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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

RITE
Research Institute of Innovative Technology for the Earth



- It is necessary to strengthen measures in each sector to achieve the 2℃ and 1.5℃ 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℃ and 1.5℃ 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:



- **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.<br>• 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. |

(Source) Based on the ICMA Overview and Recommendations for Sustainable Finance Taxonomies and materials by each organization

# Updated contents



**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;**

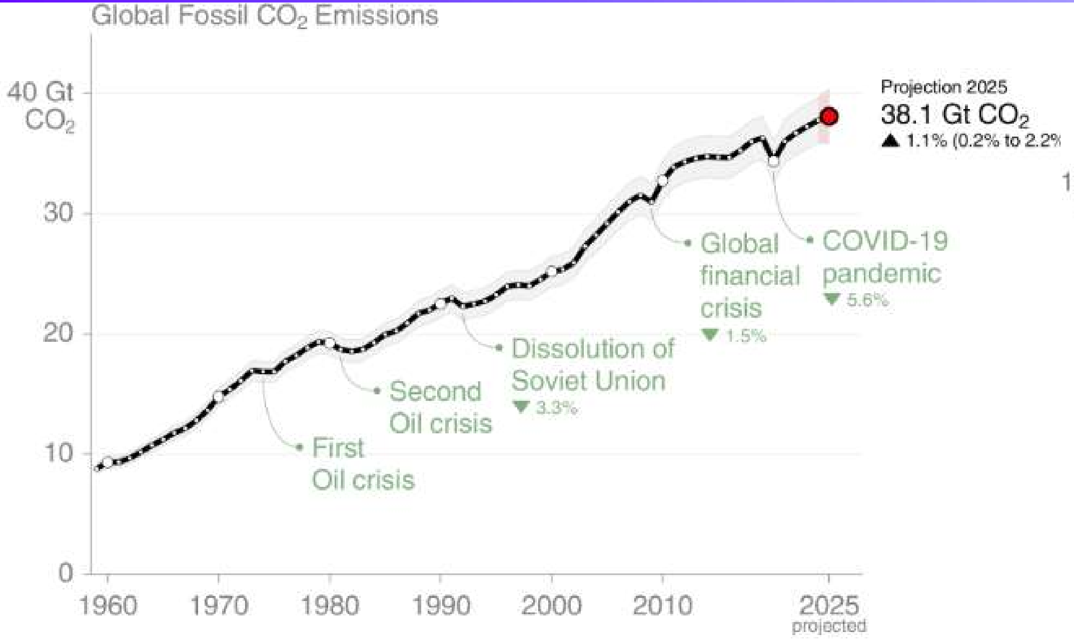
- **Upward revise of the latest actual value of global emission**
- **Downward revise of the latest crude steel production trend in Japan (to be consistent with the assumption in the 7th Strategic Energy Plan)**
- **Revise of costs and potentials of off-shore wind power (revised to the potentials including 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)**

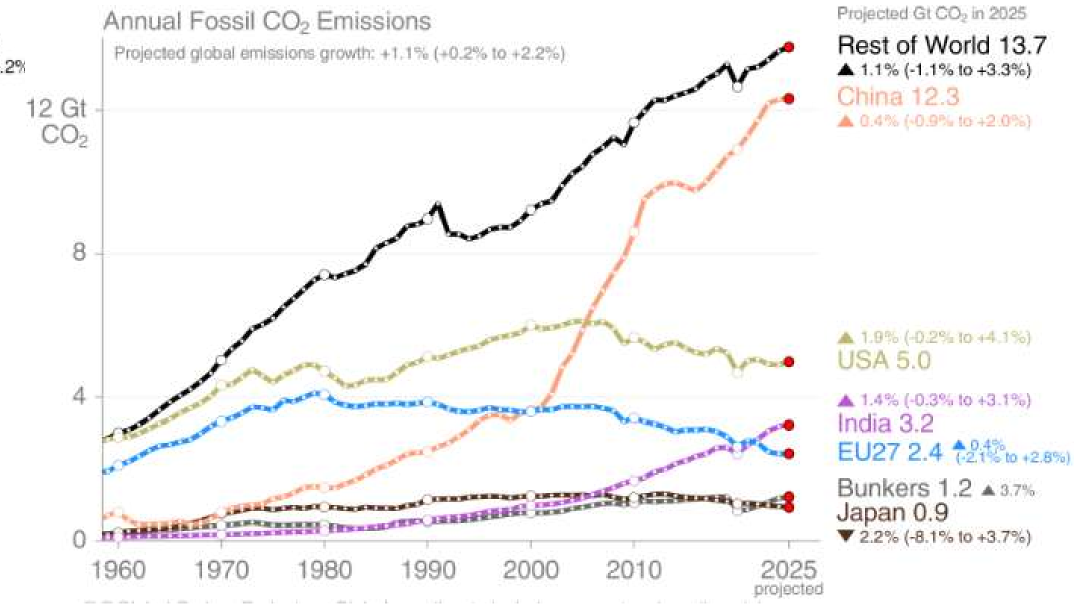
* https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2024/068/068_008.pdf

# 2. Emissions Trend and Reference Scenarios

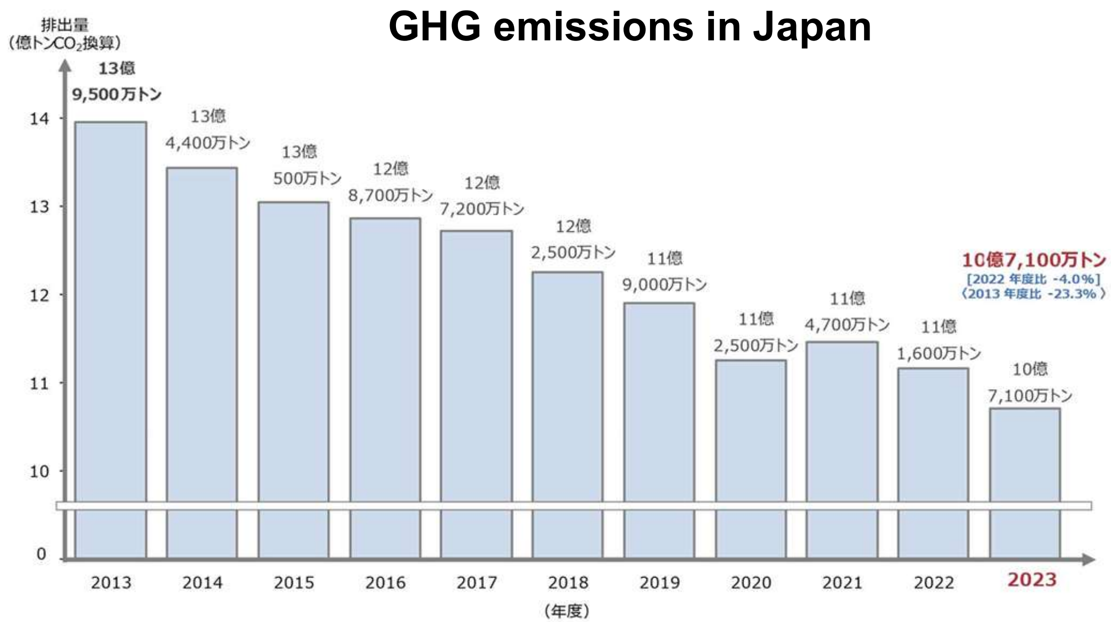
# Current Trend of Global Emissions and Outlook of NDCs

# $CO_2$ emission trajectories in the world and major countries




出典）Global Carbon Project, 2025

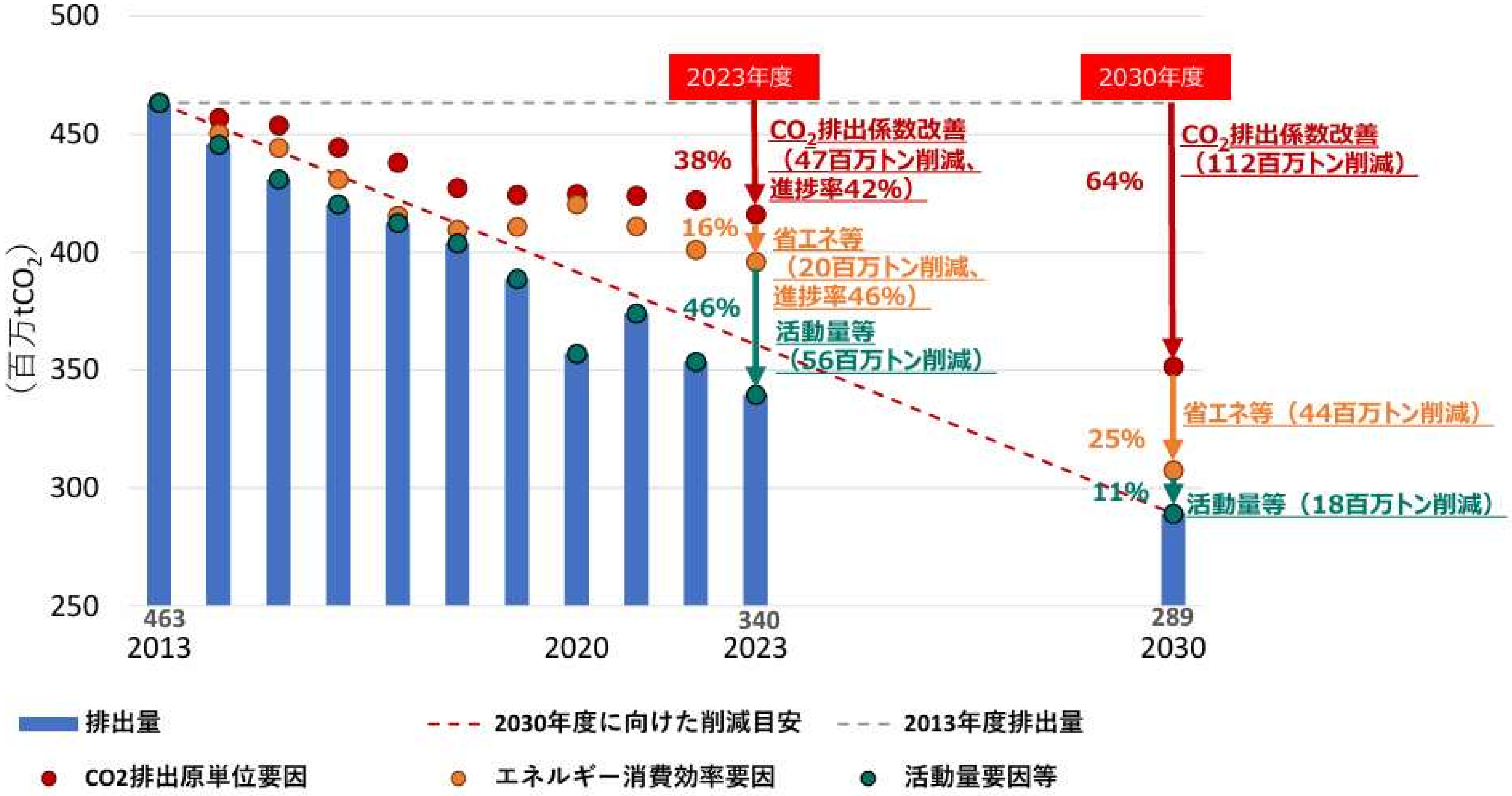



**While emissions of Japan, US, and EU are continually decreasing, global emissions keep increasing.**

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

# Japan's $CO_2$ emission reduction trend and factor analysis: 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$CO_2$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。

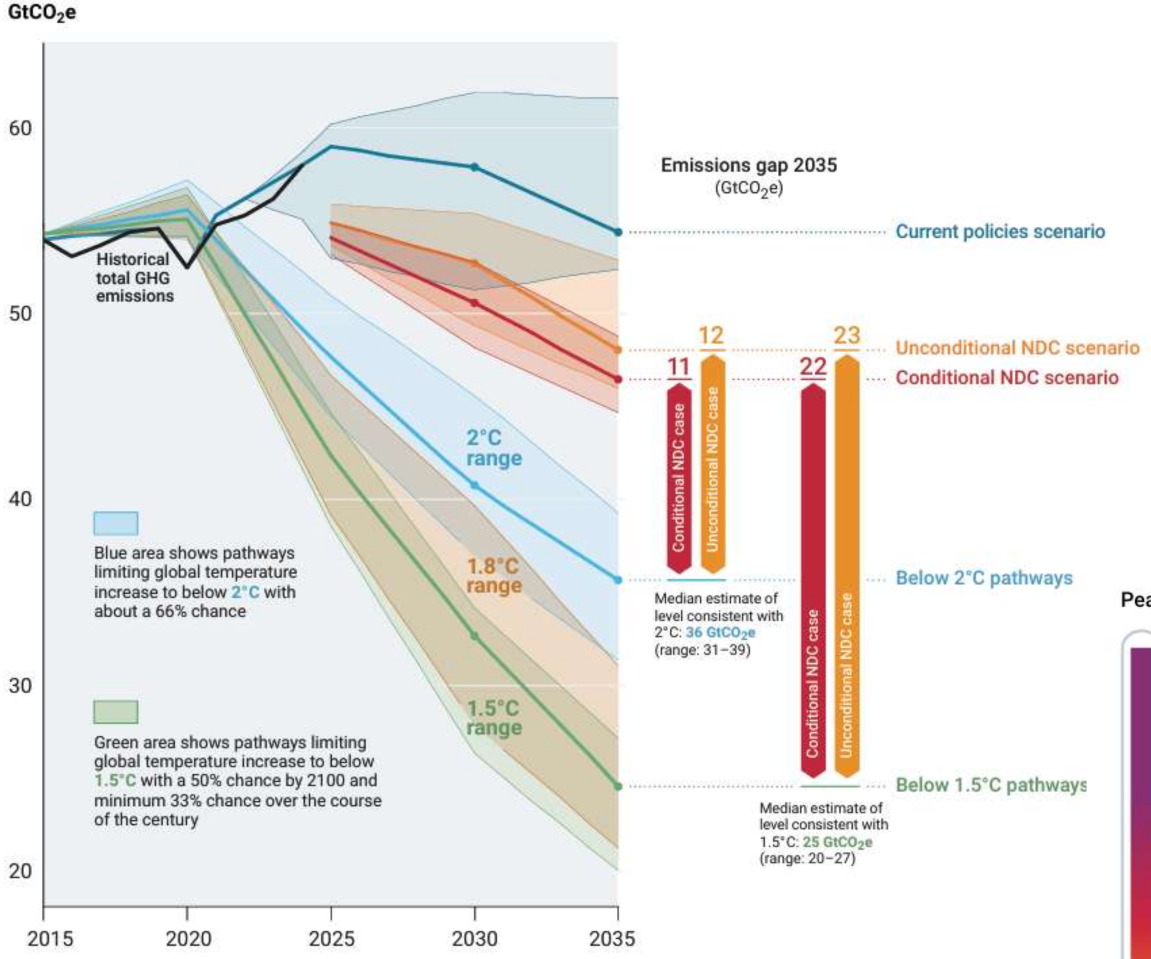
<出典>温室効果ガスインベントリ、地球温暖化対策計画、総合エネルギー統計（資源エネルギー庁）、2030年におけるエネルギー需給の見通し（関連資料）（以上、資源エネルギー庁）、鉱工業生産指数、生産動態統計（以上、経済産業省）、国民経済計算（内閣府）から作成

Source) The Government of Japan, 2025

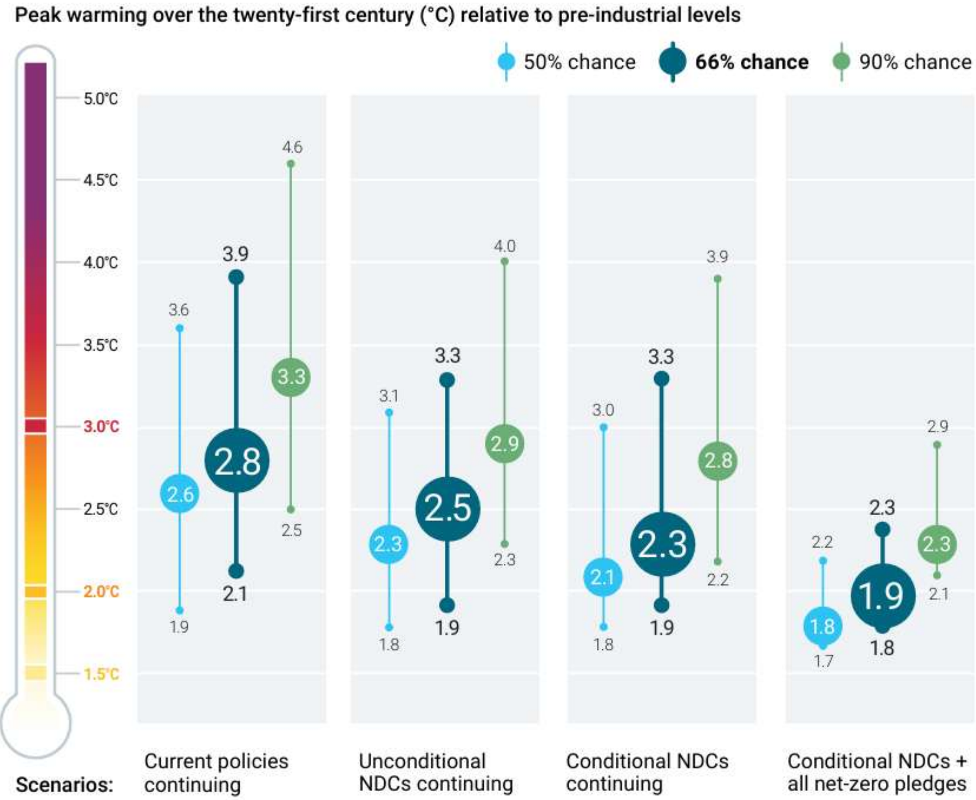
✓ **It should be noted that a main factor of emissions reduction is decrease of production activities (e.g. transfer to developing countries).**

# Emissions gap between 1.5℃/2℃ target and current policies






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



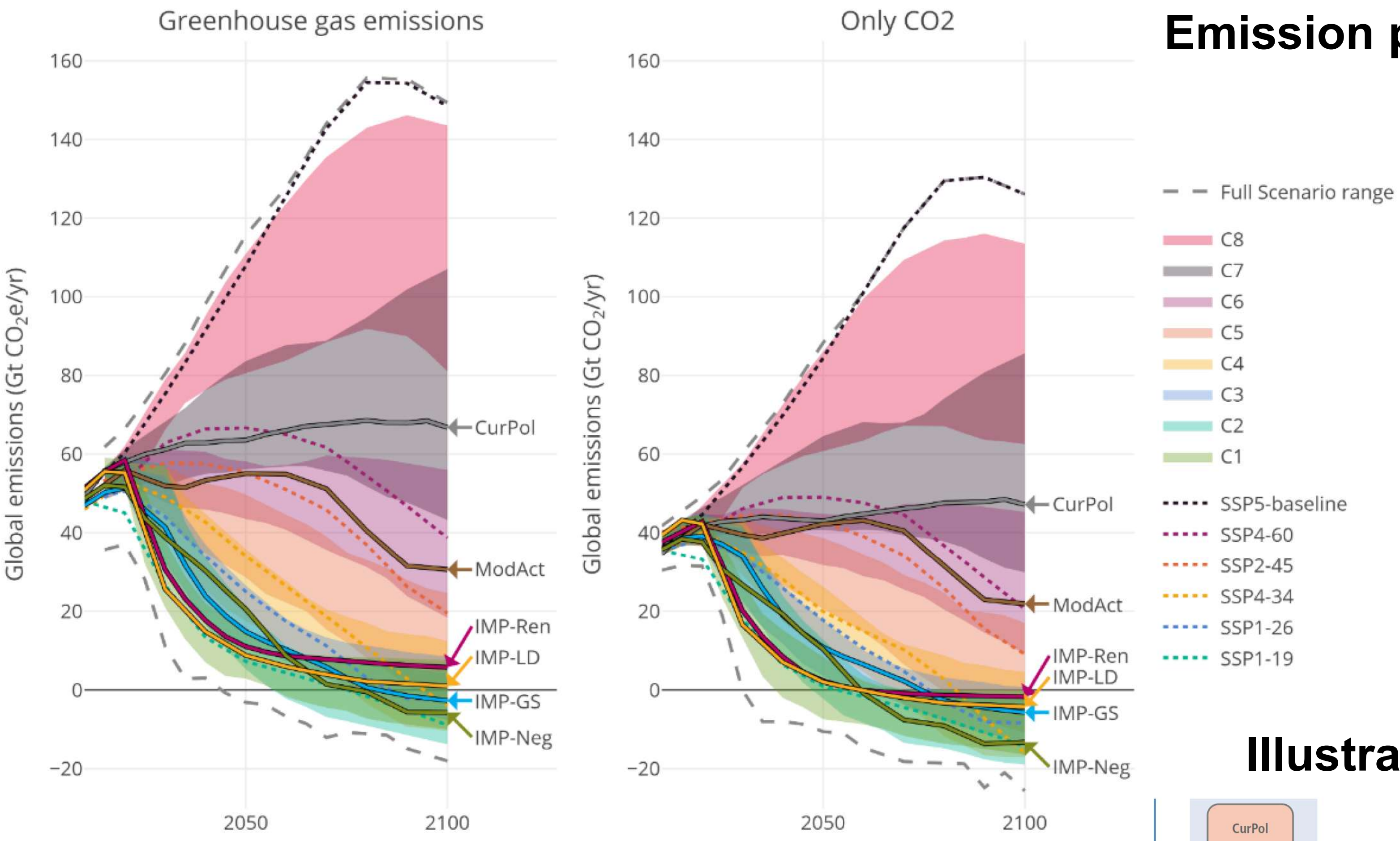

Source) UNEP, Emissions Gap Report 2025

# IPCC Scenarios

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

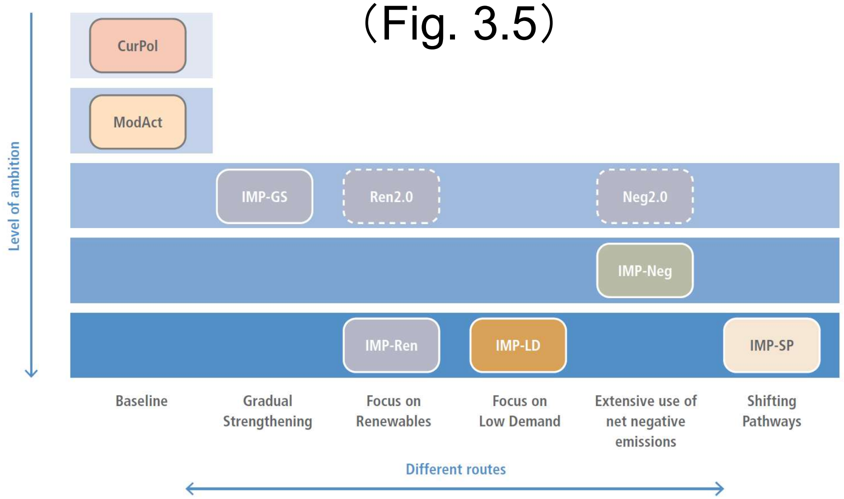


## Emission pathways（Fig. 3.10）



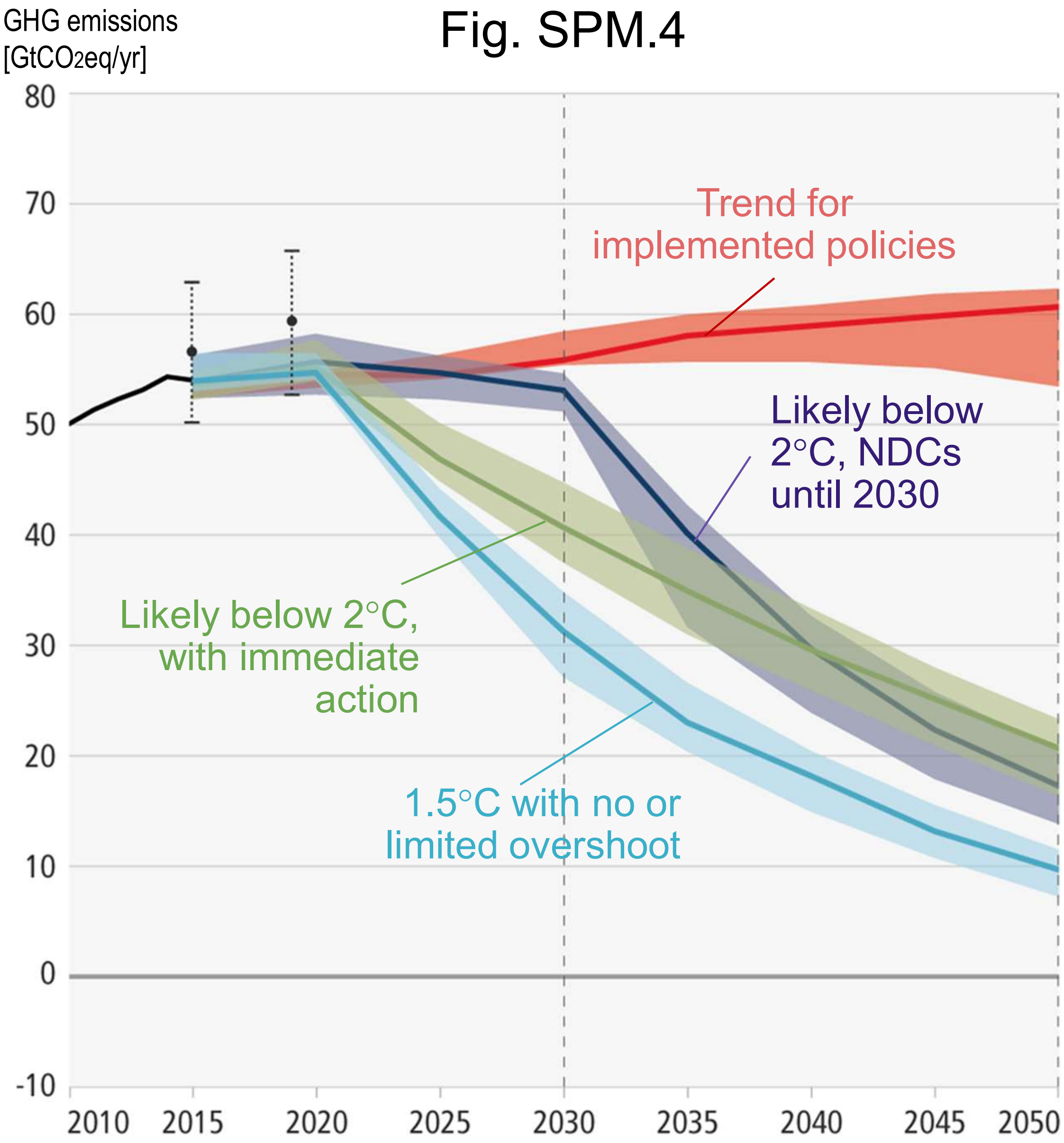

| | |
|---|---|
| C8 | ＞4℃ |
| C7 | 4℃ |
| C6 | 3℃ |
| C5 | 2.5℃ |
| C4 | 2℃（＞50%） |
| C3 | 2℃（＞67%） |
| C2 | 1.5℃-high overshoot |
| C1 | 1.5℃-no/limited overshoot |

## Illustrative Pathways (IPs)
（Fig. 3.5）




| | | | |
|---|---|---|---|
| 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 |

# NDCs and long-teem goals under Paris Agreement




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

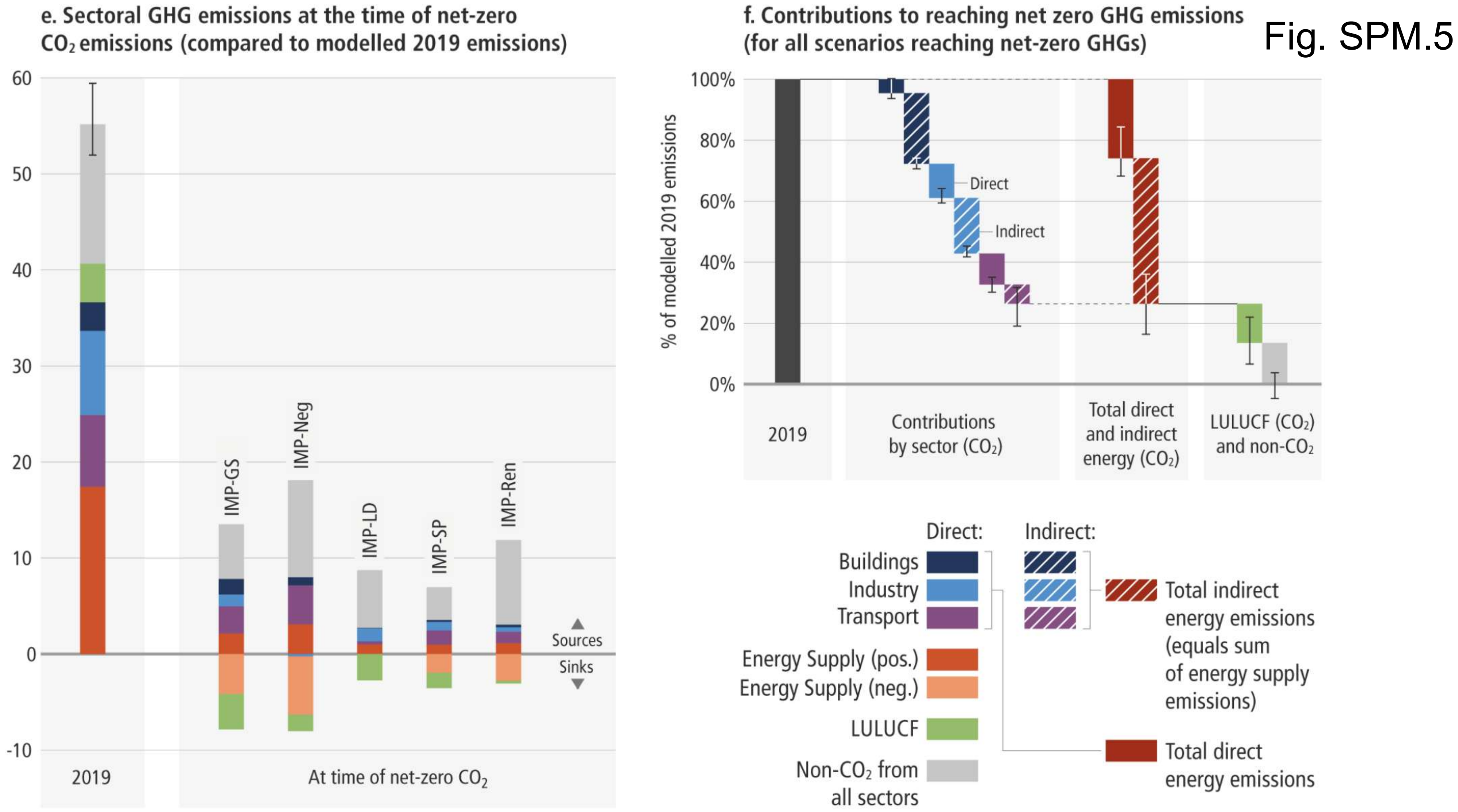
"Unconditional elements: 53 (50–57) $GtCO_2eq/yr$, Including conditional elements: 50 (47–55) $GtCO_2eq/yr$" (SPM, Table SPM 1)

- ✓ **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



Fig. SPM.5



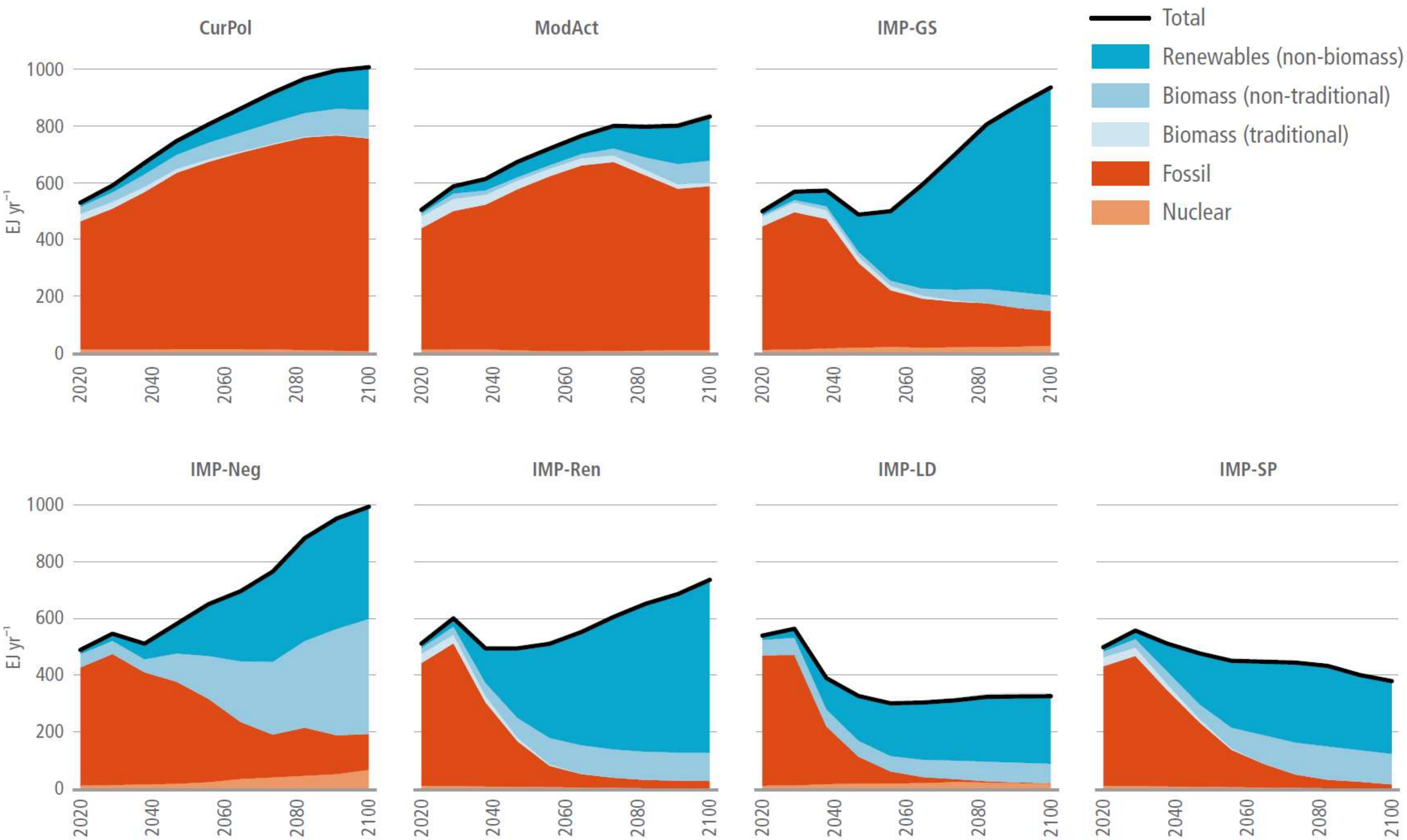

**"The deployment of CDR to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO2 or GHG emissions are to be achieved." (SPM C.11)**

**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)



Fig. 3.8



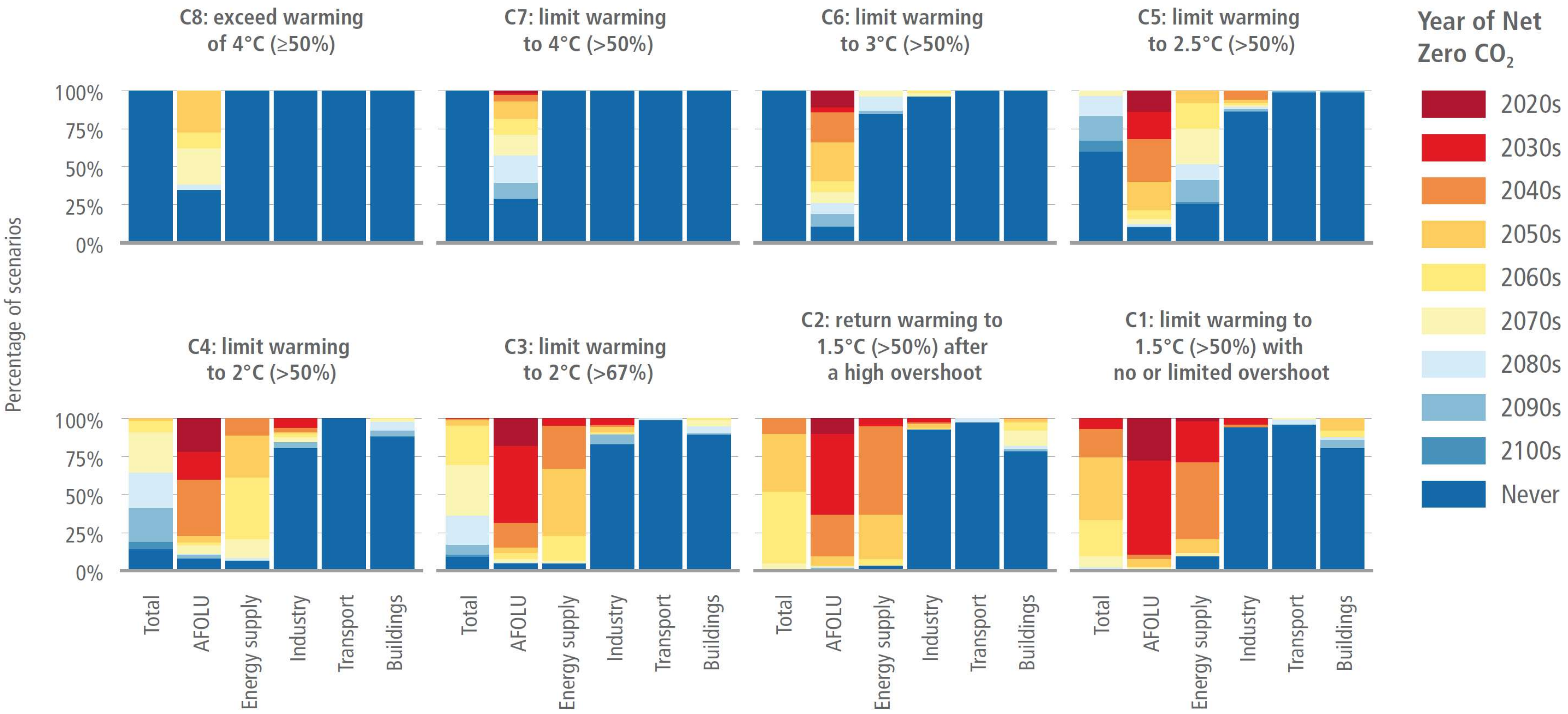

**Electricity systems powered predominantly by renewables will be increasingly viable over the coming decades, but it will be challenging to supply the entire energy system with renewable energy. (Chapter 6 ES)**

- ✓ **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 $CO_2$ emissions first reach net negative values



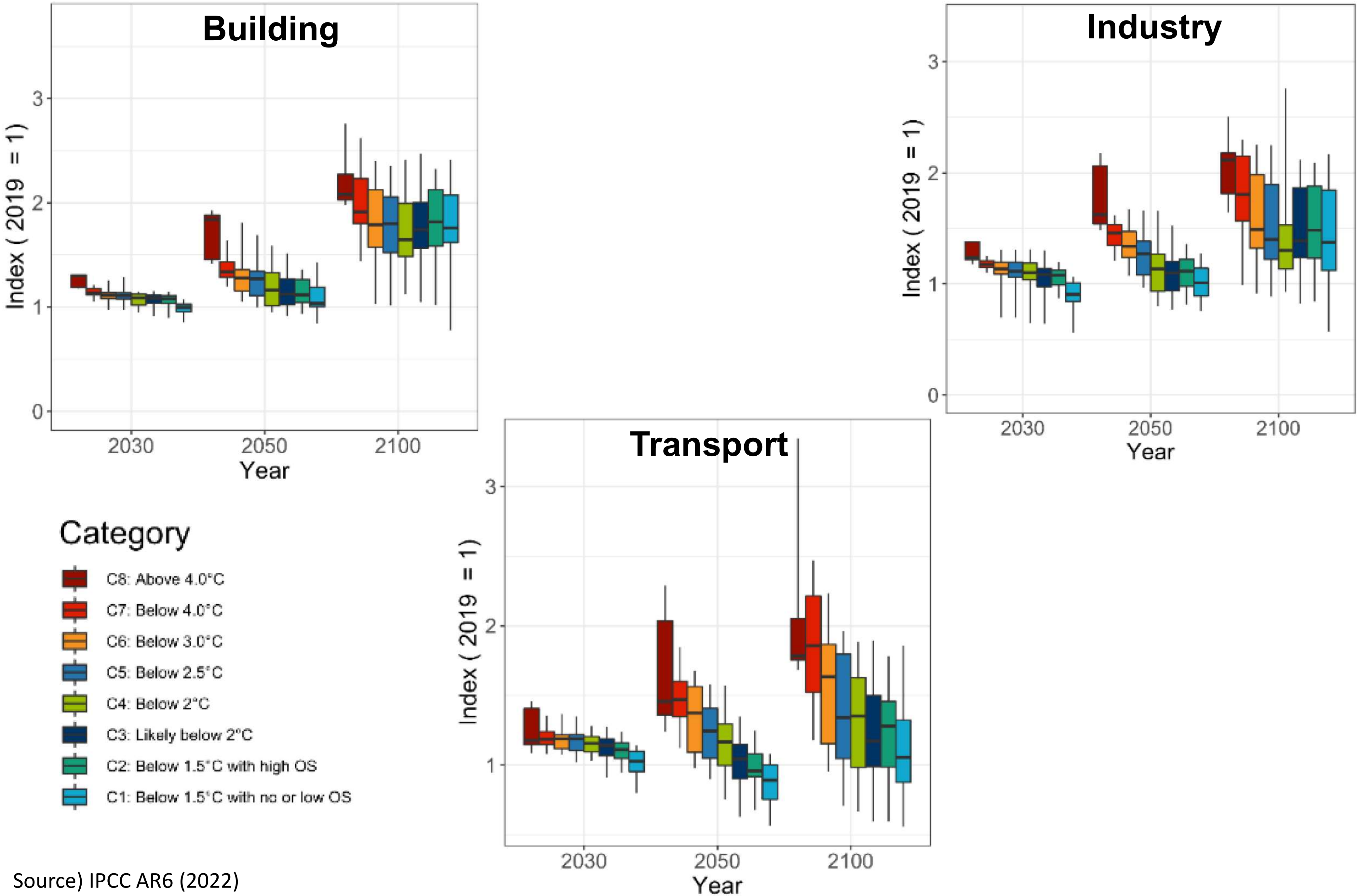
Fig. 3.19




**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

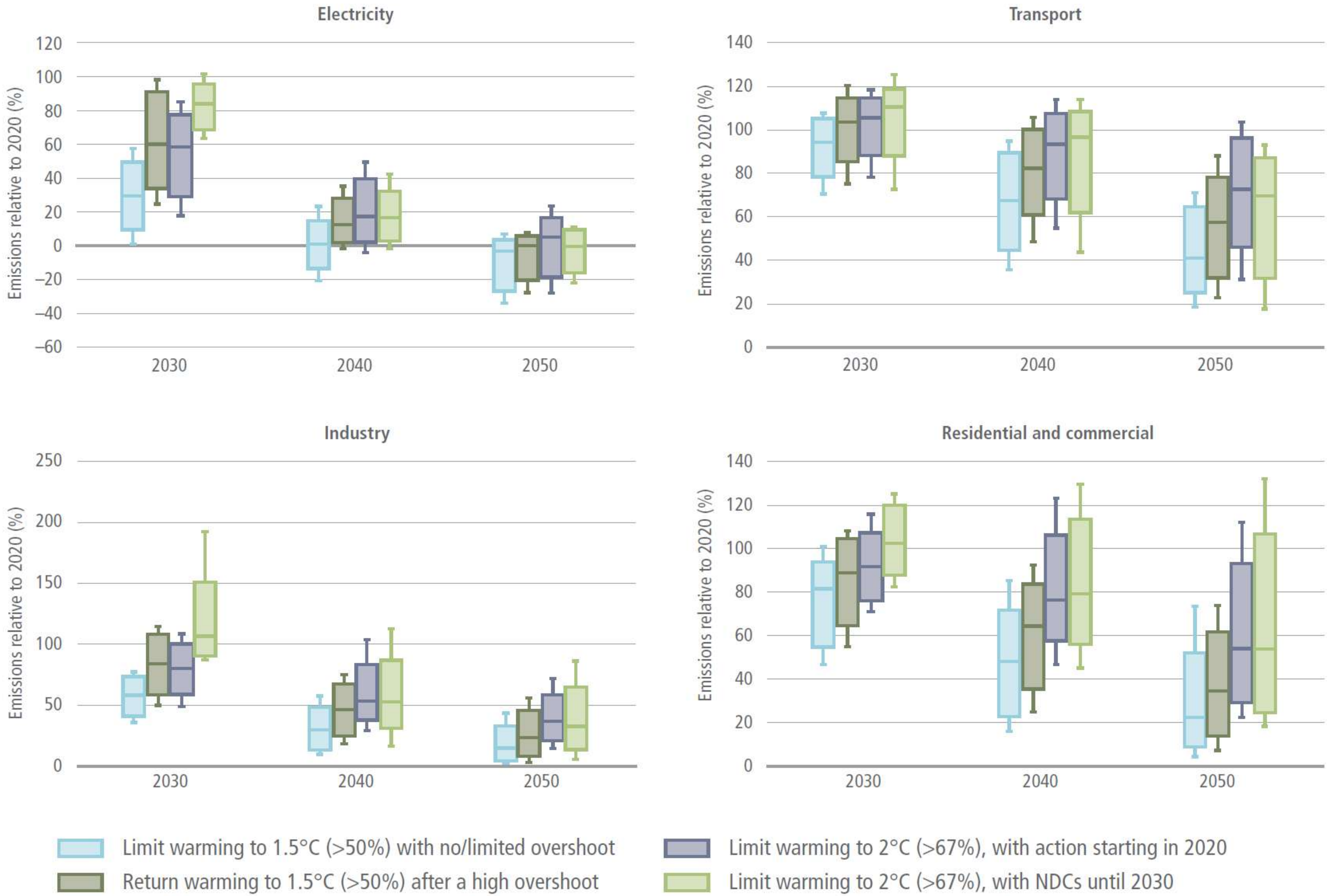





Source) IPCC AR6 (2022)

# Global $CO_2$ 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

NGFS: Network for Greening the Financial System

# Research institutions participating in NGFS scenarios and model overview



| Comparison | Climate impacts | Transition pathways | Economic impacts |
|---|---|---|---|
| External research partners | Climate Analytics<br>PIK | PIK<br>UMD<br>IIASA | NIESR |
| Models | Climate models participating in the ISIMIP project<br>CLIMADA | REMIND-MAgPIE 3.0-4.4<br>GCAM 5.3+<br>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<br>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<br>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**<br>(e.g. temperature, precipitation, river flow, agricultural yields, soil moisture)<br>**Economic indicators**<br>(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<br>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<br>MAgPIE: Partial Equilibrium model of the agriculture sector |
| Anticipation | Recursive dynamic (myopic) | Intertemporal (perfect foresight) | REMIND: Intertemporal (perfect foresight)<br>MAgPIE: Recursive dynamic (myopic) |
| Solution method | Cost minimisation | Welfare maximisation | REMIND: Welfare maximisation<br>MAgPIE: Cost minimisation |
| Temporal dimension | Base year: 2015<br>Time steps: 5 years<br>Horizon: 2100 | Base year: 1990<br>Time steps: 5 (2005-2060) and 10 years (2060-2100)<br>Horizon: 2100 | Base year: 2005<br>Time steps: 5 (2005-2060) and 10 years (2060-2100)<br>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) |

(Source) NGFS (2022)

# NGFS scenarios (Phase V)



| | | Physical risk | Transition risk | | | |
|---|---|---|---|---|---|---|
| Quadrant | Scenario | 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℃ target.

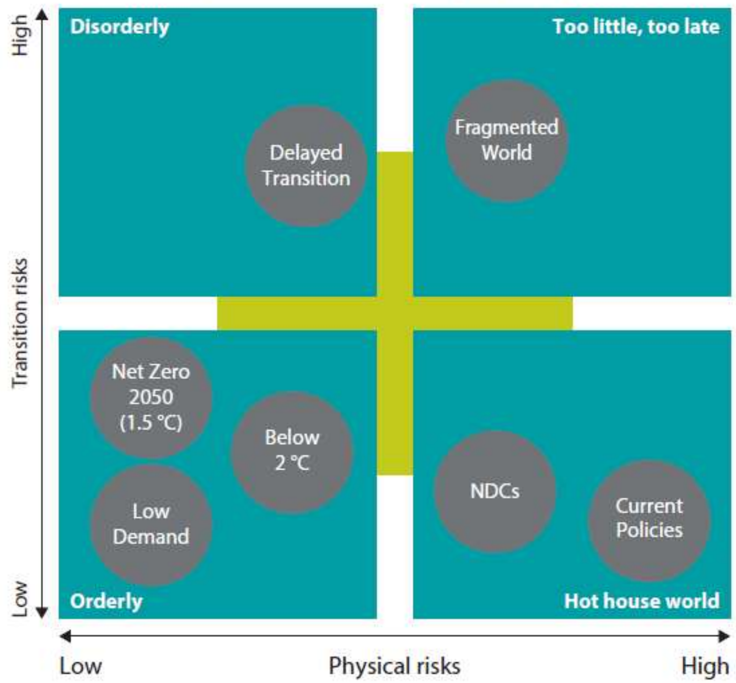
**Net Zero 2050**: Limiting global temperature rise to 1.5℃ and achieving net-zero global $CO_2$ emissions around 2050, through ambitious climate chance policies and innovation

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

**Disorderly**

**Delayed transition**: Annual emissions will not decrease until 2030, and stringent policies are needed to keep emissions below 2℃. In addition, there are constraints on the removal of $CO_2$.

