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Importance of Developing Fluorocarbons Emissions Inventory in Asia and Emissions Mitigation Analysis

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ASIA-PACIFIC INTEGRATED MODEL

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Types of Fluorocarbons

Today's Topic

	Ozone Depleting Substance	Greenhouse Gas
CFCs (ChloroFluoroCarbons)	✔	✔
HCFCs (HydroChloroFluoroCarbons)	✔	✔
HFCs (HydroFluoroCarbons)		✔
PFCs (PerFluoroCarbons)		✔
SF_6 (Sulfur Hexafluoride)		✔
NF_3 (Nitrogen Trifluoride)		✔

Fluorocarbons
- Ideal Characteristics and Various Applications -

In 1928, Midgley successfully synthesized CFC-12 and CFC-11

- ☆ Colorless, transparent, odorless gas or liquid
- ☆ Chemically stable, hard for chemical decomposition
- ☆ Thermally stable, hard for thermal decomposition
- ☆ No corrosive property
- ☆ Incombustible property, no flame and no explotion
- ☆ Very less toxicity
- ☆ Volatile property, easy to evaporate
- ☆ Liquescent property, easy to liquefy with additional pressure

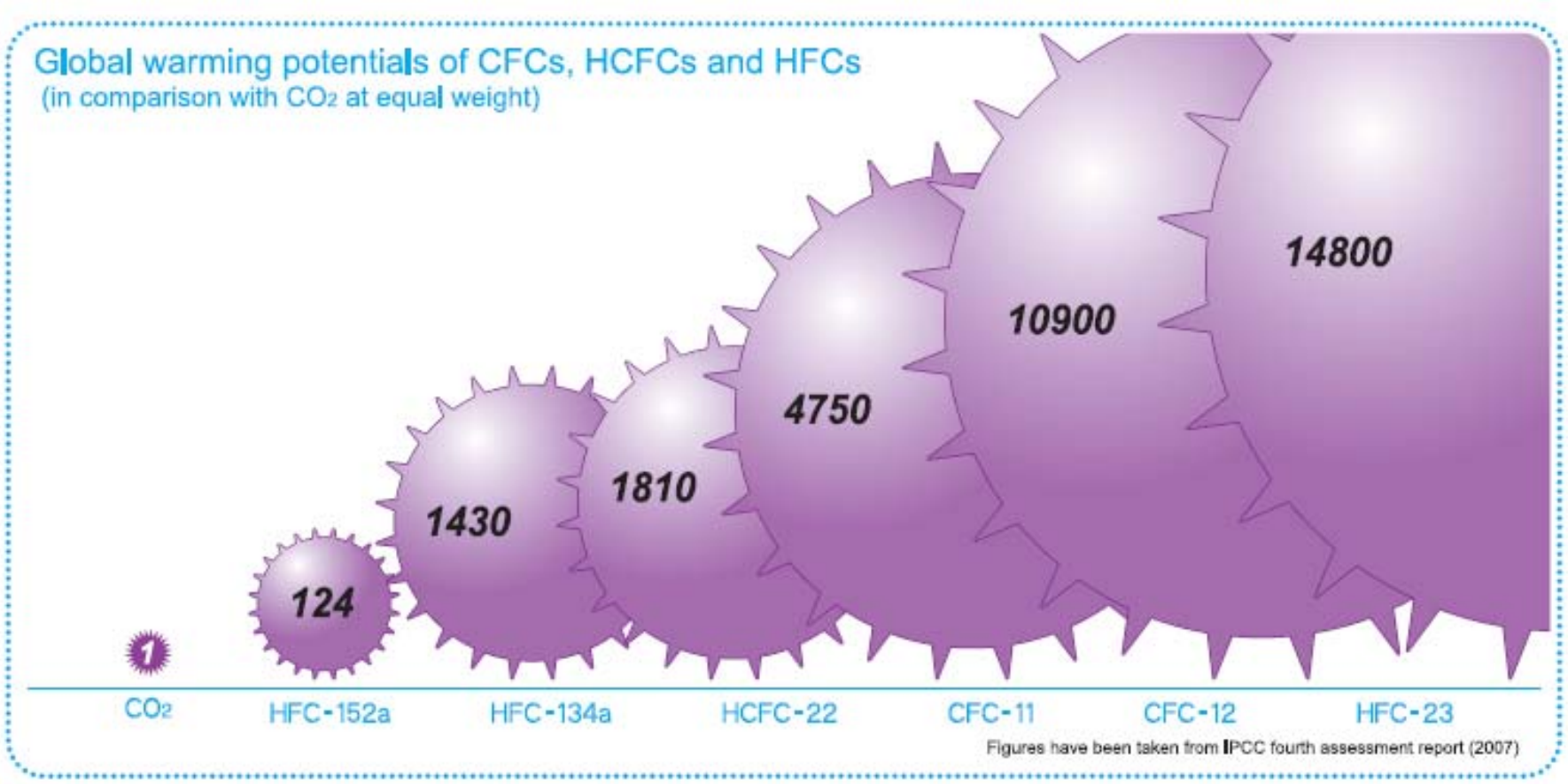
Used for various purposes as ideal artificial chemical product

Refrigerant	Thermal insulation foam	Open foam	Solvent	Aerosol propellant






Fluorocarbons Environmental Impacts
- Global Warming Potentials -



Example)

1 kg HCFC-22 refrigerant emission = 1810 kg CO_2 eq emission

Why & How Important of Recovery and Decomposition

CO_2 emissions per capita in FY2015 in Japan = 9.64 tCO2

Source: National GHG Inventory Report of Japan 2017

Equivalent to 5 devices

= around 9~10 tCO_2 eq

Average HCFC-22 refrigerant charged per household air conditioner is about 1000 g/device
= CO_2 equivalent emission per device without any recovery is 1.81 t-CO_2 eq/device

CO_2 emissions per household in FY2015 = 4.92 tCO2

Source: calculated based on the GHG Emissions Data of Japan by GHG Inventory Office, Japan

Equivalent to 1 household

= Around 4.5~4.8 tCO_2 eq

Average HFC-134a refrigerant charged per refrigeration is about 125-150g/device = 0.18-0.21 t-CO_2eq
+ Averaged HCFC-22 refrigerant charged per air conditioner is about 1000g/device = 1.18 t-CO_2eq
+ Average HFC-134a refrigerant charged per car air-conditioner is about 500-700g/device = 0.72-1.00 t-CO_2eq

Note）examples of CO2 equivalent emissions calculations when there is no recovery measure for fluorocarbons

Why & How Important of Recovery and Decomposition

Energy-related CO_2 emissions per capita in 2010

	tCO_2/pop
India	1.32
Indonesia	1.59
Viet Nam	1.42

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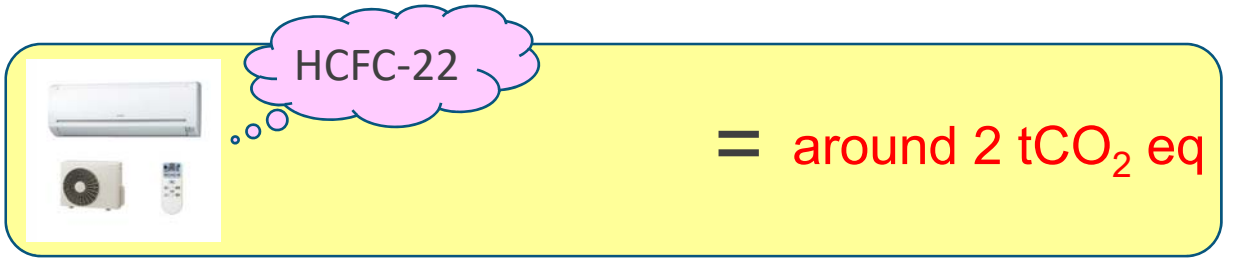

