ALPS International Symposium

Toranomon Hills Forum

February 13, 2020

Transformation of energy systems for carbon neutrality and the role of innovation

Keigo Akimoto

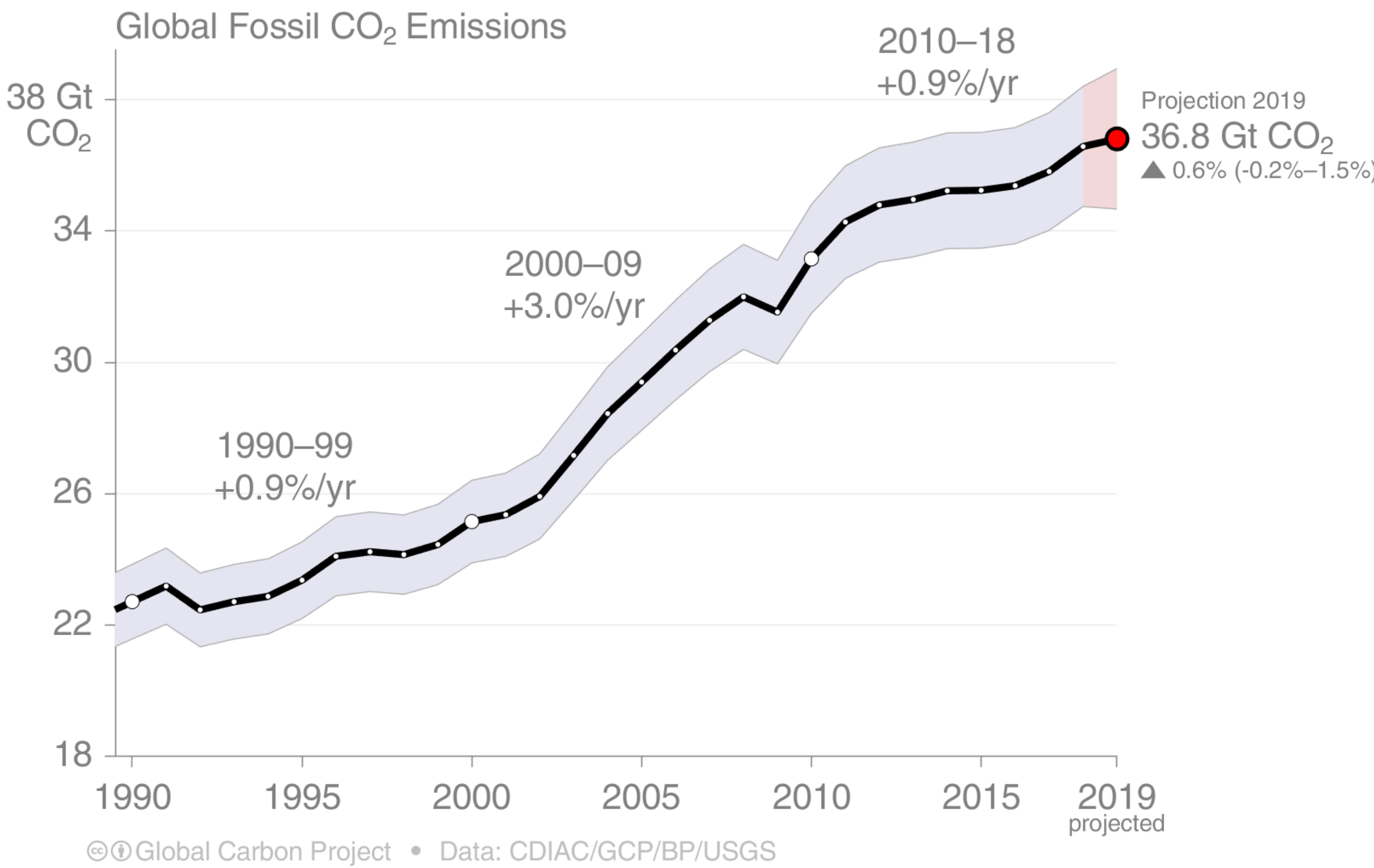
Group Leader, Systems Analysis Group

Research Institute of Innovative Technology for the Earth (RITE)

Contents

1. The status and ways of climate change response measures

Global CO2 emissions



Source: Global Carbon Project

- The increase rate of global CO2 emissions has been rapidly since 2000 although some international frameworks on climate change had been developed such as the Kyoto protocol in 1997.
- Between 2013 and 2016, the emissions were almost constant, because the adjustment for productions of iron & steel, cement etc. particularly in China, and shale gas in the US had large impacts on the emissions. After 2017, the emissions are increasing again with finish of the production adjustment.

Complexity of Int'l & Domestic Politics

♦ US: Trump Administration

- Announced in June 2007 its intention to withdraw from the Paris Agreement because of a negative impact on US industry, economy and employment and its benefits to other countries. ("I was chosen by US citizens, e.g. Pittsburgh, not the citizens of Paris.")
- Employment issues in manufacturing led to the Trump's inauguration
- Promoting policies that lower energy prices, e.g. shale gas development and coal utilization. CO2 emission regulatory policies are being abolished
- Negotiations on the topic of climate was also the most challenging one at the G20 Osaka with the negative position to the Paris by the President Trump.

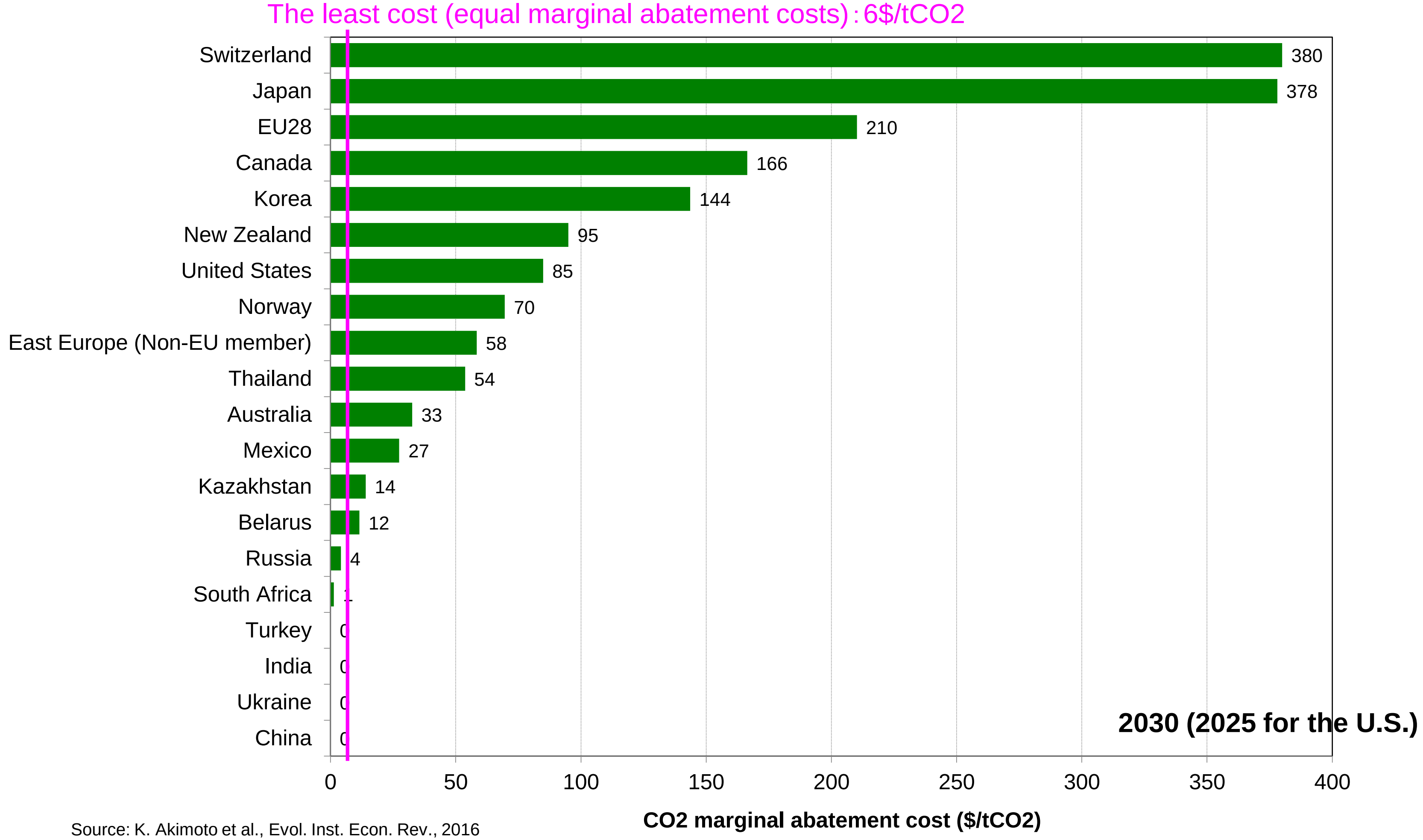
♦ France: Movement of yellow vests

- Massive protests began in November 2018 in opposition to the fuel tax hike. It irked rural residents who do not have valid alternative transport
- By globalization, it appears to be linked to the worsening employment conditions for manufacturing workers (rural middle class), and has a similar background to the US Trump's inauguration and the UK Brexit

- ■ The Bolsonaro administration inaugurated in January 2019 in Brazil also dismisses the Paris Agreement. (Originally, 2019 COP25 was scheduled to be held in Brazil, but changed to Chile (The venue was changed to Spain due to riots against subway fare increase in Chile))
- ■ The COP25 in December 2019, in effect, did not agree on key issue negotiations.

CO_2 marginal abatement costs of NDCs: Additional Costs by non-uniform MACs

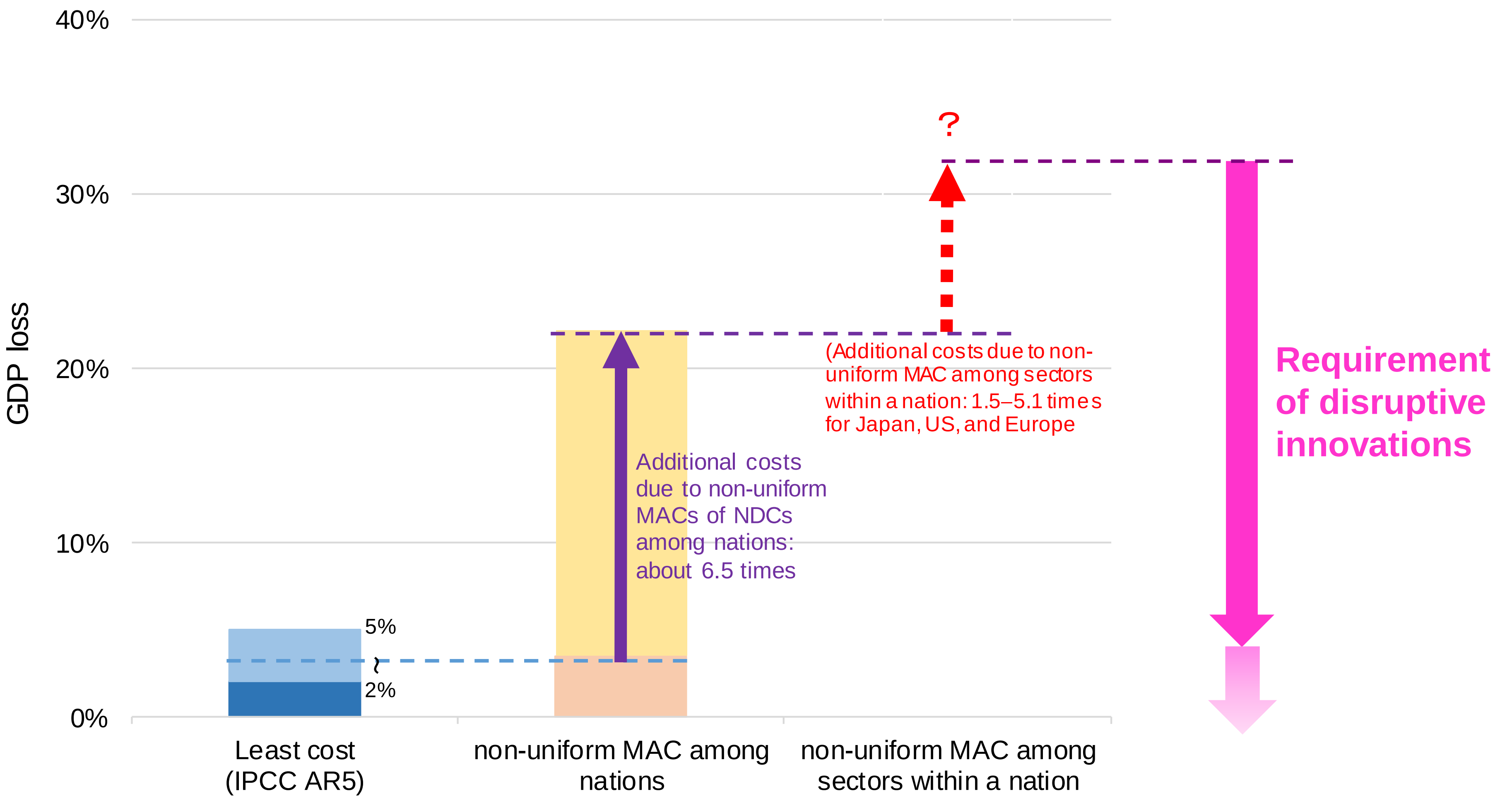
【World GDP loss due to mitigation】NDCs:0.38%; the global least cost：0.06%



Source: K. Akimoto et al., Evol. Inst. Econ. Rev., 2016

- Emission reduction costs are an important indicator for measuring emission reduction efforts.
- The estimated marginal abatement costs of NDCs are largely different among countries, and the mitigation costs are much larger than those under the least cost measures due to such large difference in marginal abatement costs.