NGFS scenarios framework in Phase V



# NGFS scenarios' assumptions (Phase V)

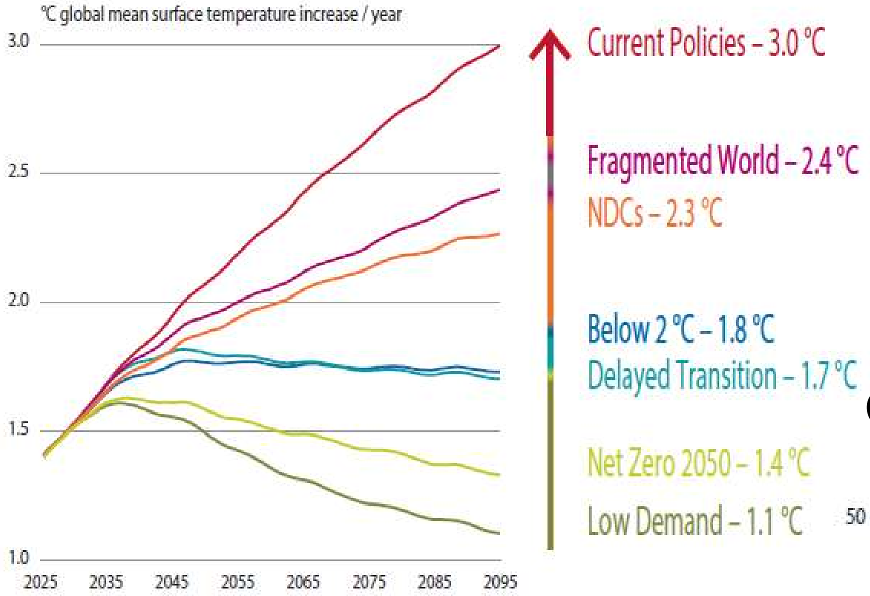


| Category | Scenario | End of century (peak) warming | Policy reaction | Technology change | Carbon dioxide removal - | Regional policy variation + |
|---|---|---|---|---|---|---|
| Orderly | Low Demand | 1.1°C (1.6°C) | Immediate and smooth | Fast change | Medium use | Medium Variation |
| | Net Zero 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)

# $CO_2$ emissions and carbon prices for each NGFS scenario

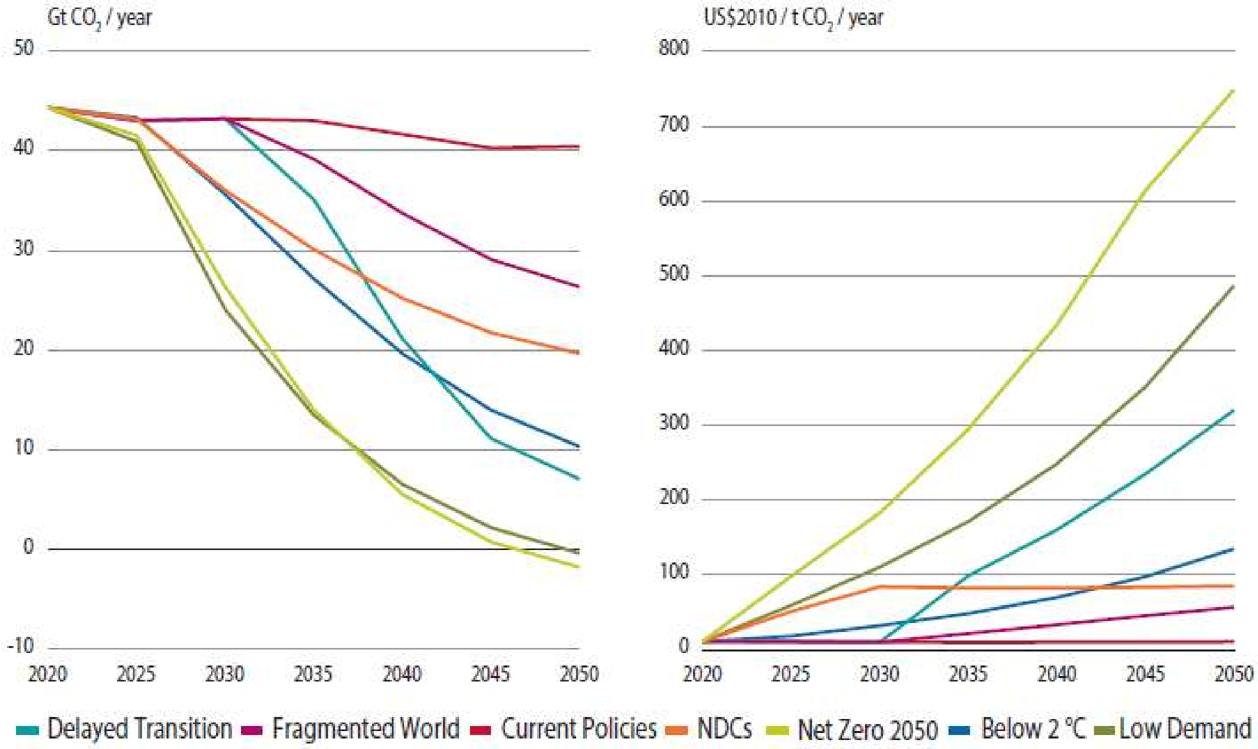





Global temperature increase

CO2 emissions by scenario

Carbon price development

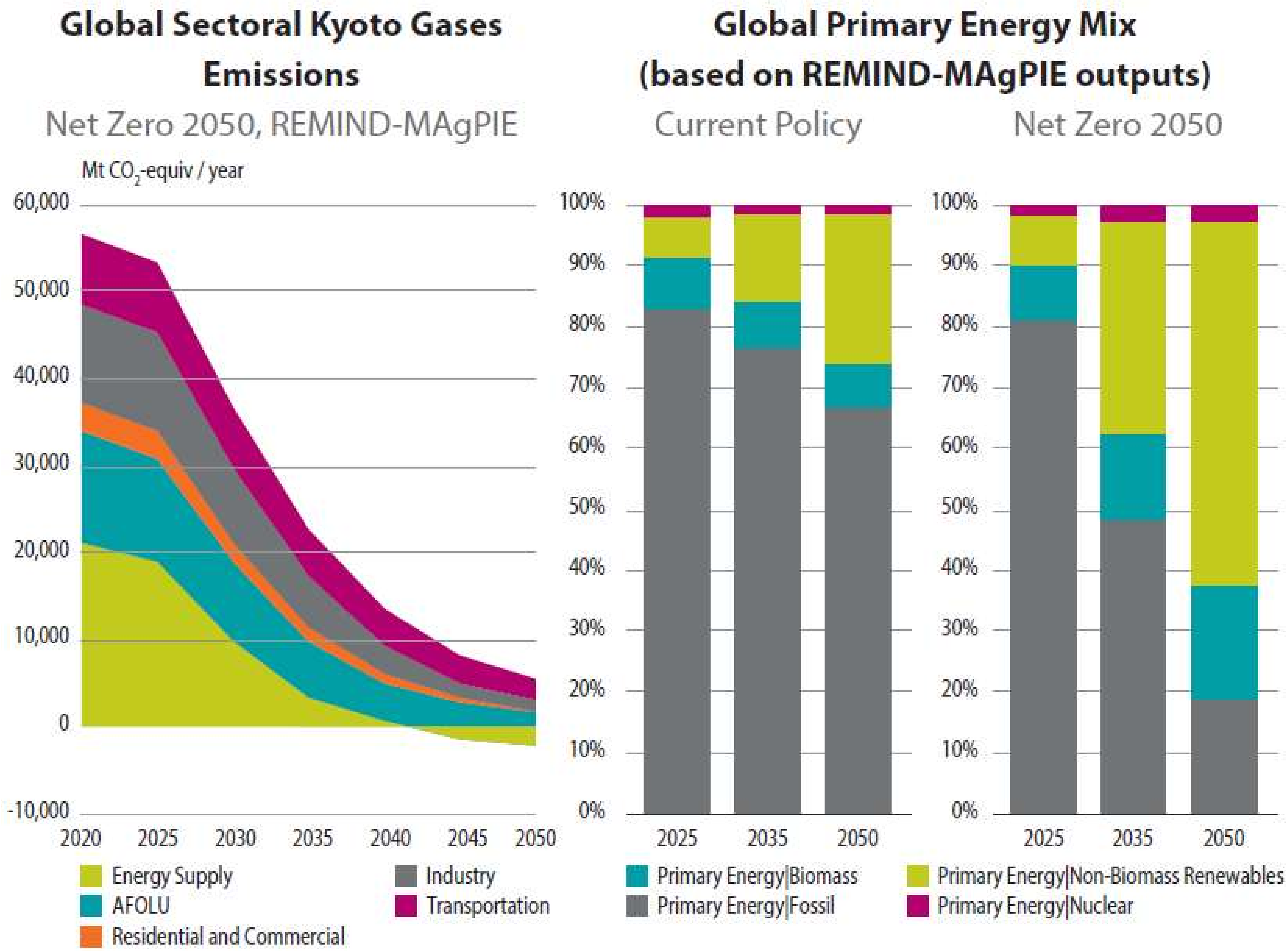



Estimates by REMIND model
(Source) NGFS (2024)

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

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

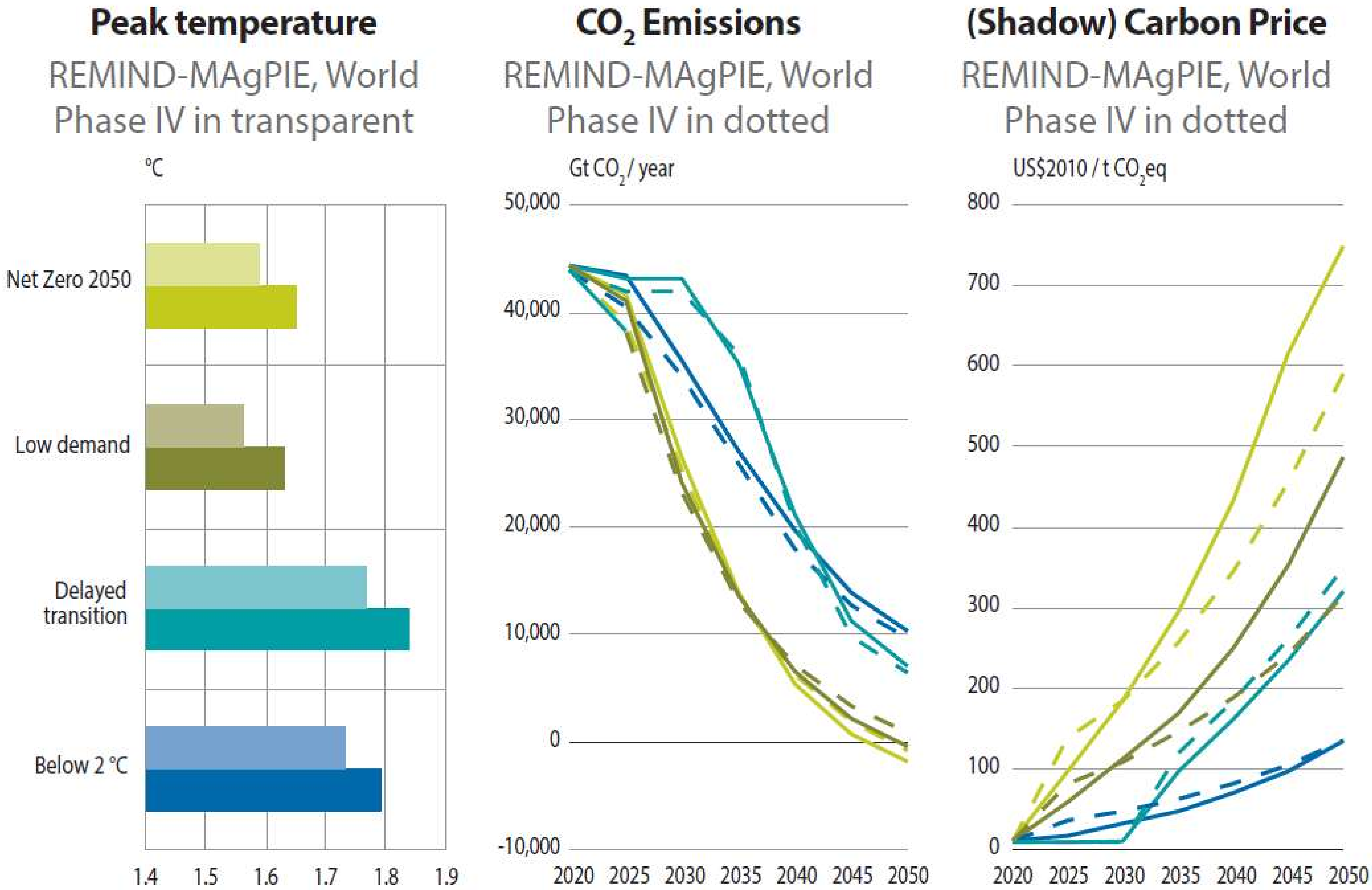





(Source) NGFS (2024)

# Comparison of NGFS Scenario Phase IV and Phase V






（Source）NGFS (2024)

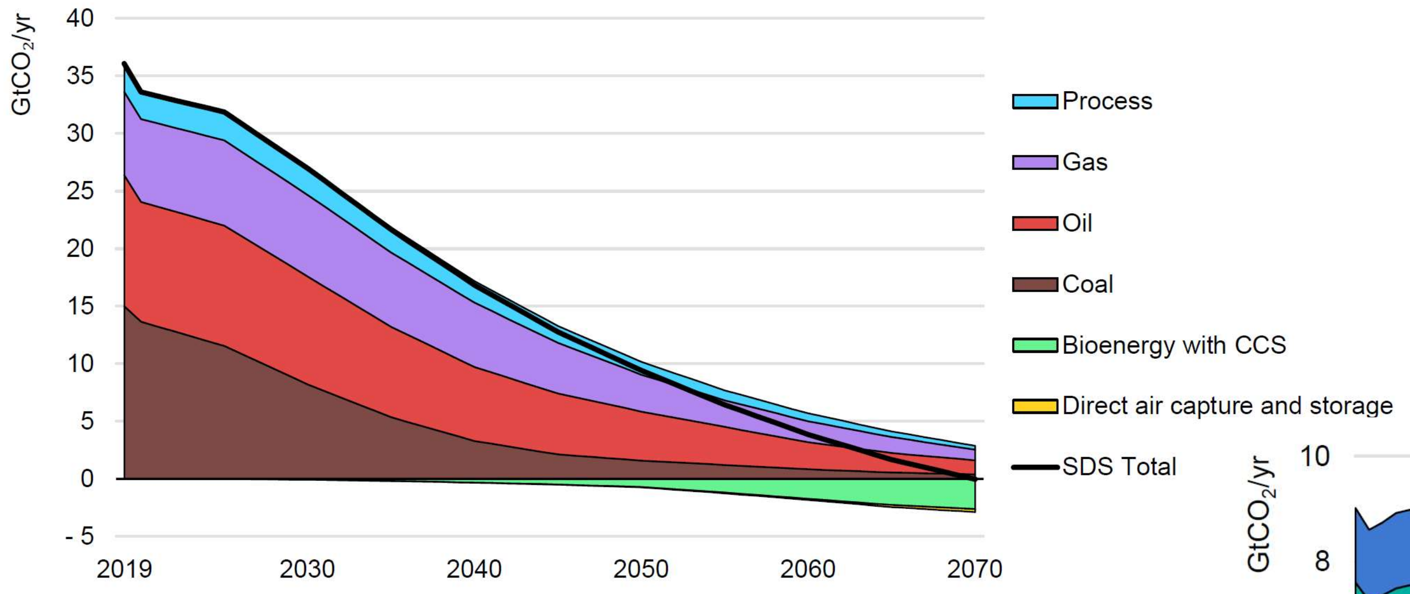
✓ **In the NGFS Phase V, the IPCC's scenario of no temperature overshoot (<0.1℃) has been eliminated. Based on current emission trends, an overshoot is considered inevitable.**

# 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.**

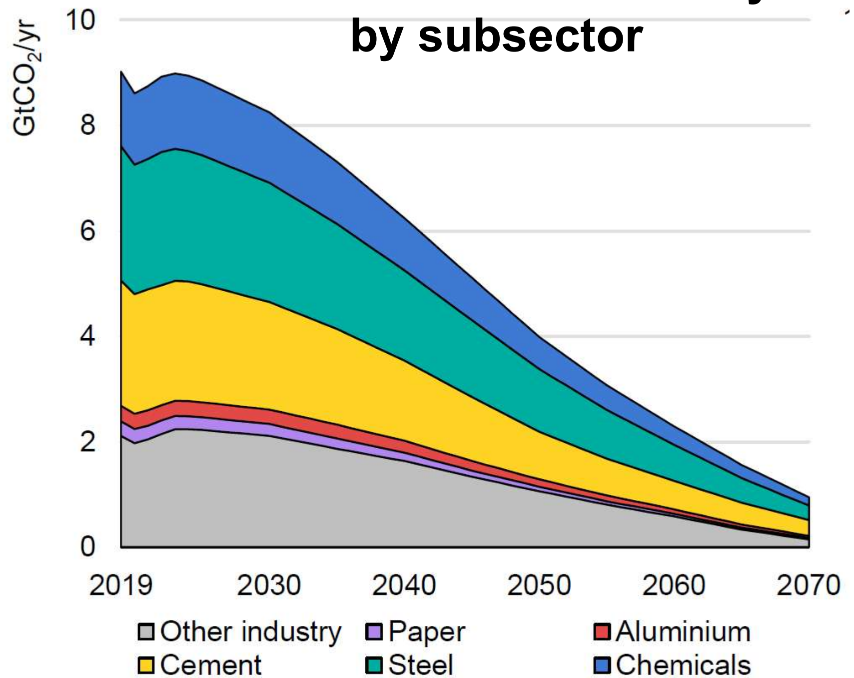
Figure 2.1 Global energy sector $CO_2$ emissions by fuel and technology in the Sustainable Development Scenario, 2019-70




IEA 2020. AI

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

**Emissions from Industry by subsector**

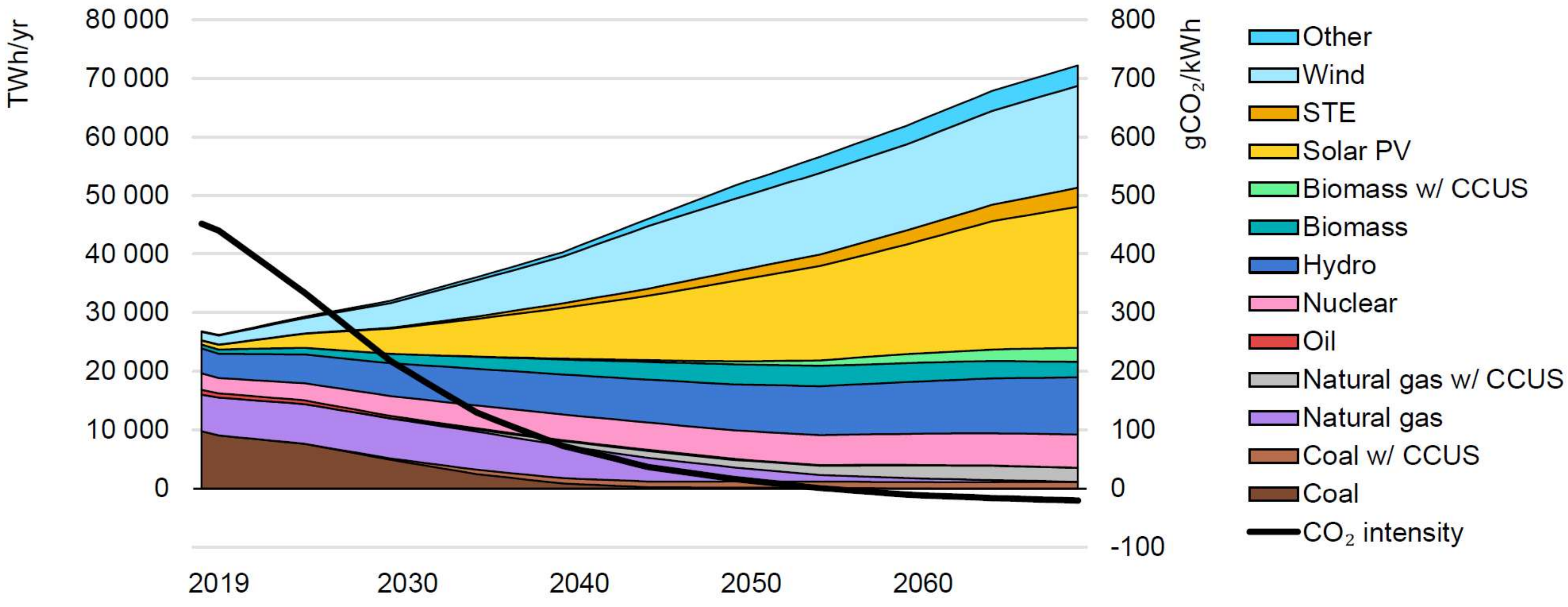



**SDS: Sustainable Development Scenario**
**A scenario with less than 1.8 °C, equivalent to "well below 2 °C" target under the Paris agreement**

# Electricity generation scenario in SDS in ETP2020



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



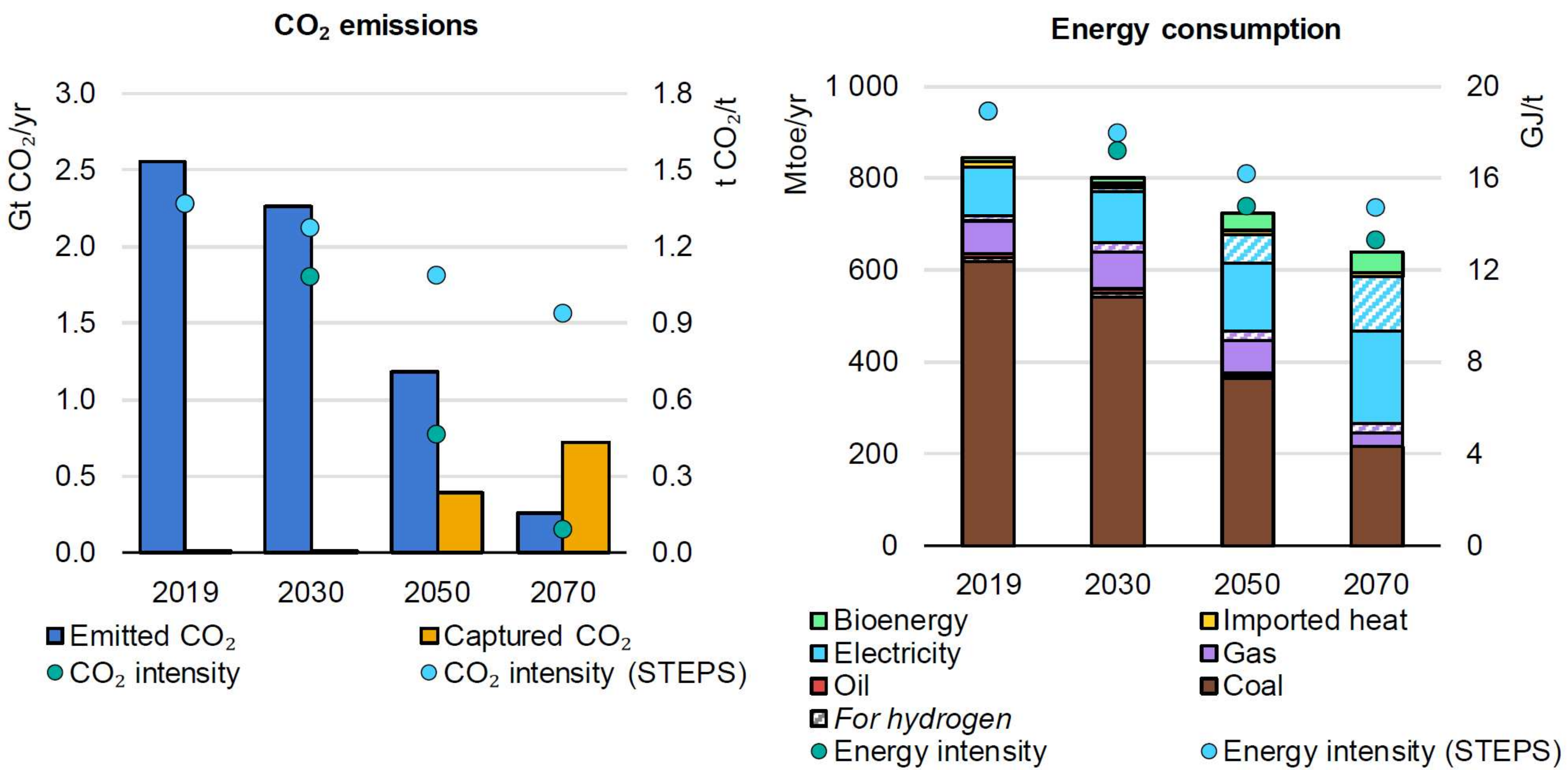



Notes: TWh = terawatt-hours; $gCO_2/kWh$ = grammes of $CO_2$ per kilowatt-hour; STE = solar thermal electricity; PV = photovoltaic; CCUS = carbon capture, utilisation storage. Other includes geothermal power, ocean energy and hydrogen.

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



Figure 4.10 Global iron and steel sector direct $CO_2$ emissions and energy consumption in the Sustainable Development Scenario, 2019-70

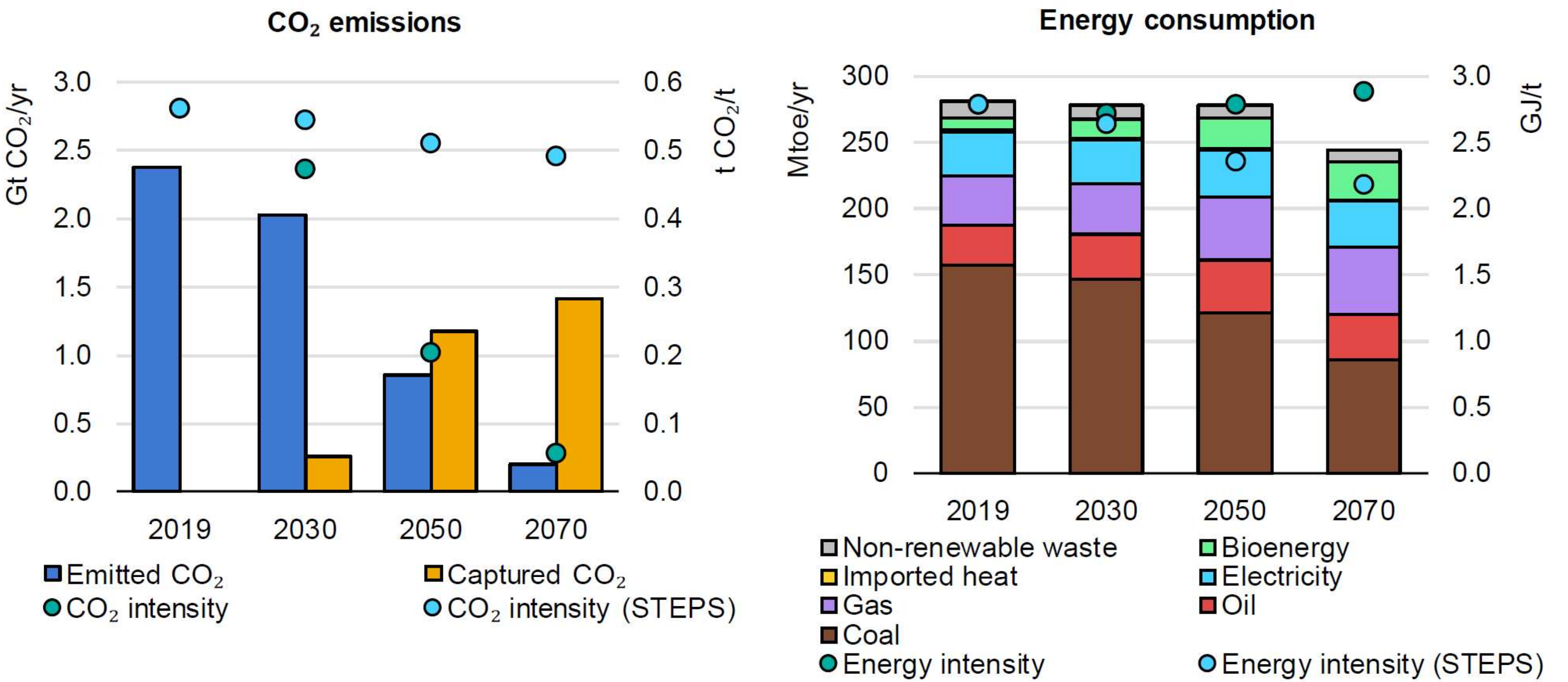





Note: STEPS = Stated Policies Scenario.

# Cement sector emissions and energy consumption in SDS in ETP2020

Figure 4.16 Global cement sector direct $CO_2$ emissions and energy consumption in the Sustainable Development Scenario, 2019-70



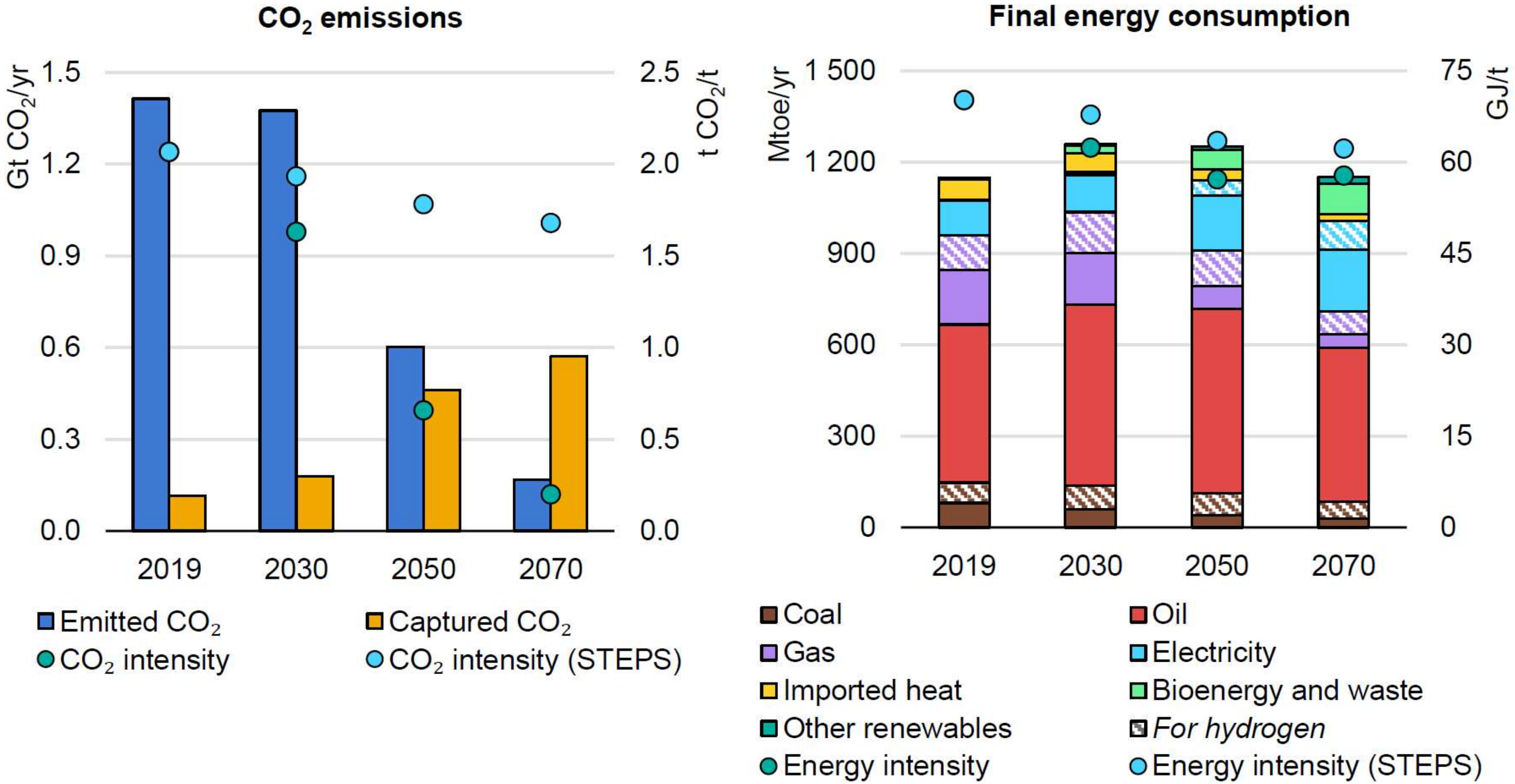



Notes: STEPS = Stated Policies Scenario. Energy intensity here includes all energy used per tonne of cement, including additional energy needs for some strategies deployed in the Sustainable Development Scenario – chemical absorption carbon capture and storage, calcined clay use and alternative fuel 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 $CO_2$ emissions and energy consumption in the Sustainable Development Scenario, 2019-70



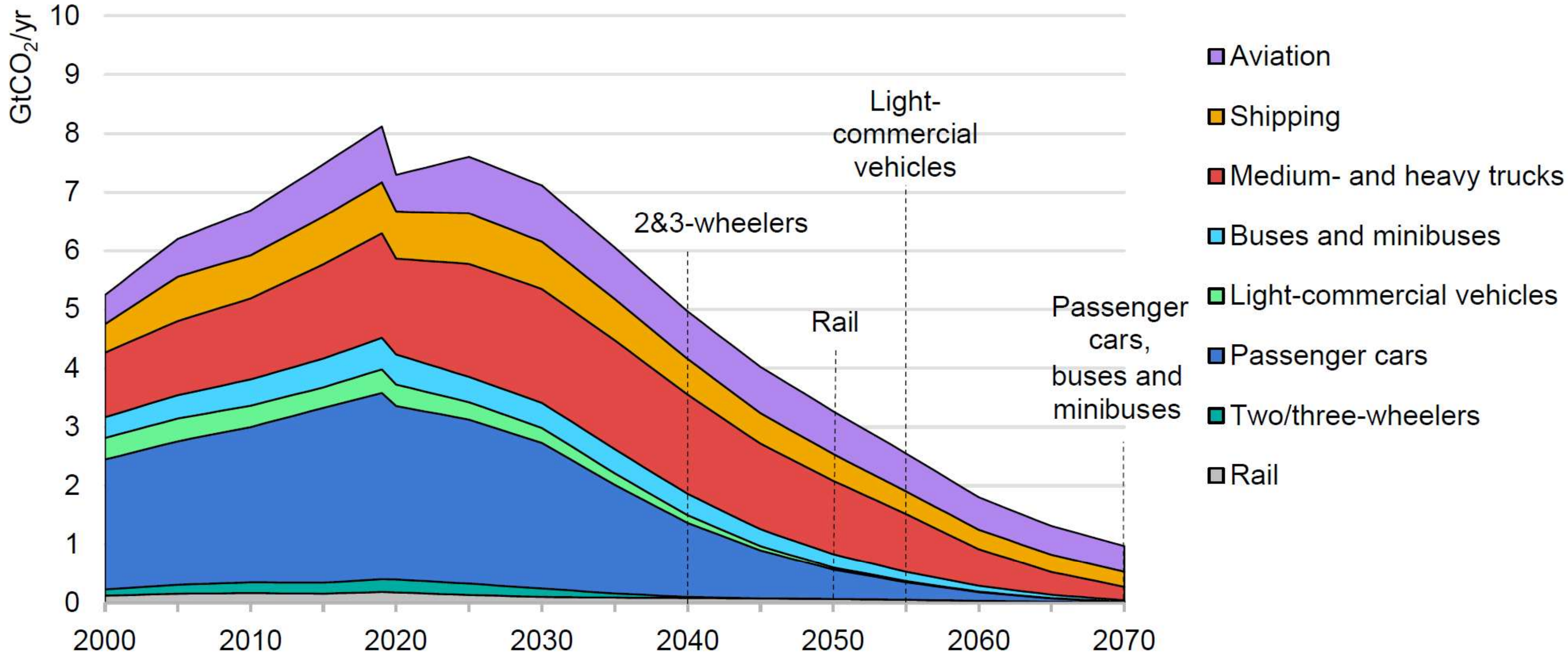



Notes: STEPS = Stated Policies Scenario. Captured $CO_2$ includes that which is captured then used as feedstock for urea production, as well as that which is captured and stored. Energy consumption includes that used as feedstock. Sectoral energy and $CO_2$ intensities are calculated based on total primary chemical production and total chemical sector energy consumption.

# Transport emissions scenario in SDS in ETP2020



**Figure 3.16 Global $CO_2$ emissions in transport by mode in the Sustainable Development Scenario, 2000-70**

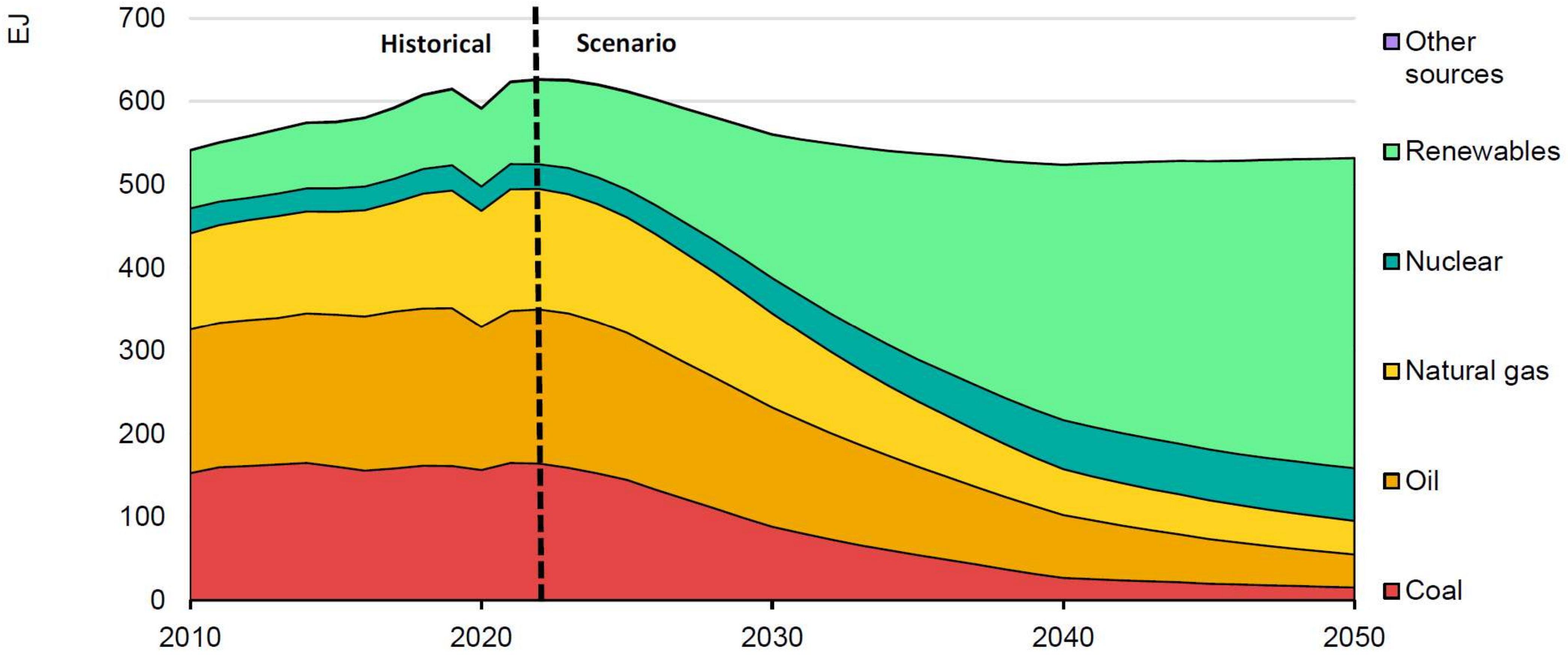





Notes: Dotted lines indicate the year in which various transport modes have largely stopped consuming fossil fuels and hence no longer contribute to direct emissions of $CO_2$ from fossil fuel combustion. Residual emissions in transport are compensated by negative emissions technologies, such as BECCS and DAC, in the power and other energy transformation sectors.

# Global primary energy supply in the NZE scenario in ETP2023





# IEA World Energy Outlook (WEO) scenarios

RITE Research Institute of Innovative Technology for the Earth



- 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

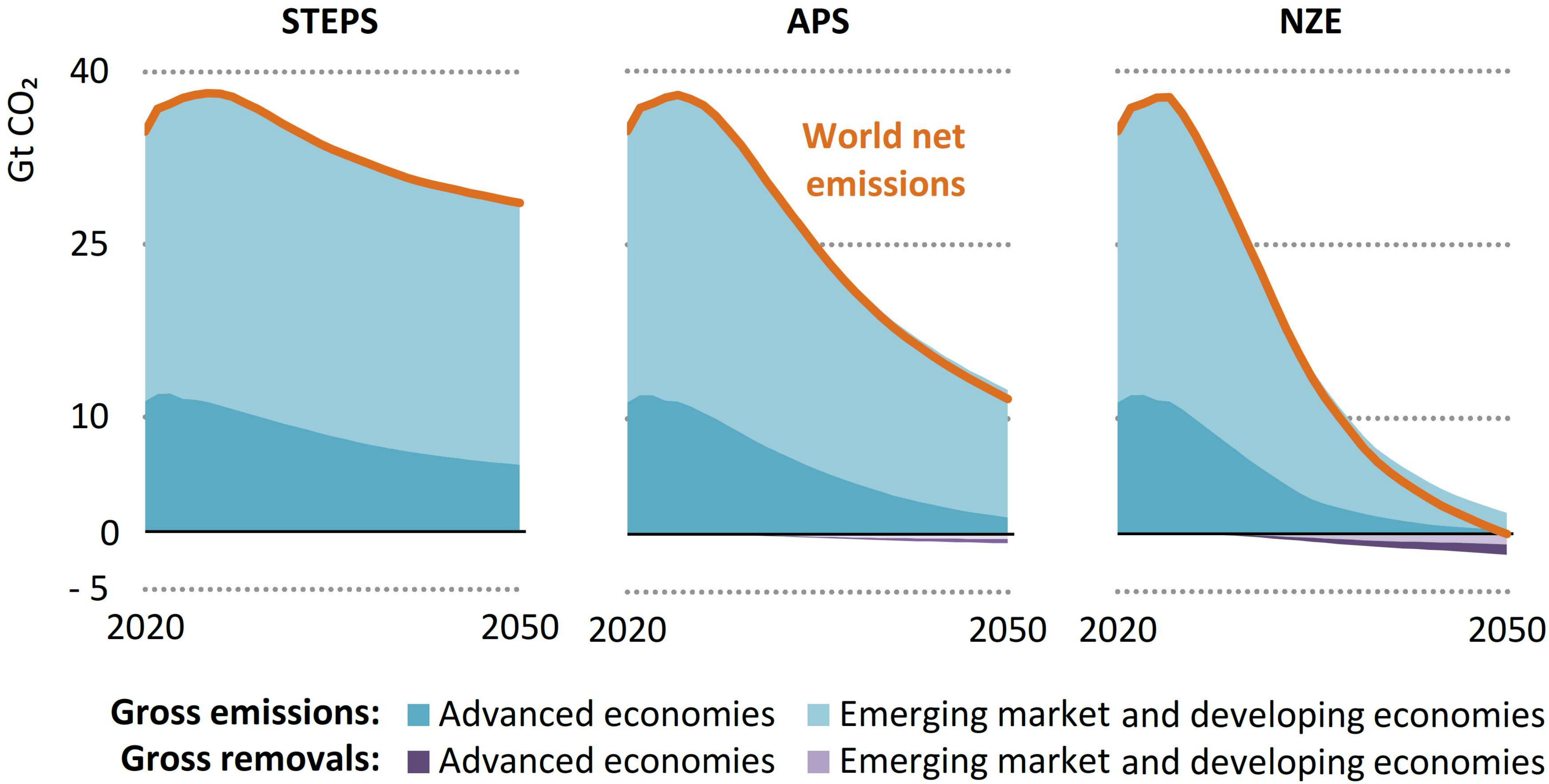
✓ **STEPS (Stated Policies Scenario)**: considers the application of broader range of policies, e.g. those formally stated but not yet adopted, official strategy documents indicating the direction

✓ **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℃

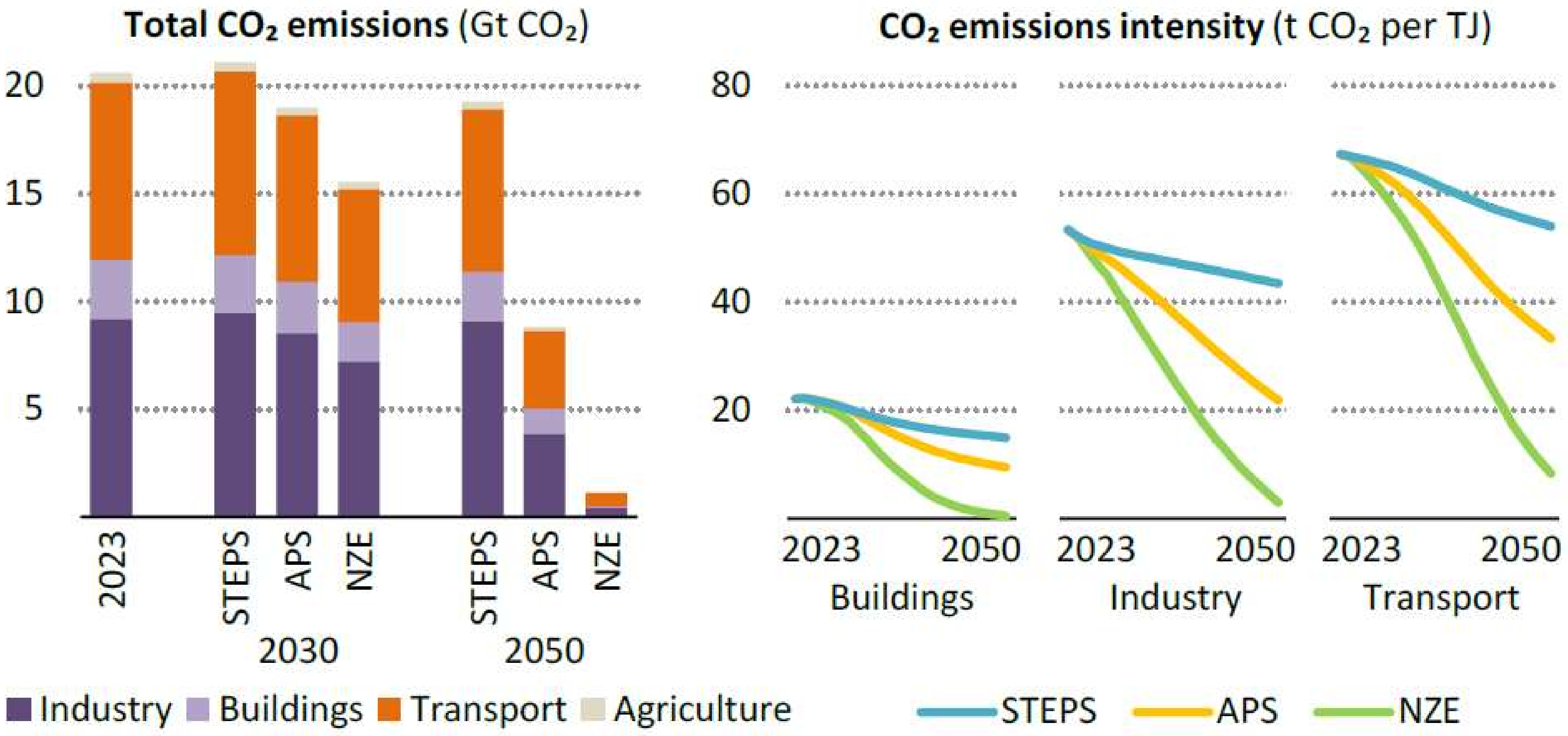
✓ **NZE (Net Zero Emissions by 2050) Scenario**: a normative scenario for the energy sector to achieve 1.5℃ and major energy-related SDGs

# $CO_2$ emissions in WEO2024



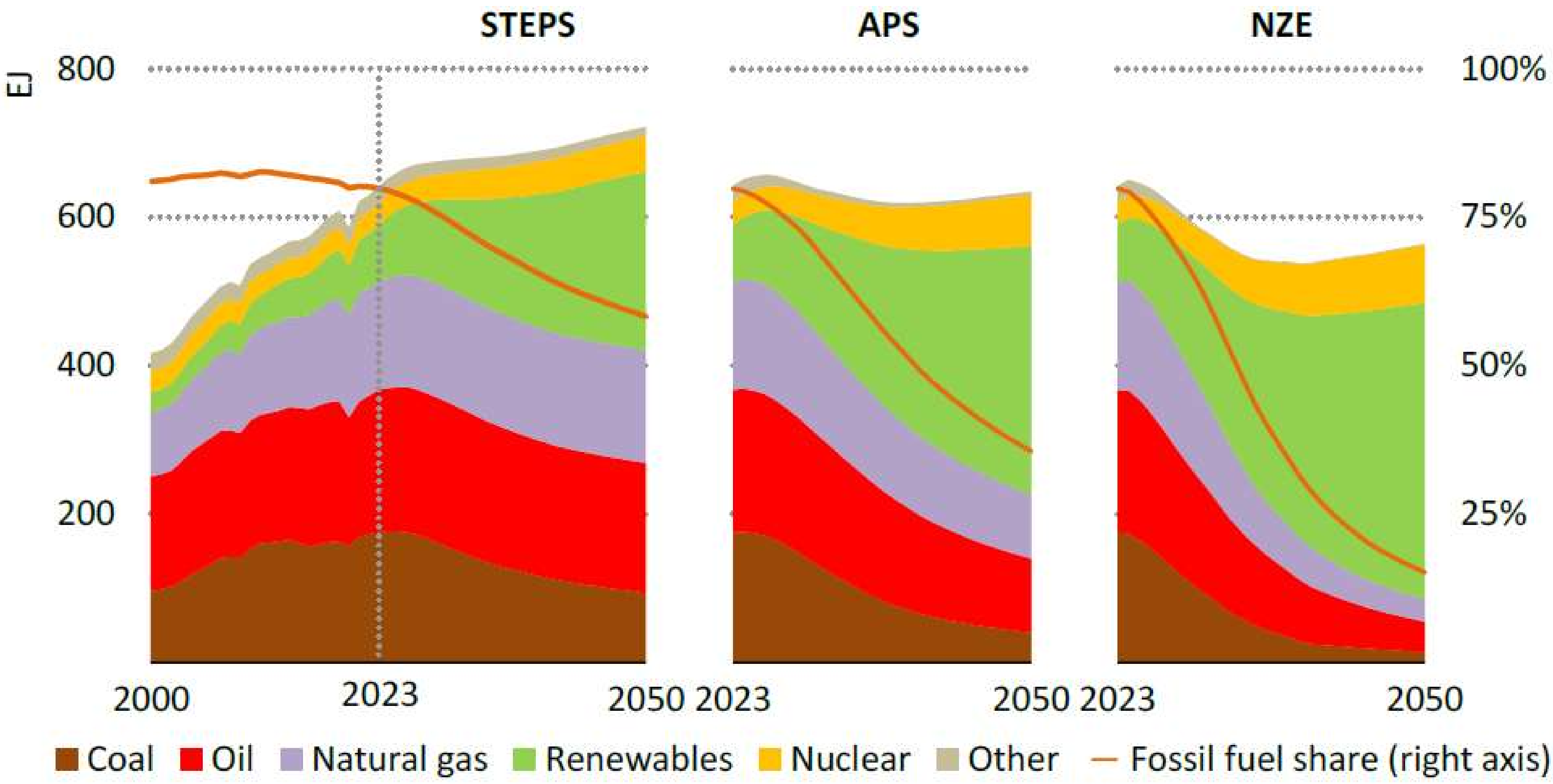


# $CO_2$ emissions and emissions intensity by end-use sector in WEO2024



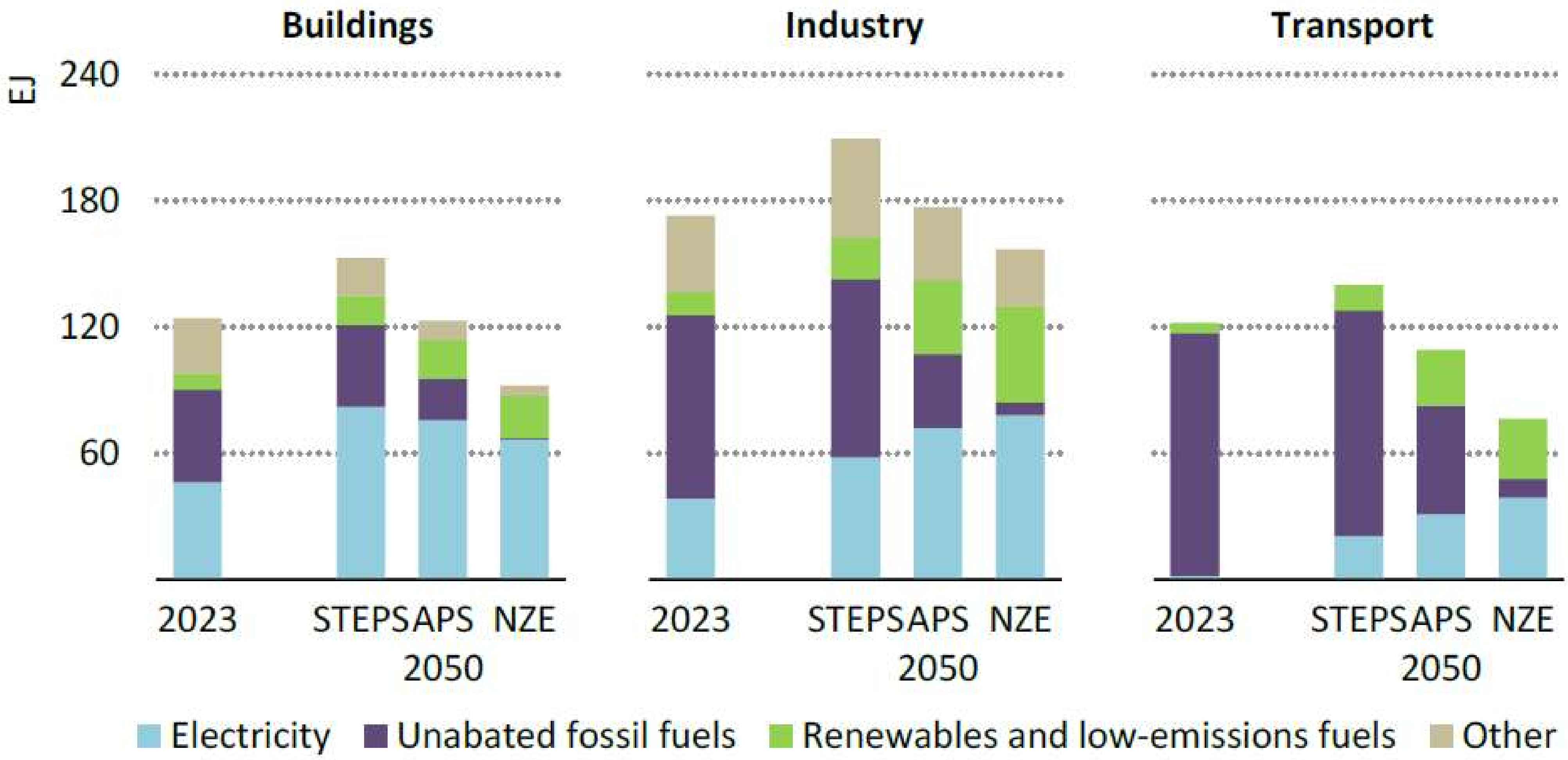
# Total energy supply in NZE and other scenarios in WEO2024





