8th February 2018
International Symposium
INPEX CORPORATION Endowed Course
"Energy Security and Environment"

- IEEJ Outlook 2018 -

Ultra-long-term Climate Analysis

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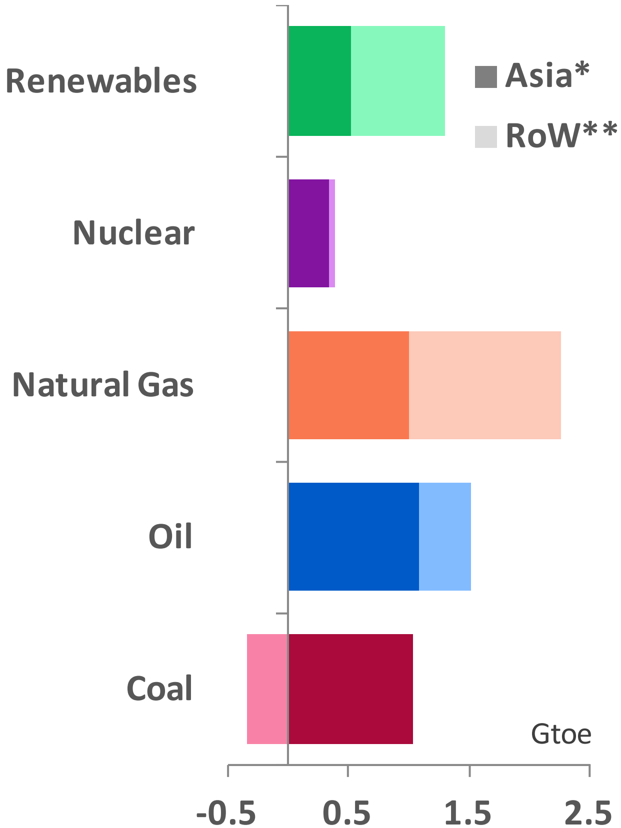
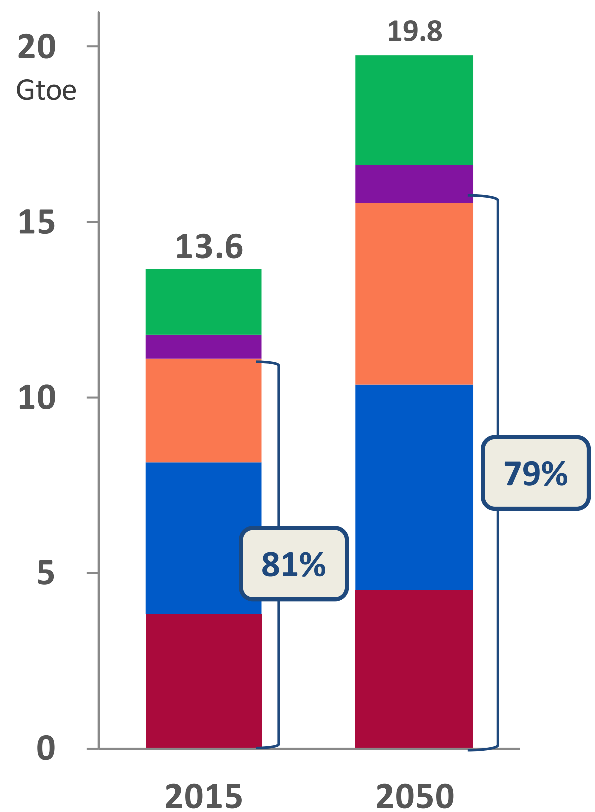
High dependence on fossil fuels continues

