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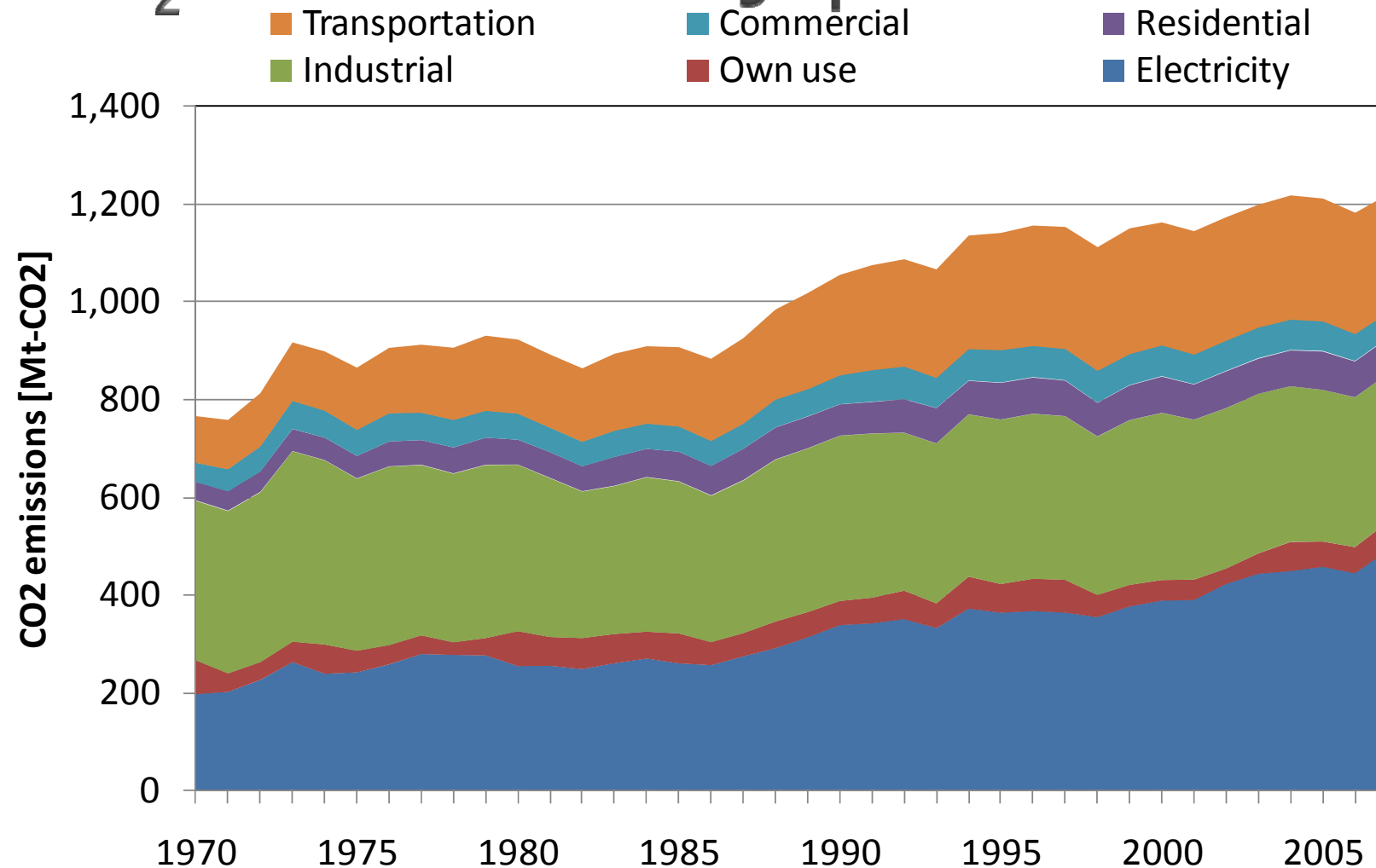
Feasibility Study for Low-Carbon Grid with Renewables in Japan

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CO₂ emissions in Japan



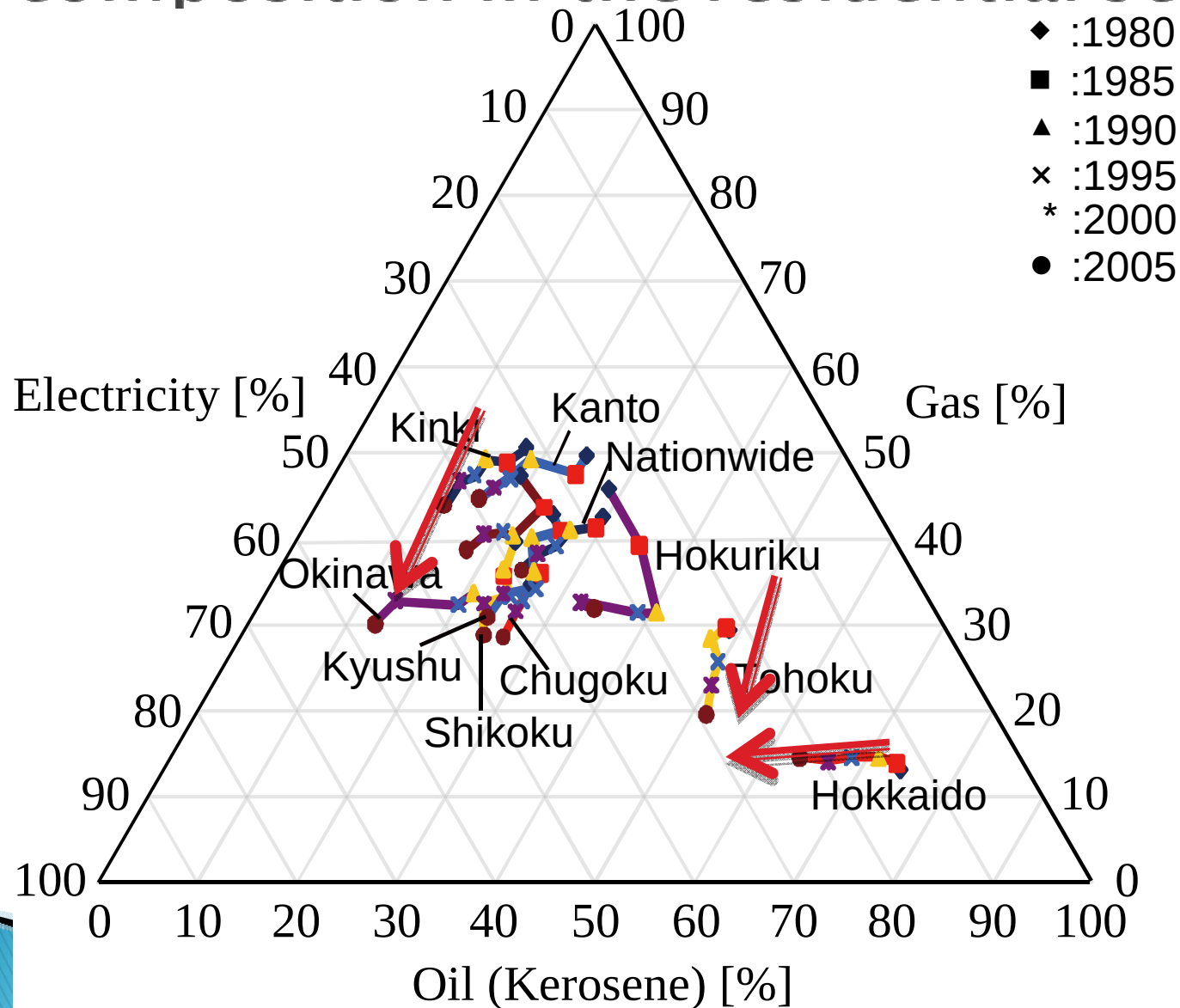
Annual growth rate from 1990 to 2007:

Ind – -0.6% / Res – +0.7% / Com – -0.8% / Trs – 1.0%

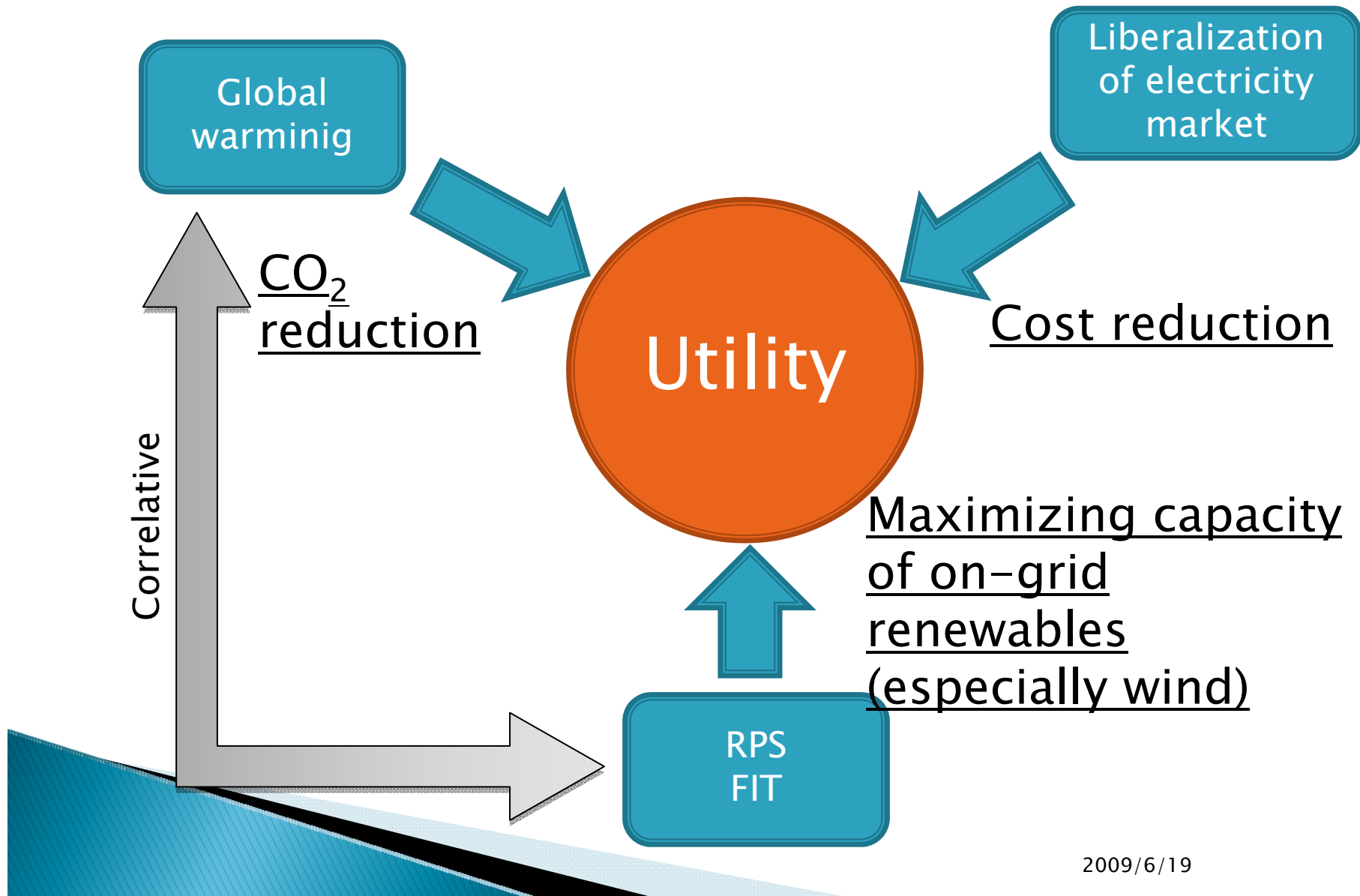
Elect – +2.2%

Japan moves electrified society

Fuel composition in the residential sector



Electric utilities face three issues

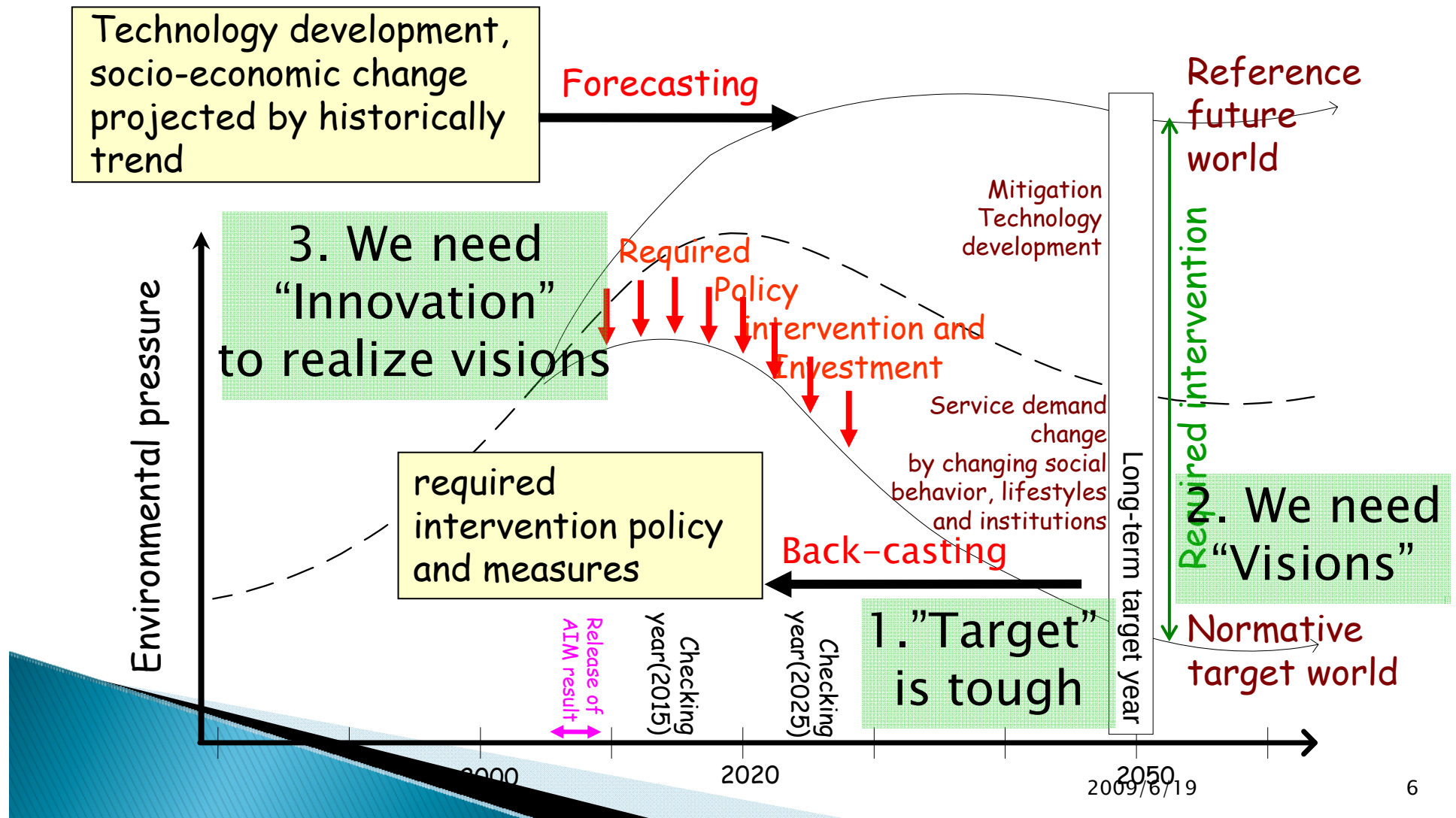


Purpose of the study is:

- ▶ To determine the feasibility of achieving all of the following three goals based on quantitative analysis from the view point of electric utilities:
 1. With amounts of on-grid renewables
 2. With high economic efficiency
 3. Less CO₂ emissions
- ▶ Target year: 2050
- ▶ Methodology: Linear generation planning model

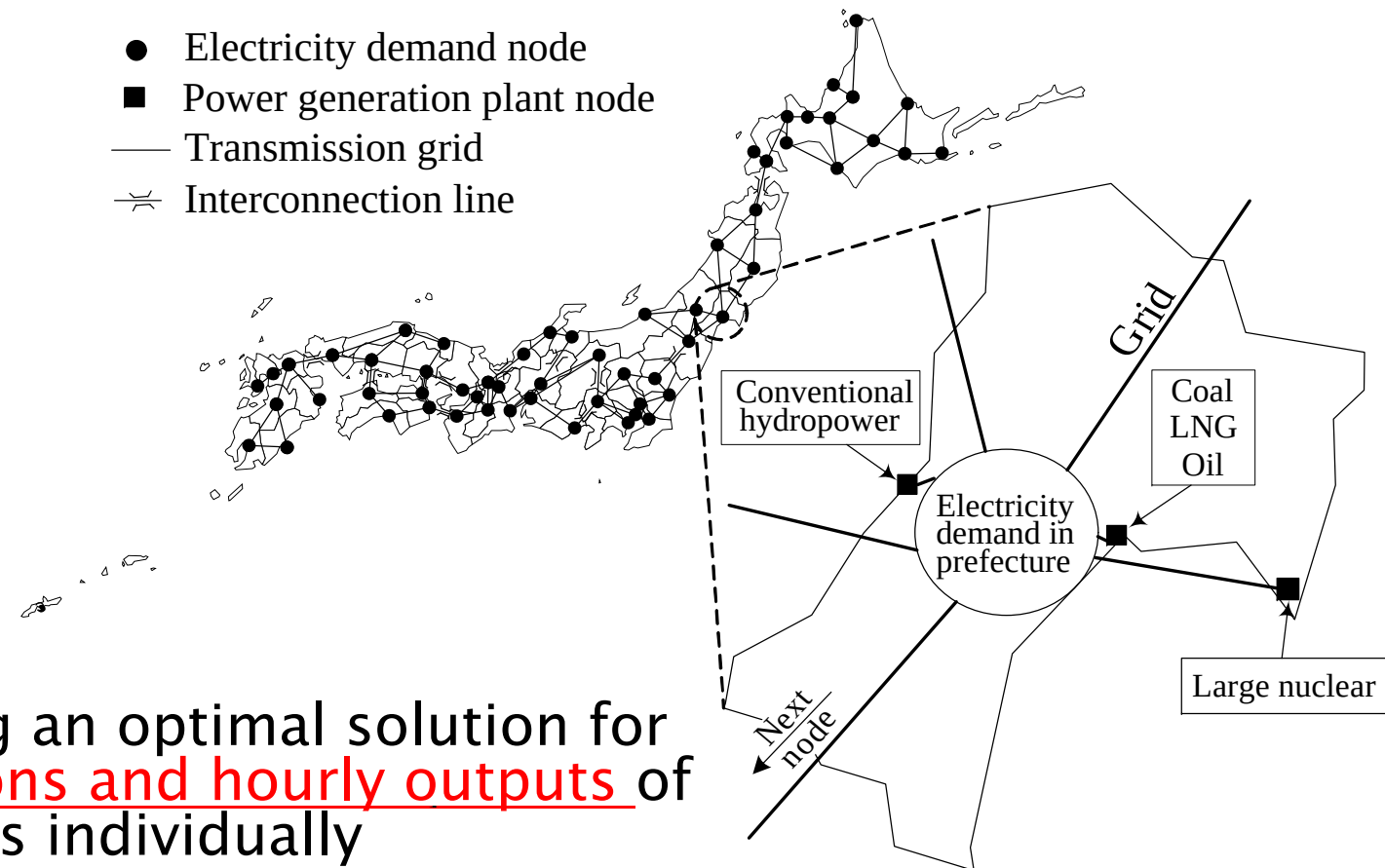
Why do we check feasibility first?

