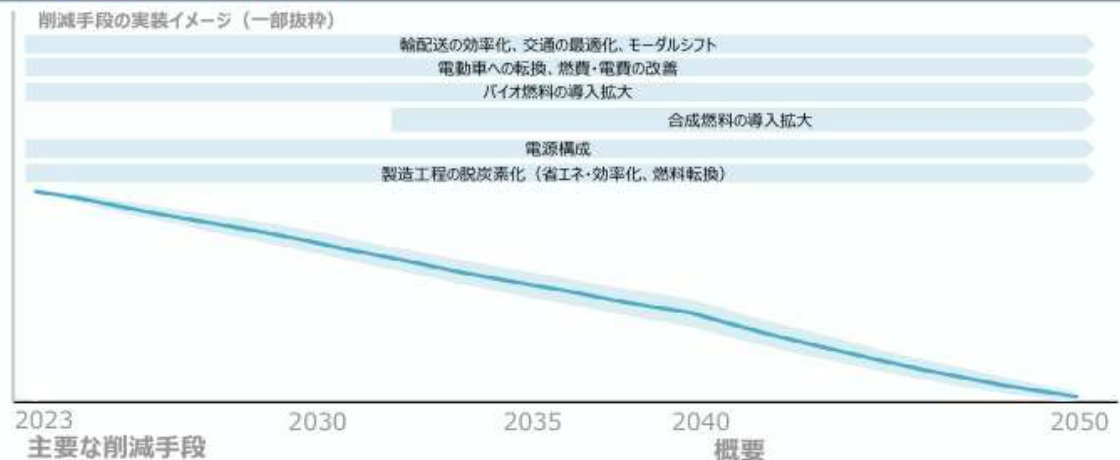
経路に大きな影響を与える主要要素

- 走行距離（輸配送の効率化、交通の最適化、モーダルシフト）
- 電動車等への転換／燃費・電費の改善
- 燃料の低炭素化・脱炭素化（バイオ燃料、合成燃料の導入拡大）
- 電源構成
- 製造工程の脱炭素化（省エネ・効率化、燃料転換）

パリ協定整合性の確認

- 削減イメージの試算結果は、「経済産業分野におけるトランジション・ファイナンス推進のためのロードマップ策定検討会」において、日本の地域・産業特性を踏まえつつ、NDCや国際的に認知されたシナリオとの整合を検証し、パリ協定整合であることを確認している。

CO₂排出の削減イメージ※1、2、3



(1) 燃費・電費の改善

- 燃費・電費の継続的な改善や、HEV・PHEVなどのよりエネルギー効率が高い自動車を導入することで、全体としての燃料・電力等消費量を削減する。

(2) 電動化・脱炭素燃料の導入

- BEV・FCVの導入を進める他、HEV・PHEV等への合成燃料利用を拡大し、走行時の排出量を削減する。

(3) 製造工程の脱炭素化

- 再エネ利用の拡大や低・脱炭素燃料への転換等により、自動車製造時の排出を削減する。

※1 我が国における自動車産業のうち本ロードマップの対象分野としての削減イメージであり、実際には各社は各々の長期的な戦略の下でカーボンニュートラルの実現を目指していくことになるため、各社に上記経路イメージとの一致を求めるものではない。

※2 上記経路はP.11記載の排出源（製品製造、エネルギー源製造・供給、車両使用）にかかる排出量を示しているが、水素・合成燃料の製造・輸送などにかかる排出量は含まれていない。

※3 省エネ技術の進展や水素・アンモニアなどの新燃料の安定・安価な供給、他産業との連携によるDAC等を含めたCCUSやその関連のインフラ、サーキュラーエコノミーなど新たな社会システムの構築などが整備されていることが前提。