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Decarbonization of Energy System & the Role of Nuclear

Ryoichi Komiyama

Associate Professor,
Department of Nuclear Engineering & Management,
The University of Tokyo

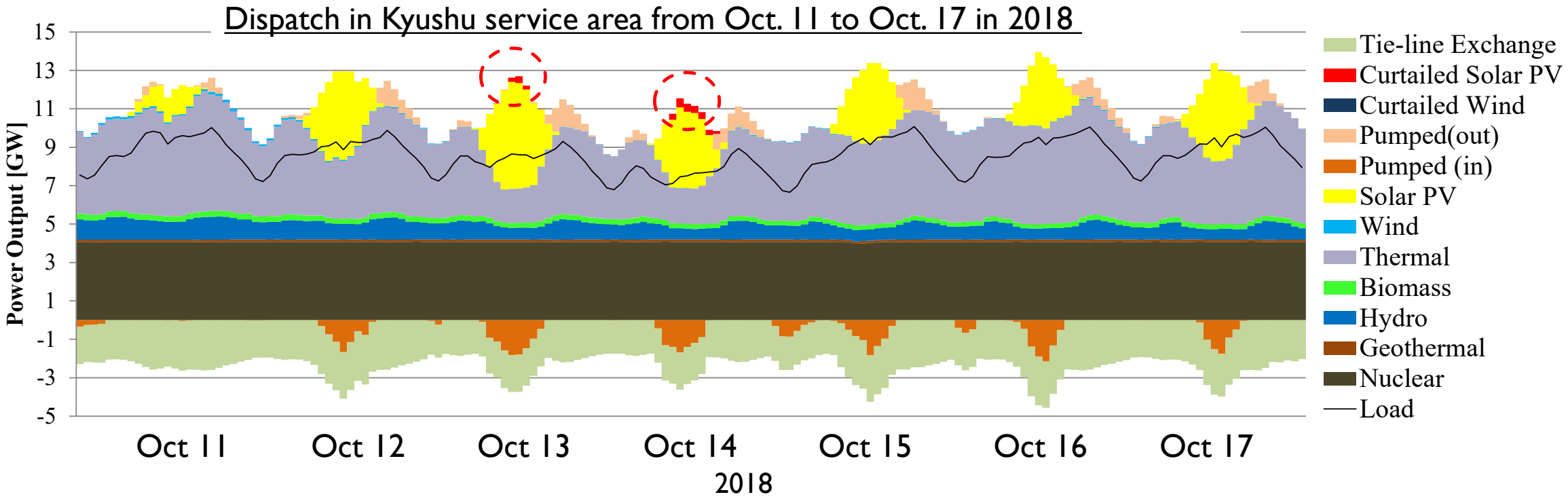
THE UNIVERSITY OF TOKYO

Energy Issues surrounding Nuclear (NU)

- Climate Change Problems
- Large-scale Variable Renewable (VRE) Integration
- Energy Security
- Electricity Market Deregulation

Impact of Solar PV in Japan (Kyushu service area)