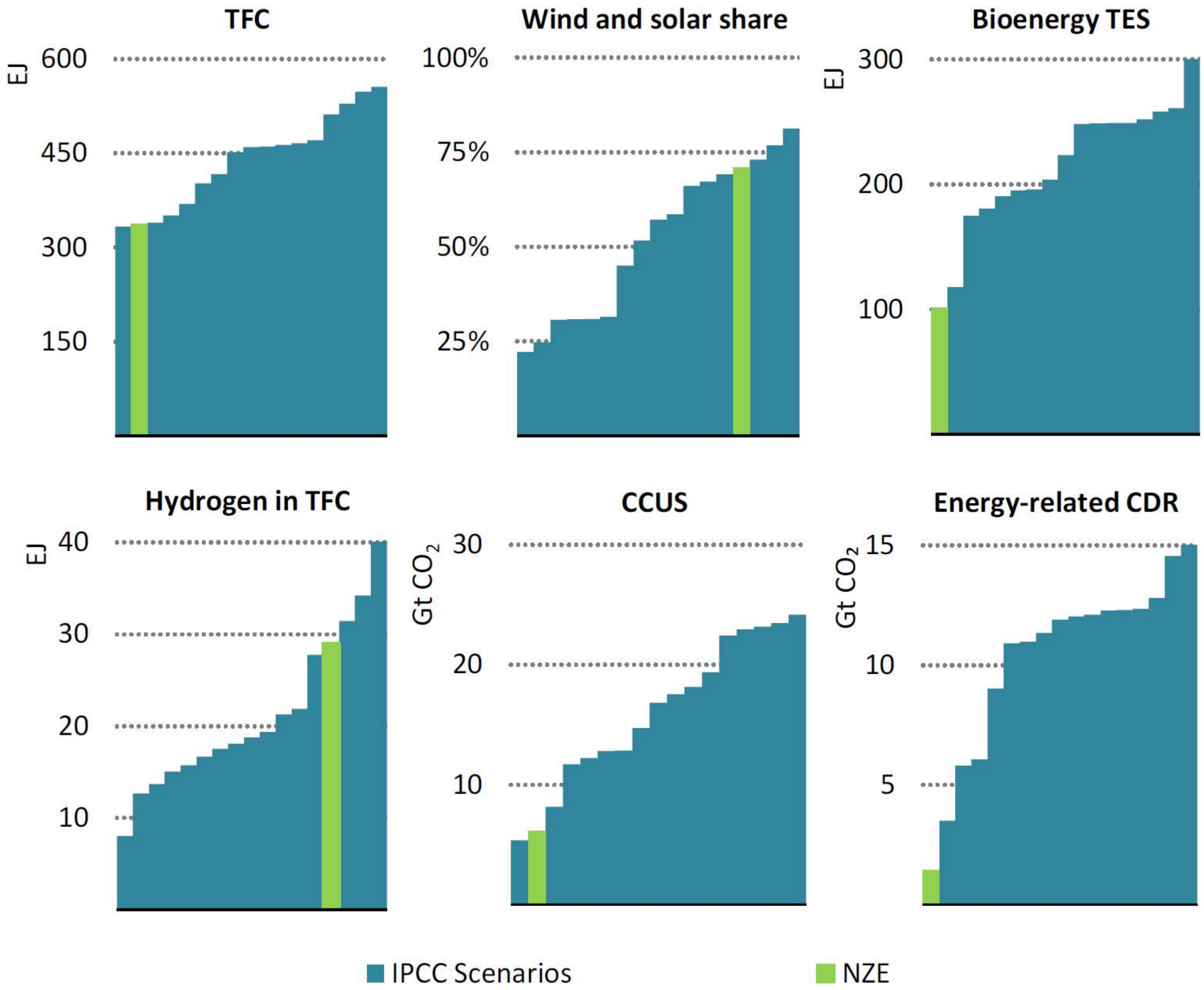
# Total final consumption in NZE and other scenarios in WEO2024





# 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**

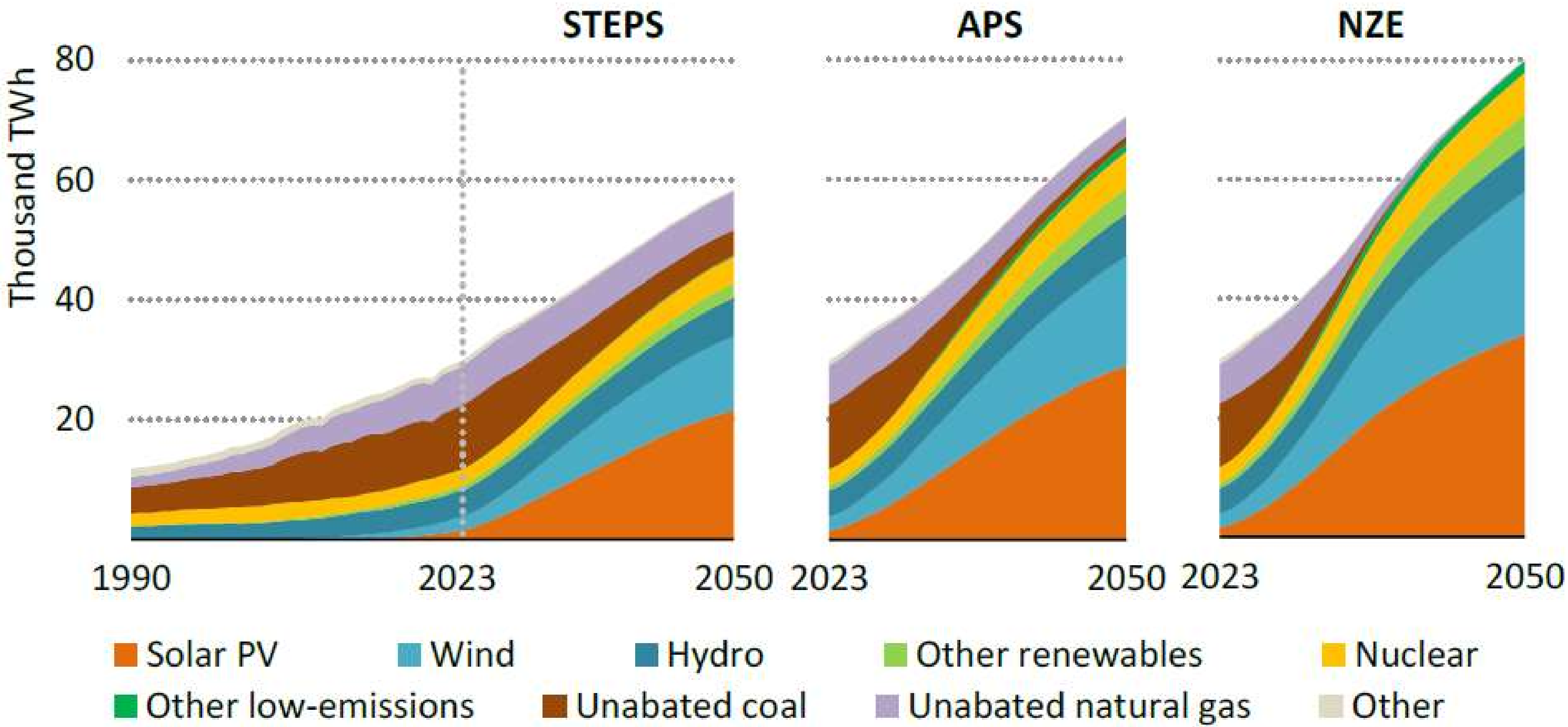
- ✓ **considerably less energy consumption**
- ✓ **higher wind and solar**
- ✓ **considerably small biomass**
- ✓ **considerably less CCS/CDR,**

**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

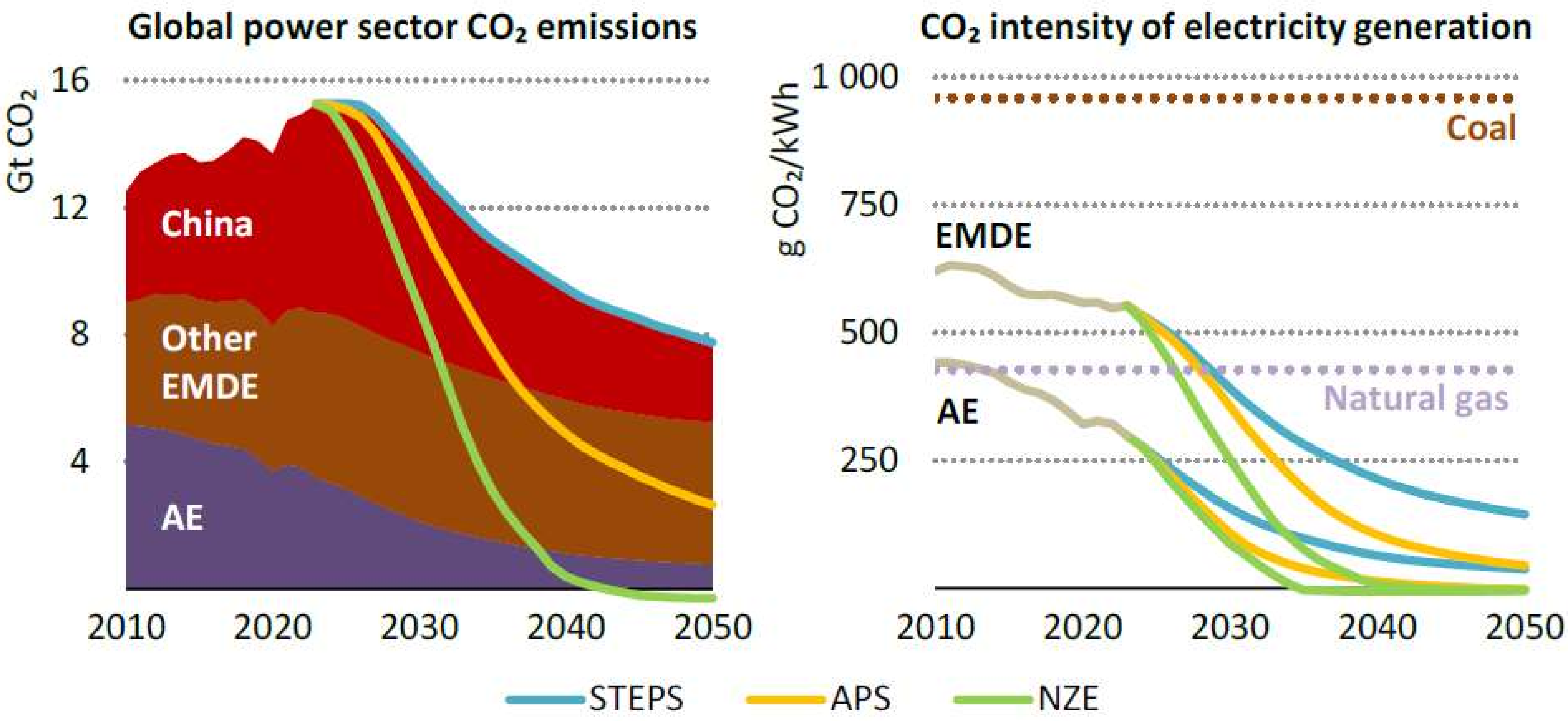





- **Electricity generation increases as the emissions reduction target is stringent and more electrification required**
- **As stated, NZE features larger renewables (especially PV and wind) and smaller CCUS compared to the standard scenarios in the IPCC report. It should be noted that the NZE scenario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

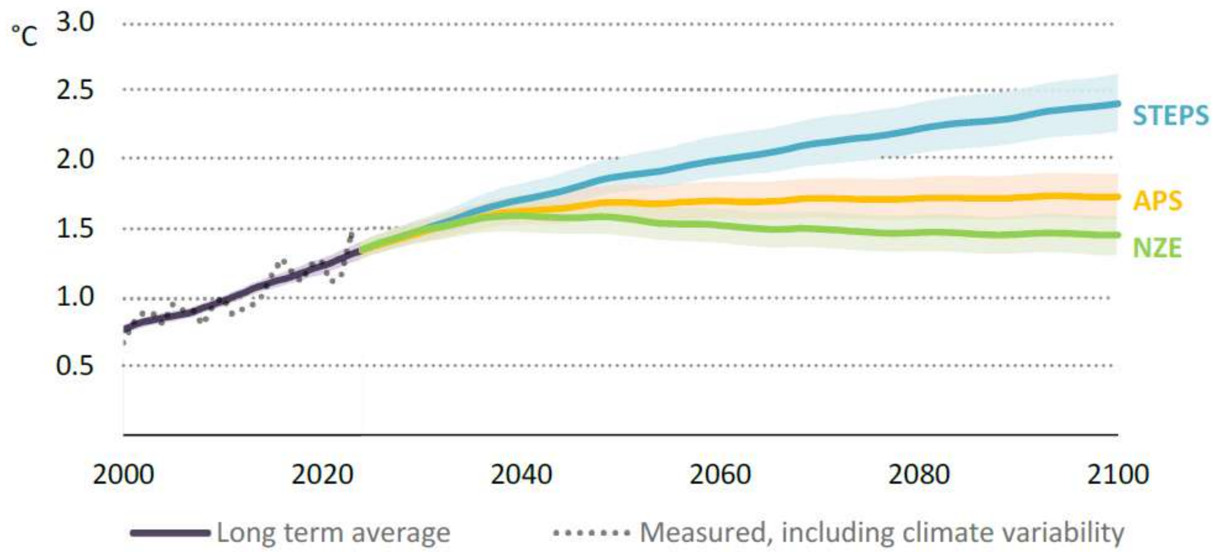
# $CO_2$ emissions and $CO_2$ intensity of electricity generation in NZE and other scenarios in WEO2024






- $CO_2$ intensity of electricity generation in advanced economies reaches zero around 2045 in APS, and around 2035 in NZE.

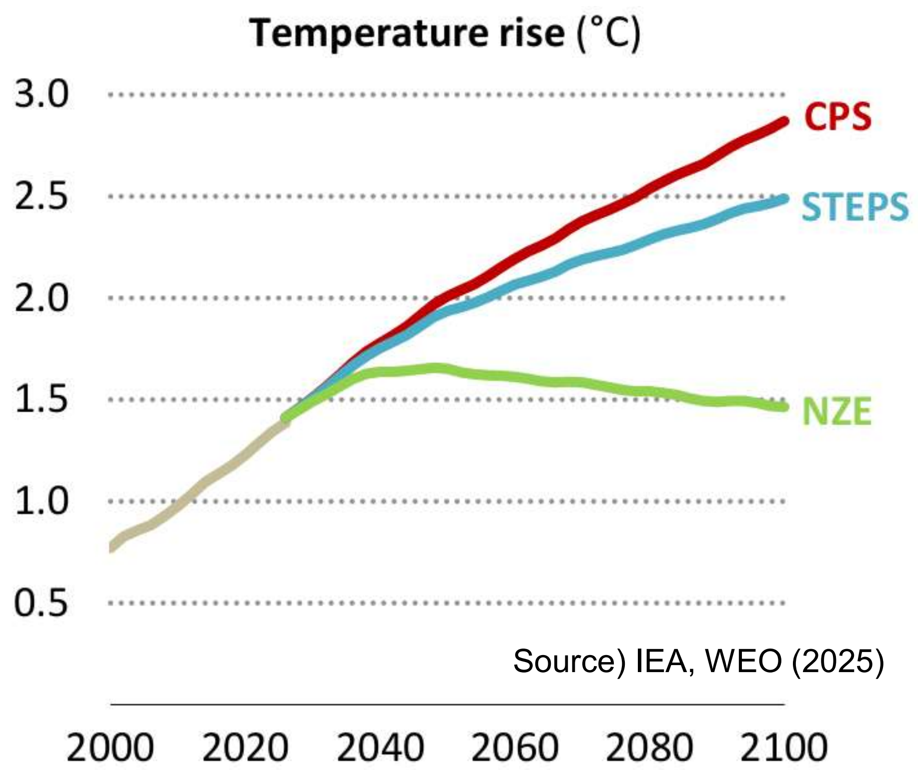
# Temperature rise in WEO2025 scenarios(changes from WEO2024)




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℃) so far, it has changed to the scenario with overshooting (1.7℃ at peak), as without overshooting is not realistic anymore.
- ✓CDR is still conservatively assumed compared to the IPCC scenario analysis.

WEO2025




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+)

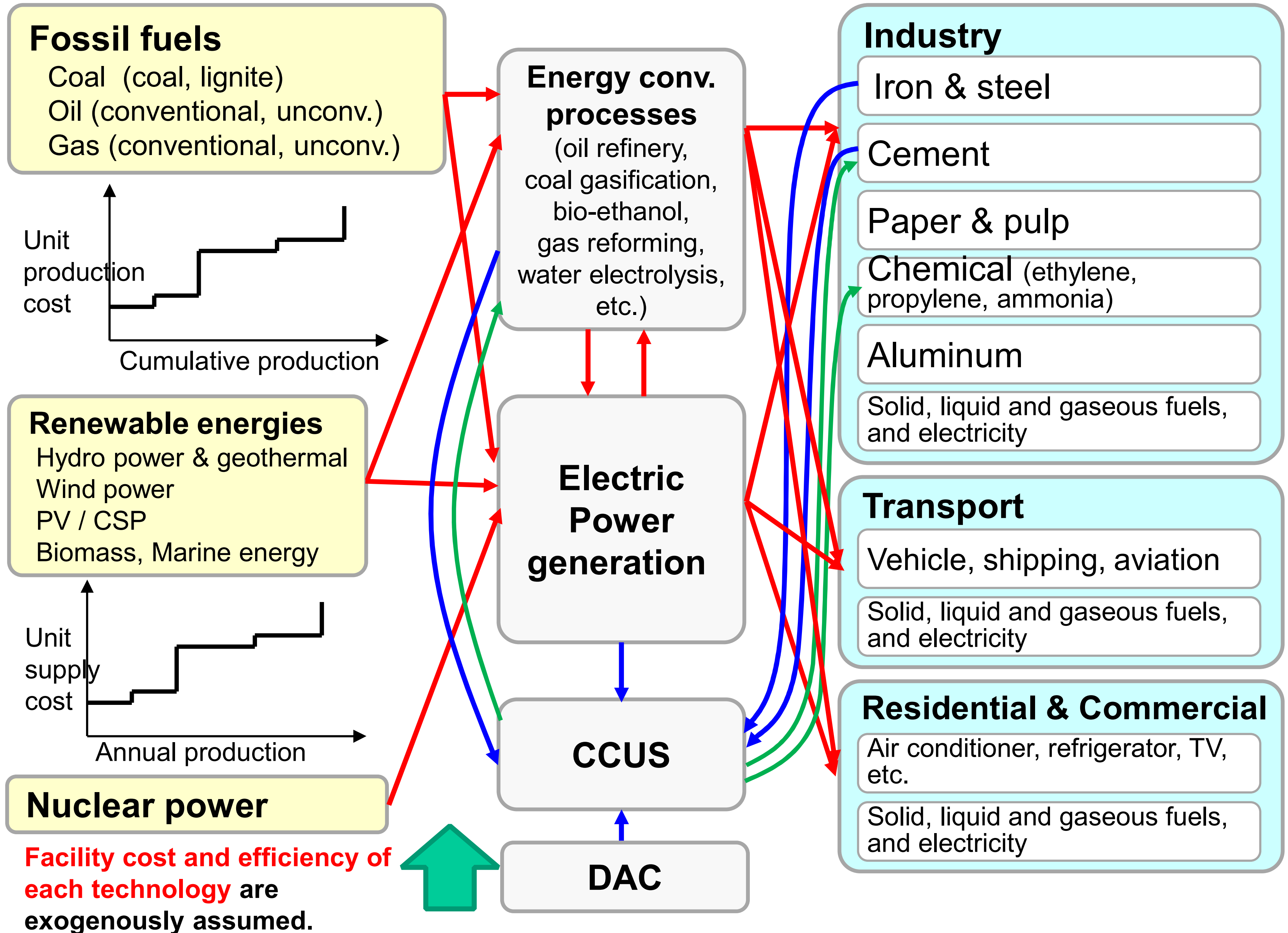
- Systemic cost evaluation on energy and $CO_2$ reduction technologies is possible.
- Linear programming model (minimizing world energy system cost; with appox. 10mil. variables and approx. 10mil. constrained conditions)
- Evaluation time period: 2000-2100
  Representative time points: 2005, 2010, 2015, 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, $CO_2$ (provided that external transfer of $CO_2$ is not assumed in the baseline)
- Bottom-up modeling for technologies on energy supply side (e.g., power sector) and CCUS
- For energy demand side, bottom-up modeling conducted for the industry sector including steel, cement, paper, chemicals and aluminum, the transport sector, and a part of the residential & commercial sector, considering CGS for other industry and residential & commercial sectors.
- Bottom-up modeling for international marine bunker and aviation.
- Around 500 specific technologies are modeled, with lifetime of equipment considered.
- Top-down modeling for others (energy saving effect is estimated using long-term price elasticity.)

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

- **Model based analyses and evaluation provide recommendation for 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.**




**For main sectors modeled in a bottom-up way, economic activities and service demands (e.g., production of crude steel and cement, passenger service demand) are exogenously assumed.**

# The caveats of the model analyses



- 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.)

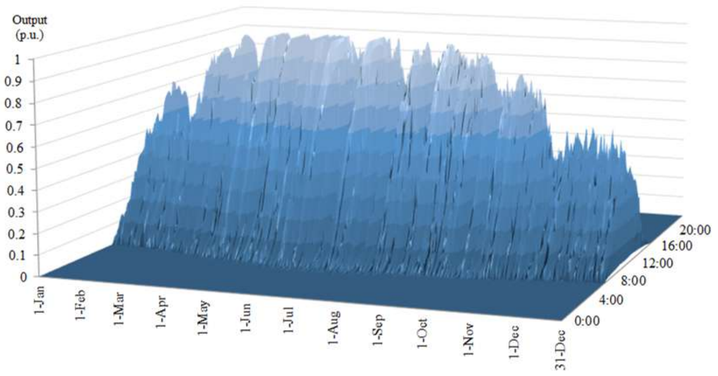
# Integration cost of VRES: integration with a power generation mix model by Univ. of Tokyo and IEEJ



- **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+.**

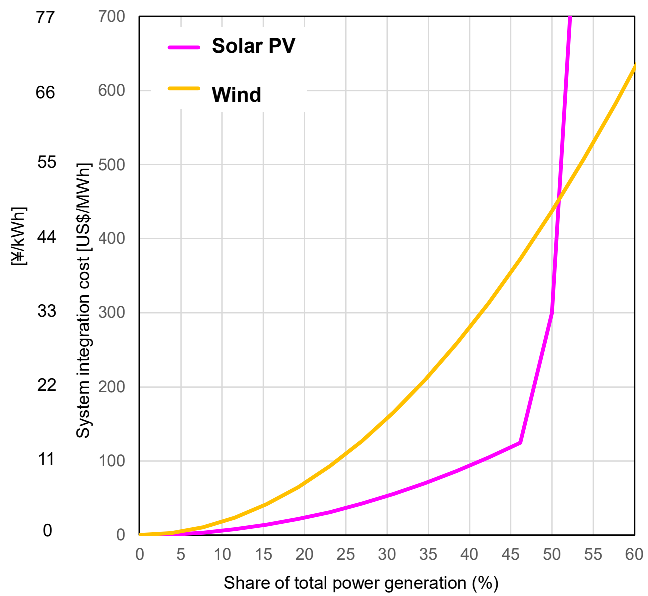
**Considered in modeling**･･･ Output control, power storage system (pumped hydro, lithium-ion battery and hydrogen storage), reduction of power generation facility utilization, inter-regional power transmission lines, electricity loss in storage and transmission

**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




**Output example of PV**

**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）**




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



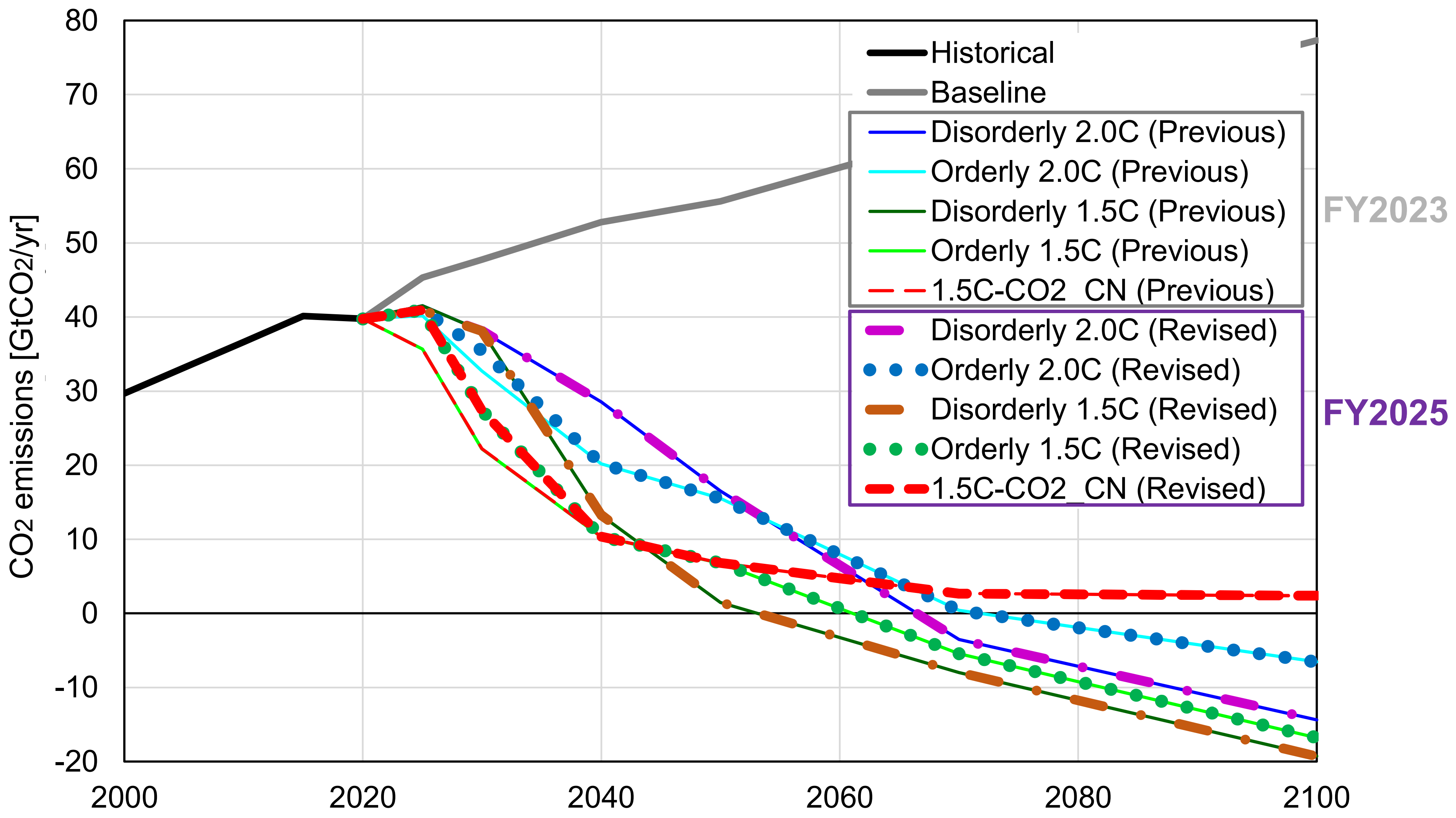
| Scenarios | Global average temp. increase | Policy speed | CDR contribution | Renewables and BEV | Differences in policy intensity among regions | Relation to other scenarios: IPCC AR6 (IPCC 2022) | NGFS (2022/2025) | IEA |
|---|---|---|---|---|---|---|---|---|
| **Disorderly Below 2 °C** | 1.7 °C 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 $CO_2$ 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 ($CO_2$)

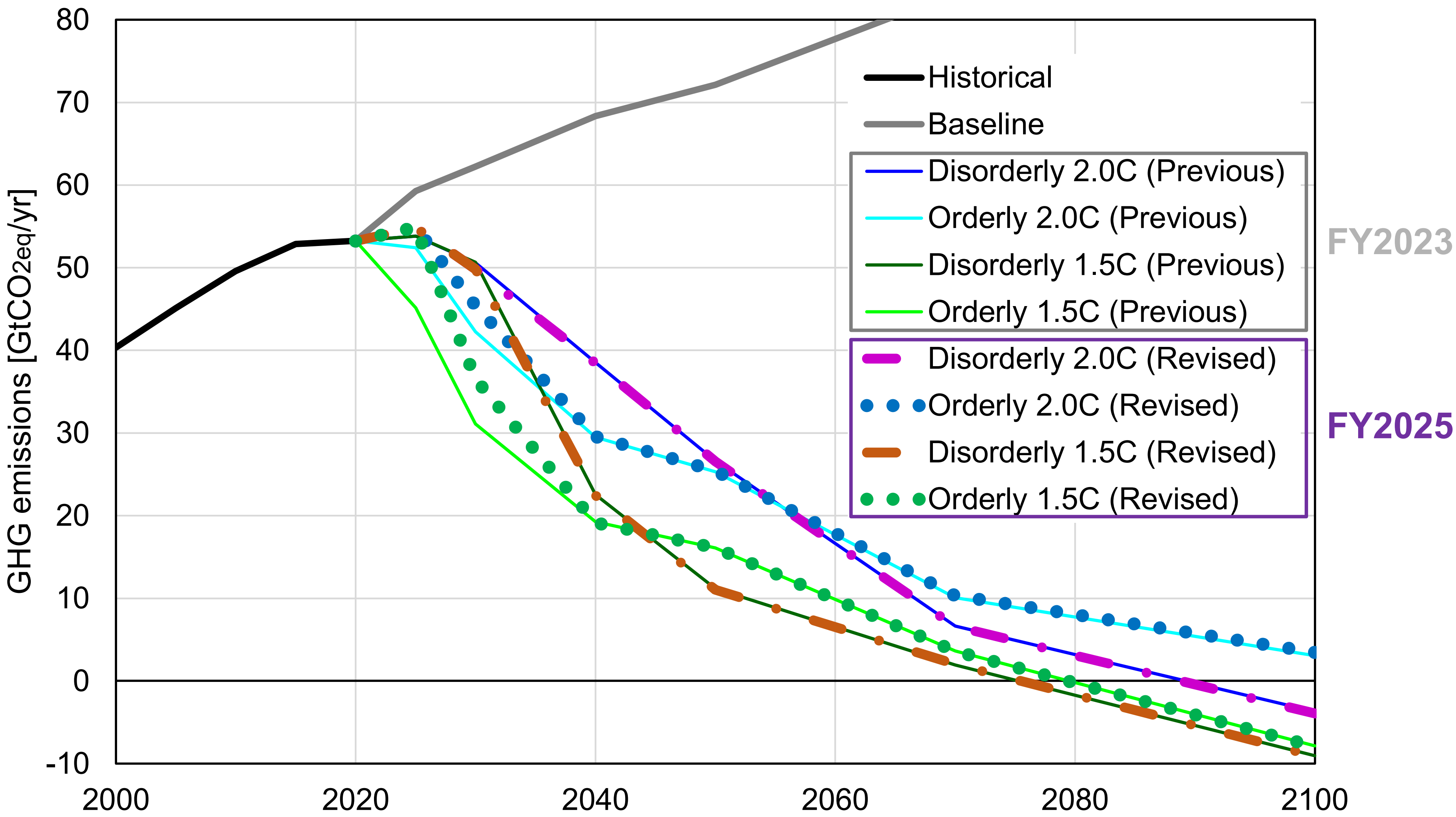





- ✓ **Based on current emission trends, the emission pathways for 2020-2025 have been revised upward from the 2023 version.**

# Global emissions pathways (GHG)



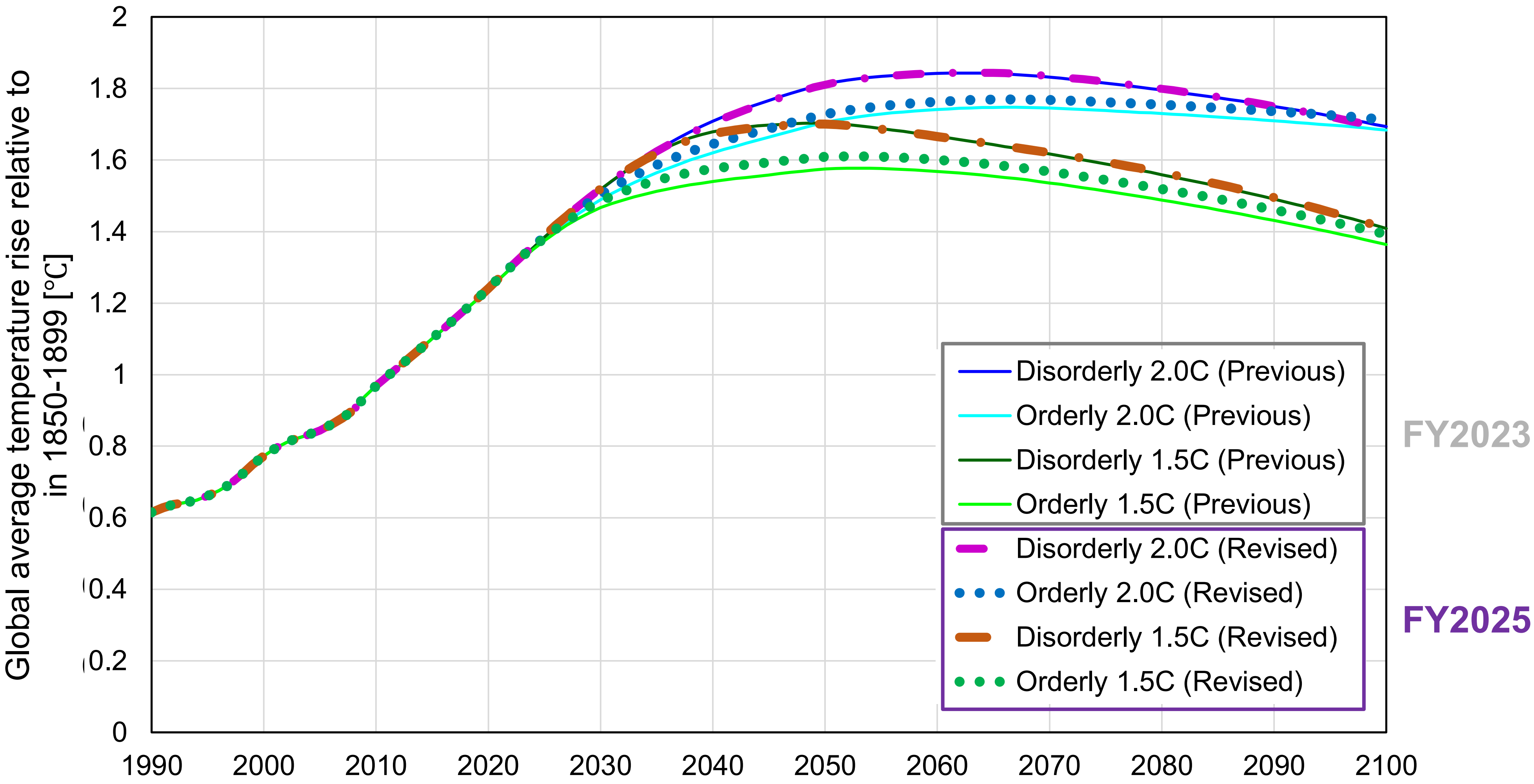



Note: The 1.5C_CO2_CN scenario evaluates only CO2 emissions, in accordance with IEA NZE standards. GHG emission pathways are not considered.

- ✓ **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

# $CO_2$ marginal abatement costs for the 2℃ 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℃ scenarios



## Disorderly 1.5C

Unit: $/tCO_2$

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

## Orderly 1.5C

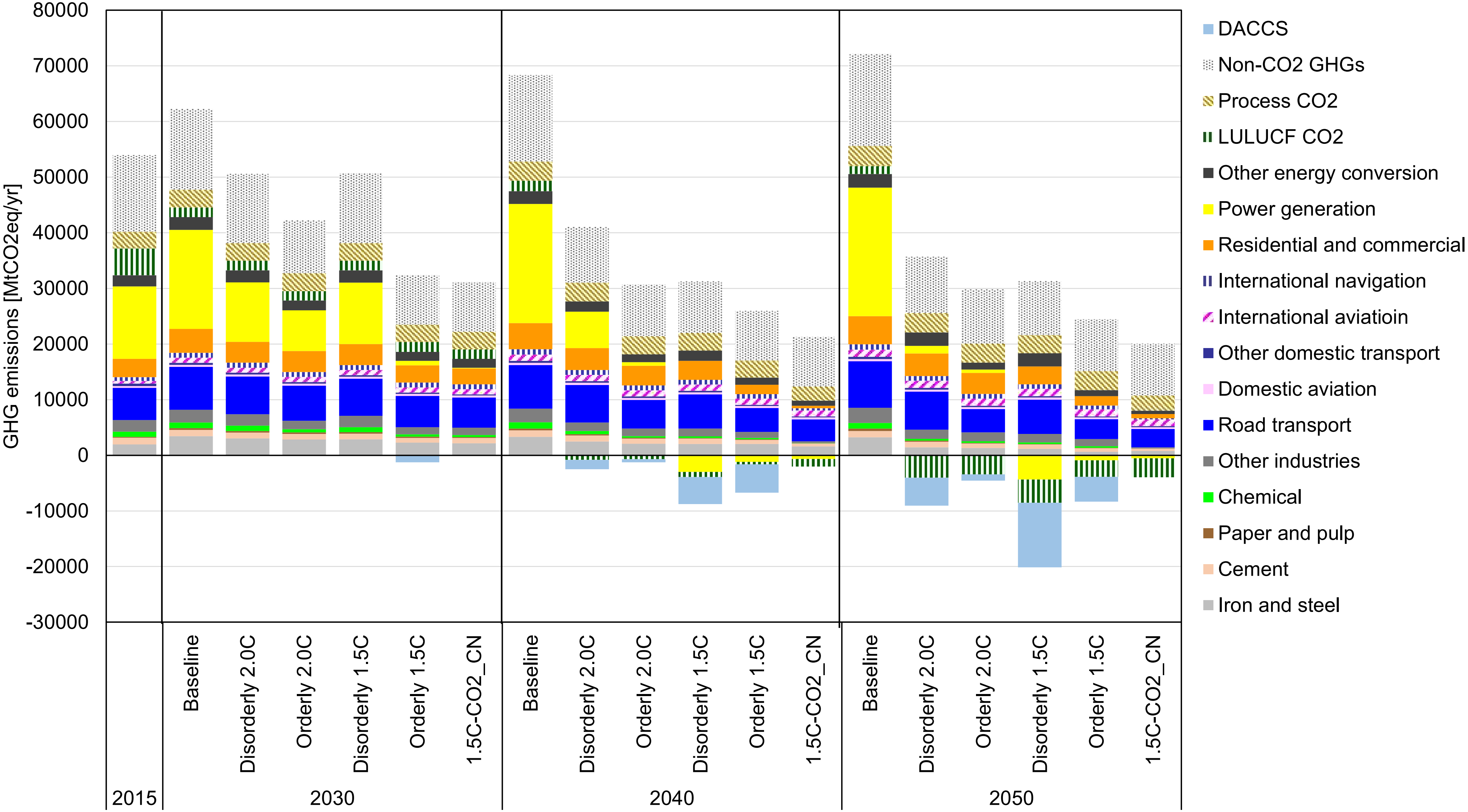
| | 2030 | 2040 | 2050 |
|---|---|---|---|
| Japan | 148 | 547 | 470 |
| US | 148 | 497 | 281 |
| EU27 | 148 | 497 | 291 |
| Korea, China and others | 148 | 497 | 262 |

## 1.5C-CO2_CN

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

# GHG emissions (World)

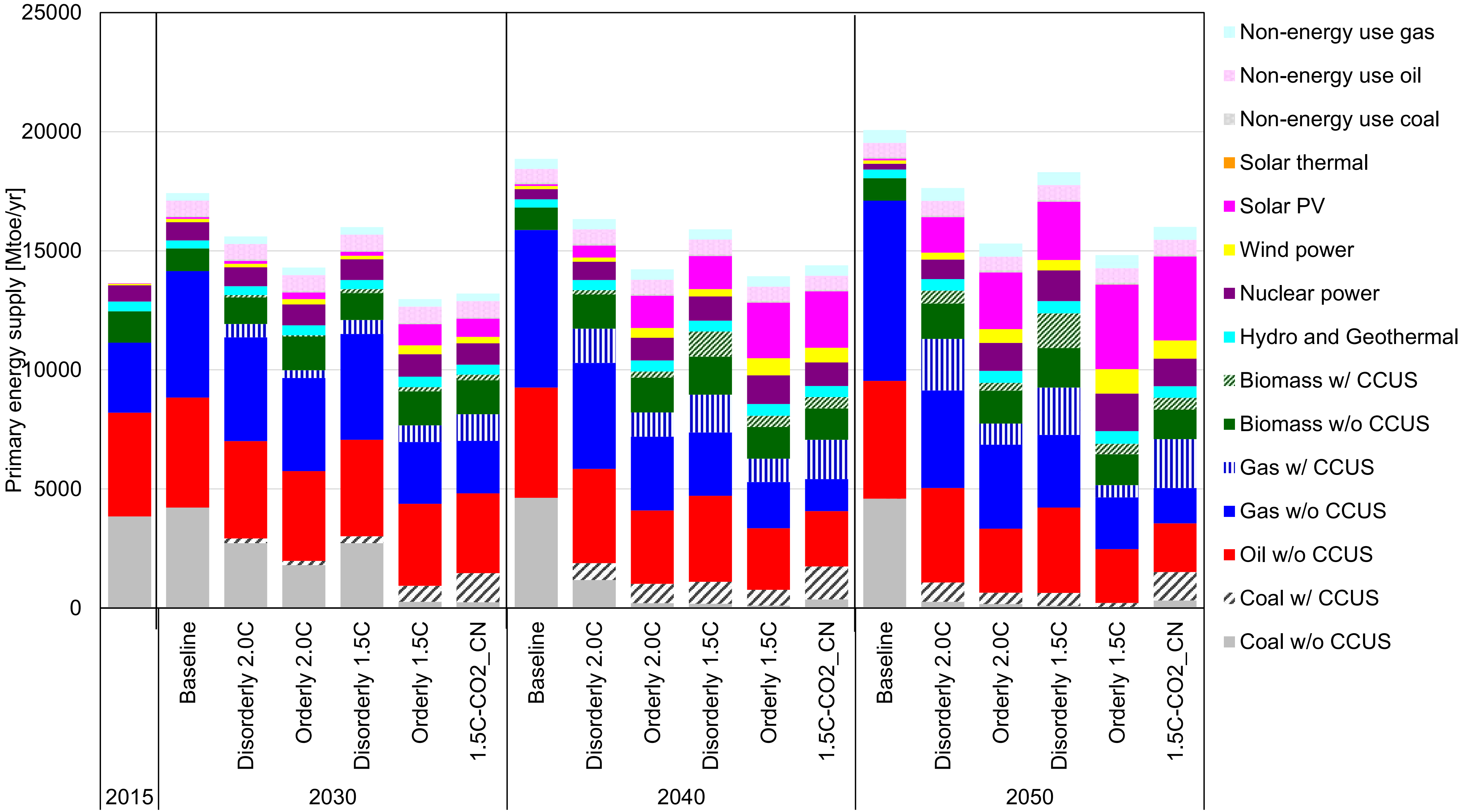





Note) The 1.5C-CO2_CN scenario analyzes only on CO2, but the figure includes non-CO2 GHG emissions of Orderly 1.5C.

- ✓ **The amounts of $CO_2$ fixations due to CDR is approximately 20G$tCO_2$eq/yr in 2050 for the Disorderly 1.5°C, and those for other scenarios are below 10 G$tCO_2$eq/yr.**
- ✓ **Non-$CO_2$ GHG emissions of approx. 10 G$tCO_2$eq/yr remain in 2050 even in both 2°C and 1.5°C scenarios.**

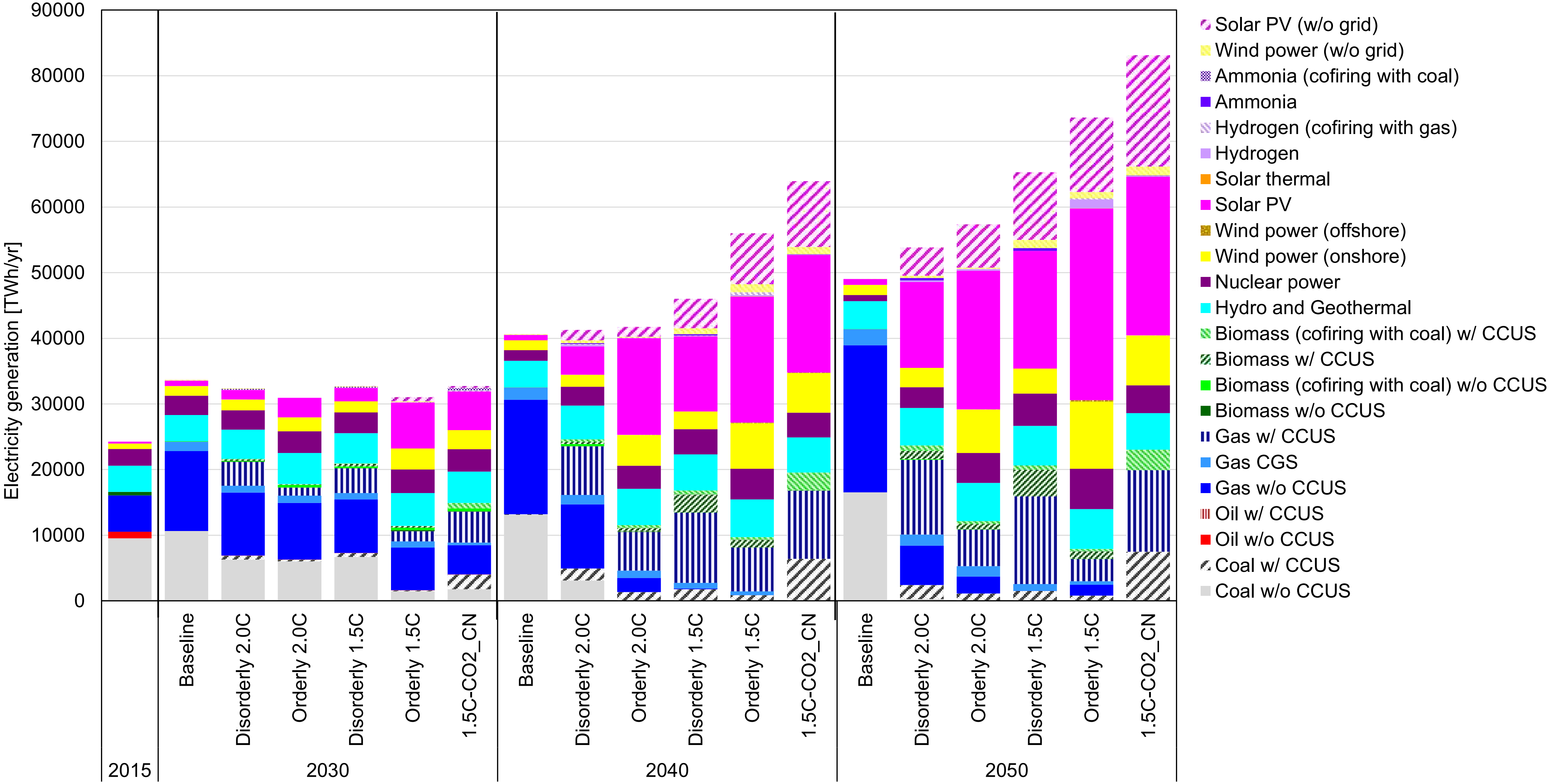
# Primary energy supply (World)




- ✓ **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)

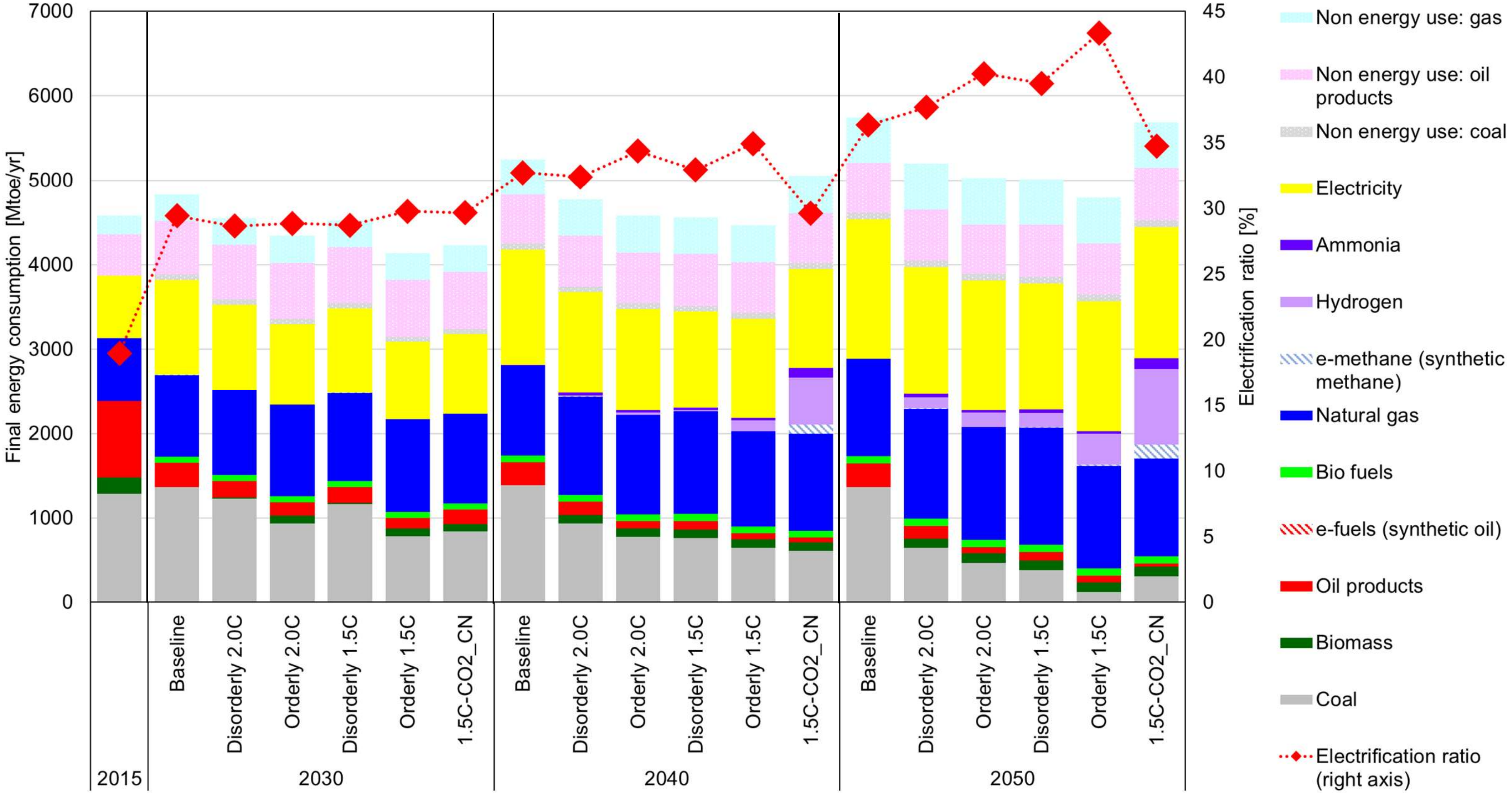





- ✓ **Potentials of CO2 geological storage is large in the world, the shares of gas power with CCS are relatively high compared with those in Japan.**
- ✓ **In the Orderly 1.5°C/2.0°C scenarios which assume larger constraints of the access of CO2 geological storage, larger deployments of solar PV and 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)

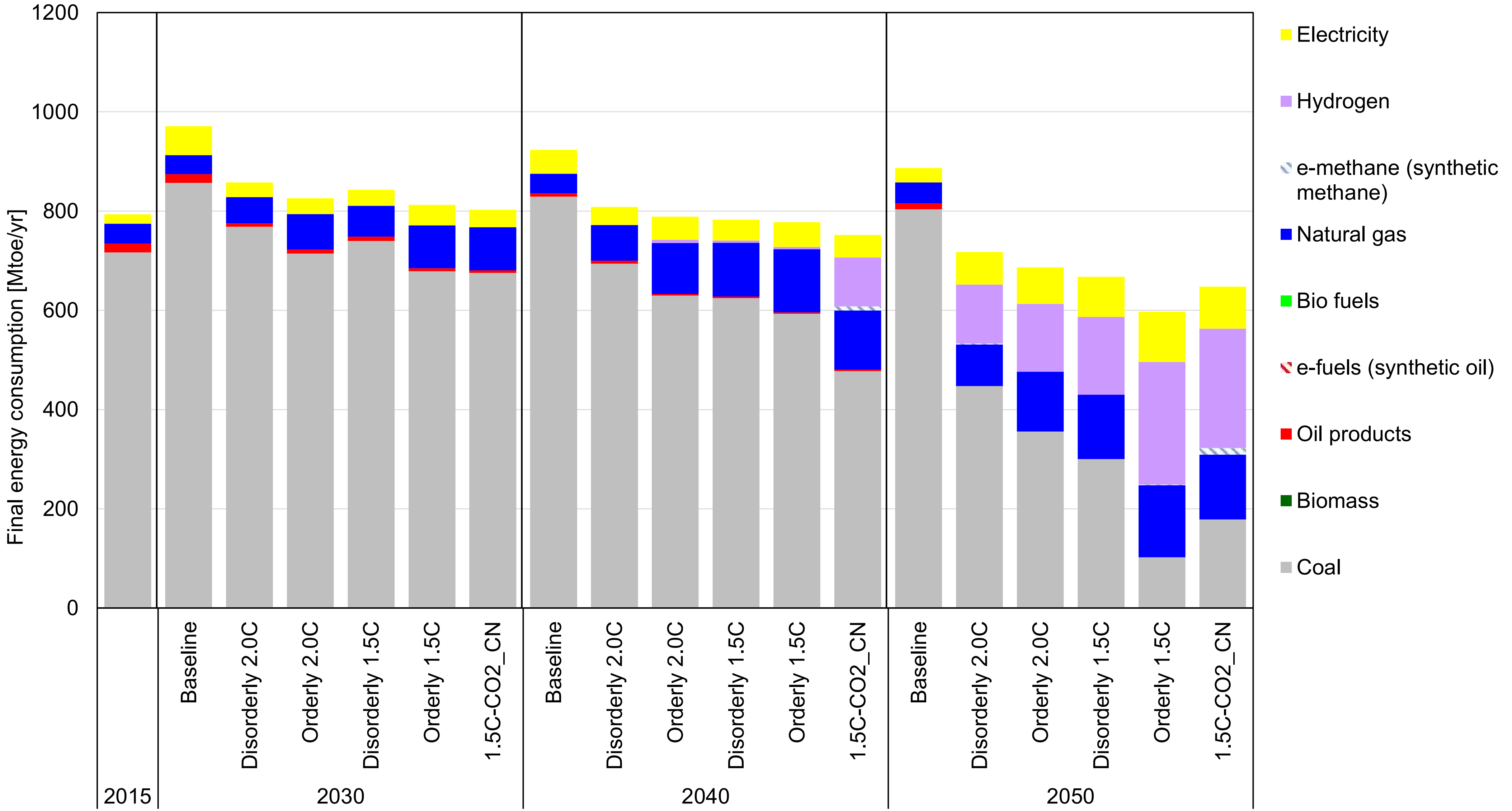





- ✓ Coal uses reduce, and gas and electricity uses increase for the 2°C/1.5°C scenarios in the world.
- ✓ The shares of hydrogen, ammonia, and synthetic methane (e-methane) uses are relatively small compared with those of Japan due to cheaper renewables and CCS, and larger power grid connections.

