新規フッ素系温室効果ガスの種類と特性、評価

Environmentally Accepted Fluorinated Gases

産業技術総合研究所

関屋 章

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2008年11月26日、ホテル機山館

The steps for acceptance of new technologies

Select Useful Alternative Technologies

What is Target

Technology Level

Sustainability
Efficiency

How to evaluate environment

What is benefit:
・Environment
・Resources

What is contribution to society

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Environment analyses

Evaluated by GWP×t

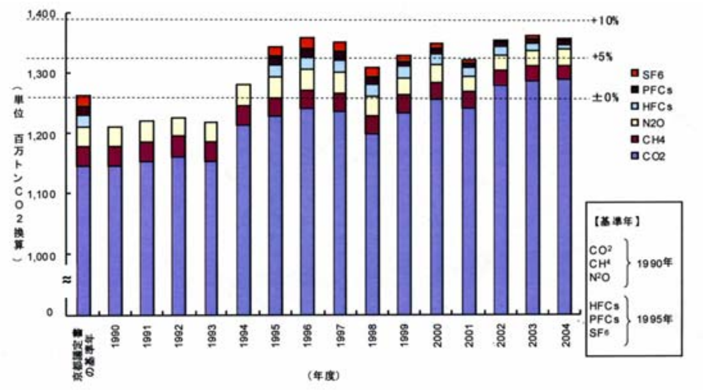
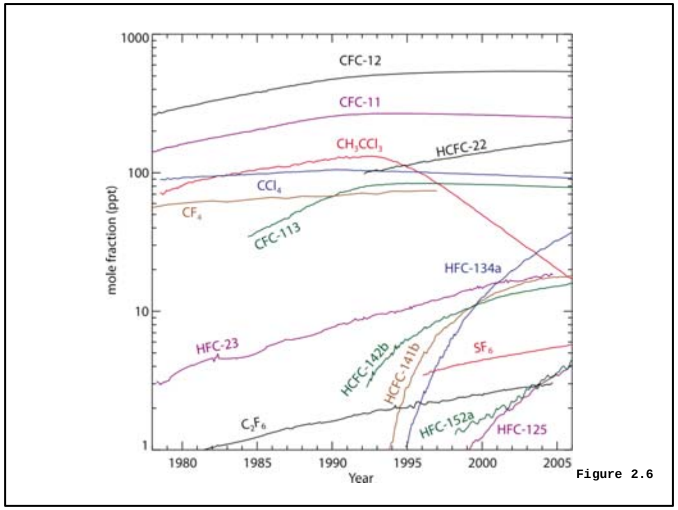


図 1 温室効果ガス総排出量の推移

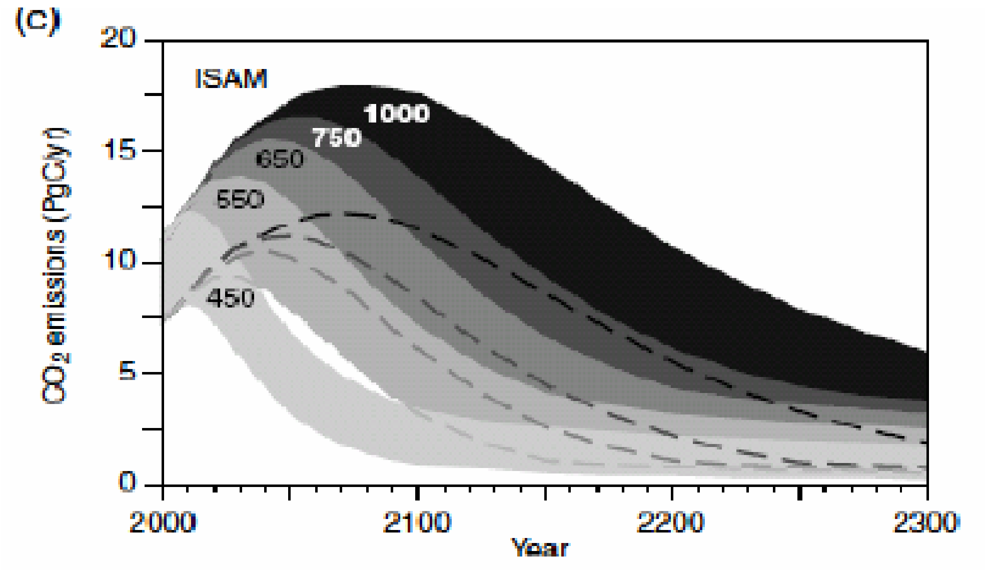
National Greenhouse Gas Inventory Report of Japan 2006 ver.2

Mole fraction (ppt) of GHGs by IPCC 2007

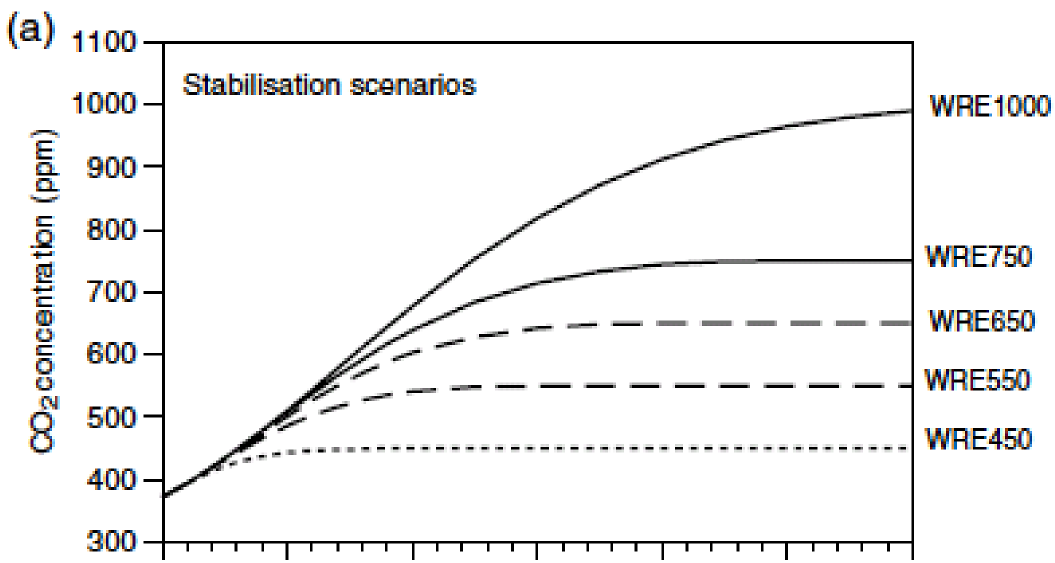


GWP ・Easy to look trend of GHGs emissions.
・Random ITH value
・Difficult to image future environment.
・Selection of Technologies
Successful to chose better technology
Weak relation to atmosphere
Which do you chose by LCCP analysis?
Tech. 1: 1000(GWP,Short LT) × 1kg = 10000
Tech. 2: 1(GWP, Long LT) × 1000kg = 10000