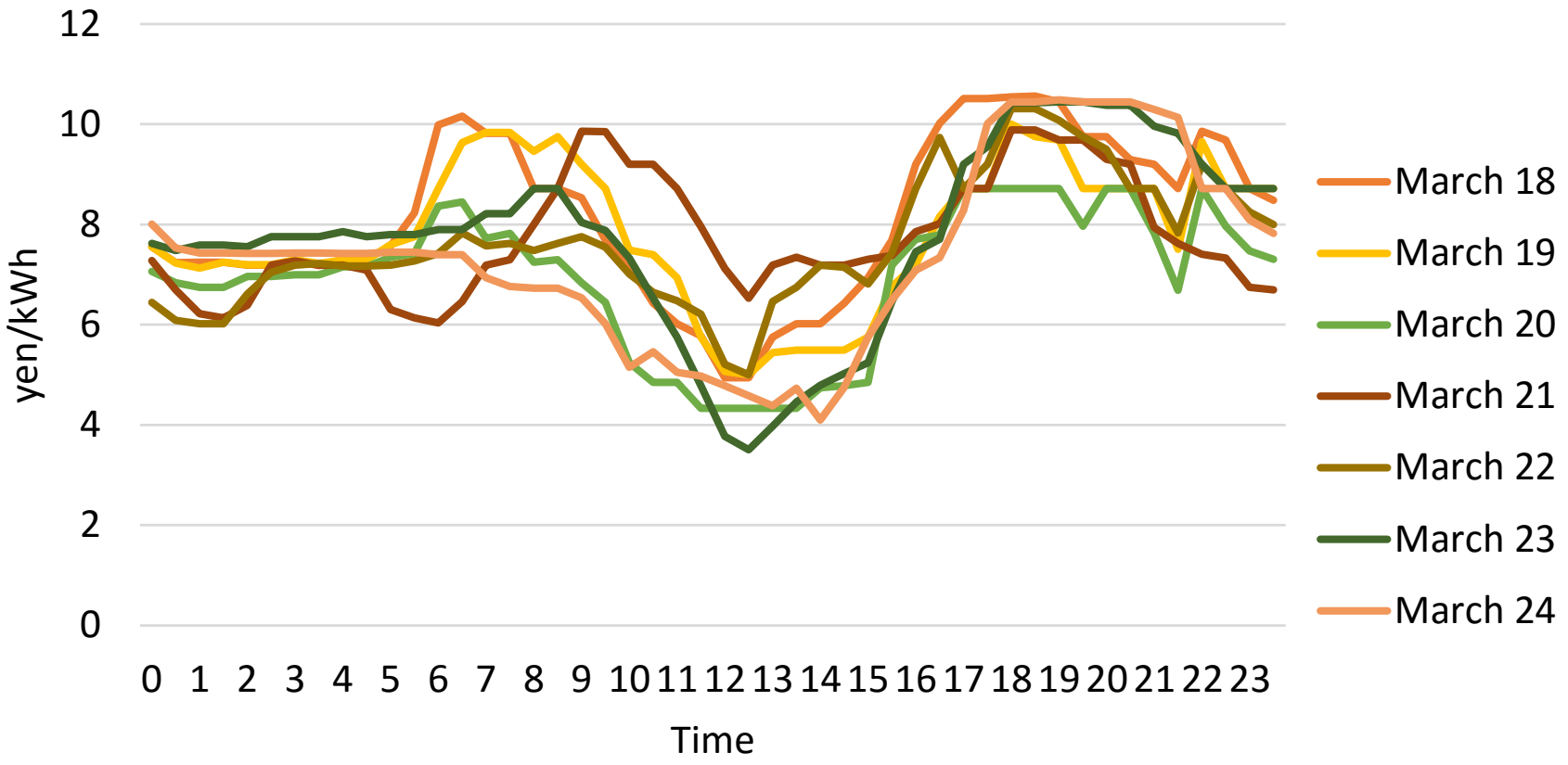
- PV system has rapidly increased in Japan (45GW, 2018).
- In October 13, 2018 in Kyushu service area, the power system operator ordered the curtailment of PV output firstly in the mainland of Japan. In the noon, PV output dominates nearly 80% of the demand.
- FIT surcharge (2018): 2.4 tril. yen (24 bil. $). More 1.3～1.6 tril. yen (13 bil.$～16 bil.$) will increase furthermore



(Source) Compiled from the data of Kyushu Electric Power Company

Wholesale Power Price in Japan (March 18～March 24, 2019)

- Price in daytime is lower than night, caused by solar PV



(Source) Japan Electric Power Exchange (JEPX)

MIT-Japan Study Future of Nuclear Power in a Low-Carbon World: The Need for Dispatchable Energy †

(Sept. 2017)