	tCO_2/pop
Thailand	3.36

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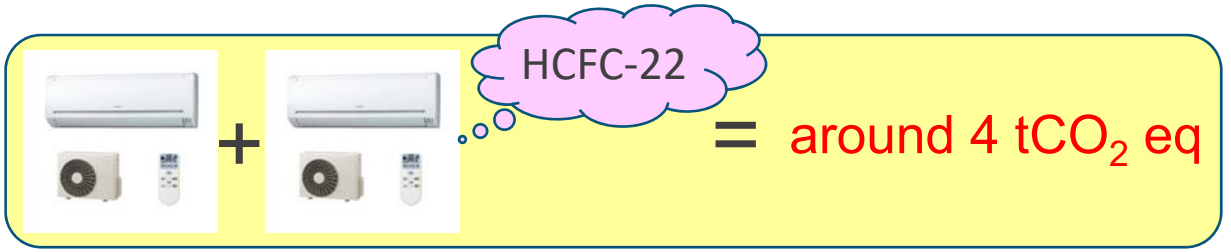

	tCO_2/pop
China	5.41

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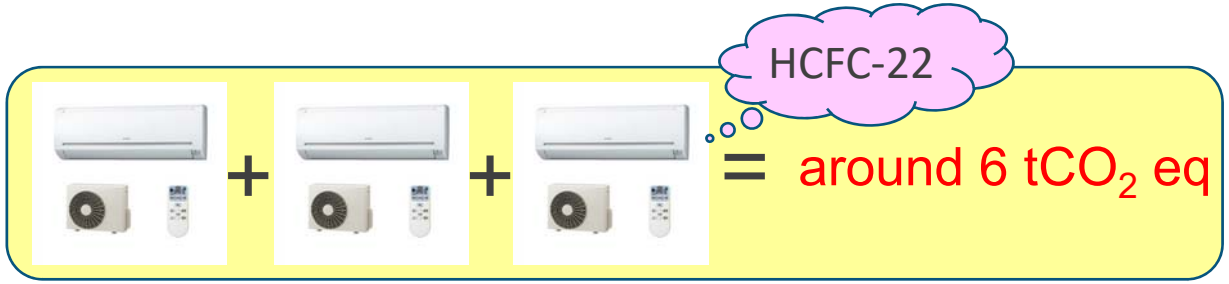

	tCO_2/pop
Myanmar	0.15

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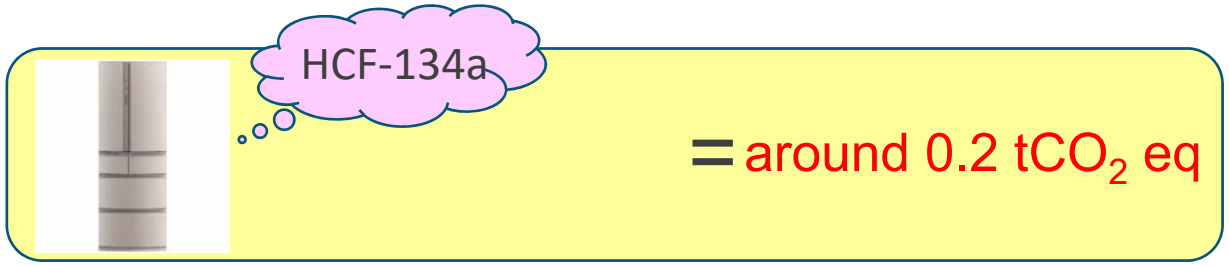
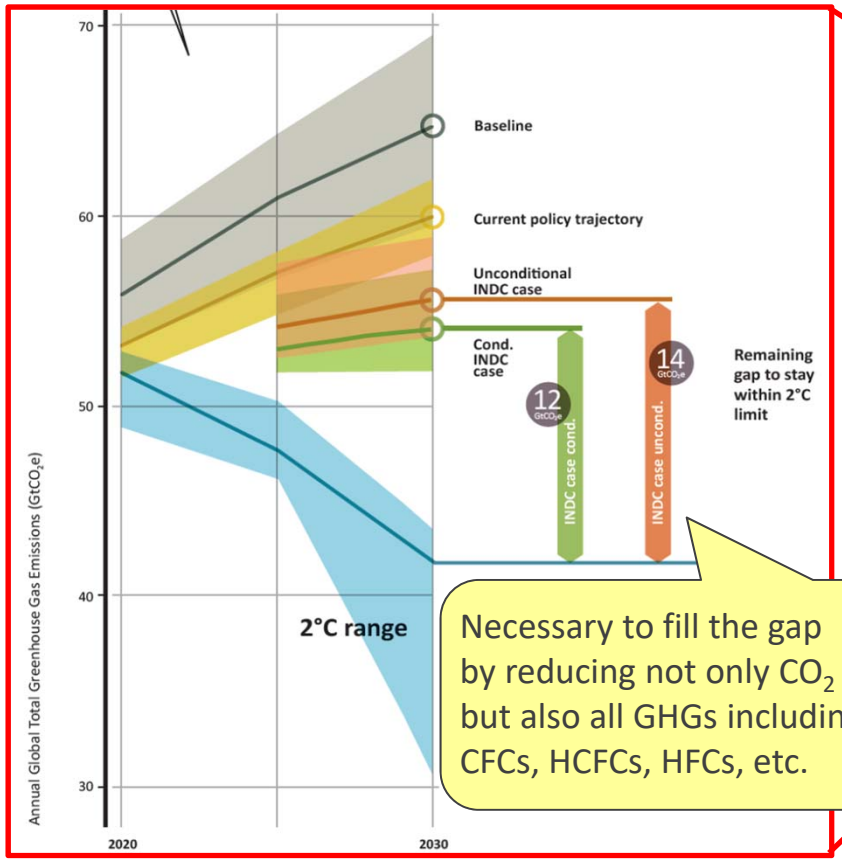


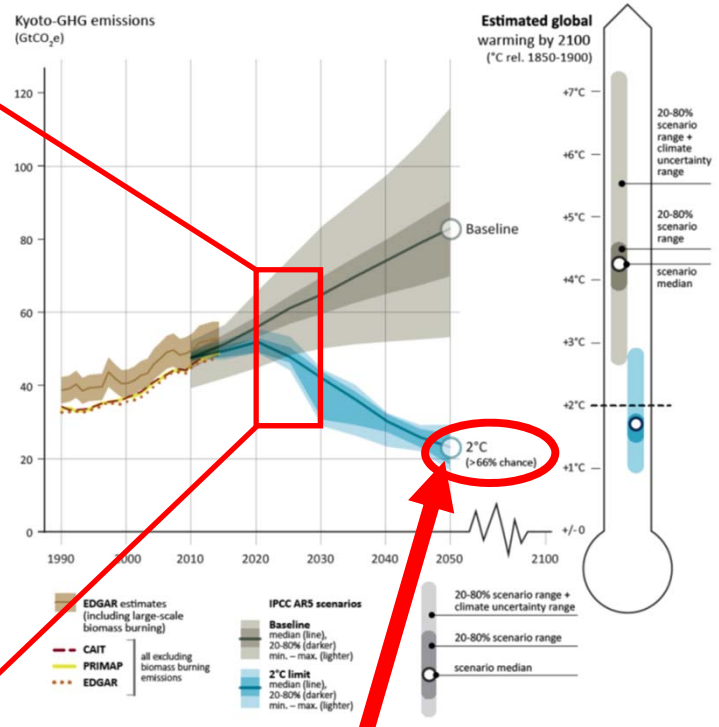
Note) Calculated by author, using IEA (2016) World CO2 emissions from Fuel Combustion and UN World Population Prospects: The 2012 Revision. If you use the national inventory, the exact value should be different, but the scale of its value should be similar.