IPCC 2001



Reduction schedule of GHGs is considered with ppm analyses



UNFCC:
Target is stabilize GHGs atmospheric concentrations

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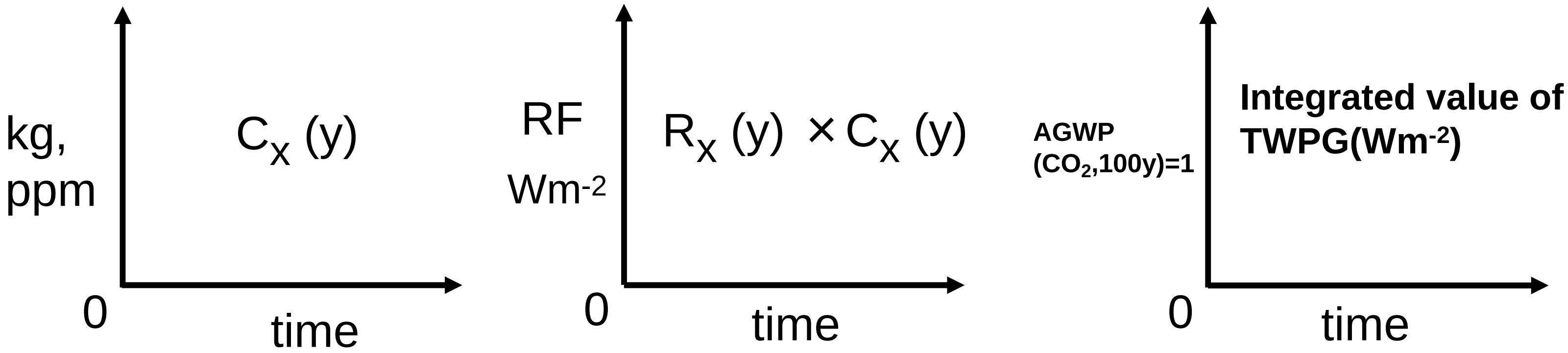
Analysis Methods of Global Warming

Current analyses: GWP

(LCCP, LCA, $LCCO_2$, Carbon Offset, CDM, Carbon Footprint, Ecological Footprint, Carbon Neutral, Carbon Positive, Eco-point, ------)

Analyses by time

TWPG (kg, ppm) | **TWPG (Wm^{-2})** | **CWP**



TWPG: Total Warming Prediction Graph
CWP: Composite Warming Effect

Calculated on the assumption that the same atmosphere is kept in the future.
(According to “Sustainable Development” Concept)

A.Sekiya, Journal of Fluorine Chemistry 128 (2007) 1137–1142

Scenarios of CO_2 emissions by TWPG and CWP

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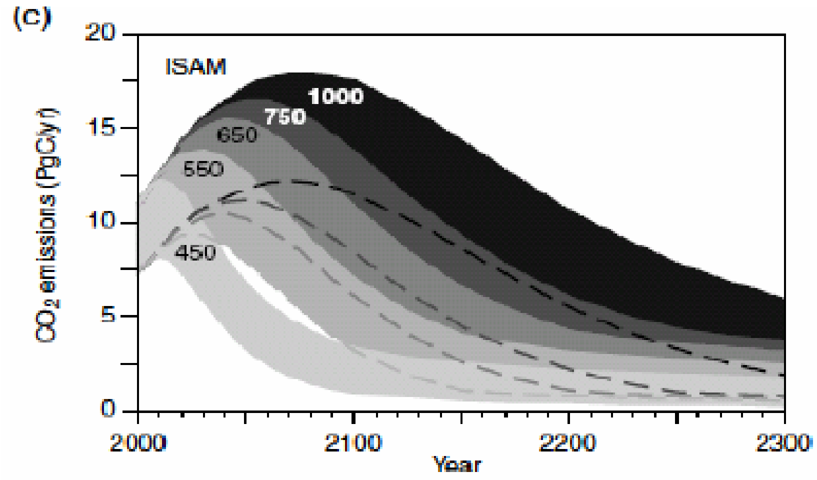
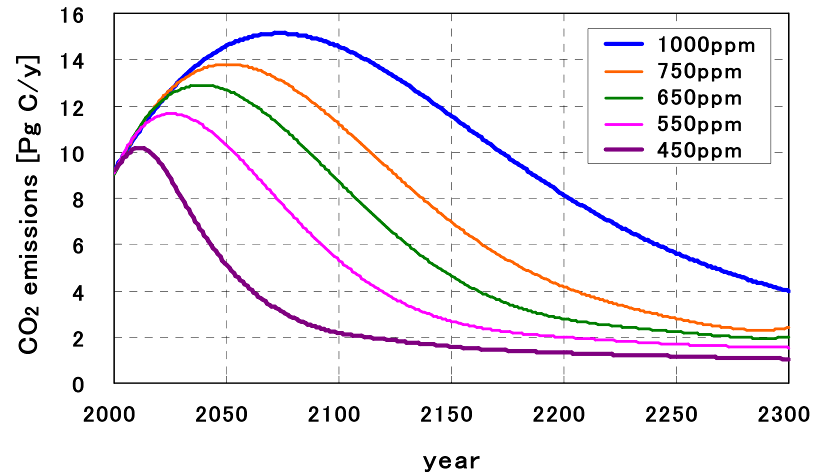
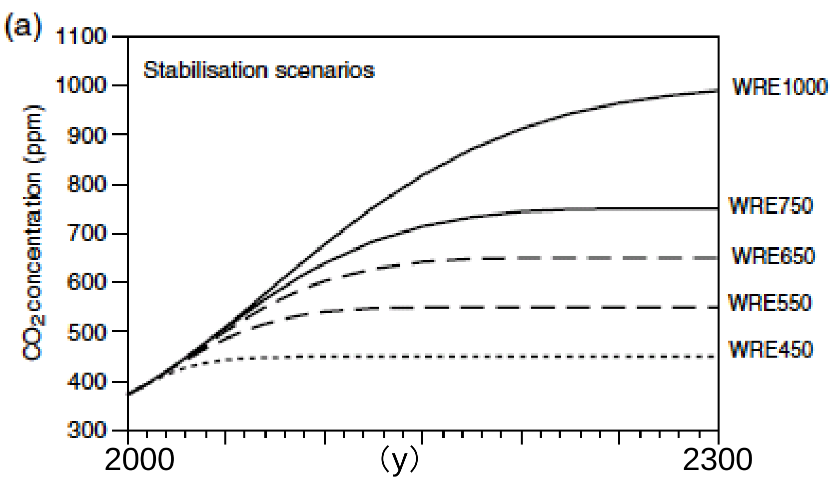


CO_2 emissions
(ISAM model)

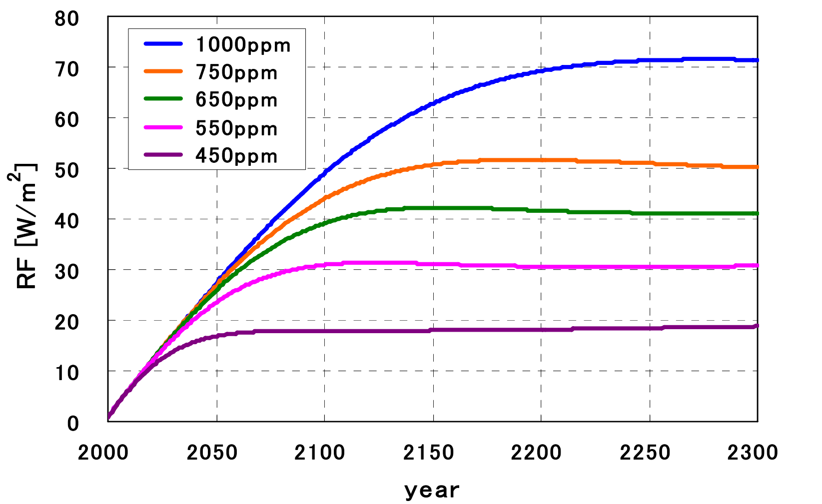
Simulation in IPCC 2001



CO_2 emissions
(simulation of ISAM model - average of the upper and lower limits)