*MIT, TiTech, The University of Tokyo, JAEA, IEEJ, IAE are involved

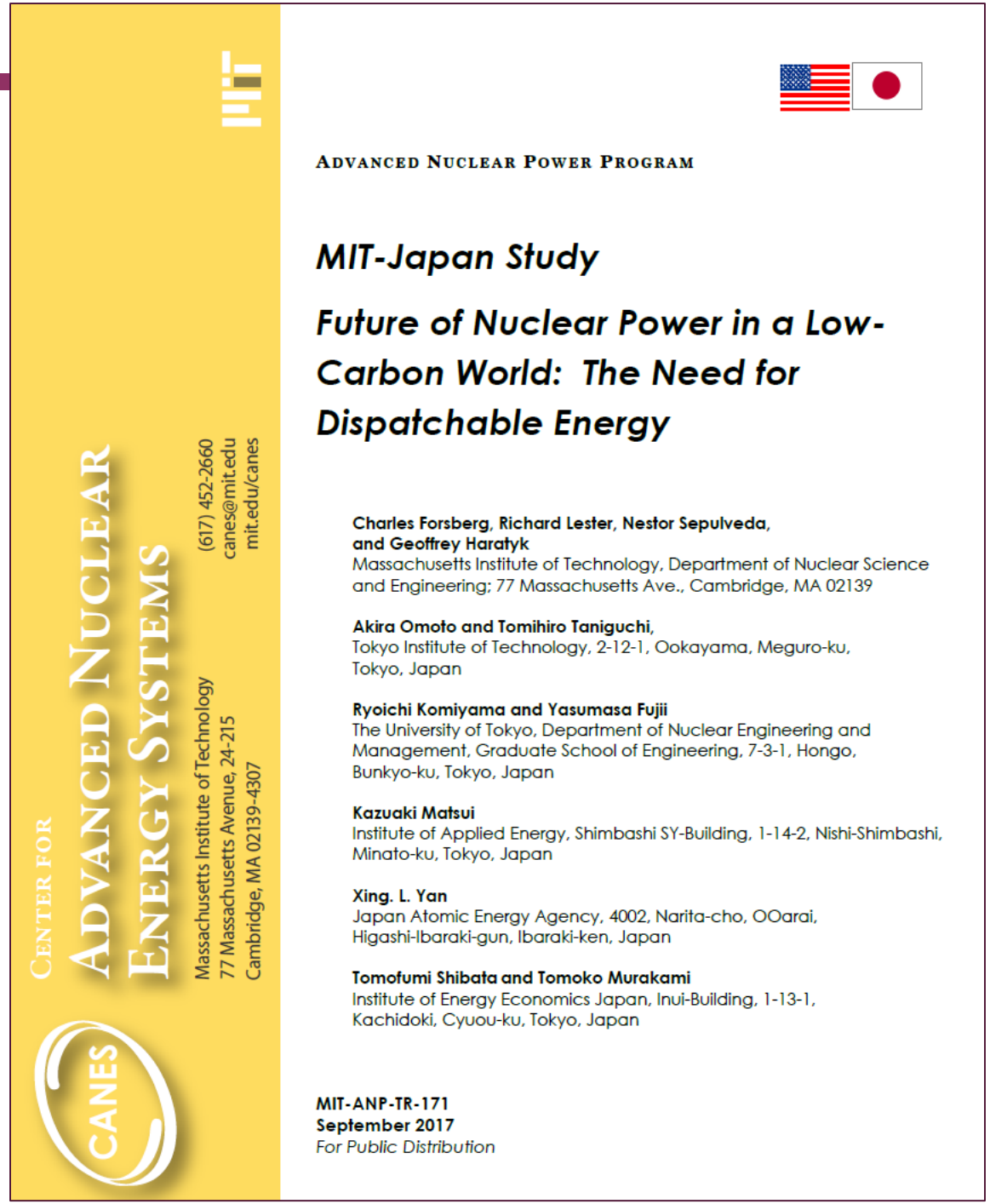
➢ Nuclear & VRE(PV, Wind) Harmonization

- Enhancement of Flexibility of Nuclear by Advanced Technology Development (Advanced Nuclear Reactor, Advanced Energy Storage such as Heat Storage)
- Best Mix Analysis of Nuclear & VRE

➢ Policy Support & Design

- Policy Support for Energy Storage (Power, Heat)
- Correction of excessive RE Subsidy
- Electricity Market Design (Capacity Remuneration Mechanism)

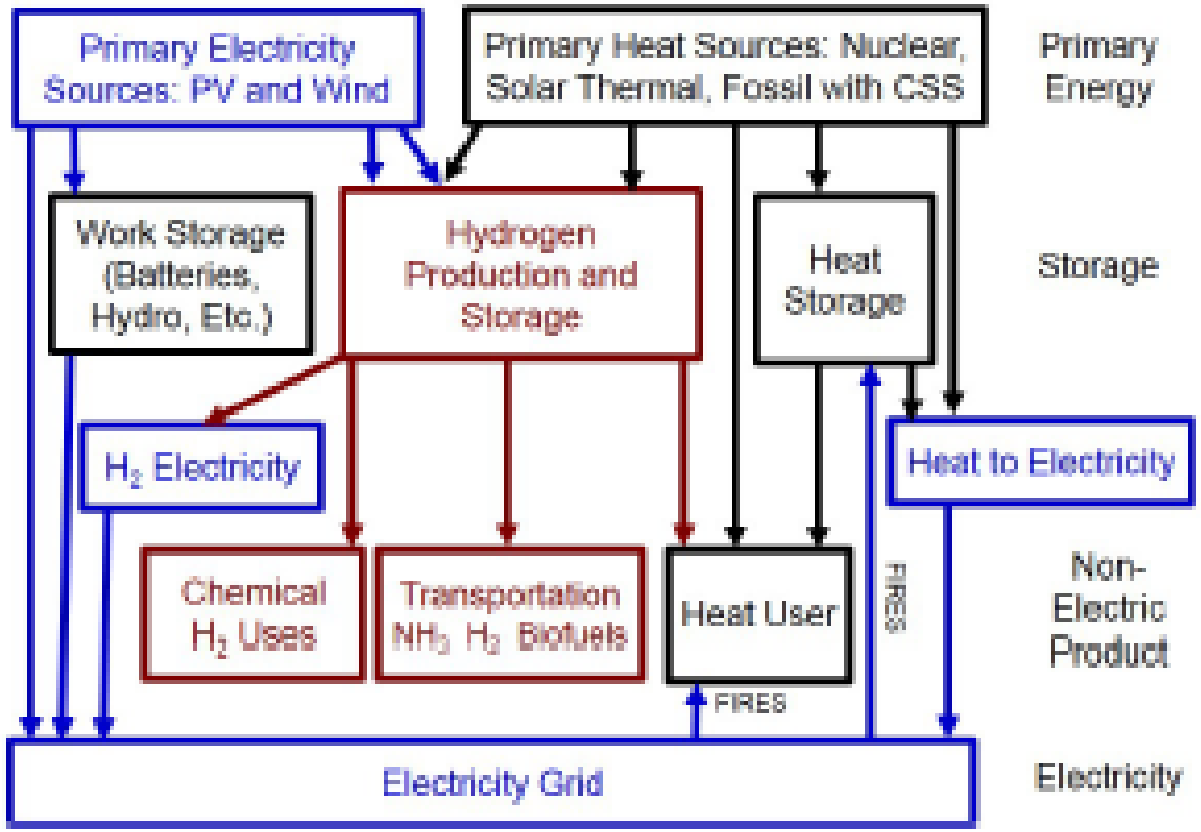
† Downloadable in MIT website：
http://energy.mit.edu/publication/future-nuclear-power-low-carbon-world-need-dispatchable-energy/