UNEP (2015) The Emission Gap Report

Emissions Pathways are in line with the 2℃ target under the Paris Agreement?

- Without enhanced ambition, the likely global average temperature increase will be in the range of **<3.0 - 3.5℃ by the end of the century**
- INDCs emission levels are **4 - 6 $GtCO_2eq$ lower than the current policy trajectory in 2030**
- However, emission gaps between INDCs and 2℃ pathways are **12 Gt — 14 Gt CO_2eq in 2030.**



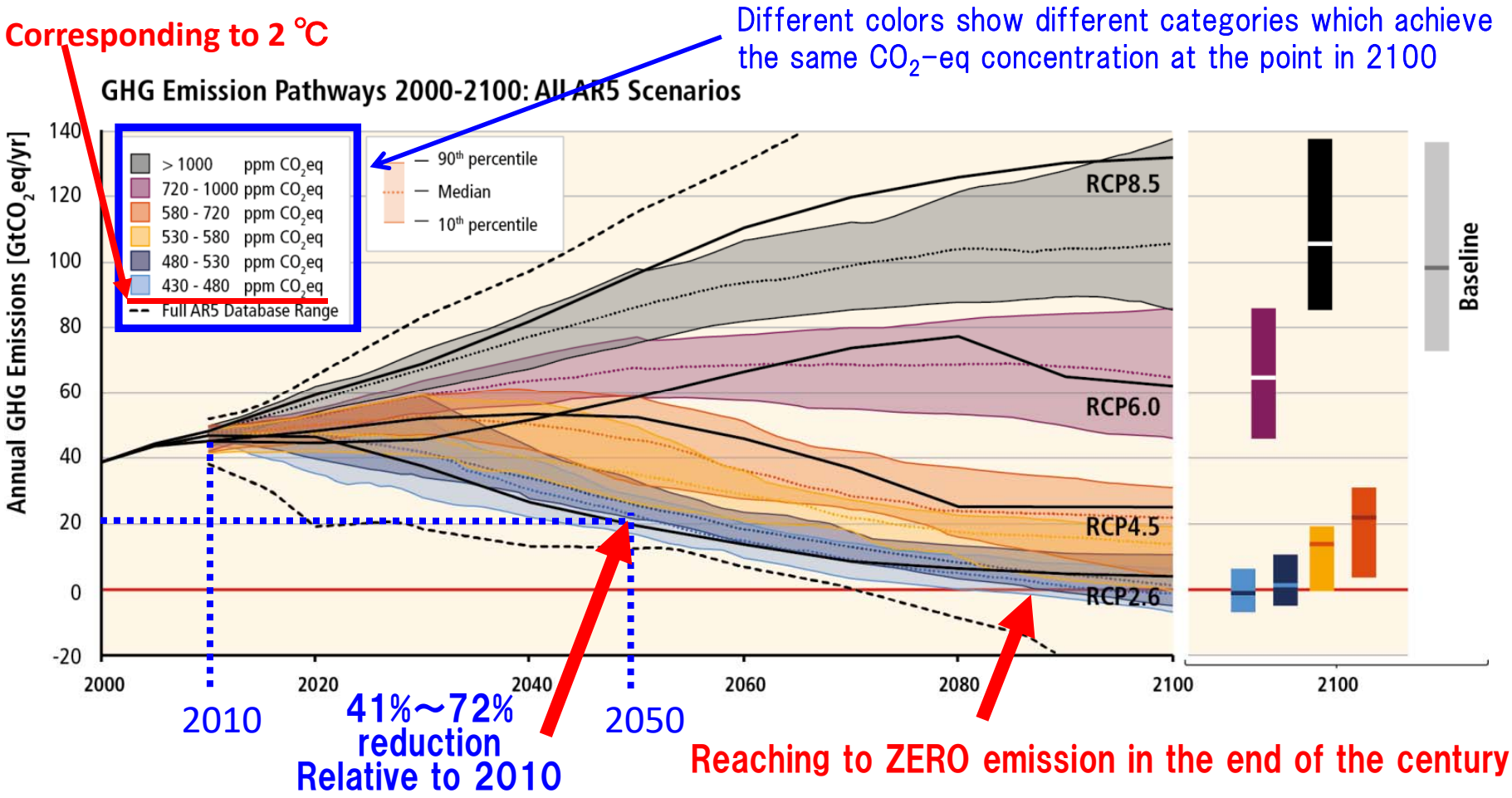


Around halving emissions by 2050 relative to 2010 (equivalent to achieving around 2 tCO_2eq per capita)

Source) UNEP (2015), FigureES1, Figure ES2
http://uneplive.unep.org/media/docs/theme/13/EGR_2015_ES_English_Embargoed.pdf

IPCC AR5 WG3 (2014)
Chapter 6: Assessing Transformation Pathways

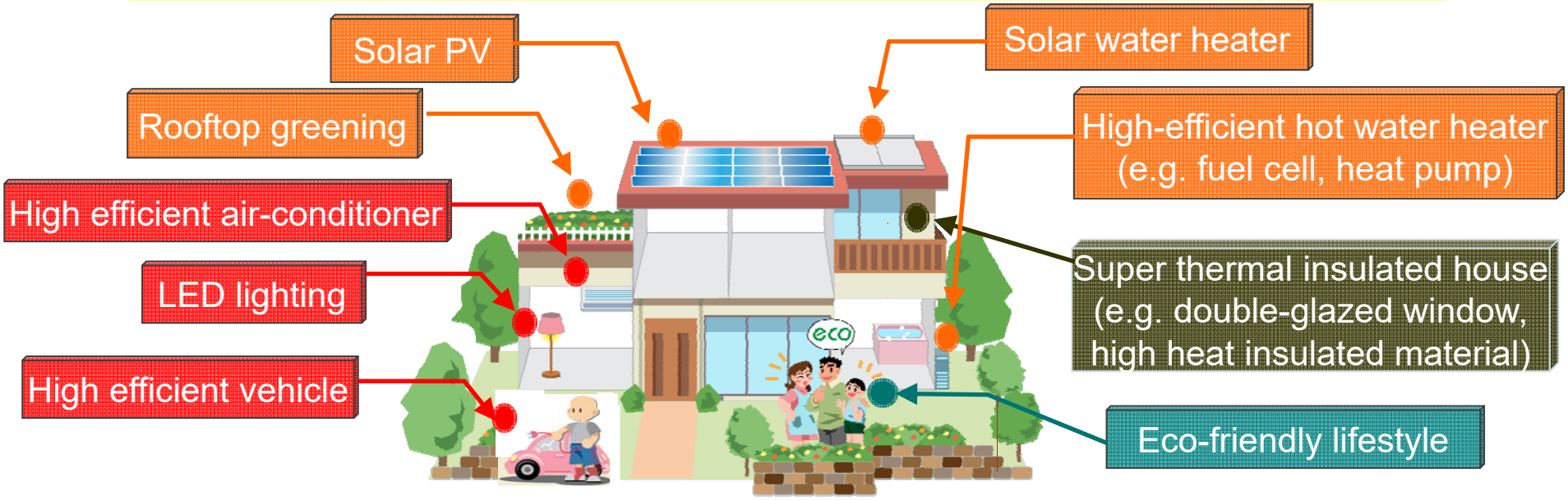
- Without more mitigation, **global mean surface temperature might increase by 3.7 – 4.8℃** by 2100.
- To stay below 2℃, **the range of GHG emissions are roughly between 30-50 Gt CO2eq in 2030.**
- To stay below 2℃, **41–72% reductions by 2050 compared to the 2010 level** are required.



