Technology evaluation of zero-carbon power generation systems in Japan in terms of cost and CO_2 emissions

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Outline

- Introduction

  Technology issues toward zero CO_2 emission power generation system.

- Methodology

  RE tech. scenarios and optimal multi-regional power generation model.

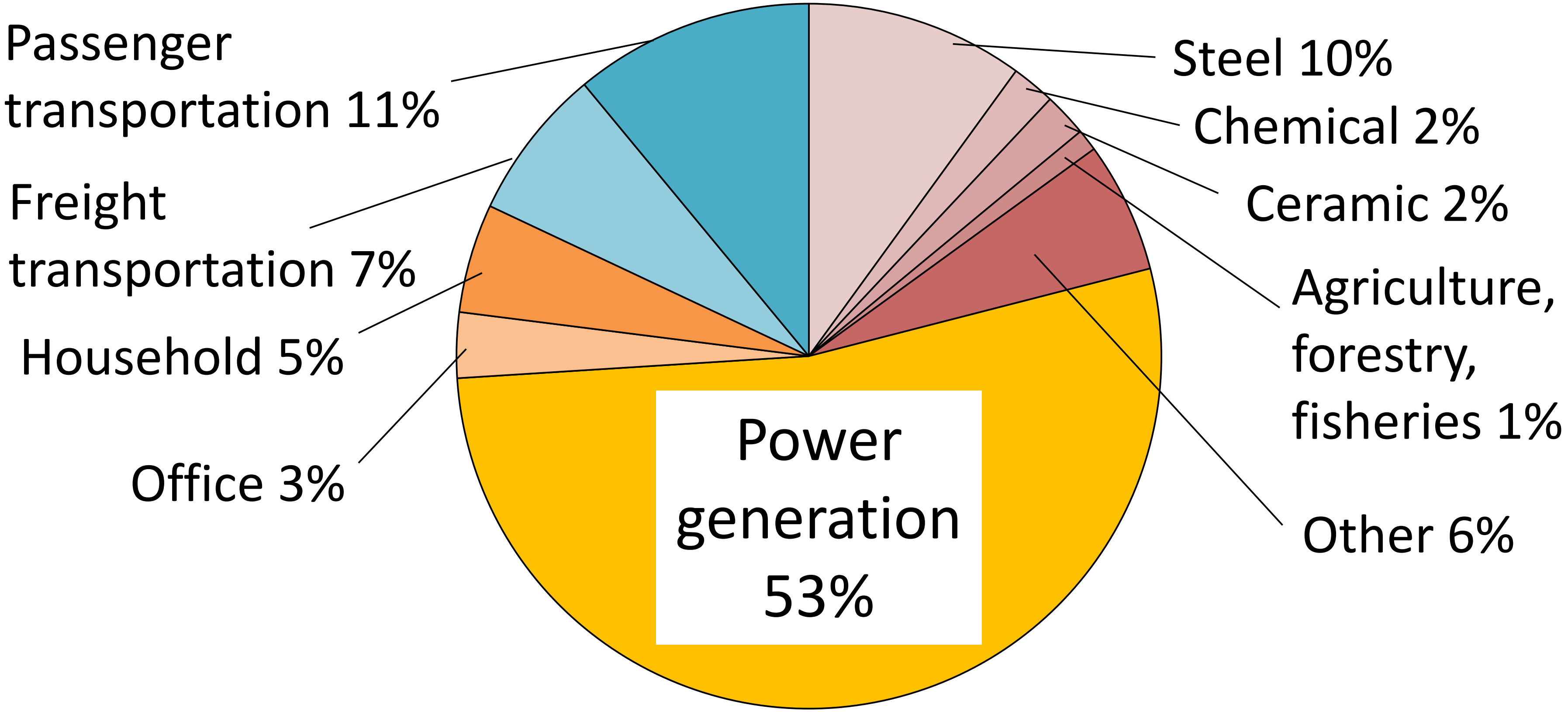
- Results and discussions
- Conclusions

CO_2 emissions in Japan by sectors (2013 FY)

