ALPS International Symposium

March 6, 2023

Analyses on the Achievements of Low Energy Demand Society Induced by Digital Transformation DX and Green Transformation GX

Research Institute of Innovative Technology for the Earth (RITE)

Keigo Akimoto

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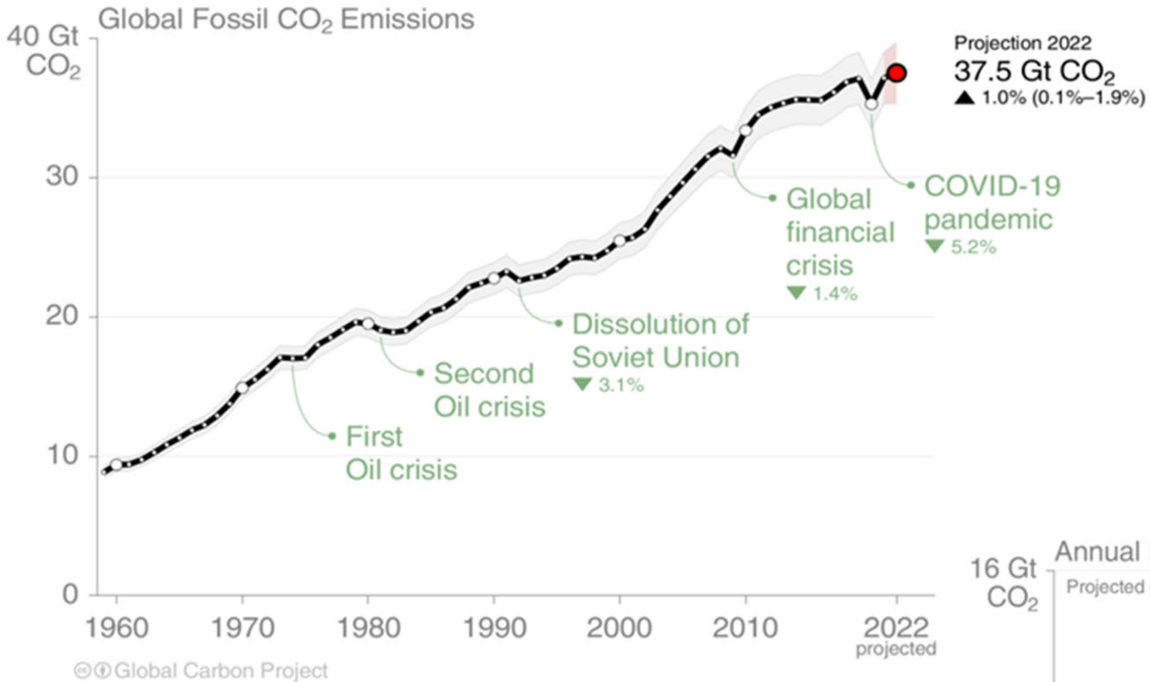
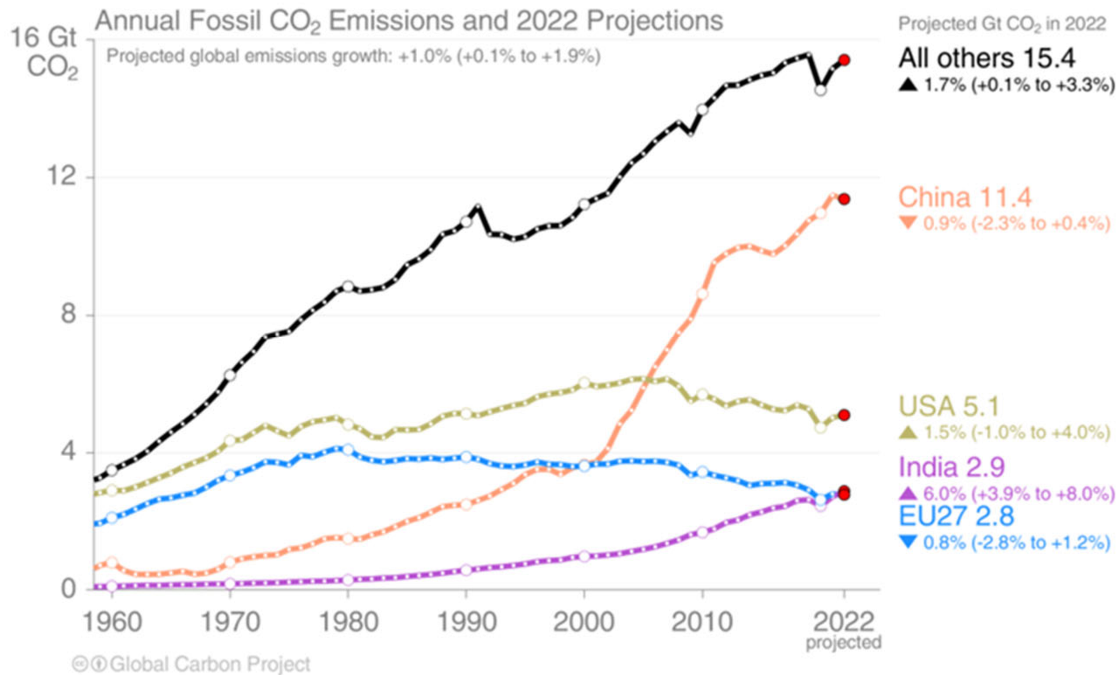
1. Trends of global GHG emissions and response measures for achieving carbon neutrality

Trajectories of Global CO_2 Emissions

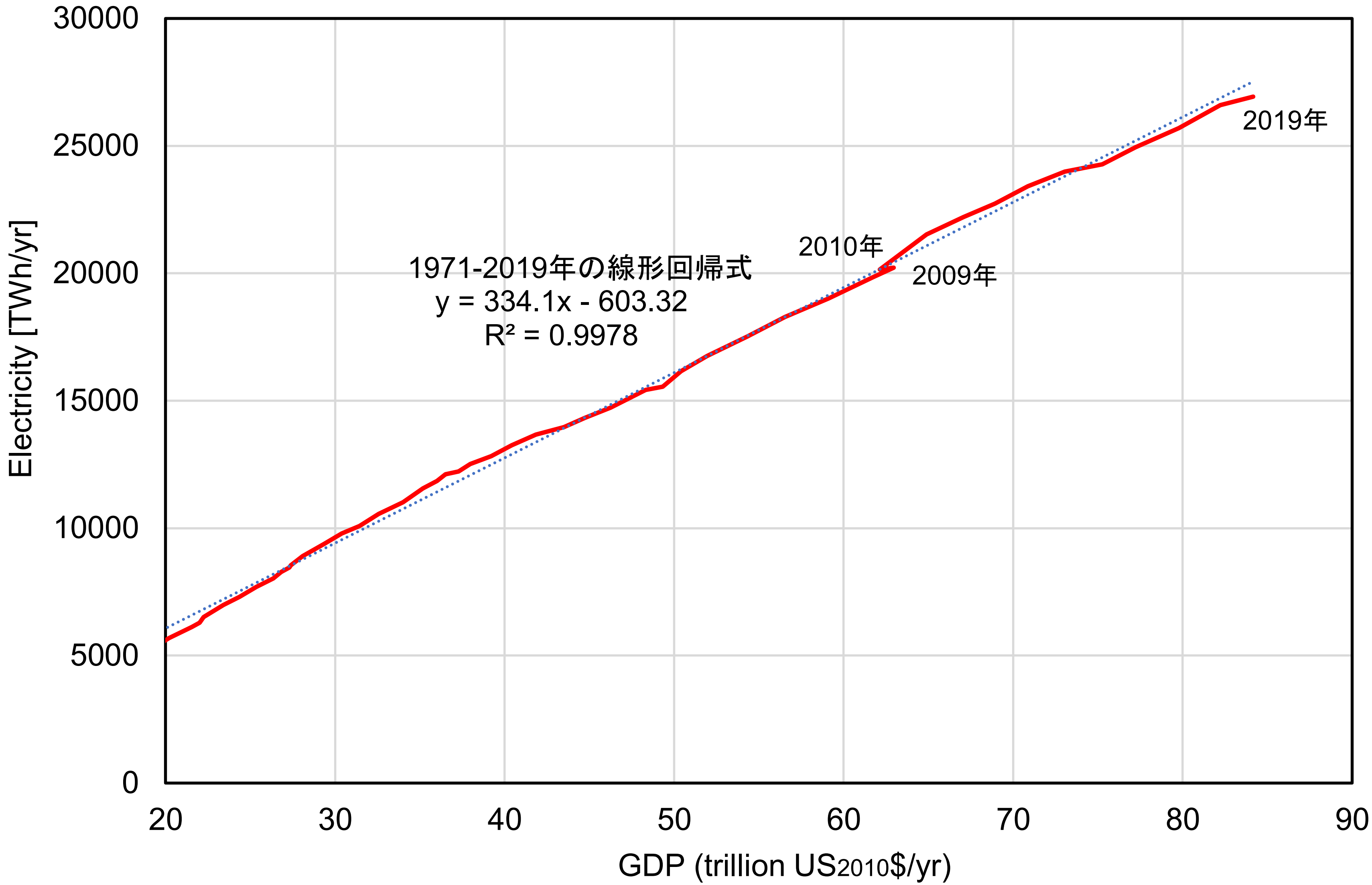




出典）Global Carbon Project, 2022

- 経済とCO2排出量のカップリングは続いている。CO2排出も大きく減少したときは、経済（GDP、所得）も悪化している状態。世界の排出量を簡単に減らせる状況にはない。

Global GDP v.s. electricity consumption



Source) IEA, 2021

The strongly linear relationship between global GDP and electricity consumptions exists and continues.