Source) IPCC AR5 WG3 (2014), Figure SPM.4

Fluorocarbon Emissions will Offset CO_2 Reduction Efforts

Energy related CO_2 emissions per household (FY2015) in Japan: 4.92 t CO_2 per household



- Replacement with high-efficient devices : around 0.1 – 1 tCO_2 reduction
- Introduction of renewable energy : more than 1 tCO_2 reduction
- Improvement of infrastructure : around 0.1 – 1 tCO_2 reduction
- Implementation of eco-friendly lifestyle : around 0.1 – 1 tCO_2 reduction

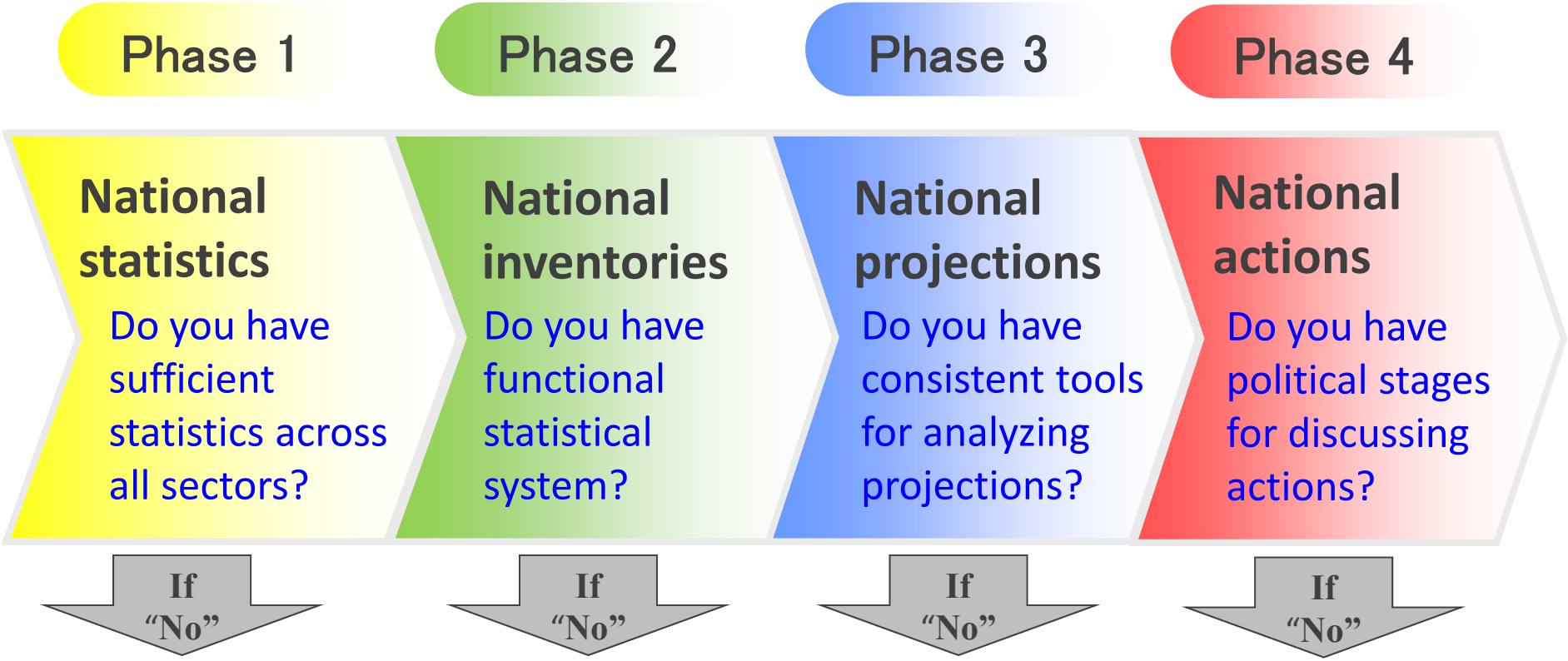
With mitigation measures and investments, CO_2 emissions per household can be reduced by around half (i.e. reduction amounts are around **2.0 -3.0 tCO_2 per household**)

If you don't recover and decompose fluorocarbons and emit all fluorocarbons from one air conditioner, refrigeration and car air conditioner, it is equivalent to **2.5 – 3.0 tCO_2eq emission**

Note: Reduction effects were approximately estimated by using information based on the Energy Conservation Center, Japan, and National GHG Inventory Report of Japan 2017. Reduction effects will vary depending on preconditions.

Bridging the GAP
- Statistics, Inventories, Projections, & Actions -

It is essential to enforce MRV(Measurable, Reportable, Verifiable) for analyzing national future GHG emissions and mitigation actions.



How to Estimate Fluorocarbons Emissions
- Step1: Collecting Statistics and Aggregating Data -

1. It is necessary to collect **statistics on the number of devices & products** which use & consume CFCs, HCFCs, HFCs, PFCs, SF_6, NF_3.
   - Refrigerator for household use, and for commercial use.
   - Air conditioner for house (separate-type, single-packaged-type)
   - Air conditioner for motor vehicle (car, truck, bus)
   - Central air conditioning equipment for building
   - Condensing unit
   - Refrigerating unit for transportation
   - Refrigerating display showcase and so on







2. It is necessary to collect data on "**average charged (consumed) amount per device & product**" and "**type of fluorocarbon gases per device & product**" based on market survey and statistics.
   e.g.) 500 – 700 g of HFC-134a refrigerant are charged in a car air conditioner
   1000g of HCFC-22 refrigerant are charged in a room air conditioner.

3. It is also significantly beneficial to collect statistics on **import, export, production, consumption** of CFCs, HCFCs, HFCs, PFCs, SF_6, NF_3.

How to Estimate Fluorocarbons Emissions
- Step2: Methodologies for Estimating Emissions Inventory -

1. Bottom-up approach

We estimate emissions by micro statistical data such as number of devices containing fluorocarbons, average consumed amount per device, leakage rate, recovery rate, etc.

e.g.) total emission in refrigerator =

total refrigerant contained at production × fugitive refrigerant ratio at product
+ Σ(number of operated devices × refrigerant contained per device × fugitive ratio from use)
+ Σ(number of disposed devices × refrigerant contained per device)
– recovered amount of refrigerant

2. Top-down approach

We estimate emissions by macro statistical data such as production, consumption, import, export, average share of service type, average lifetime distribution of service type, etc.

e.g.) total consumption in refrigerator =

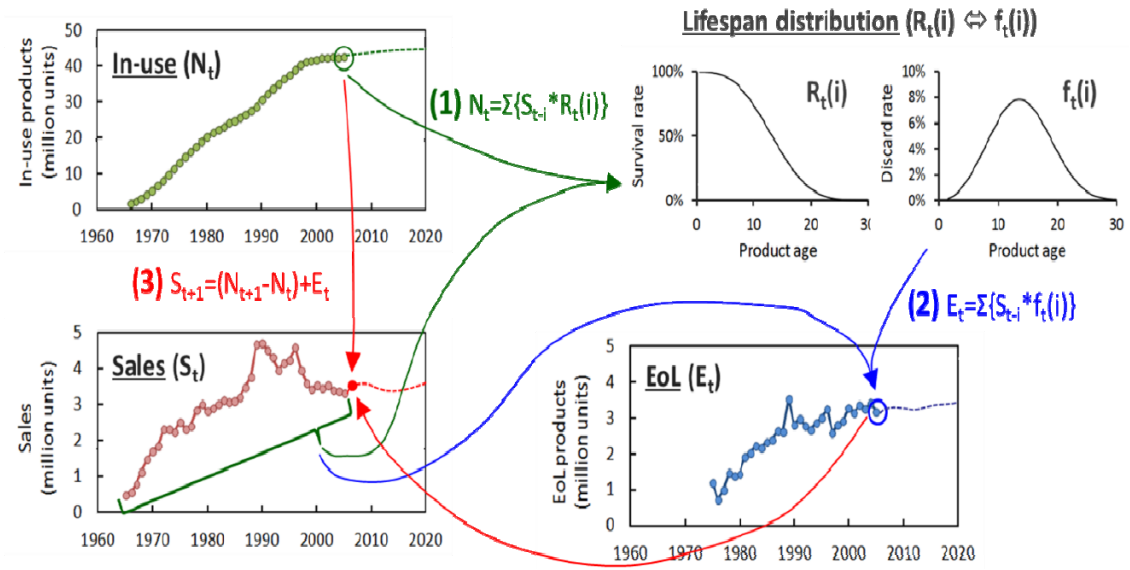
(production + import – export) × share of refrigerator use in all refrigerants

total emission in refrigerator =

total consumption in refrigerator × lifetime distribution of refrigerator for disposal
– recovered amount of refrigerant