Image of global GDP losses for 2 °C target and requirement of disruptive innovations



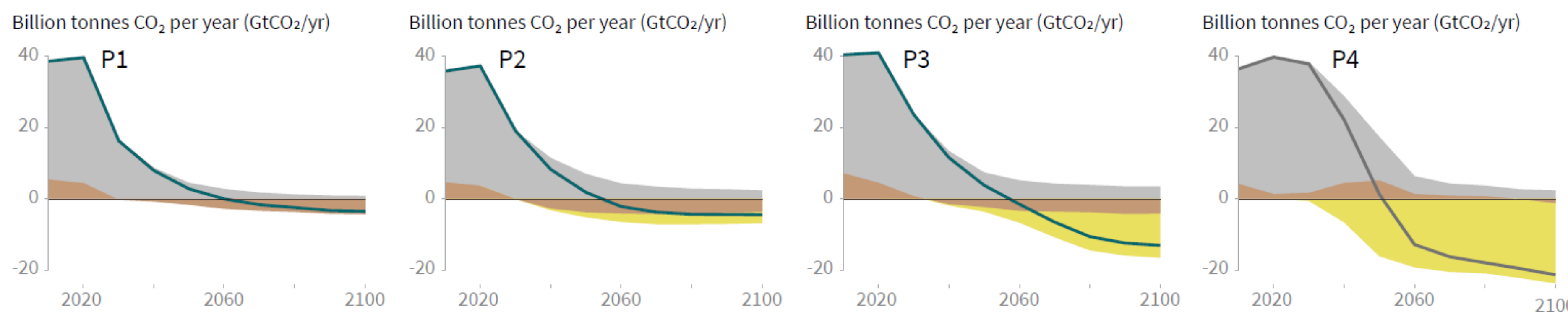
For Carbon Neutrality

- **Final energy sources are required to be electricity and hydrogen in principle (+ bioenergy and direct heat use by solar heat etc.). Fuel cells by hydrogen provide also electricity for final use.**
- **Syn. methane from CO_2-free hydrogen and recovered CO_2 can be used for final energy.** (In this case, recovered CO_2 plays only a carrier for hydrogen energy.)
- **Productions of electricity and hydrogen are required to be decarbonized using renewables, nuclear power, CCS etc.**
- **However, the completely no use of hydrocarbon will be unrealistic, and therefore, even for carbon neutrality (net zero emissions), some gross emissions combined with negative emission technologies (NETs) of forestation, bioenergy with CCS (BECCS), DACS etc. can be accepted as real world response measures.**
- **Because the scenarios based on strong dependence on NETs will be weak in achievability and exert high negative impacts on biodiversity, (economically autonomous) low energy demands will be important for the achievement of decarbonized society.**
- **The transition to decarbonization is inevitable. Emission reductions should be implemented, considering total costs of both climate change damages and mitigation costs on the way to decarbonization.**

Categorization of deep emission reduction scenarios

Fossil fuel and industry AFOLU BECCS

Source: IPCC SR15



LED
(Low energy demand scenario; technological and social innovation in end-use: large)

SSP1
(large expansion of service industries)

SSP2
(Middle scenario)

SSP5
(tech. improvement of fossil fuel mining: large)

Barrier of tech. development — **High?**

Barrier of tech. develop. and deployment — **High?**

Depend on NETs: Low → High

Final energy consumption: Low → High

Mitigation costs (difficulty in mitigation): Low → High

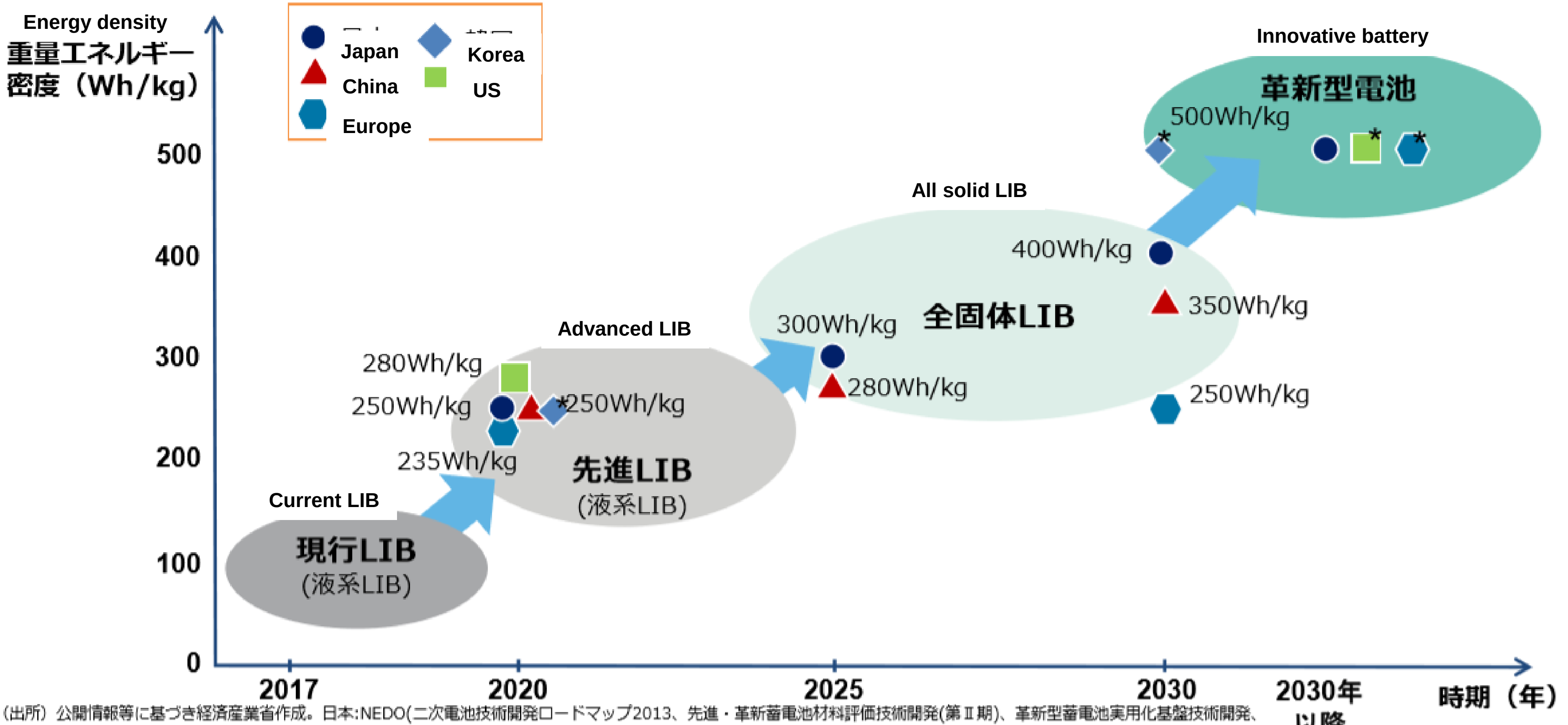
Depend on adaptation (under the achievability of mitigation): Low → High

Multiple achievement of SDGs: Relatively high achievability → Relatively low achievability

✓ **The comprehensive risk management is important and different kinds of technologies must be prepared for the possible deployment under large uncertainties.**

2. Role and issues of energy storage technologies

Goals of technology development of battery



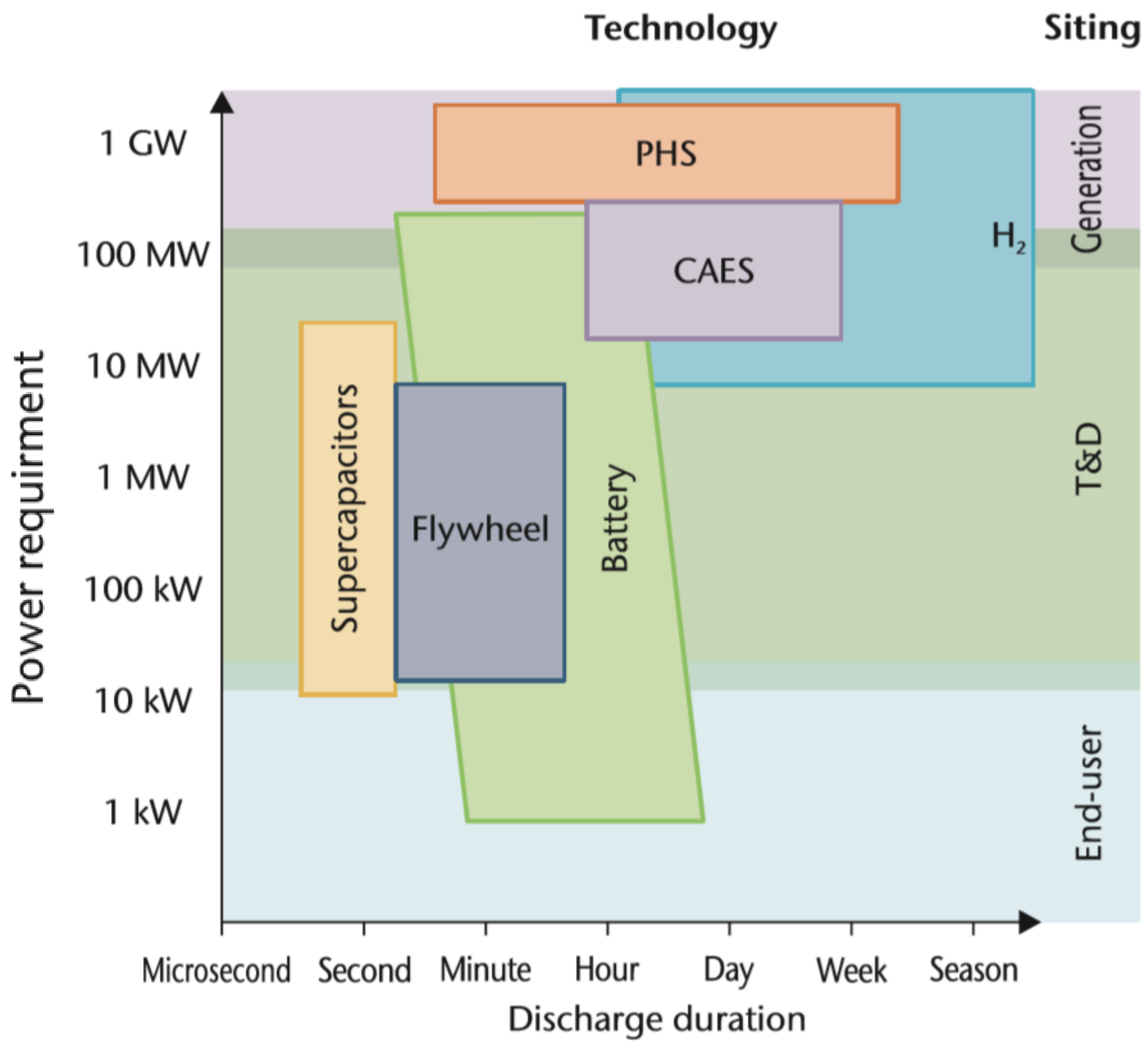
（出所）公開情報等に基づき経済産業省作成。日本:NEDO(二次電池技術開発ロードマップ2013、先進・革新蓄電池材料評価技術開発(第Ⅱ期)、革新型蓄電池実用化基盤技術開発、中国:中国汽車工程学会 (省エネルギー車と新エネルギー車の技術ロードマップ)、欧州:欧州委員会(Set-Plan/Action7/Declaration on Batteries and E-mobility」,「Horizon2020 (ALISE)」)、米国:DOE(Annual Merit Review and Peer Evaluation Meeting(2016),Battery500 project)、韓国:エネルギー技術評価院(エネルギー技術ロードマップ2013)、

※電池セル値である場合は、0.8掛けをしてパック値として算出。*は電池セルかパックか不明。

Source) METI 自動車新時代戦略会議資料

The performance of batteries is improving. Much larger improvements are not visible at present, but will be expected.