Response measures to climate change

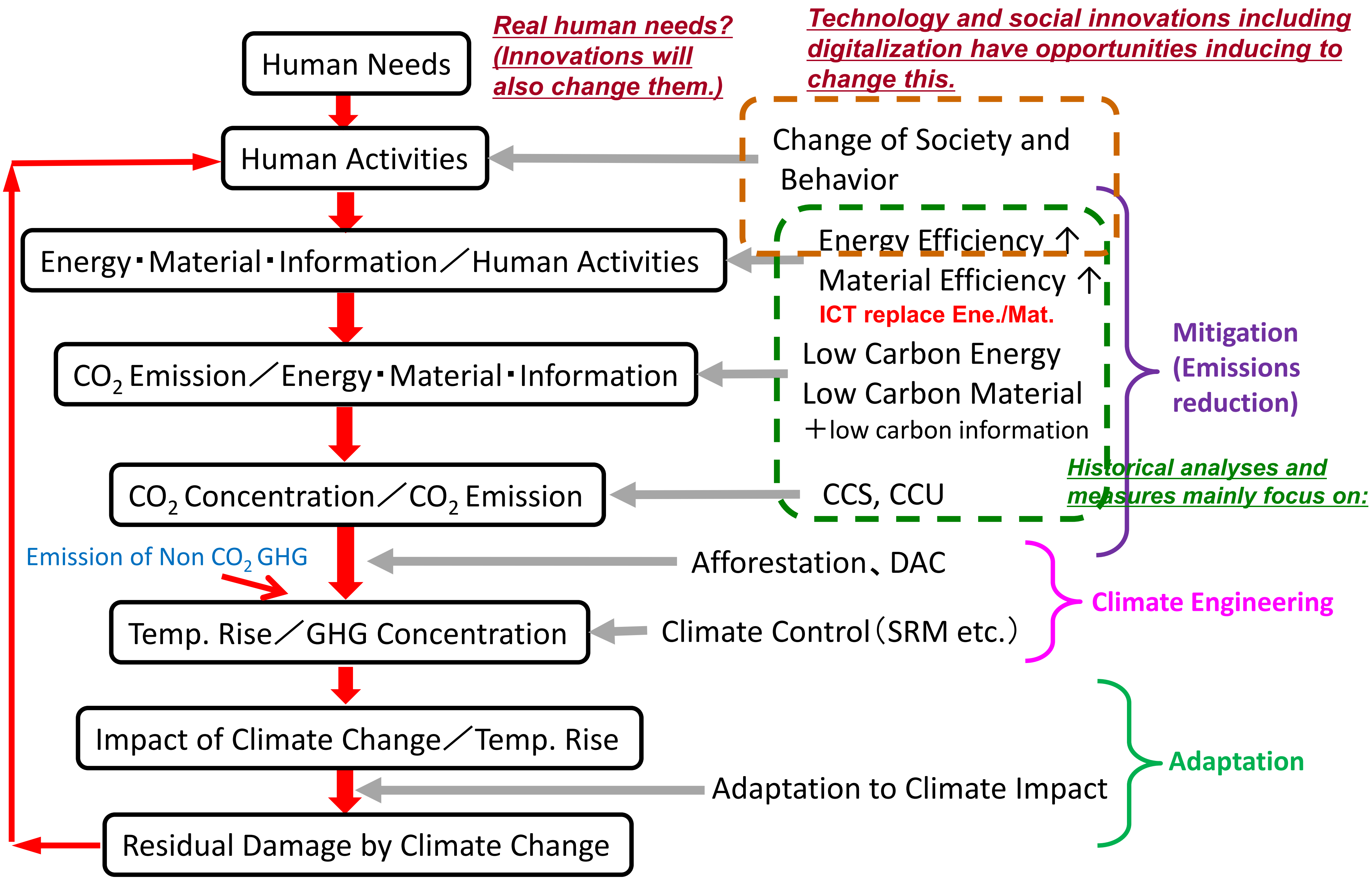
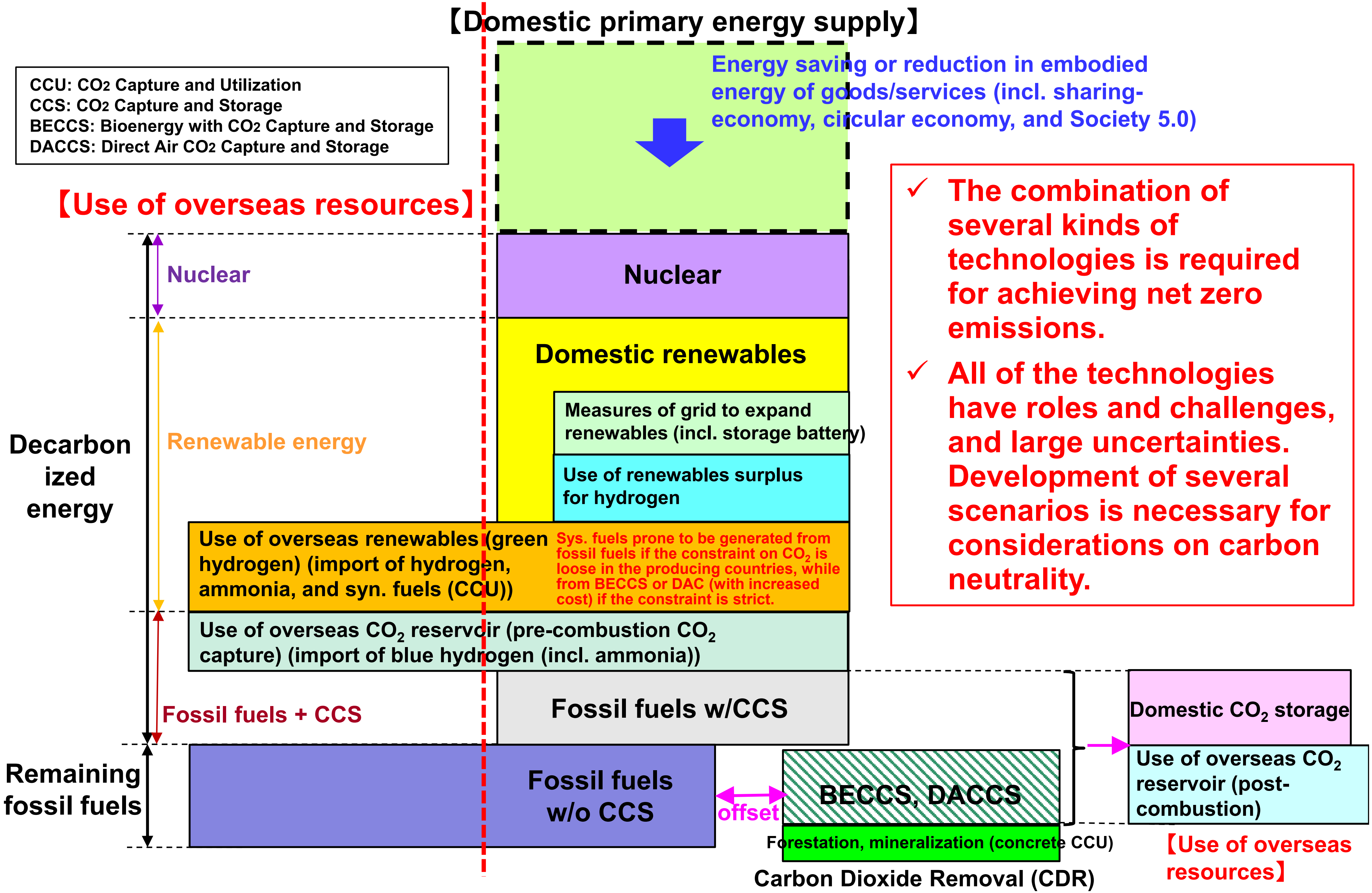


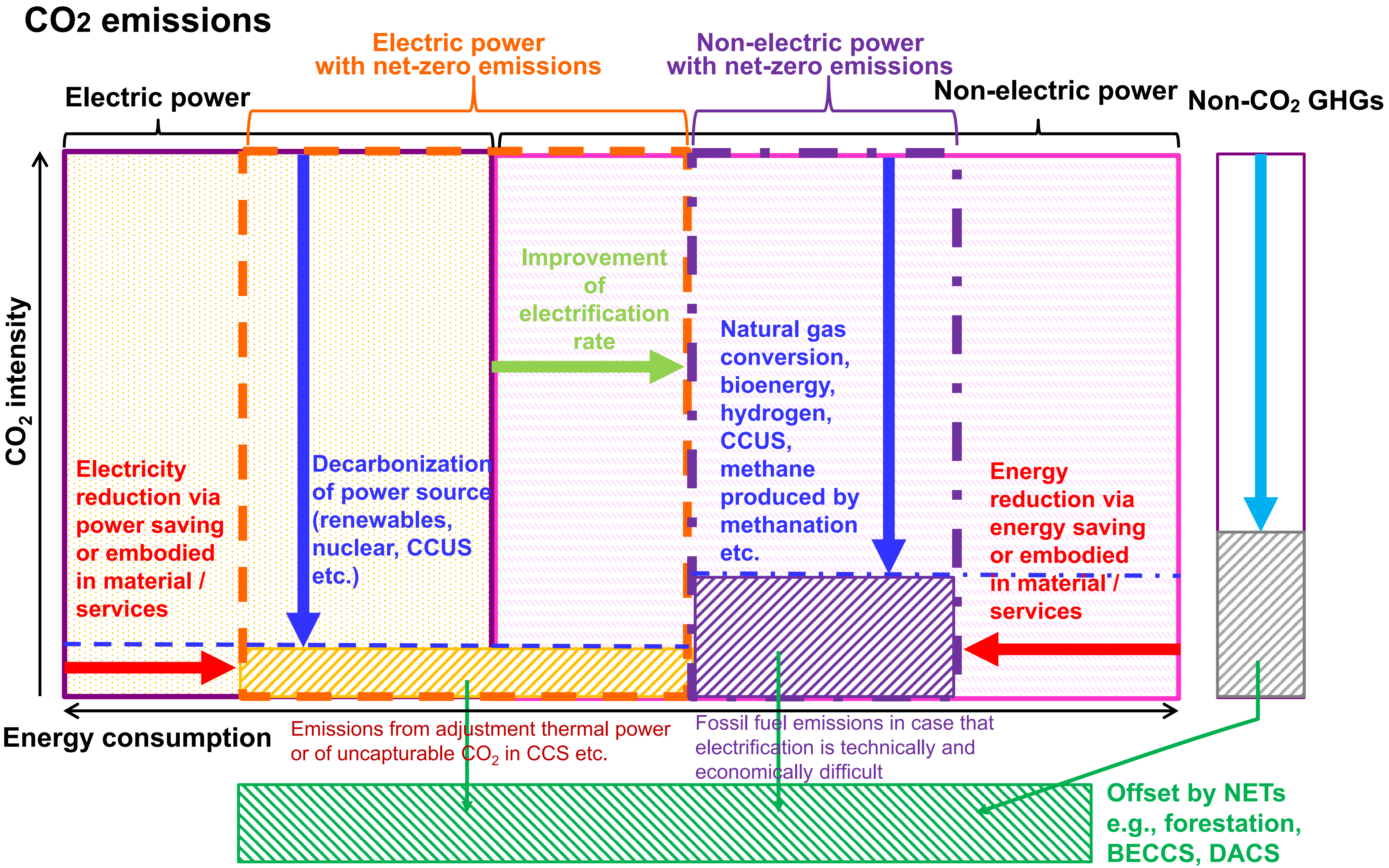
Image of Primary Energy in Japan for Net Zero Emissions (1/2)

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



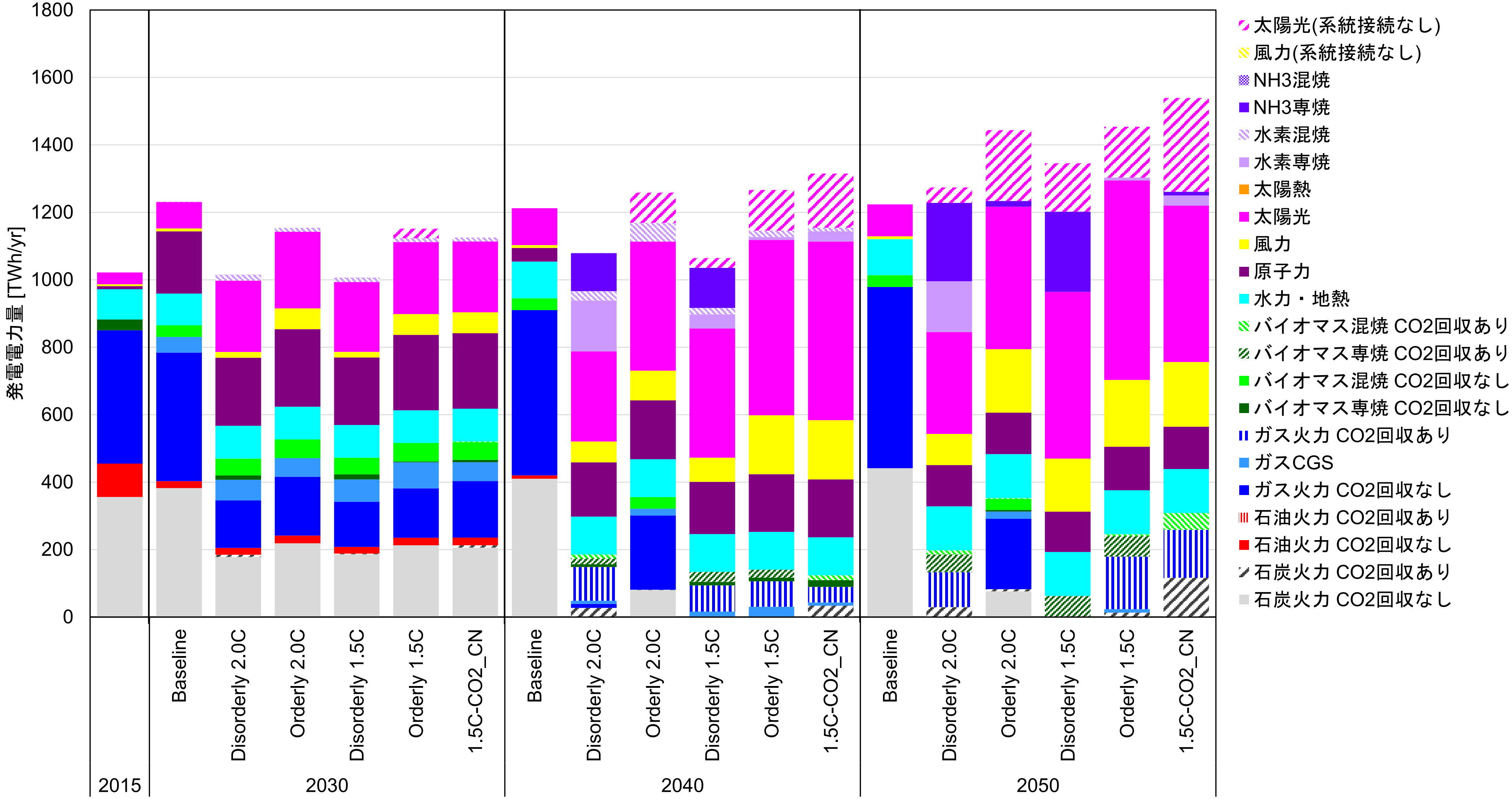
- ✓ The combination of several kinds of technologies is required for achieving net zero emissions.
- ✓ All of the technologies have roles and challenges, and large uncertainties. Development of several scenarios is necessary for considerations on carbon neutrality.