Backcasting methodology for depicting future *ambitious* visions



Overview of quantification methodology (1 / 8)

Multi-regional generation planning model

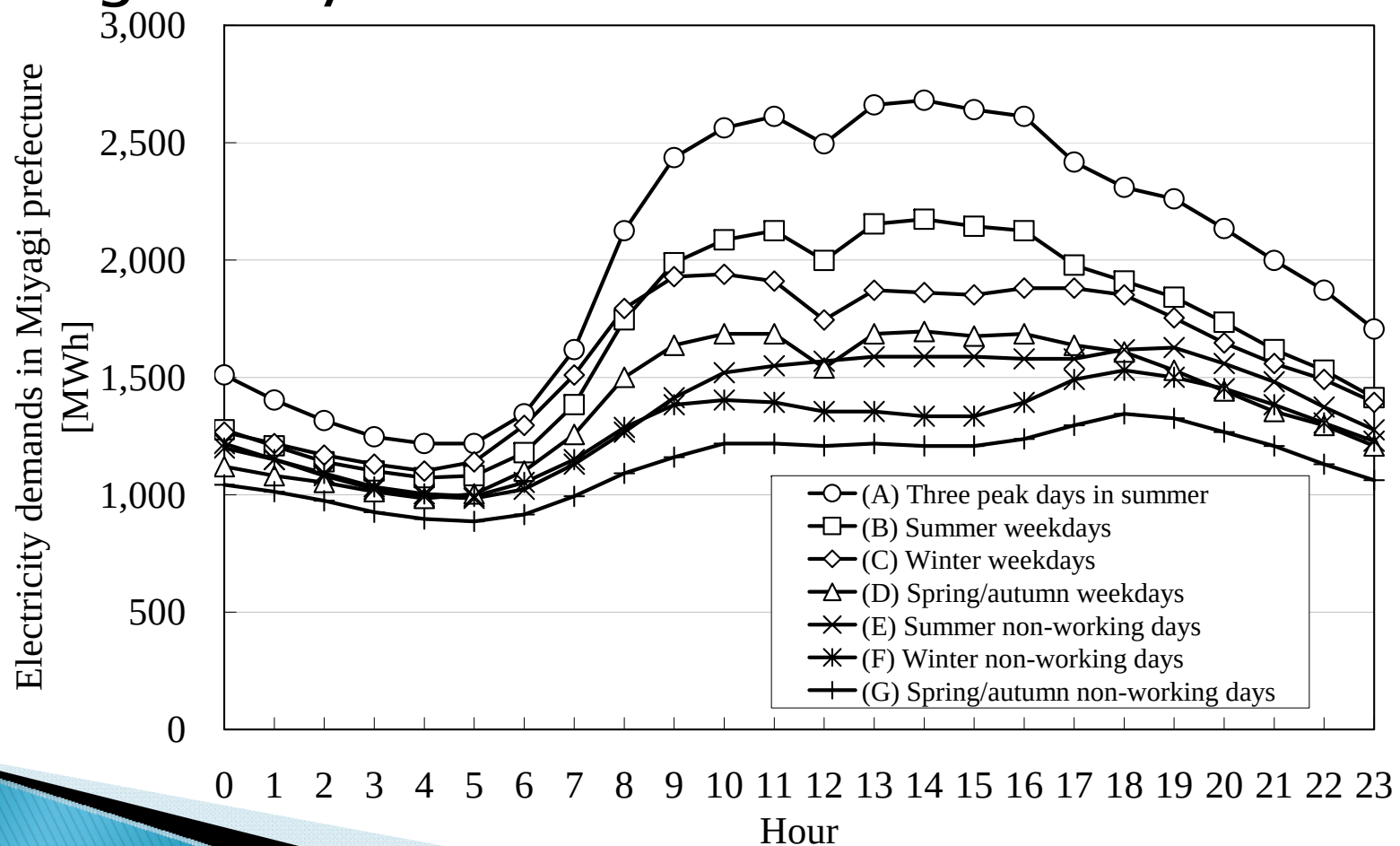


- ▶ Determining an optimal solution for configurations and hourly outputs of power plants individually
- ▶ 60 regional electricity demand and hundreds of individual power plant
- ▶ Transmission lines are modeled based on actual conditions.

Overview of quantification methodology (2 / 8)

Demand setting

- ▶ Electricity demand sets by hourly, seasonally, and regionally.



Overview of quantification methodology (3 / 8)

Major constraints

► Capacity constraint

$$CAPLO(P, T, RP) \leq POW(P, T, RP) \leq CAPUP(P, T, RP)$$

POW:	Power plant output	CAPLO:	Capacity lower limit
RP:	Power plant at region R	CAPUP:	Capacity upper limit

► Balance constraint

$$\sum_R (X(P, T, R) - S(P, T, R)) = \sum_R D(P, T, R)$$

X:	Electric supply to region R	D:	Demand at region R
S:	Pumped storage power		

Overview of quantification methodology (4 / 8)

Major constraints (Cont'd)

▶ Hourly output constraint (Mechanical request)

$$POW(P, T, PR) \leq FUP(PR) \times POW(P, T-1, PR)$$

$$POW(P, T, PR) \geq FLO(PR) \times POW(P, T-1, PR)$$

FUP	Capability upper limit for
:	load change

FLO	Capability lower limit for
:	load change

▶ Transmission constraint

$$TRANS(P, T, R1, R2) \leq TRUP(R1, R2)$$

TRANS:	Transmission
	quantity

TRUP:	Transmission capacity upper
	limit

Overview of quantification methodology (5 / 8)

Constraints for on-grid renewables potentials

- ▶ On-grid renewables potential limits:
 1. the capabilities of the power generators to absorb fluctuations both in frequency and voltage
 2. the thermal capacity of transmission lines and bank capacity of substations
 3. stability of transmission system

- ▶ The key to enhancing installation of renewables into grid is to relax the constraint condition (1)!