Electricity storage technologies: cover ranges



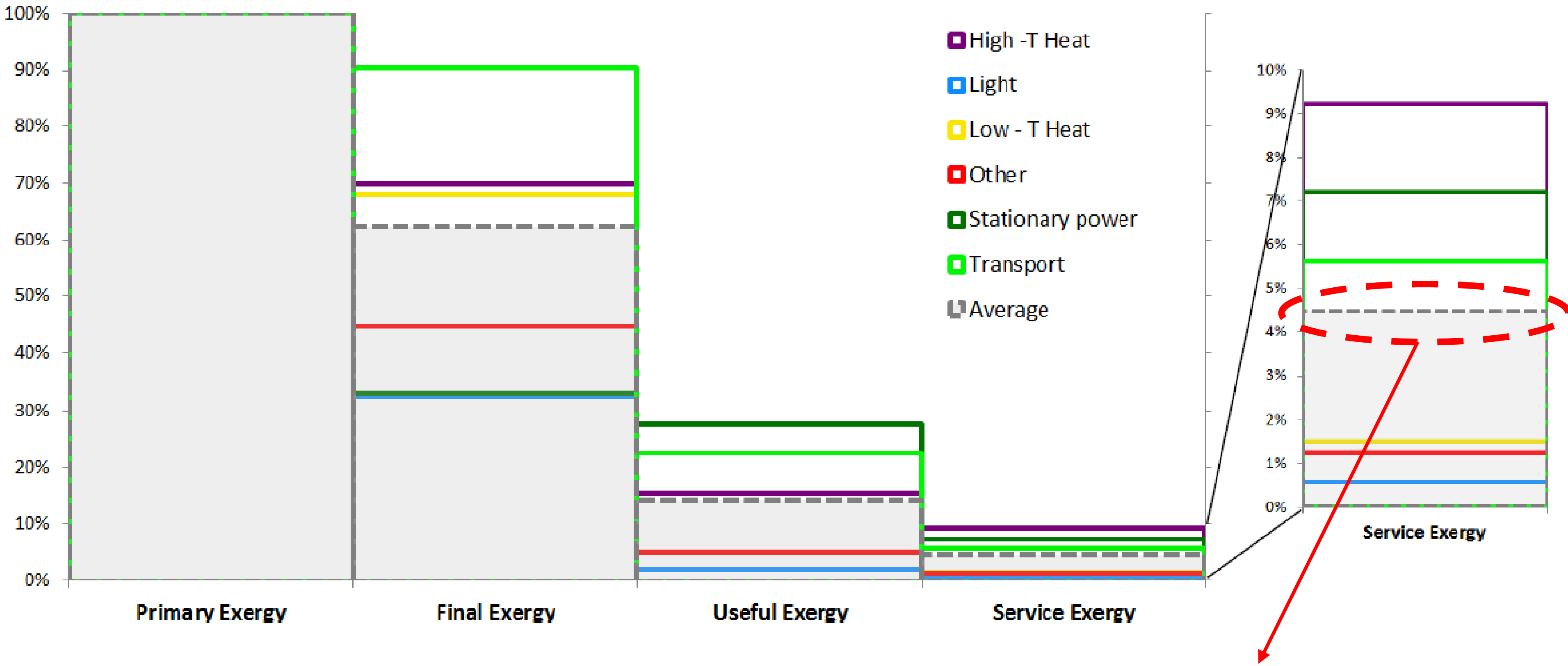
Source: IEA Technology Roadmap–Hydrogen and Fuel Cell、2015

Technologies for energy storage will have different advantageous areas.

3. Potential drastic changes of energy demands induced by progresses of digitalization

Global Exergy by Sector

Exergy of primary energy = 100



Source) A. Grubler (IIASA), ALPS International Symposium (2016)

Required services need only 4-5% of primary energy consumption.

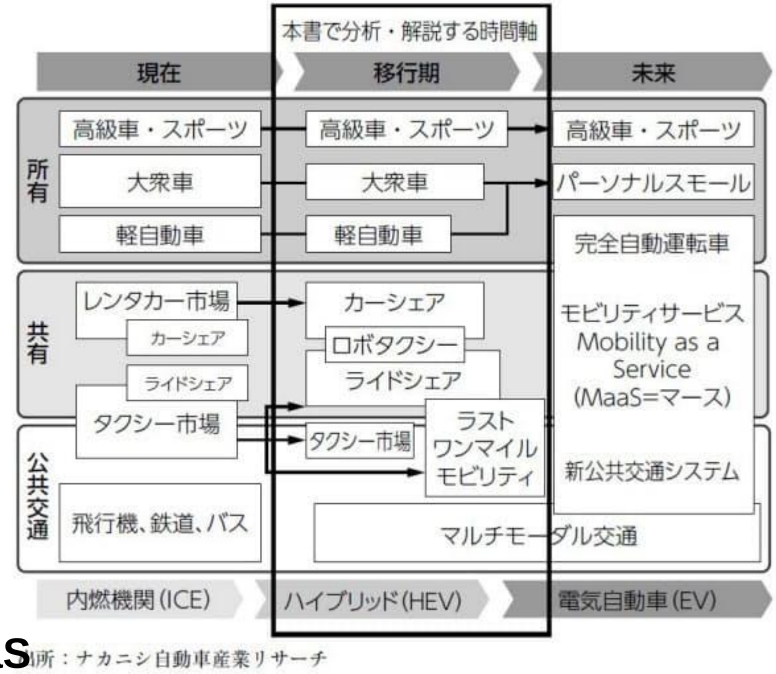
There is large room to improve energy productivity in end-use sectors. However, currently there are large barriers to enjoy the possible productivity improvement because of hidden costs. IT, AI and other related technologies may overcome the barriers at affordable costs.

Transport: CASE

Connected; Service & Shared

Autonomous; Electric

Operation ratio of automobiles is about 5%. The large room for the improvement exists by the achievement of fully autonomous cars.



EV "e-Palette" only for Autono-MaaS

photo

Changing the shape of cars

Possibility of integration of cars and near distance airplane

Airbus, Audi

The sharing may reduce number of cars and the consumptions of materials, and change the form of cities.

Source) Jari Kauppila, ALPS International Symposium (2019)

Publication

- Progresses of digitization
- Reduction of paper medium books and newspaper circulation (Paper reduction, Embodied energy reduction)
- Decrease of physical bookstores (Energy reduction for construction and maintenance, Energy reduction for access to physical bookstores)
- Newspaper delivery declining? (Reduction of transport energy）

Apparel

- It is said that 50% of clothes are unused and disposed.
- Preference changes especially among young generations, e.g. wearing suits is not popular among young people, and progress of E-commerce, e.g. anything is available without traveling.
- Just-in-time system using AI / ICT, enabling accurate demand forecast and not dependent on mass production.
- Large spaces for display and huge energy for construction and air conditioning are needed in large commercial facilities, however, they would be reduced.
- As department stores and large commercial complexes become less popular, there will be less necessity to own cars and it could accelerate car-sharing.

E-commerce
incl. used goods trading or sharing clothes

amazon	Alibaba
rakuten	mercari

Changes in department stores and large commercial complexes

These are technological or social changes not directly driven by global warming countermeasures.

Food

- It is regarded that approx. 30% of GHG emission (even more depending on boundaries) comes from food system. Also food wastes and losses are about one third of total production globally (would be less in Japan).
- More accurate food demand forecast through AI / ICT could lead to decrease of food wastes and losses and to reduction of energy consumption and GHG emission accordingly.
- Consequently, reduction of plastic containers, store spaces in supermarkets, energy for refrigerators / freezers and transport energy could be triggered.

They could be huge contribution to the achievements of SDGs as well.

4. Scenario analyses for the carbon neutrality

Energy Assessment Model: DNE21+

- Linear programming model (minimizing world energy system cost)
- Evaluation time period: 2000-2100

  Representative time points: 2000, 2005, 2010, 2015, 2020, 2025, 2030, 2040, 2050, 2070, 2100
- World divided into 54 regions

  Large area countries are further divided into 3-8 regions, and the world is divided into 77 regions.
- Bottom-up modeling for technologies both in energy supply and demand sides (over 400 specific technologies including CCUS are modeled.)
- Primary energy: coal, oil, natural gas, hydro&geothermal, wind, photovoltaics, CSP, biomass and nuclear power
- Electricity demand and supply are formulated for 4 time periods: instantaneous peak, peak, intermediate and off-peak periods
- Interregional trade: coal, crude oil/oil products, natural gas/syn. gas, syn. oil, ethanol, hydrogen, electricity and CO_2
- Existing facility vintages are explicitly modeled.

- The model has regional and technological information detailed enough to analyze regional and sectoral measures. Consistent analyses are obtained across regions and sectors .

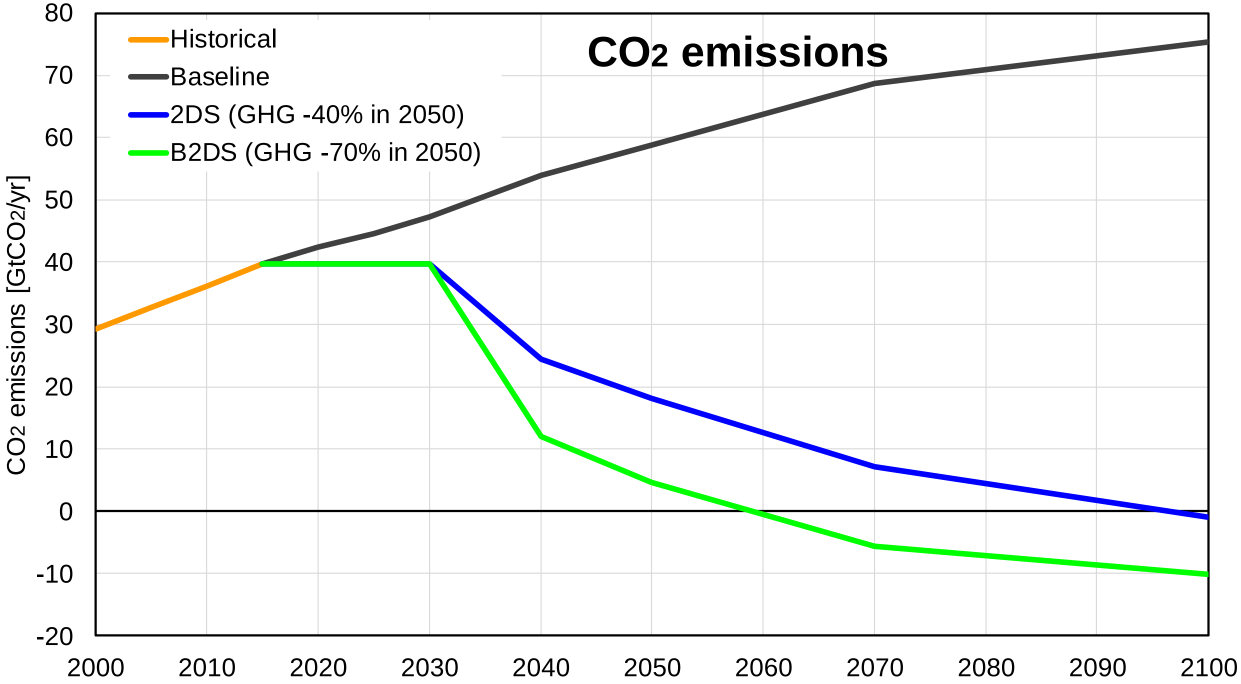
Assumed Scenarios

Scenario name	Global emission scenarios	Renewable costs (PV costs)	Share mobilities acceleration (Fully autonomous cars)
REF_1	Baseline (without specific CO_2 emission constraints)	Mid. cost reduction	w.o. consideration
2DS_1	Below 2 °C (>50%): Corresponding to IEA ETP2017 [2DS]	Mid. cost reduction	w.o. consideration
2DS_2		Low cost particularly in Middle-East & N. Africa	
2DS_3			Share mobilities acceleration (Fully autonomous cars)
B2DS_1	Well below 2 °C (>66%): Corresponding to IEA ETP2017 [B2DS]	Mid. cost reduction	w.o. consideration
B2DS_2		Low cost particularly in Middle-East & N. Africa	
B2DS_3			Share mobilities acceleration (Fully autonomous cars)

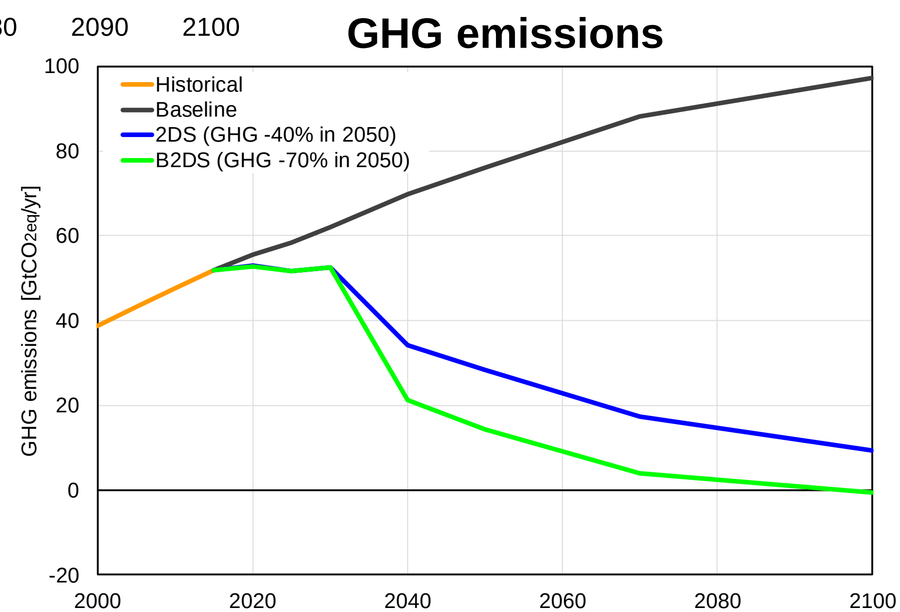
Socioeconomic scenarios

- **SSP2 ("Middle of the Road" scenario); Global population: 9.2 billion in 2050, and global GDP growth: 2.4%/yr between 2000 and 2050.**
- **SSP1 ("Sustainability" scenario); Global population: 8.6 billion in 2050, and global GDP growth: 2.6%/yr between 2000 and 2050.**

Baseline Global Emissions and the Assumed 2 °C Scenarios



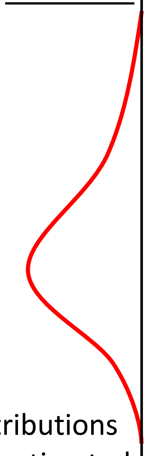
Note) Baseline emissions are not the assumed scenarios but are the resulting emissions by using the DNE21+ model.
The figure shows the emissions of SSP2.