Energy consumption: 1.37 GJ/y

Power generation: 1,090 TWh/y

CO_2 emission from energy sector in Japan 1.24 Gt-CO_2/y



CO$_2$ emission reduction targets

LCS Technology scenarios

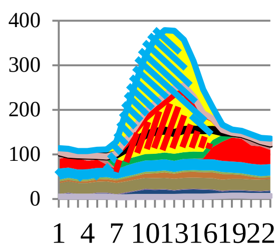
Elec. Demand

Indicators of technology (Cost, utility rate, parameters in operation)

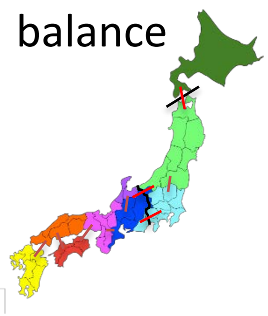
Demand curve

Power generation model（Cost minimized）

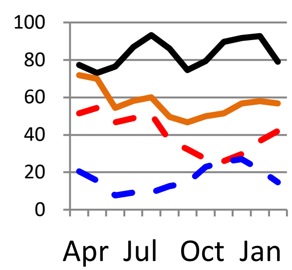
Supply and demand balance



Regional balance



Seasonal balance



Constraints eq.

Capacity constraints（Capacity, rate of output change）

Fluctuation constraints（Operating reserve, LFC, Inertia）

Trans mission constraints（cap and energy loss of trans）

Storage system constraints（Pumped hydro, battery, H_2）

Regional constraints（conditions of climate and location）

Output & cap. of power generation systems

Cap. of storage systems

Fuels

Capacity of transmission

Total cost of electricity system, CO$_2$ emissions

Platform for Design & Evaluation of LCT ("Modeling Tool")

Automated process design support system developed by LCS.