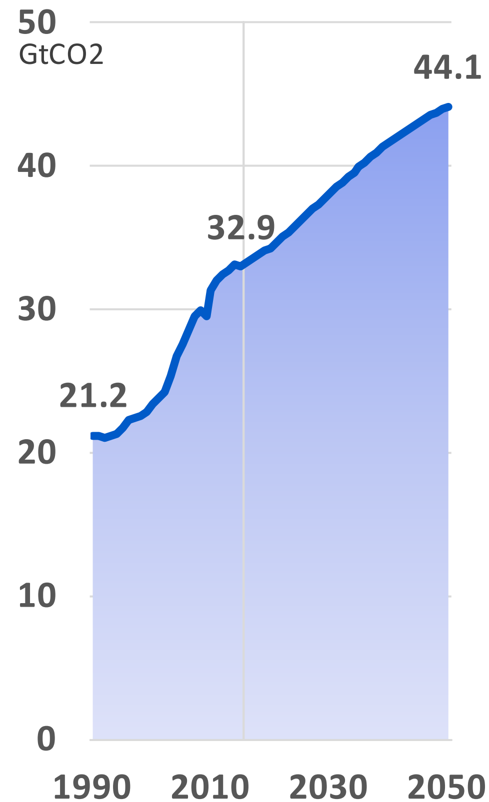
❖ Growth in Primary Energy



❖ Energy Mix



❖ Energy-related CO_2



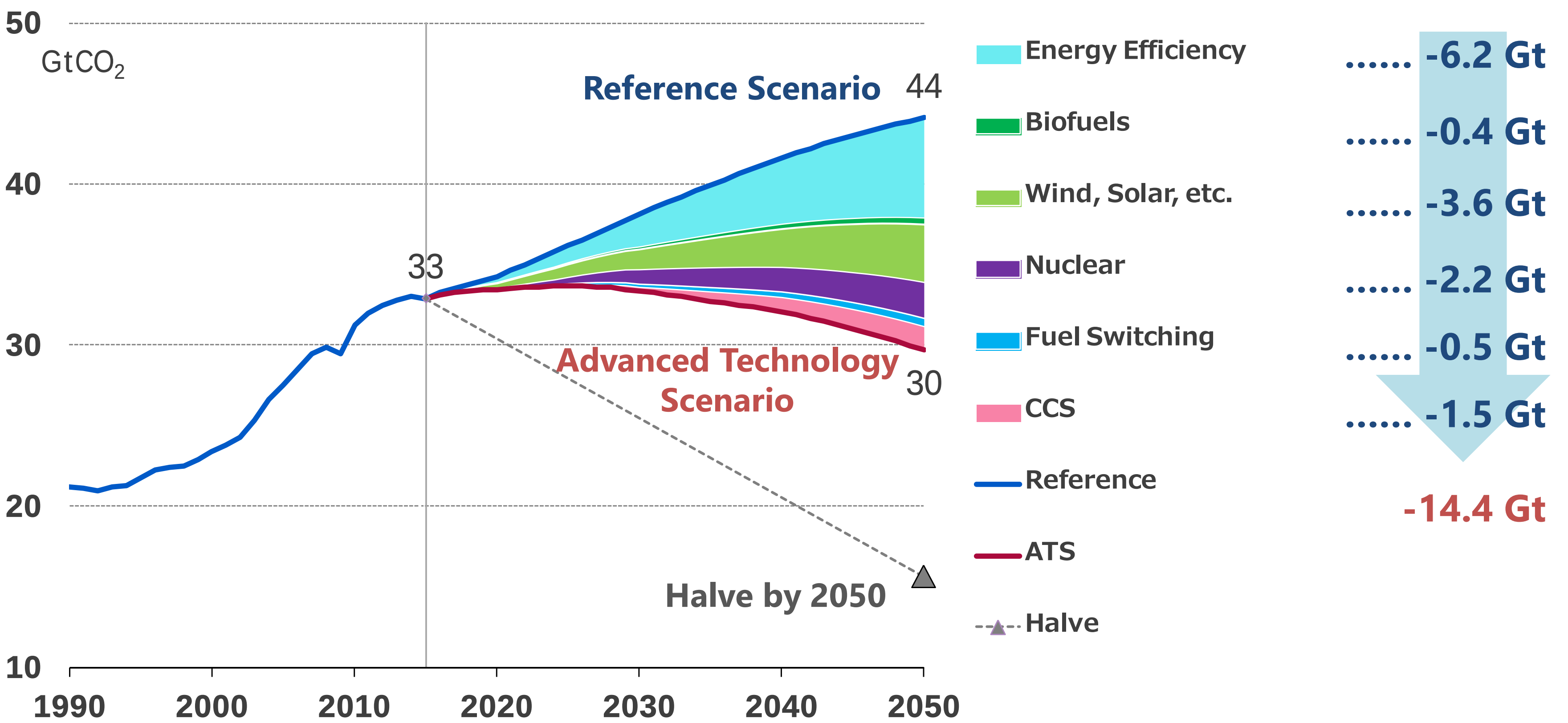
* Non-OECD Asia, **Rest of the world

Sixty percent of the growth in electricity demand will be met by thermal power generation, especially natural gas. Asia leads the large global increase in fossil fuels required for power generation as well as for transportation. The high dependence on fossil fuels remains unchanged and energy related CO_2 emissions increase by 34% by 2050.

Emissions peak in Advanced Tech. Scenario

❖ Energy-related CO_2 Emissions

❖ Reductions by technology



Energy-related CO_2 emissions in ATS decline after 2020s but are still very far from reaching half of current levels by 2050. Efficiency is the most contributor for CO_2 reductions from the reference. Two thirds of the total reductions are electricity-related technologies, including non-fossil power, thermal power with CCS and energy efficiency in power supply/demand.