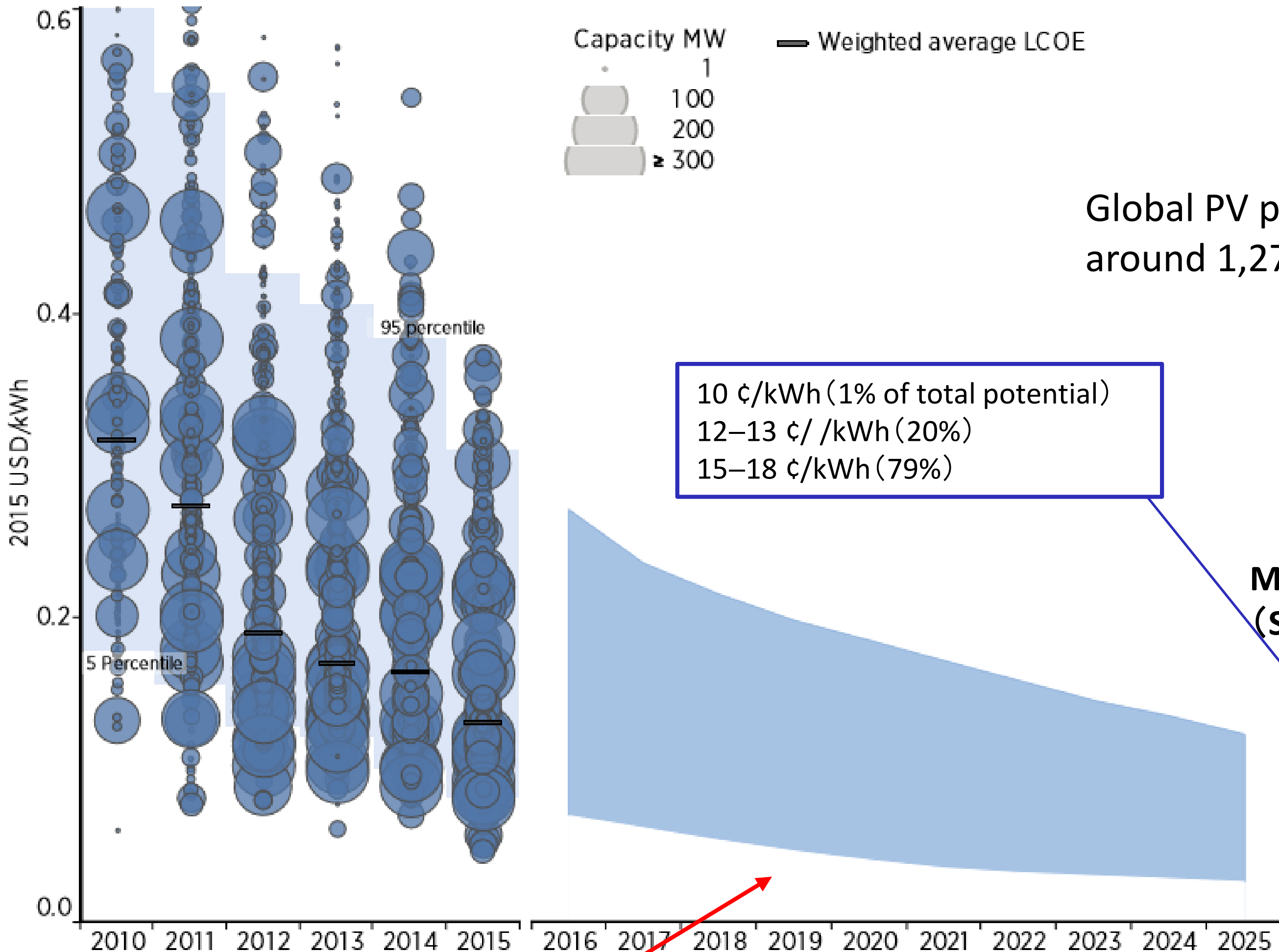
※ The emissions of 2DS and B2DS by 2030 were constrained by the submitted emission targets of NDCs of individual nations.

Image of the assumed cases for cost reductions of PV: middle and low costs

<u>In 2010</u>



Distributions are estimated by GIS of solar radiation



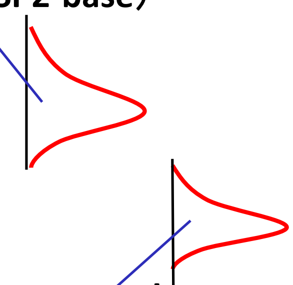
Source) IRENA

Global PV potentials:
around 1,270,000 TWh/yr

10 ¢/kWh（1% of total potential）
12–13 ¢/ /kWh（20%）
15–18 ¢/kWh（79%）

<u>In 2050</u>

Middle case （SSP2-base）



Low case (mainly in Middle-East & N. Africa)

2 ¢/kWh（1% of total potential）
3–4 ¢/ /kWh（20%）
6–9 ¢/kWh（79%）

<u>Around 3 ¢/kWh has been already observed in UAE, for example.</u>

※ DNE21+ model assumes the requirement of additional costs for maintaining grid stability in the case of large share of VRE.

Major assumptions of car- and ride-sharing and the estimated impacts

[Major assumptions] (mainly following Fulton et al. (2017))

- Fully autonomous car can be realized in 2030
- Additional costs for fully autonomous cars:
  +10,000$ in 2030, +5,000$ in 2050, +2,800$ in 2100
- Operation ratio of cars: depending on travel service demands of cars per area
- Considering driving free benefits, time costs for waiting shared cars, and safety benefits for fully autonomous cars
- Life times of cars: 13-20 years for conventional cars, 6-20 years for share cars
- Number of riding per car:
  1.1-1.5 people in 2050 and 1.1-1.3 people in 2100 for conventional cars
  1.75 people in 2050 and 2 people in 2100 for shared cars

[Estimated impacts]

- Number of shared car owned in 2050: 60% compared to that of conventional car owned
- Number of shared car sales in 2050: 70% compared to that of conventional car sales

[Impacts on iron and steel productions]

- Ton of steel for shared cars: 78% compared to that for conventional cars
- Total iron and steal productions in the SSP1 and car- & ride-sharing scenario: 98% of those in the SSP1 without consideration in car- & ride-sharing

[Impacts on productions of ethylene and propylene]

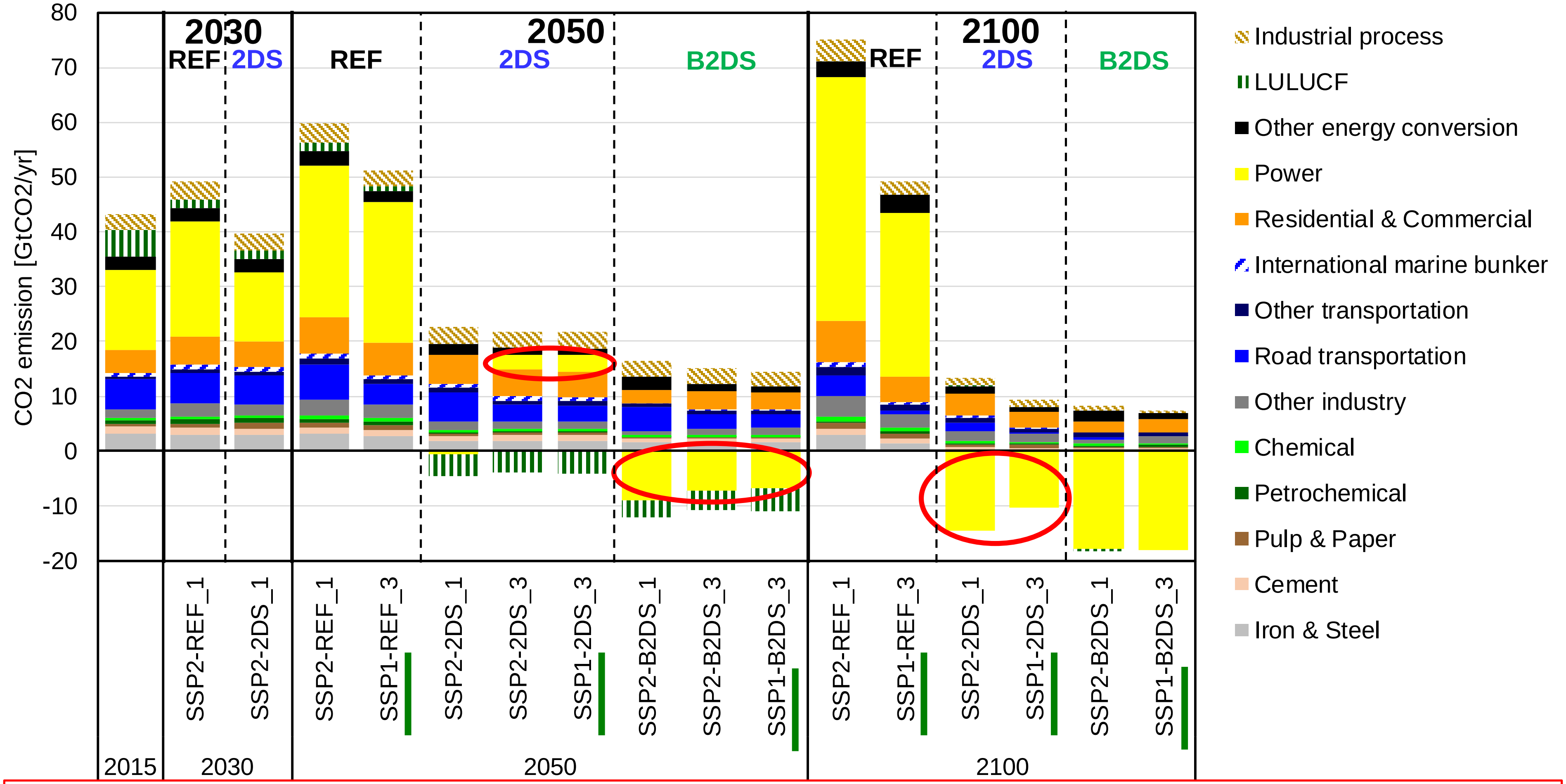
- Share of productions of ethylene and propylene in productions of plastics:85%
- The share for cars in the productions of ethylene and propylene: 8%
- Total productions of ethylene and propylene: 99% (accordingly reductions in naphtha and ethane)

Emission Reduction Costs in 2050

	SSP2			SSP1	SSP2			SSP1
	2℃、>50%				2℃、>66%			
	2DS_1	2DS_2	2DS_3	2DS_3	B2DS_1	B2DS_2	B2DS_3	B2DS_3
Carbon price (MAC) [\$/tCO_2]	166	158	129	120	530	483	299	252
CO_2 emission reduction costs [billion US\$/yr]	1761	1313	Negative	Negative	5601	4757	Negative	Negative