PFD with mass & energy balance

Equipment selection & sizing

Equipment cost & weight

Production cost & CO_2 emissions

PFD

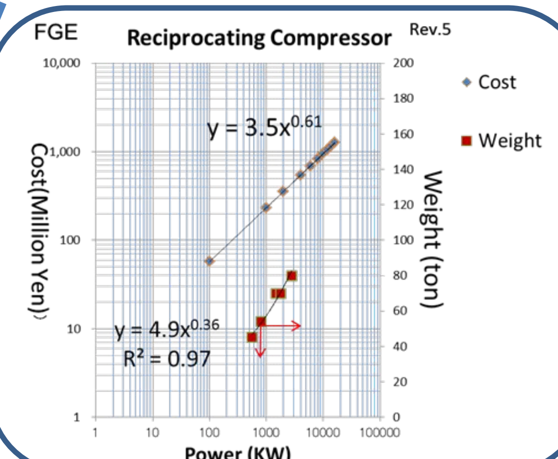
Equipment sizing

Equipment cost & weight

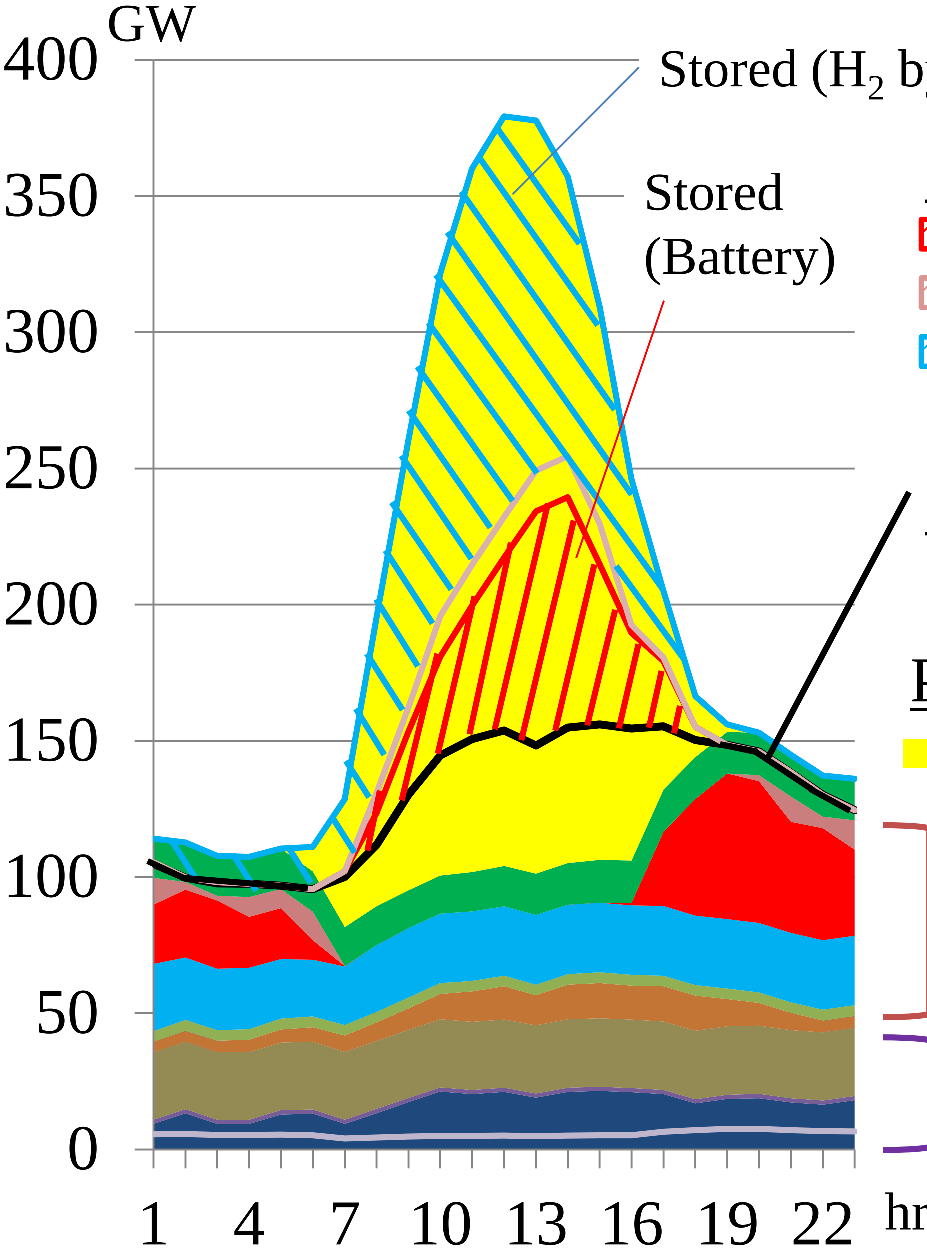
Raw materials, utilities cost

Environmental load

- PV
- Battery
- FC
- Wind Power
- Med-sized hydraulic
- Geothermal
- Woody biomass
- Biogas
- CCS



Multi-regional power generation model



(Average output of summer days, 2050 scenario)

Storage sys.
Battery,
Pumped hydro,
Hydrogen
(Electrolysis, H_2 turbine)

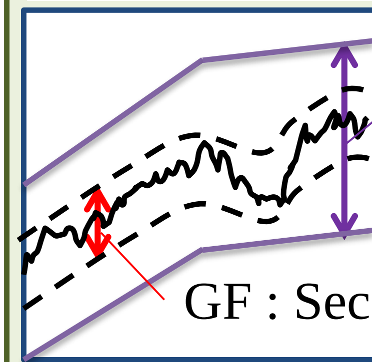
Demand curve

Power generation with fluctuation
PV, Wind power

Load following power plants
LNG, Oil, Hydro(ROR. Pumped),
Hydrogen turbine, Battery output