Nuclear & VRE Harmonization Strategy

- Nuclear Power → Baseload Power Source
- VRE increase, Wholesale power price down & fluctuation → Only by baseload operation, NU cannot maintain its economics
- Technology development is important, enabling NU & VRE harmonization
- Cross-industrial Utilization of Multiple Carrier produced by NU energy
  - ➢ Production, conversion, distribution, storage, consumption of various energy carrier (heat, hydrogen, methanol, ammonia etc.)
    - Usage in lower electricity-intensive sector, such as Industry and Freight Transport Sectors

Integrated Energy Network



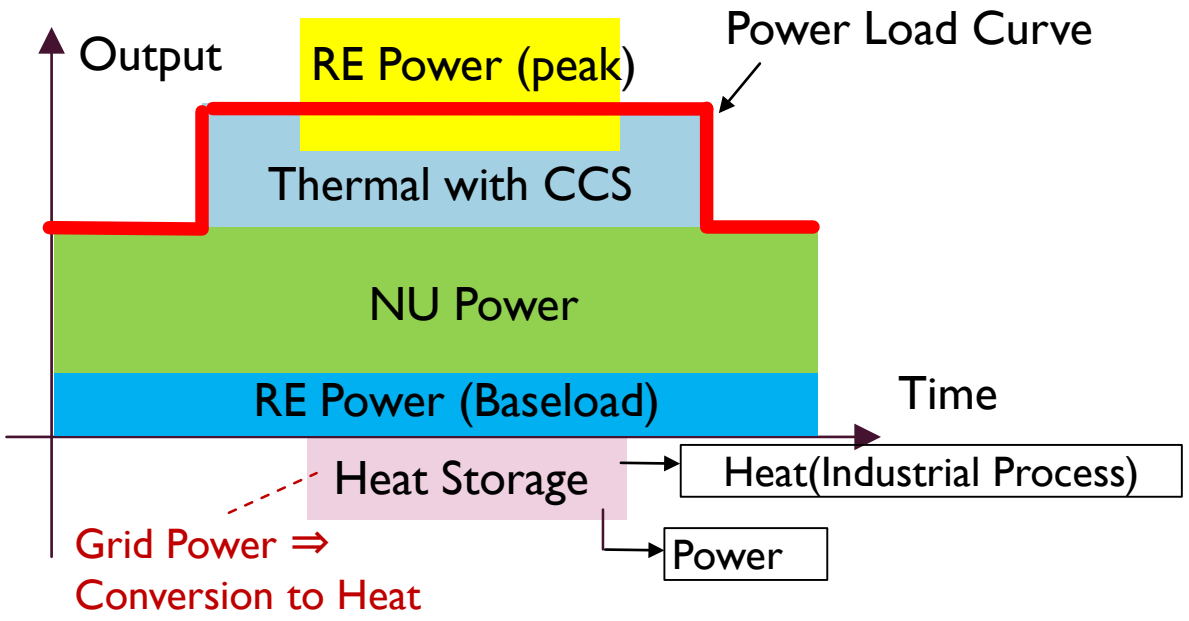
(Source)"MIT-Japan Study Future of Nuclear Power in a Low-Carbon World: The Need for Dispatchable Energy" (2017)

Nuclear & VRE Harmonization Strategy (Heat Storage & Usage)