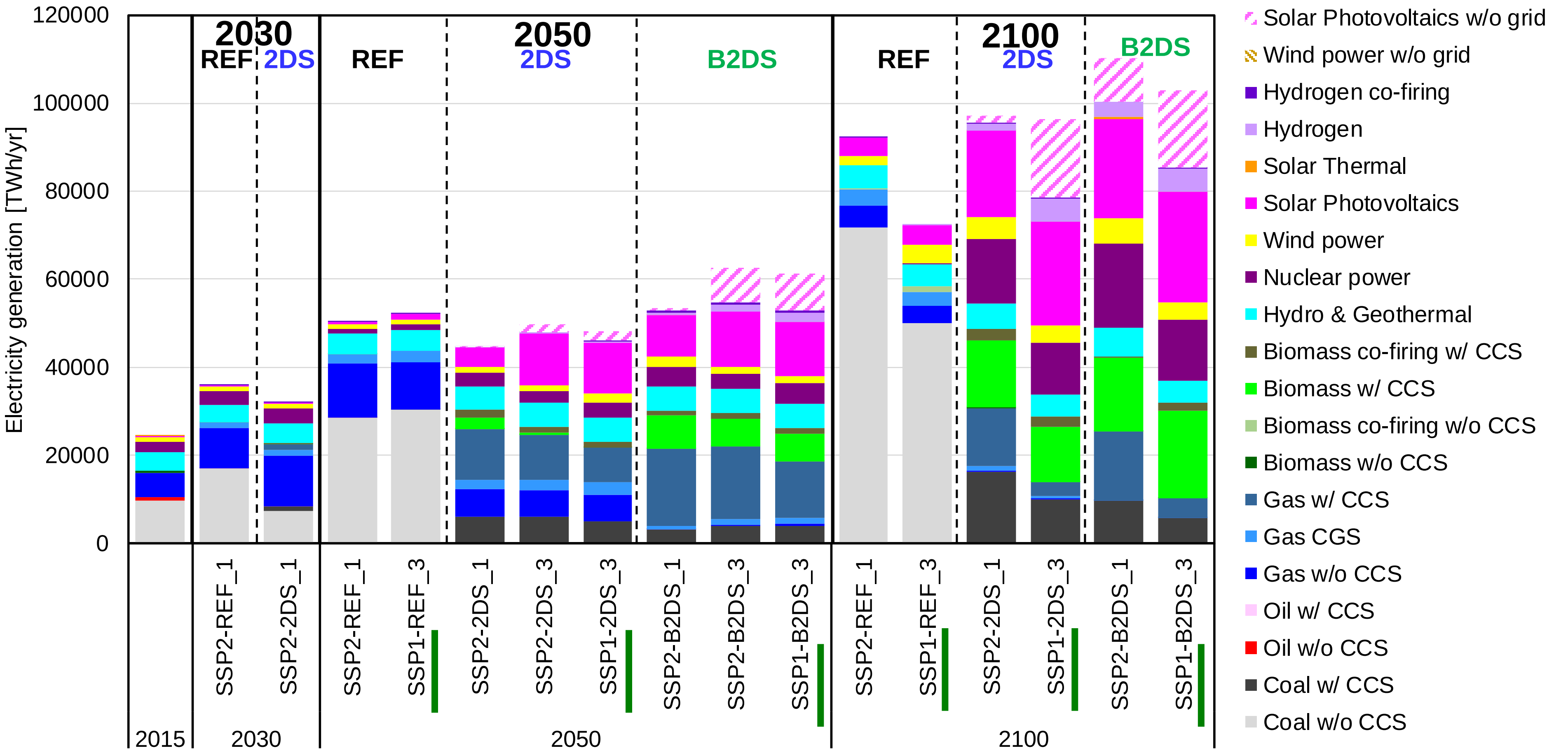
- ✓ Large differences can be estimated for the emission reduction costs for the achievement of 2 °C target with >50% probability (2DS) and >66% probability (B2DS).
- ✓ Costs reductions of renewable energy mainly in Middle-East etc. (Cases 2 and 3) will contribute to the reductions of global mitigation costs.
- ✓ Accelerating share-mobility induced by fully autonomous cars (Case 3) will decrease the MAC considerably and may achieve negative costs even for 2 °C target.

Global CO2 Emissions by Sector



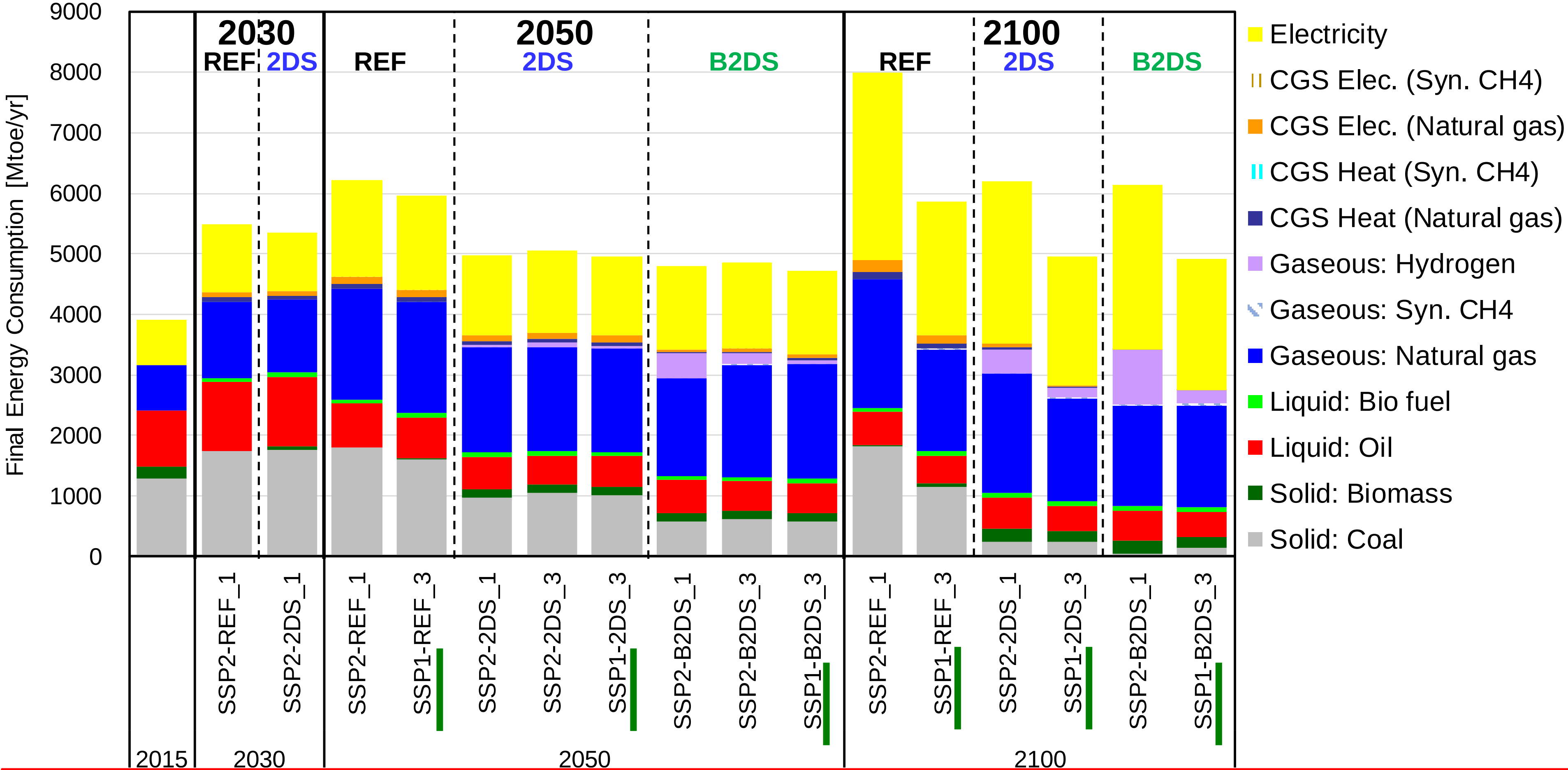
- ✓ **Deeper the emission reductions are, larger the emission reductions in power sector (renewables, nuclear, CCS etc.), and by afforestation, HV and PHV in transport sector etc. can be estimated.**
- ✓ **Much deeper emission reductions will require larger deployments of BECCS, CCS for steel productions, EV and FCV in road sector etc.**
- ✓ **Net nearly zero or negative CO2 emissions will require FCV trucks and methanation etc.**
- ✓ **The achievement of fully autonomous cars and the induced sharing mobility will alleviate efforts for large remission reductions in power sector around 2050.**

Global Electricity Supply



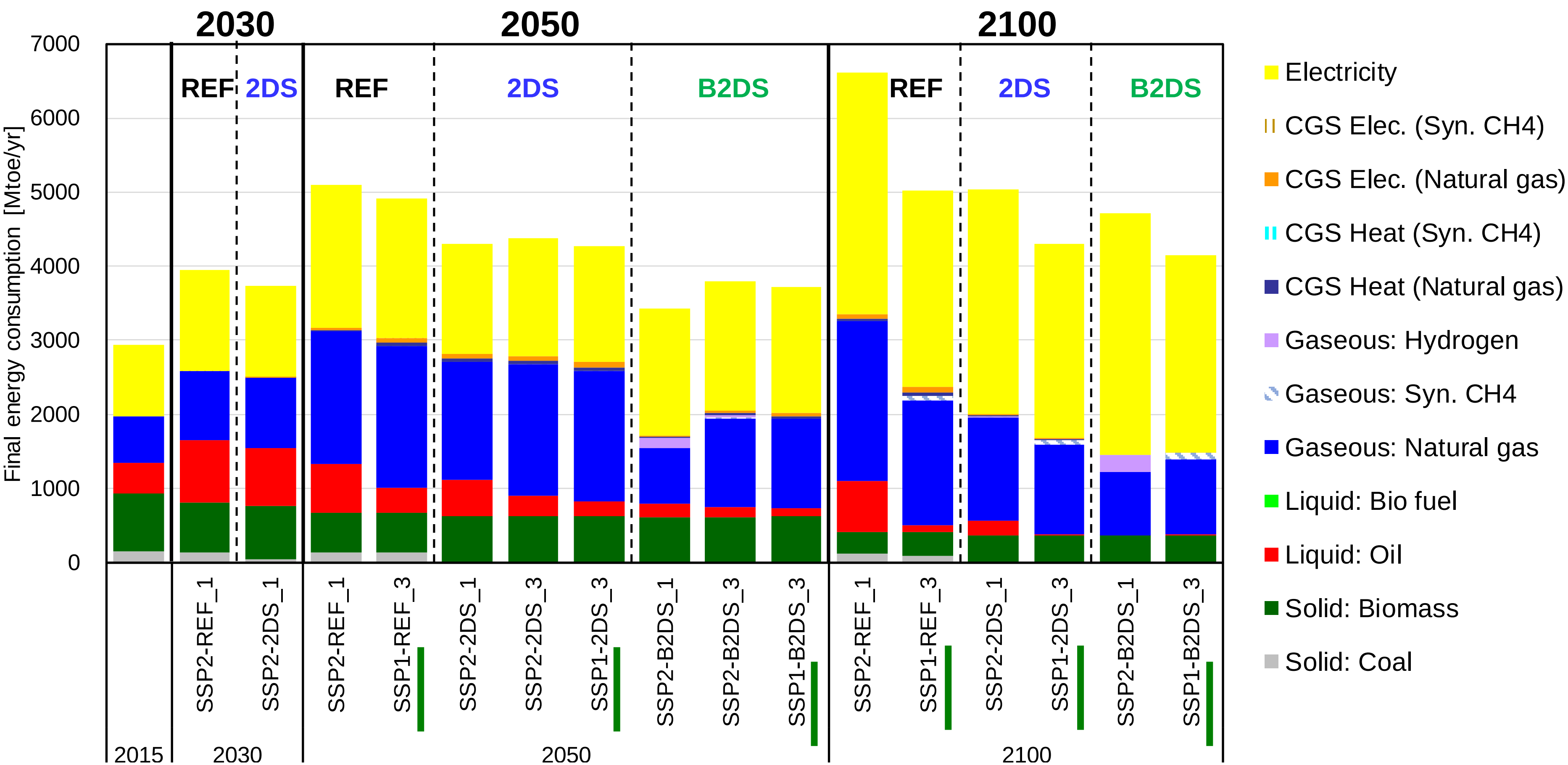
- ✓ **Global electricity consumption will increase greatly for any of the scenarios。**
- ✓ **In the 2 °C scenarios, the gas uses increase toward 2030, and after 2050 renewables, nuclear power and CCS increase. In the 2DS scenarios, co-generation will be cost-efficient toward 2030.**
- ✓ **In 2DS and B2DS which require net CO2 zero emissions around 2100 and 2070, respectively, BECCS will be cost-effective. (while the reality in such a large amount of the use of BECCS should be discussed.)**
- ✓ **In the sharing mobility cases, the role of BECCS will decrease particularly around 2050.**
- ✓ **In the low PV cost scenarios, the PV share including for the productions of hydrogen increases in 2100.**