Image of Primary Energy in Japan for Net Zero Emissions (2/2)



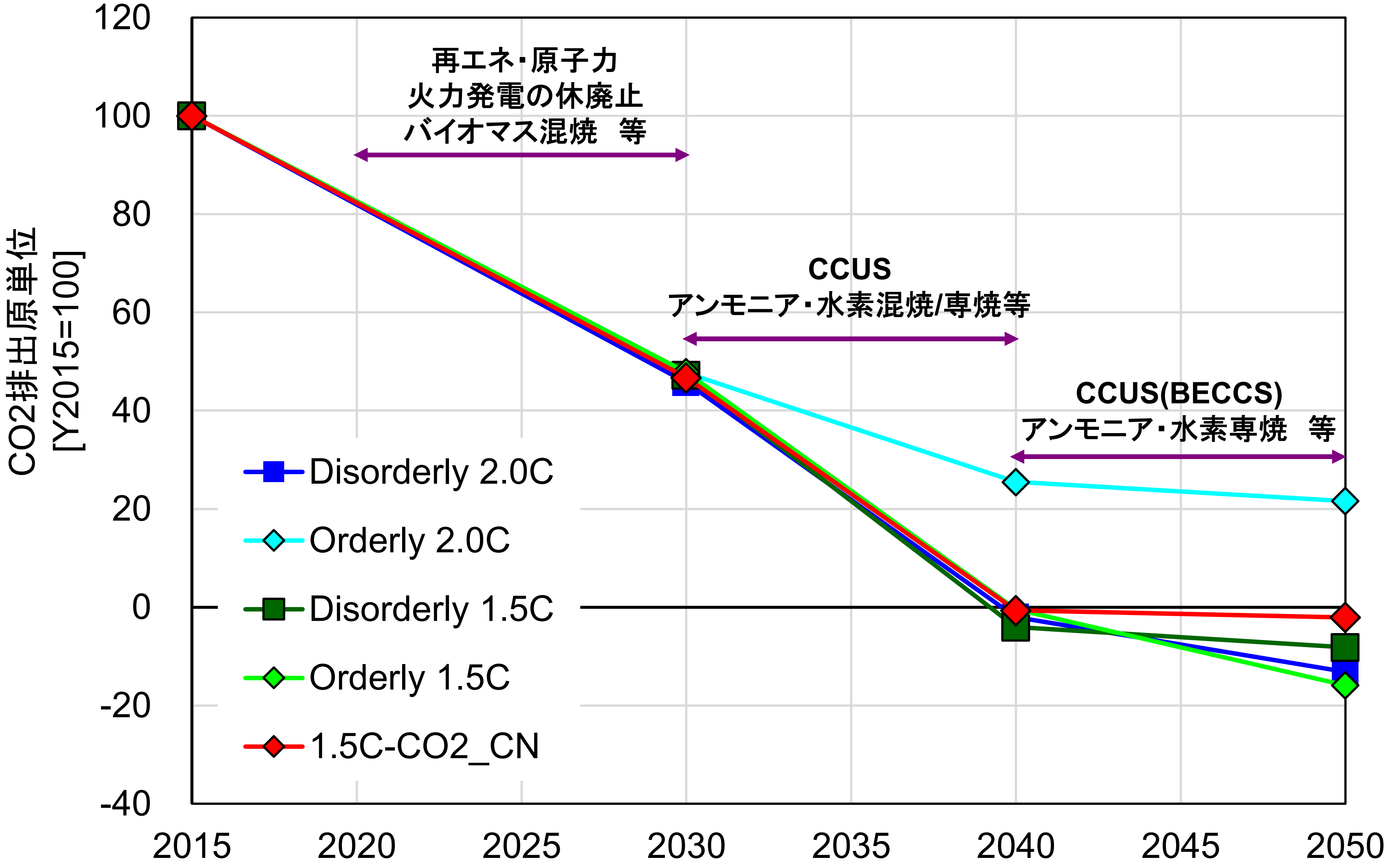
2. Outlooks of emissions reductions toward the Paris long-term goals

Electricity generation in Japan



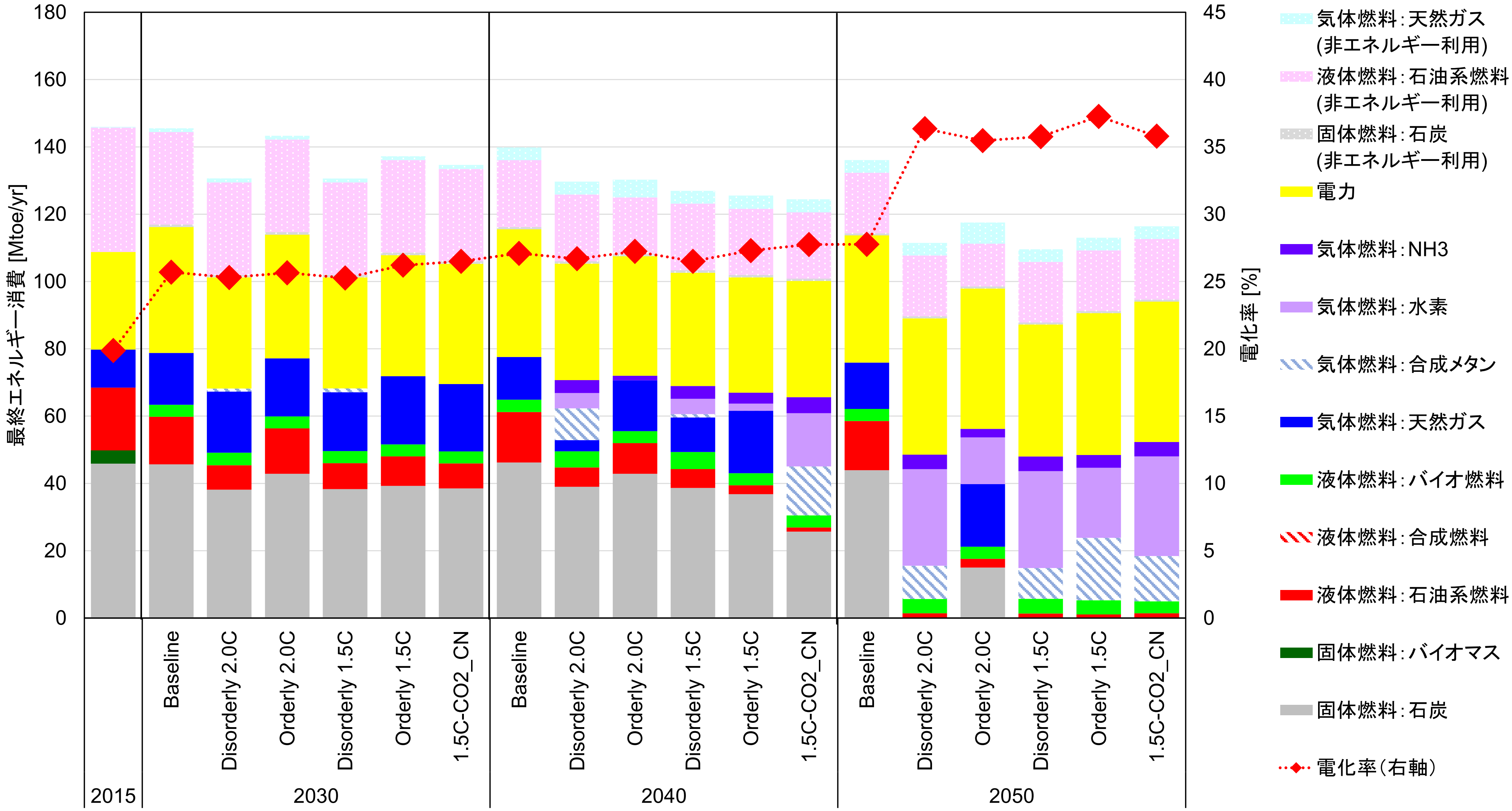
- ✓ 発電電力量は、とりわけ厳しい排出削減シナリオ下で上昇傾向有
- ✓ 太陽光等の再エネの普及拡大やCCSの利用の他、輸入した水素・アンモニアによる発電が行われる。また、ガス火力発電は、2050年において、Orderly 2.0C以外のシナリオの下ではe-メタンが利用されている。
- ✓ 太陽光、風力発電の更なるコスト低減を見込んでいるOrderly 1.5Cでは、より普及が進む結果
- ✓ 1.5C-CO_2_CNでは、BECCS及びe-メタン+CCSの制約によりり、CCS付き石炭火力の比率が上昇