How to Estimate Fluorocarbons Emissions
- Step3: Estimating Future Emissions using Bottom-up Approach-

Methodology	Overview	Required variable for future scenario
Multi regression model	Using historical correlation between objective variable and basic socio-economic variable.	GDP, POP, per capita GDP
Lifetime model	Using historical correlation between number of sales by device and lifetime duration by device.	Sales numbers by device. lifetime duration by device.
Population balance model	Using historical correlation between number of stocks by device and lifetime duration by device.	Stock (in-use) numbers by device. Lifetime duration by device.



Overview of how to estimate end-of-life products (=dispose of used products) by using Population Balance Model

Source) Oguchi M., Terazono A., Hanaoka T. (2017) Estimating the potential amount of fluorocarbons in end-of-life products generated in Asian developing countries, 2017 Joint Conference ISIE and ISSST.

How to Estimate Fluorocarbons Emissions
- Step4: Assumptions and Scenarios Settings-

It is necessary to set the following assumptions based on market survey and statistics.

1. Average amount of charged (consumed) refrigerant per device & product

e.g.) 1000g refrigerant per room air conditioner. 500 – 700 g refrigerant per car air conditioner

2. Transitions of refrigerant type in the sales, in the past and the future

e.g.) HCFC22, R410A, HFC32 in room air conditioner. HFC134a in car air conditioner conditioner

3. Transitions of share of refrigerant type in the sales, in the past and the future (based on expert interviews and Kigali Amendment etc)

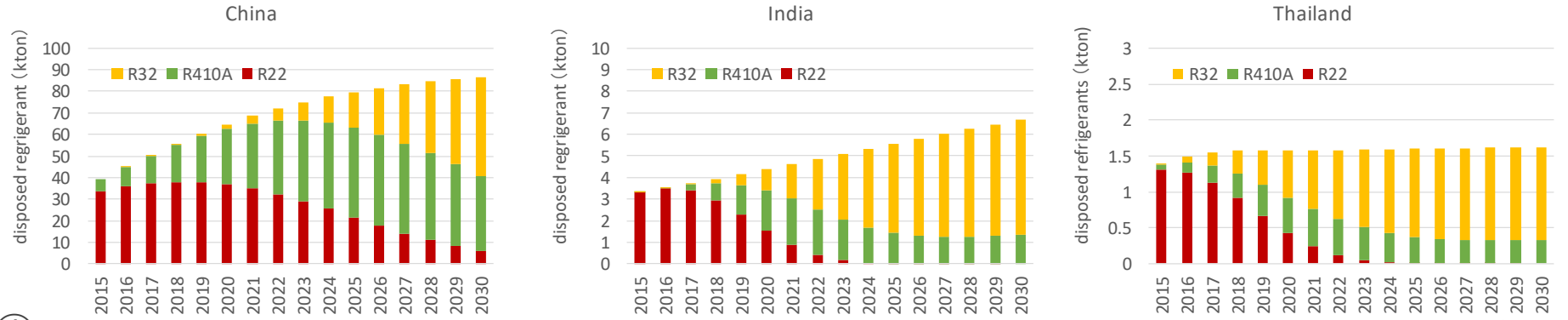
Example overview of transitions of types & shares in the sales of refrigerant in room air conditioner

Source) Oguchi M., Terazono A., Hanaoka T. (2017) Estimating the potential amount of fluorocarbons in end-of-life products generated in Asian developing countries, 2017 Joint Conference ISIE and ISSST.

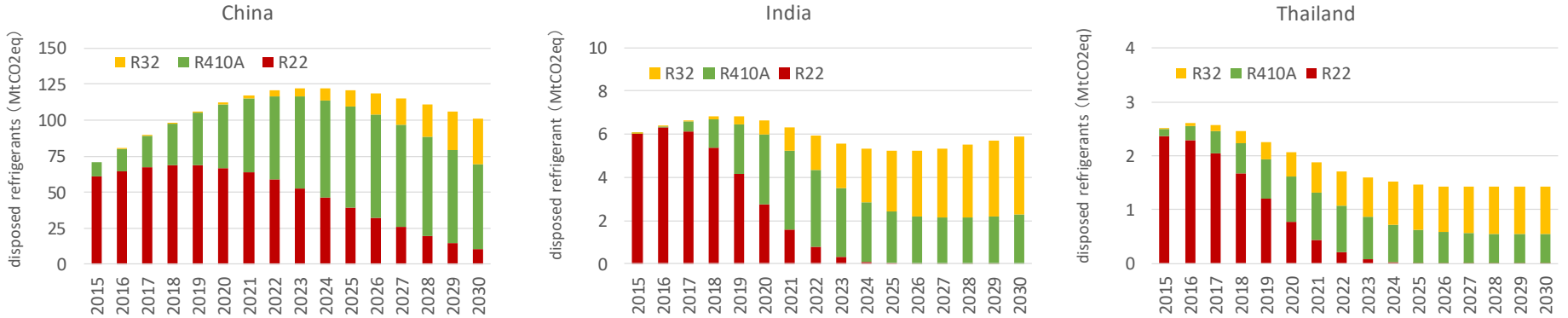
How to Estimate Fluorocarbons Emissions
- Step5: Emission Estimation Analysis-

After analyzing emissions by device and by fluorocarbon, we can find detailed characteristics.

- Necessary to analyze the trend in the unit of CO2 eq as well as ton of refrigerant.
- **HCFC-22 is still large in the near term**, thus necessary to recover HCFCs as well as HFCs.



① Example emission projections of disposed refrigerants from room air conditioners (k ton)



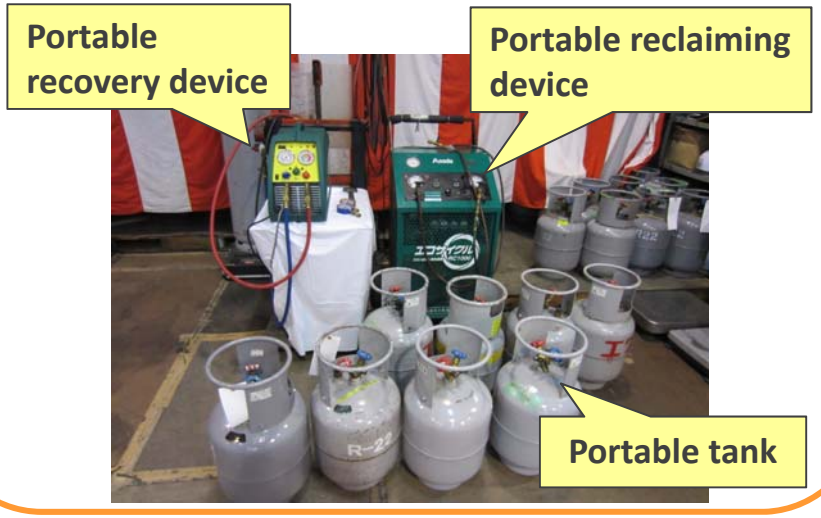
② Example emission projections of disposed refrigerants from room air conditioners (Mt CO_2 eq)

Source) Oguchi M., Terazono A., Hanaoka T. (2017) Estimating the potential amount of fluorocarbons in end-of-life products generated in Asian developing countries, 2017 Joint Conference ISIE and ISSST.