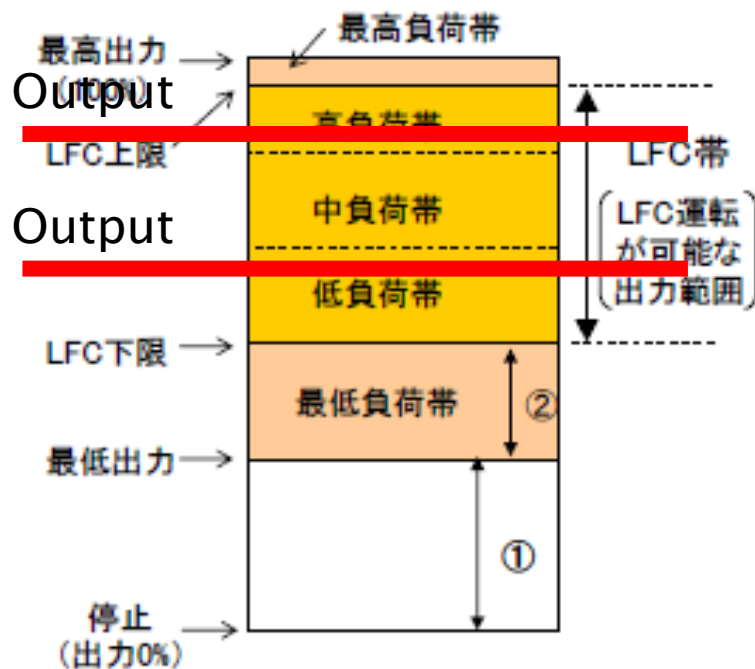
Overview of quantification methodology (6 / 8)

How to address constraints?

- ▶ Utilities meets fluctuations by
 - A) governor–fee control (short–period region, with a cycle ranging from 2 to 3 minutes)
 - B) load frequency control, LFC (intermediate–period region, with a cycle ranging from a few minutes to 20minutes)
 - C) economic–load dispatching control, EDC (long–period region, with a cycle ranging over 20 minutes)
- ▶ On–grid potentials of renewables are mainly affected by the capacity of LFC to absorb output fluctuations (LFC capability).

Overview of quantification methodology (7 / 8)

Quantification of on-grid renewables potentials



Schematics for on-grid potential evaluation

- On-grid potentials comes from only fossil fueled power plants, such as coal-fired, oil-fired and gas-fired.

- Hydropower and nuclear does not contribute to the potentials.

- On-grid potentials were determined by:

$$RNW_t = \min(|g_{\max} - g_t|, |g_t - g_{\min}|)$$

- Upper limit of output is set to capacity of power plants, and lower limit is minimum output level of practical operation.

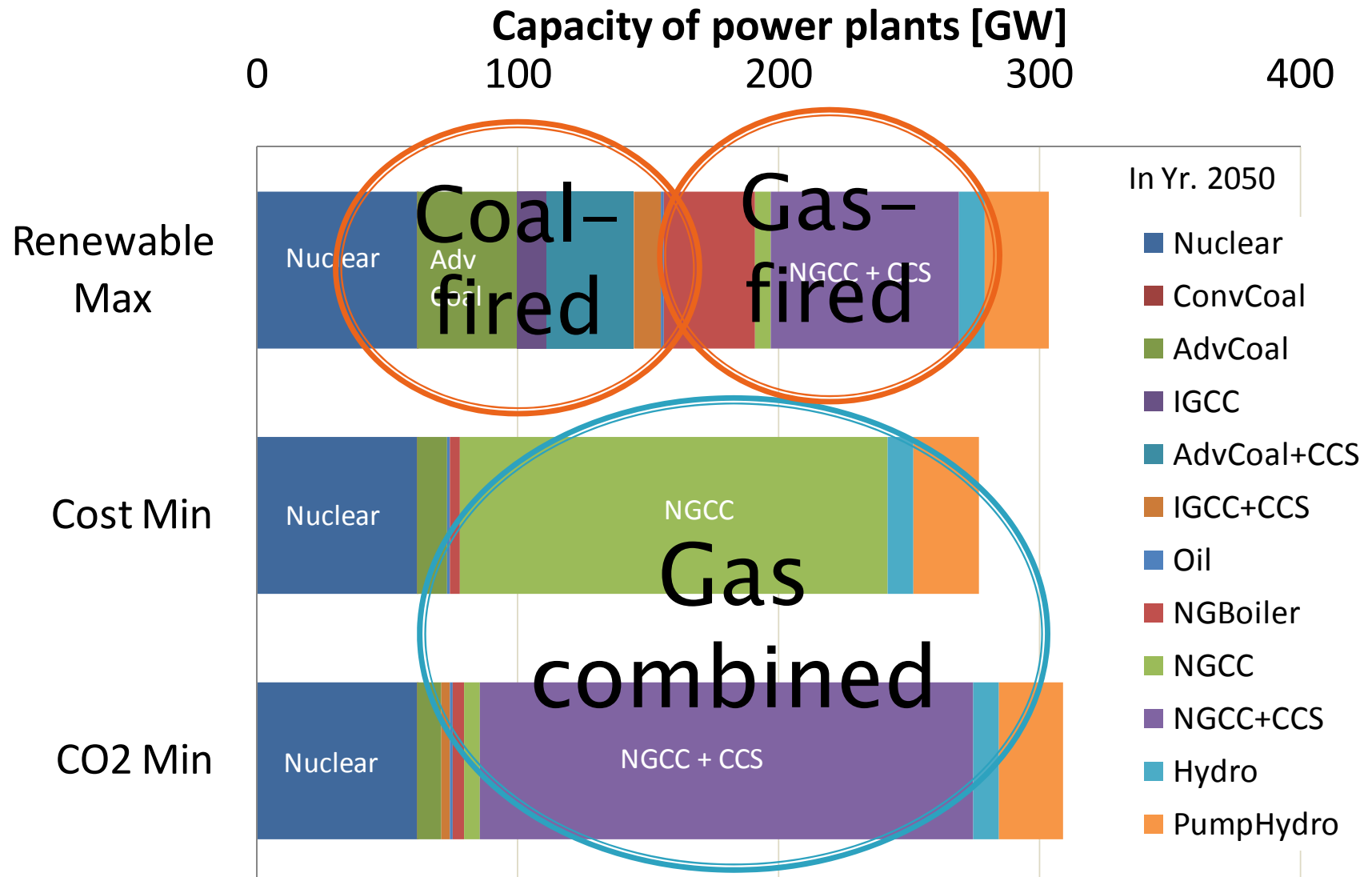
- For example, coal-fired: 30% of capacity, oil-fired boiler: 25%, gas-fired boiler: 20% and combined cycle: 25%.