CO_2 emission intensity of electricity in Japan



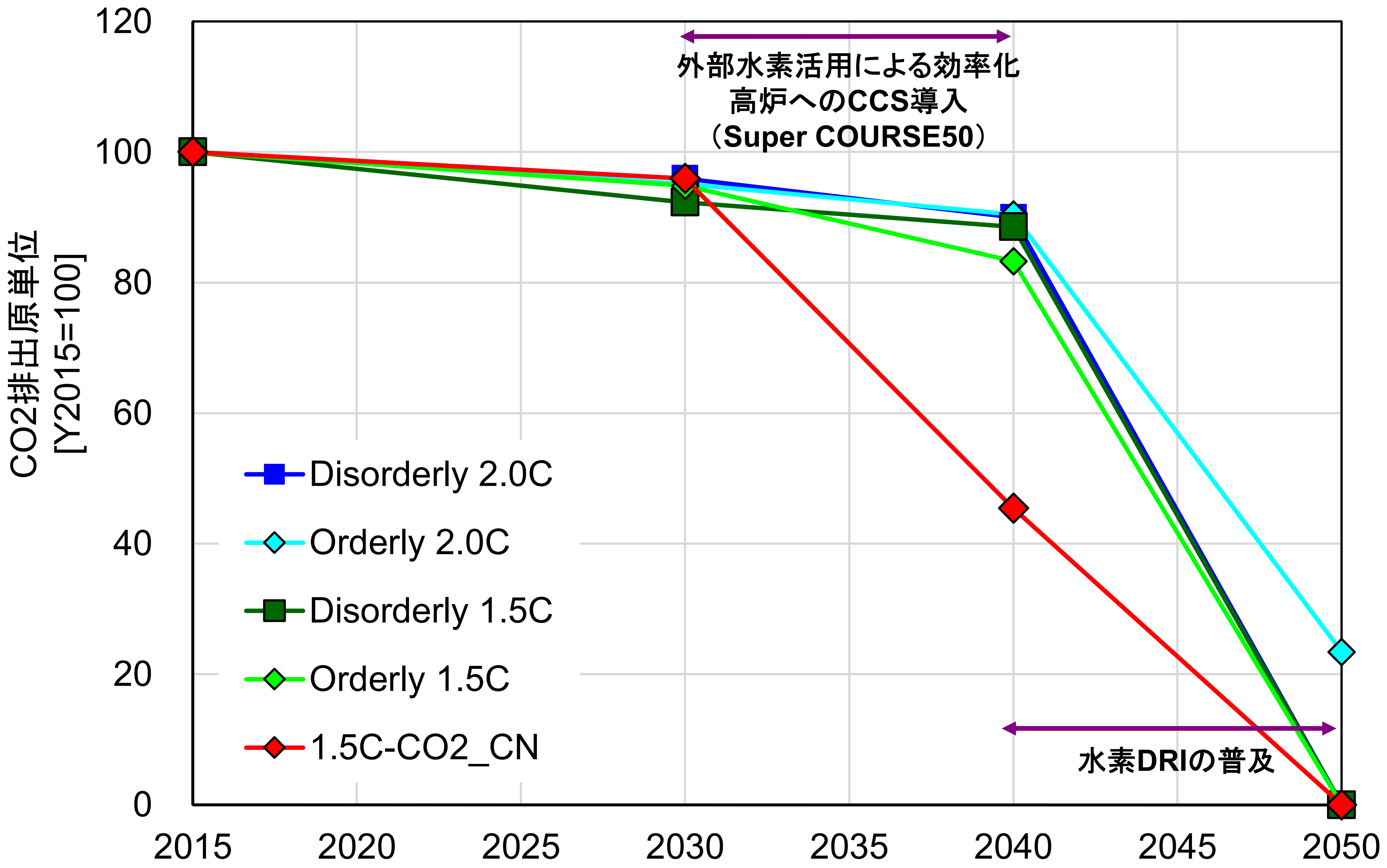
✓ **2050年にGHG排出をゼロとするDisorderly 1.5C/2.0C、Orderly 1.5Cでは電源構成は異なるものの、CO_2排出係数の推移に大きな差異はなく、2040年頃にはCNとすることが全体として費用効率的との評価。**

Final energy consumption in Industry in Japan



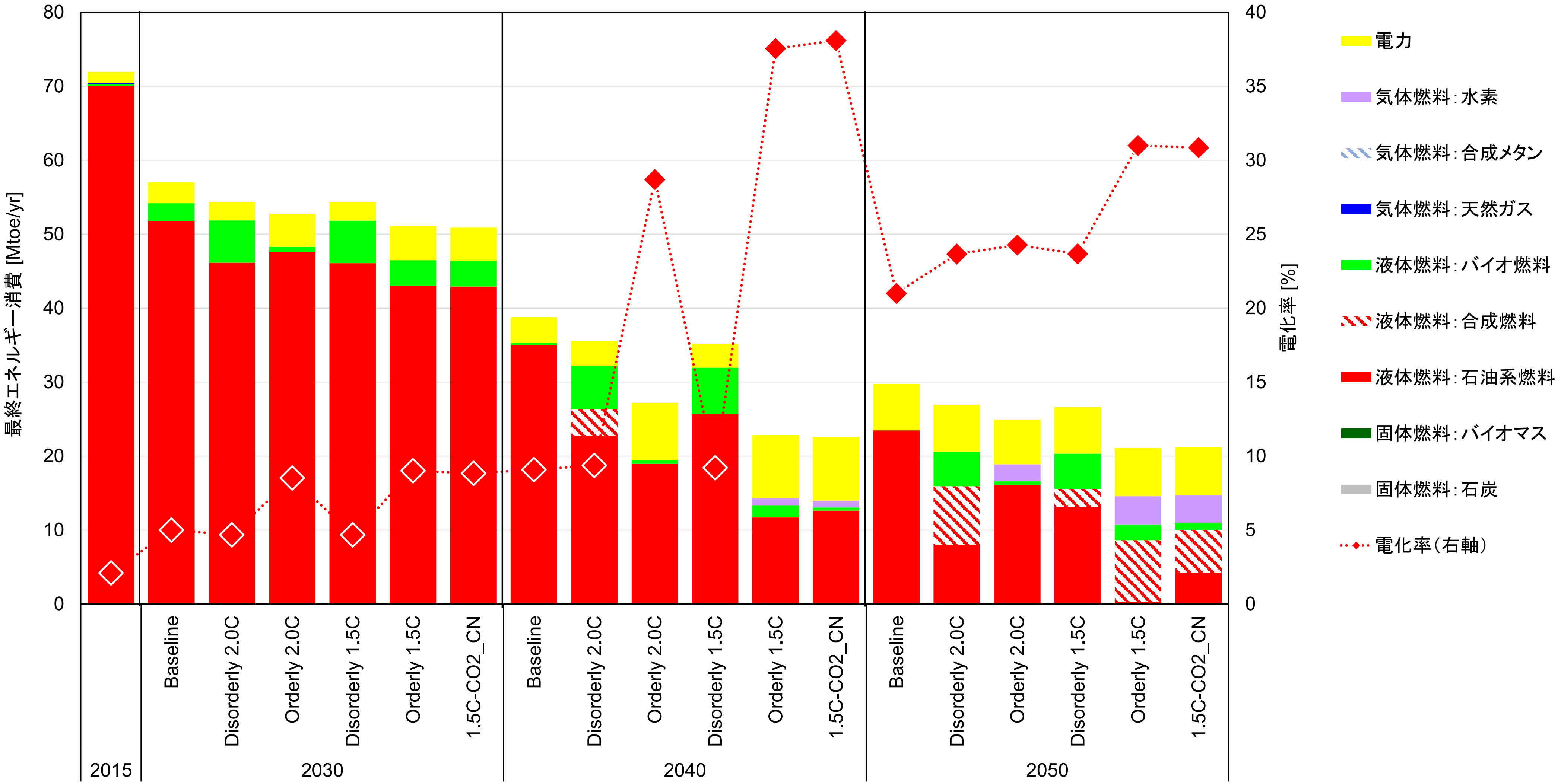
- ✓ 2040年は、鉄鋼部門の高炉・転炉法での石炭利用が残っている。
- ✓ 2050年はOrderly 2.0C以外では石炭の利用は無く、水素やアンモニア、e-メタンの利用が見られる。

CO_2 emission intensity in iron & steel in Japan



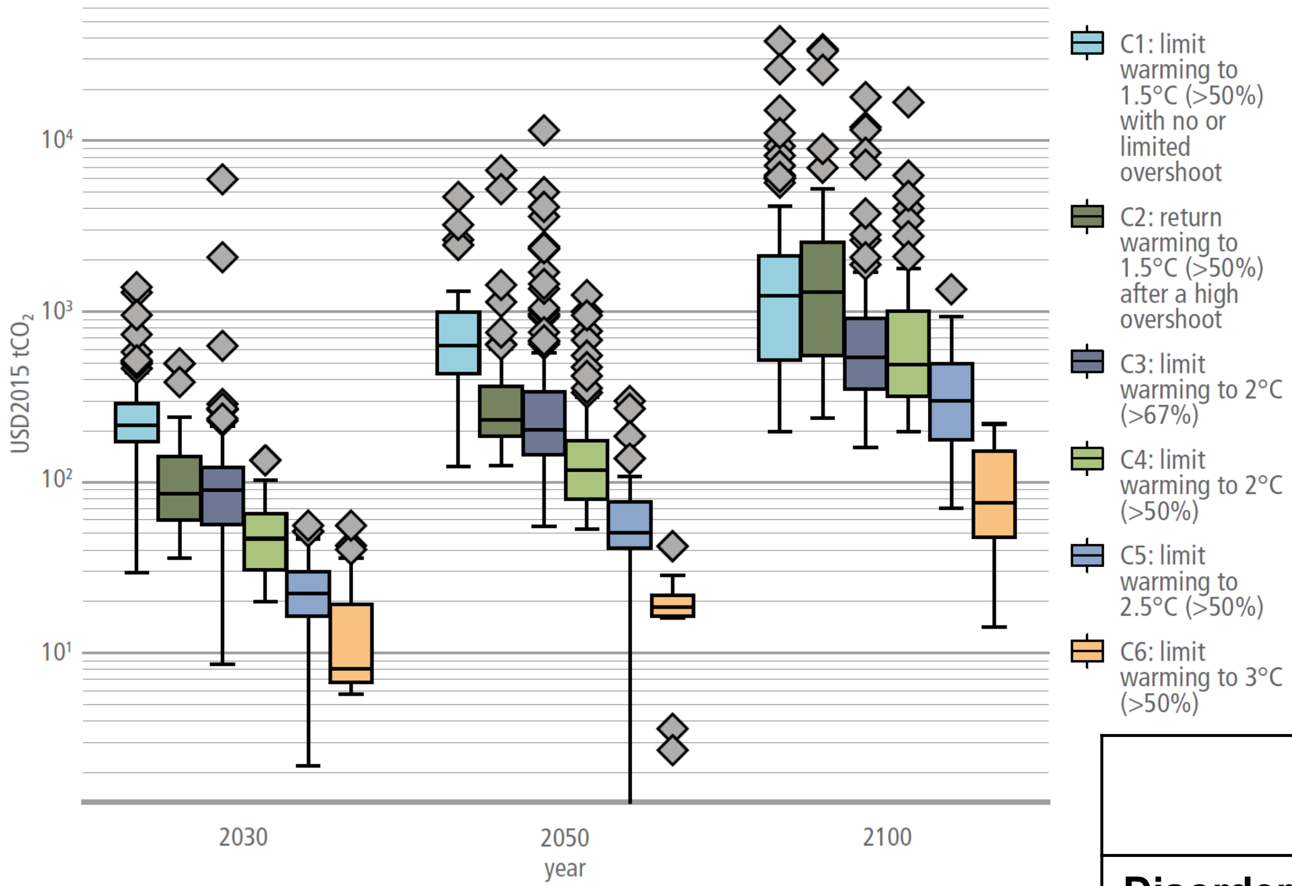
✓ いずれのシナリオも2030年以降高炉へのCCS導入および外部水素利用を進め、更に2040年以降は水素DRIへと転換することで2050年にほぼゼロエミッションとしている。ただし、Orderly 2.0Cでは2050年で一部排出が残る。

Final energy consumption in transport in Japan



- ✓ **2050年においても、Orderly 1.5Cを除いて、石油は一定程度残る。**
- ✓ **2040年頃からは2050年にかけて、水素、合成燃料等の利用が見られる。**

Comparisons in CO2 marginal abatement costs between the scenarios by the IPCC and this study



AR6, Fig. 3.33

IPCC AR6（2050年） 【25-75%タイル】
C3: 150～350 USD/tCO2程度
C2: 200～350 USD/tCO2程度
C1：450～1000 USD/tCO2程度