Base load plants
Coal, Nuclear, Hydro (Run-of-the-river),
Biomass, Geothermal

Constraints of fluctuation

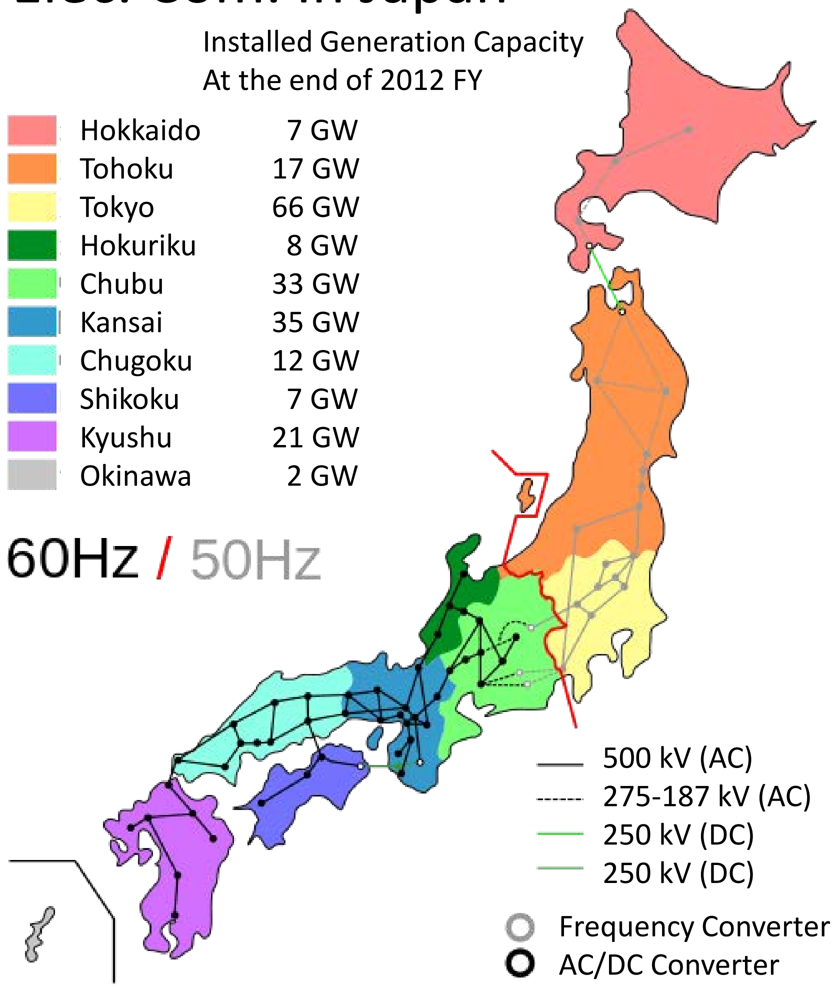


▪ Including system stability

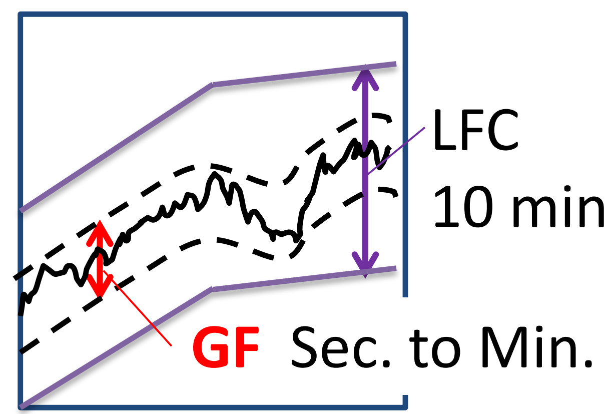
*LFC: Load frequency control,
GF: Governor-free control