Rule for ultra long-term: Reduce the total cost

❖ Mitigation+Adaptation+Damage=Total Cost

Mitigation

•Typical measures are GHG emissions reduction via energy efficiency and non-fossil energy use.
• Includes reduction of GHG release to the atmosphere via CCS
• These measures **mitigate** climate change.

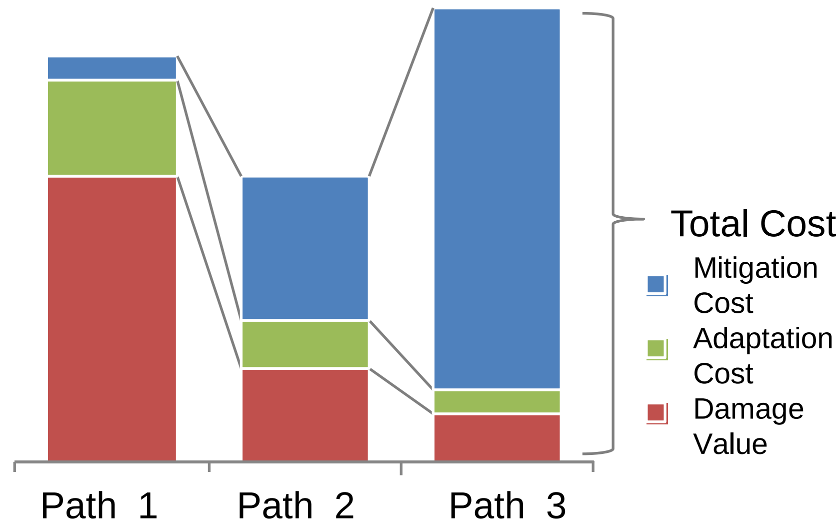
Adaptation

•Temperature rise may cause sea-level rise, agricultural crop drought, disease pandemic, etc.
• **Adaptation** includes counter measures such as building banks/reservoir, agricultural research and disease preventive actions.

Damage

If mitigation and adaptation cannot reduce the climate change effects enough to stop sea-level rise, draught and pandemics, **damage** will take place.

❖ Illustration of Total Cost for Each Path



	Path 1	Path 2	Path 3
Mitigation	Too Small	Reasonable	Too Big
Adaptation	Big	Medium	Small
Damage	Big	Medium	Small

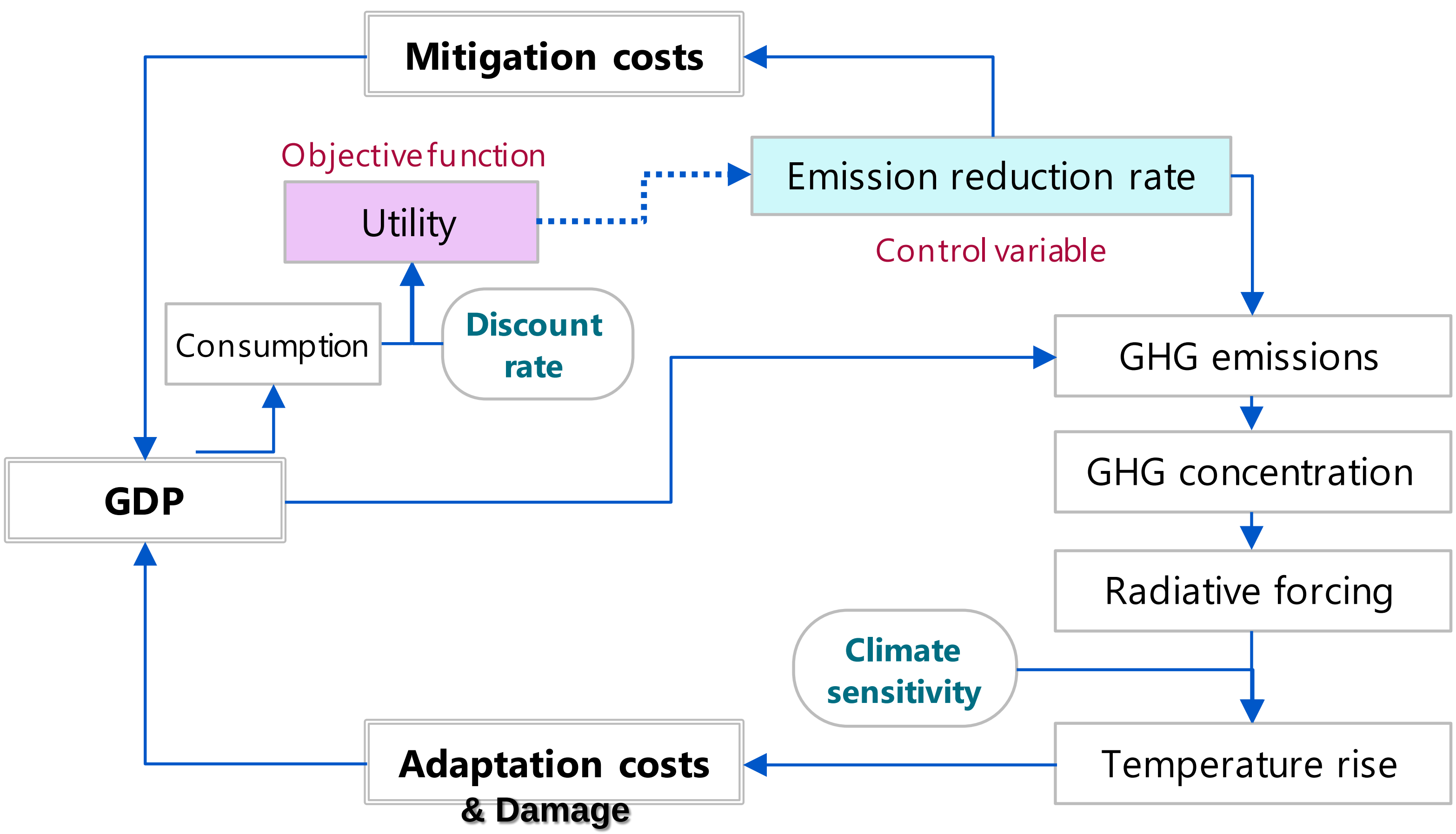
Without measures against climate change, the mitigation cost is small, while the adaptation and damage costs become substantial. Aggressive mitigation measures on the other hand, would reduce the adaptation and damage costs but the mitigation costs would be notably colossal.