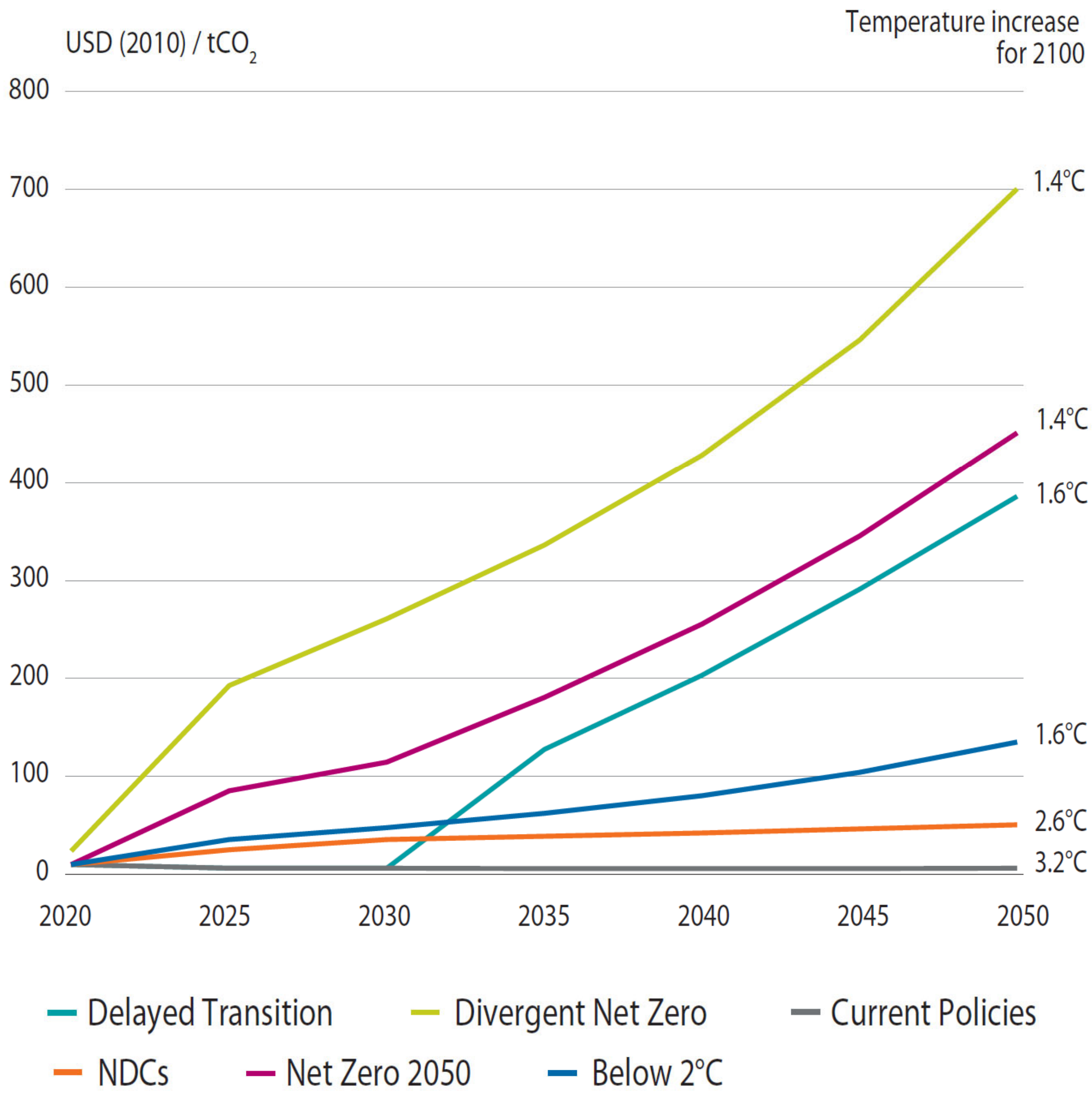
IEA WEO2022 NZE 【IPCC C1相当】
2050年炭素価格：180～250 $/tCO2
（IPCC報告、DNE21+シナリオと比較すると、かなり安価な推計

DNE21+シナリオ（2050年）

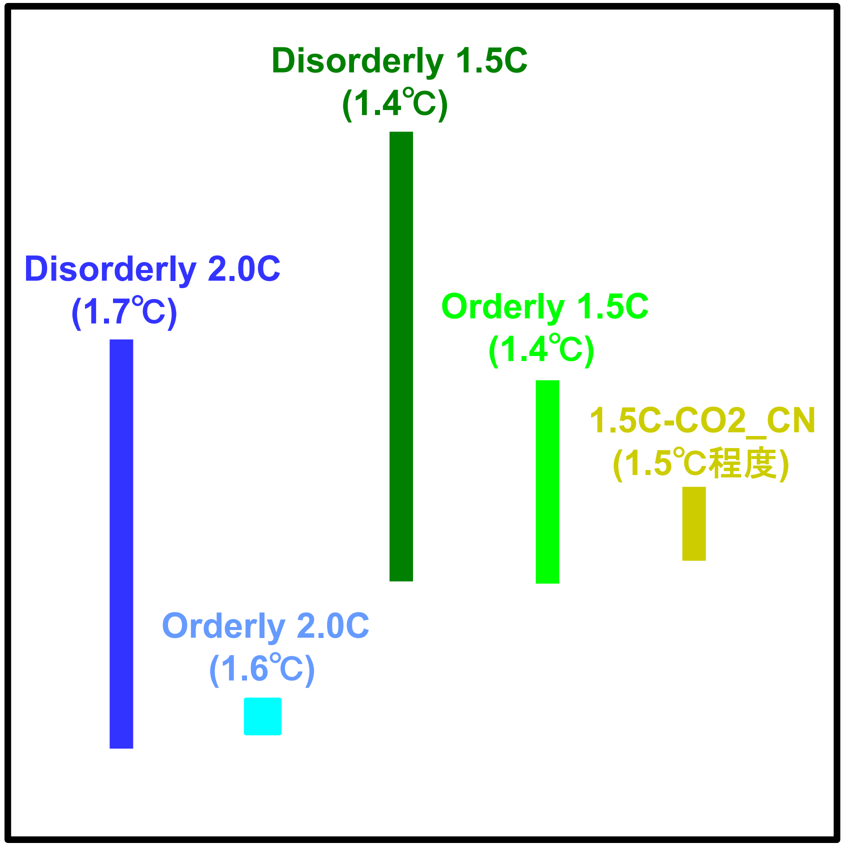
	CO2限界削減費用（炭素価格） $/tCO2eq.	IPCC
Disorderly 2.0C	119～500	C3
Orderly 2.0C	158	C3
Disorderly 1.5C	268～685	C2
Orderly 1.5C	268～465	C1
1.5C-CO2_CN	293～351	C1

IPCC報告の多くのモデルでは、限界削減費用の均等化の条件下で計算。DNE21+シナリオは、IPCC報告値と整合的な水準。なお、IPCCシナリオでは、DACCSの想定がほとんどなされていないが、DNE21+分析ではDACCSを想定している。そのため、2050年の費用は、IPCC報告のC1と比較すると若干安価な推計

Comparisons in carbon prices between the scenarios by the NGFS and this study



DNE21+シナリオ：2050年



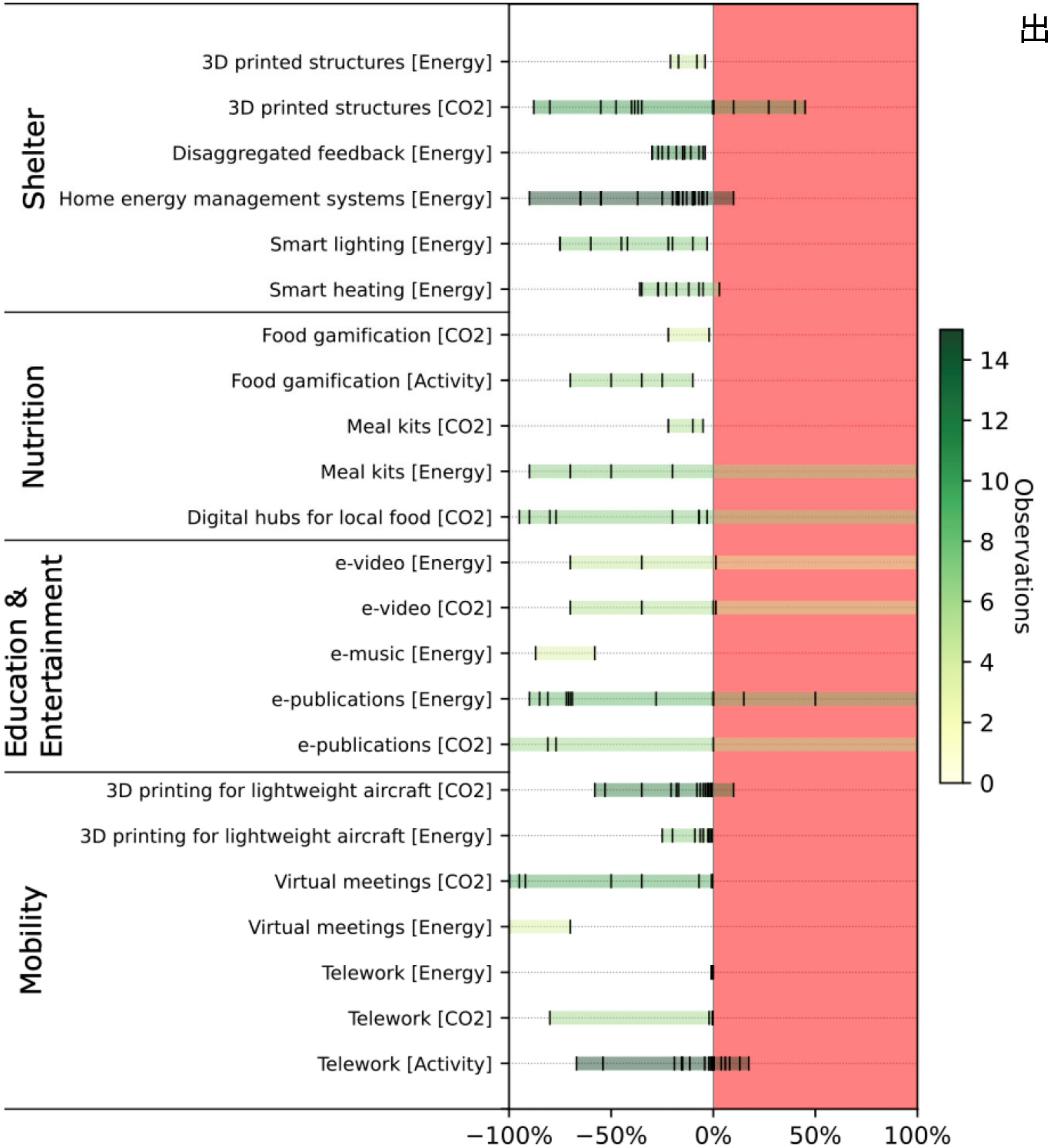
注）括弧内は2100年の気温上昇

- ✓ DNE21+ではDACCSを想定しているため、特に1.5℃シナリオでは、CO2限界削減費用（炭素価格）がNGFSシナリオよりも若干抑制される傾向有
- ✓ 全般的にはNGFS推計と整合的