Overview of quantification methodology (8 / 8)

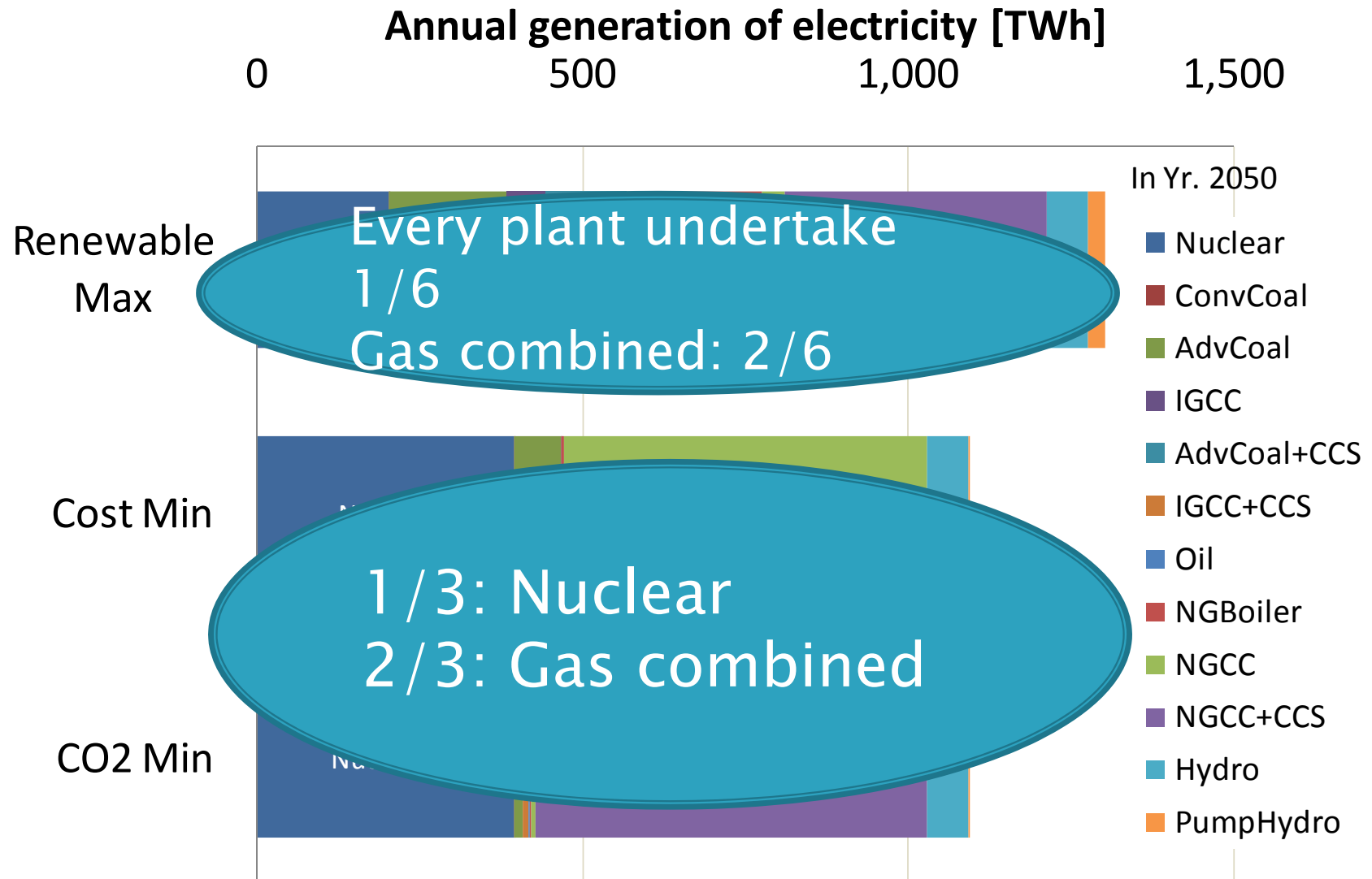
Objective functions

1. Maximization of on-grid renewables potential (Renewables Max case)
 2. Minimization of the annual cost (Cost Min case)
 3. Minimization of CO₂ (CO₂ Min case)
- ▶ Optimal solutions are obtained by using GAMS/Cplex

Results: Power plant capacity in 2050



Results: Annual generation by plants



Summary of cost, CO₂

	Annual generation cost			CO ₂
	Fixed	Variable	Total	
	(10 ¹² JPY)	(10 ¹² JPY)	(10 ¹² JPY)	(Mt-C)
Renew Max	7.17	5.10	12.27	105.6
Cost Min	4.37	3.47	7.84	82.4
CO ₂ Min	6.73	4.15	10.88	13.1

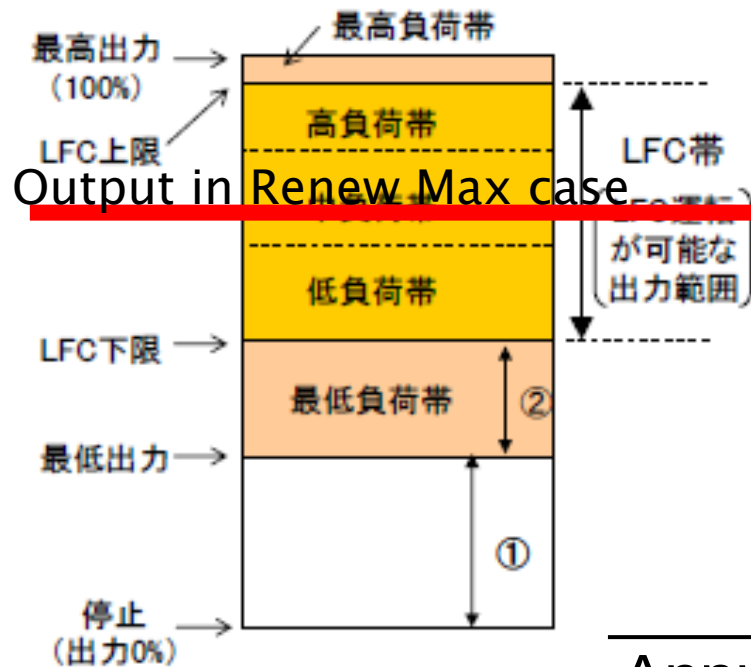
22 Million JPY/tC

2009/6/19

Summary of potentials of nationwide on-grid wind

	Annual		Peak	
	(TWh/yr.)	vs. generation (%)	(GWh/h r)	vs. capacity (%)
Renew Max	181.3	13.9	47.8	15.7
Cost Min	167.9	15.3	47.0	17.0
CO ₂ Min	113.9	10.4	41.9	13.5