The climate change issue is a long-term challenge influencing vast areas over many generations. As such, and from a sustainability point of view, the combination (or the mix) of different approaches to reduce the total cost of mitigation, adaptation and damage is important.

IAM (Integrated Assessment Model)

IAM is a model that can assess economy and climate change at the same time.

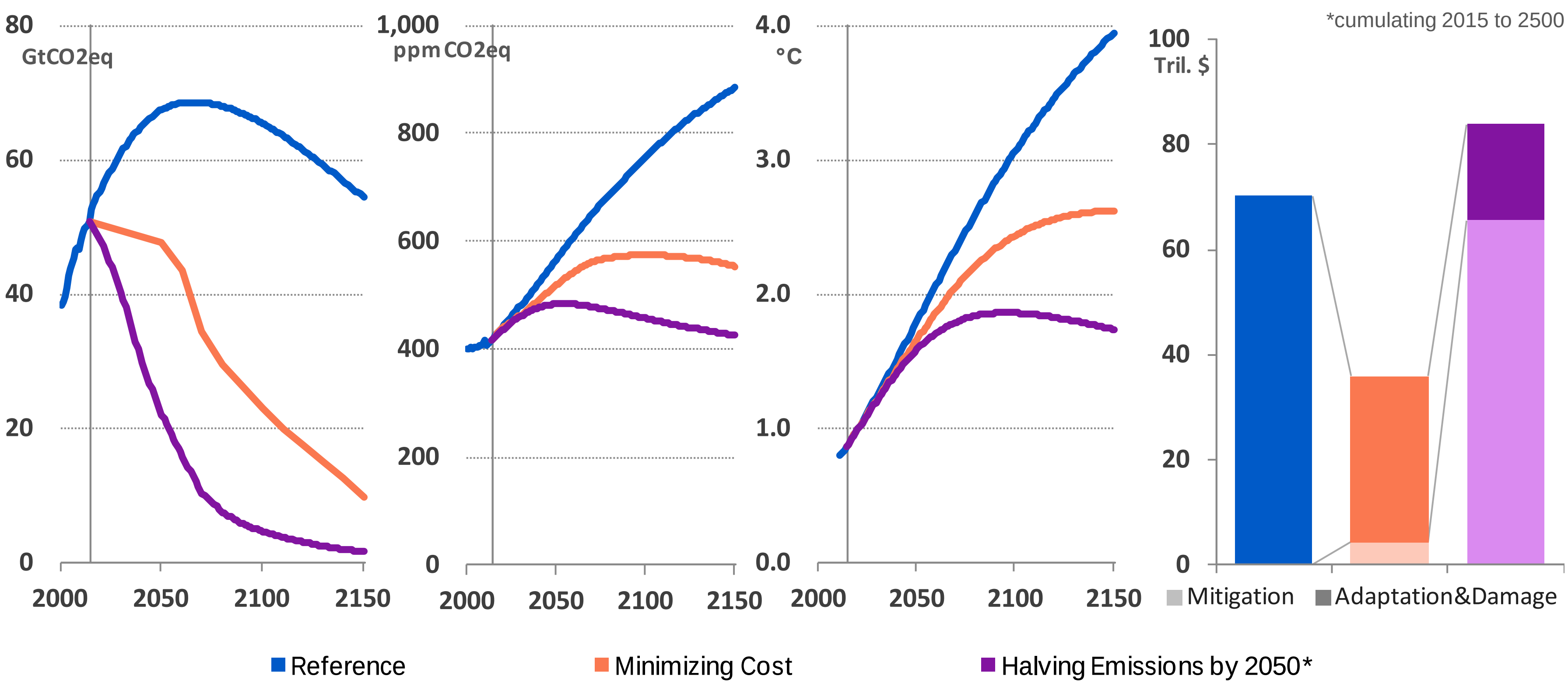
Control variable: Emission reduction rate
Objective function: Maximizing utility
Estimation Period: 2015-2500 (but by 2200 for useful solution)