How to Analyze Mitigation Measures
- Step1: Collecting Information on Mitigation Measures -

Collecting data about initial cost, O&M cost, reduction efficiency, etc in each measures

Recovery measures



Leakage measures

Decomposition measures

[Mixed combustion furnace]
1. Cement kiln
 (i.e. mixing with cement production process)
2. Rotary kiln
 (i.e. mixing with waste incineration process)

[Single purpose furnace]
3. Submerged combustion method
4. Superheated steam reaction method
5. Catalytic method
6. Plasma method

Note) Photos taken by author when visiting ASADA corporation

How to Analyze Mitigation Measures
- Step2: Variety of Future Scenarios -

- Depending on purposes of analyses, it is better to set wide range of future scenarios, for example, the worst case, the best case, middle of the road case, etc.
- As for fluorocarbon mitigations, there is no recovery and decomposition in Asian developing countries yet, thus it is better to differentiate scenarios of “domestic measures only by international technology cooperation” and “domestic measures mixing with cooperation of overseas transportation of fluorocarbon wastes”.

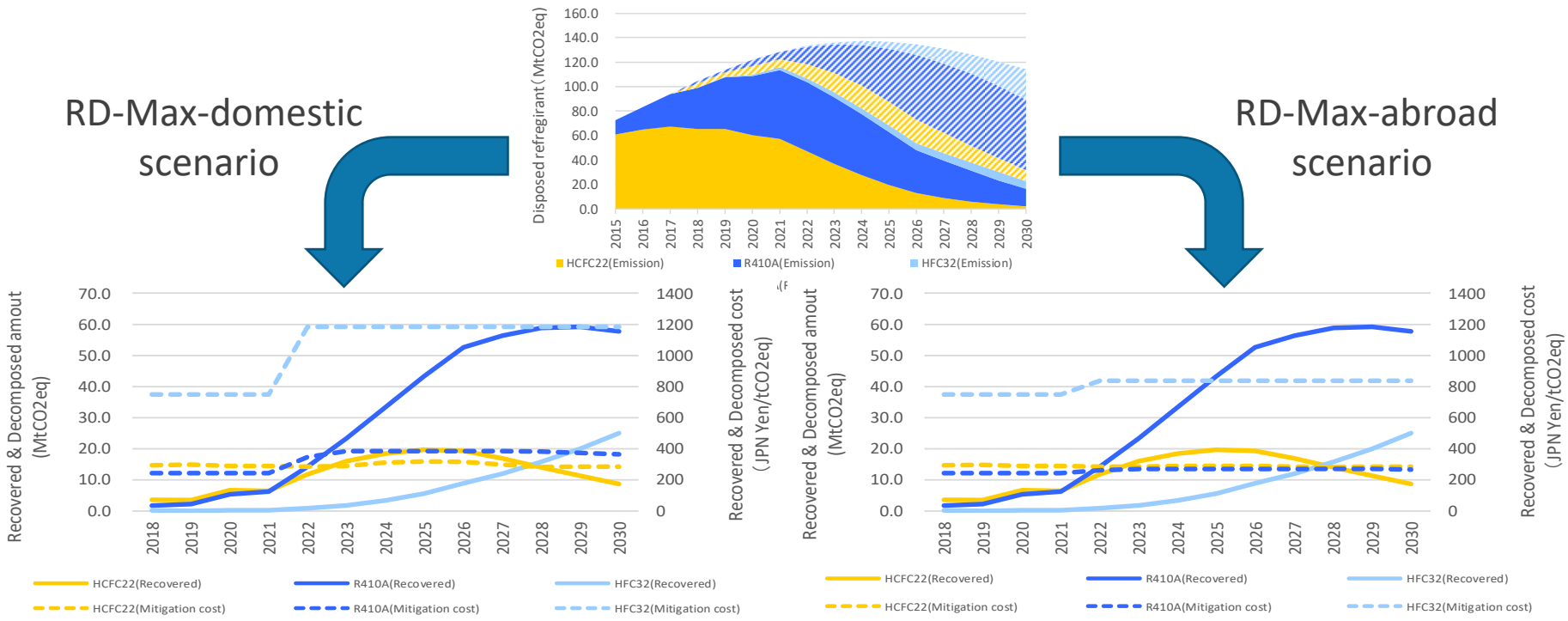
Example of recovery & decomposition scenarios about room air conditioners in Asia

Scenario name	Scenario description
BaU	Emissions without any measures (i.e. no recovery and decomposition)
RD	Recover the amount of fluorocarbons up to the capacity level of existing decomposition facilities (such as cement kiln, rotary kiln)
RD-Max-domestic	Recover fluorocarbons at a maximum and decompose fluorocarbon waste by the existing facilities (such as cement kiln, rotary kiln). In addition, in order to deal with all fluorocarbon waste within its country independently, decomposition facilities are newly installed by international technology cooperation.
RD-Max-Abroad	Recover fluorocarbons at a maximum and decompose fluorocarbon waste by the existing facilities (such as cement kiln, rotary kiln). If the capacity level of existing decomposition facilities are not enough, remaining fluorocarbon wastes are transported by ship to Japan and decomposed by using Japanese facilities.

How to Analyze Mitigation Measures
- Step3: Mitigation Potentials and Mitigation Cost Analyses -

- Costs of mitigating fluorocarbons are estimated around 100 – 1300 JPN yen/tCO_2eq (equivalent to around 1-13 US$/$tCO_2eq$) in 2030 in developing countries. Compared to costs of achieving the 2℃ target, costs of recovery & decomposition are cost competitive.
- Costs of CO_2 mitigation for achieving the 2℃ target are around 50-100US $/$tCO_2$ by 2030 at least. (Source: Carbon Pricing Leadership Coalition (2017) Report of the High-Level Commissions on Carbon Prices)

Example of recovery & decomposition of refrigerants from room air conditioners in China



Source) Oguchi M., Terazono A., Hanaoka T. (2017) Estimating the potential amount of fluorocarbons in end-of-life products generated in Asian developing countries, 2017 Joint Conference ISIE and ISSST.

Summary

1. To achieve the 2 ℃ target under the Paris Agreement at COP21, it is **necessary to reduce all GHGs** (not only the Kyoto Baskets of CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3 but also other GHGs such as CFCs, HCFCs)

2. Fluorocarbon emissions will offset CO_2 reduction efforts. It is **necessary to recover and decompose fluorocarbon** emissions.

3. Even if implementing Kigali Amendment, there are still large amount of emissions of CFCs and HCFCs in Asian developing countries. Thus, it is **important to take measures on recovery and decomposition of CFCs, HCFCs as well as HFCs**.

4. **Costs of fluorocarbon mitigation measures are more cost competitive than costs of CO_2 mitigation measures** to achieve the 2℃ target.