Grid system and the issues

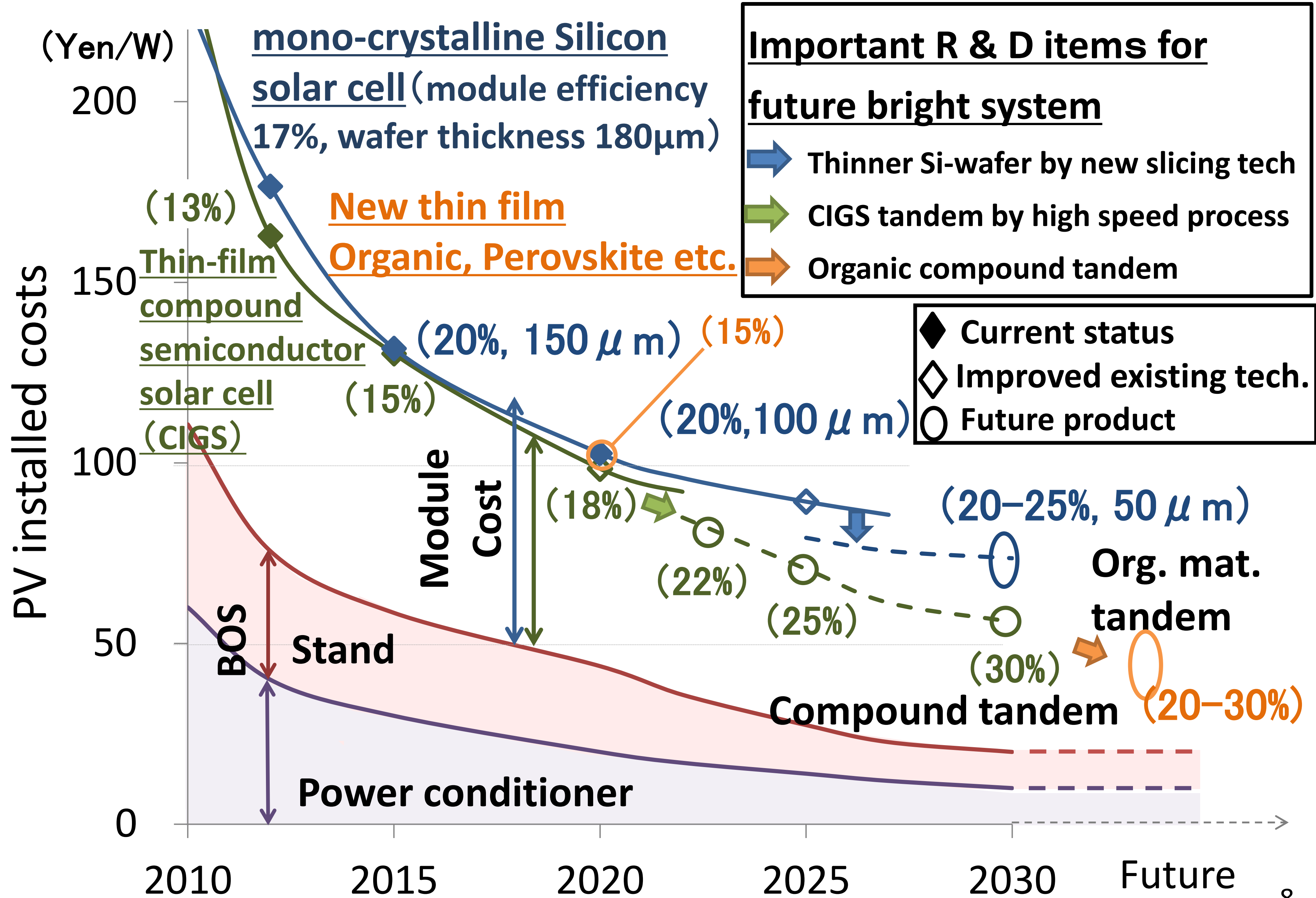
Elec. Com. In Japan



- Short term:
  Governor Free,
  LFC (Load frequency control)
- Long term: hourly, seasonal
- Grid system stability
  (a generator is considered synchronized to the grid)