Minimizing Total Cost in IAM

IEE JAPAN

❖ GHG Emissions ❖ GHG Concentrations (incl. aerosol etc.) ❖ Temperature Rise (vs. 1850-1900) ❖ Total Cost (cumulative present value*)



Total cost of "Minimizing Cost" is half of the reference. In 2150, GHG emissions decrease by 80% from now and temperature rises by 2.6 ° centigrade from the late 19th century. In "Halving Emissions by 2050", temperature peaks at 2100, resulting in 1.7° C in 2150. However, total cost is 20% higher than the reference and double of the "Minimizing Cost" path.

*Emissions path reflected "RCP 2.6" in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC).

Uncertainties in the climate analysis (1)

Subjective Discount Rate (ρ)
This model uses 2.5%. There are a range of 1.1 to 4.1% summarized by IPCC 5th Annual Report.

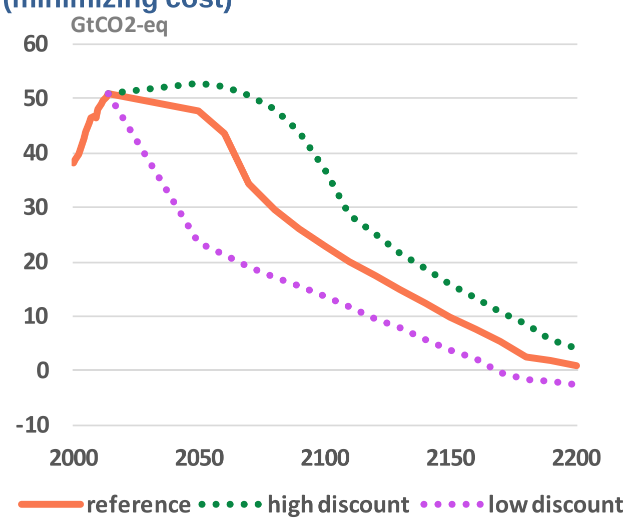
$$\rho = \delta + \eta g$$

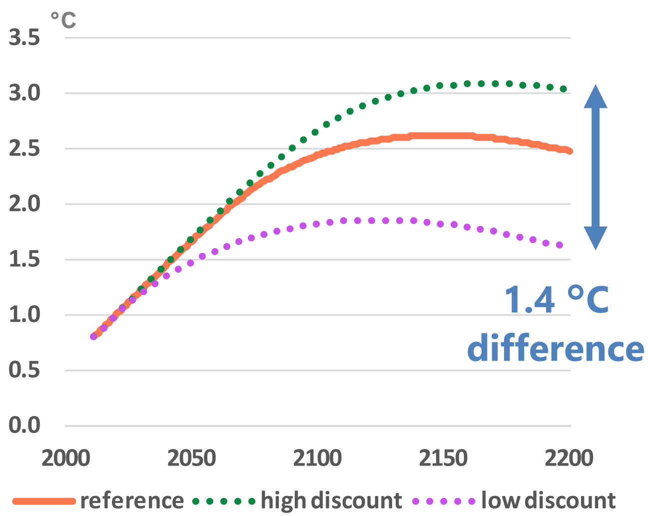
δ : pure time preference rate
η : elasticity of marginal utility of consumption
g : consumption growth rate

	Pure time preference rate	Elasticity of marginal utility of consumption	Average discount rate (2015-2300)
Cline (1992)	0%	1.5	
IPCC (1996)	0%	1.5 – 2	
Arrow (1999)	0%	2	
UK: Green Book (2003)	1.5%	1	
France: Rapport Lebègue (2005)	0%	2	
Stern (2007)	0.1%	1	
Dasgupta (2007)	0.1%	2 – 4	
Weitzman (2007a)	2%	2	
Nordhaus (2008)	1%	2	
Higher discount rate	**2.0%**	**2.0**	**4.1%**
Reference (average)	**0.5%**	**2.0**	**2.5%**
Lower discount rate	**0.1%**	**1.0**	**1.1%**