Global final energy consumption: Industry



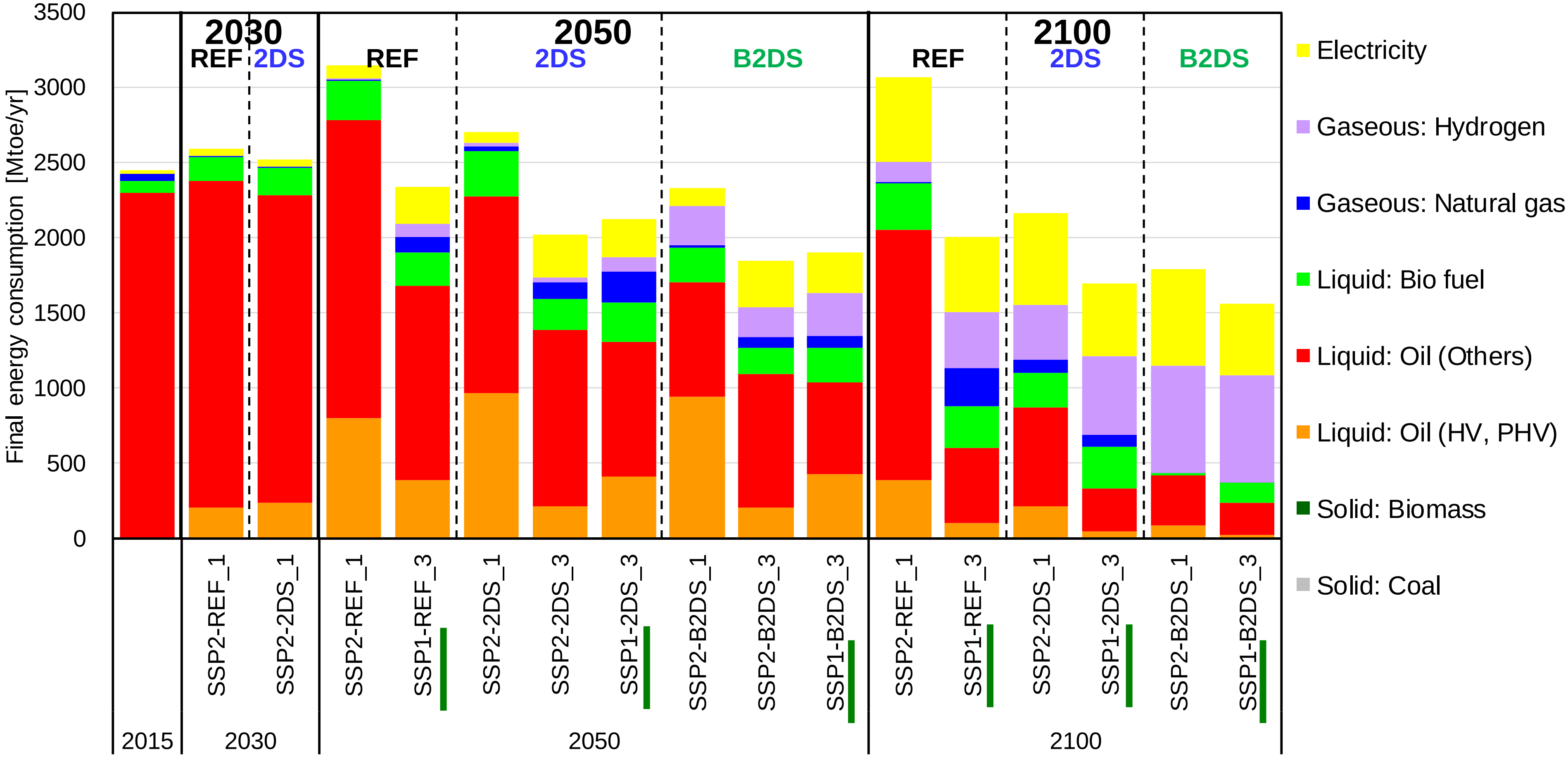
- ✓ In all the scenarios, electricity and gas shares increase excepting the gas share around 2100 in B2DS.
- ✓ For the 2 °C scenarios, steel productions through direct hydrogen reduction will be a cost efficient option in the second half of 21st century (switching from coal to hydrogen in iron & steel sector).
- ✓ For the 2 °C scenarios, switching from coal to gas in cement sector will be cost efficient after around 2050.
- ✓ Synthetic methane (methanation) will be also cost efficient in industry sector around 2100.

Global final energy consumption: Building



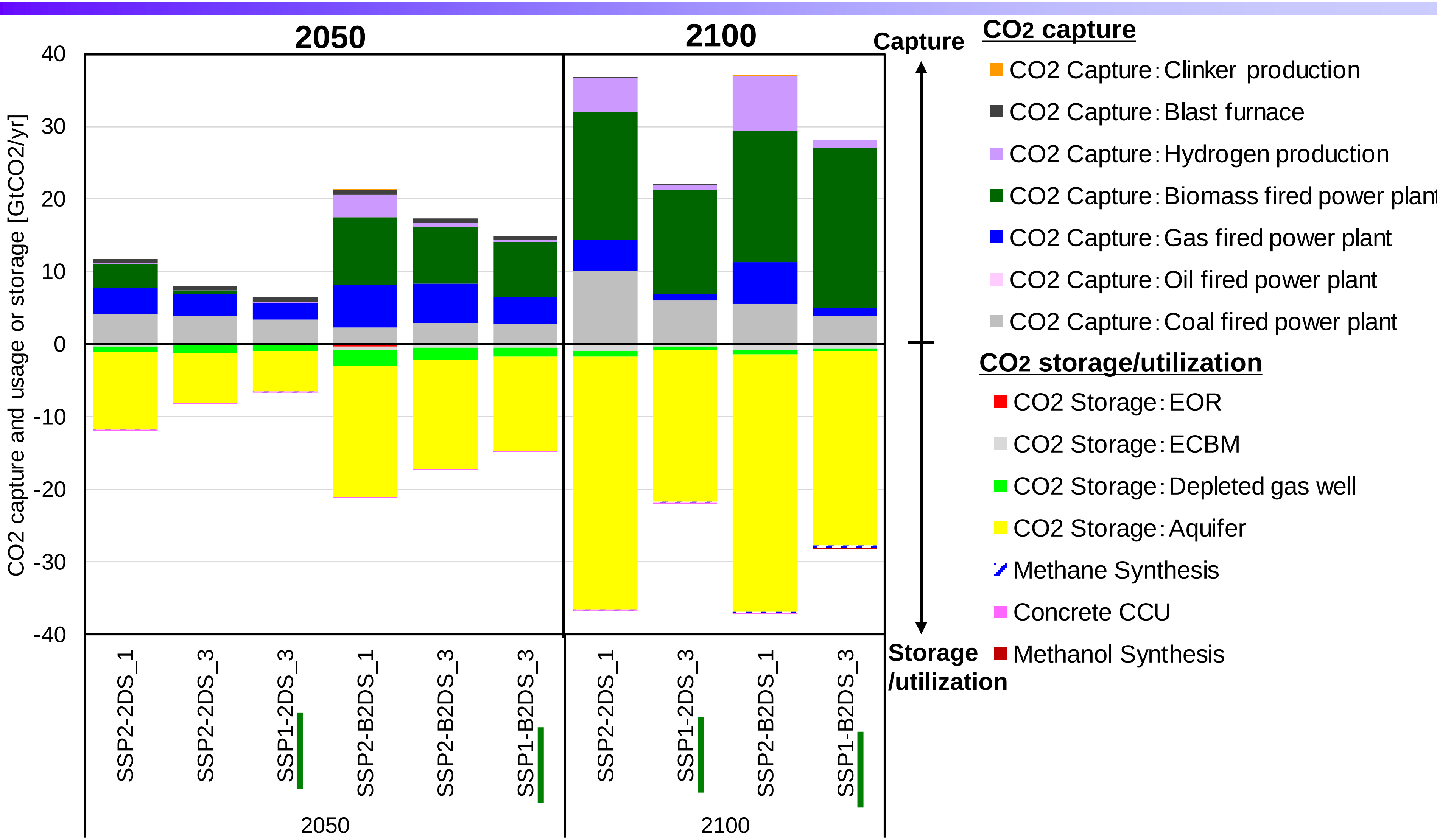
- ✓ In all the scenarios, electricity and gas shares increase.
- ✓ In the 2 °C scenarios, the increases particularly in electricity share compared with those in the REF scenario are observed.
- ✓ In the B2DS, gas uses decrease considerably after 2050. But in the case 3 which assume sharing mobility, the decrease in gas use in 2050 will be mitigated due to the decrease in MAC.
- ✓ In the 2 °C scenario with the low PV cost assumption, a part of city gas will be switched to syn. methane (methanation) around 2100.

Global final energy consumption: Transport



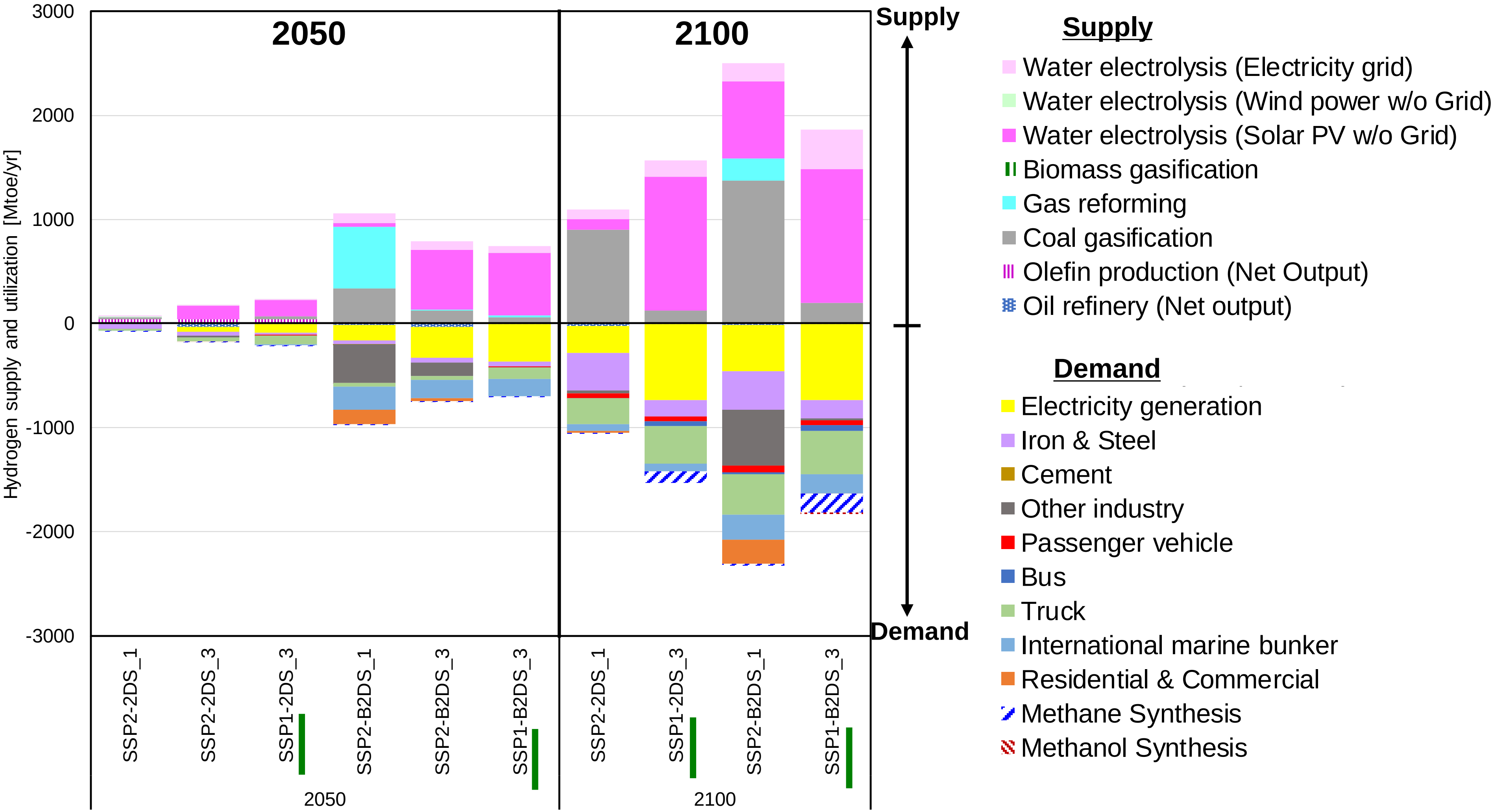
- ✓ **In the 2 °C scenarios, EV, FCV and bioenergy increase.**
- ✓ **In B2DS, hydrogen uses particularly for FC truck increase after 2050.**
- ✓ **The gas use for the international marine bunkers around 2050 is observed. But toward 2100, the gas use will shift to the hydrogen use.**
- ✓ **In B2DS, bioenergy in the transport sector decreases around 2100, because the biomass uses are more cost-effective in power sector as BECCS.**
- ✓ **The final electricity uses (HV, PHV, EV, FCV) in total transport uses in 2050 are about 35% and 55% in 2DS and B2DS, respectively.**

Global balances of CO_2 recovery, utilization and storage in 2050 and 2100



- ✓ For a deeper emission reduction scenario, B2DS, the amounts of recovered CO_2 particularly for BECCS will increase.
- ✓ For the case 3 which assumes fully self-driving cars and sharing mobility, the MAC decreases, and it induces the decreases in the amounts of the recovered CO_2 from biomass power and hydrogen productions and the CO_2 storage.