# Final energy consumption in iron & steel (World)

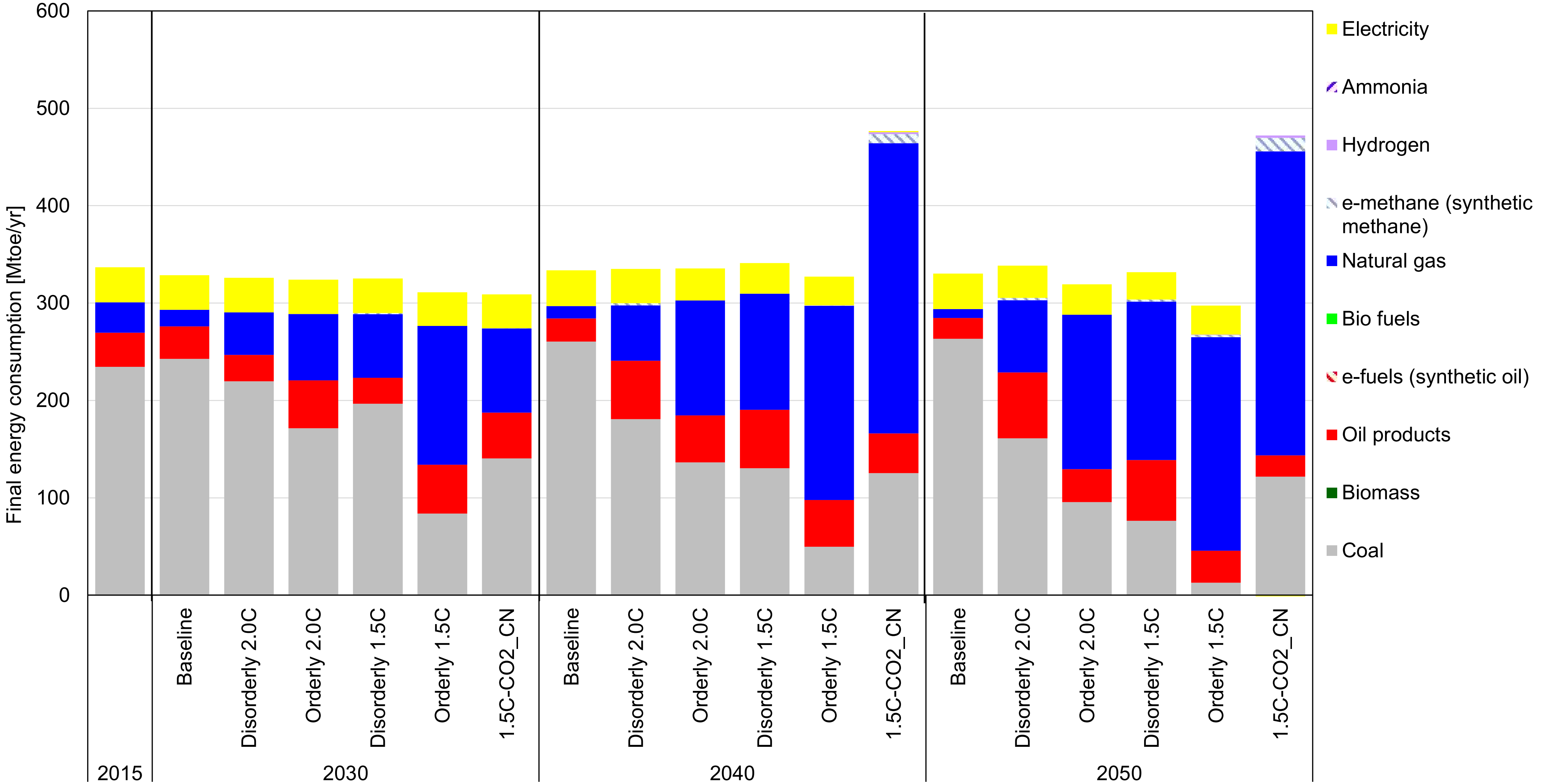





- ✓ **Total final energy consumption will decrease due to energy savings and shifts to electric furnace. Meanwhile coal is still major energy sources by around 2040.**
- ✓ **After 2040, hydrogen from outside of steel making processes (e.g., Super COURSE50) are used, and hydrogen-use DRI are cost-effective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

# Final energy consumption in cement (World)

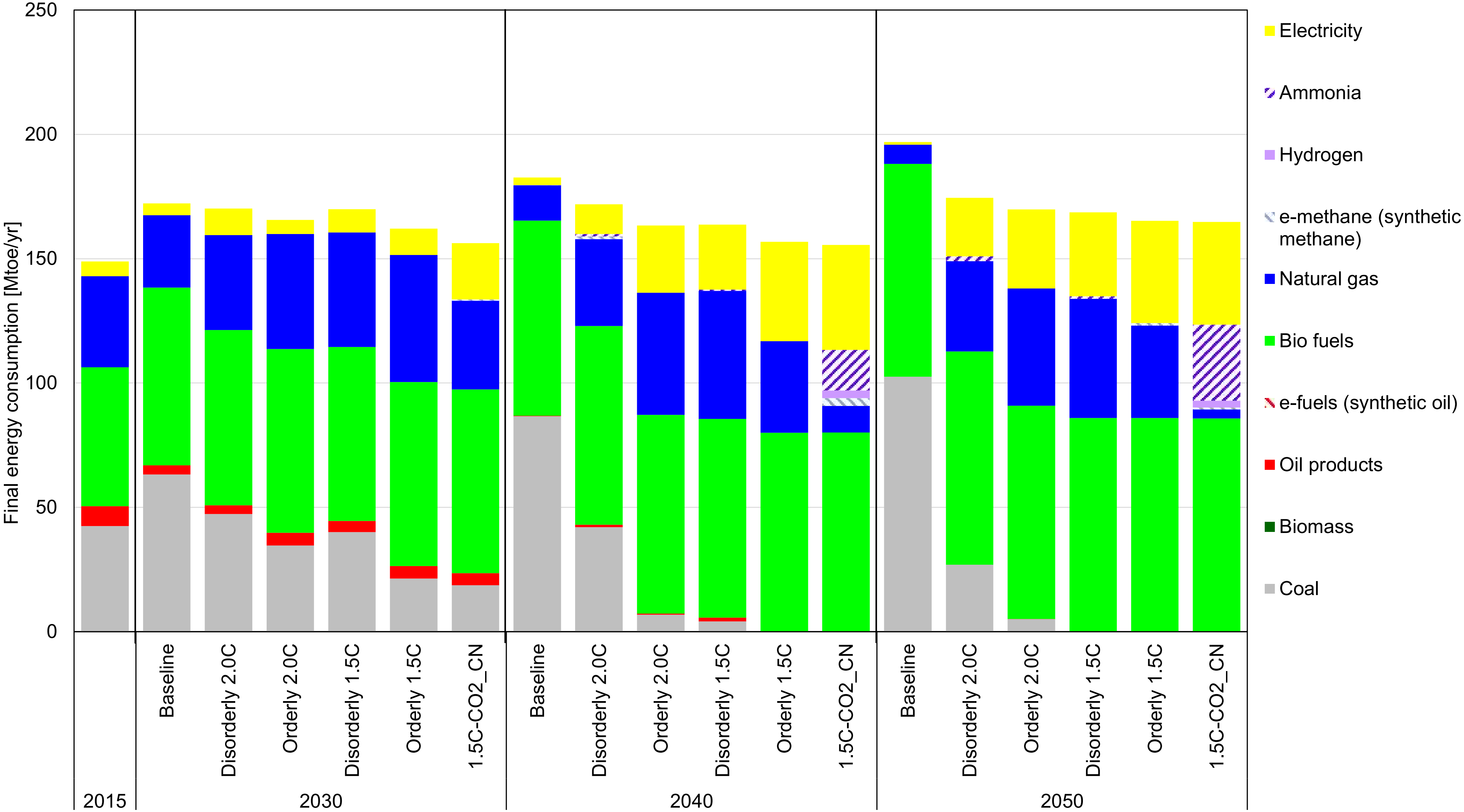





- ✓ A shift from coal to gas is cost-effective under 2°C/1.5°C scenarios.
- ✓ While efficiency continues to improve, there are some cases in which slightly more energy is consumed compared with the Baseline, due to energy use for $CO_2$ capture, especially in 1.5C-CO2_CN which assumes a small contribution of CDR.

# Final energy consumption in paper & pulp (World)



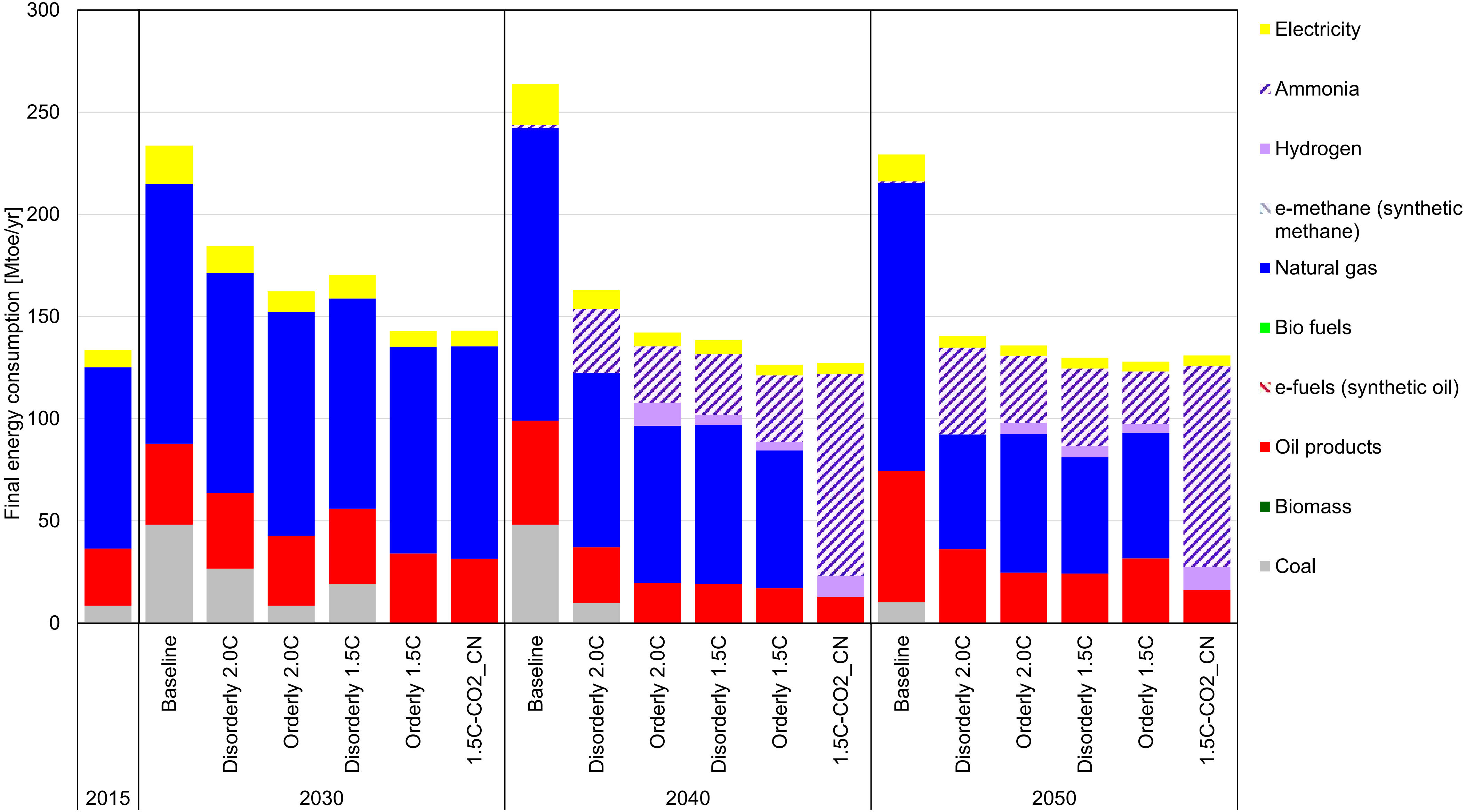



Note) The use of black liquor is included in biofuels consumption.

- ✓ **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)



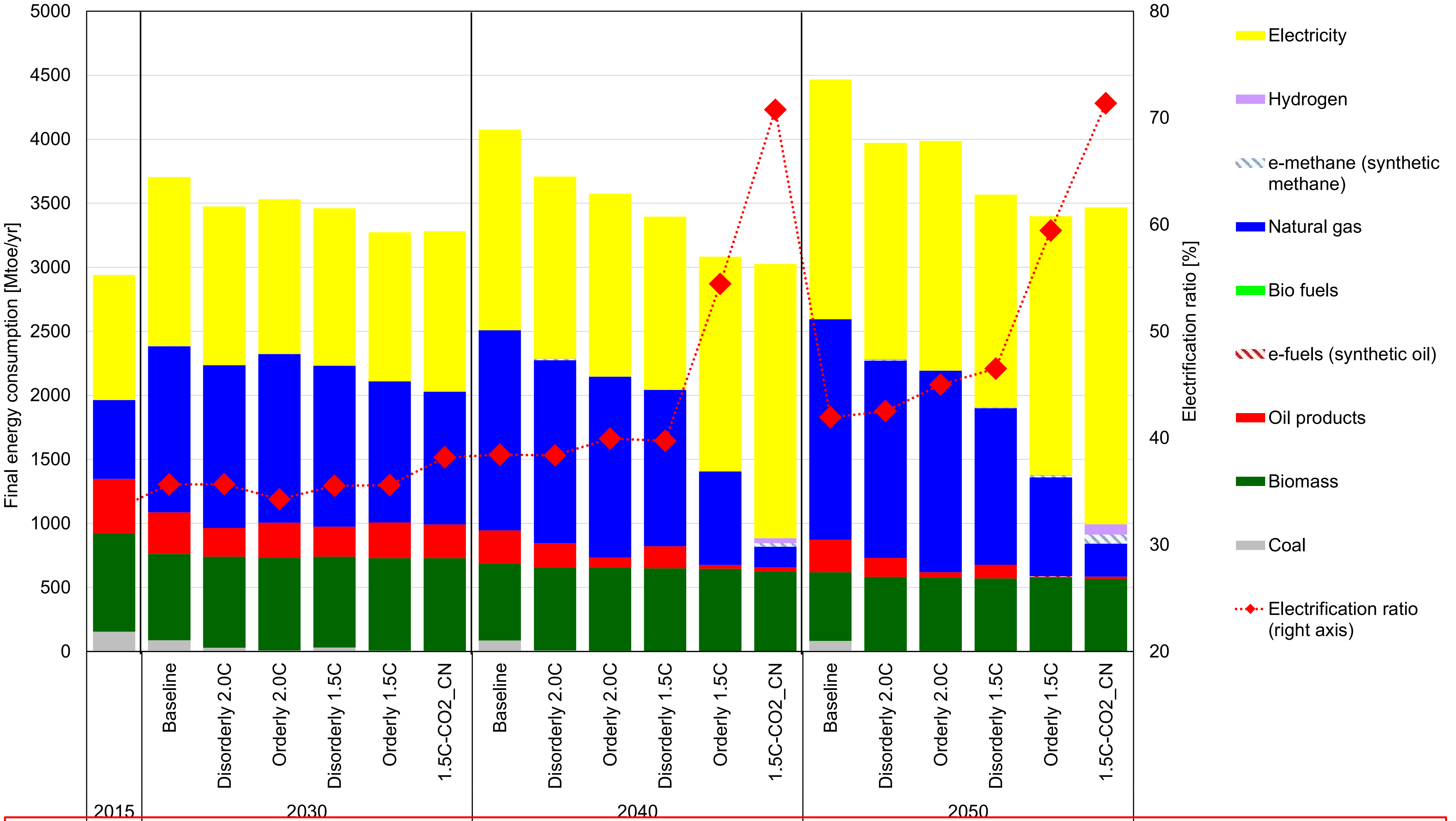



Note) The graph shows only energy usage consumption, and energy for raw material is not included.

✓ **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)

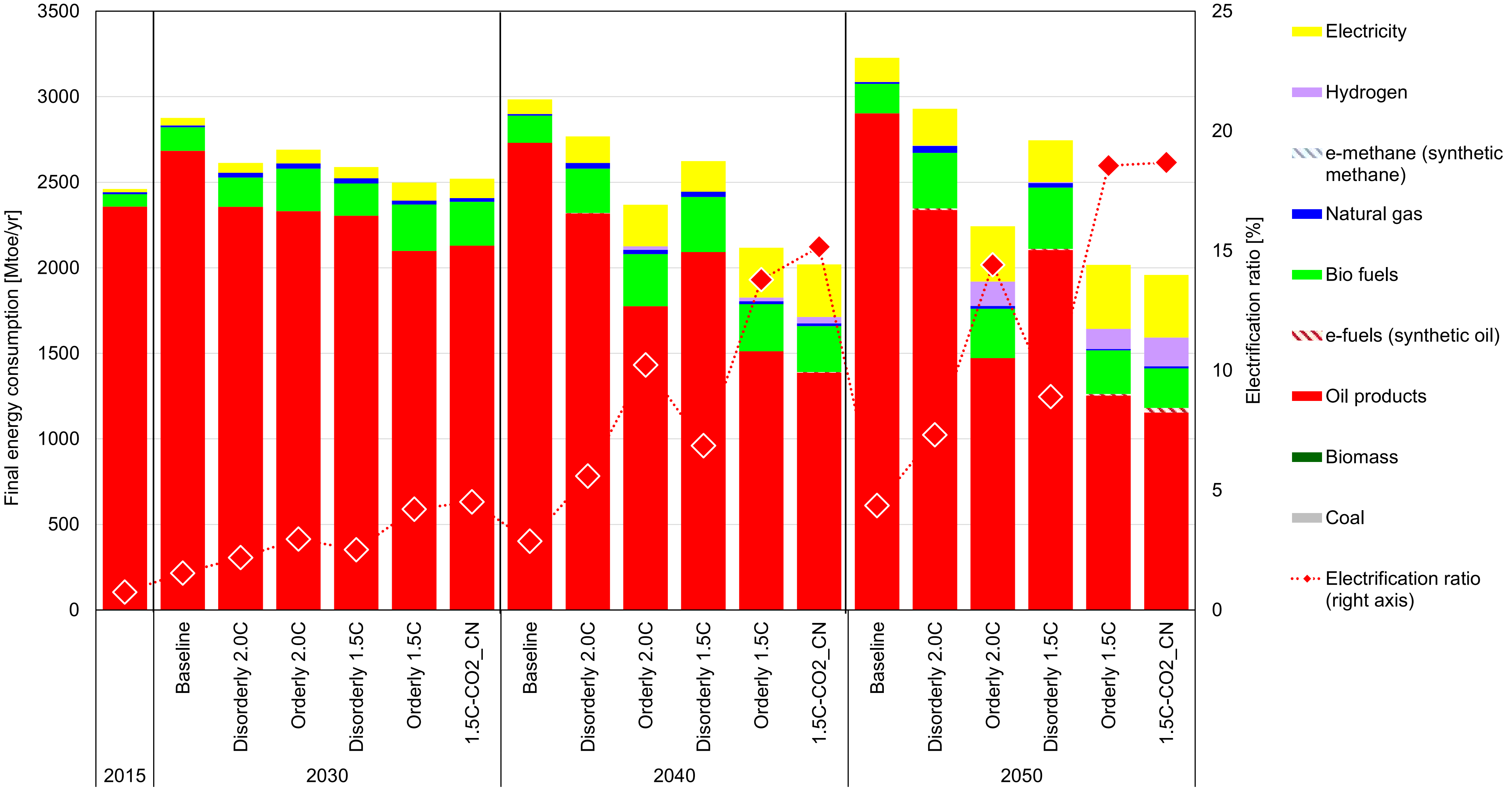





- ✓ In building sector, electricity consumptions will increase greatly even for the baseline scenario. Under the 2°C/1.5°C scenarios, larger shares of electricity consumptions will be economical measures.
- ✓ On the other hand, for the 2°C scenarios and Disorderly 1.5°C, a certain amounts of natural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

# $CO_2$ emissions reduction cost (Japan)



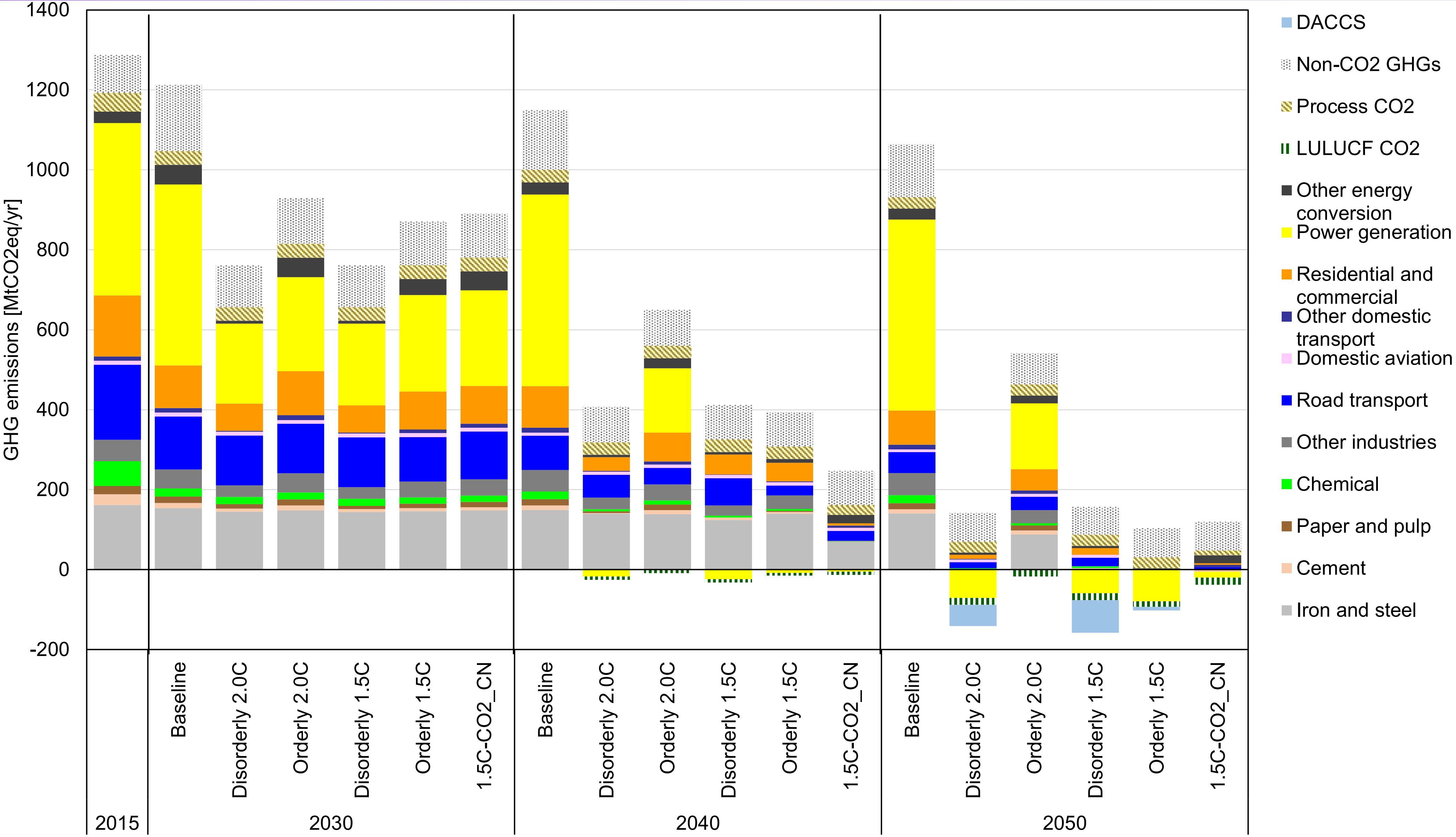
Unit: billion US$/yr

| | 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)



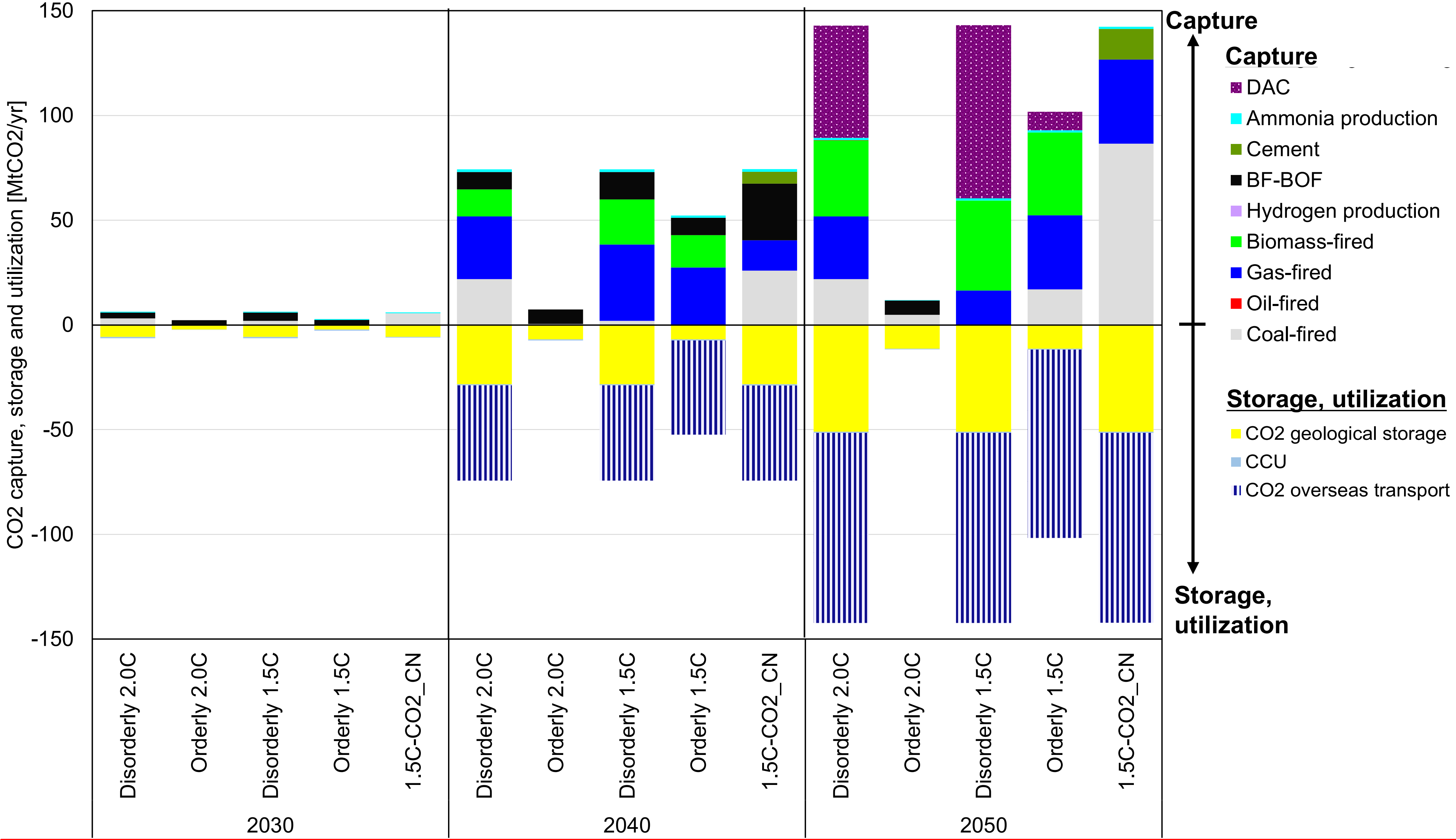



Note) The 1.5C-CO2_CN scenario analyzes only on CO2, but the figure includes non-CO2 GHG emissions of Orderly 1.5C.

- ✓ **To achieve CN in GHG emissions in 2050, DACCS, the use of LULUCF $CO_2$ (fixation by forestation), and the measures for net negative $CO_2$ 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 $CO_2$ emissions from the Power sector and the Iron and steel sector.**

# $CO_2$ balance (Japan)

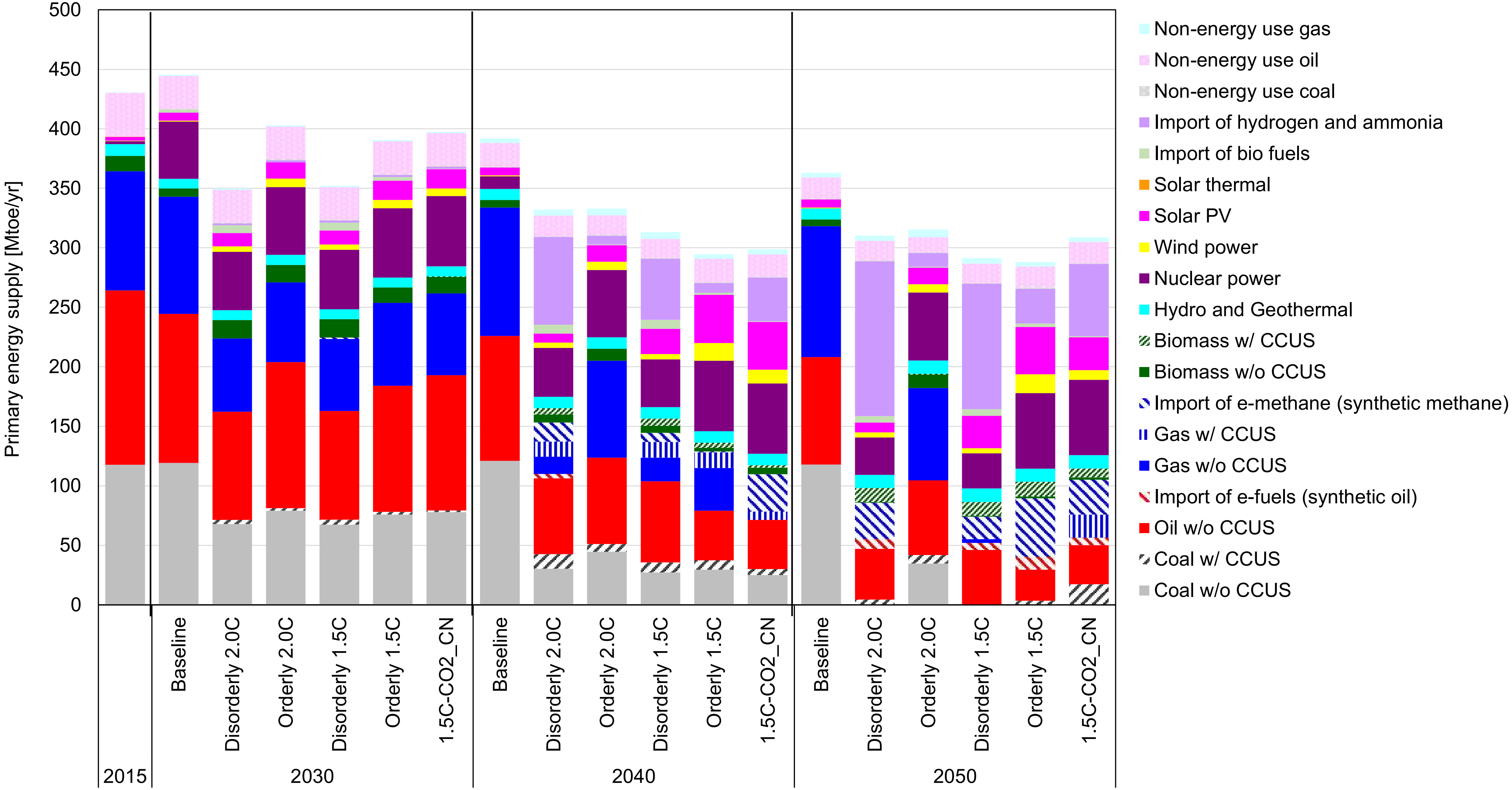





- ✓ $CO_2$ capture through fossil-fired power generation and BF process (Super COURSE50) are observed in 2040.
- ✓ $CO_2$ capture through DAC and Biomass processes will be large in 2050.
- ✓ Under 1.5C-$CO_2$_CN, with limited CDR uses including BECCS and synthetic methane+CCS in the Power sector, $CO_2$ is captured from coal-fired (incl. Biomass co-firing) and gas-fired, and in the Cement sector in 2050. Captured $CO_2$ via DAC is used for CCU.

# Primary energy supply (Japan)

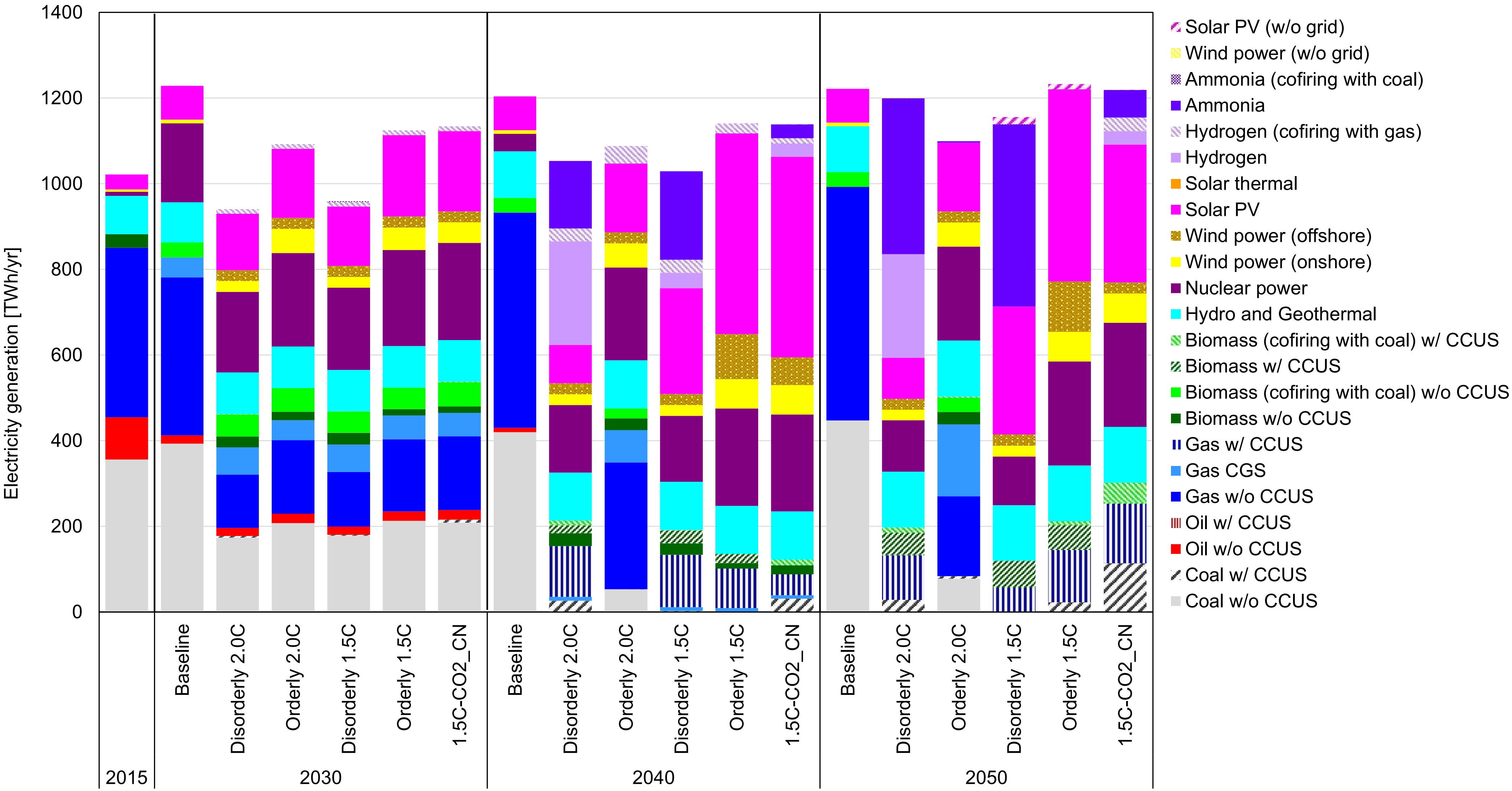





- ✓ **Import of hydrogen and ammonia, e-methane, and biofuels would be cost-effective as the MAC of Japan is higher than other countries. However, those amounts in Orderly 2.0°C are relatively small (approx. ▲63% relative to 2013 in 2050).**
- ✓ **Coal use incl. with CCUS is scarcely observed in the 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-$CO_2$_CN.**

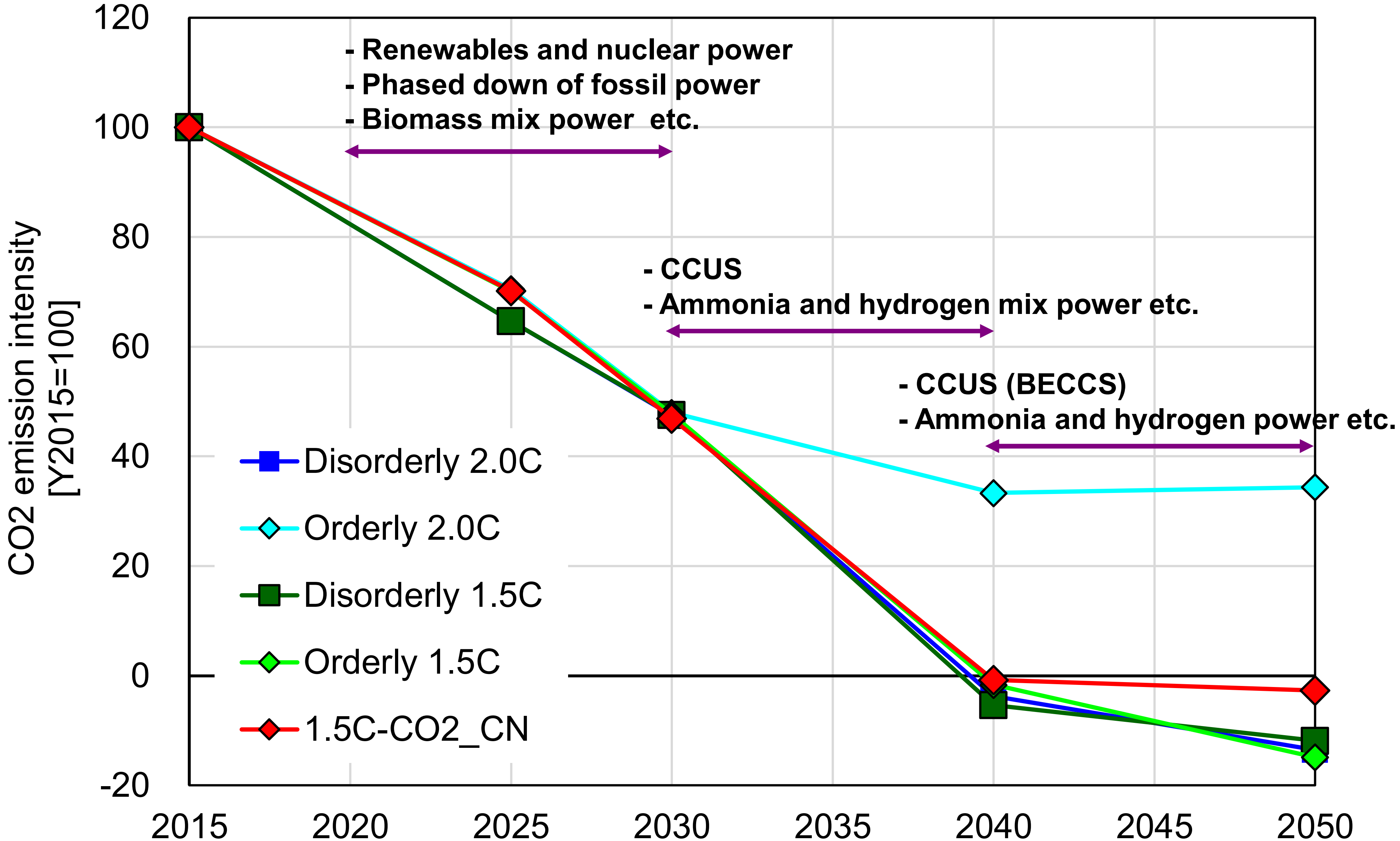
# Electricity supply (Japan)






- ✓ **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-$CO_2$_CN, a portion of coal with CCUS increases due to the constraint of BECCS and synthetic methane+CCS.**

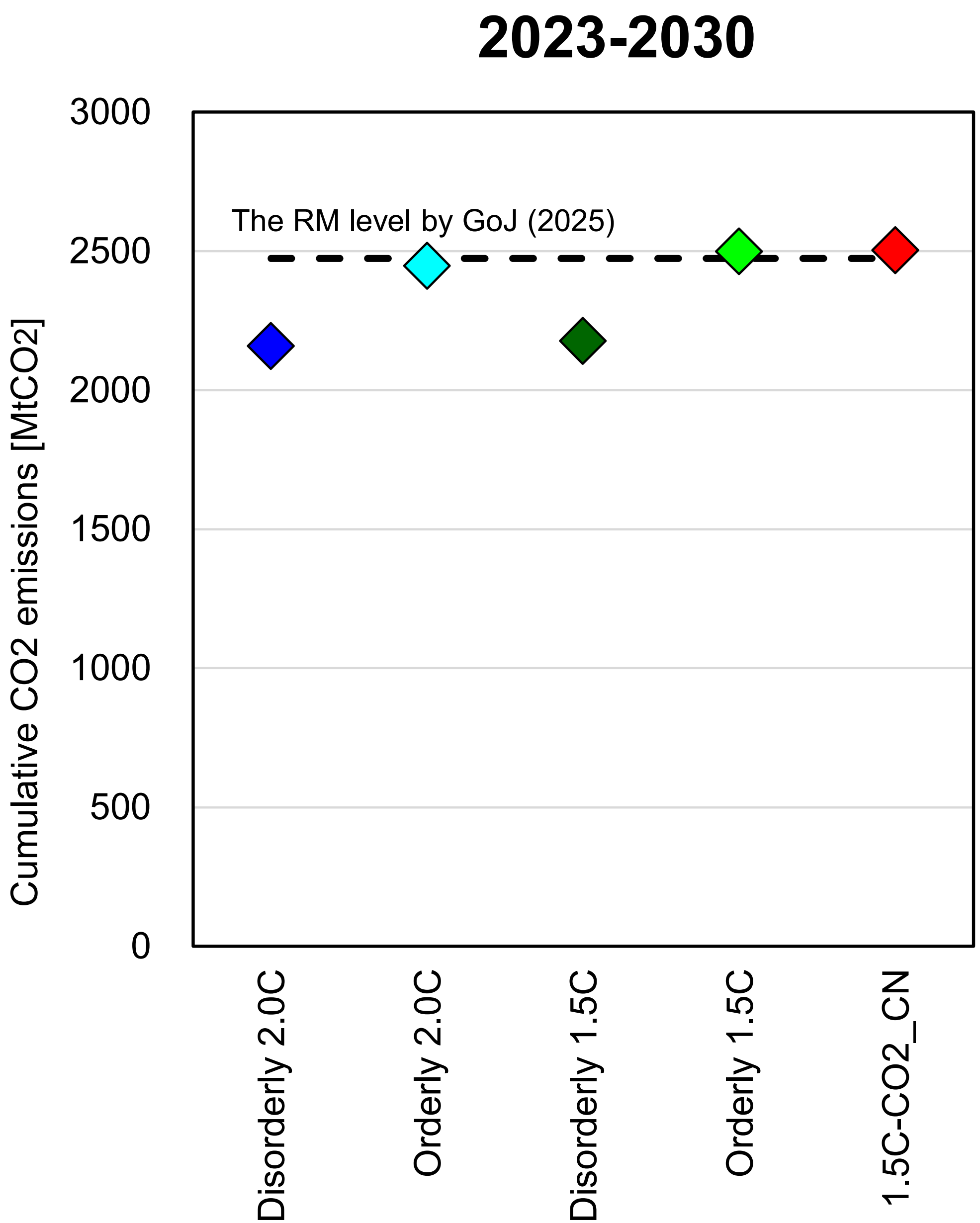
# $CO_2$ intensity of electricity (Japan)

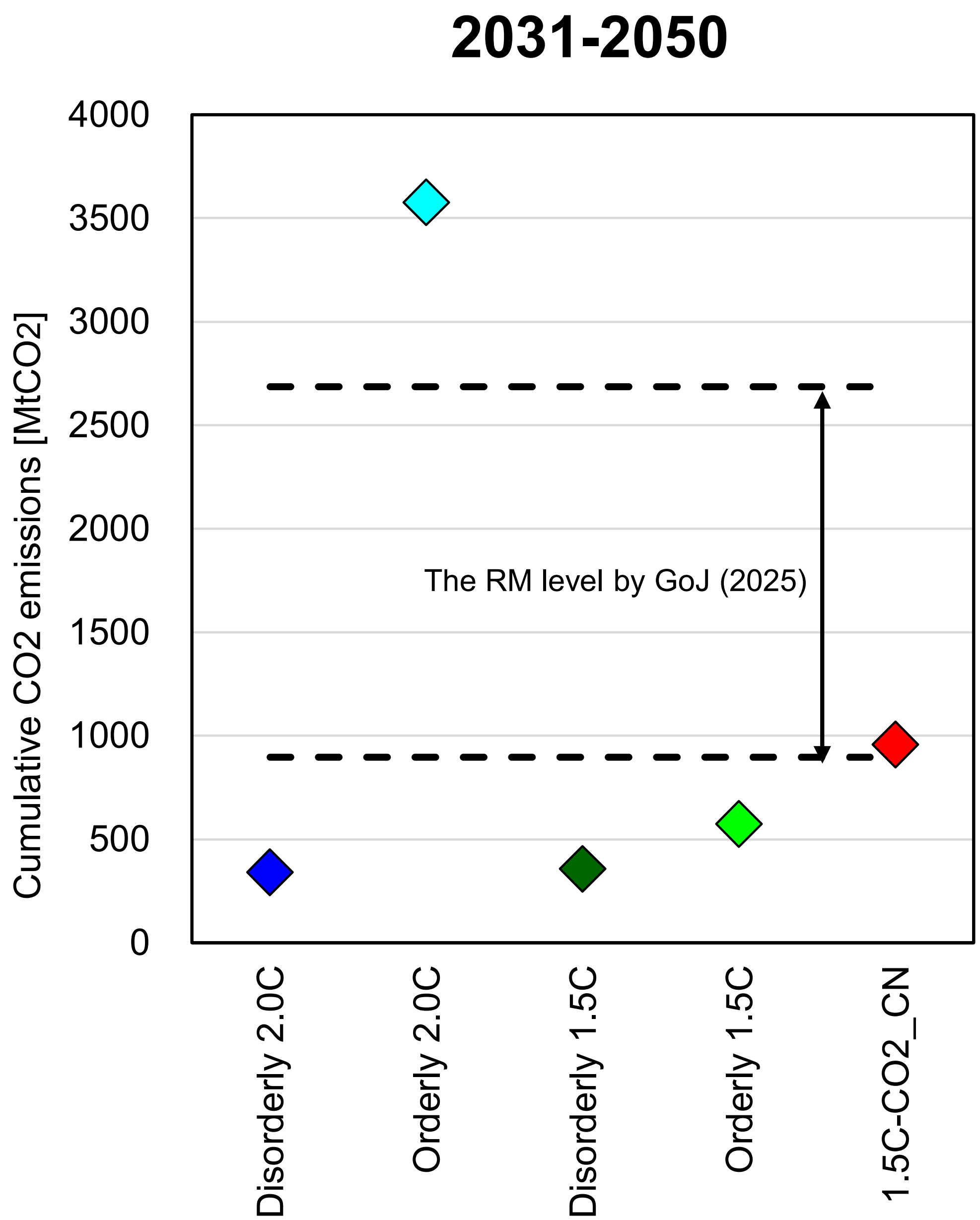



✓ There is no big differences in the trend of $CO_2$ intensity among Disorderly 1.5°C/2.0°C and Orderly 1.5°C, which assume GHG net zero emissions in 2050, although the power mixes are varied, and achieving CN by around 2040 would be cost-effective as a whole.