Acknowledgement:
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Appendix

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Global Warming Potentials
- major fluorinated GHGs in the time horizon of 100 years -

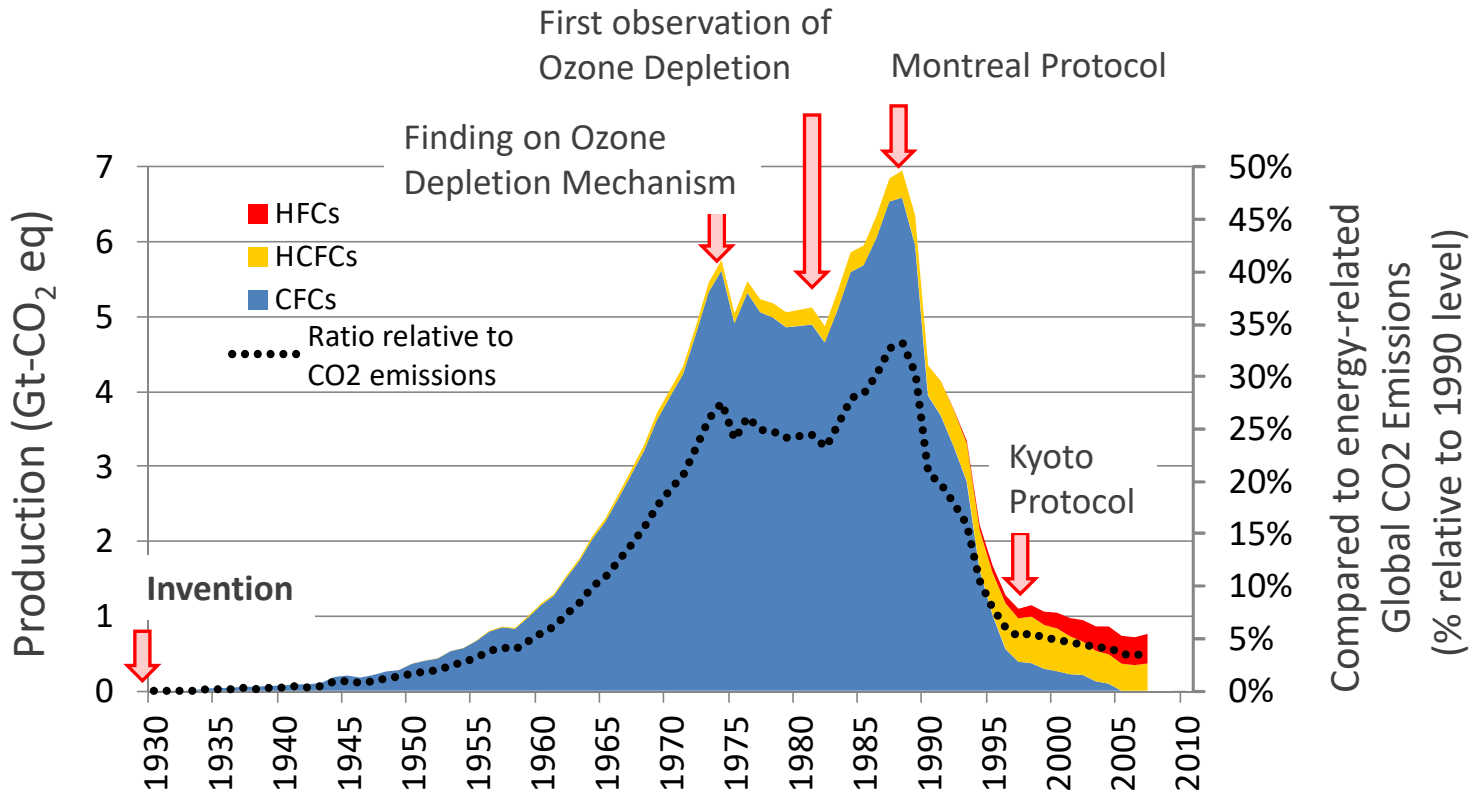
	Gas	ODP	GWP (SAR)	GWP (AR4)	GWP (AR5)	Major sectors
CFC	CFC-11	1.0	4000	4750	4660	Closed foam, Open foam, Aerosols, etc
	CFC-12	1.0	8500	10900	10200	Refrigerant (automobile air-conditioning, refrigeration etc)
	CFC-113	0.8	5000	6130	5820	Solvent (Electronic component, dry-cleaning etc)
	CFC-114	0.8	9300	10000	8590	Open foam
HCFC	HCFC-22	0.055	1700	1810	1760	Refrigerant (room air-conditioning, commercial refrigeration etc)
	HCFC-141b	0.11	630	725	782	Closed foam, Open foam, Solvent(Electronic component), etc
	HCFC-142b	0.065	2000	2310	1980	Open foam
HFC	HFC-23	0	11700	14800	12400	By-product of HCFC-22 production
	HFC-134a	0	1300	1430	1300	Refrigerant (automobile air-conditioning, refrigeration etc)
	HFC-152a	0	140	124	138	Aerosols
	HFC-32	0	650	675	677	Refrigerant (room air-conditioning, etc)
PFC	CF4	0	6500	7390	6630	AL production, Semiconductor Manufacturing, etc
	C2F6	0	9200	12200	11100	AL production, Semiconductor Manufacturing, etc
SF6	SF6	0	23900	22800	23500	Semiconductor Manufacturing, Electric Utilities, etc
NF3	NF3	0	—	17200	16100	Semiconductor Manufacturing, Electric Utilities, etc

Note1) Previously, GWP values in the time horizon of 100 years in the IPCC SAR have been used for GHGs national inventory reports under UNFCCC, because of the stipulation in the Kyoto Protocol.

Note2) The new official decision was made by the COP19 under the UNFCCC in 2013 that all countries need to use the GWP values in the time horizon of 100 years reported in the IPCC AR4 used for GHGs national inventory reports from 2015

Global Historical CFCs, HCFCs, HFCs Productions Trends
- effects of regulations and policies -

Using GWPs in the time horizon of 100 years in IPCC SAR

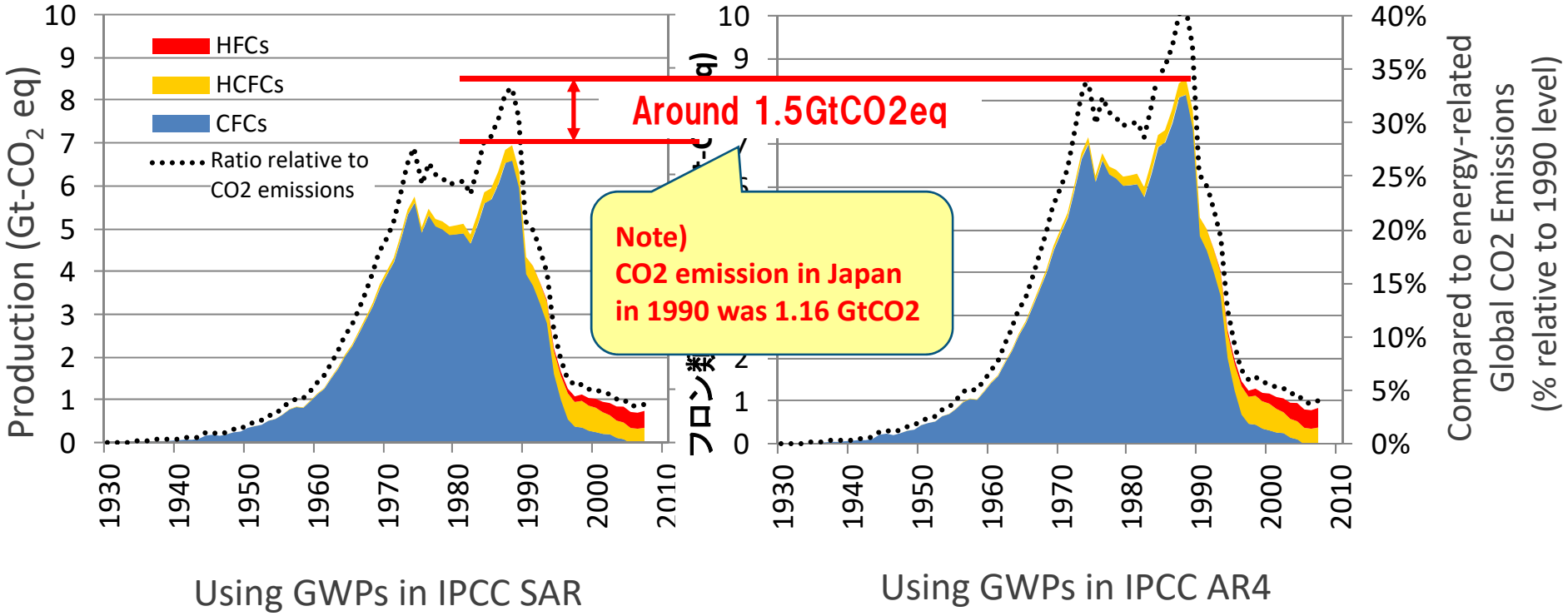


Source) Calculated by author based on AFEAS database. Energy-related CO2 emissions are based on IEA

Regulations on productions under the Montreal Protocol was, in a sense, successful internationally. However, the another issue is about emissions of "banked fluorocarbons" in various devices at the time of disposal.