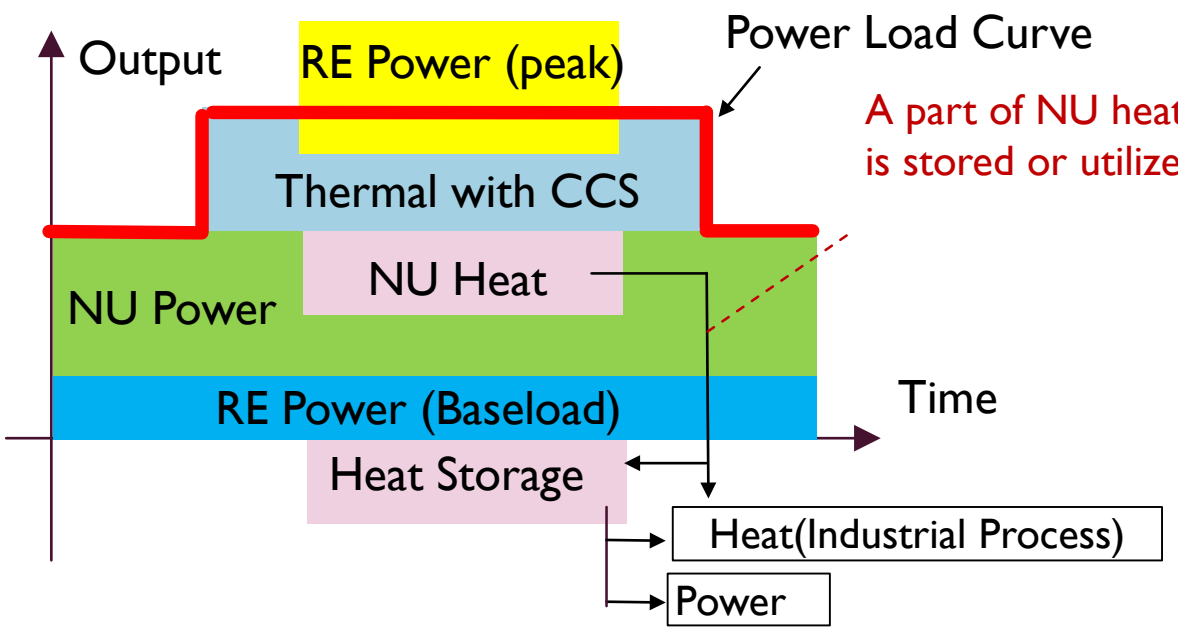
- Remedy Only by Power Technology (Battery, Power Line Extension) → Electricity Cost Soaring
- Heat Storage & Utilization Technology → Economical Power Storage Option
- NU: Baseload Operation + Electricity Output Adjustment, VRE: No Curtailment
  - Stored High-Temperature Heat → Consumption in Industrial Process → Reduction of Fossil Fuel & CO_2
  - Lower Wholesale Price → Heat storage, Higher Wholesale Price → Heat Discharge or Convert to Electricity

    ⇒ Enhancement of NU Economics in Electricity Market

Baseload NU Output of Heat & Power



Baseload NU Output of Heat & Adjusting Power Output



Nuclear & VRE Harmonization Strategy (NU load-follow)

Utilization of Nuclear FPO (Flexible Power Operations)

- ➢ Lower ratio of fuel cost in operation cost → NU baseload operation is favorable
- ➢ VRE penetration→ Growing needs for NU FPO
- • NU has similar output controllability as thermal power units
  e.g. USA (URD), Europe (EUR)
- • Operation continuity under blackout (NU isolated operation) → Contribution to resilience, that is, power grid restoration

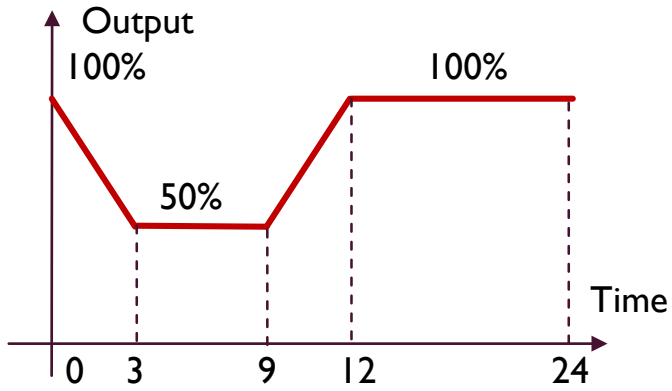
Daily Load Follow

- ➢ Load following operation toward daily load cycle
- ➢ Control of heat flow in steam turbine → 50% NU output suppression

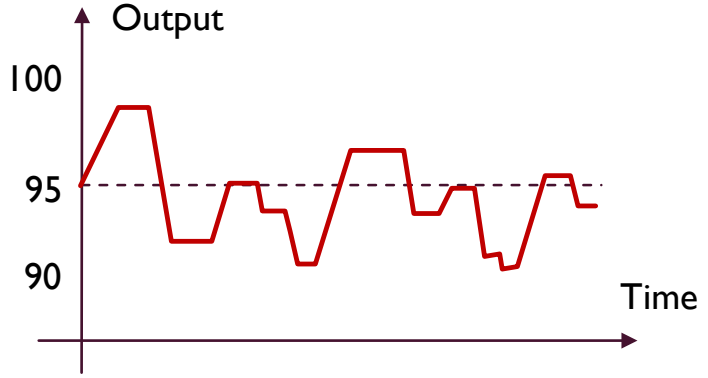
Automatic Frequency Control (AFC), Governor Free Control (GF)