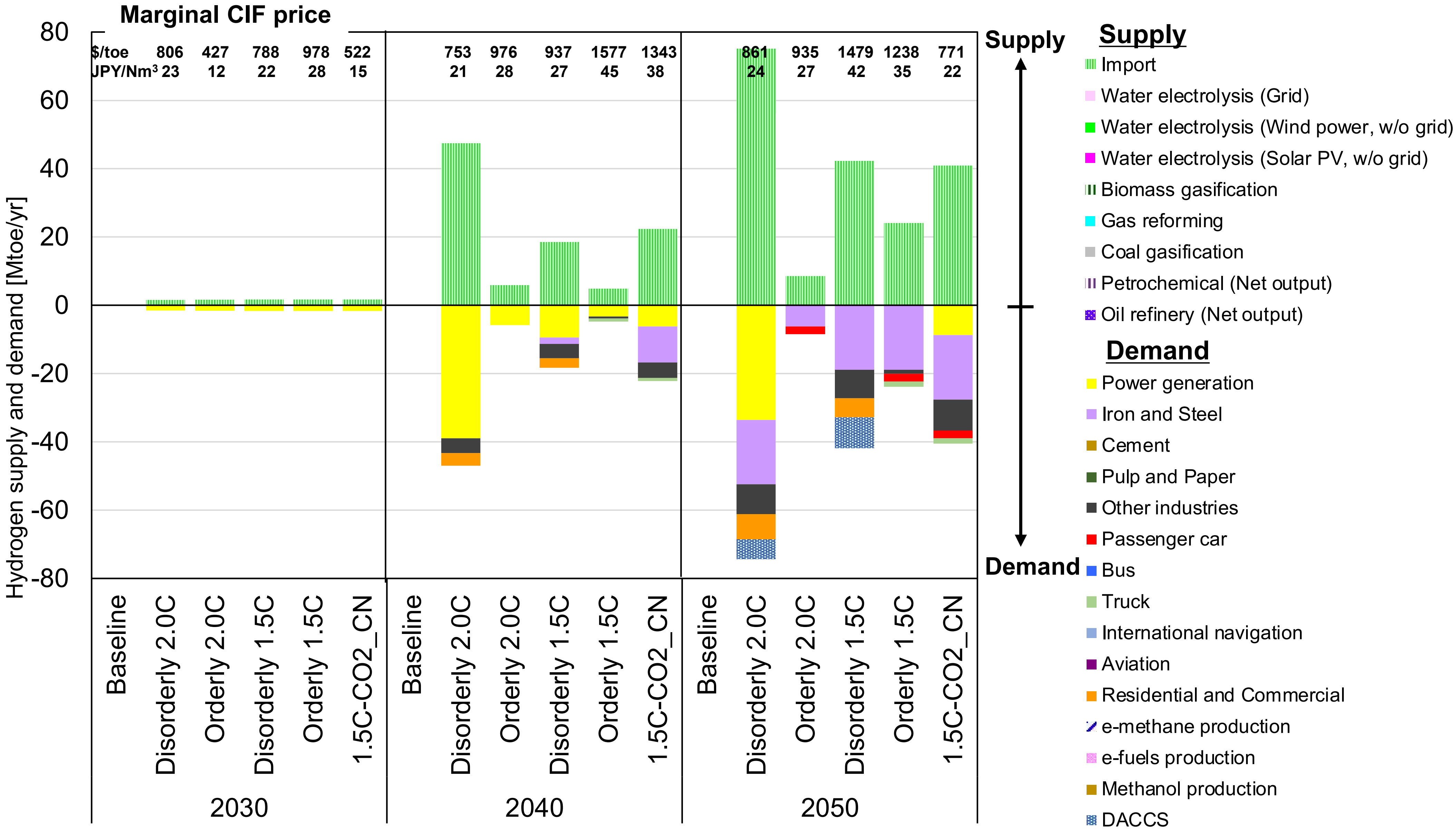
# $CO_2$ emissions in power sector (Japan): comparison with the RM by GoJ





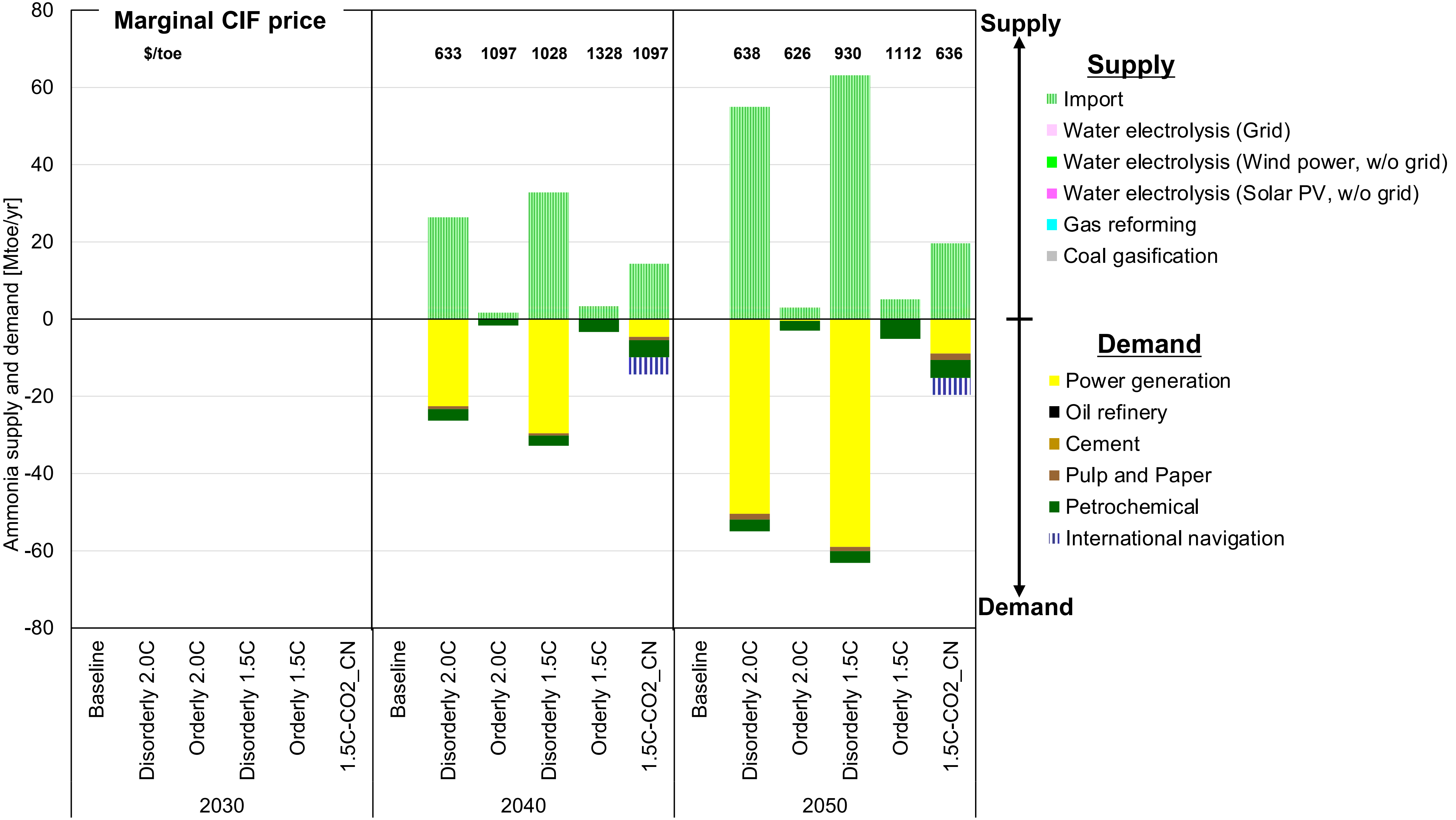
# Supply and demand of hydrogen (Japan)




- ✓ **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)

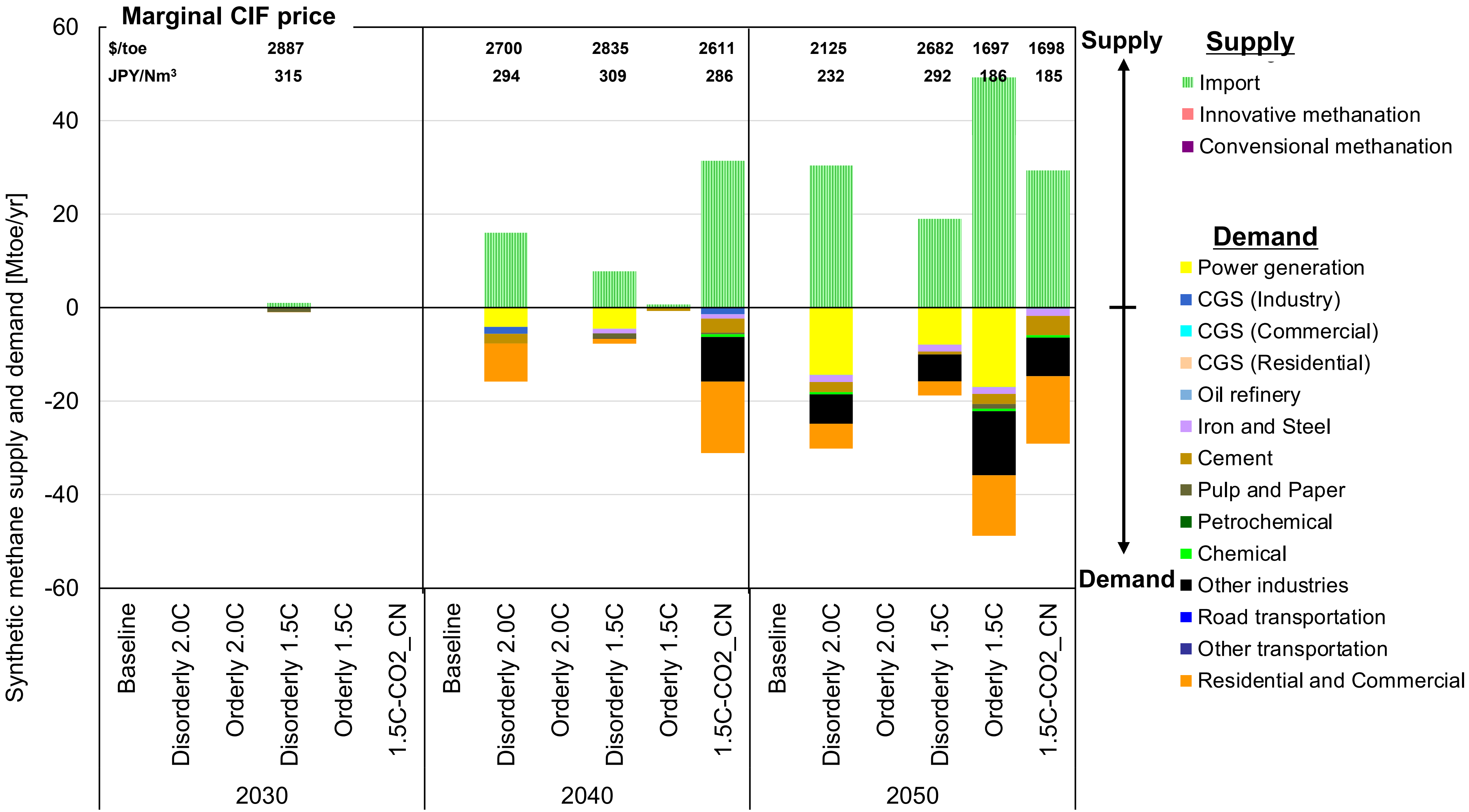





- ✓ **In the Disorderly 1.5°C/2.0°C scenarios, the cost reductions of VRE are gradual, and blue ammonia from overseas plays an important role in the power sector.**
- ✓ **Ammonia uses for industrial sectors are also economical options in Japan.**

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

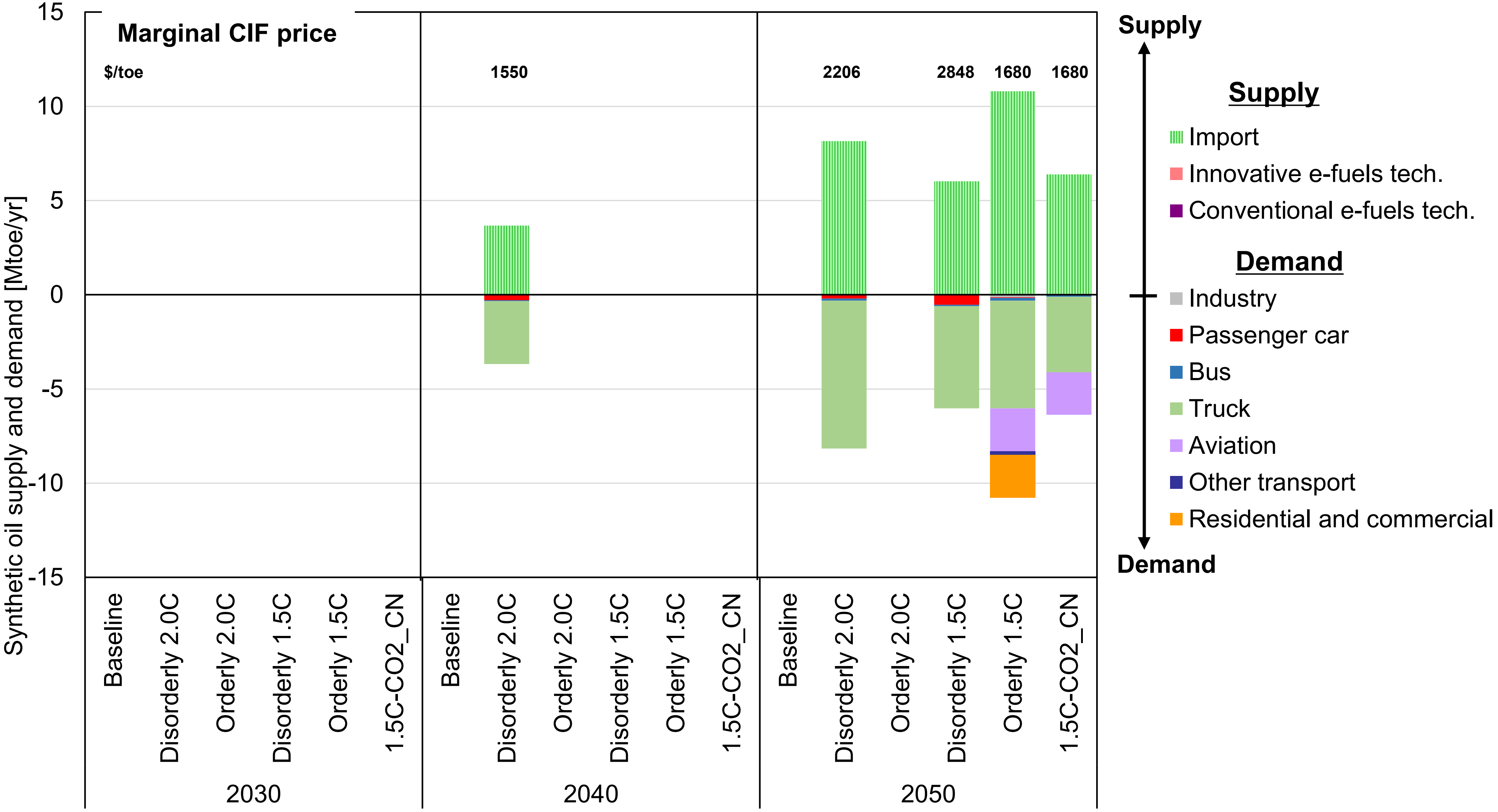





- ✓ e-methane will contribute to power sector as well as building and industrial sectors.
- ✓ Productions of synthetic methane overseas are dominant due to differences in renewable energy costs.

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

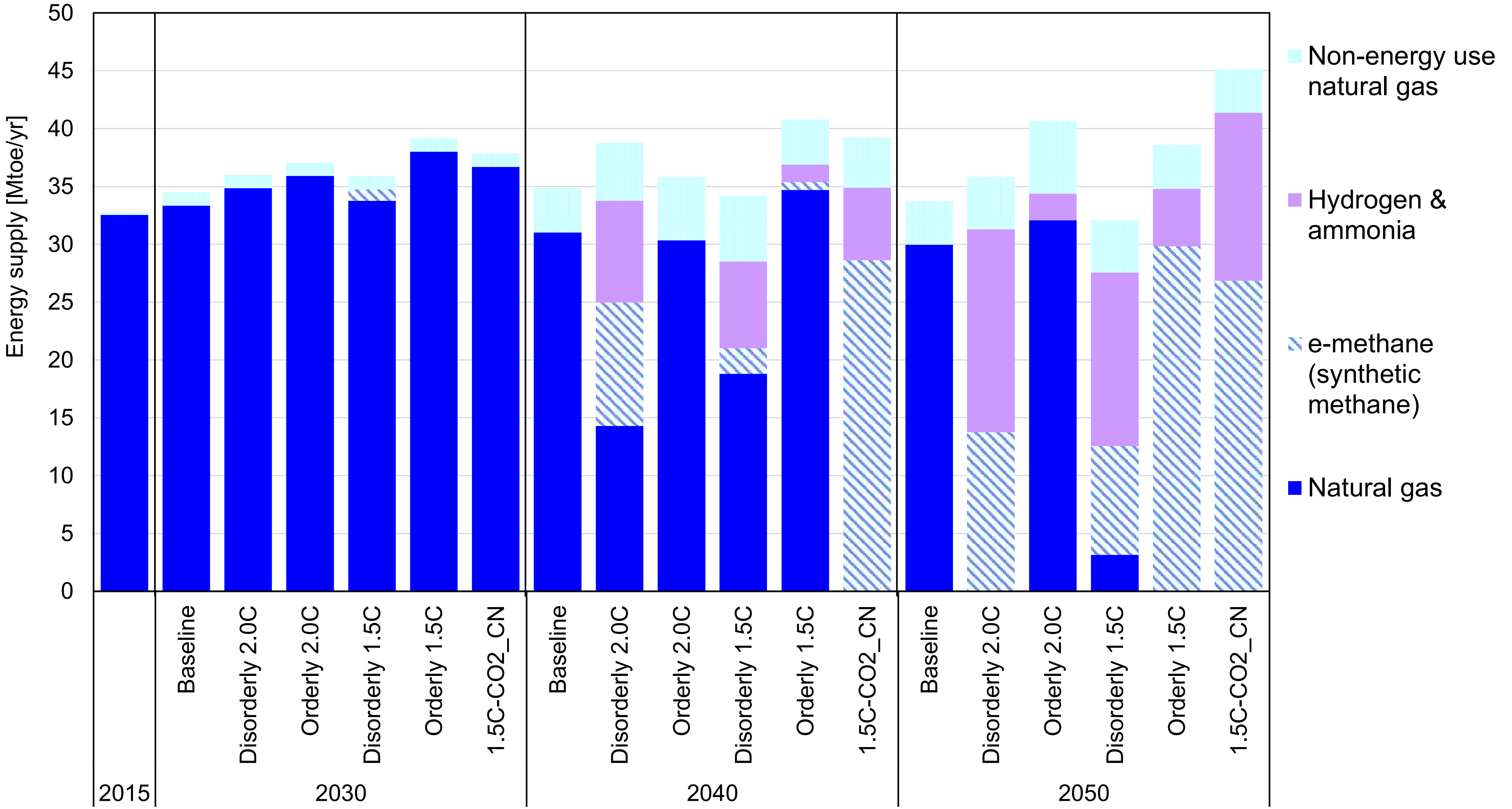





- ✓ Uses of passenger car is observed, but relatively large uses are for truck and aviation due to their limited alternatives.
- ✓ Synthetic oil is produced overseas, where the costs of renewables are cheaper.

# Gas supply (Japan)

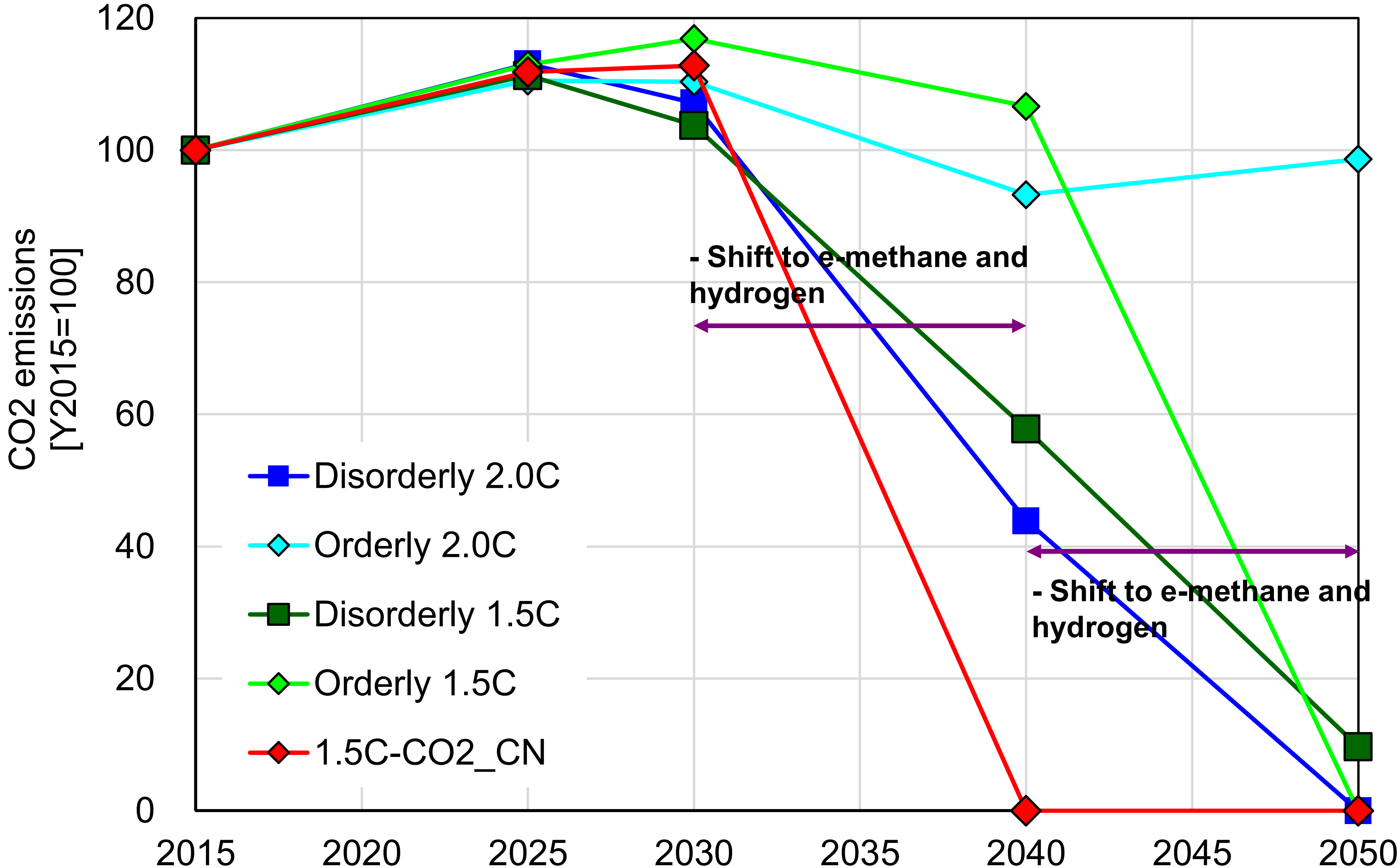





**Note) The uses in power, iron & steel, and petrochemical sectors are not included here and described in each sectoral analysis.**

- ✓ **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.**

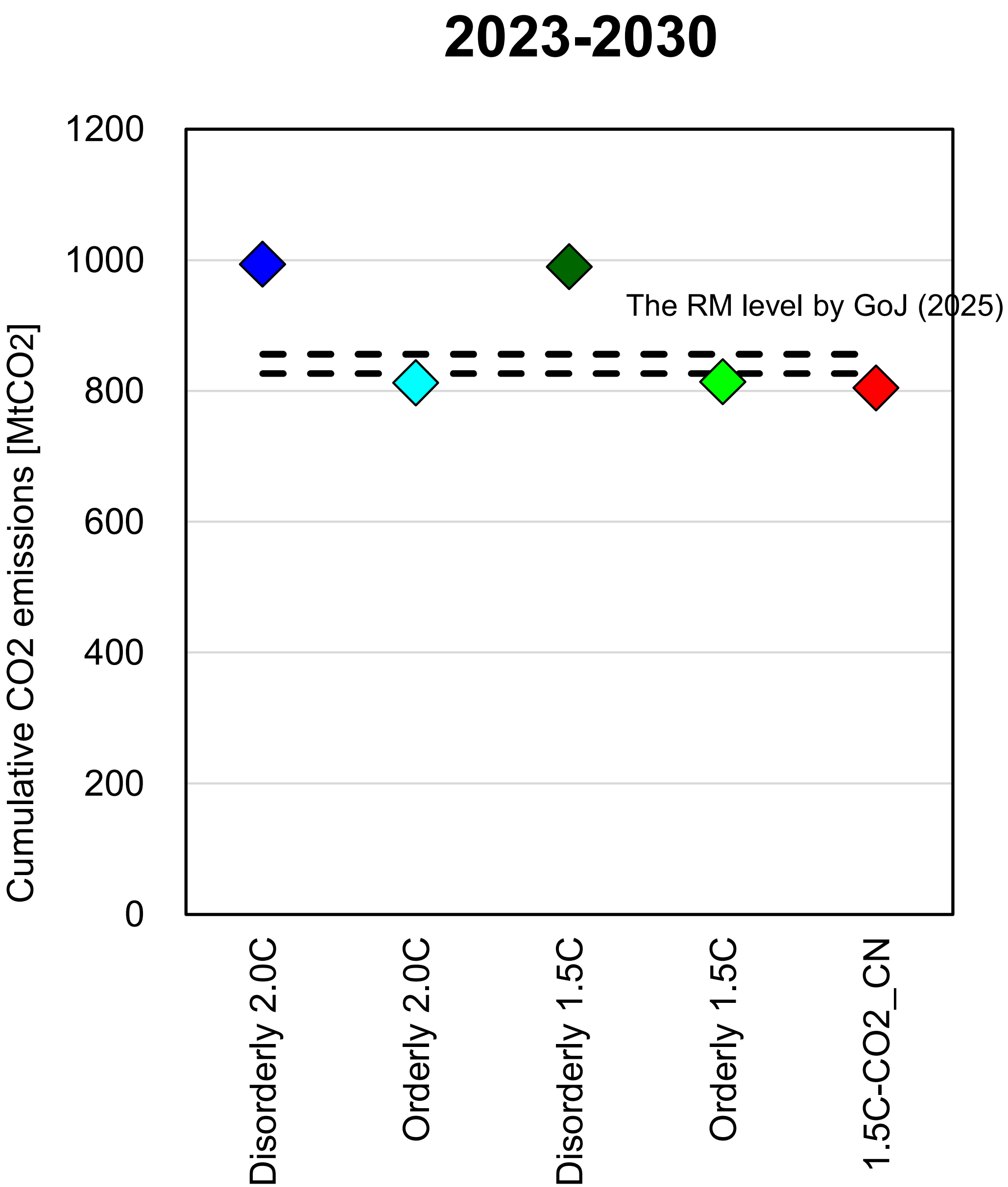
# $CO_2$ emissions from gas (Japan)

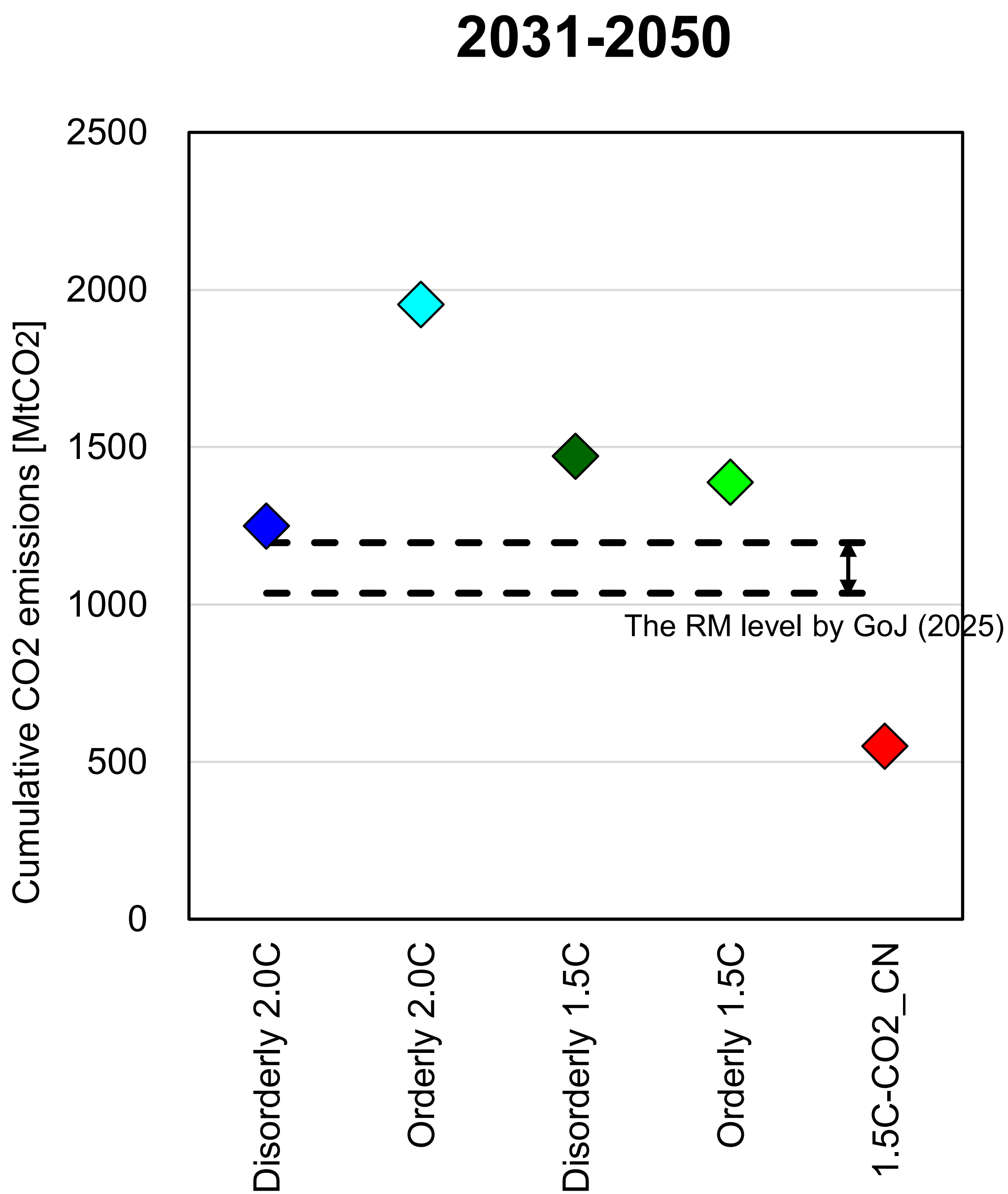



✓ **As for Orderly 1.5°C, it can be interpreted that the MAC would be close to those of other countries in 2040, causing competition in importing synthetic fuels and hydrogen (the marginal CIF price is also high), and the $CO_2$ emissions in 2040 is relatively large.**

# $CO_2$ emissions in gas sector (Japan): comparison with the RM by GoJ

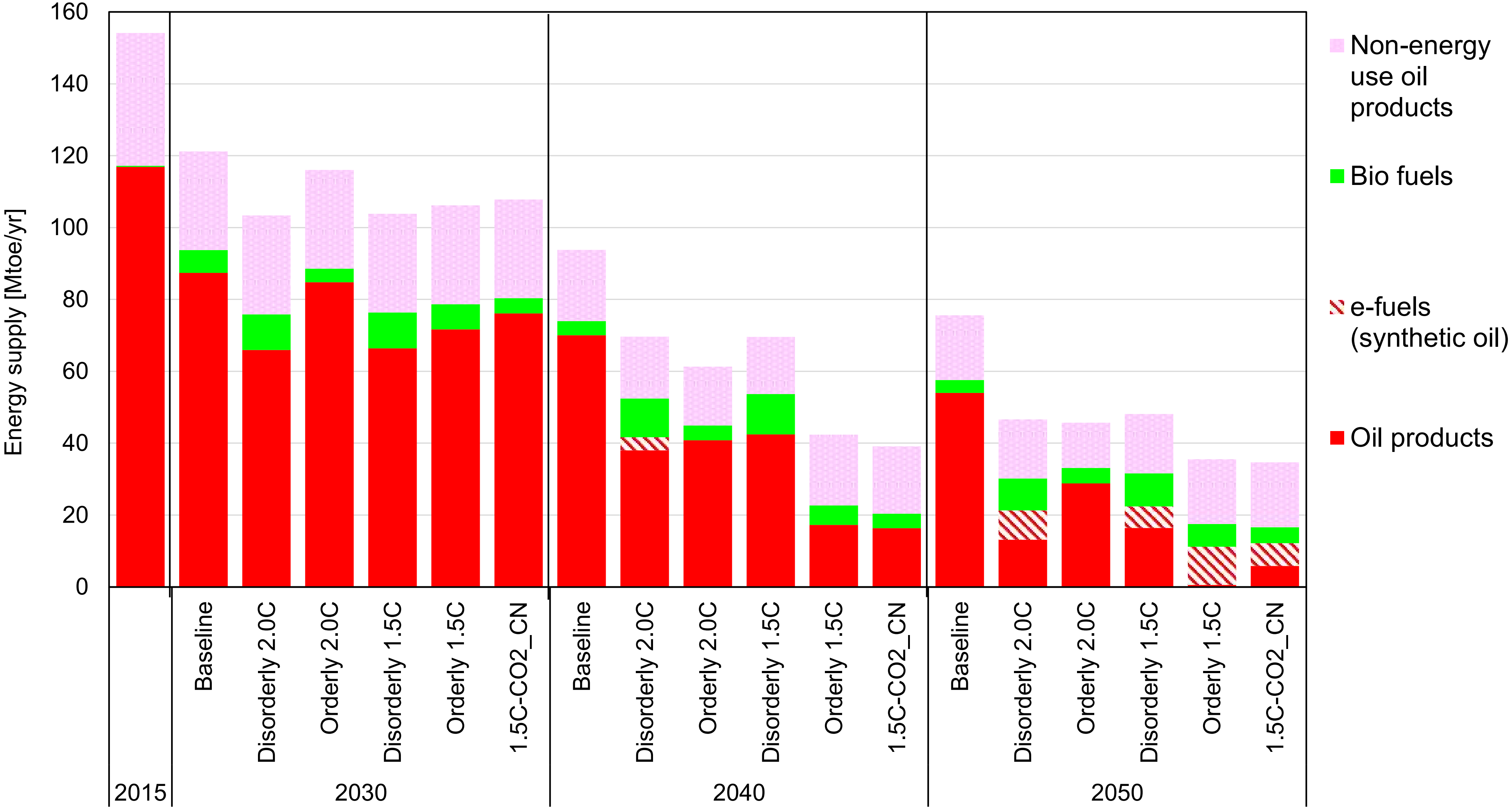




# Oil (liquid fuels) supply (Japan)



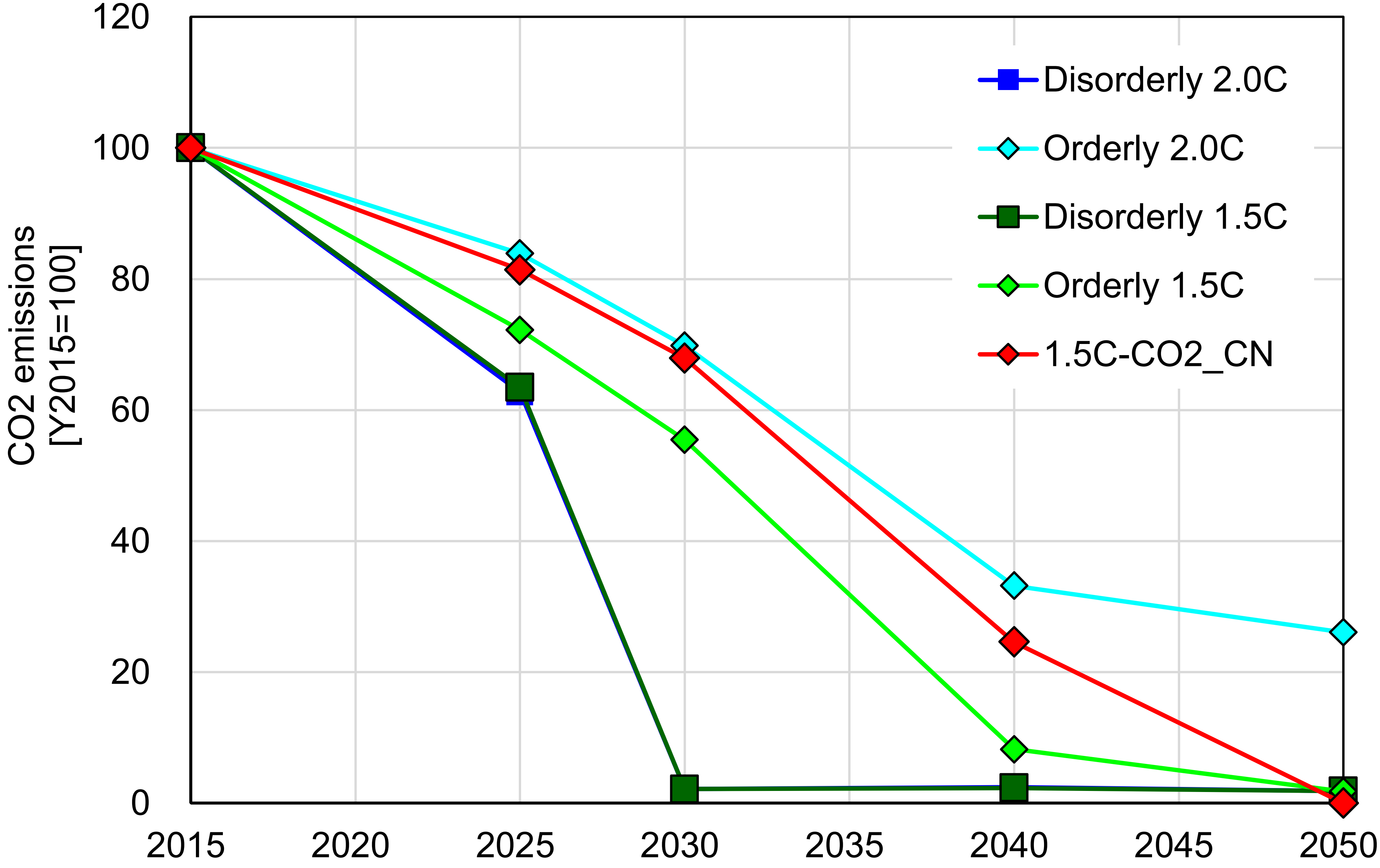



Note) The use in the power sector is not included.

- ✓ **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.**

# $CO_2$ emissions in oil refinery: Scope 1 (Japan)

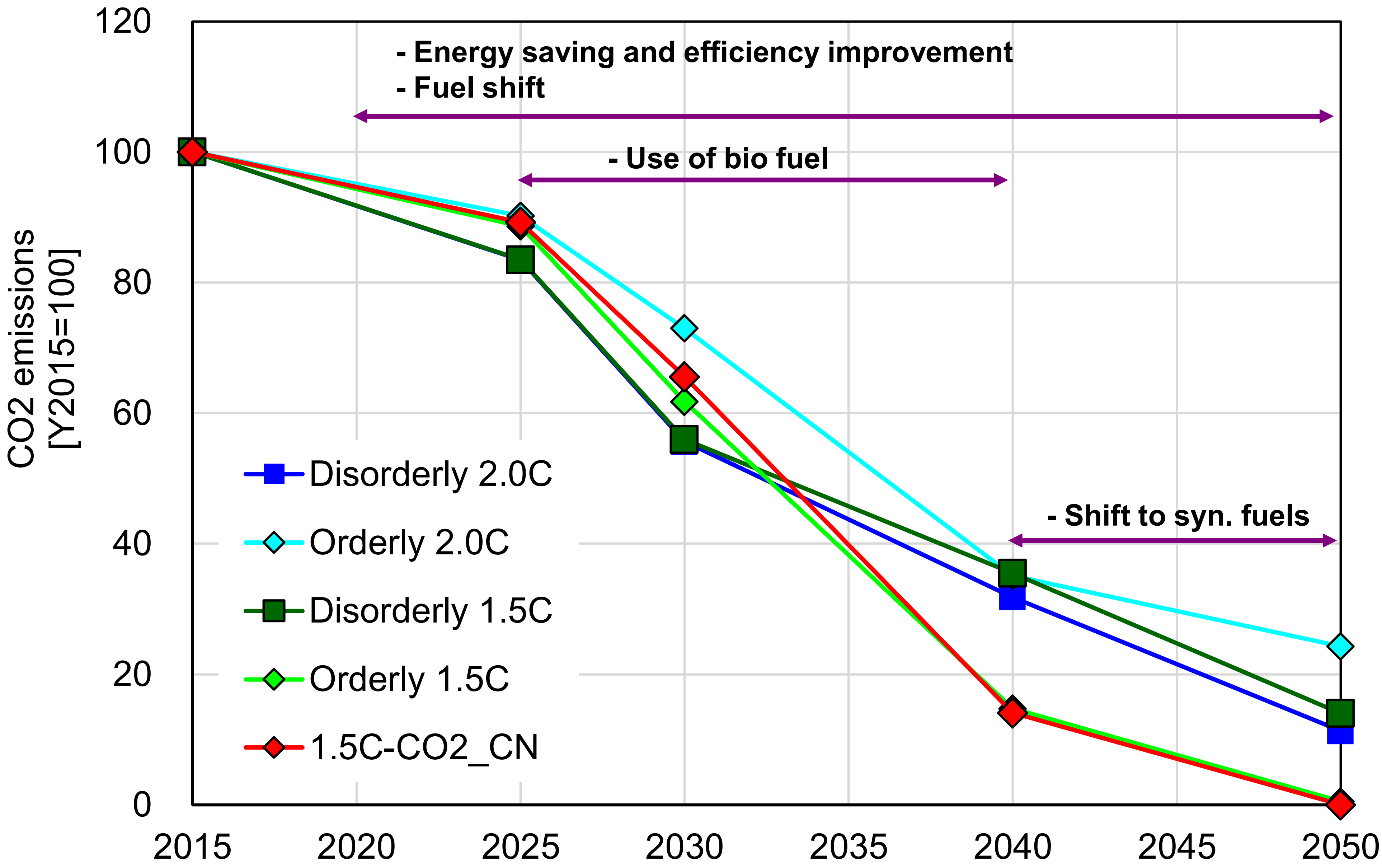





- ✓ **Scope1 emissions are decreasing as oil refining volume decreases. This trend is particularly strong in Disorderly scenarios, where there are large differences in $CO_2$ MAC with other countries.**

# $CO_2$ emissions from oil (Japan)

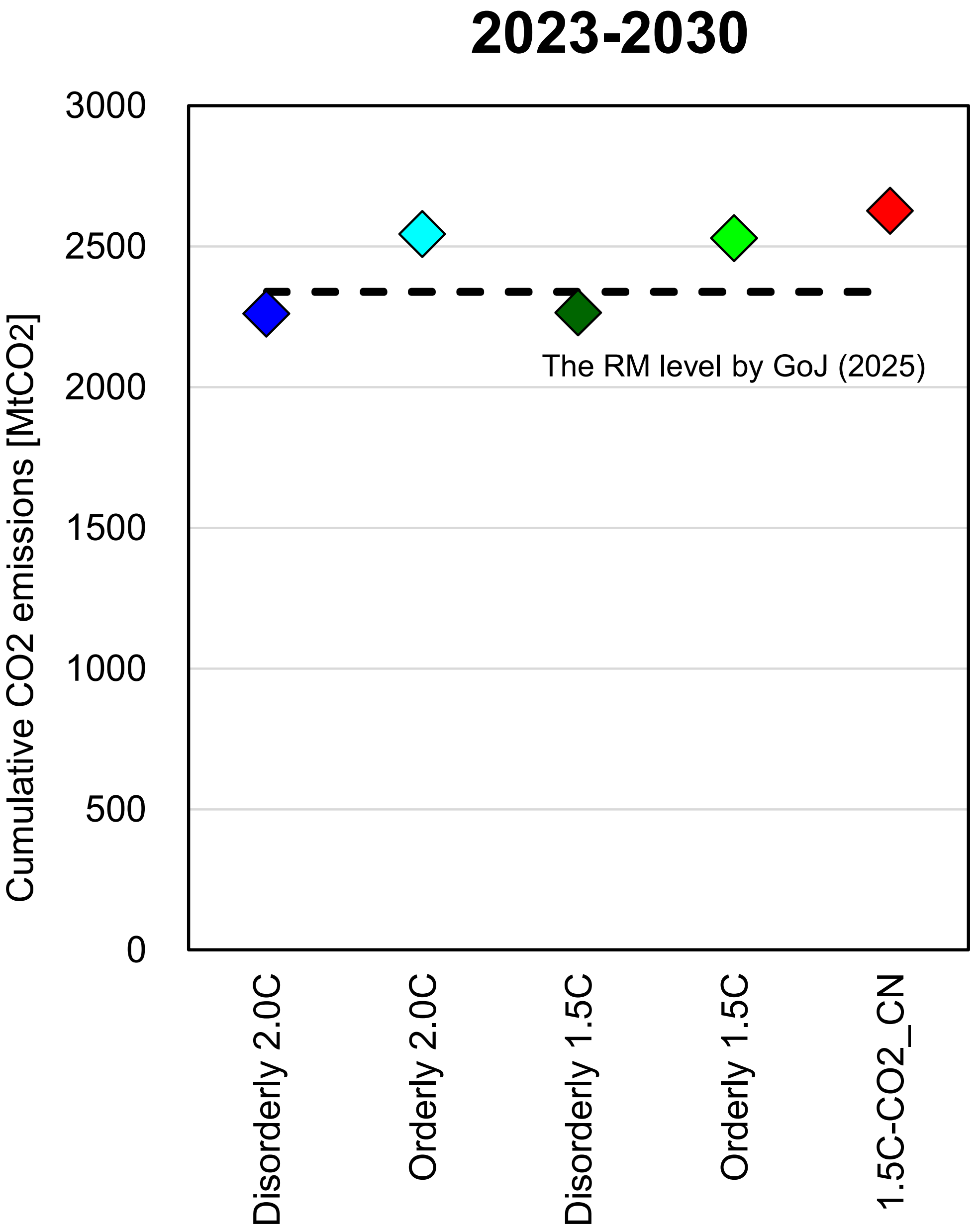


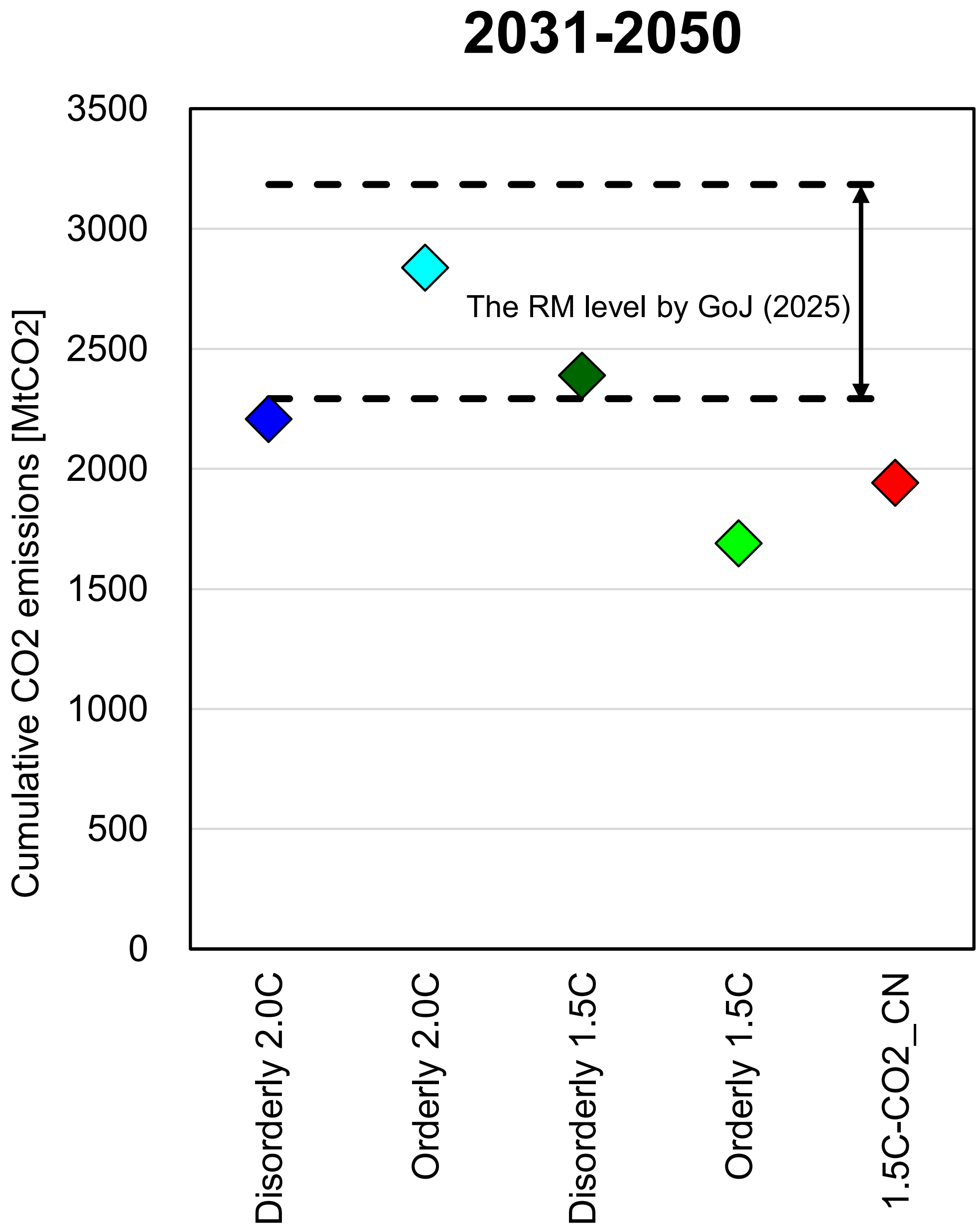



✓ **In Orderly 1.5°C, which assumes strict constraints on CCS, $CO_2$ emissions in 2050 would be reduced to almost zero because there is a small room for offsetting emissions through DACCS, etc.**

# $CO_2$ emissions in oil sector (Japan): comparison with the RM by GoJ

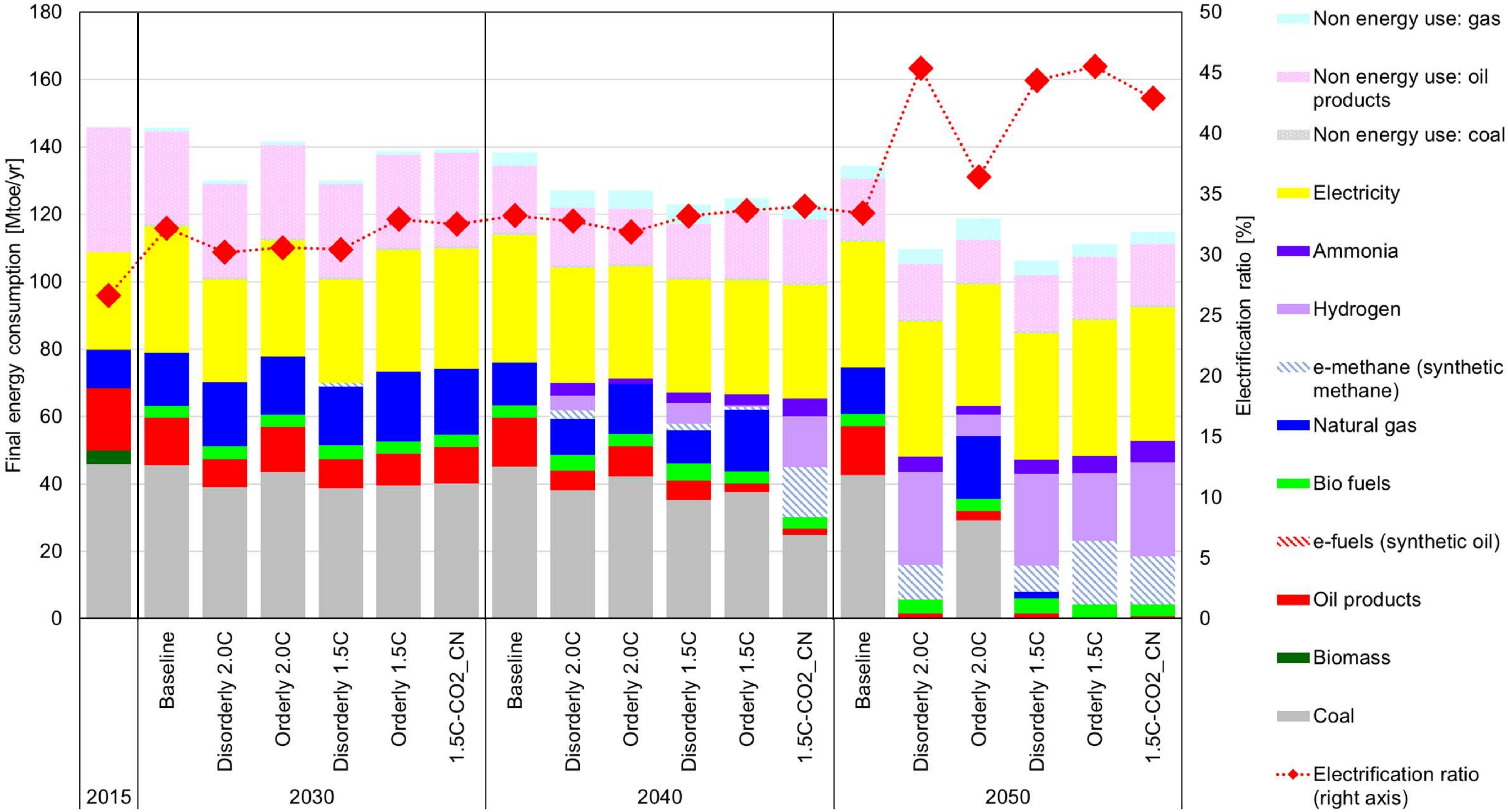




# Final energy consumption in industry (Japan)

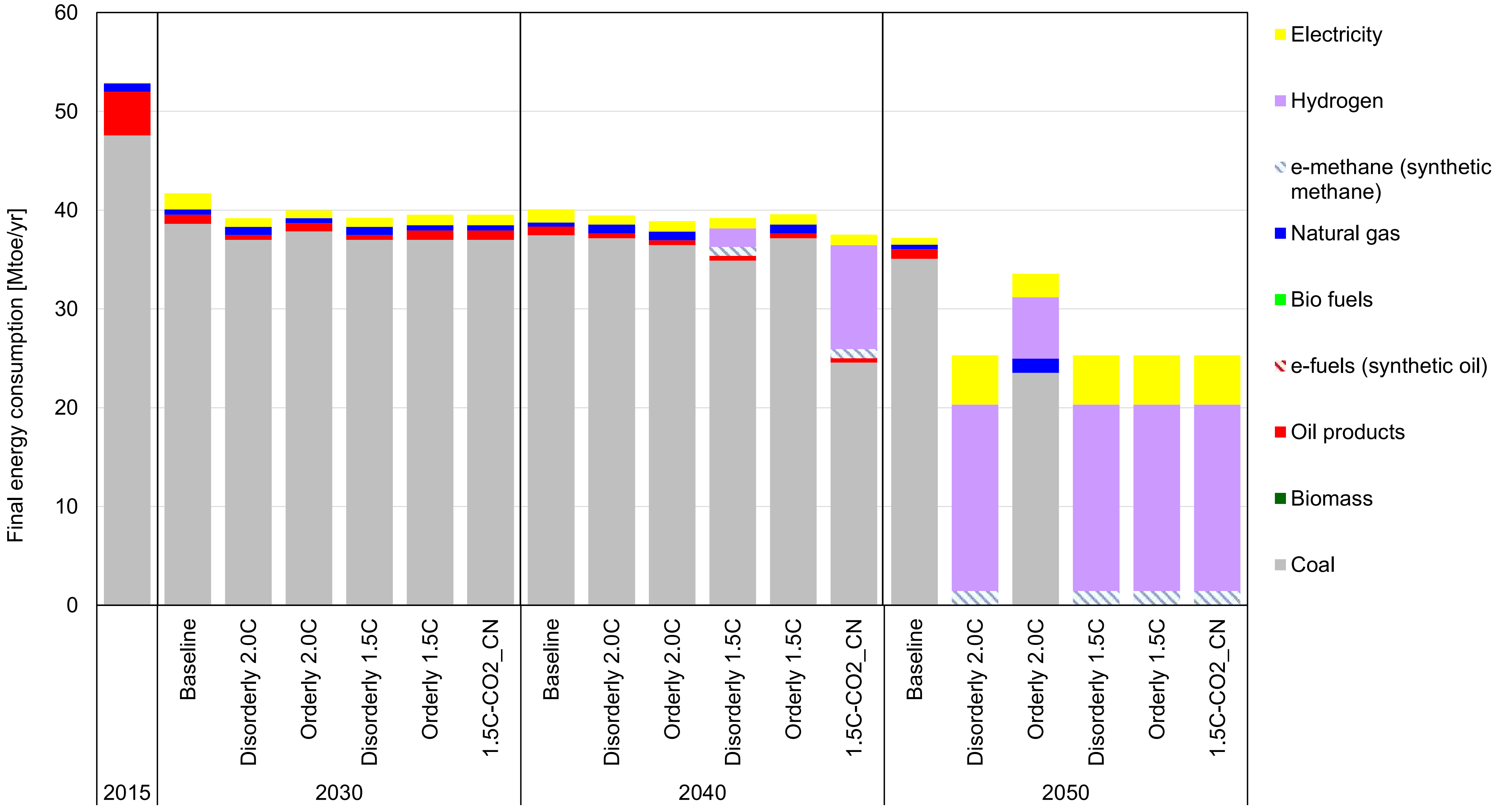





- ✓ Coal uses remain for BF-BOF in the iron and steel sector in 2040.
- ✓ In 2050, coal is not used, and the uses of hydrogen, ammonia, and synthetic methane are observed in the scenarios other than Orderly 2.0°C.