TWPG



Ref. IPCC 2001 ← Similar to IPCC → Our Method

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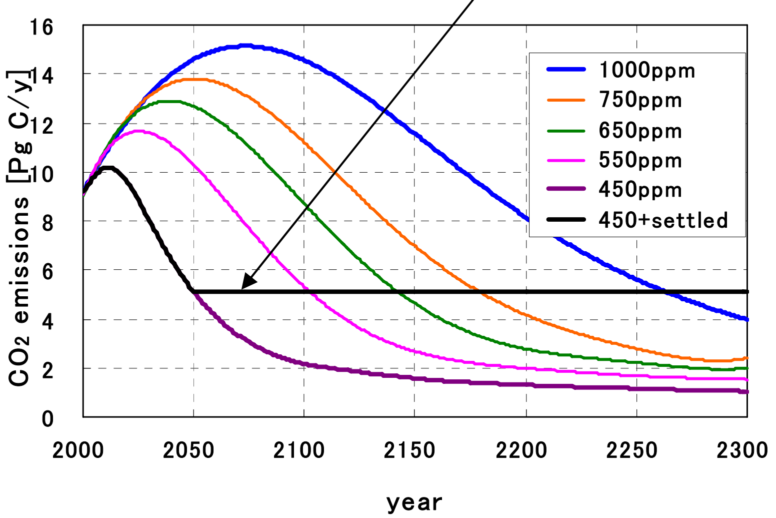
TWPG and CWP Analyses

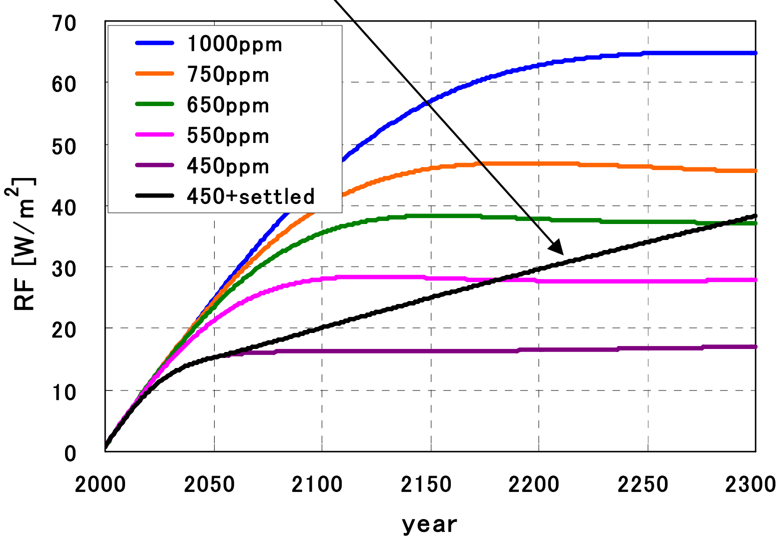
Scenarios of CO_2 Emissions

1) Scenario of IPCC 2001
2) 450 ppm scenario before 2050 + the same emissions after 2050

TWPG

After 2050, the same emissions





Continuous reduction of CO_2 emission is necessary

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1) The energy related to carbon emissions must be phased out in the near future.
2) New non-carbon energy has to be developed urgently.

Setting Technology level is Important

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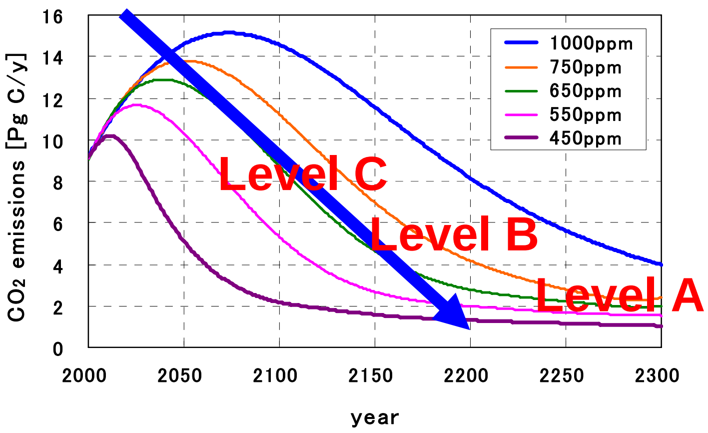
Level of technologies



1) Continuous reduction of CO_2 emission is necessary

Level set is necessary

2) Technologies have to chose by high level setting

Level C： 6%(Japan) reduction, but no effect for more reductions
Level B： 50% (World) reduction, but no effect for more reductions
Level A： Sustainable technologies

・Backcasting (Level A)

1) What technology will be accepted in Level A technologies ?
2) Develop Level A technologies urgently.

・Forecasting (Level C, B, A)

1)New technologies which could reduce GHG emissions are under development.
2) Even if reduction amount of GHGs is small, quite high cost must be paid.

Current Alternative Technologies

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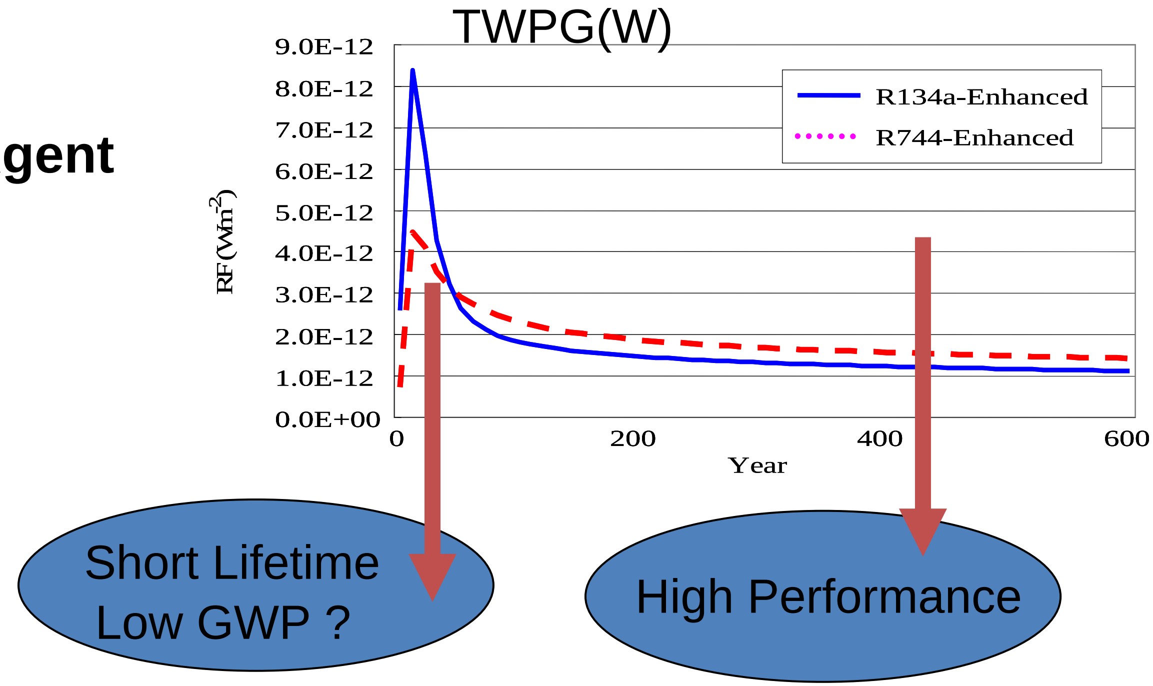
Example