3. Analyses on a low-energy society induced by DX

IPCC report: Impacts of DX on energy consumptions and CO_2 emissions

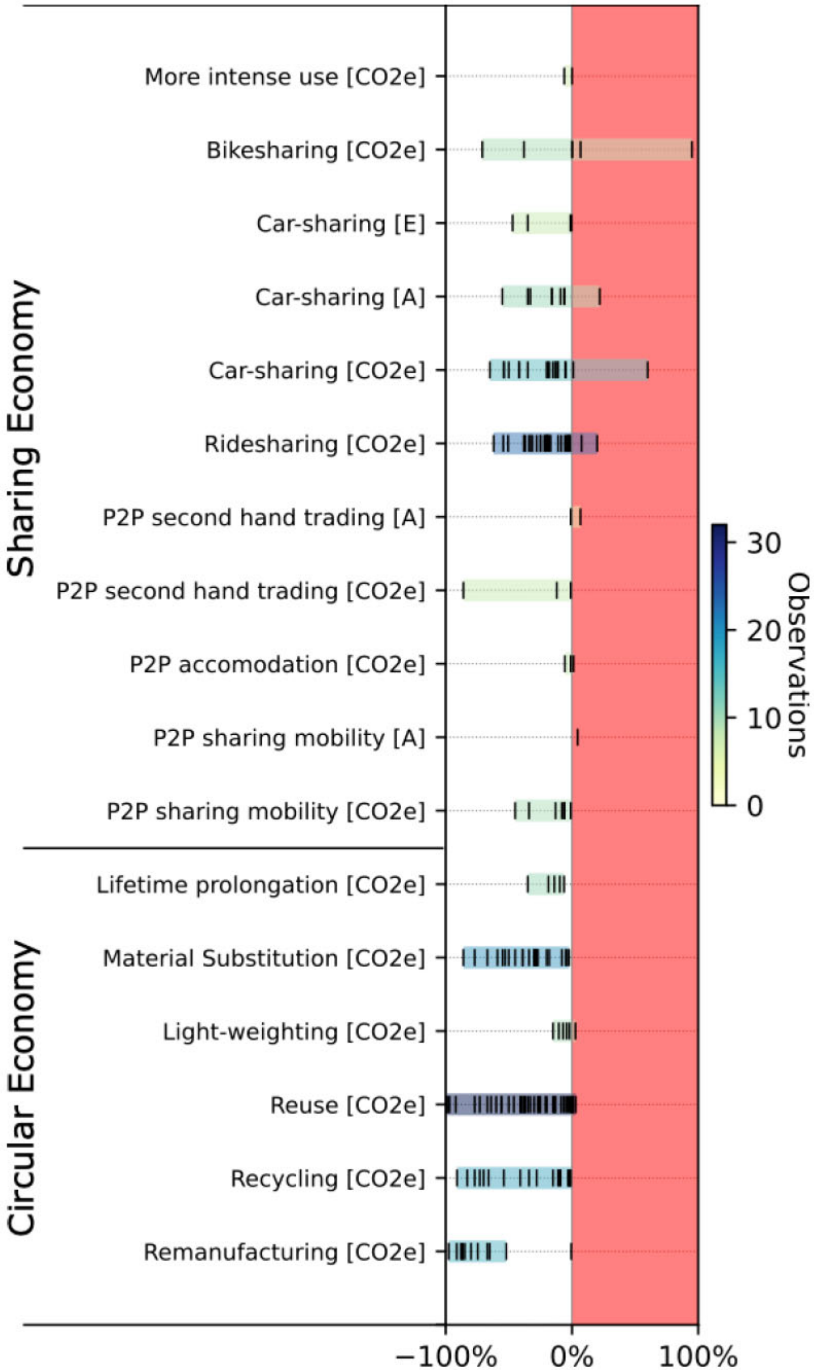
出典）IPCC第6次評価報告書 (2022), Fig. 5.12

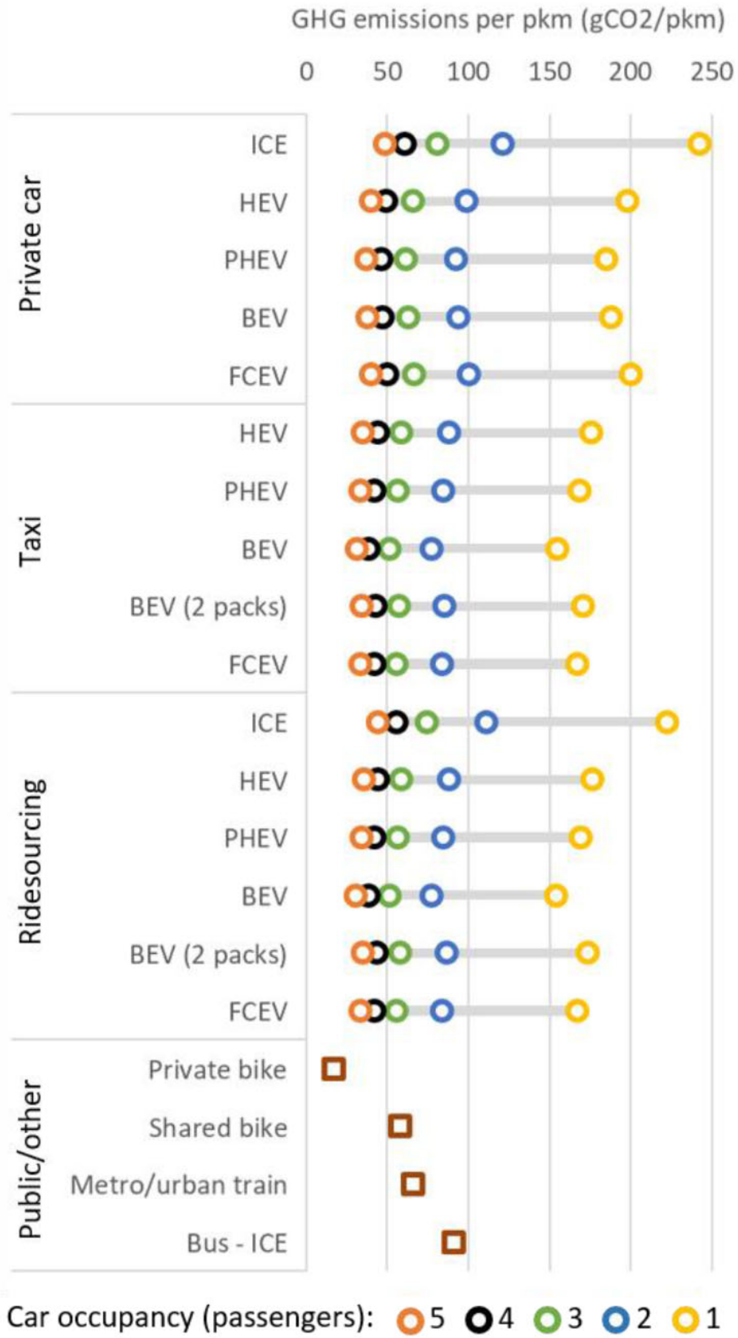


- ✓ 各種デジタル化によって、大きなエネルギー消費低減やCO_2排出量の低減が推計される。
- ✓ 一方、推計の不確実性は極めて大きい。大きなリバウンド効果もあり得る。

IPCC report: Impacts of sharing- and circular-economy on energy consumptions and CO_2 emissions

出典）IPCC第6次評価報告書(2022), Fig. 5.13

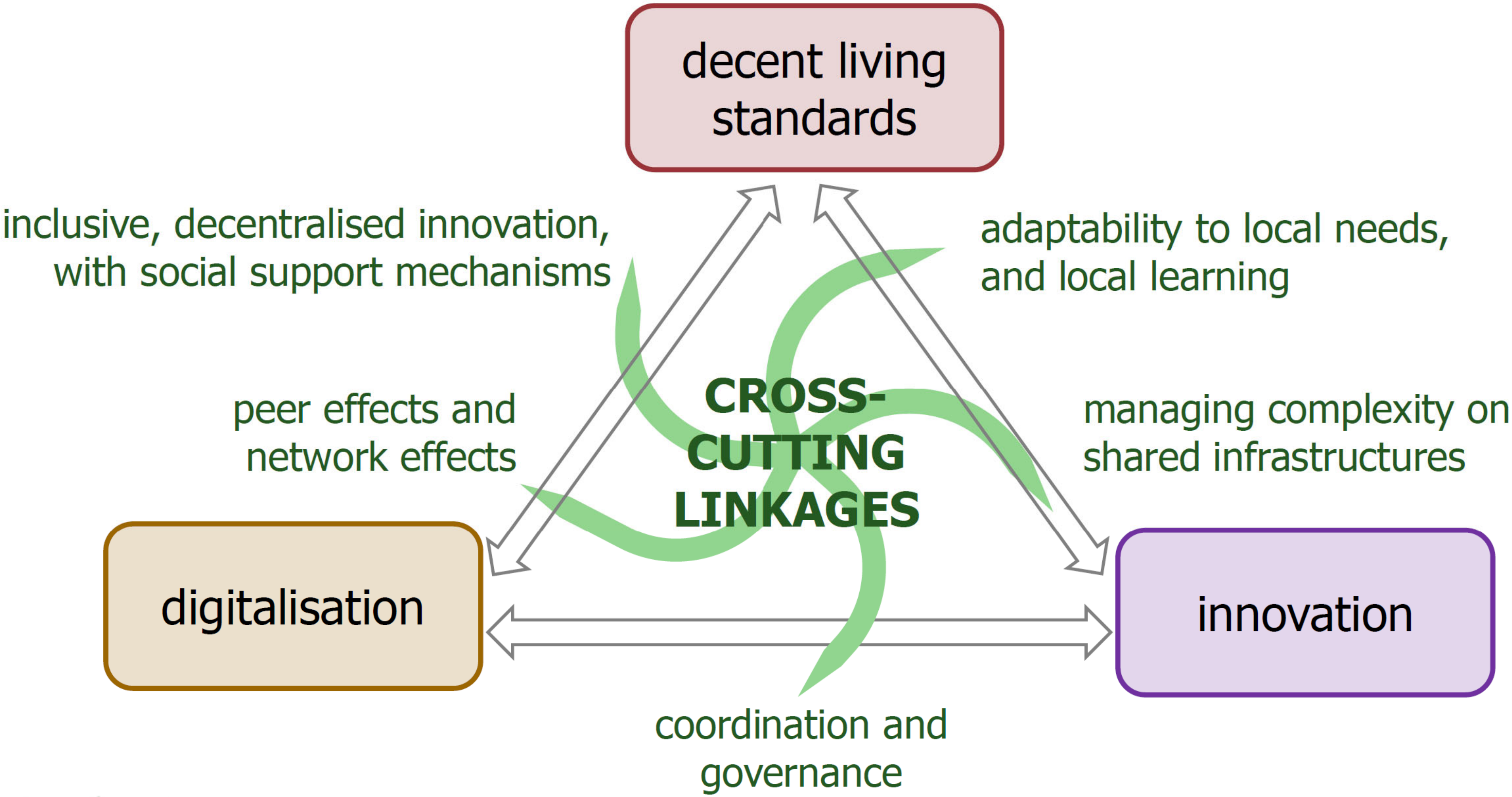




- ✓ シェアリングエコノミー・サーキュラーエコノミーによる排出削減余地は大きい。
- ✓ 一方、推計の不確実性は極めて大きい。

‘High-with-Low’ Narrative Scenario

high wellbeing with **low** resource use



Source: EDITS WG3 Narratives group (Arnulf Grubler, Greg Nemet, Shonali Pachauri, Charlie Wilson), The 'High-with-Low' Scenario Narrative (2022)

Circular-economy (CE) related Assumptions (1/2)

Changes due to digitalization	Direct impacts	Indirect impacts	Model assumptions (tentative)
1) Ride and car-sharing associated with fully autonomous cars	- Energy consumption reductions due to ride-sharing	- Reductions in consumption of basic materials, e.g., iron and steel, plastics, tire, glass, and concrete, due to reductions in number of cars associated with car-sharing - Reductions in freight shipping => 8)	- Iron and steel production: -4% compared with standard scenarios - Plastic production: -1% - Tire production (for cars): -28% - Glass production (for cars): -28% - Cement production: -1% (only for multi-storey car park)
2) Virtual meeting and teleworking	- Reductions in travel service demand and the associated reductions in energy consumptions in transport sector	- Potential reductions in numbers of commercial building, and the resulting reductions in iron and steel, concrete, and others *[Not yet considered]*	- Reductions in person-km travel by passenger cars, buses, and aircraft by 10%
3) E-publication etc.	- Reductions in paper consumptions due to large deployment e-publications etc.	- Potential reductions in freight services for papers. *[Not yet considered]*	- Reductions in paper/pulp by 20%
4) Recycling and reductions in apparels due to e-commerce and other digitalization	- Reductions in energy consumptions for apparel productions	- Potential reductions in energy consumption at shopping centers etc., and the resulting reductions in iron and steel, concrete, and others *[Not yet considered]*	- Reduction in new productions of apparels by 20%. No explicit modeling for apparels in DNE21+, and corresponding reductions in energy consumption in textile and leather sector by 20%

Red: residential sector, Green: commercial sector, Blue: transport sector, Purple: industry sector , Brown: Non-CO2 GHGs etc.