- ➢ AFC: Automatic control of power output in a minute basis by TSO order
- ➢ GF: Second-order control is technically feasible
- • Demonstrations were implemented in Japan and AFC/GF control were technically verified

Power Output Adjustment
(Daily Load Follow mode)



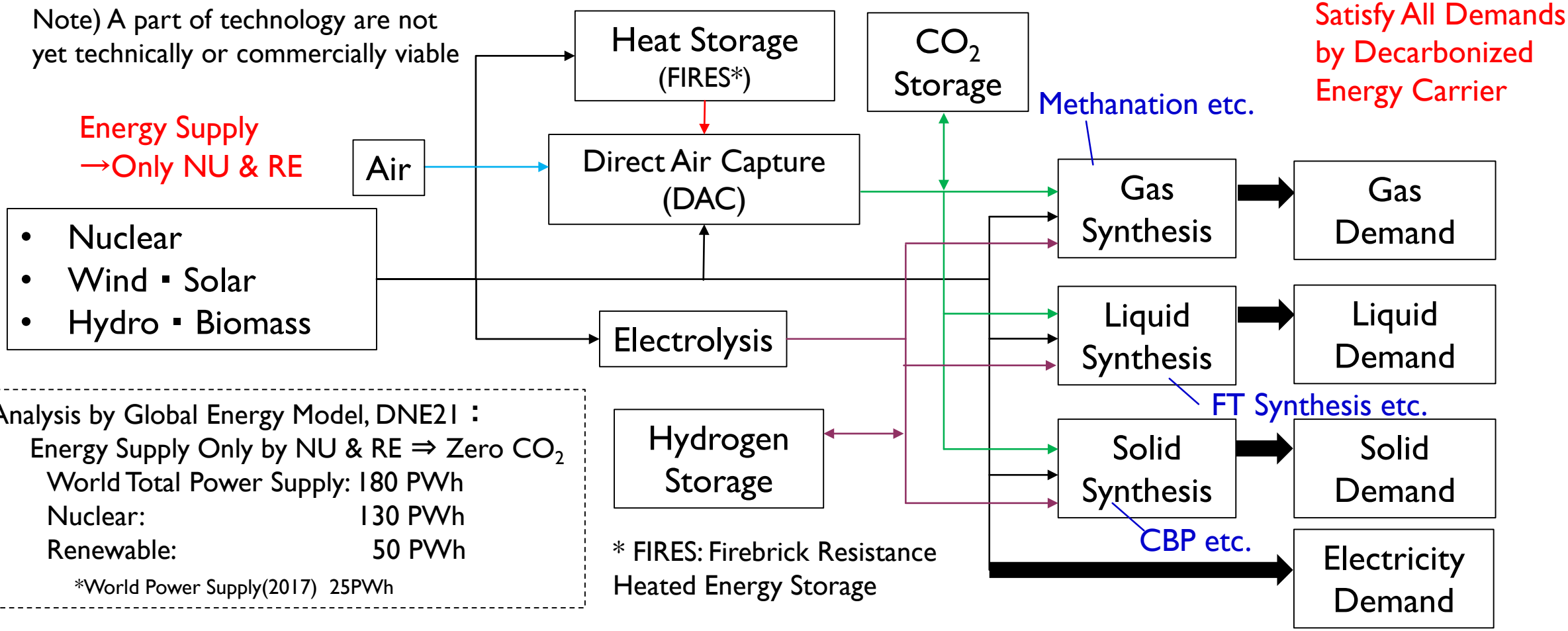
Power Output Adjustment
(AFC mode)



Defossilization of Energy System

- By NU & RE, defossilization of all energy carrier and cross-industrial energy supply is indispensable, other than electricity sector