Note) AFEAS provided data on production and consumption, thus many researchers used this database. However, this figure under-estimated production amounts due to data availability; for example, 1) AFEAS included data only from AFEAS member countries, thus data from China, Russia, India etc were excluded, 2) AFEAS did not report all type of fluorocarbons.

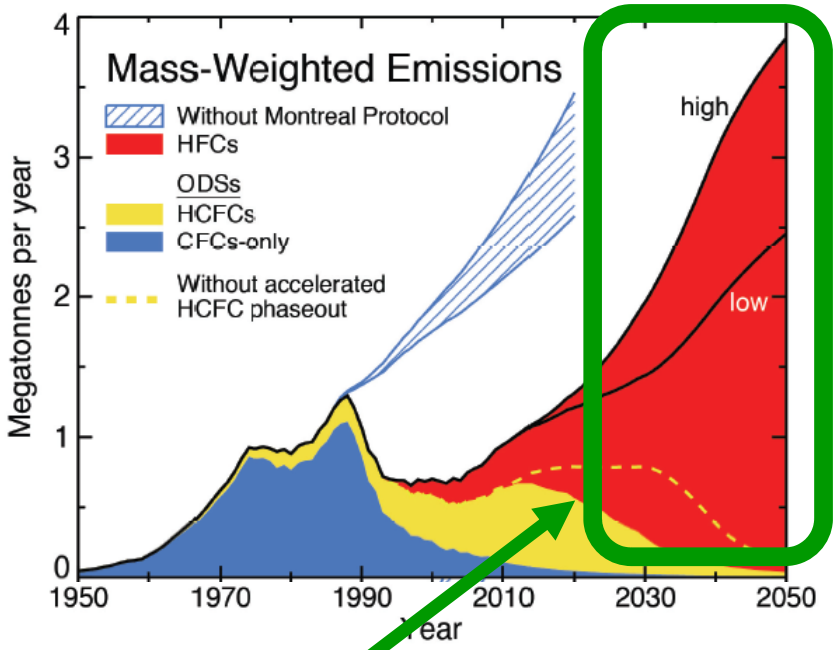
Global Historical CFCs, HCFCs, HFCs Productions Trends
- Comparison between IPCC SAR GWP and IPCC AR4 GWP -



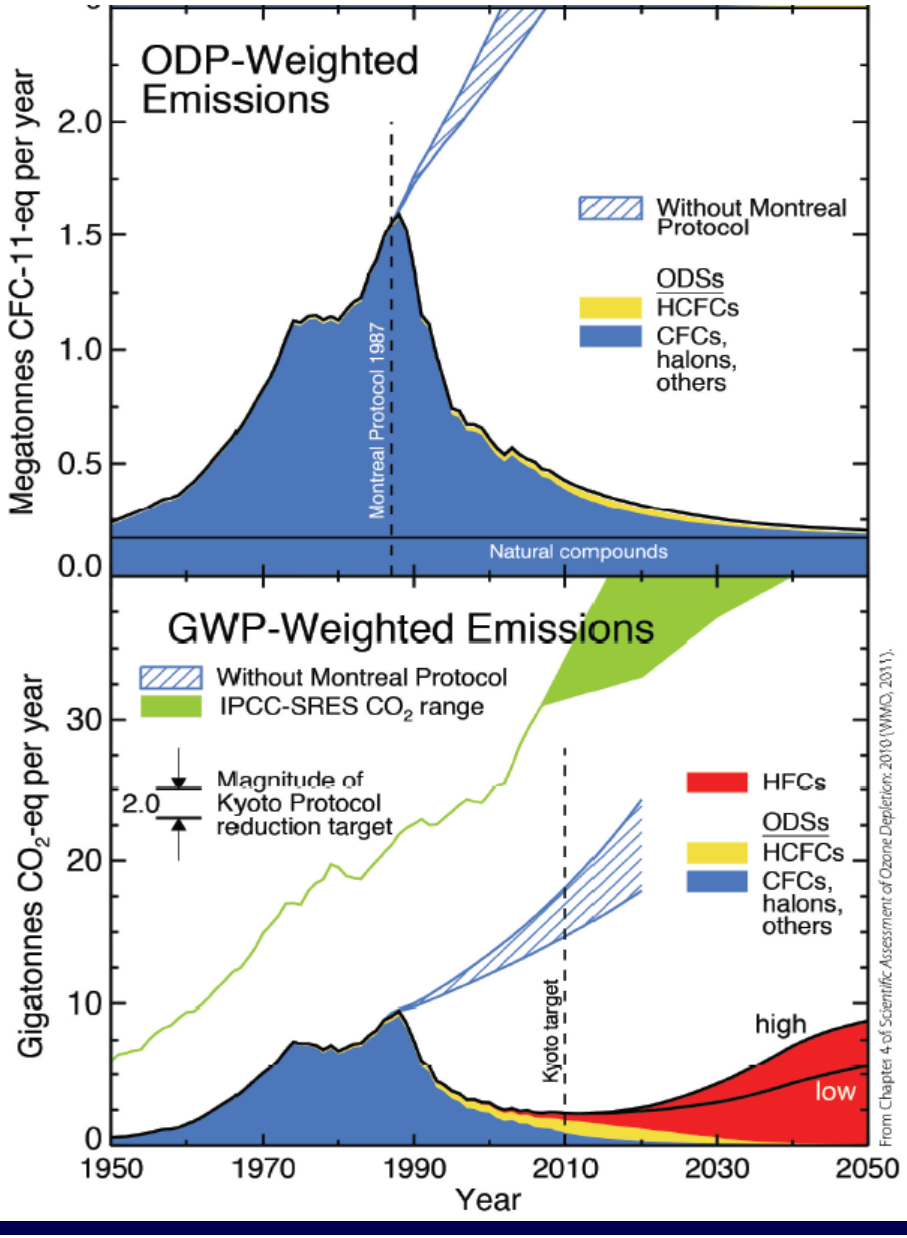
Source) Calculated by author based on AFEAS database. Energy-related CO2 emissions are based on IEA

Note）AFEAS provided data on production and consumption, thus many researchers used this database. However, this figure under-estimated production amounts due to data availability; for example, 1) AFEAS included data only from AFEAS member countries, thus data from China, Russia, India etc were excluded, 2) AFEAS did not report all type of fluorocarbons.

Example of Previous Study
- Future Emissions Projections of Fluorocarbons -



Upper left : in the unit of metric ton
Upper right: in the unit of ODP ton
Lower right: in the unit of CO2 ton
Source) Velders et al. [2009], PNAS



We need to carefully discuss about effects of Kigali Amendment on future HFCs emissions projections

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Thank you for your attention