# Final energy consumption in iron & steel (Japan)

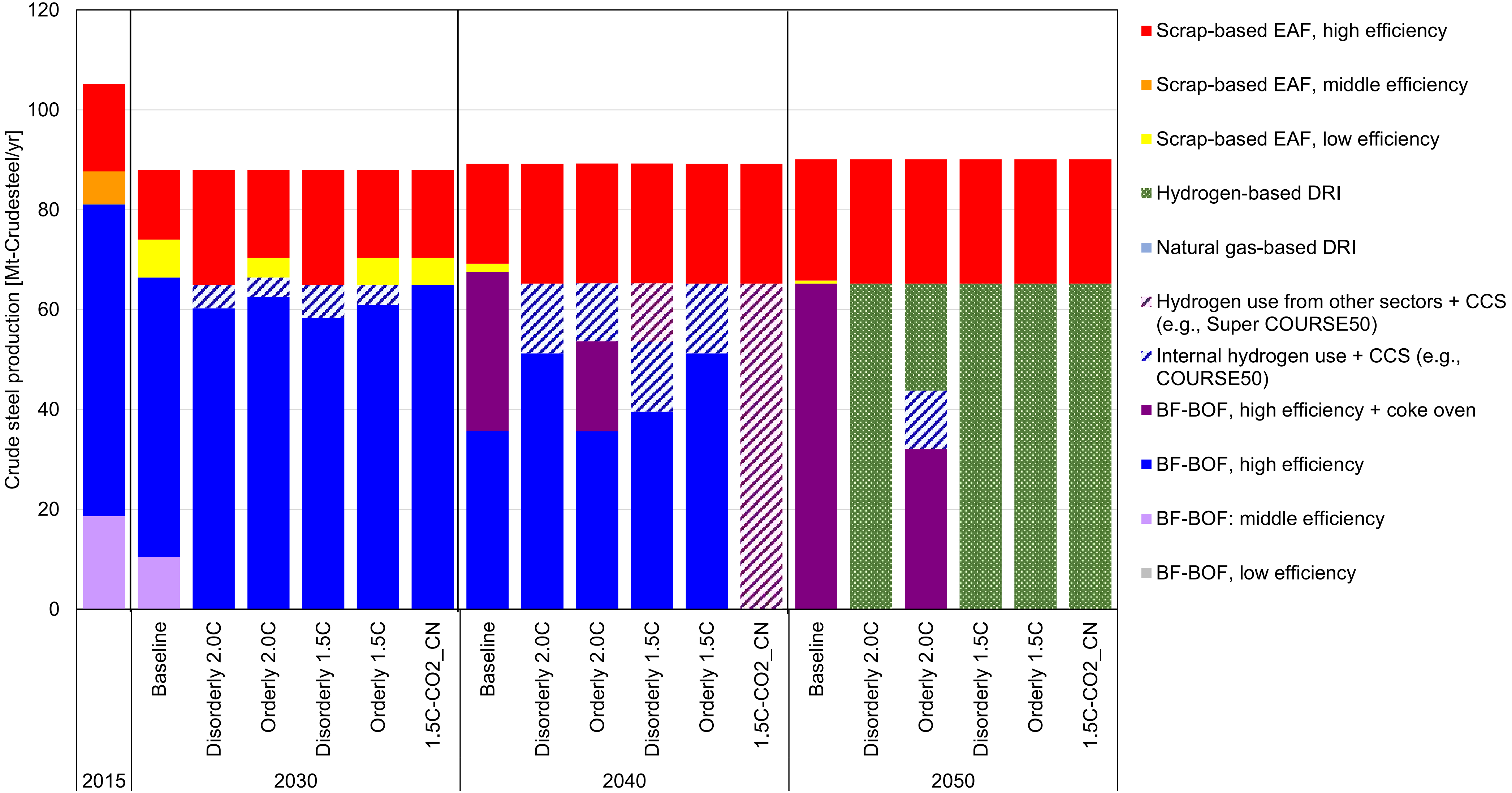





- ✓ Coal is used in BF-BOF in 2040. Hydrogen use from other sectors (Super COURSE50) is also observed.
- ✓ In 2050, coal is not used and replaced with hydrogen-based DRI in other scenarios than Orderly 2.0°C, in which total emission is predicted to be ▲63% relative to 2013. Synthetic methane is used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

# Steel production by technology (Japan)

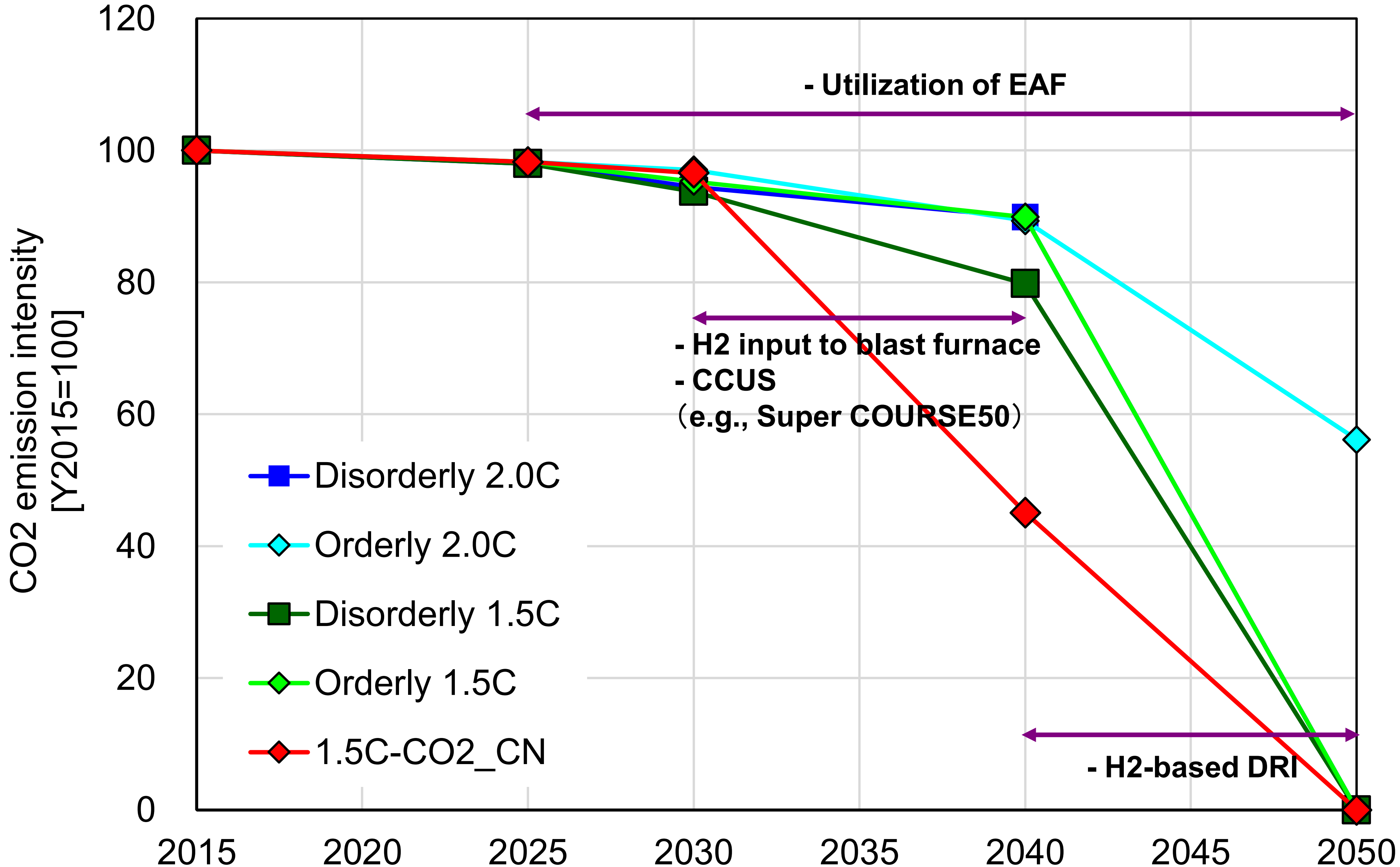





- ✓ **Up to 2040, CCS will play an important role.**
- ✓ **In 2050, hydrogen-based DRI will play a main role in iron and steel production processes.**
- ✓ **Under the 1.5C-$CO_2$_CN scenario, hydrogen use from other sectors in BF (e.g., Super COURSE50 like technologies) will be large.**

# $CO_2$ intensity of iron and steel sector (Japan)

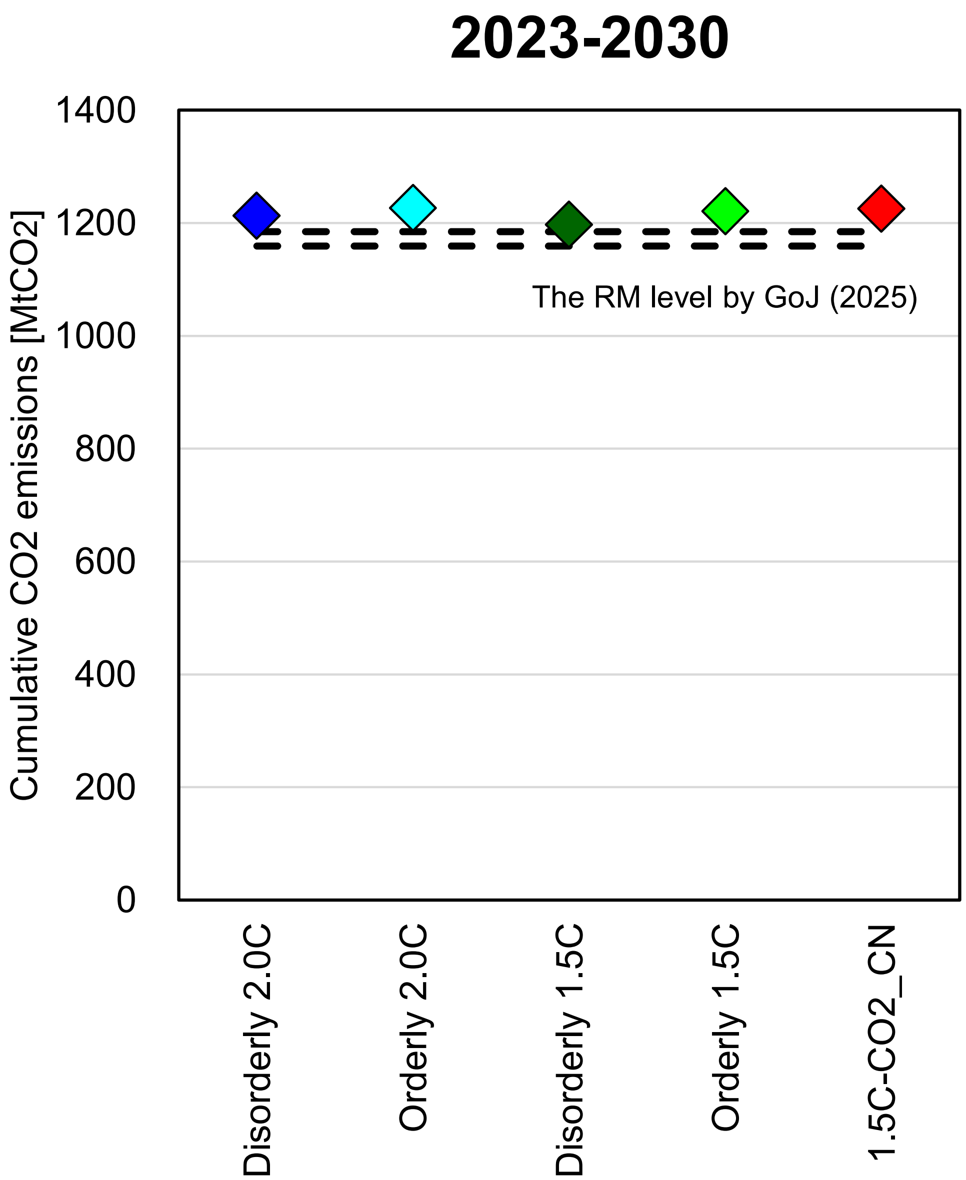


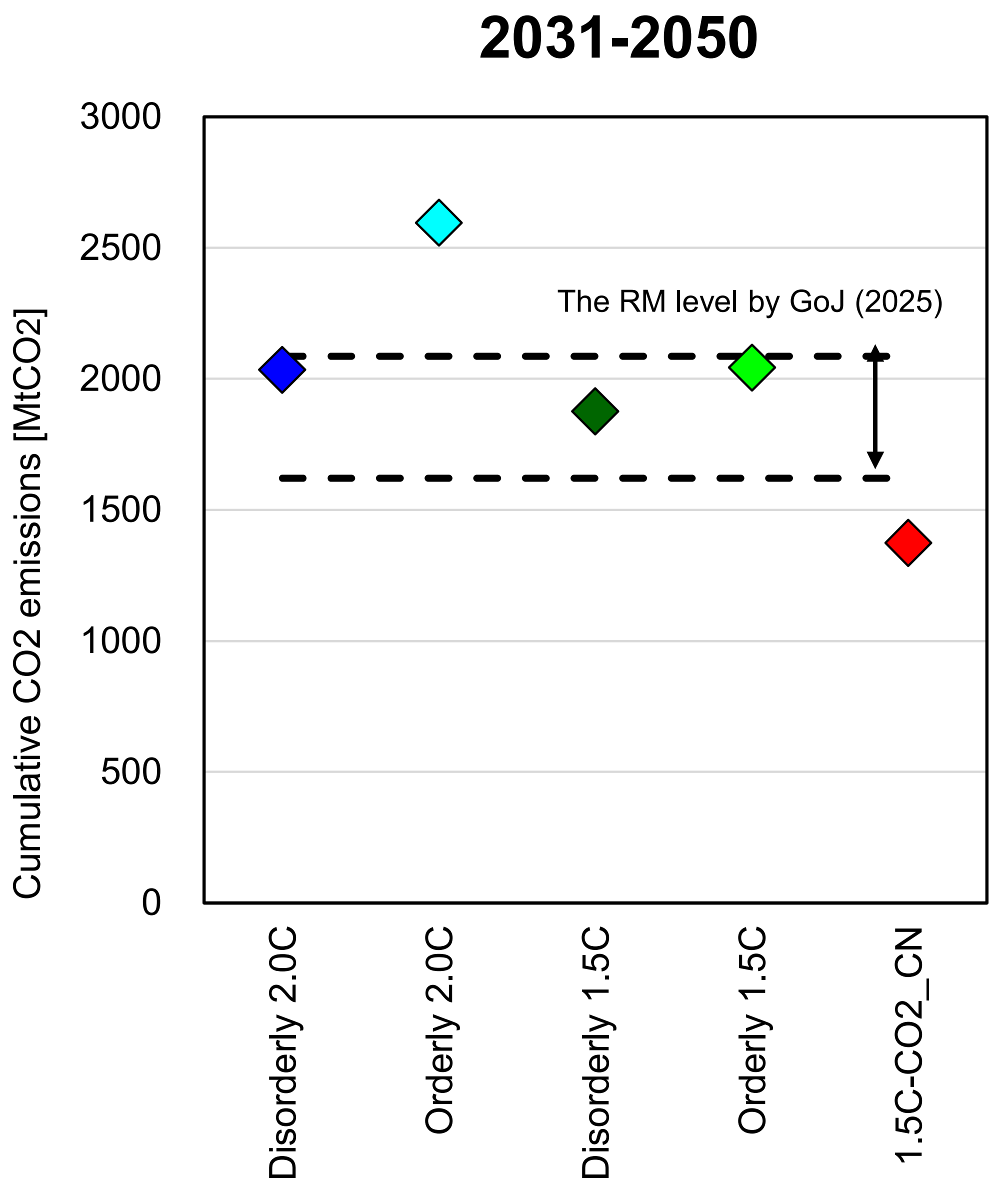



✓ In any scenarios, nearly zero emissions would be achieved in 2050 by CCUS and hydrogen input to BF after 2030, and by a shift to hydrogen-based DRI after 2040. However, a part of emissions remains in 2050 in Orderly 2.0°C.

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

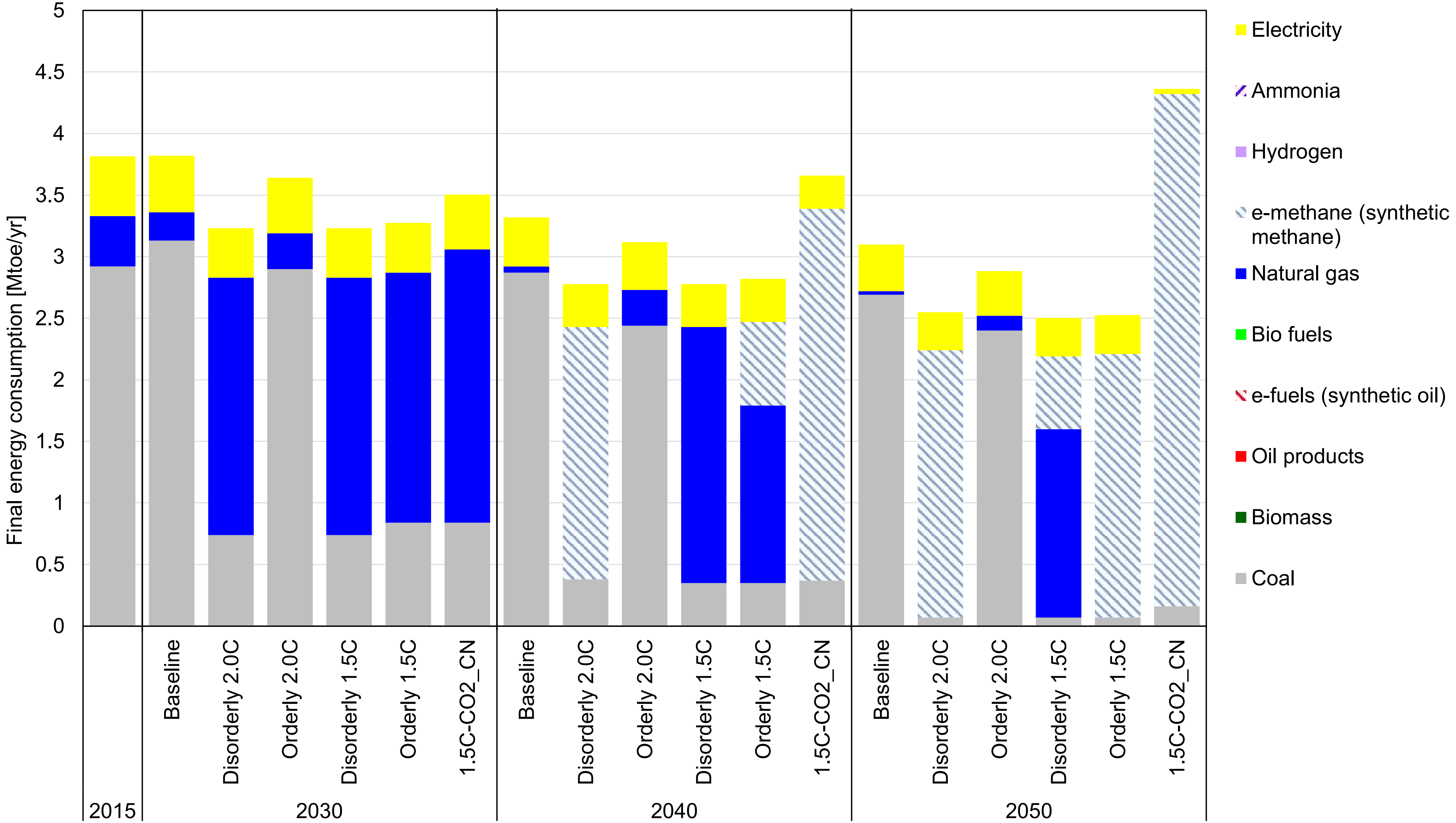




# Final energy consumption in cement (Japan)

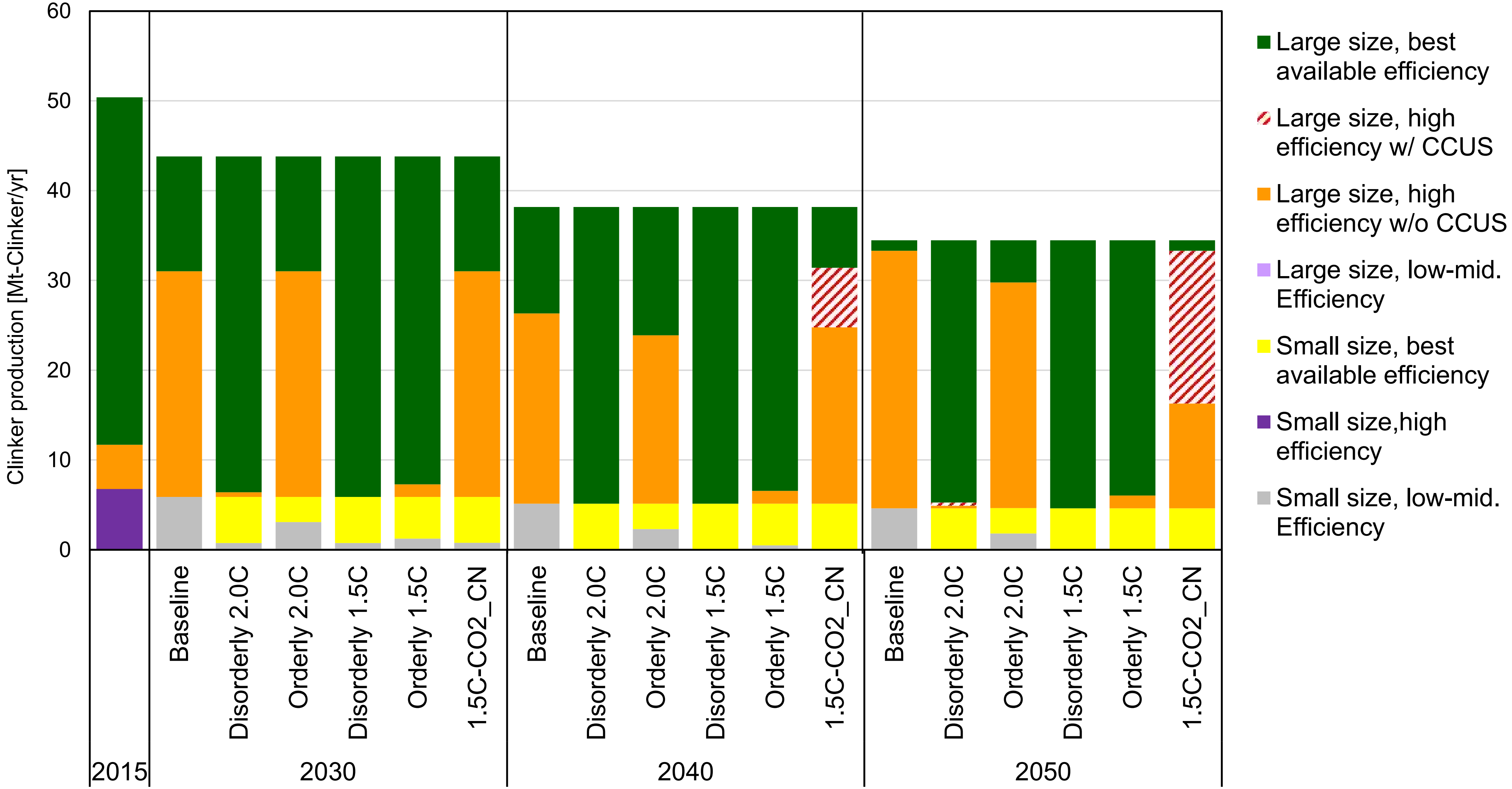





- ✓ **A shift from coal to gas is cost-effective in 2030 except Orderly 2.0°C.**
- ✓ **A further shift to gas is promoted toward 2040, and synthetic methane is evaluated to be cost-effective around 2050 in the scenarios which assume CN in Japan.**

# Clinker production by technology in cement sector (Japan)

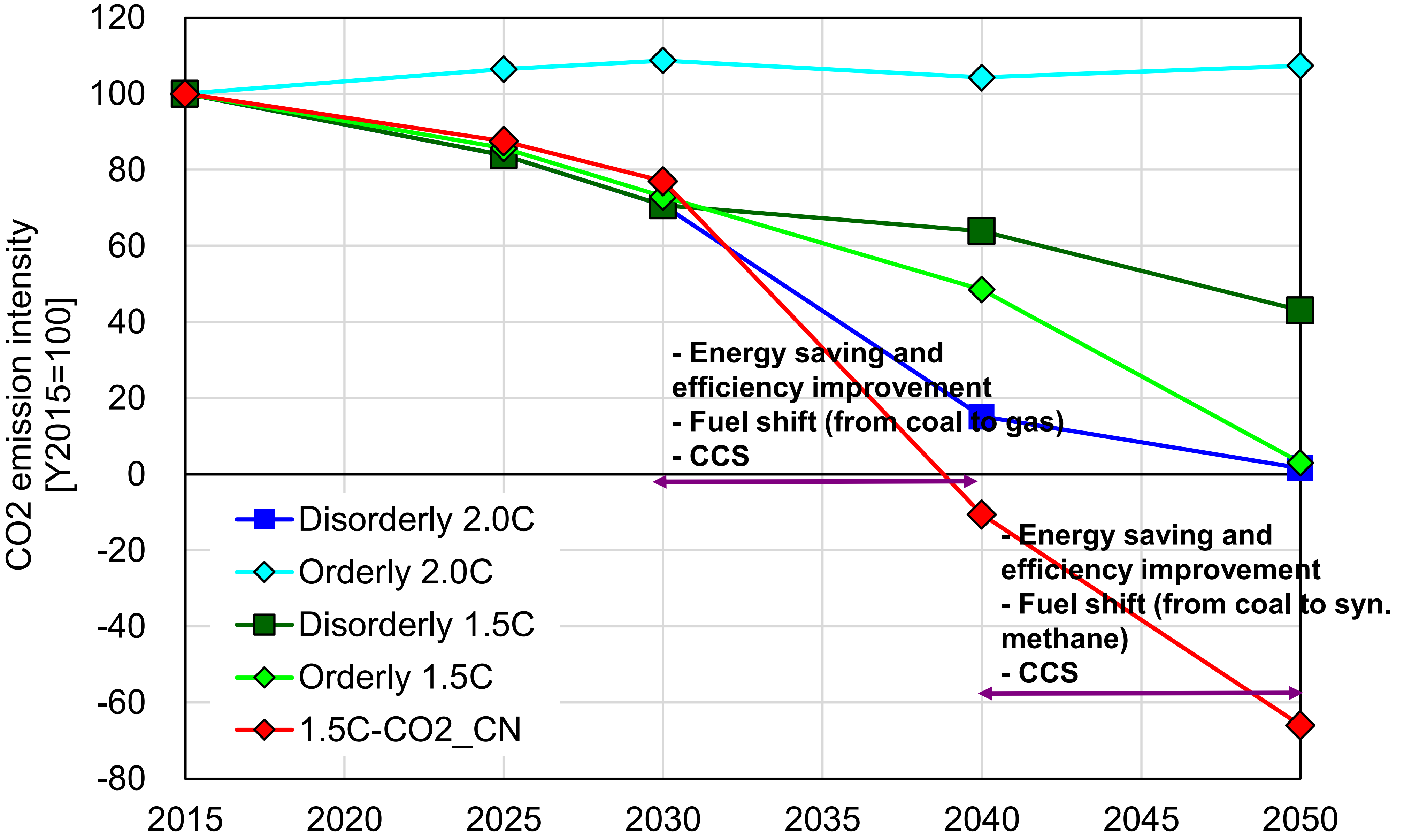





- ✓ **$CO_2$ capture in clinker production is not selected as a cost-effective measure in Japan in other scenarios than 1.5C-$CO_2$_CN. Some possible reasons are that CCS cost is relatively high in the cement sector and that negative emission measures, such as DACCS, are prioritized due to the constraint on overall $CO_2$ storage potential.**
- ✓ **On the other hand, $CO_2$ capture is also introduced in large size production facility in 1.5C-$CO_2$_CN.**

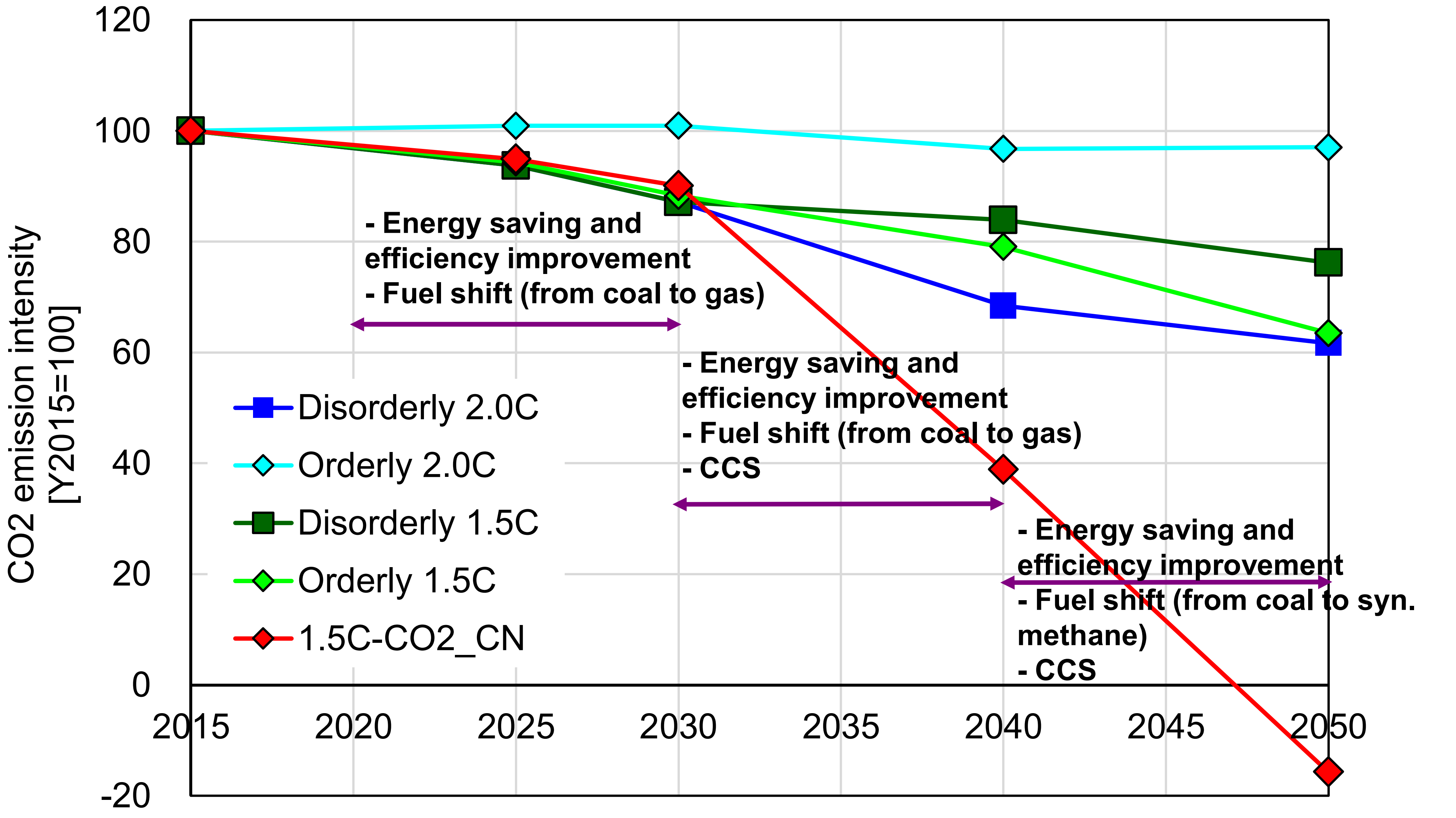
# Energy-related $CO_2$ intensity of cement sector (Japan)





# $CO_2$ intensity of cement sector (Japan)

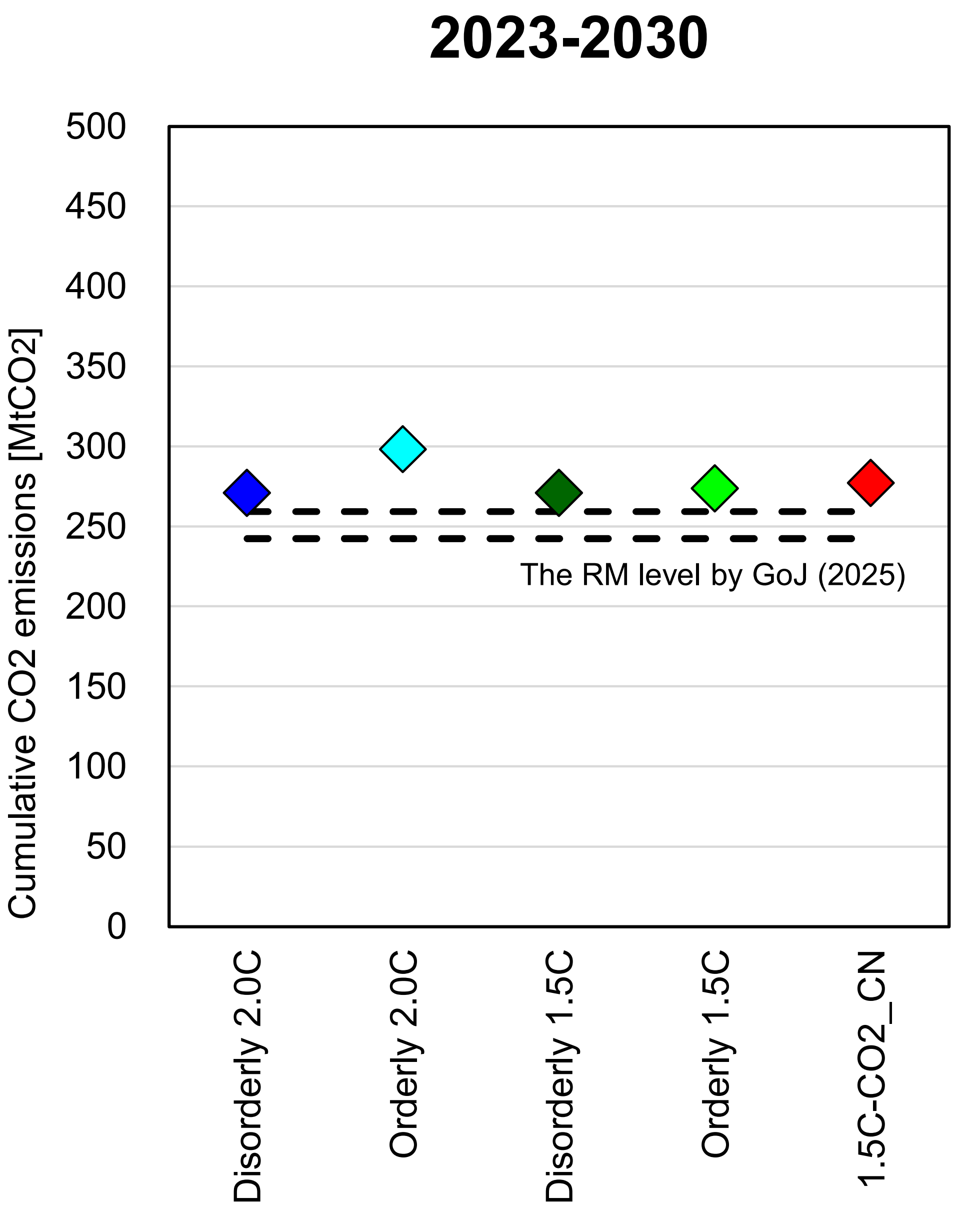


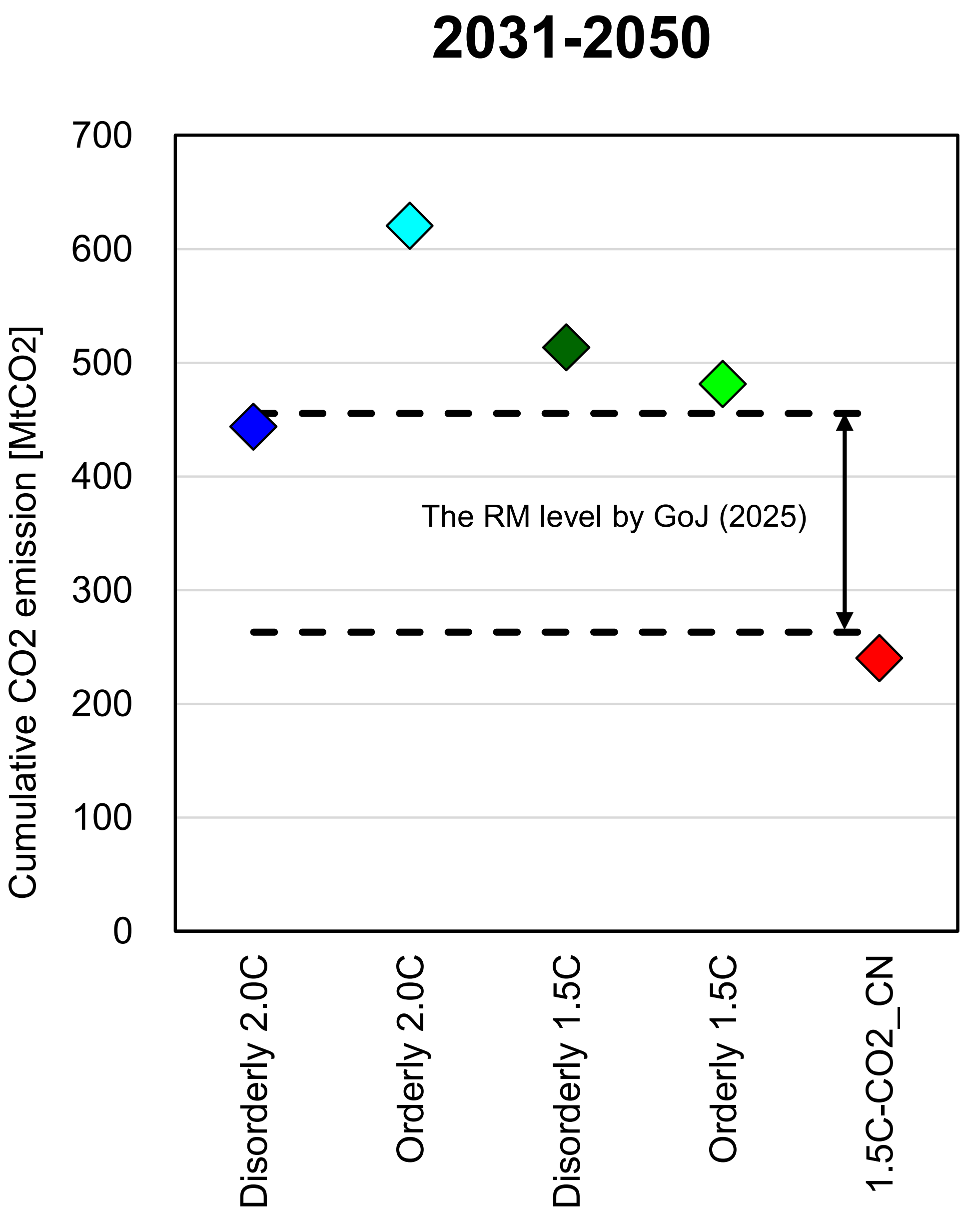



- ✓ In other scenarios than 1.5C-$CO_2$_CN, emissions from processes still remain in 2050 as there is no CCS deployment.
- ✓ In 1.5C-$CO_2$_CN, CN is achieved by the introduction of synthetic methane+CCS.

# $CO_2$ emissions in cement sector (Japan): comparison with the RM by GoJ

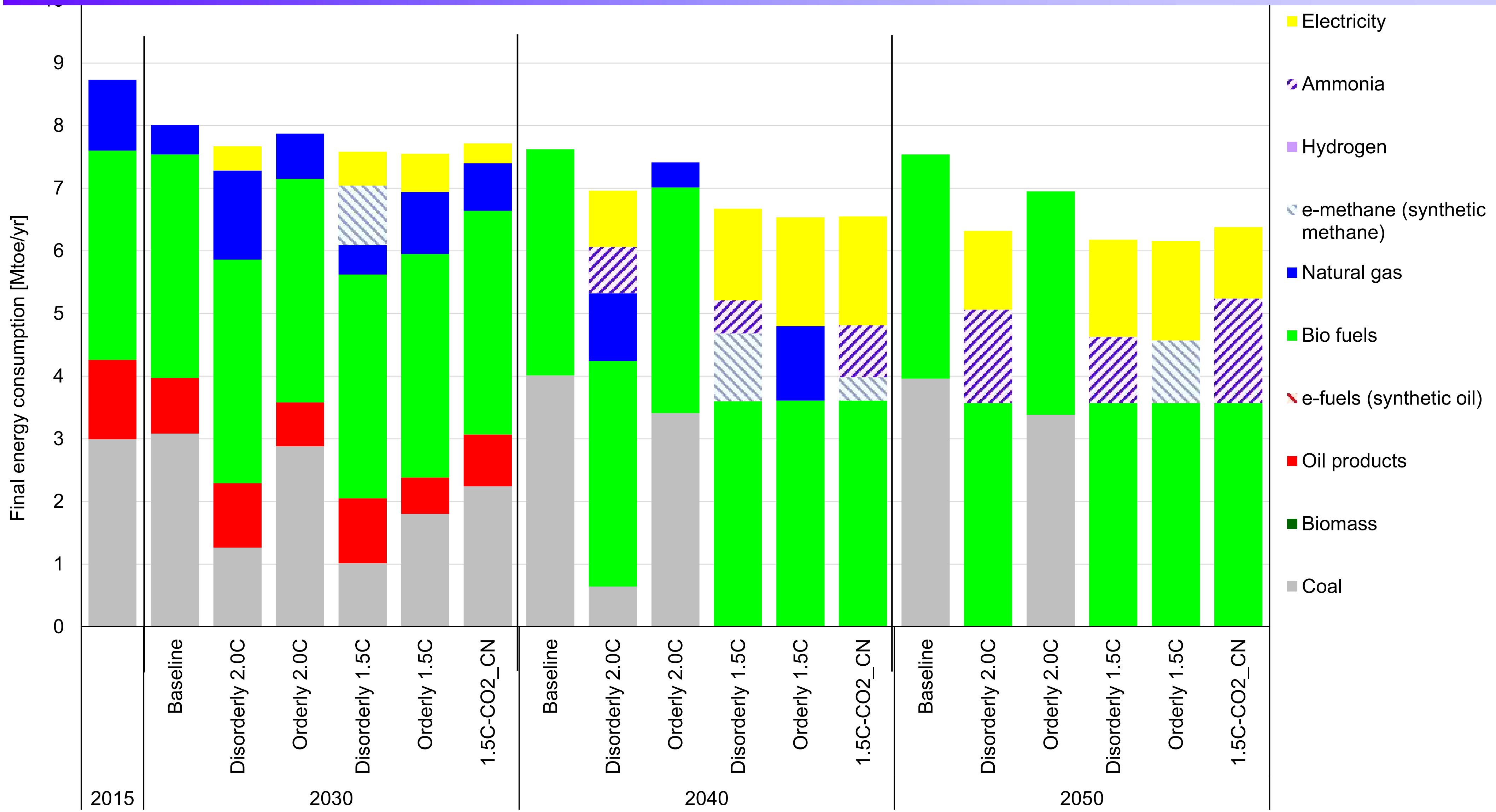




# Final energy consumption in paper & pulp (Japan)



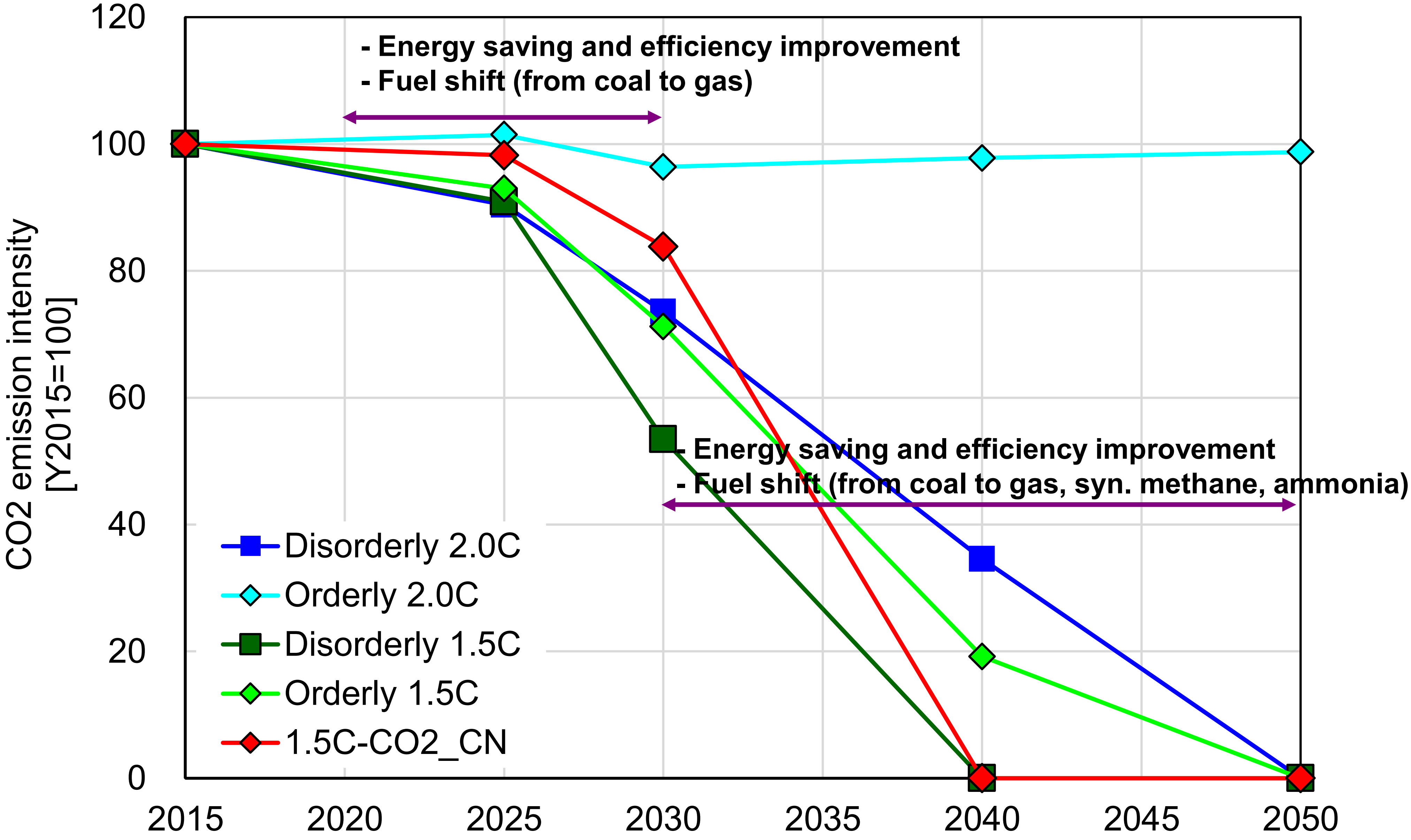



Note) Black liquor use is included in biofuels consumption.

- ✓ **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.**

# $CO_2$ intensity of paper & pulp sector (Japan)

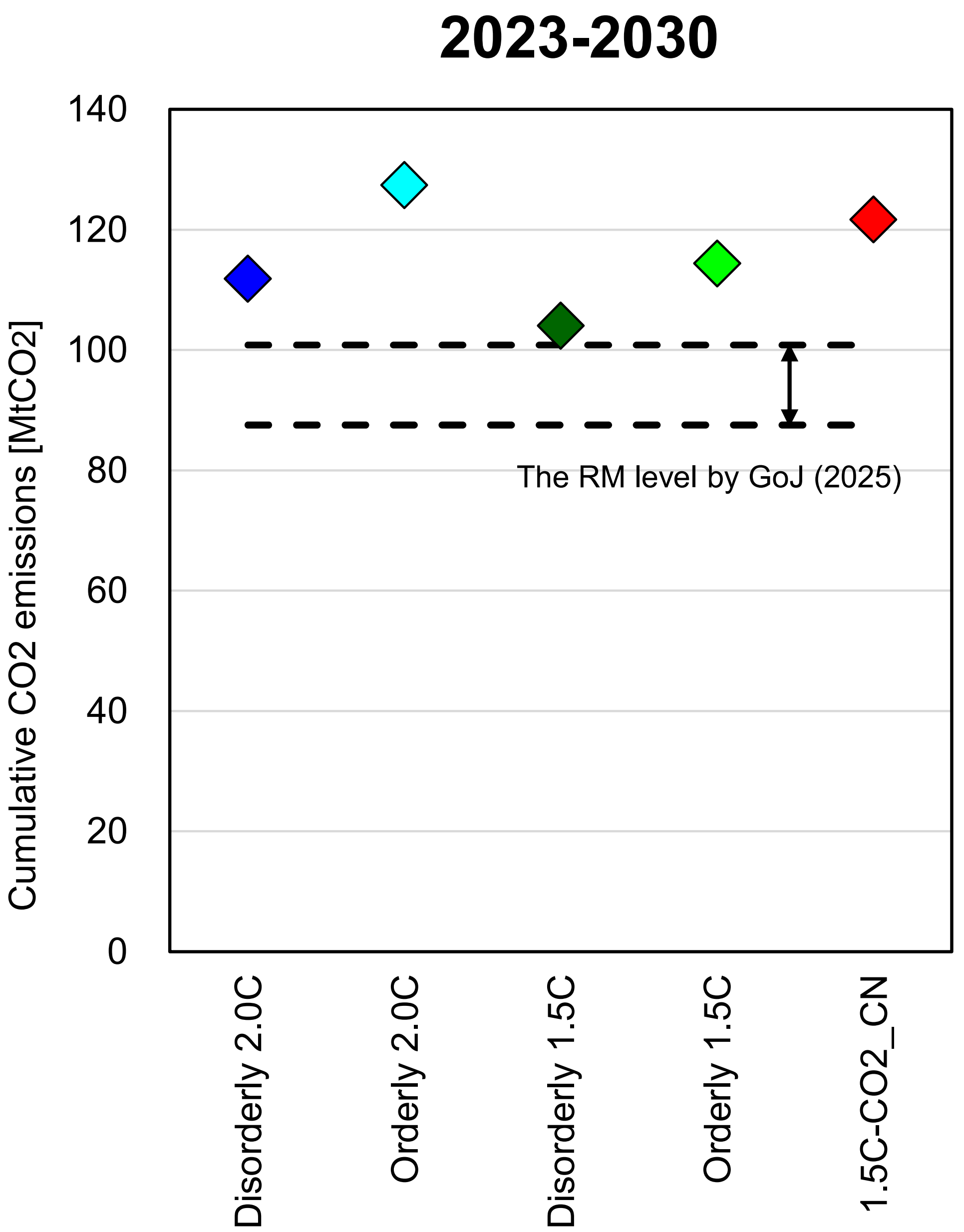


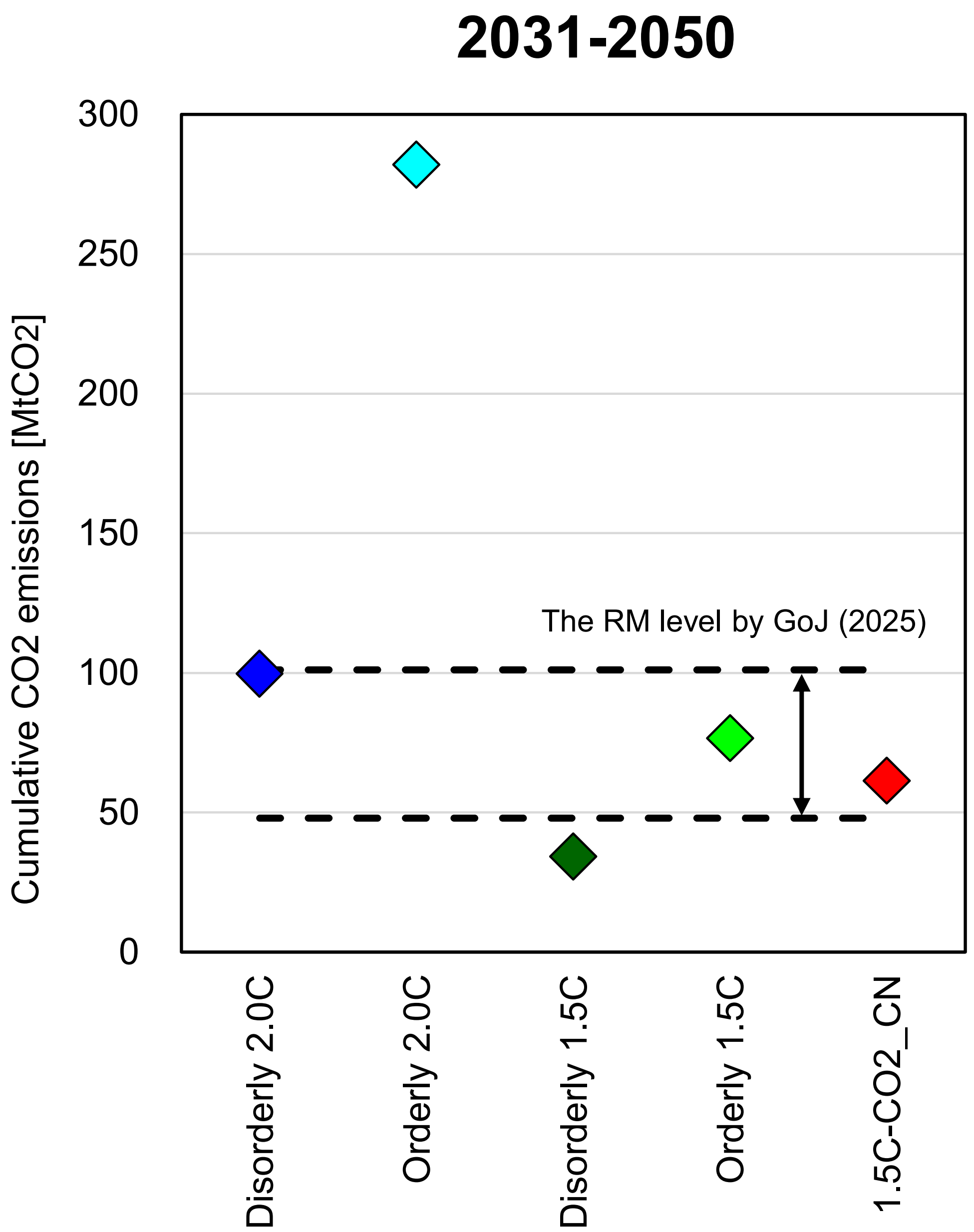



- ✓ A certain amounts of emissions remains in Orderly 2.0°C, where emissions reduction is modest.
- ✓ In other scenarios, zero emission is achieved in 2050 by the introduction of synthetic methane or ammonia.