Refrigerant
Foam Blowing Agent
Solvent

Semiconductor ?
・PFCs
・NF_3



LCCP analysis

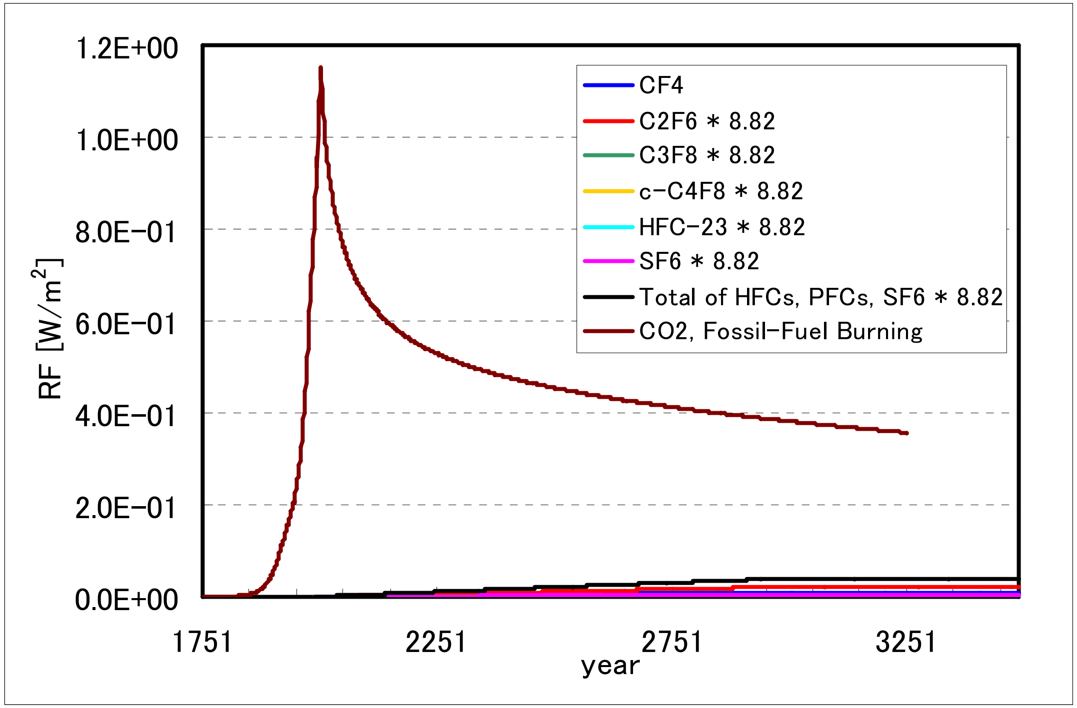
LCCP analysis shows total warming but doesn't shows the difference of two

Gases	HFO↓, HFC,	PFC↑, SF6↑,NF3↑
Energy		CO2↑

Semiconductor

TWPG (RF) of predicted emissions of PFCs

TWPG on the assumption that the same amount of 2001-2006 is emitted continuously until 3000.



Emissions and predicted emissions of PFCs from semiconductor manufacture in US

The graph shows the comparison between RF of PFCs' continuous use and of CO_2 emissions until 2004.

Continuous emissions of PFCs bring the large RF in the future.

Environmental Impacts of Semiconductor Gases

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1kg analysis based on IPCC 2007

Unsustainable ↑

↓ Sustainable

Comp.	Lifetime [year]	CWP				GWP
		100 y	500 y	1000 y	1500y	100 y
CF_4	50,000	7,390	36,802	73,239	109,313	7,390
C_2F_6	10,000	12,200	59,798	116,680	170,787	12,200
C_3F_8	2,600	8,830	40,941	74,721	102,591	8,830
SF_6	3,200	22,800	107,197	198,888	277,316	22,800
NF_3	740	17,200	66,837	100,797	118,149	17,200
C_4F_6	0.016	6.5	8.9	11.2	70.3	0.027
c-C_5F_8	0.98	91	93	96	152	90
COF_2	～0	0.7	2.1	3.6	40.0	0
F_2	0	0	0	0	0	0

・CWP includes the decomposed products and CO_2.

- Tier 3
- Remote
- SiN
- Abate. on/off

(Incineration, City Gas)

TWPG analyses of Semiconductor Cleaning system

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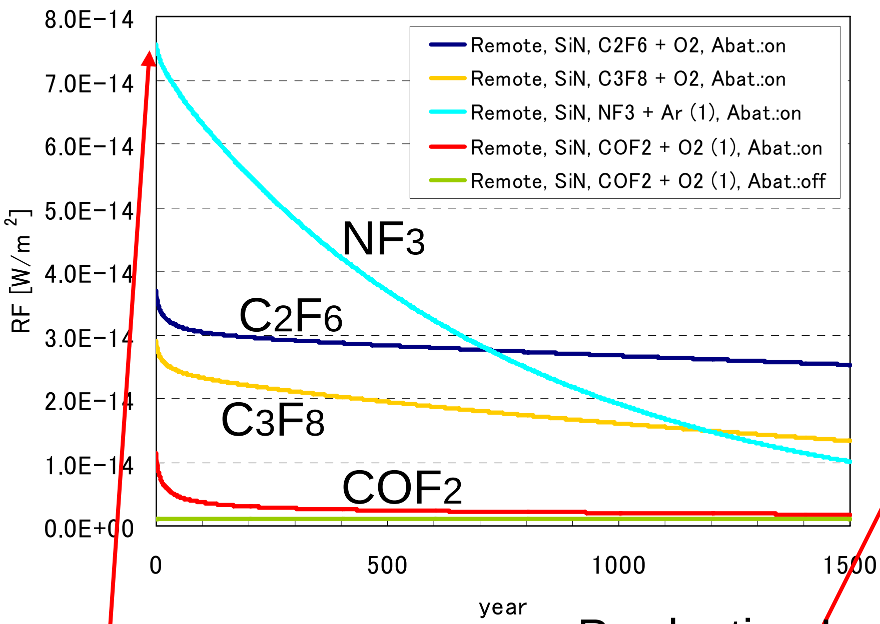
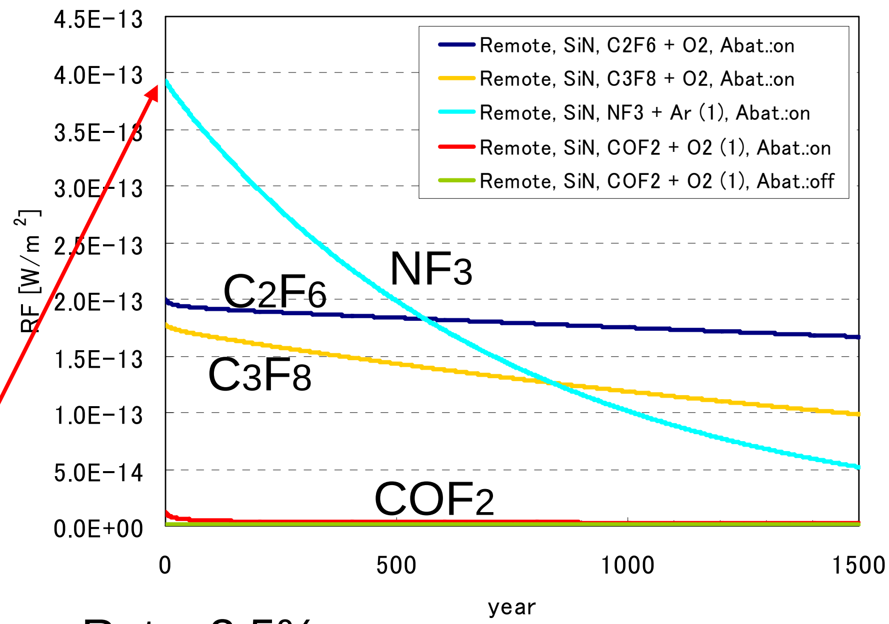
TWPG Warming effects at the time



TWPG Warming effects at the time



Production Leakage Rate: 3.5%

Destruction Efficiency Parameters for Abatement (Equipment Specific)

PFCs, NF_3 = 0.99 → 0

7.6×10^{-14} → 3.9×10^{-13}

(5.2 times larger)

TWPG(RF) becomes 5.2 times larger

CWP increases similarly.