Imaginary NU & RE Energy System



Analysis by Global Energy Model, DNE21：

- Energy Supply Only by NU & RE ⇒ Zero CO_2

  World Total Power Supply: 180 PWh

  Nuclear: 130 PWh

  Renewable: 50 PWh

  *World Power Supply(2017) 25PWh

* FIRES: Firebrick Resistance Heated Energy Storage

Small Module Reactor: SMR

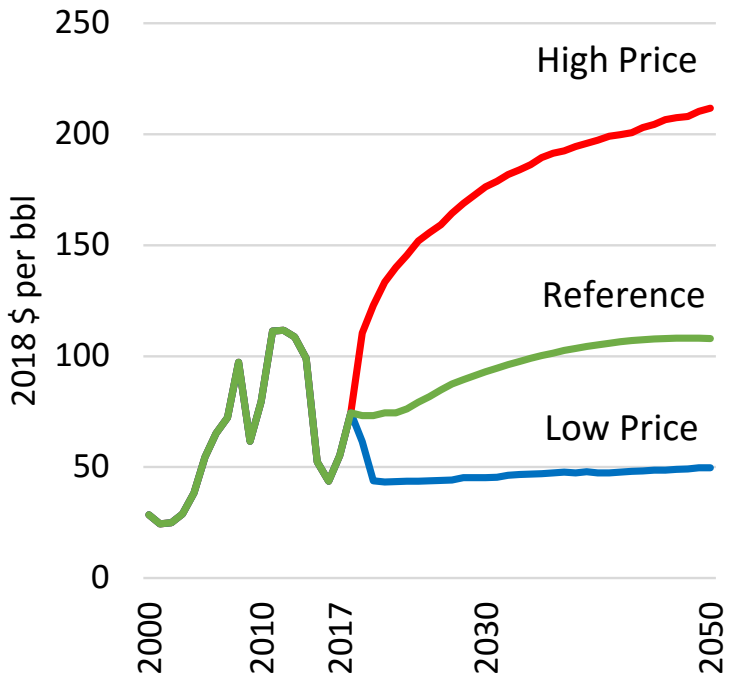
- Construction Cost
  - Investment Cost Reduction (100 mil.$-order/unit) ⇔ (Large-scale Reactor) Escalation of Const. Cost
- Engineering in Reactor Construction
  - Short Construction and Pay-back Period ⇔ (Large-scale Reactor) Delay Risk of Construction (US,EU)
- Safety
  - Passive Safety Design ⇔ (Large-scale Reactor) Escalation of Safety Cost
- Risk of Accident
  - Limited Evacuation Area in Accidents, Install near Demand Area
    ⇔ (Large-scale Reactor) Wider Evacuation Area
- e.g. High Temperature Gas Reactor (HTGR)
  - Inherent Safety, Multiple Energy Production (Power,Heat,H_2), Pu Consumption, VRE Harmonization (Ability of Load-following Control)
- Significance and Challenge of SMR
  - Succession of Nuclear Technology, Contribution to Nuclear Industry, Decentralization of Power System
  - Economies of Scale (Learning Effect？), CO_2 Mitigation (Limited？)

Energy Security & NU Role

Risk in Crude Oil Price

- Low Oil Price by Sluggish Oil Demand, Tight Oil Booming
  - Stagnation of Upstream Investment → Flash Point for Future Oil Crisis
  - Oil Revenue Decrease, Political Volatility of Middle East Region
- Crude oil price (2050) → more than $200/bbl in High Price Scenario

Crude Oil Price Outlook (Brent Oil)



(Source) EIA/DOE, Annual Energy Outlook 2018

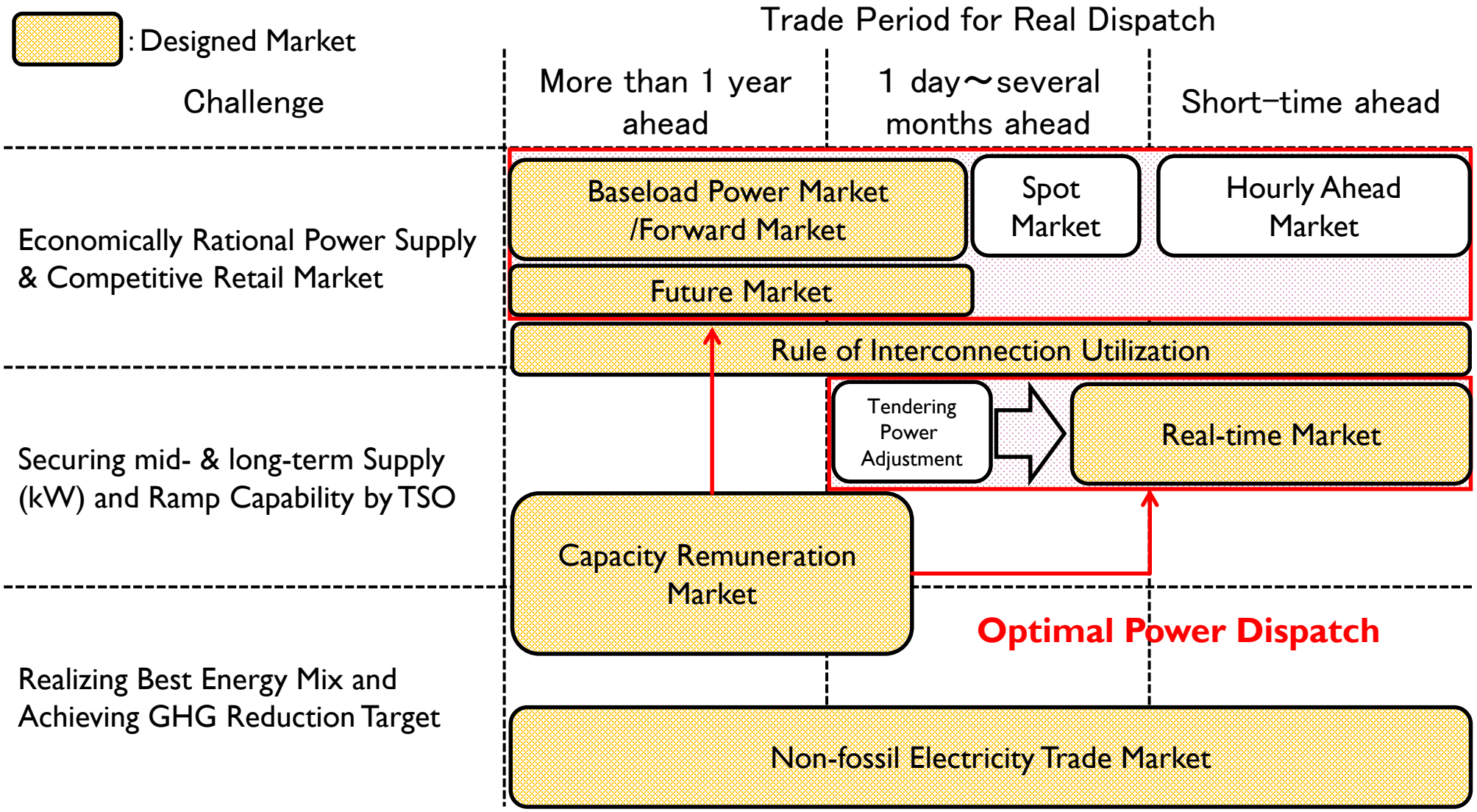
Contribution of Nuclear for Energy Security