# $CO_2$ emissions in paper & pulp sector (Japan): comparison with the RM by GoJ

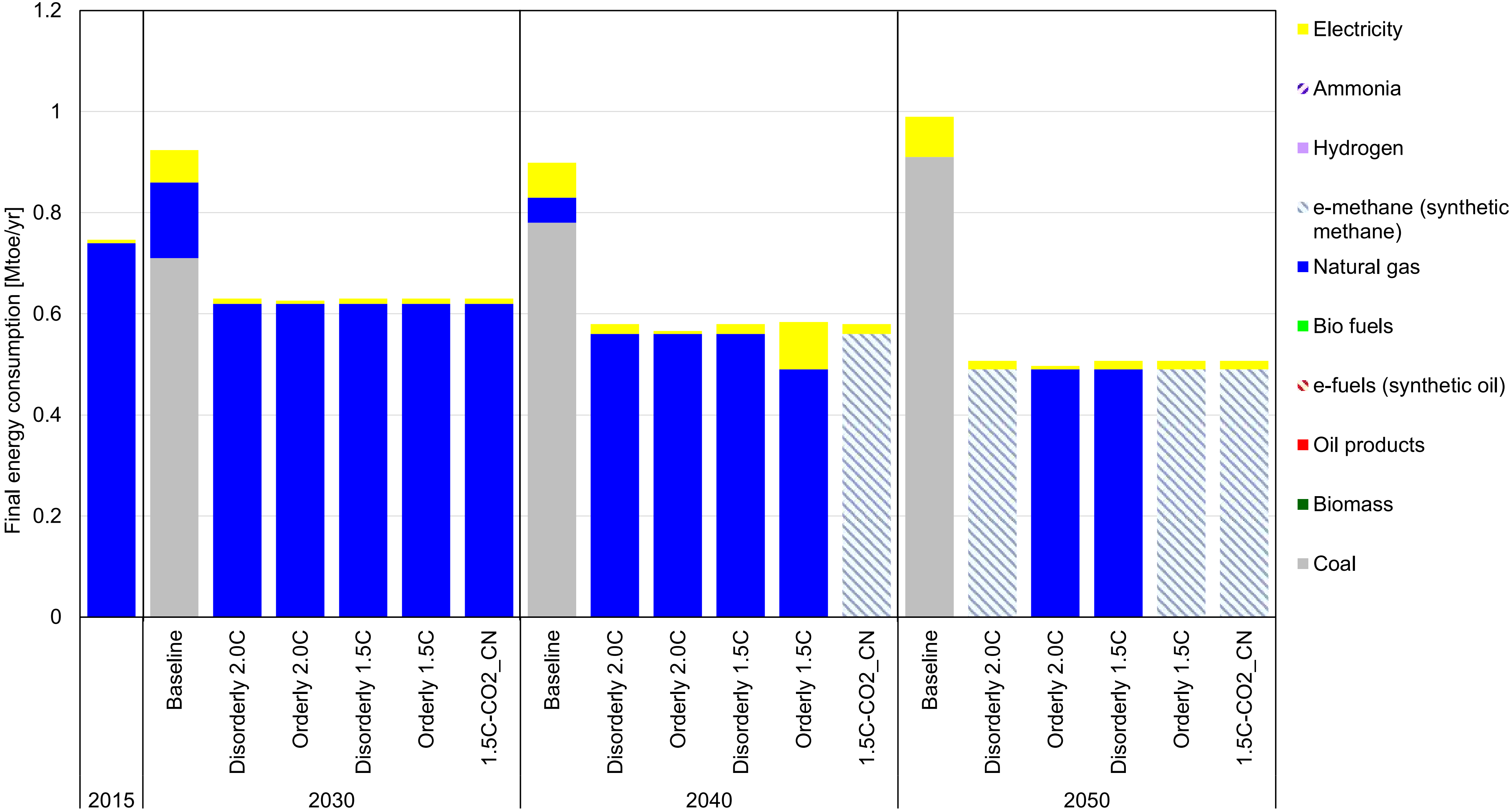




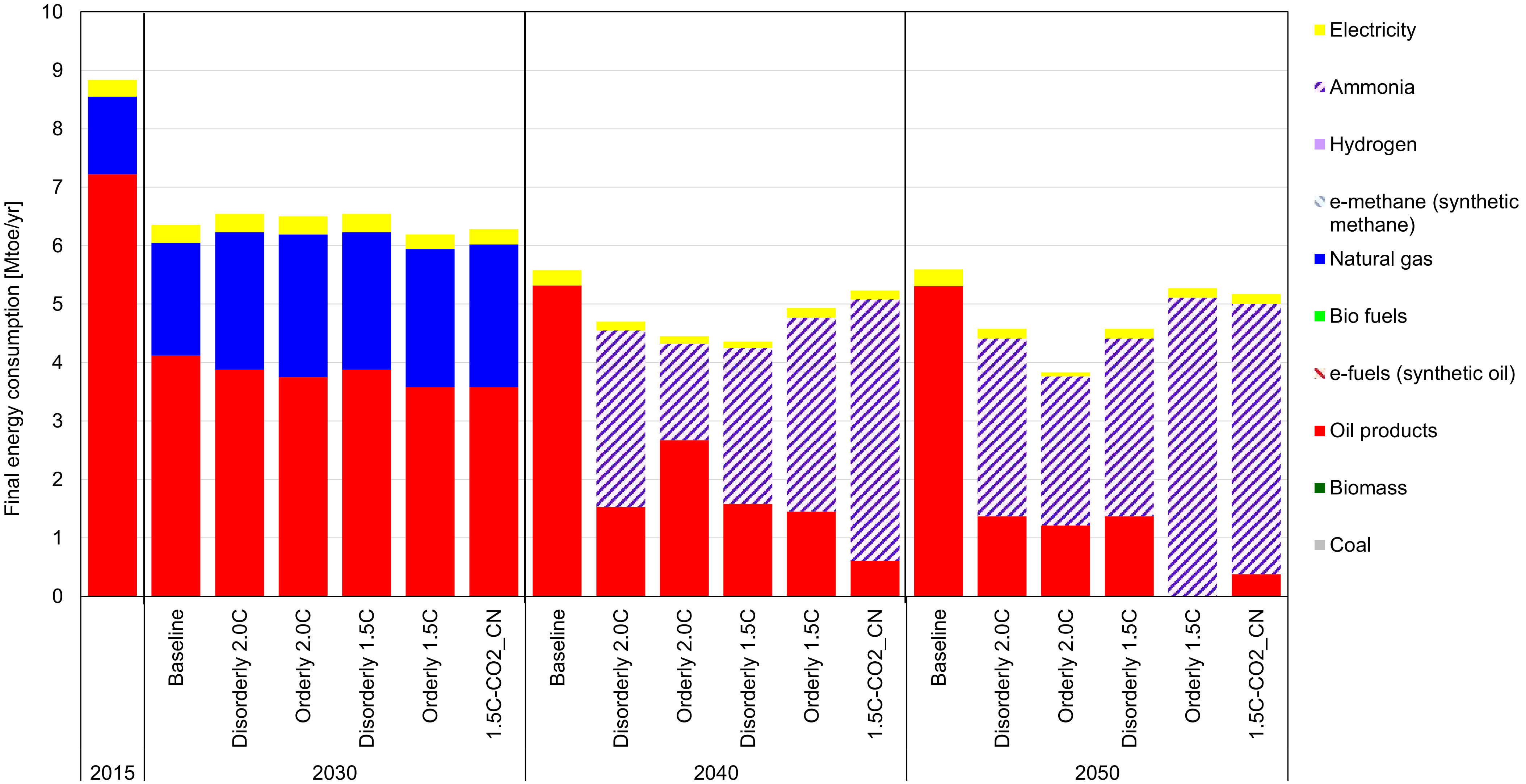
# Final energy consumption in ammonia productions of chemical sector (Japan)





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



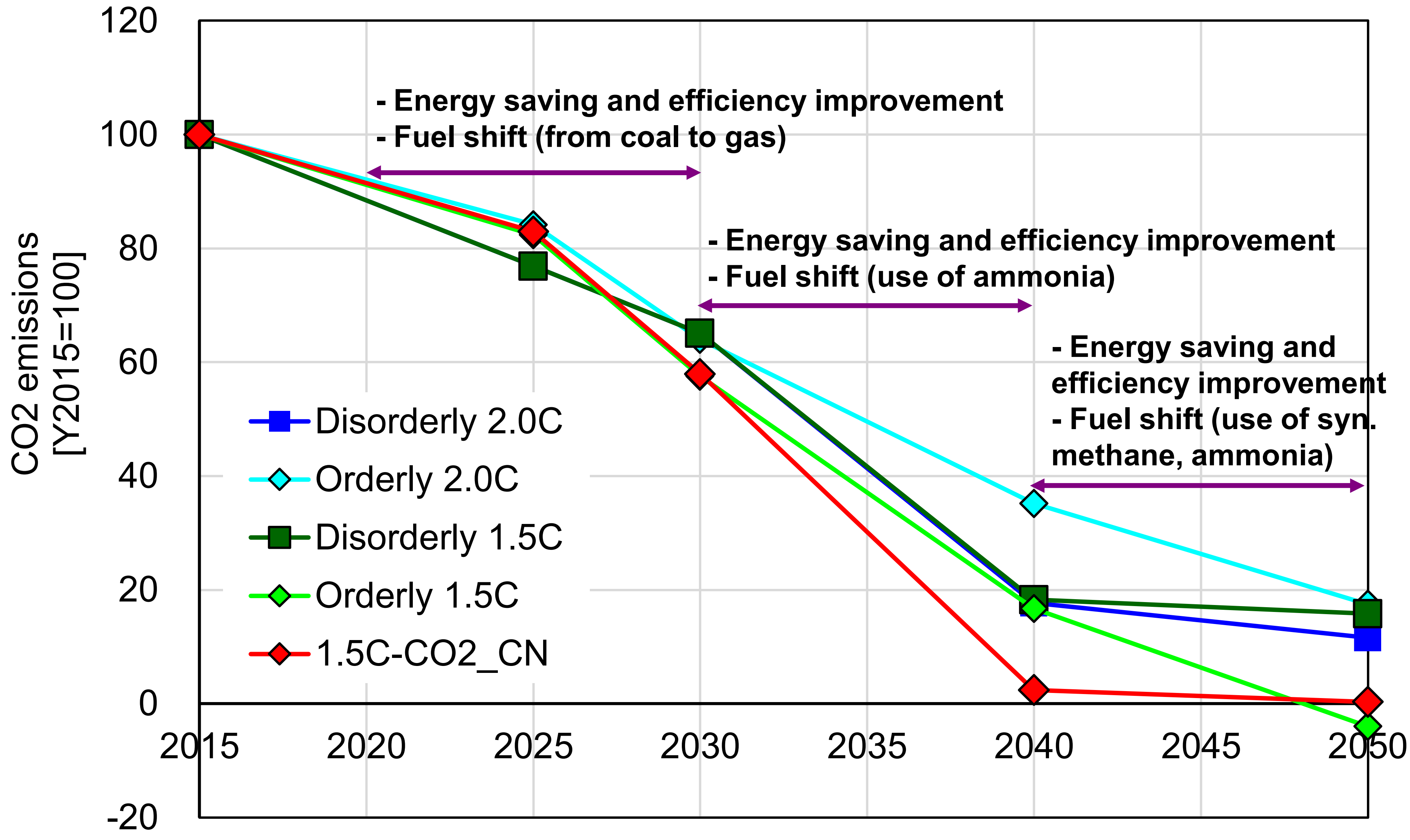



Note) The graph shows only energy usage consumption, and energy for raw material is not included.

✓ **The use of ammonia expands in 2040 and 2050.**

# $CO_2$ emissions in chemical sector (Japan)

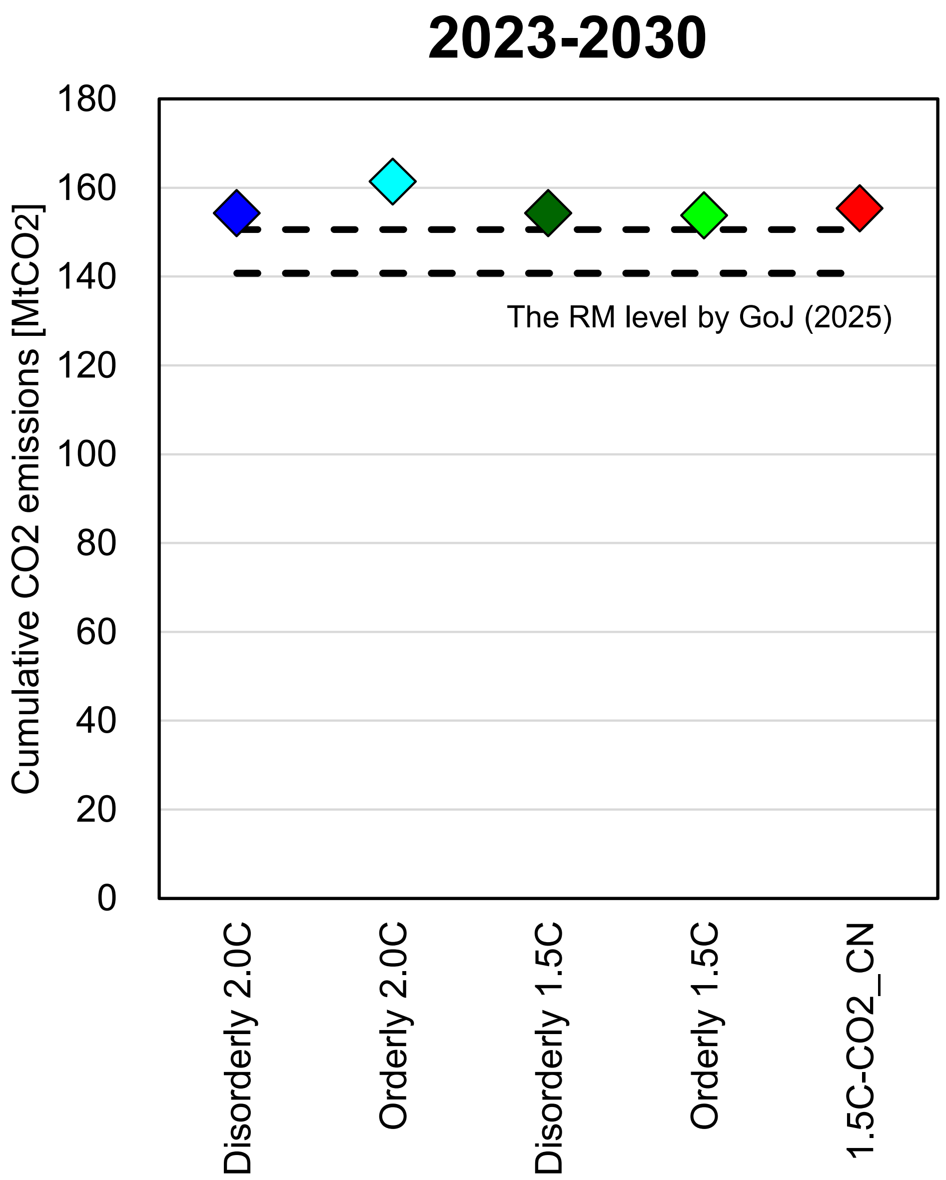


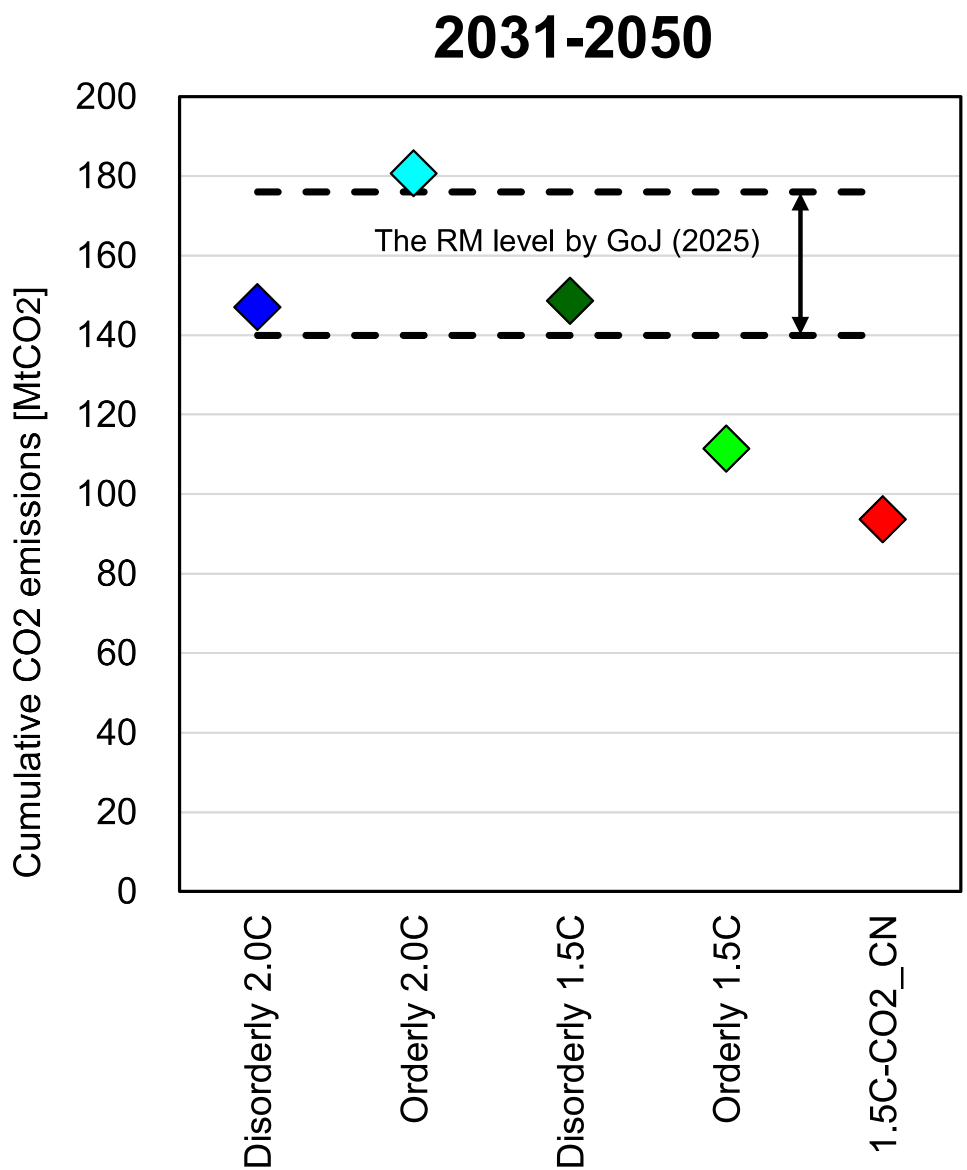



✓ **Emissions reduction is progressed by use of ammonia and synthetic methane and electrification.**

# $CO_2$ emissions in chemical sector (Japan): comparison with the RM by GoJ

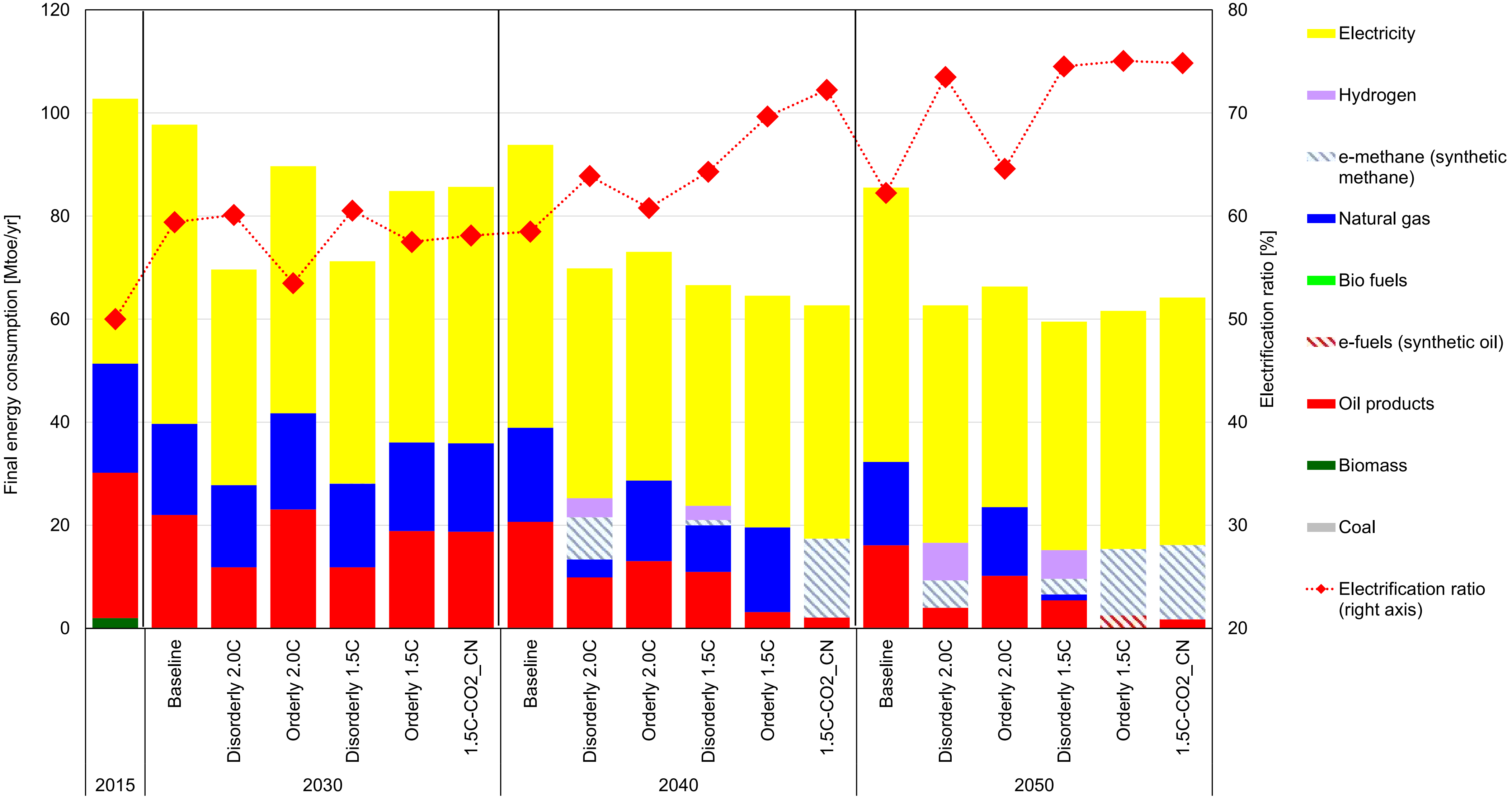




# Final energy consumption in building (Japan)

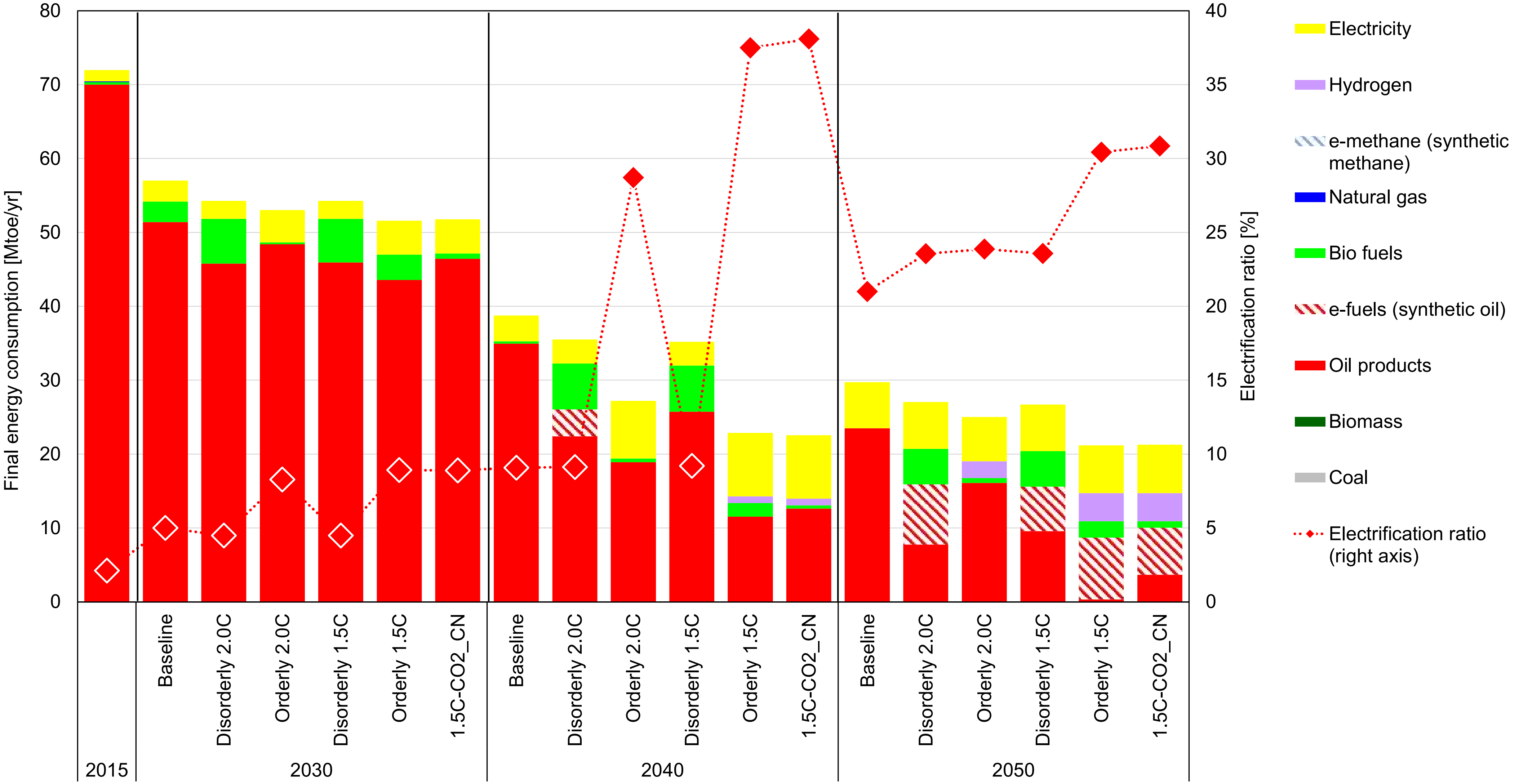





- ✓ **The improvement of electrification ratio is cost-effective as emissions reduction is stricter.**
- ✓ **In Orderly 2.0°C, natural gas remains even in in 2050. It is replaced with synthetic methane in other scenarios.**

# Final energy consumption in transport (Japan)

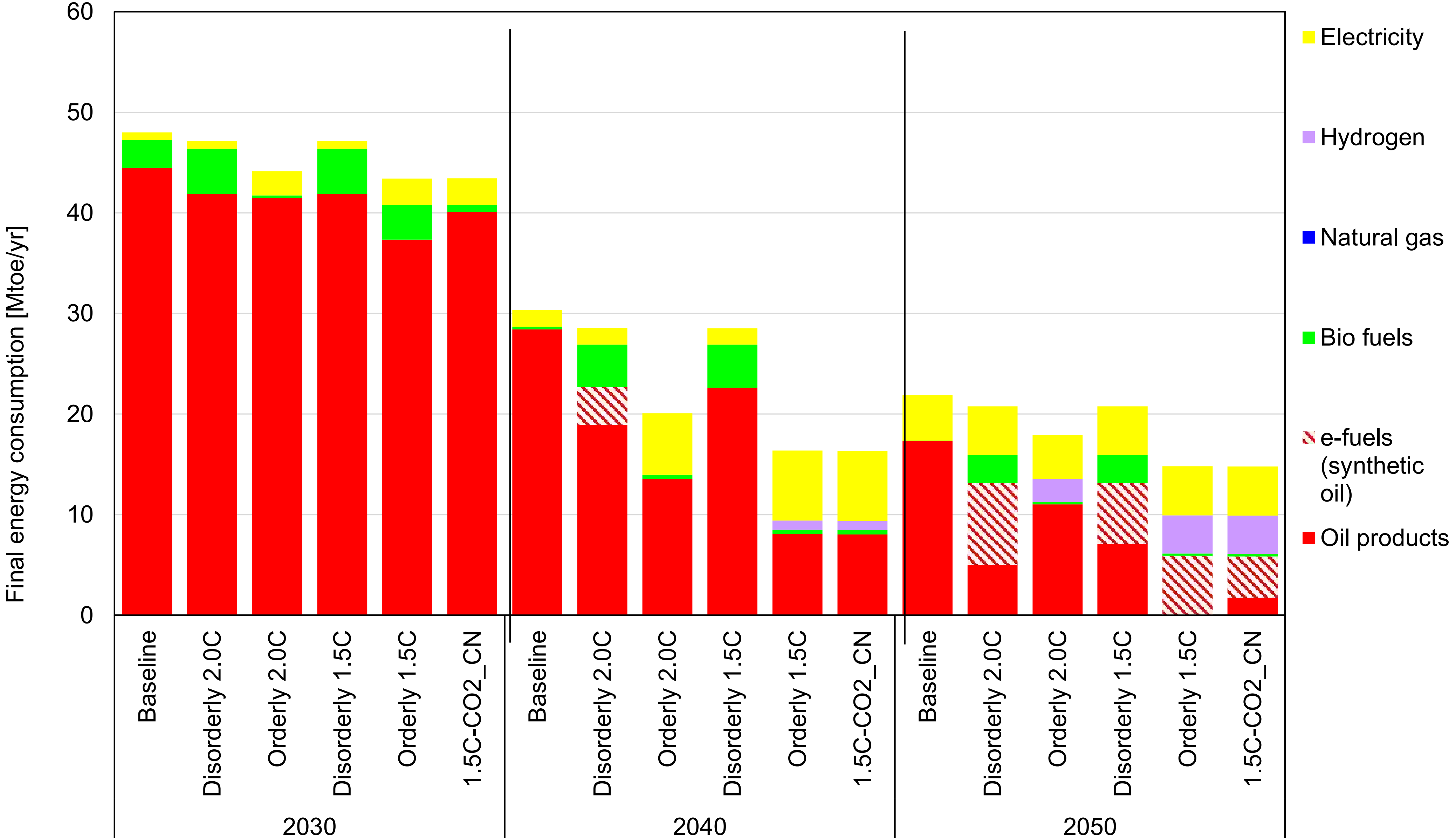





- ✓ Oil remains to some extent even in 2050 in the scenarios other than Orderly 1.5°C.
- ✓ The uses of hydrogen and synthetic fuels, etc. are observed after around 2040 toward 2050.

# Final energy consumption in road transport (Japan)



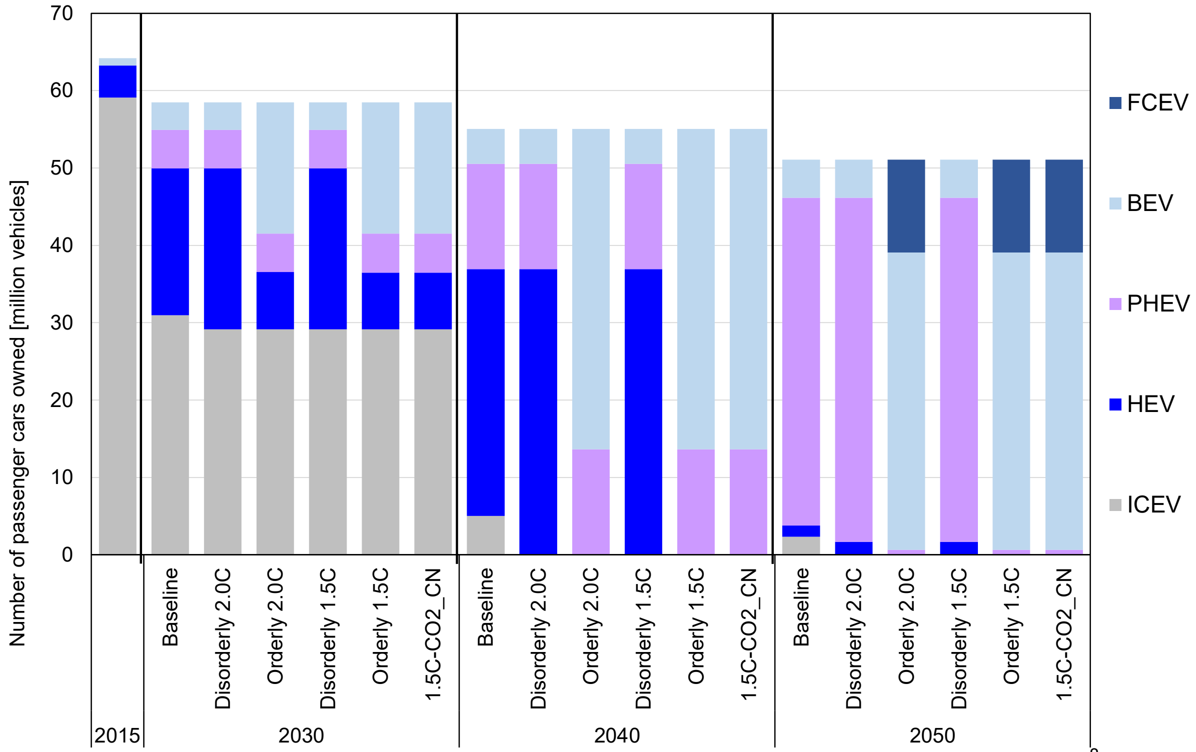



- ✓ **Electricity notably increases from around 2040 in Orderly scenarios, which assume significant cost reduction in renewables and EV.**
- ✓ **Synthetic fuels are also used in 2050. Almost all passenger cars would be BEV, and synthetic fuels are used mainly for trucks in Orderly 1.5°C.**

# Number of vehicles owned (Japan)

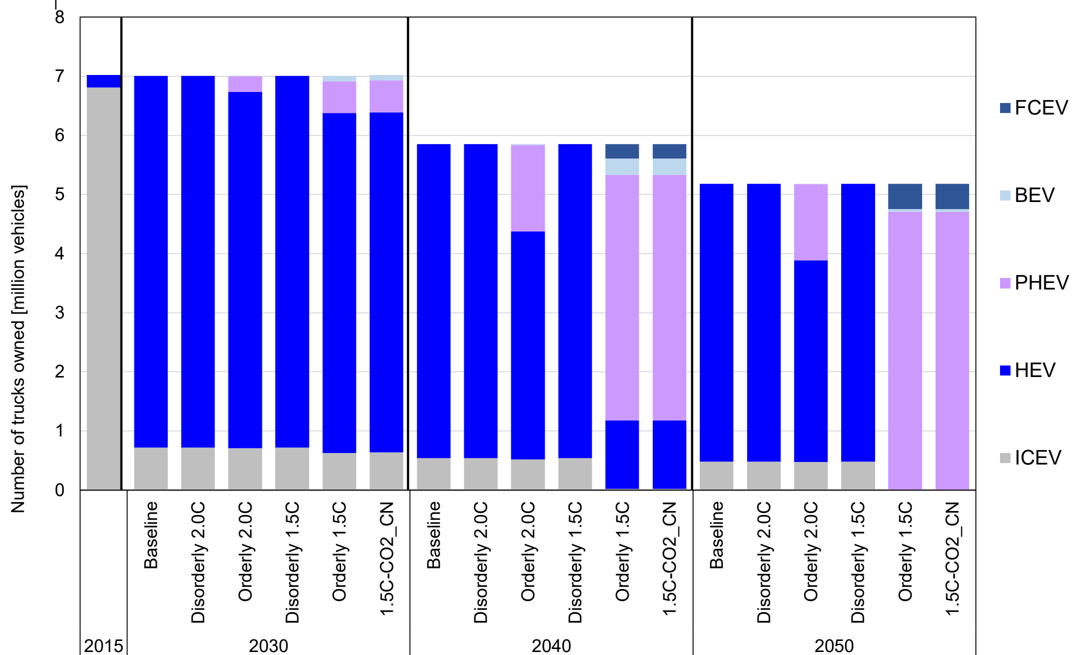


## Passenger cars




- ✓ 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.

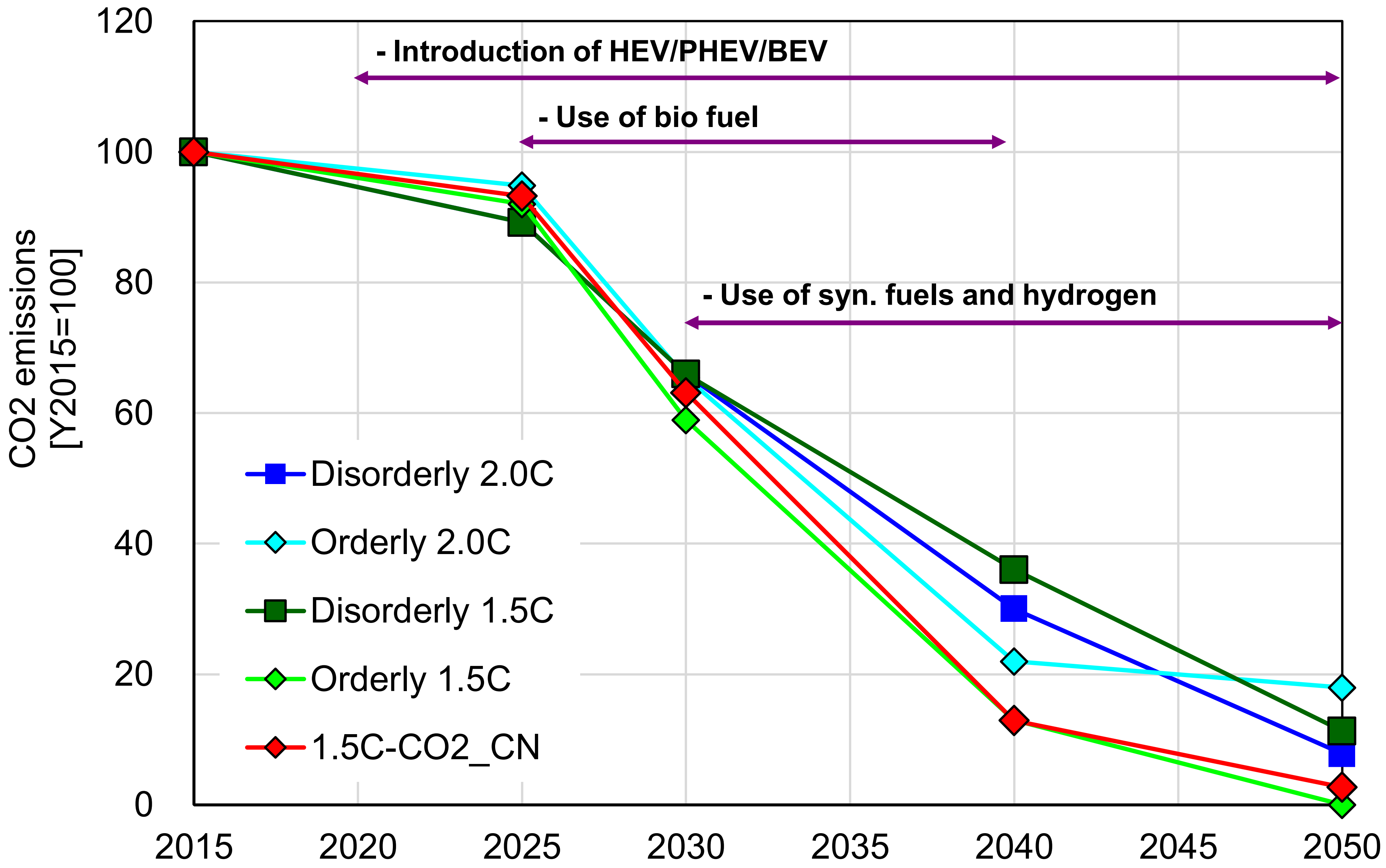
## Trucks




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

# $CO_2$ emissions in road transport (Japan)



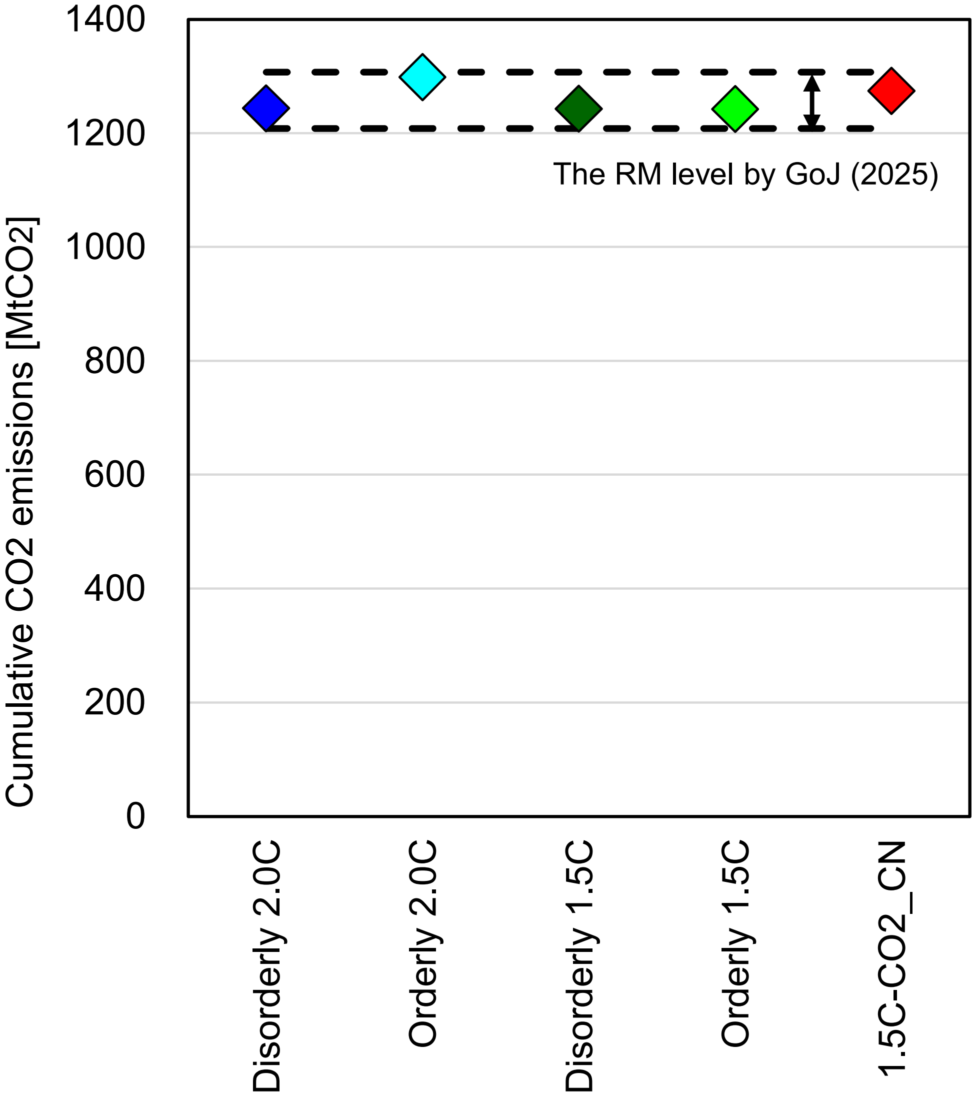



- ✓ Continuous $CO_2$ emissions reduction is expected due to the enlarged introduction of HEV/PHEV/BEV.
- ✓ The use of hydrogen and synthetic fuels is expected from around 2040.

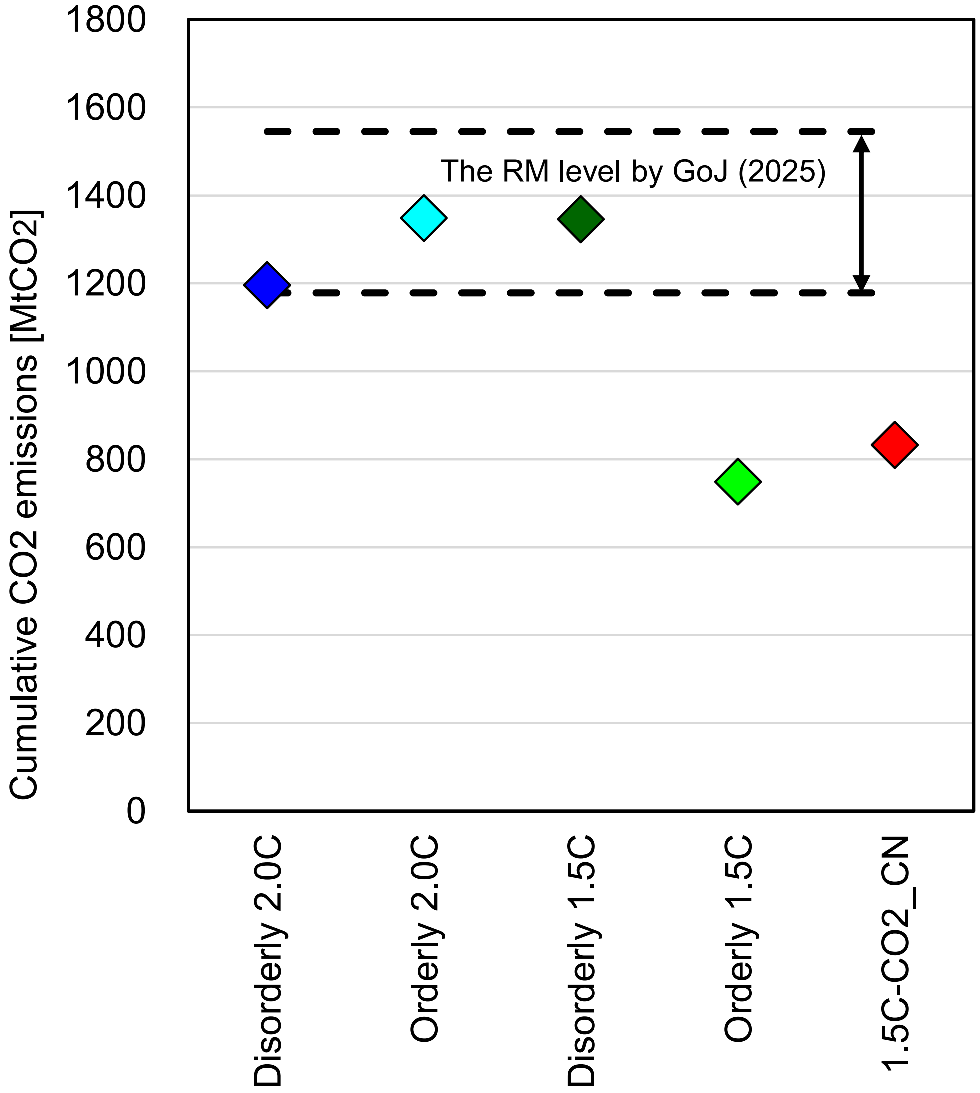
# $CO_2$ emissions in road transport sector (Japan): comparison with the RM by GoJ



## 2023-2030



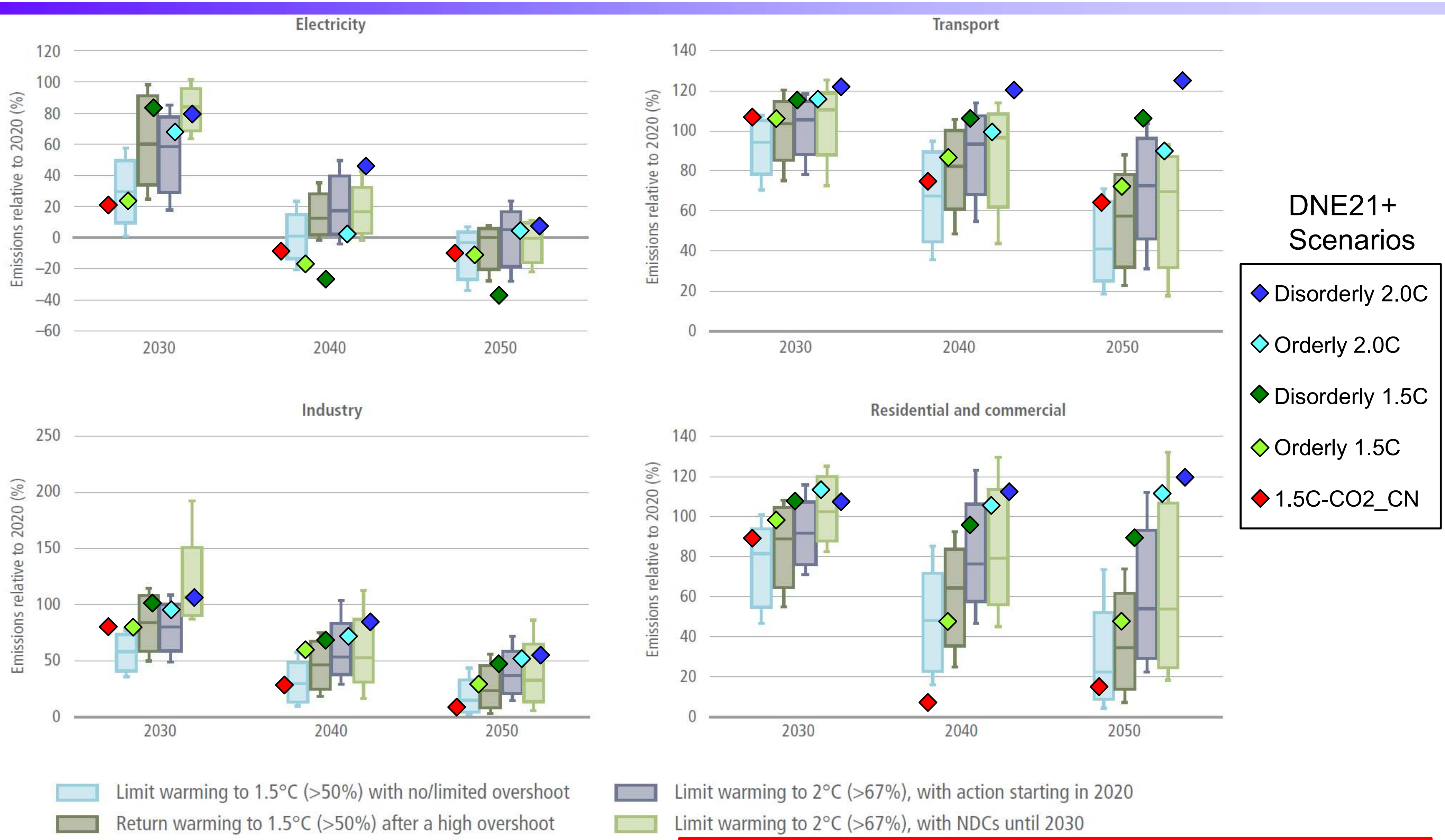

## 2031-2050



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

# Comparison with global $CO_2$ emission scenarios of IPCC



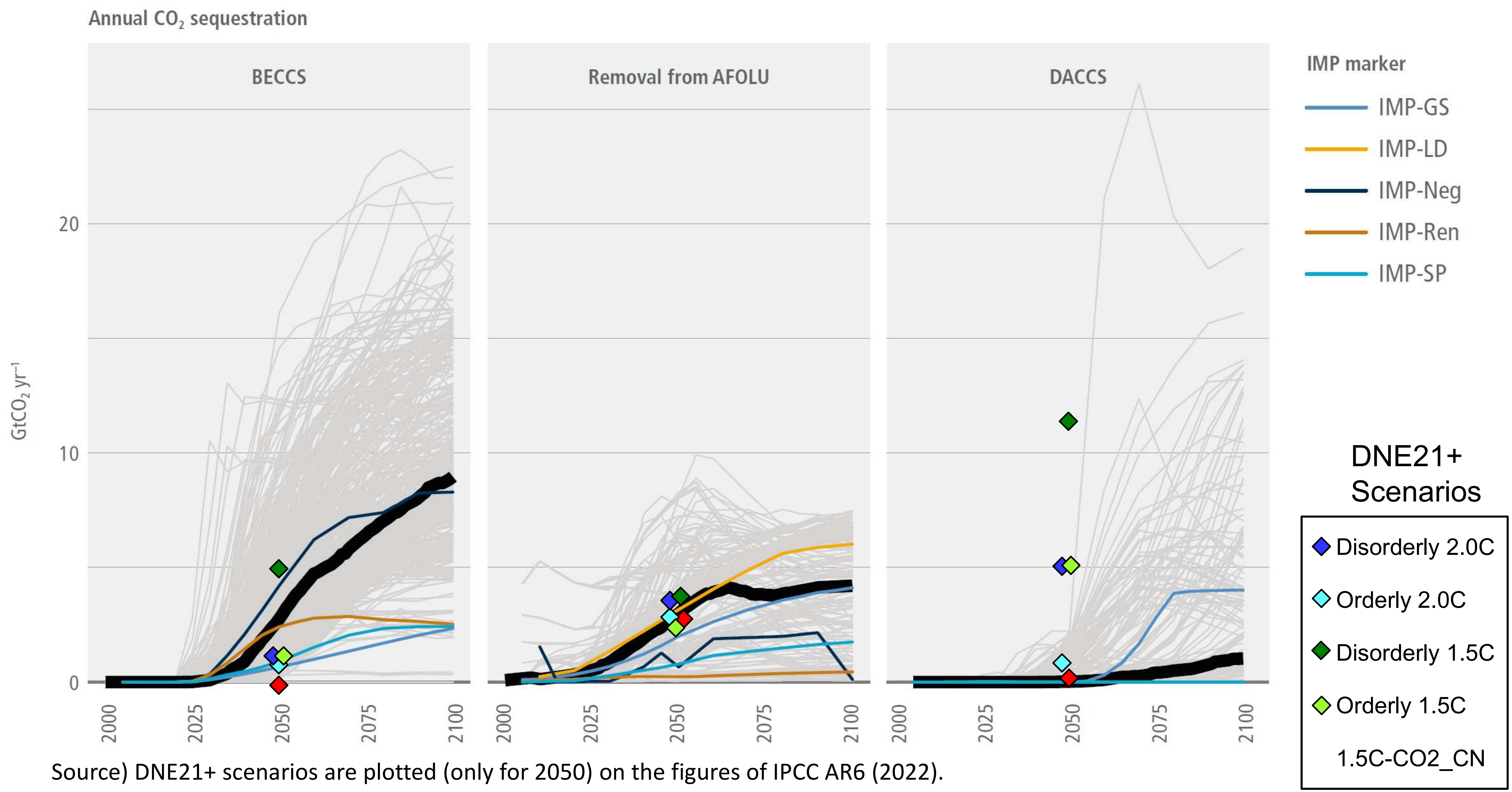



Source) DNE21+ scenarios are plotted on the figures of IPCC AR6 (2022).
Note) Boxes indicate 25th and 75th percentiles, while whiskers indicate 5th and 95th percentiles in IPCC scenarios.