Prospects of PV System Cost



RE technology scenarios

110Yen = 1$

	Capacity factor*	Power Cost [Yen/kWh]		
Case, Technology level**		A Tech.2015	B Tech.2020	C Tech.2030
PV	11%	16.0	9.5	5.7
Wind	23%	14.1	10.2	8.4
Geothermal	70%	12.5	12.5	8.0
Geothermal HDR*	70%	-	-	6.9
Biomass	70%	33.6	10.9	10.9
Hydro	54%	10.8	10.8	10.8

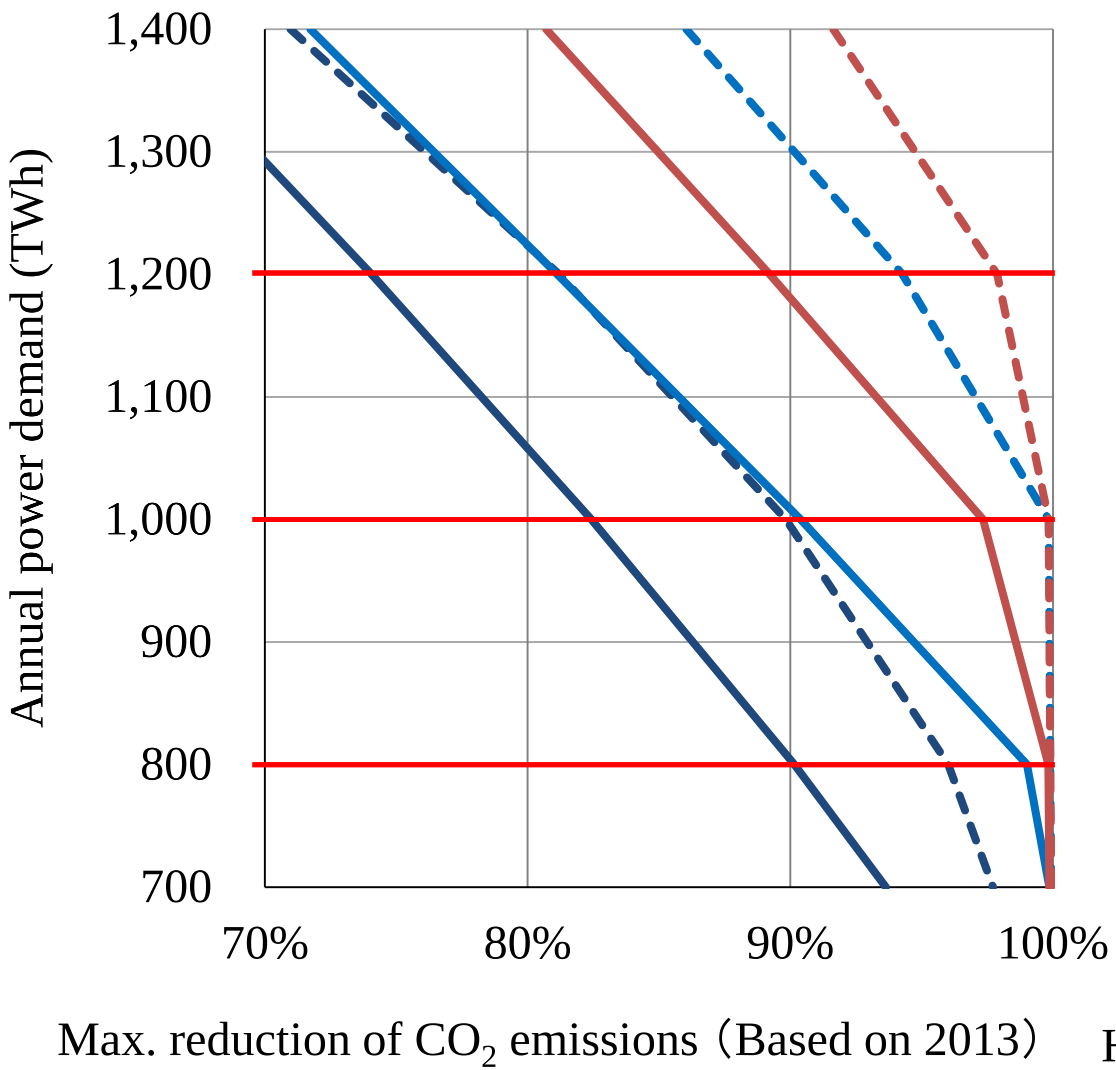
Battery (system cost)	-	19 Yen/Wh	10 Yen/Wh	6 Yen/Wh