❖ GHG emissions and temperature rise using different discount rates

(minimizing cost)





Uncertainties in the climate analysis (2)

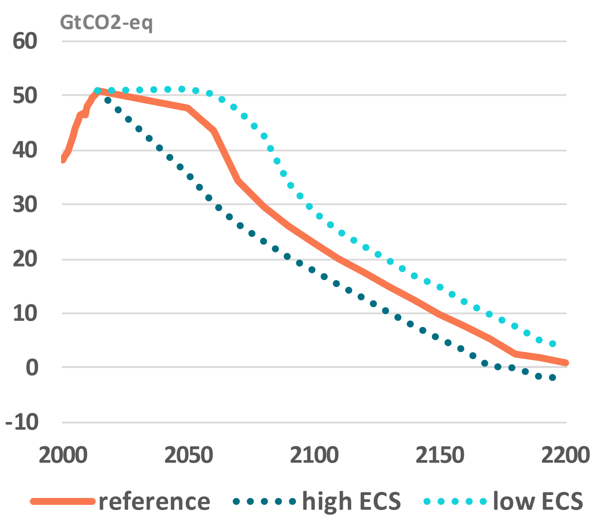
Equilibrium Climate Sensitivity (ECS)

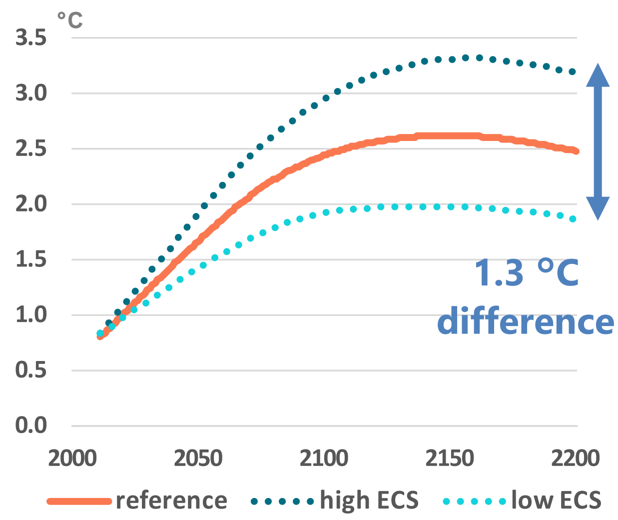
This model uses 3 degree.
According to AR5, there is a high possibility that ECS is between 1.9 and 4.5 degree.

ECS is a parameter indicating how many degrees centigrade the temperature will rise when the atmospheric greenhouse gas concentration (CO2 equivalent concentration) doubles.

IPCC reports	ECS (ºC)	Best estimate (ºC)
1st (1990)	1.5-4.5	2.5
2nd (1995)	1.5-4.5	2.5
3rd (2001)	1.5-4.5	2.5
4th (2007)	2.0-4.5	3.0
5th (2014)	1.5-4.5	n.a.