JICOP セミナー、2008.11.26、東京

- **Tier 3**
- **Remote**
- **SiN**
- **Abate. on/off**

(Incineration, City Gas)

TWPG analyses of Semiconductor Cleaning system

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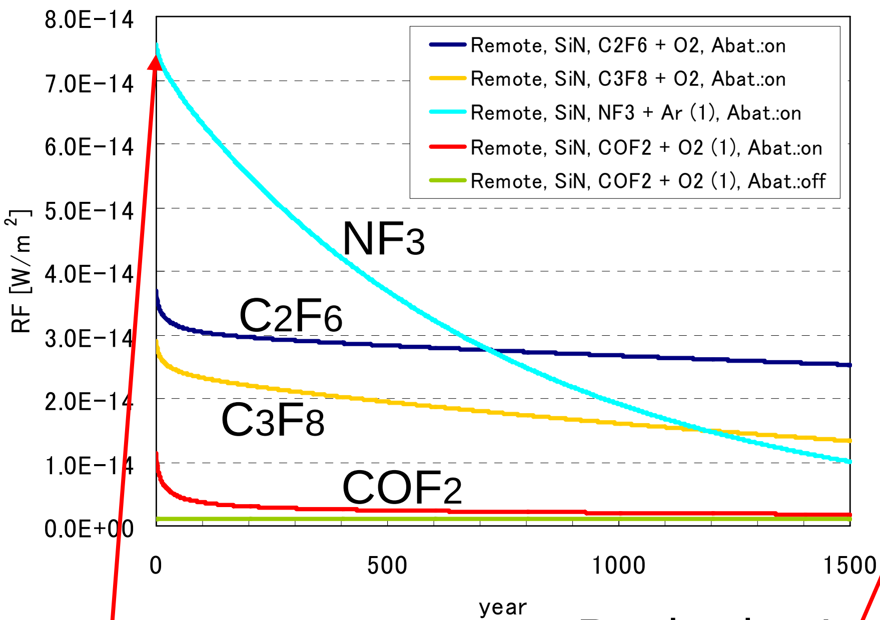
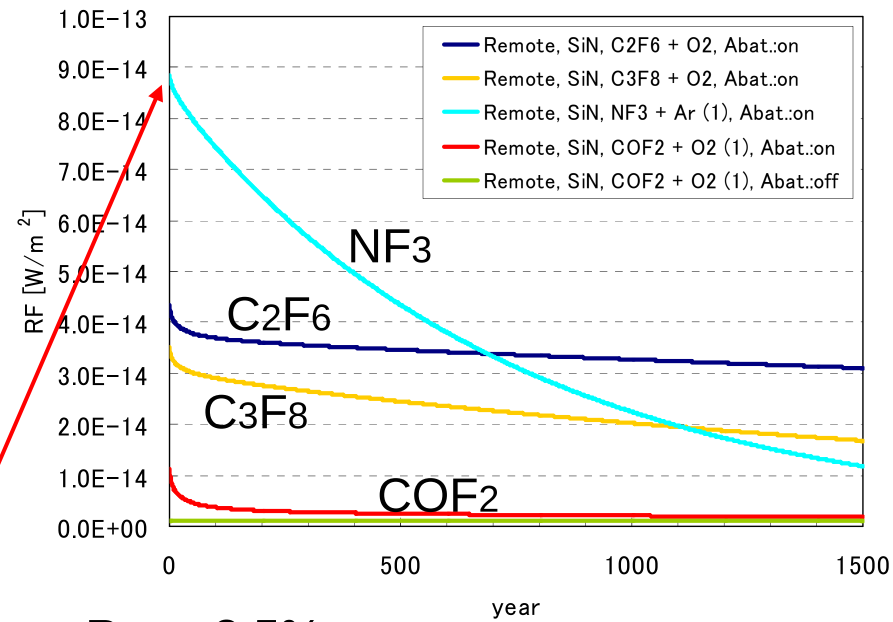
TWPG Warming effects at the time



TWPG Warming effects at the time



Production Leakage Rate: 3.5%

Destruction Efficiency Parameters for Abatement (Equipment Specific)

PFCs, NF_3 = 0.99 → 0.95

7.6×10^{-14} → 8.9×10^{-14}

(17% larger)

TWPG(RF) becomes 17% larger

CWP also becomes 17% larger

・Tier 3
・Remote
・SiN
・Abate. on/off
(Incineration, City Gas)

TWPG and CWP analyses of Semiconductor Cleaning system

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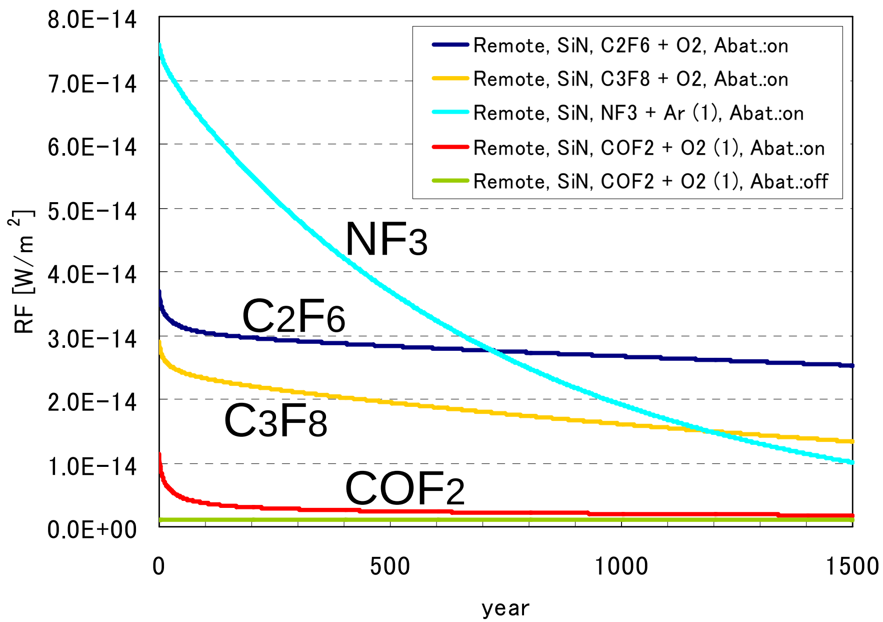
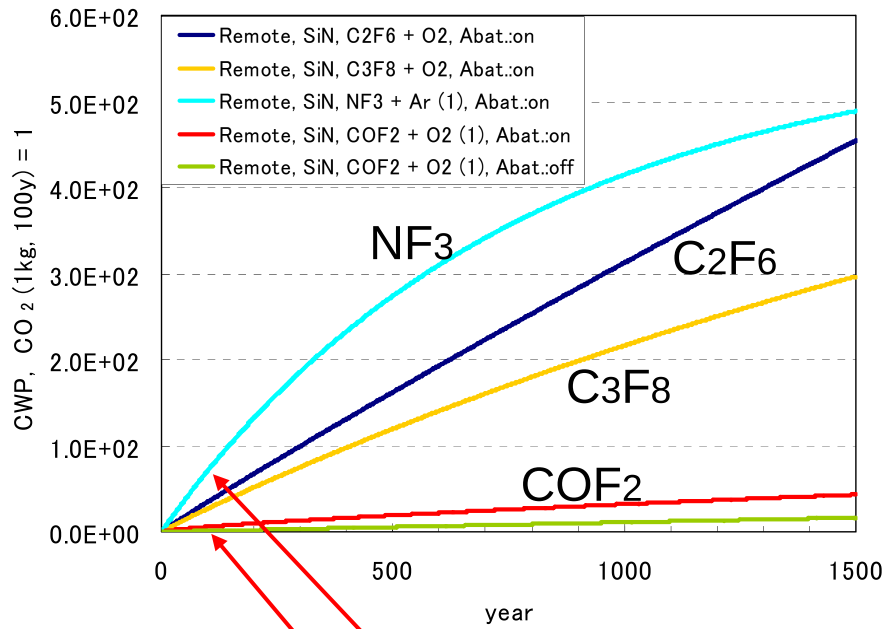
TWPG(W) Warming effects at the time