*The capacity factors are calculated within the model. Standard capacity factors are used to estimate power cost that shows in this table.
**A Tech level 2015; current technology, B Tech level 2020; improving technology, C Tech level 2030; developing technology
***HDR: Hot dry rock geothermal power is optional technology

Result

Relationship between CO_2 reduction potential and power demand

－ Effect of inertia force power ratio on CO_2 reduction rate －



a) Current grid, Inertia fraction **50%**, HDR 0TWh

b) Current grid, Inertia fraction **25%**, HDR 0TWh

c) Enhancing grid, Inertia fraction **50%**, HDR 0TWh

d) Enhancing grid, Inertia fraction **25%**, HDR 0TWh

e) Enhancing grid, Inertia fraction **50%**, HDR **100TWh**

f) Enhancing grid, Inertia fraction **25%**, HDR **100TWh**

HDR：Hot dry rock geothermal power

Power Cost, zero CO_2 emission (Inertia regulation 50%, 25%)

Case		2013	1	2	3	4
Power demand (TWh/y)		990	1000	800	1000	
Inertia fraction			50%	25%	25%	
CO_2 reduction		565 Mt-CO2/y	**80%**	**100%**	**100%**	**100%**
Generation Power (TWh/y)	Nuclear power	0	130	**0**	**0**	**0**
	Hydro power	94	0	130	130	130
	LNG	285,697	317	0	0	0
	Coal,Oil	697	0	0	0	0
	PV	9	0	595	555	692
	Wind power	5	524	402	344	559
	Geothermal	1	211	12	12	12
	Geothermal (HDR)	–	12	**0**	**100**	**0**
	Biomass	–	31	22	31	29
	Total	1190	1,225	1,160	1,172	1,422
H_2 Generation (TWh/y)		–	51	67	9	106
Battery output (TWh/y)		–	227	252	294	242
Battery Cap (GWh)		–	801	821	983	809
Gene. Cost (¥/kWh)		12.9	11.7	14.3	11.1	16.5

Power Cost, zero CO_2 emission (Inertia regulation 25%)

Case		5	7	8
Power demand (TWh/y)		1200		
Inertia fraction		25%		
CO_2 reduction		**100%**	**98%**	**90%**
Generation Power (TWh/y)	Nuclear power	**0**	**0**	**0**
	Hydro power	130	130	130
	LNG	0	32	159
	PV	592	673	672
	Wind power	509	537	441
	Geothermal	12	12	12
	Geothermal (HDR)	**200**	**100**	**0**
	Biomass	31	30	30
	Total	1,465	1,514	1,443
H_2 Generation (TWh/y)		24	43	29
Battery output (TWh/y)		156	297	308
Battery Cap (GWh)		643	920	1,013
Gene. Cost (¥/kWh)		12.1	12.9	11.7

(¥10/kWh = €85/MWh)

To construct a CO_2 zero-emission power generation system

1. Large-scale introduction of renewable energy, in particular, solar cell technology (30% eff.) to reduce plant area.
2. Storage batteries: 500 to 1000 GWh in order to alleviate short- and medium-term fluctuations and to integrate daily operations.
3. Electricity grid system reinforcement by at least 10 times the current level in order to use renewable energy in rural area.
4. The inertial force constraint has the greatest influence on power generation cost. Set the fraction of the electricity supply provided by inertial generators to 25%(half of the current).
5. Reduce power demand. On the other hand, when the demand for electricity increases, the introduction of a stable power source of 100 to 200 TWh (such as HDR) is indispensable.

Thank you for your attention

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