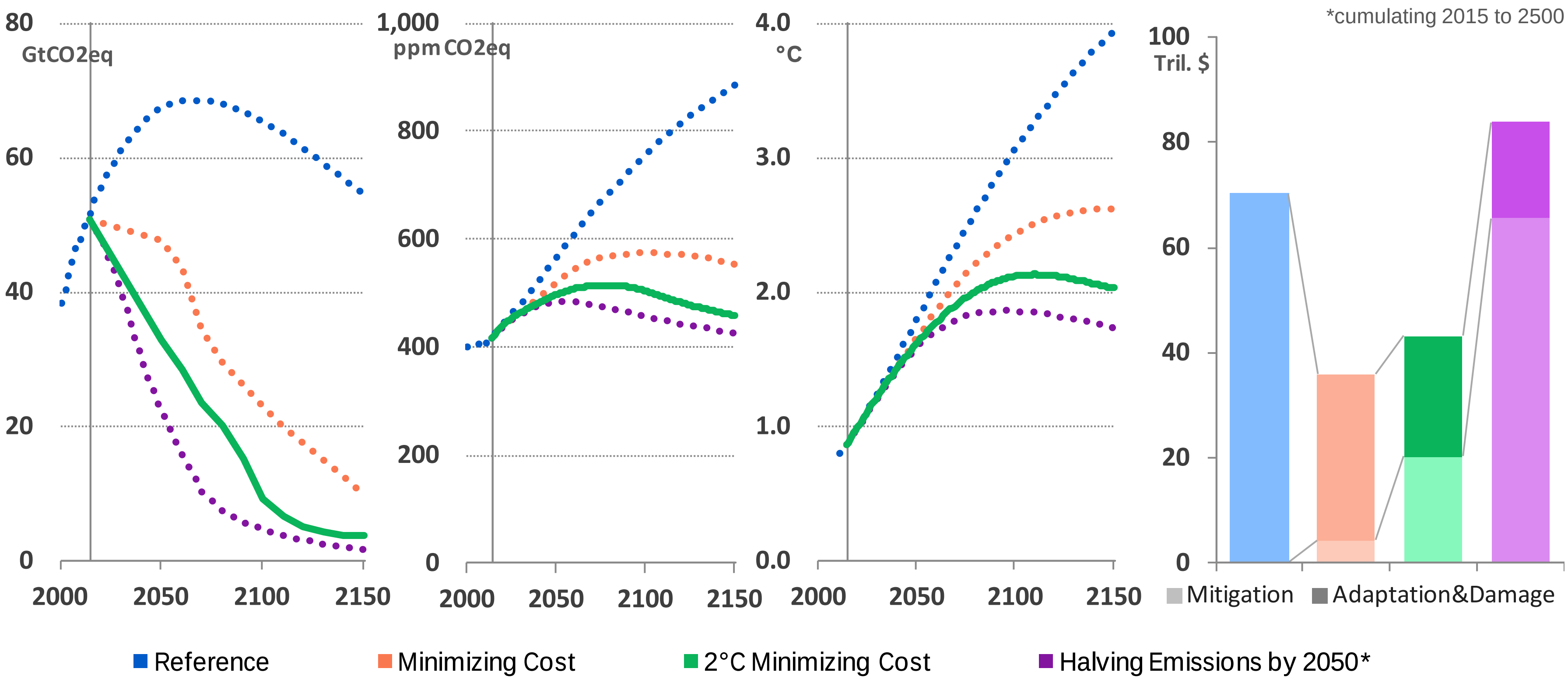
❖ **GHG emissions and temperature rise using different ECS** (minimizing cost)





Another path to “2 °C target”

❖ **GHG Emissions** ❖ **GHG Concentrations** (incl. aerosol etc.) ❖ **Temperature Rise** (vs. 1850-1900) ❖ **Total Cost** (cumulative present value*)



“2° C Minimizing Cost”, for example, is a path that minimize total cost under the condition of 2° C temperature rise in 2150. Its total cost is 20% higher than “Minimizing Cost” without the temperature limit. GHG emissions decrease by 30% in 2050 and needs almost zero-emissions after 2100. Temperature rises to just over 2° C in 2100 and then declines to 2° C.

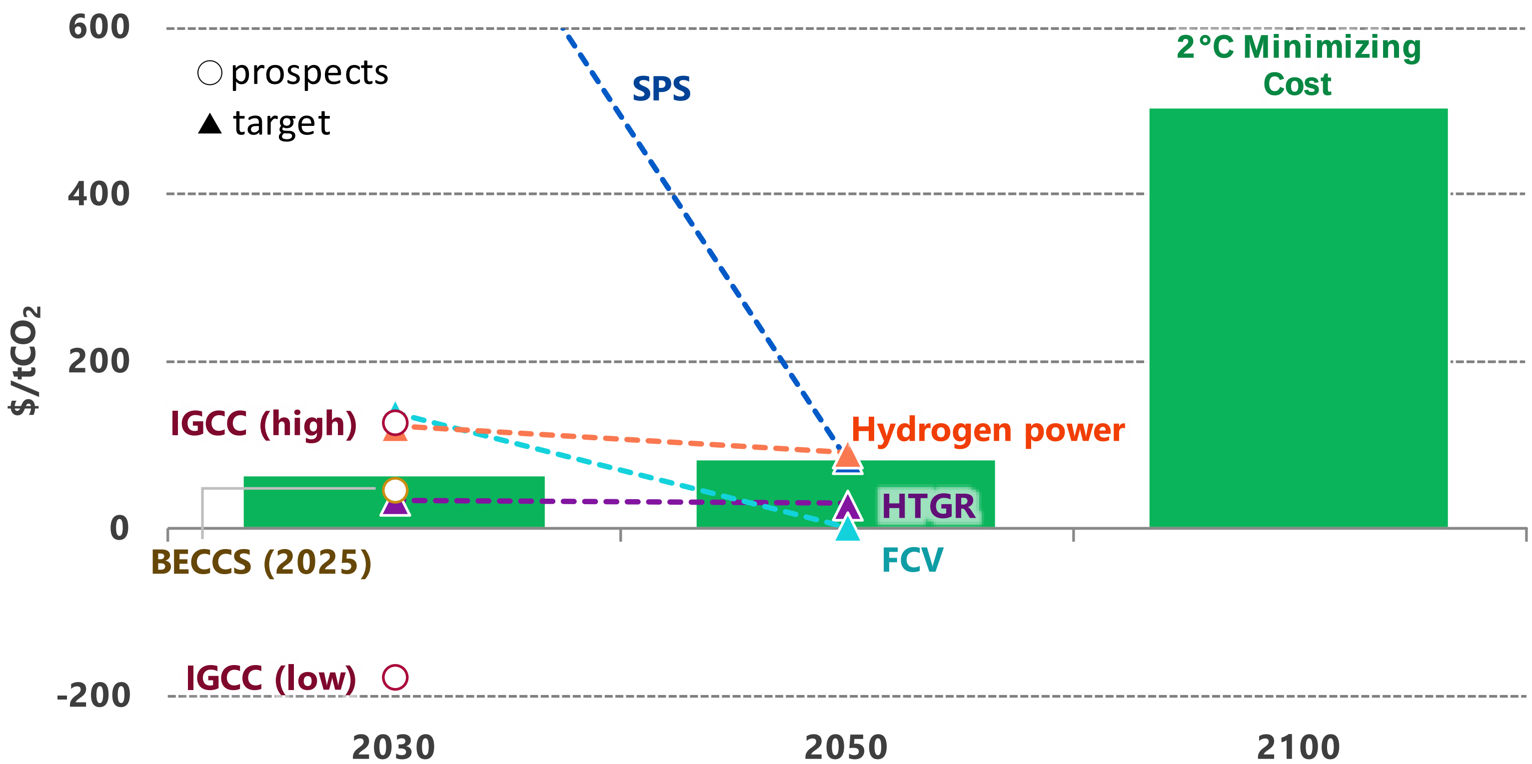
*Emissions path reflected “RCP 2.6” in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC).