CWP Integrated warming effects



Production Leakage Rate: 3.5%

Destruction Efficiency Parameters for Abatement (Equipment Specific)
PFCs, NF_3 = 0.99

Integrated warming effect ・・・ COF_2 vs. NF_3 = 1 : 62 (100y)

COF_2(1.14) vs. NF_3(71.05) = 1 : 62.3

Comparison of NF_3 and COF_2 as semiconductor cleaning gases

Remote system, SiN

		Reduction (W)	
NF_3 → COF_2		62 → 1	Level A
Destruction ratio （No abatement system）			
0 →	0.99	5.2 → 1	Level B
Destruction ratio			
0.95 →	0.99	1.2 → 1	Level C

Alternative technologies is the best choice.
It is much better than abatement system

Scientific analyses guide the high level technologies

About GTP

Keith P. Shine, Jan S. Fuglestvedt, Kinfe Hailemariam, Nicola Stuber, Climatic Change, 68, pp.281-302, 2005.
"Alternatives to the Global Warming Potential for Comparing Climate Impacts of Emissions of Greenhouse Gases"

Abstract (part)

The Global Warming Potential (GWP) is used within the Kyoto Protocol to the United Nations Framework Convention on Climate Change as a metric for weighting the climatic impact of emissions of different greenhouse gases. The GWP has been subjected to many criticisms because of its formulation, but nevertheless it has retained some favor because of the simplicity of its design and application, and its transparency compared to proposed alternatives. Here, two new metrics are proposed, which are based on a simple analytical climate model. The first metric is called the Global Temperature Change Potential and represents the temperature change at a given time due to a pulse emission of a gas (GTP_P); the second is similar but represents the effect of a sustained emission change (hence GTP_S). Both GTP_P and GTP_S are presented as relative to the temperature change due to a similar emission change of a reference gas, here taken to be carbon dioxide.

- There are uncertainties between the GWP metric and the environment change.
- The global warming is figured out using the metric based on the surface temperature change.

GTP is also described in IPCC 2007 and UN.

Characteristics of GTP, GWP and TWPG

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GWP：time-integrated radiative forcing after a pulse emission over normally a 100-year time horizon (CO_2 = 1)

The contribution of the past RF remains over 100 years. A 100-year makes little sence.

TWPG (AGWP)： radiative forcing (W) after a pulse emission

A time-based value. After disappear from atmosphere, the radiative forcing is not counted. The value does not employ CO_2 as a reference.

$AGTP_P$：global mean surface temperature change after a pulse emission

A time-based value. A gradual recovery of the heat from the sea is counted. The value does not employ CO_2 as a reference.

GTP_S：global mean surface temperature change due to sustained emission change

A sustained emission change is similar into the integrated value and is not a practical case. This value employs CO_2 as a reference.

Comparison among GTP, GWP and TWPG

metrics		value	unit	reference
GWP	atmosphere	*Integrated* RF of pulse emission	dimensionless (ratio)	CO_2
TWPG (AGWP)	atmosphere	RF change of pulse emission	Watt	stand-alone
analytical -GTP_P	atmosphere & sea	Temp. change of pulse emission	dimensionless (ratio)	CO_2
analytical -$AGTP_P$	atmosphere & sea	Temp. change of pulse emission	K (temperature)	stand-alone
GTP_S	atmosphere & sea	Temp. change of sustained emission change	K year (temperature)	CO_2

The results of GTP_P evaluation

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KEITH. P. SHINE ET AL.

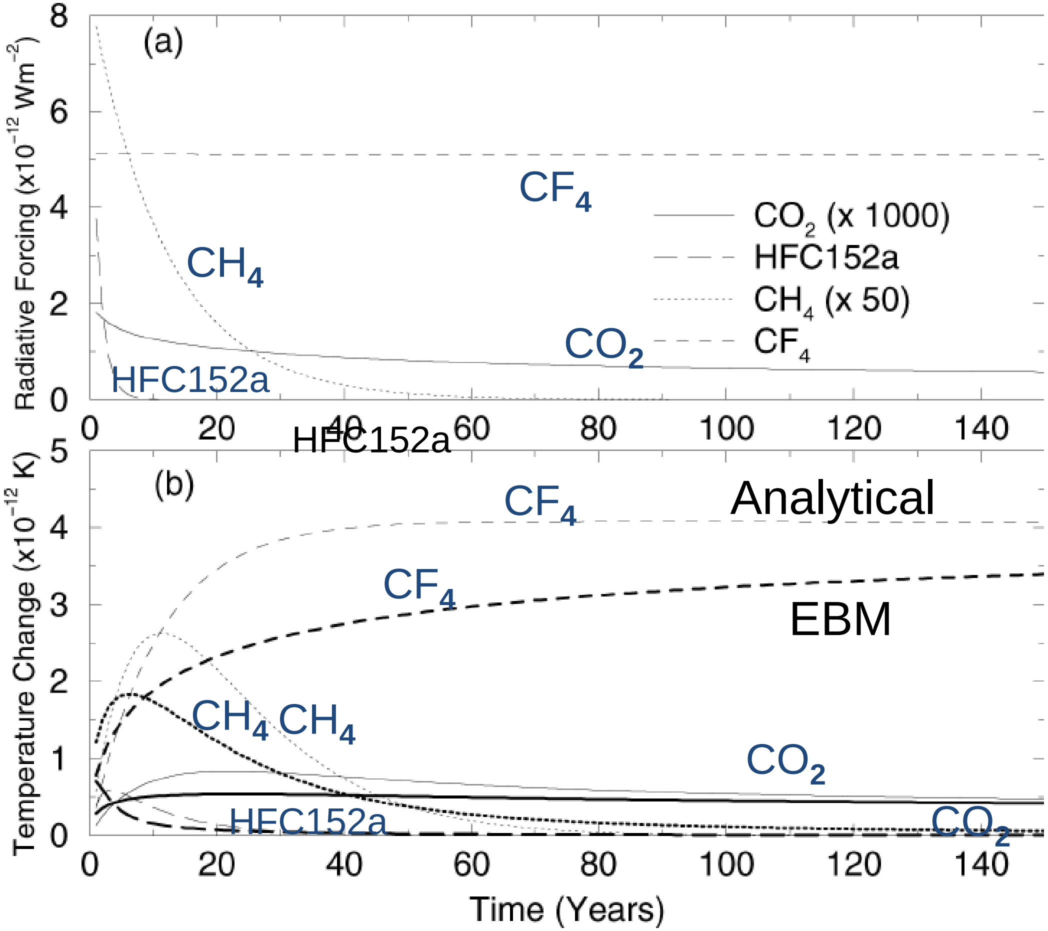

Figure 1. (a) Radiative forcing due to a 1-kg pulse emission of greenhouse gases with a range of lifetimes (see Table AI). The AGWP is the integral under these curves to a given time horizon. (b) Temperature response using the analytical $AGTP_P$ (thin lines) and the Energy Balance Model (thick lines) to the radiative forcing shown in (a).