**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



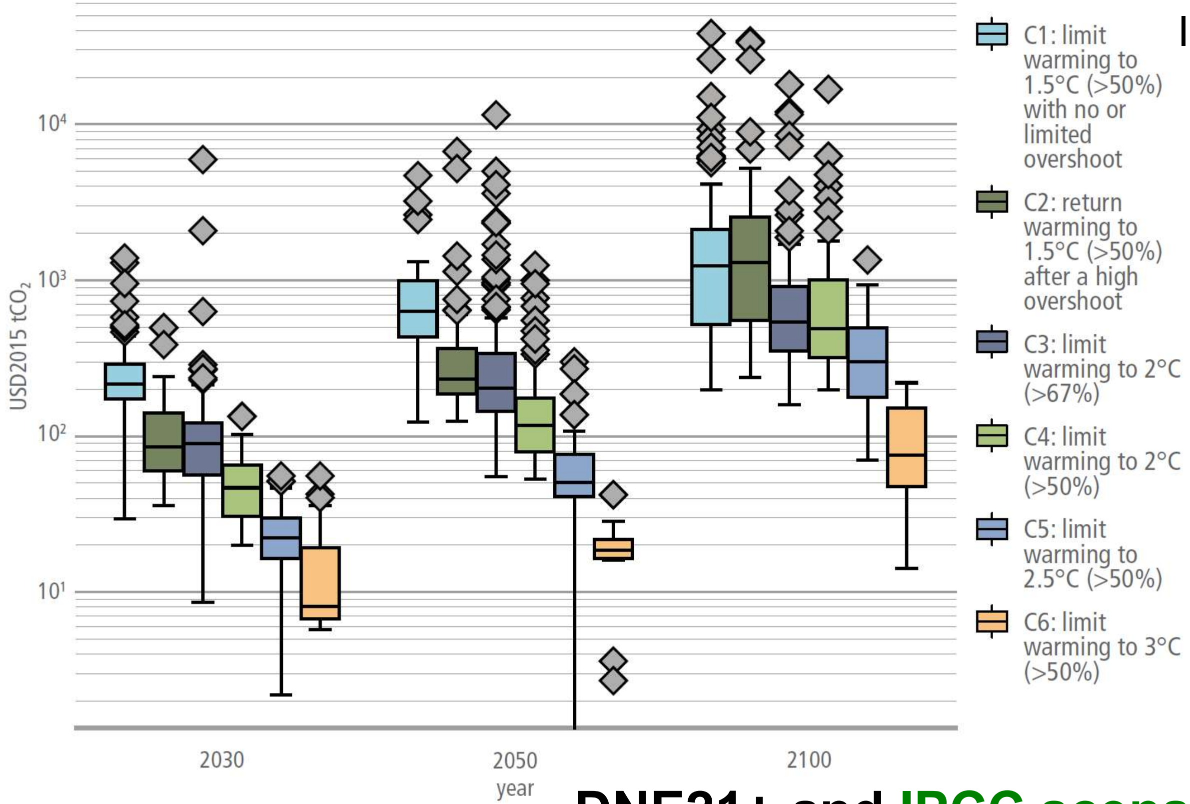



Source) DNE21+ scenarios are plotted (only for 2050) on the figures of IPCC AR6 (2022).
Note) As for IPCC AR6, only the scenarios categorized as C1-C3 are shown.

**The $CO_2$ 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.**

# $CO_2$ marginal abatement costs: compared with IPCC and IEA






IPCC AR6, Fig. 3.33

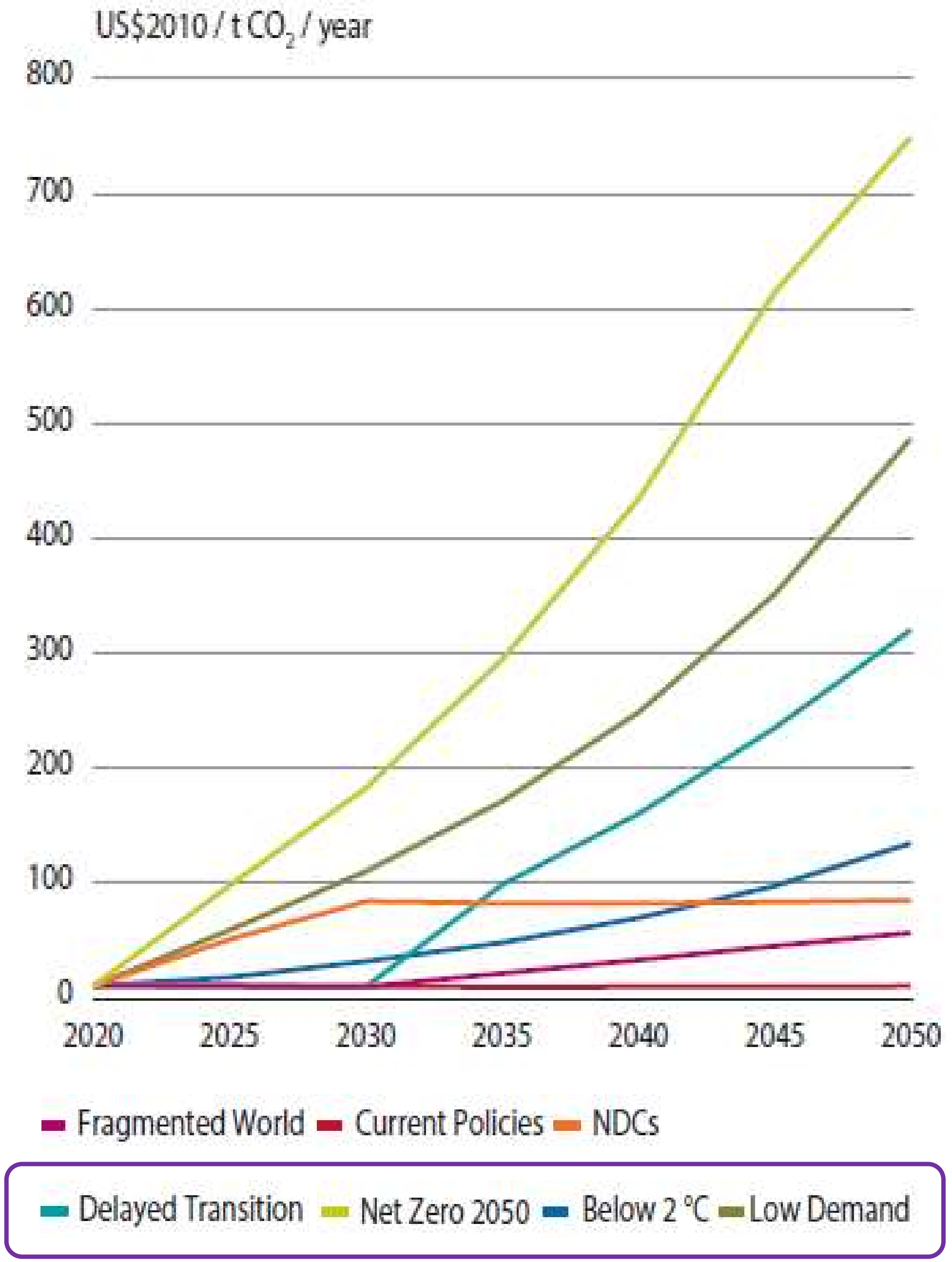
- Most of the carbon prices in the IPCC reports had been estimated under the equal MAC across countries. The prices of DNE21+ scenarios are consistent with those of the IPCC report.
- Most of the IPCC scenarios had not considered DACCS explicitly, while DNE21+ considers. Thanks to DACCS, the carbon prices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

# $CO_2$ marginal abatement costs: compared with NGFS

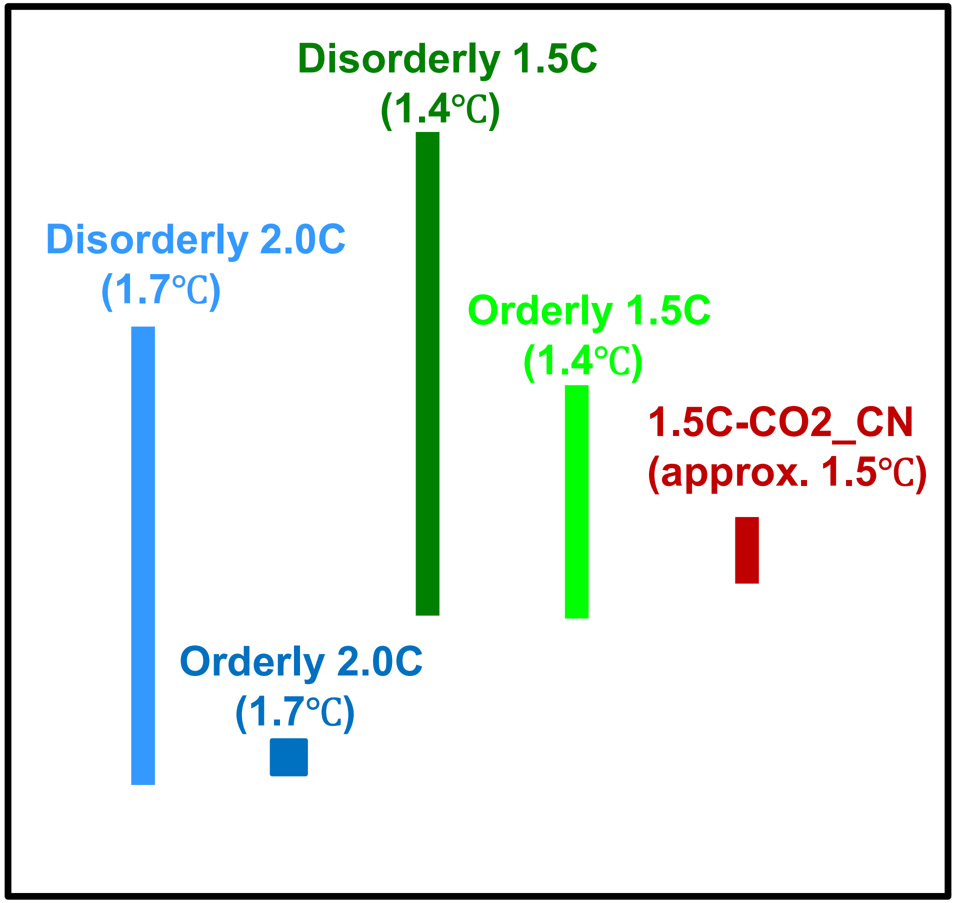





NGFS (2025)

Scenarios consistent with the 2℃ and 1.5℃ 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 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℃ and 1.5℃ 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℃ target but also with the 1.5℃ 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

# Examples of literature for DNE21+ model



[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

RITE Research Institute of Innovative Technology for the Earth

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.

| | | | Capital costs in 2000 [US$/kW] | Capital costs in 2018 [US$/kW] |
|---|---|---|---|---|
| **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.

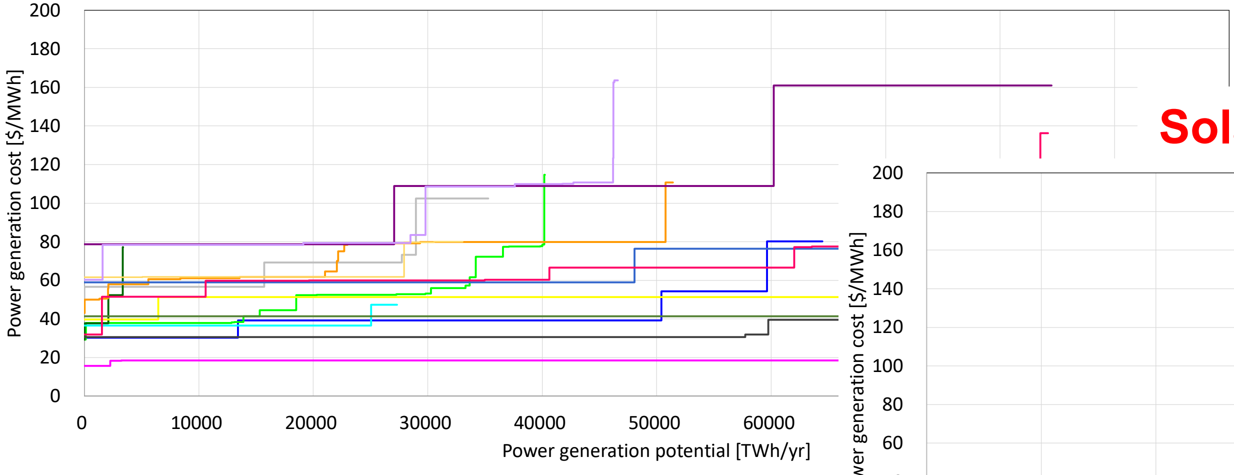
*2 Since the base year of the model is 2000, the 2000 price is also shown; the conversion from the 2000 price to the 2018 price is multiplied by 1.46 (based on CPI of U.S.).

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

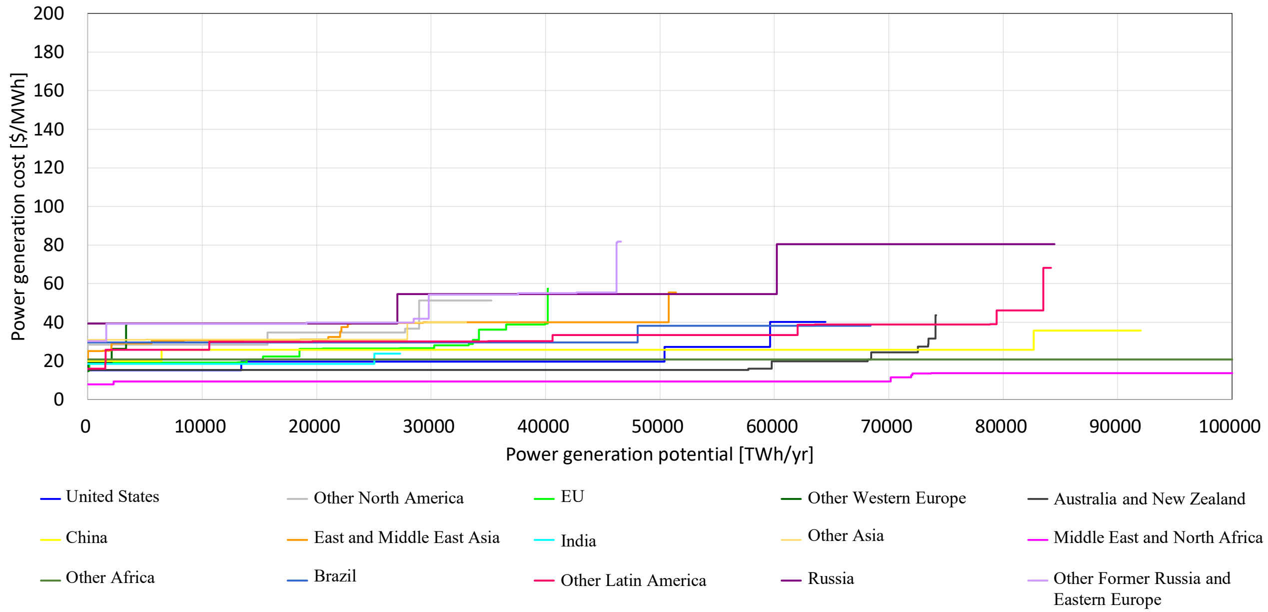
# Assumptions on the costs and potentials of solar PV and wind power



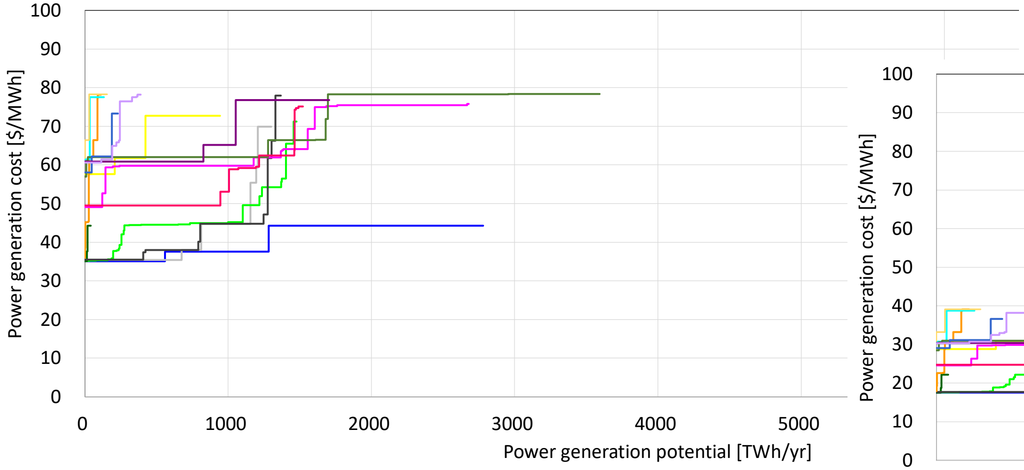
## Solar PV: middle cost reduction



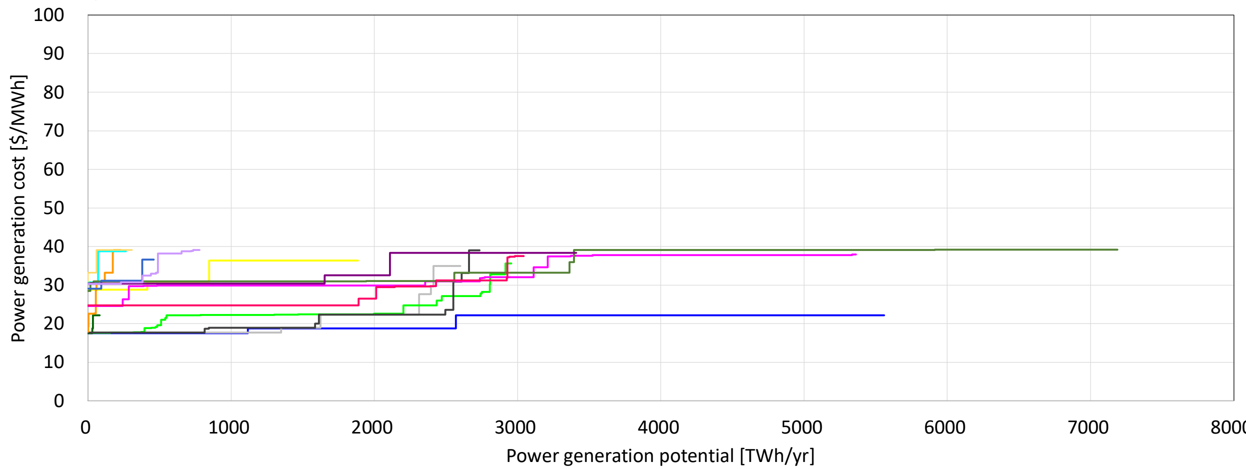

## Solar PV: high cost reduction




## 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 $CO_2$ 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$/(tCO2/hr))** | **Required electricity (MWh/tCO2)** | **$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$/(tCO2/hr))** | **Required fuels (GJ/tCO2) Recovered electricity (MWh/tCO2)** | **$CO_2$ capture ratio (%)** |
| $CO_2$ capture from clinker manufacturing*2 | 2485 - 2246 | 4.87 – 3.66<br>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 $CO_2$ capture technologies in the power sector, but also $CO_2$ 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 $CO_2$ geological storage

| | $CO_2$ storage potentials ($GtCO_2$) | | 【References】 IPCC SRCCS (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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ /yr in Japan's case).**

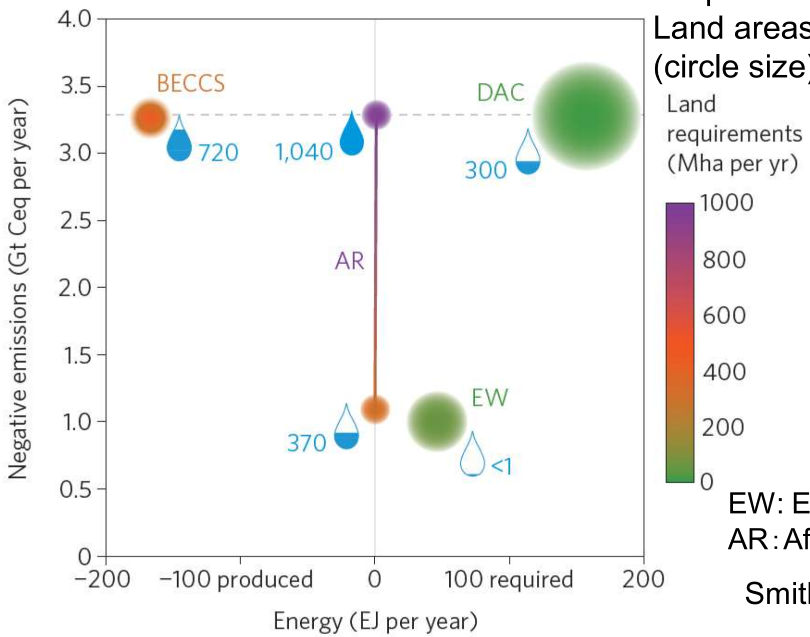
**【$CO_2$ transportation cost】**

- **The $CO_2$ transportation costs from the sources to the reservoirs are assumed separately as 1.36$/$tCO_2$ (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 $CO_2$ transportation costs are estimated according to the transportation distance.**
- **Cross-border $CO_2$ transport is also assumed. Annual export ceiling of 91 Mt $CO_2$ is set for Japan.**

# Assumption for Direct Air Capture (DAC)

- DAC is a technology to capture atmospheric $CO_2$ 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 $CO_2$ storage) can achieve negative emissions.
- It is economical to deploy in area close to $CO_2$ storage and where energy supply is available at low cost such as low cost PV.

Climeworks




Required energy (horizontal axis), Land areas (color), Investments (circle size) etc.

EW: Enhanced weathering
AR: Afforestation and reforestation

Smith et al. (2015)

**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（/tCO2） | | Facility costs（Euro/(tCO2/yr)） | |
|---|---|---|---|---|---|
| | | 2020 | 2050 | 2020 | 2050 |
| **High temperature (electrification) system (HT DAC)** | Elec. (kWh) | 1535 | 1316 | 815 | 222 |
| **Low temperature systems（LT DAC）**: use of hydrogen or gas for heat | Heat (GJ) | 6.3 (=1750 kWh) | 4.0 | 730 | 199 |
| | 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 $CO_2$ 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<br>Other energy: US\$/(toe/yr)<br>$CO_2$ : US\$/(t$CO_2$/yr) | Energy: US\$/toe<br>$CO_2$: US\$/t$CO_2$ |
| **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 |

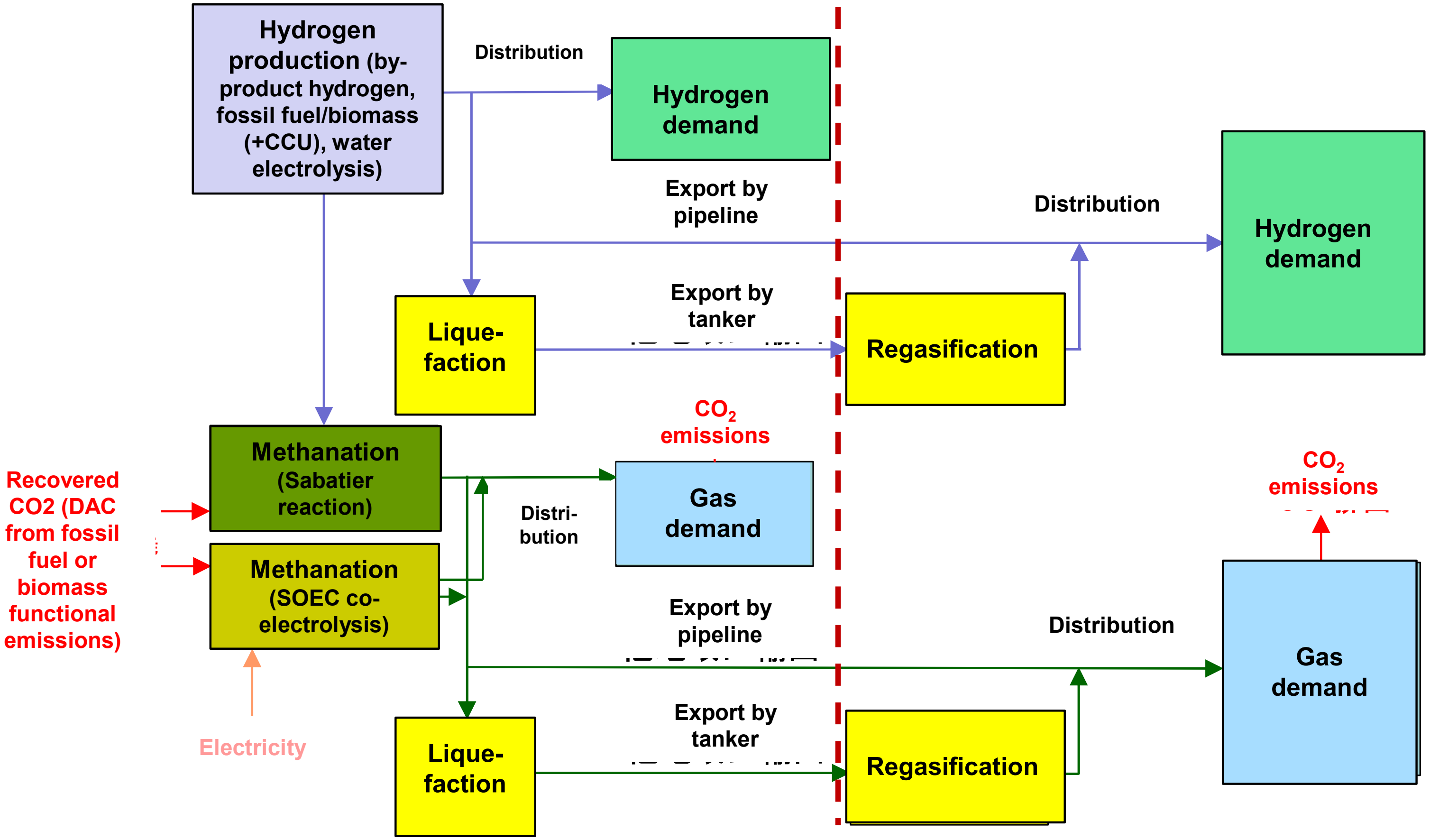
L: Distance between regions (1000km)

*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 to the assumed scenarios.

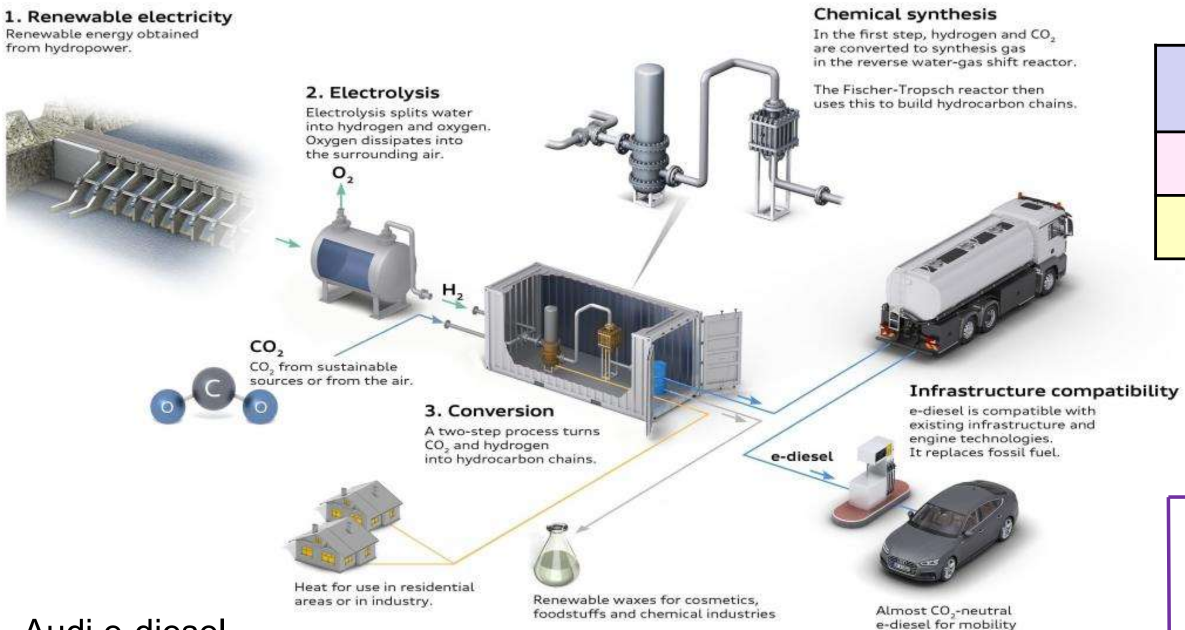
Note) In this analysis in order to provide incentives to use of synthetic fuels for the countries that use the fuels, CO2 emissions are not recorded in the countries that use them, but in the countries that produce them.

**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)

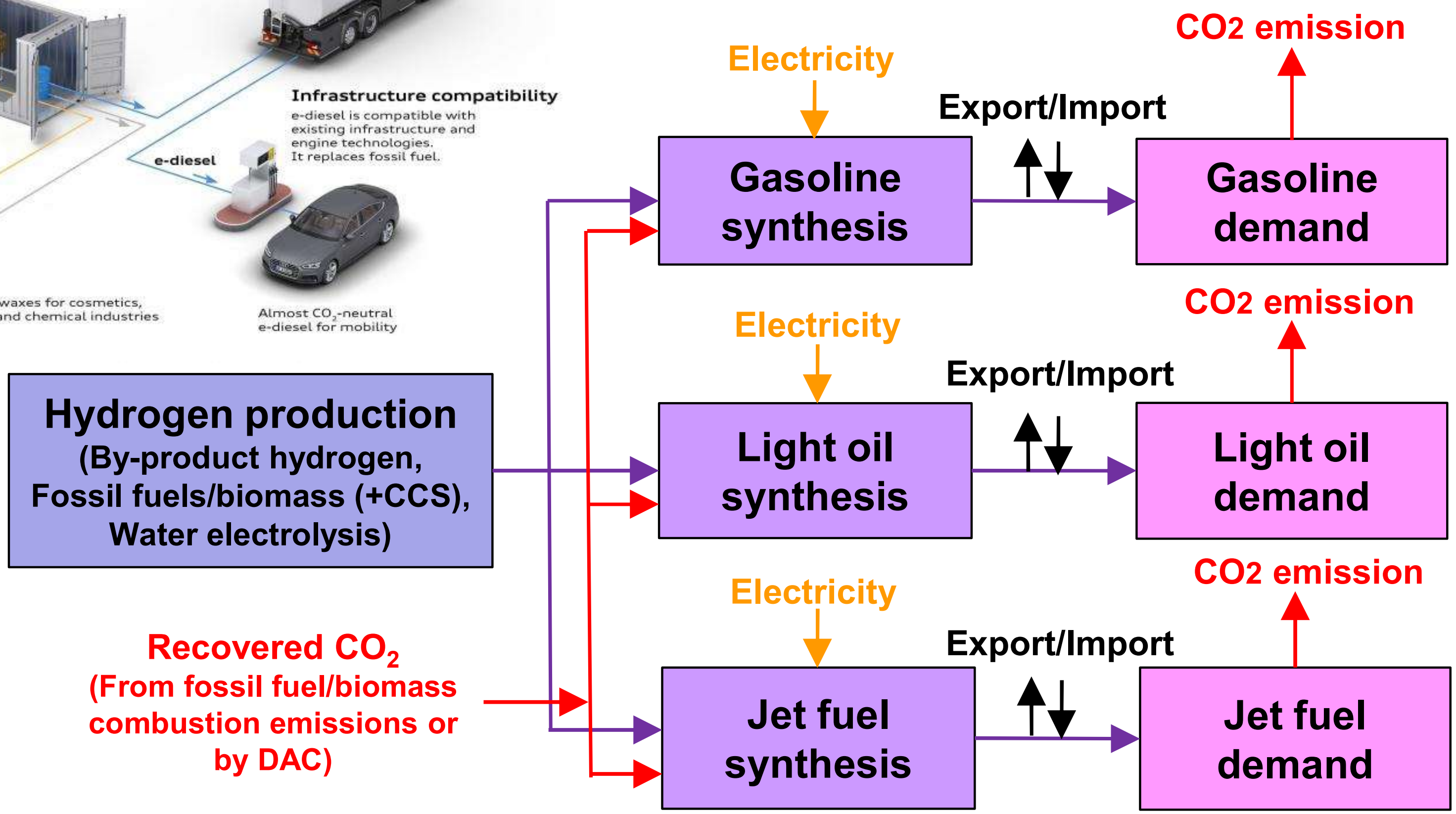
- ✓ **Hydrogen is not limited to renewable-based hydrogen (green hydrogen). The most economical one is selected according to the assumed scenarios.**
- ✓ **Recovered $CO_2$ can be obtained from fossil fuel / biomass combustion emissions or by DAC. The most economical one is selected according the assumed scenarios.**




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 tCO2 | | | |
| Electricity | 0.02 toe | | | |

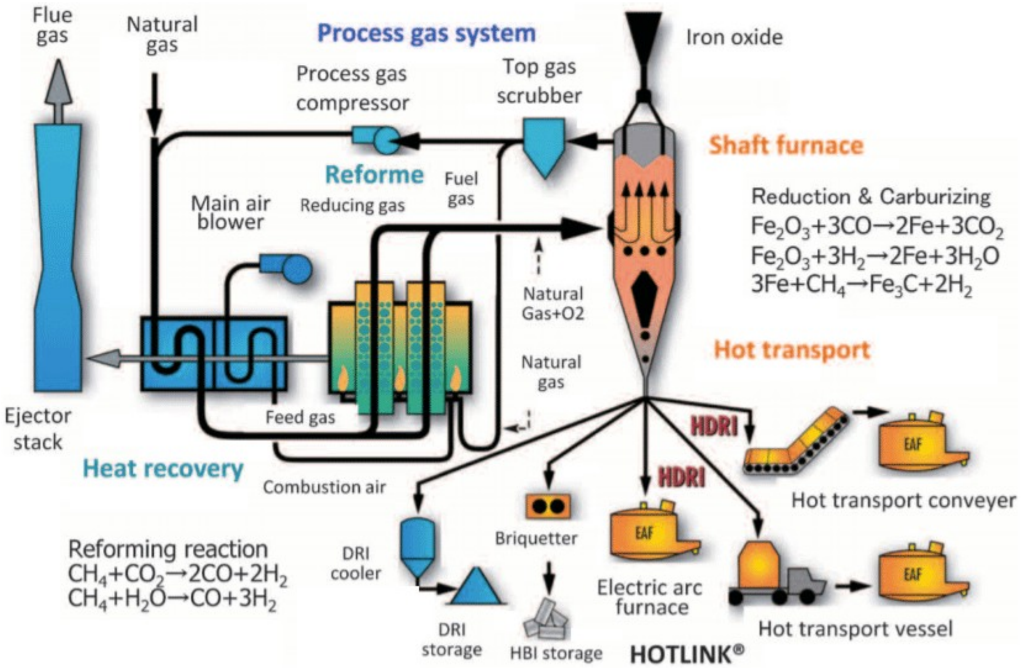



Note) In this analysis in order to provide incentives to use of synthetic fuels for the countries that use the fuels, CO2 emissions are not recorded in the countries that use them, but in the countries that produce them.

# 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).
- ✓ $H_2$-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 $H_2$-based DRI process [capital cost: 438.1$/(t-cs/yr), $H_2$ consumption: 12.1GJ/t-cs, power consumption: 695kWh/t-cs]
- ✓ In the $H_2$-based DRI acceleration scenario, it is assumed that new construction will be possible from 2041.

**Example of gas-based DRI making process**




J. Kopfle et al. Millenium Steel 2007, p.19

**Demonstration plant for $H_2$-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]*

# The roadmap by GoJ (2025 edition): Power



- 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。

## $CO_2$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。

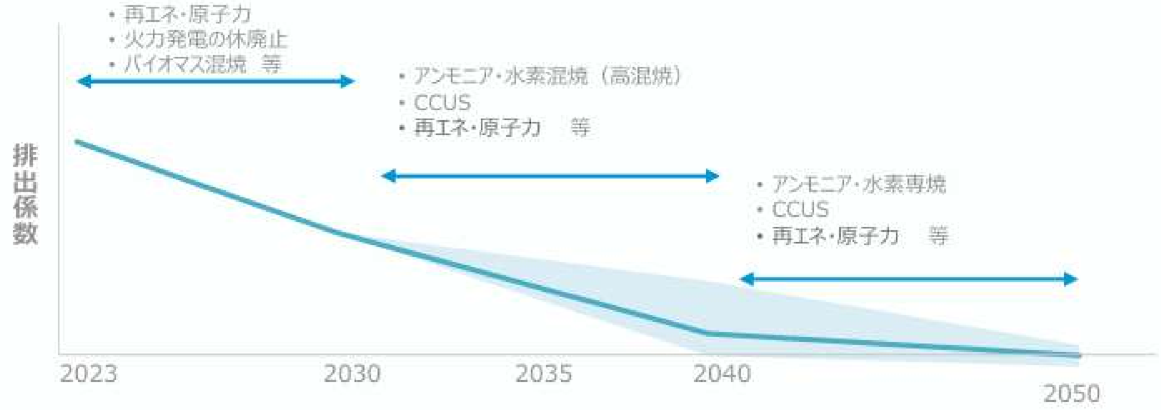
**経路に大きな影響を与える主な要素**

- 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。

## $CO_2$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。
- 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。

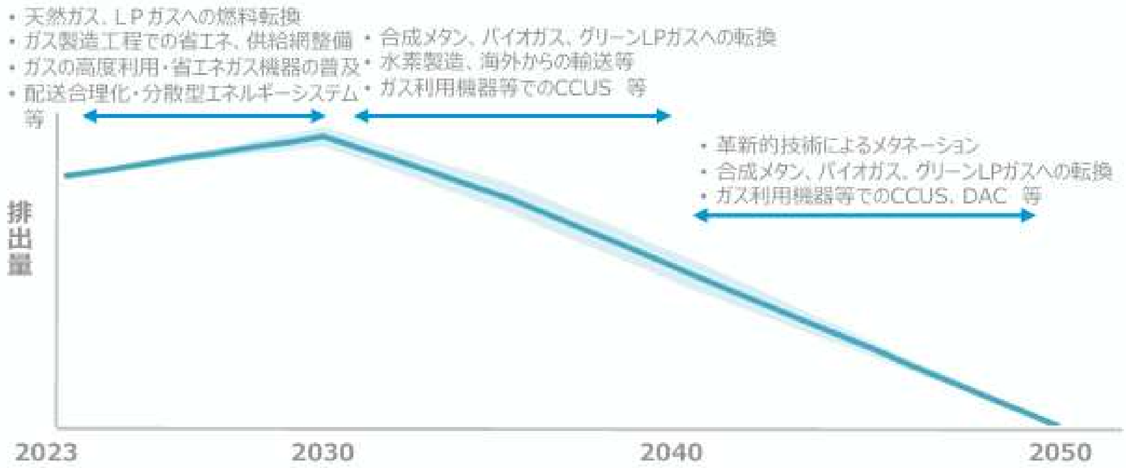
**経路に大きな影響を与える主な要素**

- 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の活用量

**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 | ・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 |
| 2. 2030~2040 | ・合成メタン、バイオガス、グリーンLPガスの製造技術を確立し、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。 |
| 3. 2040~2050 | ・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。 |

※ 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。

# The roadmap by GoJ (2025 edition): Oil



- 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。

## $CO_2$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。

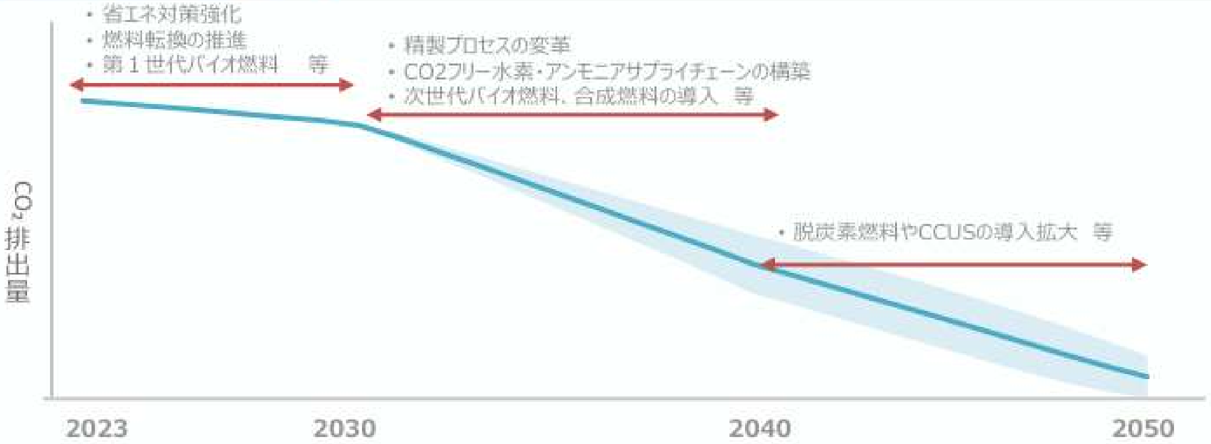
**経路に大きな影響を与える主な要素**

- 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※




**1　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。

**2　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。

**3　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。

# The roadmap by GoJ (2025 edition): Iron & Steel



- 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術の実現・導入により、2050年のカーボンニュートラルを実現する。

## $CO_2$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。

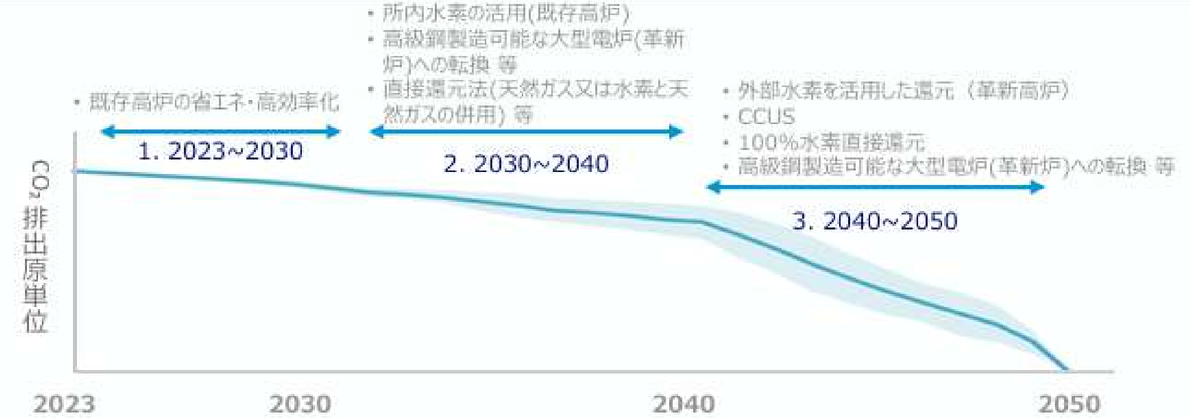
**経路に大きな影響を与える主な要素**

- 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)等の新技術を導入。<br>• 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術の確立を目指す。 |
| 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術の導入により、2050年に向けたCO2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。

# The roadmap by GoJ (2025 edition): Cement



- 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。

## $CO_2$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。

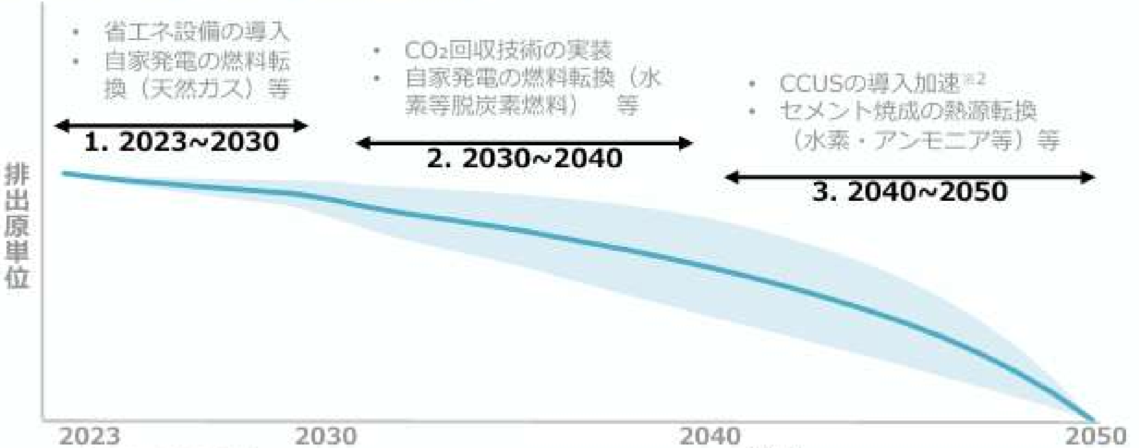
**経路に大きな影響を与える主な要素**

- 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。

## $CO_2$排出削減イメージの試算結果※1、2、3




| 主要な削減方法 | 概要 |
|---|---|
| 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。<br>・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。<br>・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。

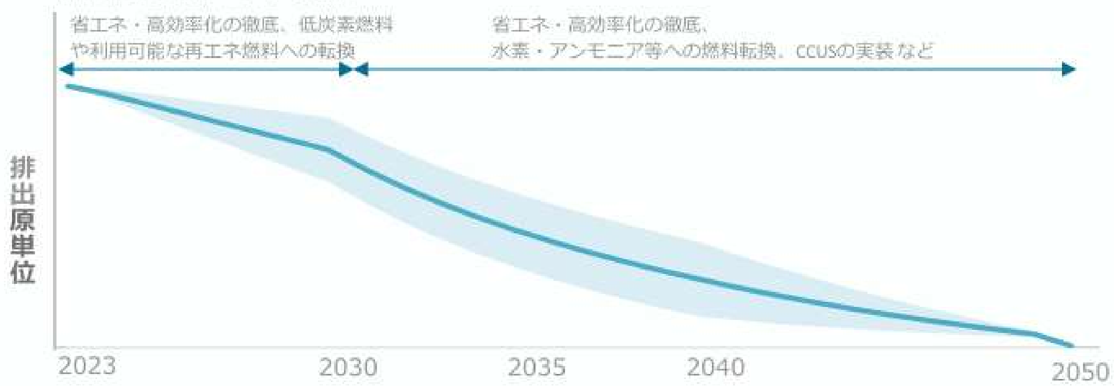
## $CO_2$削減イメージの試算概要・根拠等

**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な要素**
- 自家発・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。

## $CO_2$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<br>2040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。 |

※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は、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。

# The roadmap by GoJ (2025 edition): Chemical



- 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。

## $CO_2$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。

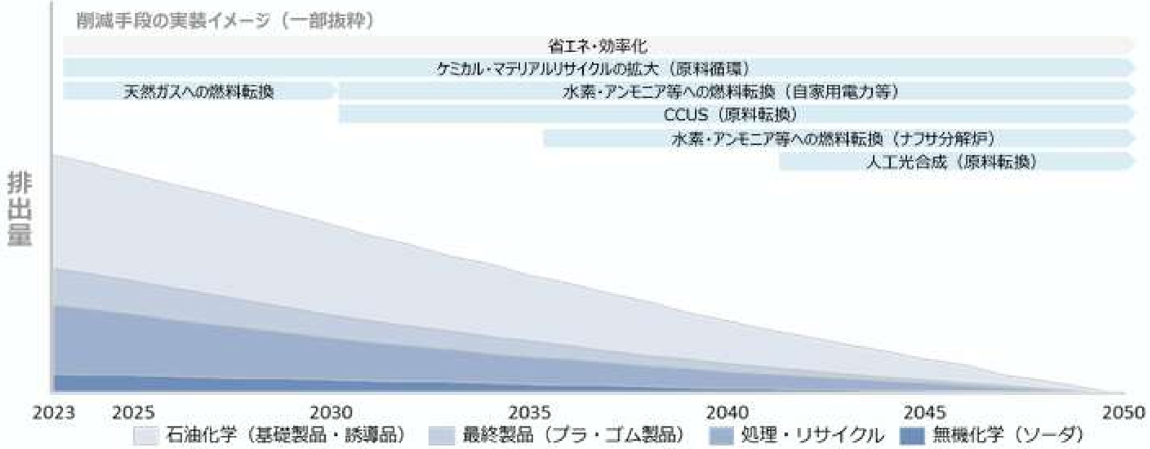
**経路に大きな影響を与える主な要素**

- 各種化学品の需要・生産量
- 自家発・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。

## $CO_2$排出削減イメージの試算結果※1、2、3




| 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用発電等について、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CO2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

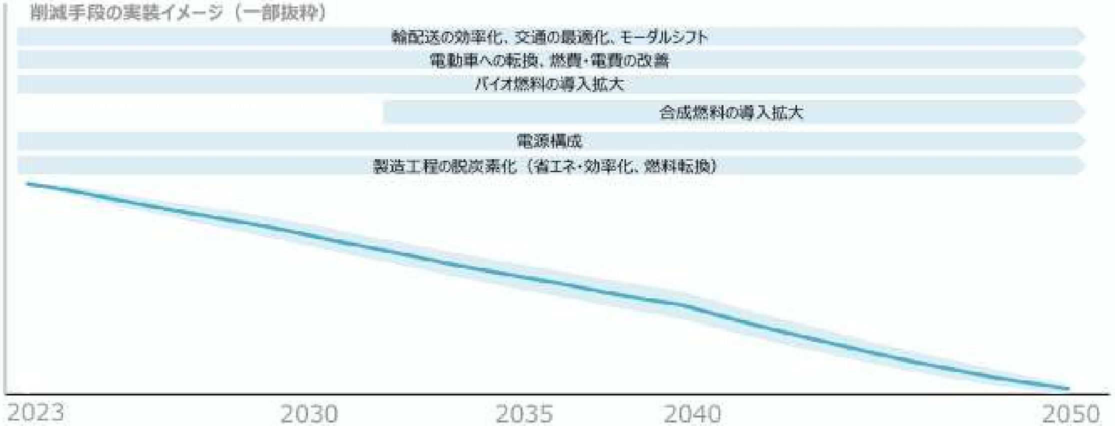
## $CO_2$削減イメージの試算概要・根拠等

**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。
- 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な要素**
- 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




| 主要な削減手段 | 概要 |
|---|---|
| （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。