Global hydrogen balances in 2050 and 2100



- ✓ **In the standard scenario of PV cost reduction, hydrogen productions from coal gasification with CCS are cost-efficient, but in the acceleration scenario of PV cost reduction, hydrogen productions from electrolysis by using the electricity from PV are cost-efficient.**
- ✓ **There are several kinds of demands for hydrogen uses.**

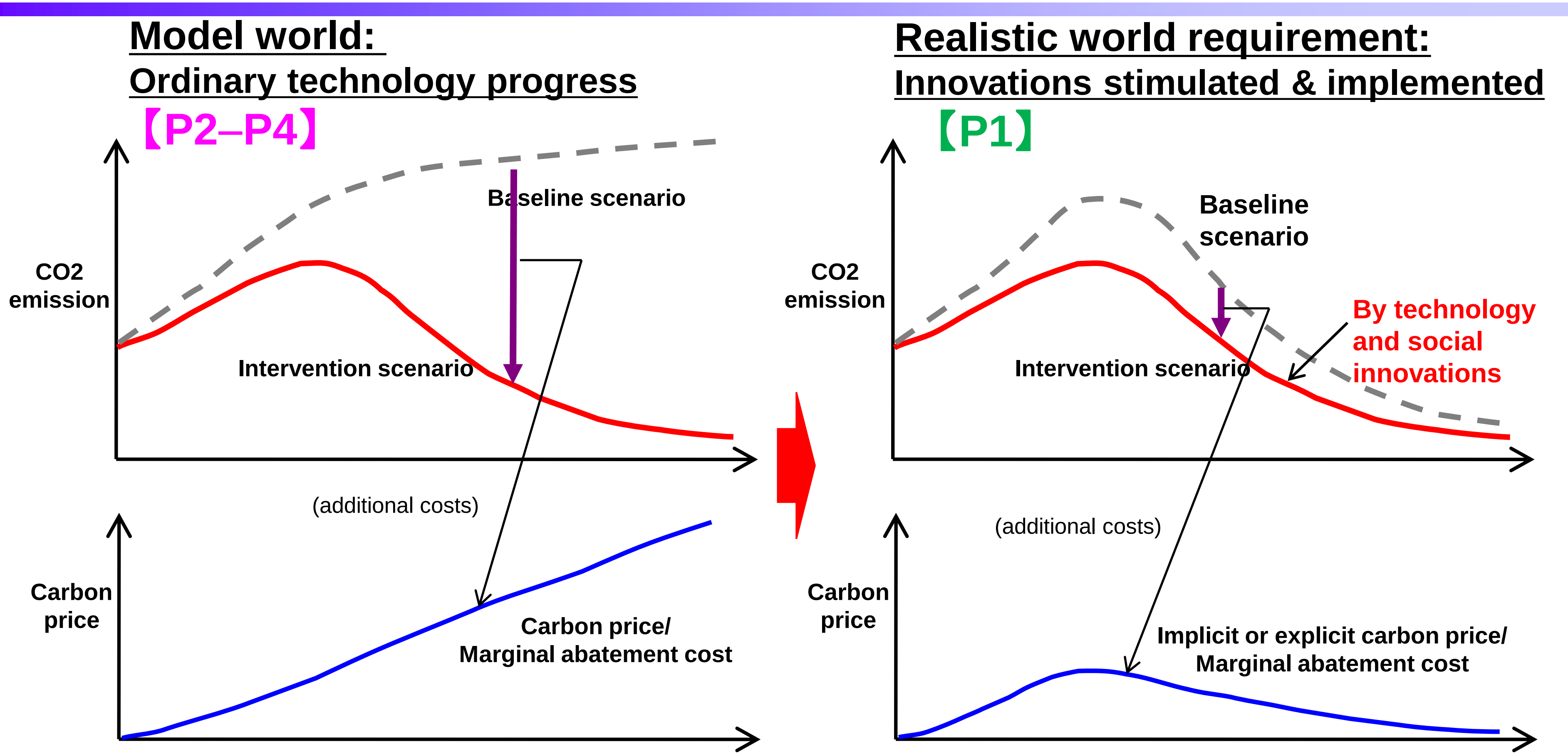
5. Conclusion

Conclusion

- The Paris Agreement states the 2 °C/1.5 °C targets and the net zero emission target in the second-half of this century. On the other hand, there are several kinds of uncertainty such as climate physical science, international policies. Better risk management will be required recognizing the uncertainties. But in order to stabilize temperature, global net CO_2 emissions are required to be nearly zero regardless of the temperature level.
- Increase in electrification is important with improvement of and achievement of zero emission intensity of electricity. But there exist several opportunities to decarbonize in the series of energy conversion processes to final electricity uses including which energy carriers should be utilized.
- The role of the technologies for the carbon neutrality is different depending on the outlook of each technology. Multiple technologies should be developed while continuing the evaluation of the economic efficiency of each technology at different development stages and at levels of uncertainties resolution.
- Energy storage technologies such as battery and hydrogen will be important options for decarbonization of energy and electricity. For the wide deployments of hydrogen system, the great cost reductions will be required, but for the reductions, appropriate levels of demand increase will also be required.
- Large mitigation costs for achieving the 2 °C, net zero emissions etc. have been estimated even assuming the strong international cooperation, and therefore wide and disruptive innovations will be necessary for lowering the cost. Digital technologies and the induced social changes are progressing. The acceleration particularly of the energy end-use technologies and the social change will be key for the carbon neutrality world as well as the innovations of energy supply technologies.

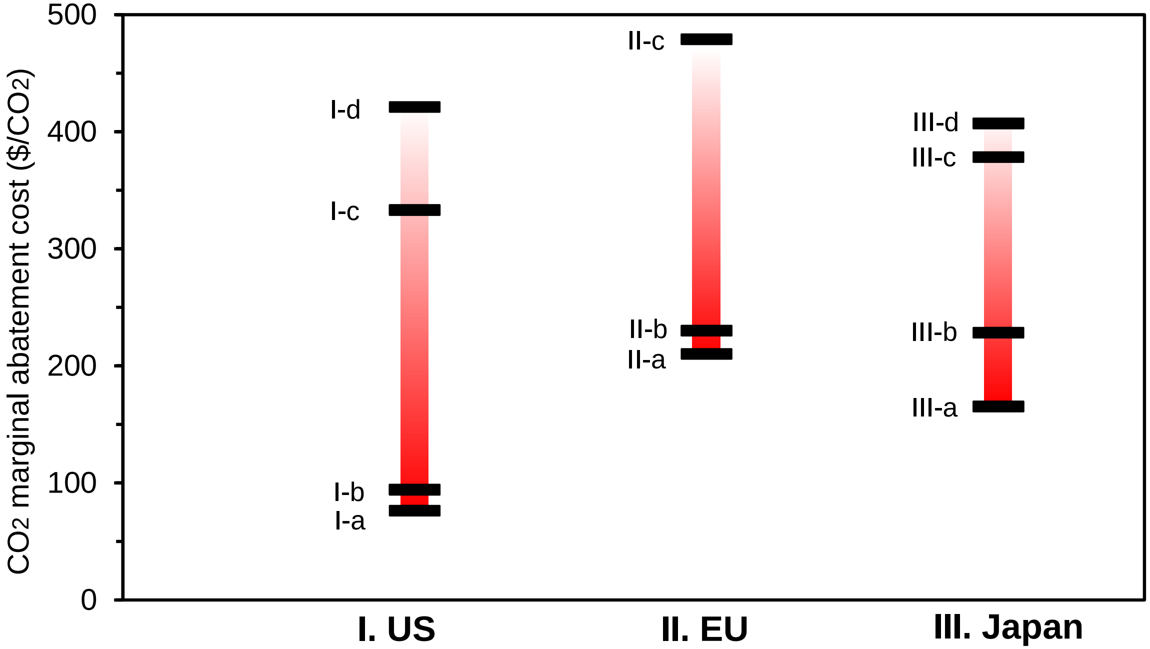
Appendix

Image of standard scenarios by models and scenarios required for deep cuts in a real world



- ✓ High carbon prices are unlikely to be accepted globally in a real world. Under high carbon prices, the international cooperation for emission reductions will be really challenging, and the large difference of carbon prices will induce carbon leakage.
- ✓ Technology and social innovations which will bring low (implicit or explicit) carbon prices (including coordination of secondary energy prices) are key to achieve deep emission cuts.
- ✓ The technologies having cost efficiency under high carbon prices such as BECCS and DACS will play a role for responses to risks in the case of high climate damages.

CO_2 marginal abatement cost for the U.S, EU and Japan: Additional costs by domestic policies



I-a: -26%; the least cost
I-b: -28%; the least cost
I-c: -26%; power sector according to CPP
I-d: -28%; power sector according to CPP

* CPP: Clean Power Plan

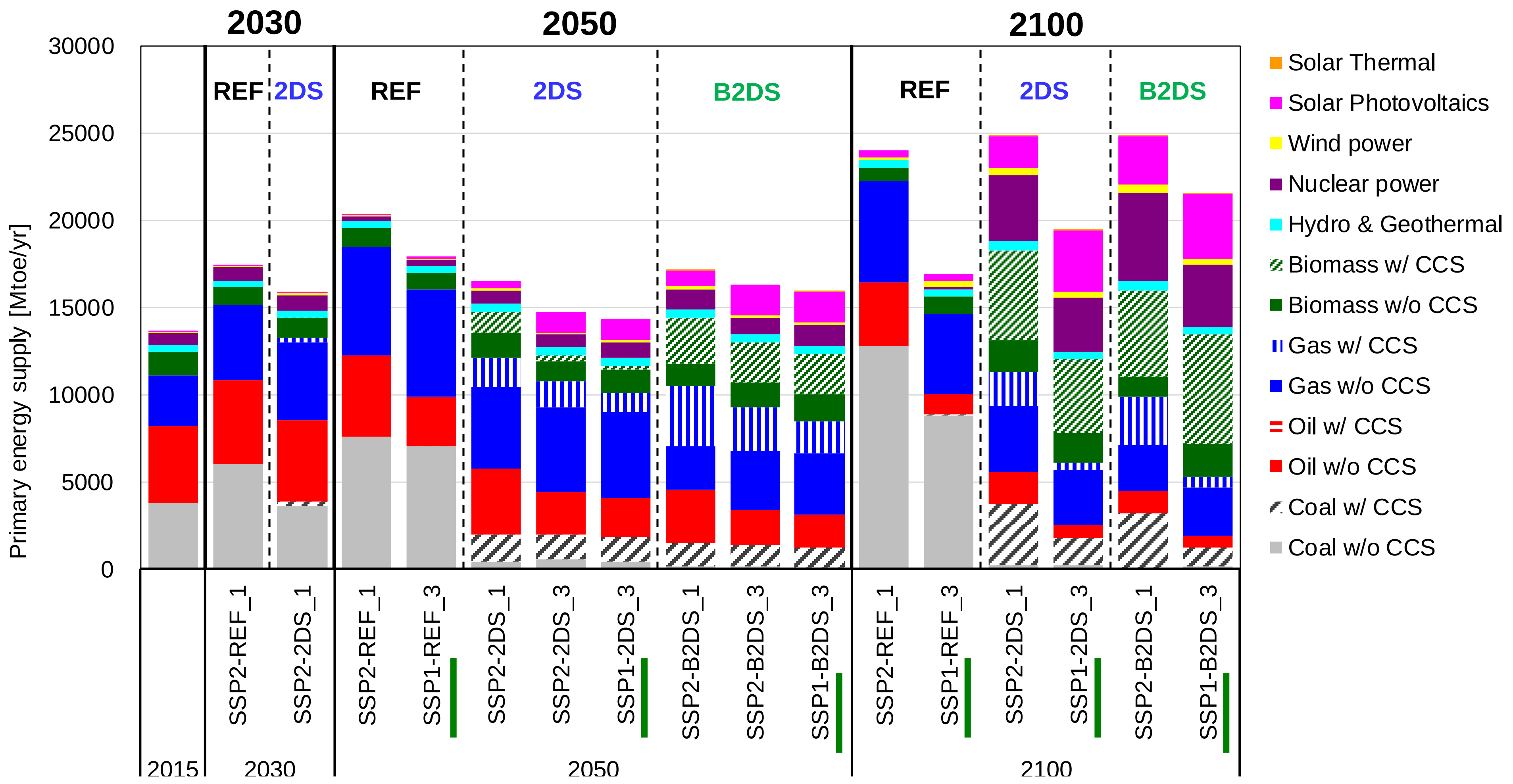
II-a: the least cost
II-b: Brexit (-40% for UK)
II-c: splitting into ETS and non-ETS sectors