“Renewables potential maximization” does not mean “Capacity ratio maximization”



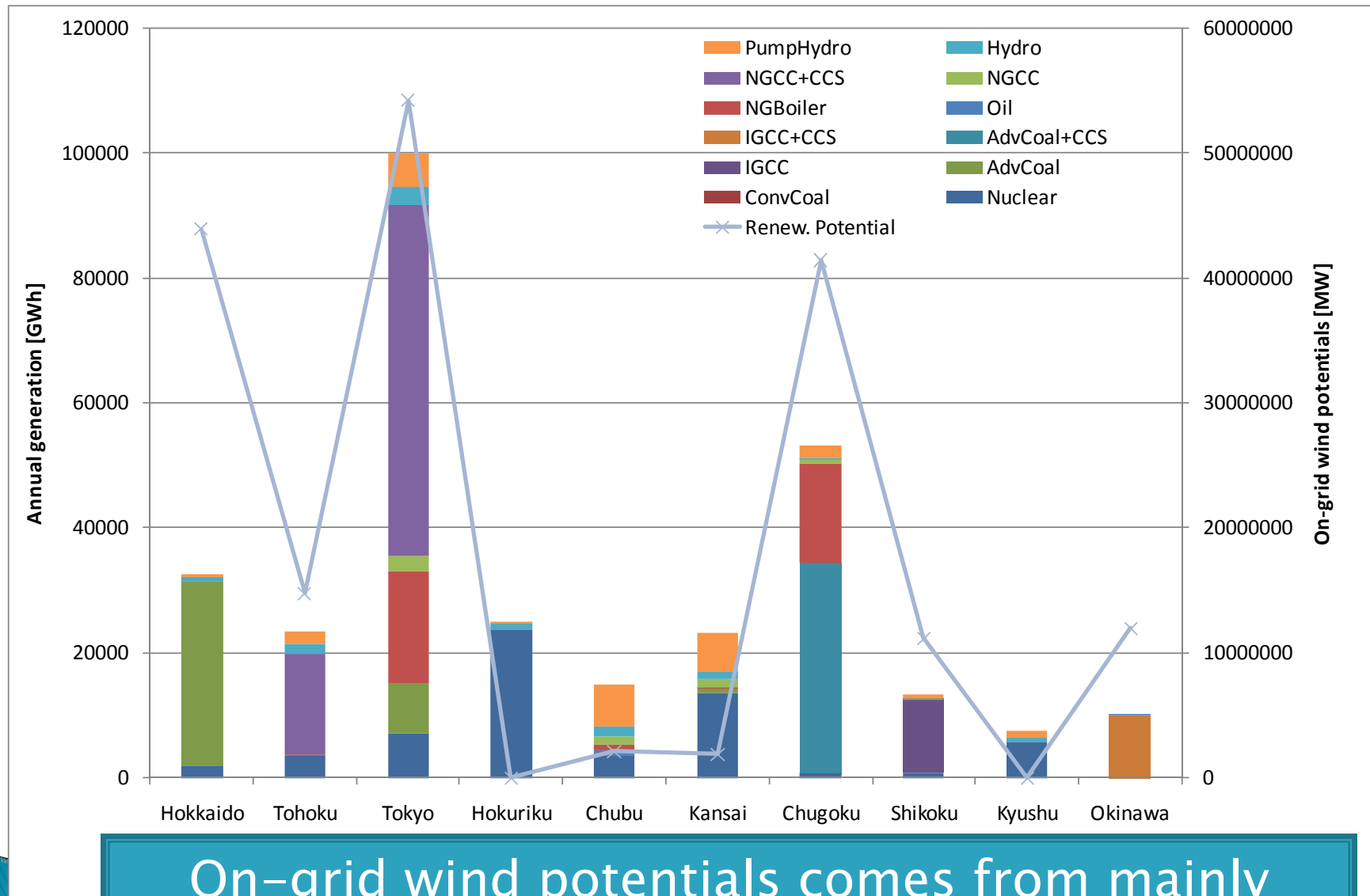
Unprofitable capacity

Worsening capacity ratio, and increasing cost!

		Annual		Peak	
Total Cost		vs. generation		vs. capacity	
		(TWh/yr.)	(%)	(GWh/hr)	(%)
Renew Max	12.27	181.3	13.9	47.8	15.7
Cost Min	7.84	167.9	15.3	47.0	17.0