Radiative forcing after 1 kg release

- The same as TWPG
- The time-integrated this value is equal to AGWP.

The temperature change corresponding to RF in figure (a)

- **thin lines**: Analytical $AGTP_P$
- **thick lines**: $AGTP_P$ based on EBM
- During the first a few years, EBM is higher.
- Analytical $AGTP_P$ both overestimates the peak response and underestimates the recovery from the pulse.

TABLE I

AGWP (in 10^{-14} W m^{-2} kg^{-1} year) and $AGTP_P$ (in 10^{-16} K kg^{-1}) from both the analytical equations and the energy balance model (EBM) for carbon dioxide, and the GWP and GTP_P for five other greenhouse gases at time horizons of 20, 100 and 500 yr

	GWP			Analytical GTP_P			EBM GTP_P		
	20	100	500	20	100	500	20	100	500
Absolute CO_2	2.66	9.05	29.1	8.34	5.46	3.47	5.38	4.55	3.38
HFC152a	400	120	37	170	0.15	0	135	22	4.0
CH_4	62	22	7	52	0.35	0	46	5	0.8
HFC134a	3290	1260	390	2840	34	0	2550	300	44
N_2O	270	290	150	290	270	13	290	270	35
CF_4	3850	5650	8730	4150	7490	11700	4320	7090	11200

Note. The values for methane include the indirect forcing. The analytical GTP values are calculated with a climate sensitivity of 0.8 K (W m^{-2})$^{-1}$ and a mixed layer with a depth of 100 m. The EBM GTP_P values are derived using the same climate sensitivity, with other parameters given in Appendix B.

TABLE II

AGWP (in 10^{-14} W m^{-2} kg^{-1} year) and AGTP$_S$ (in 10^{-14} K (kg year^{-1})$^{-1}$) from both the analytical equations and the energy balance model (EBM) for carbon dioxide and GWP and GTP$_S$ for five other greenhouse gases at time horizons of 20, 100 and 500 yr

	GWP			Analytical GTP$_S$			EBM GTP$_S$		
	20	100	500	20	100	500	20	100	500
Absolute CO_2	2.66	9.05	29.1	1.24	6.67	23.0	0.95	4.94	20.0
HFC152a	400	120	37	570	130	40	500	140	40
CH_4	62	22	7	69	24	7	66	25	8
HFC134a	3290	1260	390	3590	1370	400	3470	1420	430
N_2O	270	290	150	260	290	160	270	290	160
CF_4	3850	5650	8730	3610	5480	8690	3700	5430	8520

Note. The values for methane include the indirect forcing. The analytical GTP values are calculated with a climate sensitivity of 0.8 K (W m^{-2})$^{-1}$ and a mixed layer with a depth of 100 m. The EBM GTP$_S$ values are derived using the same climate sensitivity, with other parameters given in Appendix B.

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6 August 2008

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UNFCCC Framework Convention on Climate Change

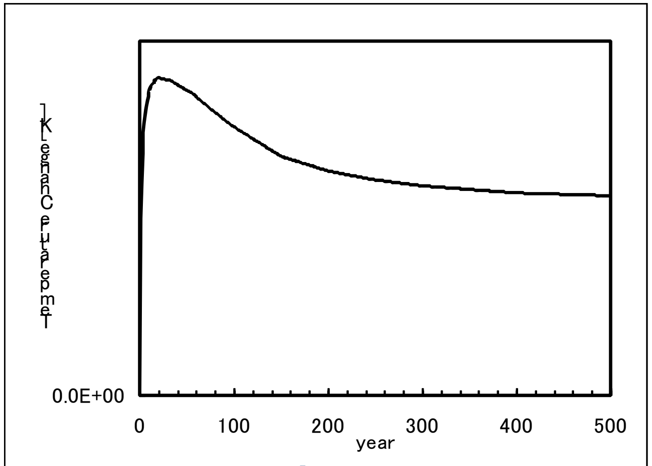
Table. Global warming potentials and global temperature potentials

Species	Chemical formula	Coverd by Kyoto Protocol	Covered by Montral Protocol	Estimation method in 2006 Guidelines	IPCC 1995 Global Warming Potential			IPCC 2001 Global Warming Potential			IPCC 2007 Global Warming Potential			Shine et al 2005 Analytical GTP_P			Shine et al 2005 EBM GTP_P		
					20 years	100 year	500 years	20 years	100 year	500 years	20 years	100 year	500 years	20	100	500	20	100	500
Carbon dioxide	CO2	x		x	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Methane	CH4	x		x	56	21	6.5	62	23	7	72	25	7.6	62	0.36	0	46	5	0.8
Nitrous oxide	N2O	x		x	280	310	170	275	296	156	289	298	153	290	270	13	290	270	35
Substances controlled by the Montreal Protocol																			
CFC-11	CCl3F		x					6300	4600	1600	6730	4750	1620						
CFC-12	CCl2F2		x					10200	10600	5200	11000	10900	5200						
CFC-13	CClF3		x					10000	14000	16300	10800	14400	16400						
CFC-113	CCl2FCClF2		x					6100	6000	2700	6540	6130	2700						
CFC-114	CClF2CClF2		x					7500	9800	8700	8040	10000	8730						
CFC-115	CClF2CF3		x					4900	7200	9900	5310	7370	9990						
Halon-1301	CBrF3		x					7900	6900	2700	8480	7140	2760						
Halon-1211	CBrClF2		x					3600	1300	390	4750	1890	575						
Halon-2402	CBrF2CBrF2		x								3680	1640	503						
Carbon tetrachloride	CCl4		x					2700	1800	580	2700	1400	435						
Methyl bromide	CH3Br		x					16	5	1	17	5	1						
HCFC-21	CHCL2F		x					700	210	65									
HCFC-22	CHClF2		x					4800	1700	540	5160	1810	549						
HCFC-123	CHCl2CF3		x					390	120	36	273	77	24						
HCFC-124	CHClFCF3		x					2000	620	190	2070	609	185						
HCFC-141b	CH3CCl2F		x					2100	700	220	2250	725	220						
HCFC-142b	CH3CClF2		x					5200	2400	740	5490	2310	705						
HCFC-225ca	CHCl2CF2CF3		x					590	180	55	429	122	37						
HCFC-225cb	CHClFCF2CClF2		x					2000	620	190	2030	595	181						
Hydroflurorocarbons																			
HFC-23	CHF3	x		x	9100	11700	9800	9400	12000	10000	12000	14800	12200						
HFC-32	CH2F2	x		x	2100	650	200	1800	550	170	2330	675	205						
HFC-41	CH3F	x		x	490	150	45	330	97	30									
HFC-125	C2HF5	x		x	4600	2800	920	5900	3400	1100	6350	3500	1100						
HFC-134	C2H2F4	x		x	2900	1000	310	3200	1100	330									
HFC-134a	CH2FCF3	x		x	3400	1300	420	330	1300	400	3830	1430	435	2840	34	0	2550	300	44
HFC-143	C2H3F3	x		x	1000	300	94	110	330	100									
HFC-143a	C2H3F3	x		x	5000	3800	1400	5500	4300	1600	5890	4470	1590						
HFC-152	CH2FCH2F			x				140	43	13									
HFC-152a	CH3CHF2	x		x	460	140	42	410	120	37	437	124	38	170	0.15	0	135	22	4
HFC-161	CH3CH2F			x				40	12	4									
HFC-227ea	C3HF7	x		x	4300	2900	950	5600	3500	1100	5310	3220	1040						
HFC-236fa	CF3CH2CF3	x		x	5100	6300	4700	7500	9400	7100	8100	9810	7660						
HFC-236cb	CH2FCF2CF3			x				3300	1300	390									
HFC-236ea	CF3CHFCF3			x				360	1200	390									
HFC-245ca	C3H3F5	x		x	1800	560	170	2100	640	200									
HFC-245fa	CHF2CH2CF3			x				3000	950	300	3380	1030	314						
HFC-365mfc	CH3CF2CH2CF3			x				2600	890	280	2520	794	241						
HFC-43-10mee	CF3CHFCHFCF2CF3			x	3000	1300	400	3700	1500	470	4140	1640	500						