Technology development for ultra long-term

Technologies		Description	Challenges
Technologies to reduce CO_2 emissions	Next Generation Nuclear Reactors	Fourth-generation nuclear reactors such as ultra-high-temperature gas-cooled reactors(HTGR) and fast reactors, and small- and medium-sized reactors are now being developed internationally.	Expansion of R&D support for next generation reactors
	Nuclear fusion reactor	Technology to extract energy just like the sun by nuclear fusion of small mass number such as hydrogen. Deuterium as fuel exists abundantly and universally. Spent nuclear fuel as high-level radioactive waste is not produced.	Technologies for continuously nuclear fusion and confining them in a certain space, energy balance, cost reduction, financing for large-scale development and establishment of international cooperation system, etc.
	Solar Power Satellite (SPS)	Technologies for solar PV power generation in space where sunlight rings abundantly above than on the ground and transmitting generated electricity to the earth wirelessly via microwave, etc.	Establishment of wireless energy transfer technology, reduction of cost of carrying construction materials to space, etc.
Technologies to sequestrate CO_2 or to remove CO_2 from the atmosphere	Hydrogen production and usage	Production of carbon-free hydrogen by steam reforming of fossil fuels and by CCS implementation of CO_2 generated.	Cost reduction of hydrogen production, efficiency improvement, infrastructure development, etc.
	CO2 sequestration and usage (CCU)	Produce carbon compounds to be chemical raw materials, etc. using CO_2 as feedstocks by electrochemical method, photochemical method, biochemical method, or thermochemical method. CO_2 can be removed from the atmosphere.	Dramatic improvement in quantity and efficiency, etc.
	Bio-energy with carbon capture and storage (BECCS)	Absorption of carbon from the atmosphere by photosynthesis with biological process and CCS.	It requires large-scale land and may affect land area available for the production of food etc.

Lower cost is key for innovative technologies

❖ CO_2 Reduction Cost by Innovative Technology



Note: Cost (=carbon price) for “2 ° C Minimizing Cost” is the highest cost of the technology adopted at each year. Refer to the main report for detail.

Implicit carbon price for “2° C Minimizing Cost” is $85/tCO$_2$ in 2050. The target costs for innovative technologies, such as BECCS, hydrogen power, FCV, HTGR, SPS, are within the range of the carbon price. The 2° C target can be reached with using these technologies. It is important to enhance R&D from the long term view and international collaboration is dispensable.

Closing

- The climate issue is a long-term challenge over many generations. Given the sustainability of measures, economic assessment is necessary.

- On the other hand, it is also a fact that there are many uncertainties in the climate issue. We will continue our analysis further in a neutral position.
  - ✓ Search better model structure and parameters
  - ✓ Split the model to regions
  - ✓ Incorporate technology list

- Among many uncertainties, it is R&D for low/zero/negative-emissions technologies that is certainly necessary.

Thank you for your kind attention