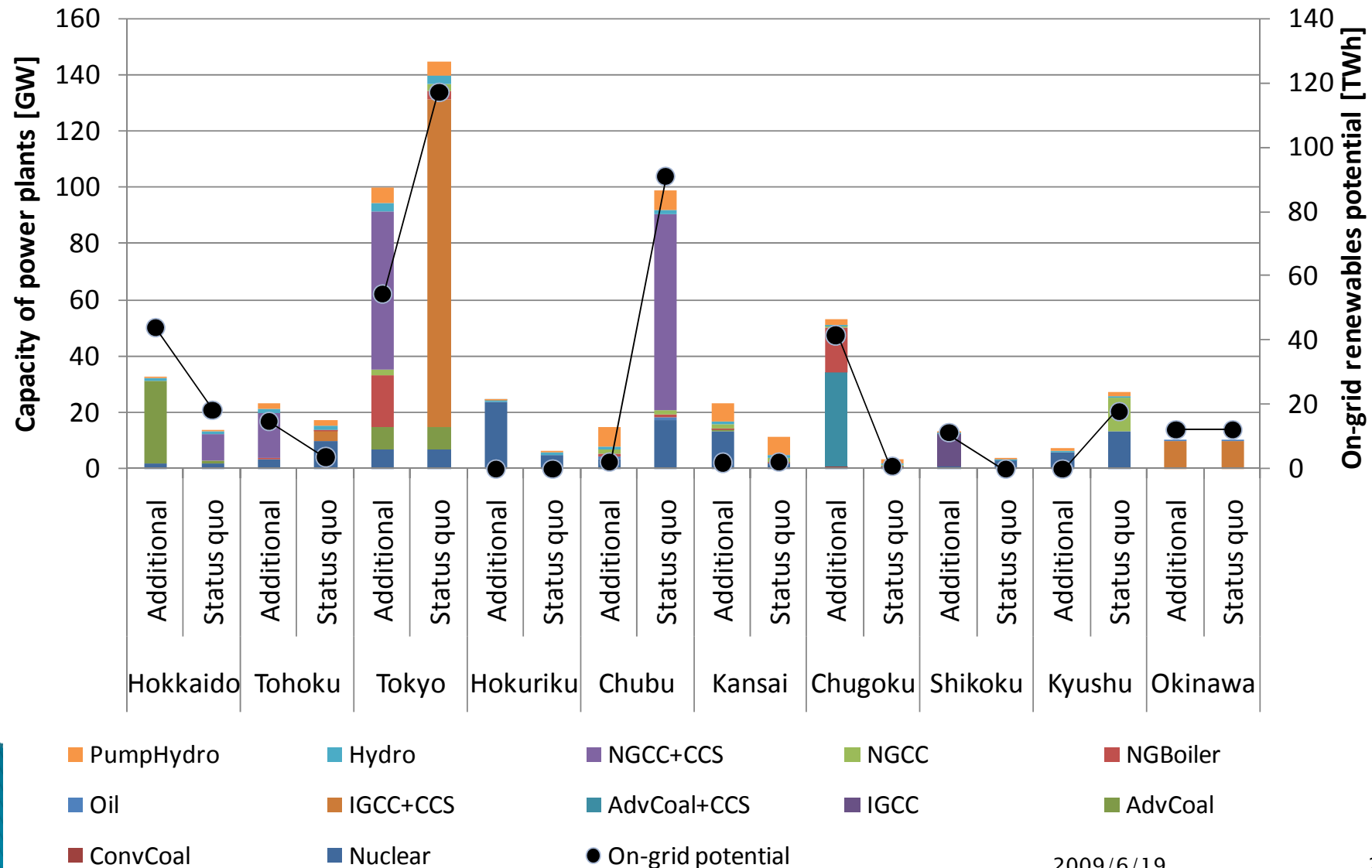
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Regional variation of potentials

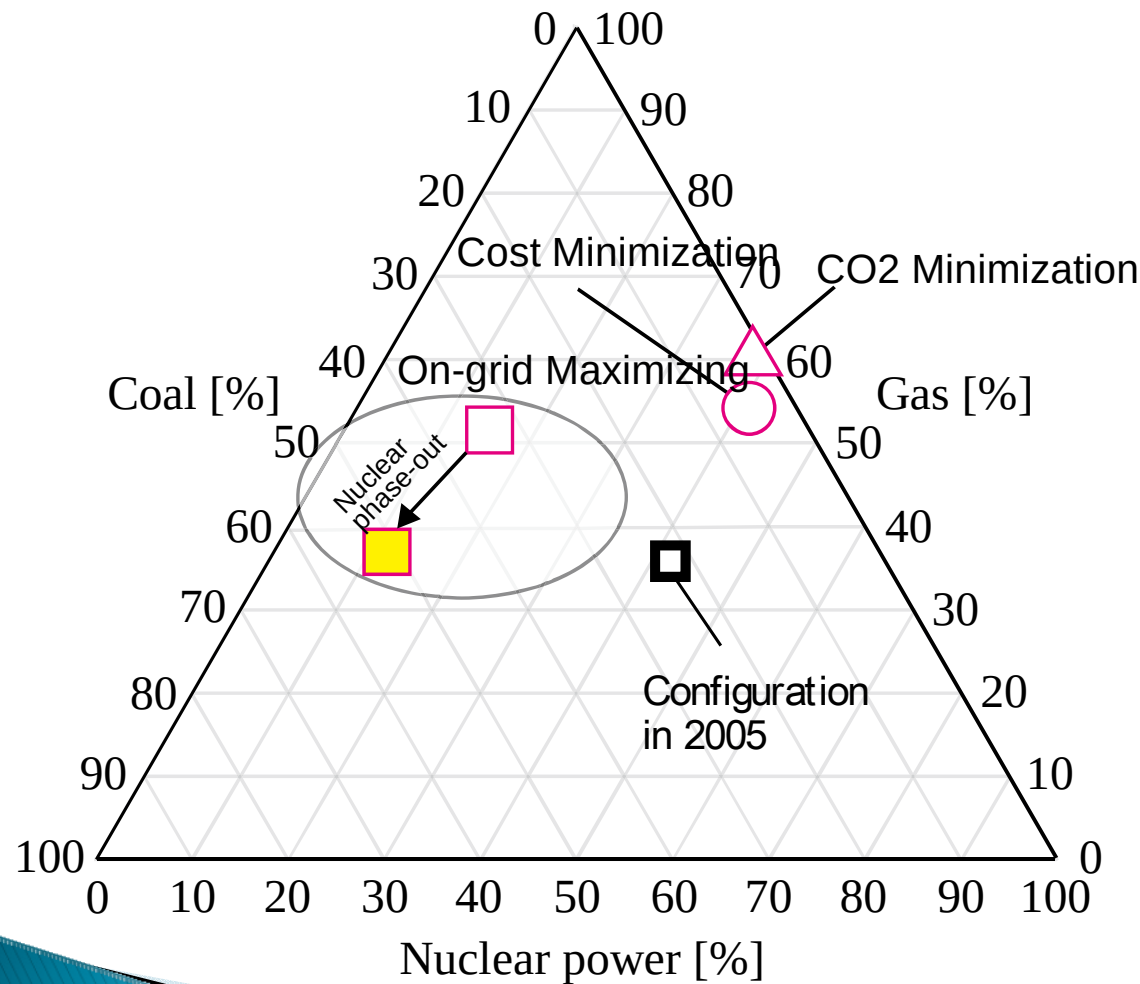


On-grid wind potentials comes from mainly three regions: Hokkaido, Tokyo, and Chugoku

Does collaboration of utilities expand on-grid potentials?



Conclusion: Feasible or Infeasible?



- ▶ Visions for cost minimization and for CO₂ minimization locates very close: Both of visions relies Gas combined cycle
- ▶ Enhancing on-grid potentials has top priority, utilities require certain amount of coal-fired plants

Thank you for your
attention!

<http://2050.nies.go.jp>

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