III-a: the least cost under nuclear of maximum 20%
III-b: the least cost under nuclear of maximum 15%
III-c: following the NDC including the energy mix (nuclear of 20%)
III-d: following the NDC including the energy mix but nuclear of 15%

Source: estimated by RITE DNE21+

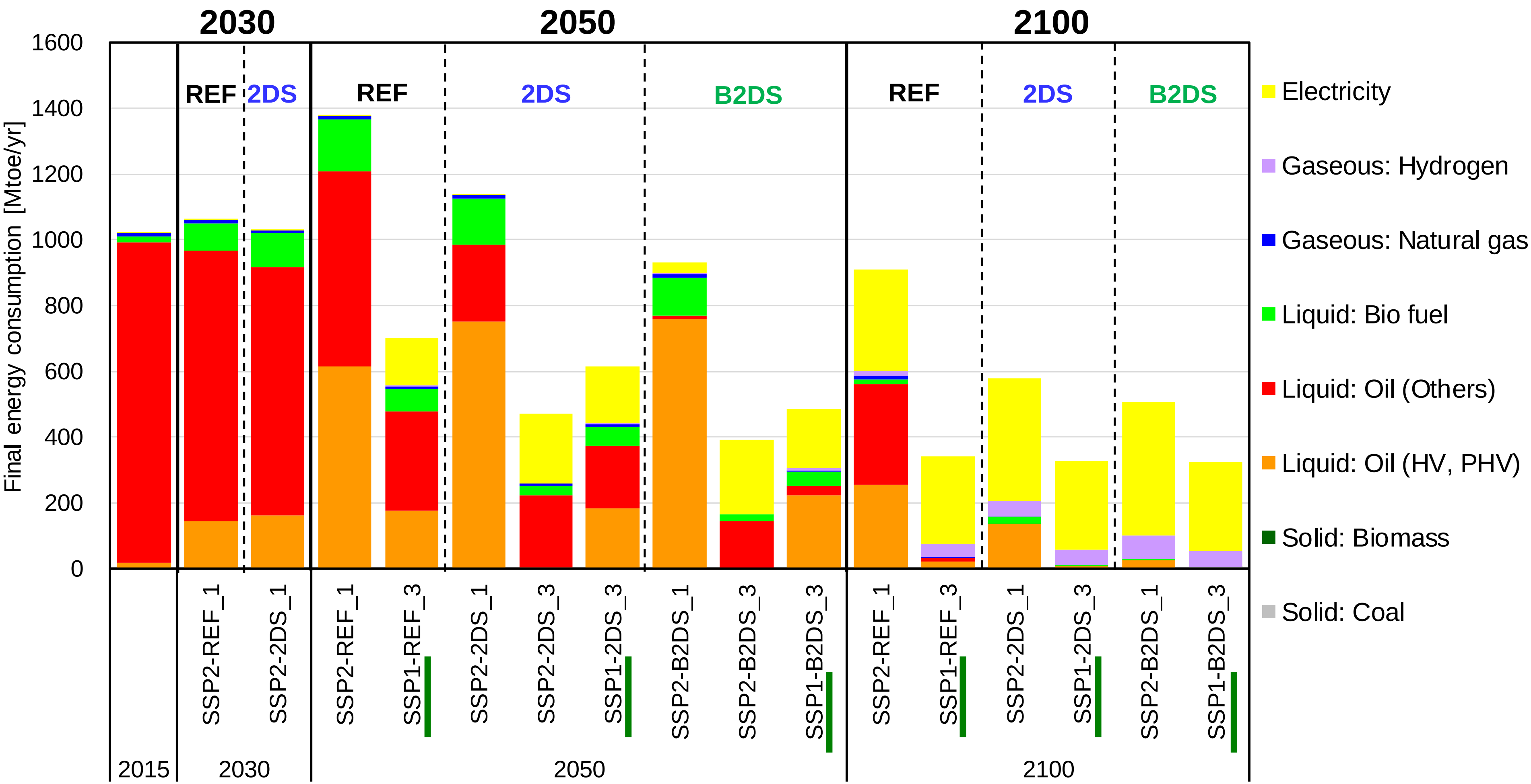
- It is not easy to achieve the least cost measures because there are several kinds of social and political constraints in each nation.
- The mitigation costs constrained by other policies can be much higher than those under the least cost measures.

Global Primary Energy Supply



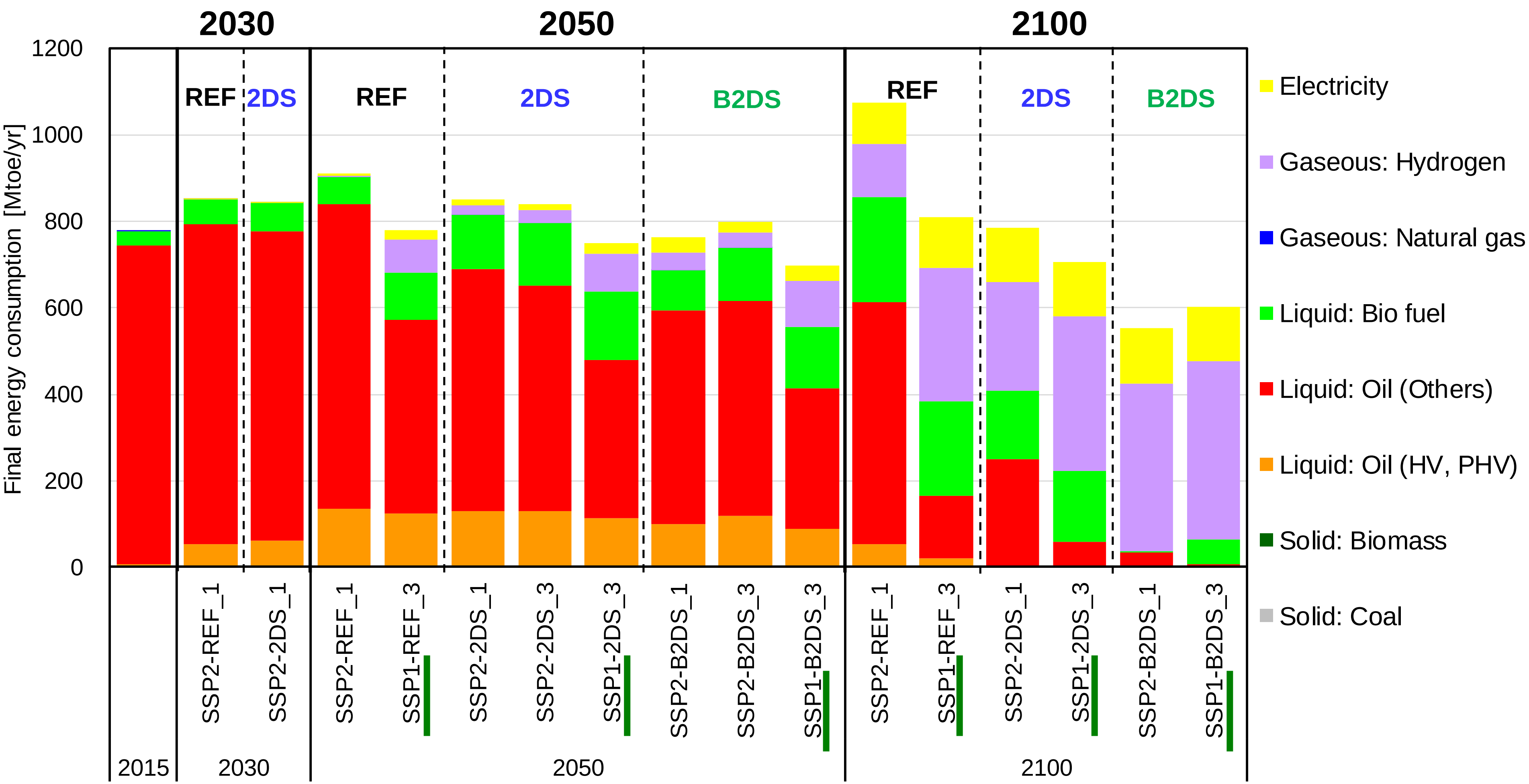
- ✓ **Renewable energy, nuclear power, and CCS are expanding toward 2100 in both scenarios with the 2 °C targets.**
- ✓ **However, even in 2100, a certain amount of fossil fuel use without CCS will remain.**

Global final energy consumption: automobiles



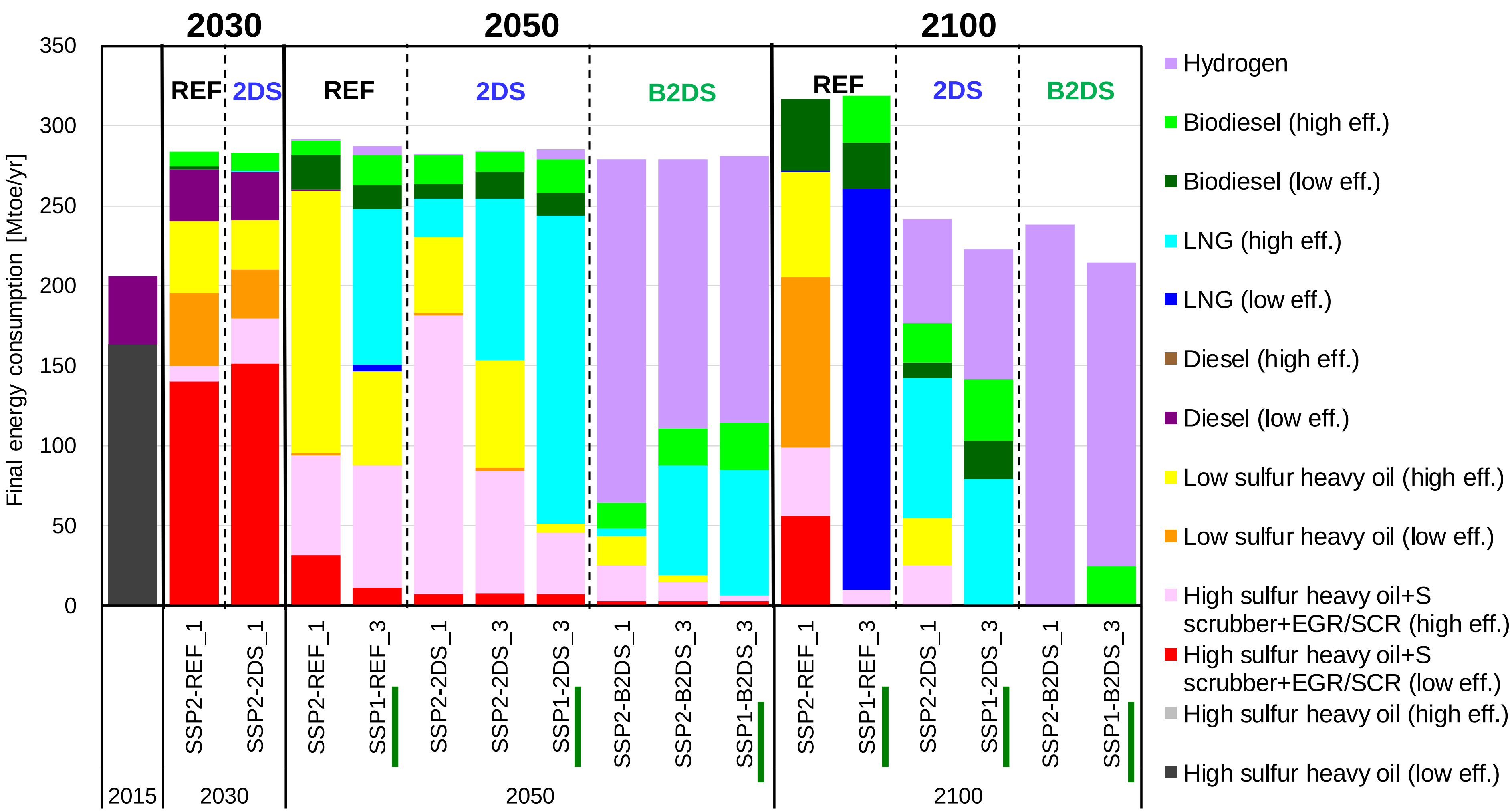
- ✓ Even under the 2 C scenarios, in many of the scenarios, oil fuels (HV, PHV) still play a main role by around 2050.
- ✓ In the sharing mobility scenarios (case 3), the EV share will increase compared with that in the standard scenarios (cases 1 and 2).
- ✓ In 2100, EV plays a main role in all of the 2 °C scenarios.

Global final energy consumption: Truck



- ✓ **Even in the 2 °C scenarios, oil fuels will be dominant by around 2050. Biofuels also play a considerable role.**
- ✓ **For the 2 °C scenarios, hydrogen (FCV) plays a main role in 2100.**

Global final energy consumption: Int'l marine bunkers



- ✓ 国際海事機関（IMO）によるSOx、NOx規制をすべてのシナリオで想定。
- ✓ 2DSでは2050年頃以降はLNG利用の経済効率性が大。B2DSでは2050年以降、水素利用が支配的。