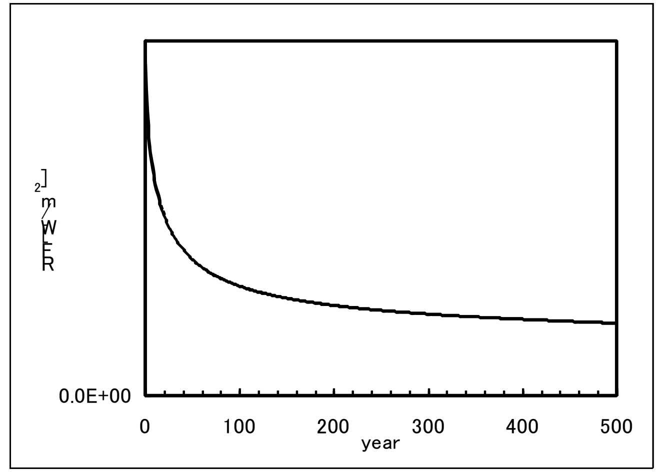
p.79

AGTP-EBM and TWPG

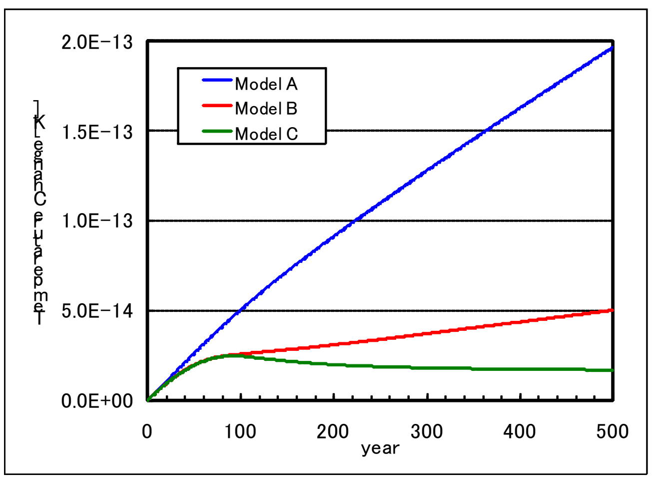
AGTPP – EBM due to 1kg pulse emission



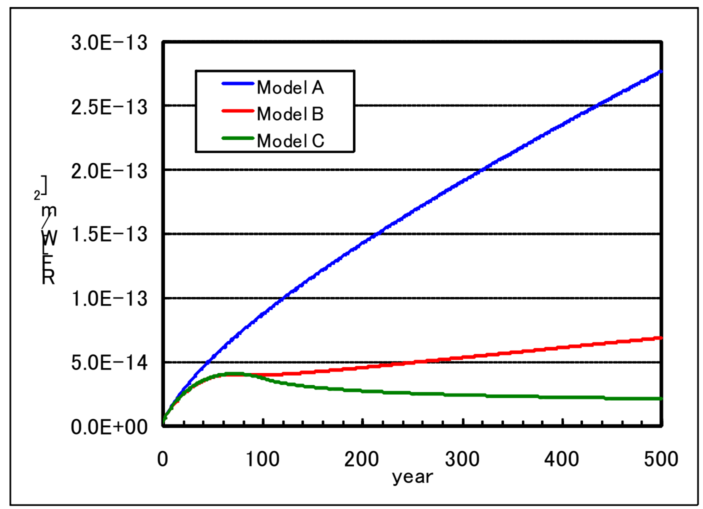
TWPG(W) due to 1kg pulse emission



AGTPP – EBM due to emissions based on the model cases



TWPG(W) due to emissions based on the model cases



Model A: Every year 1 kg for 500 years
Model B: First year: 1kg, 2-80 years: 1% reduction, 81-: 0.2kg for every year
Model C: First year: 1kg, 2-100 years: 1% reduction, 101-: no emission for every year

TABLE I

AGWP (in 10^{-14} W m^{-2} kg^{-1} year) and $AGTP_P$ (in 10^{-16} K kg^{-1}) from both the analytical equations and the energy balance model (EBM) for carbon dioxide, and the GWP and GTP_P for five other greenhouse gases at time horizons of 20, 100 and 500 yr

	GWP			Analytical GTP_P			EBM GTP_P		
	20	100	500	20	100	500	20	100	500
Absolute CO_2	2.66	9.05	29.1	8.34	5.46	3.47	5.38	4.55	3.38
HFC152a	400	120	37	170	0.15	0	135	22	4.0
CH_4	62	22	7	52	0.35	0	46	5	0.8
HFC134a	3290	1260	390	2840	34	0	2550	300	44
N_2O	270	290	150	290	270	13	290	270	35
CF_4	3850	5650	8730	4150	7490	11700	4320	7090	11200

Note. The values for methane include the indirect forcing. The analytical GTP values are calculated with a climate sensitivity of 0.8 K (W m^{-2})$^{-1}$ and a mixed layer with a depth of 100 m. The EBM GTP_P values are derived using the same climate sensitivity, with other parameters given in Appendix B.

$TWPG_P$*		
20	100	500
10	6.2	4.1
1.5	1.47	1.46
29	3.2	2.9
2300	12.9	0.95
350	274	12.4
6800	11000	16000

*) TWPGをCO2基準に変形し、$TWPG_P$*とした。A.Sekiya

	Climate	Atmos.	Energy Sea	Dec. Prod.	VOC O_3	Ozon Layer Cooling
GWP	×	○	×	×	×	△
Anal-GTP_P	○	○	○	×	×	×
EBM-GTP_P	○	○	○	×	×	×
$TWPG_P$*	○	○	×	○	○	○

Needed data for calculations: RF, Lifetime

Values
GWP ≒ GTP_S、

Similar
TWPG ≒ $AGTP_P$

Conclusion

National Institute of Advanced Industrial Science and Technology
AIST

Level A Technologies

How to find

All technologies

Scientific evaluations
Future estimations

AGTP$_p$
TWPG

Selections of level A technologies

How to introduce

Reductions by Kyoto

（GWP is using now）

GWP

GWP use ?
Replace GWP?

Factors
etc.

Push　Level A Tech.

Sustainable Society

Thank you for the attention