Circular-economy (CE) related Assumptions (2/2)

Changes due to digitalization	Direct impacts	Indirect impacts	Model assumptions (tentative)
5) Longer life time of buildings due to improv. in city planning	- Potential Reductions in cement and steel due to longer life time of buildings		- Longer lifetime of building: +40%; the related reductions in cement (-3%) and steel (-3%) productions
6) Reductions in food losses due to better demand projection	- Reductions in nitrogen fertilizer, plastics, etc. and the resulting energy consumption reductions - Potential reductions in energy consumption at supermarkets etc. - Red. in CH4 and N2O	- Reductions in freight shipping services => 8) - *Pot. red. in construction for supermarkets etc., and the resulting reductions in steel, concrete, and others [Not yet considered]* - *Pot. increases in afforestation due to increase in rooms of land area [Not yet considered]*	- Reduction in petrochemical products including ammonia by 1% - Reduction in plastics by 1% - Reduction in paper and pulp by 0.5% - Reduction in transport services by 1% and others (according to I/O analysis results) - Reduction in CH_4 and N_2O emissions: -493 $MtCO_2eq/yr$ in 2050
7) AM (3D-printing) for applying aircraft	- Reduction in aluminum and steel production - Reduction in electricity for productions	- Energy efficiency improvements of aircraft and the energy consumption reductions - *Energy efficiency improvements of cars and the energy consumption reductions [Not yet]*	- Red. in aluminum and steel prod. by 1% and 0.02%, respectively - Reduction in elec. consumption by 1% - Increase in energy efficiency of aircraft by about 10%
8) Red. in freight shipping services due to red. in basic materials and products	- Energy consumption reductions in freight shipping		- Reduction in freight shipping demand by 1%

Red: residential sector, Green: commercial sector, Blue: transport sector, Purple: industry sector , Brown: Non-CO2 GHGs etc.

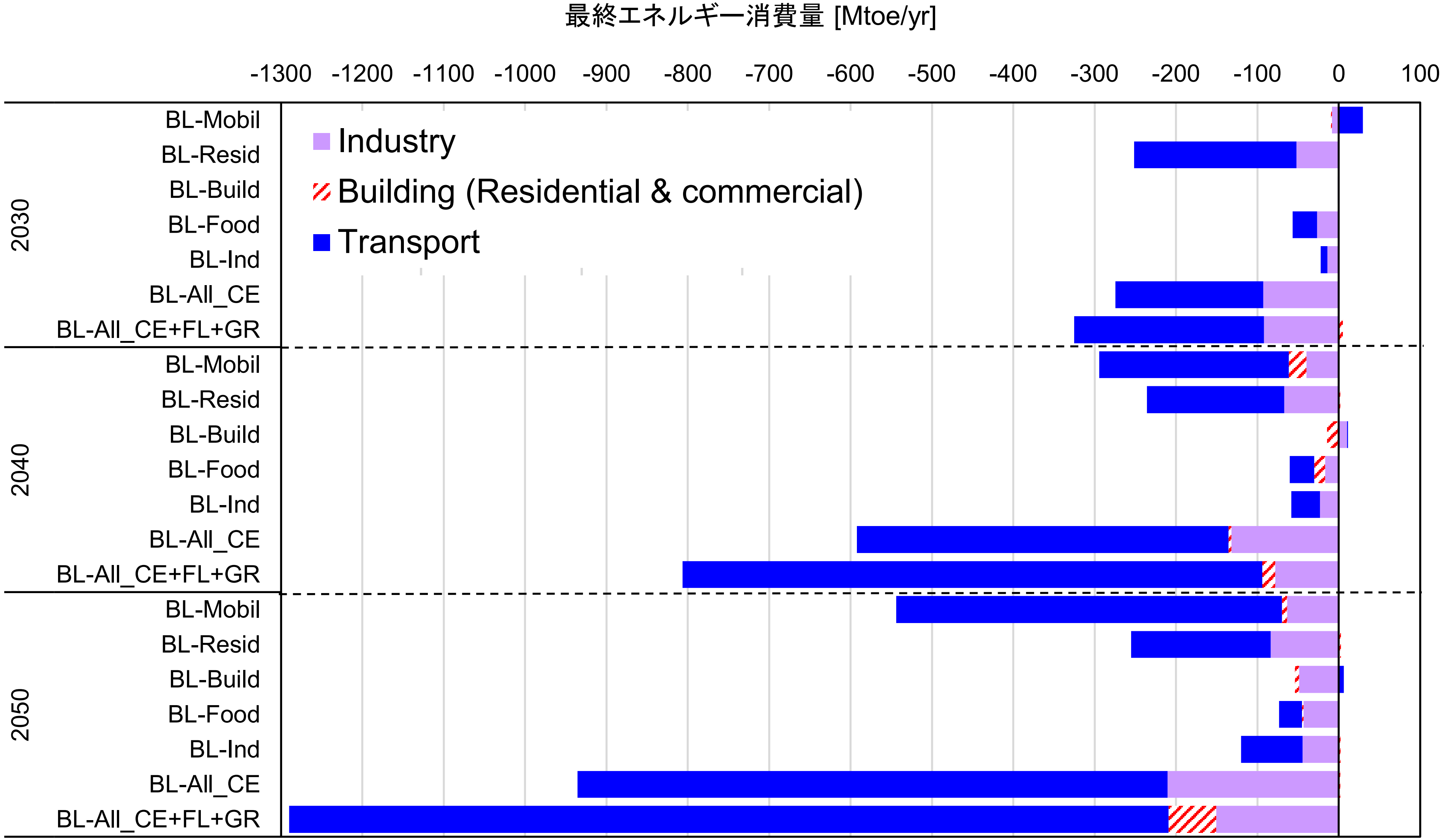
Scenario assumptions

	Emissions reduction	Energy demand reductions due to mainly digitalization						Rapid cost red. in granular tech's, e.g., PV, Wind, EV	Demand flexibilities in electricity (EV, HP, CGS)
		Transport 1)	Resid. 2, 3, 4)	Building 5)	Food 6)	Industry 7)	Spillover 8)		
BL-Std	**Baseline** (non specific climate policies)	—	—	—	—	—	—	—	—
BL-Mobil		X							
BL-Resid			X						
BL-Build				X					
BL-Food					X				
BL-Ind						X			
BL-All_CE		X	X	X	X	X	X		
BL-All_CE+FL		X	X	X	X	X	X	X	
BL-All_CE+FL		X	X	X	X	X	X	X	X
B2DS-Std	**B2DS** (well below 2C; NDCs in 2030; CN by 2050 in G7 countries)	—	—	—	—	—	—	—	—
B2DS-Mobil		X							
B2DS-Resid			X						
B2DS-Build				X					
B2DS-Food					X				
B2DS-Ind						X			
B2DS-All_CE		X	X	X	X	X	X		
B2DS-All_CE+FL		X	X	X	X	X	X	X	
B2DS-All_CE+FL		X	X	X	X	X	X	X	X

注1）今回の分析では、IPCC等で用いられている共有社会経済パス（SSP）は、中位的なSSP2ベースで分析
注2）本来、DXによる電力消費量の増大等のリバウンド効果も考えられるが、CO2限界削減費用低下に伴うリバウンド効果以外のリバウンド効果は今回考慮していない

Changes in global final energy consumption under the CE scenarios

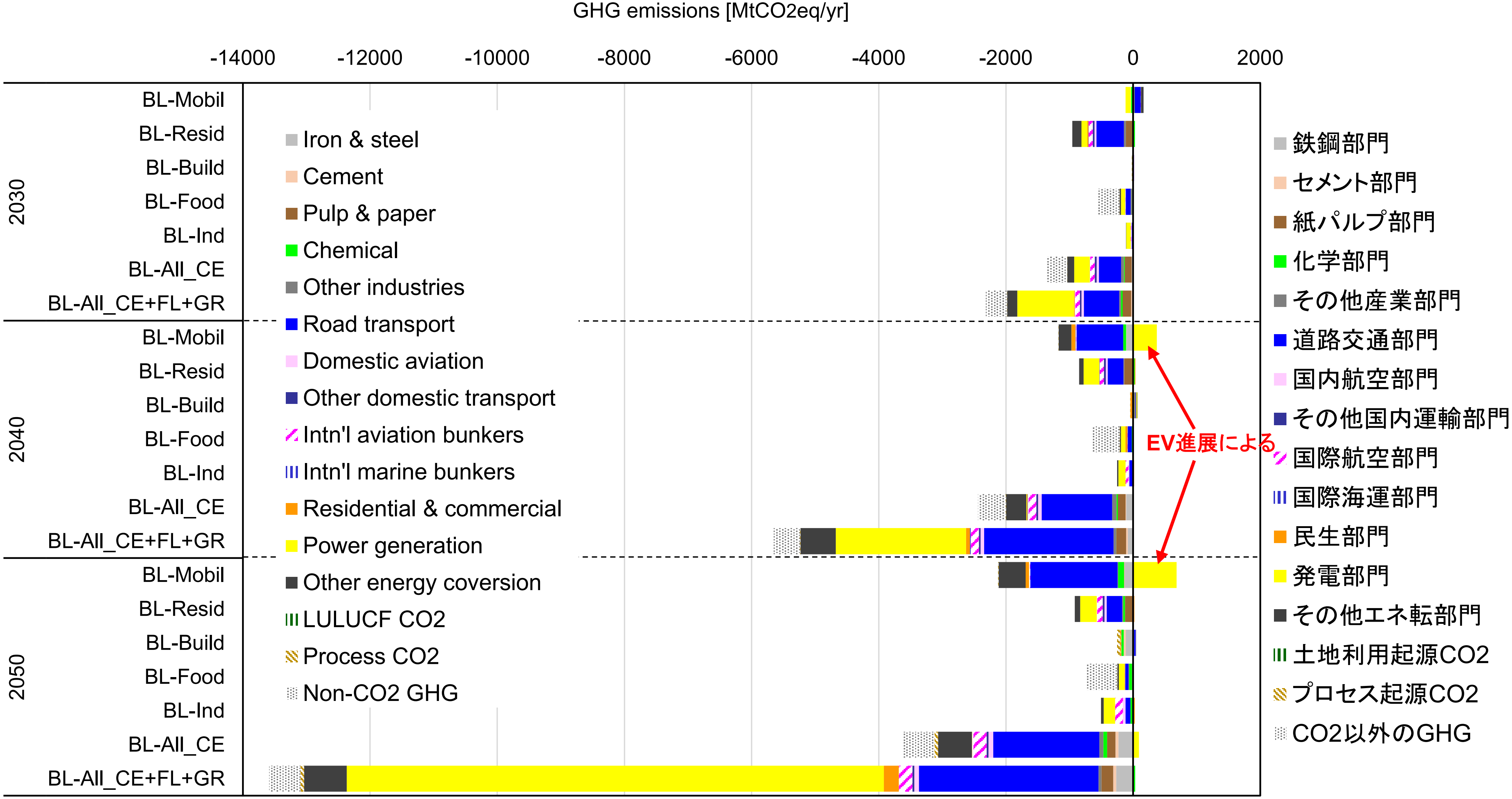
Baseline (w.o. specific climate policies)



✓ かなり限定された波及効果のみを考慮した分析段階ではあるものの、想定したサーキュラーエコノミー・シェアリングエコノミー実現によって部門横断的に大きな省エネ効果が期待できる。

Changes in global GHG emissions under the CE scenarios

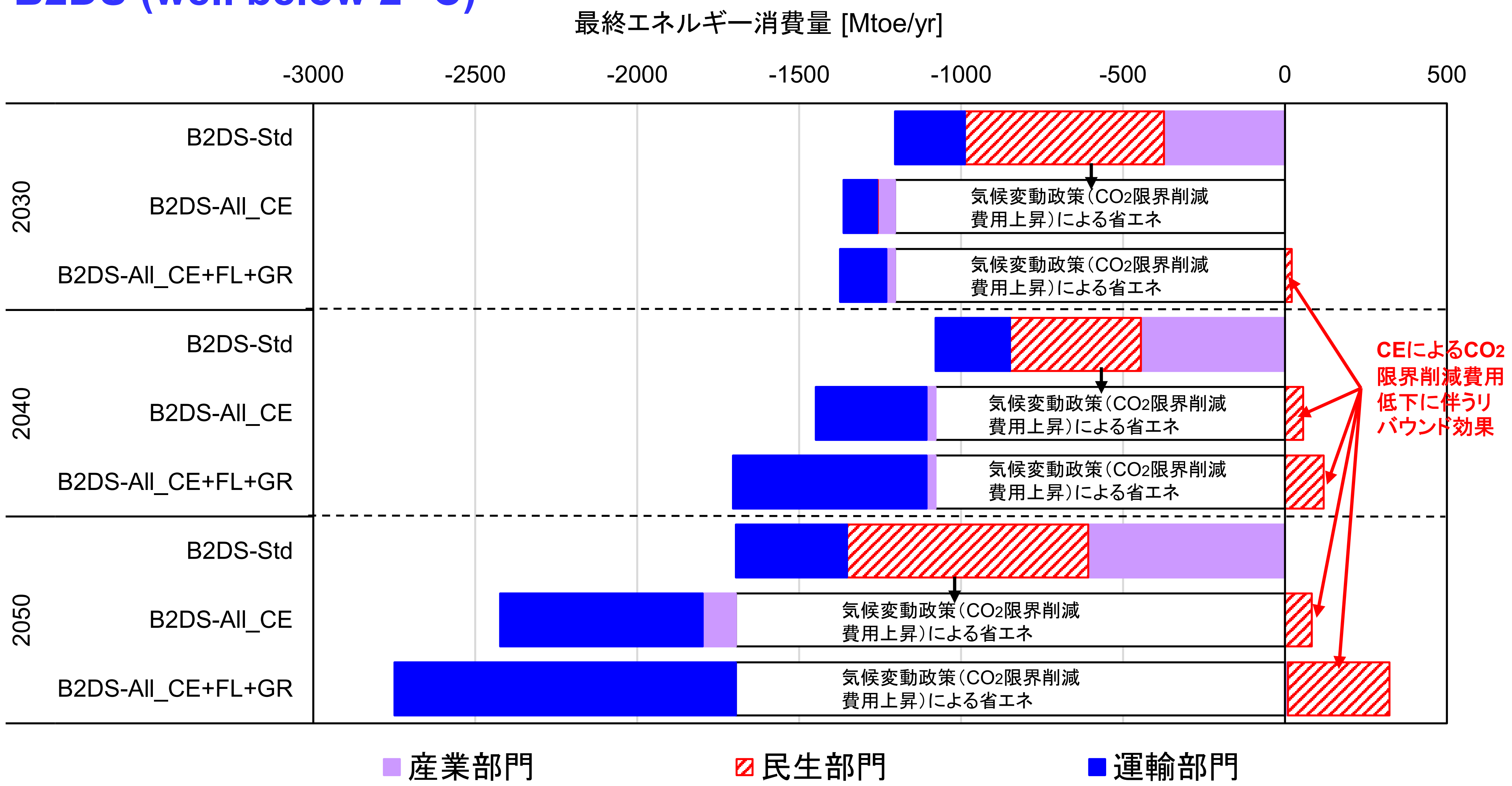
Baseline (w.o. specific climate policies)



✓ かなり限定された波及効果のみを考慮した分析段階ではあるものの、想定したサーキュラーエコノミー・シェアリングエコノミー実現によって部門横断的に大きなGHG排出削減効果をもたらし得る。

Changes in global final energy consumption under the CE scenarios

B2DS (well below 2 °C)

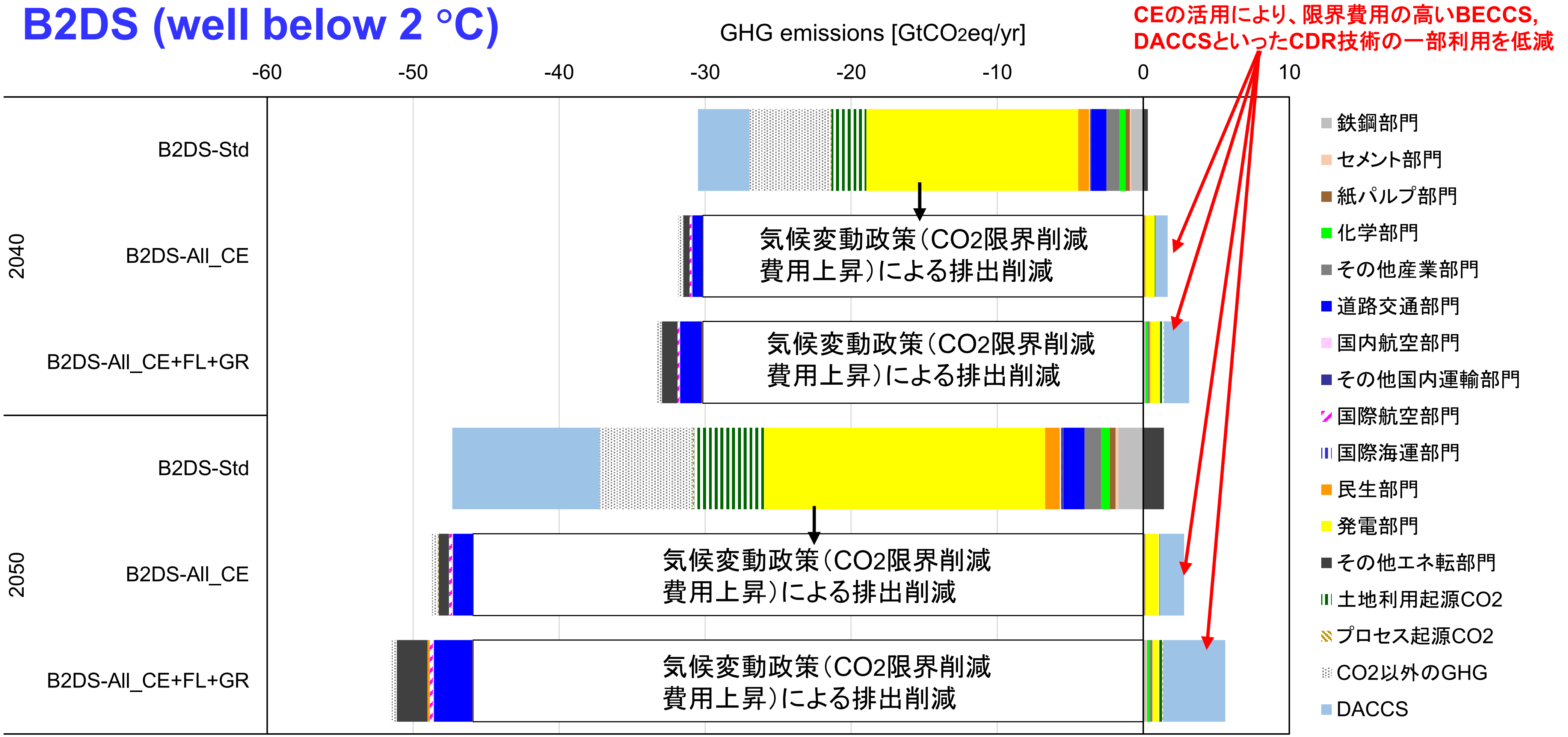


参考）2019年の世界の最終エネルギー消費量実績値：10 Gtoe/yr、2050年のベースラインの最終エネルギー消費量推計値：14 Gtoe/yr

✓ **かなり限定されたCEの事例および波及効果のみを考慮しただけでも、2050年では、現在の世界の最終エネルギー消費量全体の6%程度、また、2℃目標下で経済合理的と推計される省エネ量の半分程度もの省エネが、サーキュラーエコノミー・シェアリングエコノミーによって更に追加できる可能性が示唆される。**

Changes in global GHG emissions under the CE scenarios

B2DS (well below 2 °C)



参考)2019年の世界のGHG排出量実績値:59 GtCO2eq./yr、2050年のベースラインの排出量推計値:73 GtCO2eq/yr

- ✓ **排出削減目標が決まっている条件では、想定したサーキュラーエコノミー・シェアリングエコノミー対策は相対的に費用が安価なため、限界的な費用の対策と評価される、CCS付きバイオエネルギー(BECCS)や大気中CO_2直接回収貯留(DACCS)といった二酸化炭素除去(CDR)技術への寄与を低減し得る。**
- ✓ **なお、最終エネルギー消費量の低減効果は大きいが、CO_2削減効果は、エネルギー供給側のCO_2原単位低減も伴っているため、エネルギー消費量ほど、大きくは算定されない。ただし、費用低減効果がある(後述スライド)。**

Decreases in global emissions reduction costs

Reductions in energy systems costs：under CE scenarios (Billion USD/yr)

	Scenarios	Mobil	Resid	Build	Food	Ind	All_CE	All_CE +FL	All_CE +FL+GR
2030-2040年の間の年平均値	Baseline	▲547	▲339	▲1	▲57	▲4	▲894	▲894	▲963
	B2DS	▲556	▲352	▲0	▲64	▲5	▲926	▲928	▲1038
2040-2050年の間の年平均値	Baseline	▲1601	▲459	▲1	▲74	▲7	▲1971	▲1971	▲2085
	B2DS	▲1635	▲477	▲6	▲90	▲14	▲2037	▲2038	▲2266

CO_2 marginal abatement costs for B2DS (USD/tCO_2eq)

	B2DS-Std	B2DS_All-CE	B2DS_All-CE+FL	B2DS_All-CE+FL+GR
2040年	68–310	57–238	57–240	50–195
2050年	146–739	123–524	122–522	60–364

注）費用の幅は国による差異（主要先進国に別途2050年CN制約を想定していることによる）

- ✓ DXに誘因されたCEの推進により、エネルギーシステムコストの大きな低下が推計される。
- ✓ 2℃目標等の長期目標の実現において、CO_2限界削減費用の低下（2～3割程度）が期待できる。

4. Conclusion

Conclusion

- While most of the countries set ambitious long-term goals, the real global emissions are still increasing. The leakages of CO2 intensive industries from developed to developing countries can be observed.
- Several options of emissions reduction, including energy savings, electrification, renewables, nuclear power, CCUS/CDR, batteries/energy storage, hydrogen-based energy source (e.g., hydrogen ammonia, e-methane, e-fuels) will be required for achieving CN. There are no silver bullet technologies, and all the technologies have uncertainties in technology improvements in the future and some social constraints. A risk hedging strategy having plural scenarios will be required.
- Large emissions reduction costs are estimated for CN. Achieving a low energy demand society induced by DX can help reduce the costs. It is important to implement DX for green transformation GX, while the policies with cross-sectoral measures are not easy.
- The emission reduction measures in transition toward CN are also important. The cost-efficient measures are different across regions/countries and sectors. The measures without cost-efficient could induce industrial leakages and hinder the emissions reduction at a global level.
- Sharing such scenarios with comprehensive and quantitative analyses with several stakeholders will help an effective emissions reduction.

Appendix

Three assessment models for climate change mitigation in the NGFS scenarios

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

Source: NGFS (2022)

Global CO2 emissions and sectoral emissions of IEA WEO2022 NZE

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