- Suppression of Energy Price Increase
- Fuel Stockpile Effect (effective for energy supply disruption)
- Efficient Fuel Usage by Nuclear Fuel Cycle (Fuel Recycle)
- Security of Fuel Procurement
  - China outstrips Japan in Gas Import of 2018, Gas Supply Security is Important for Japan.
  - Global Gas Demand in 2040* ⇒ 50% increase (2.7 bil. LNG-t(2017)⇒3.9 bil. LNG-t(2040))

*BP Energy Outlook 2019 <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf>

Electricity Market Deregulation in Japan

What's impact on Nuclear Power Plant?



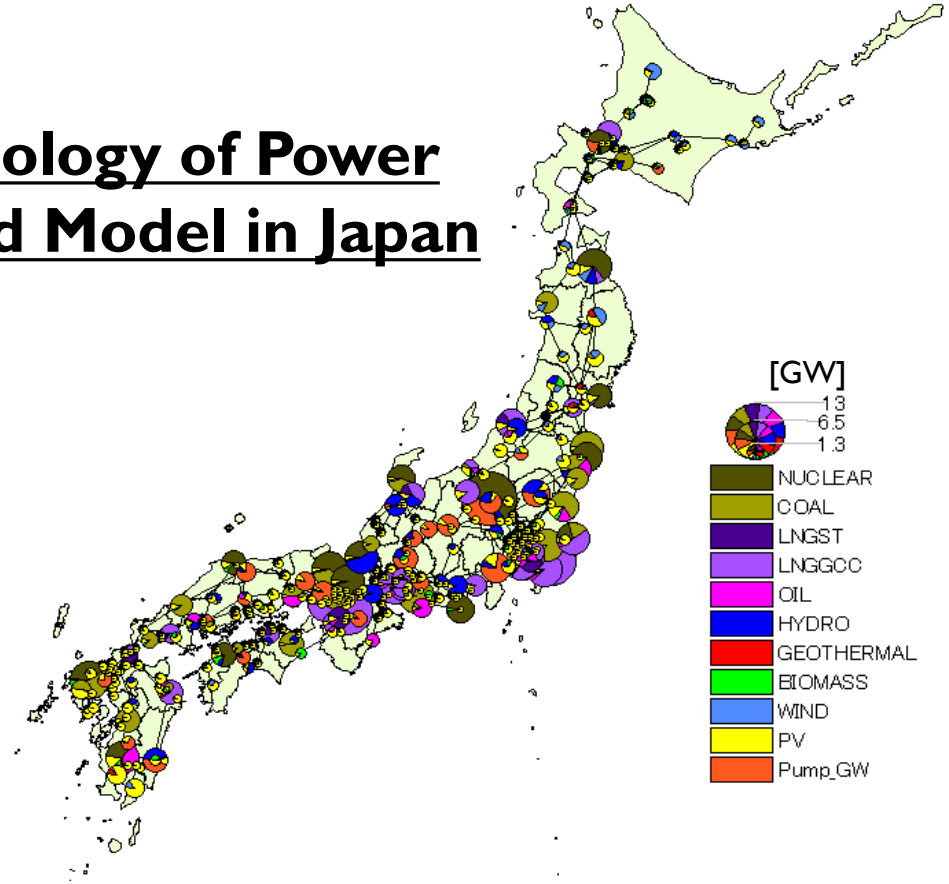
(Source) Ministry of Economy, Trade and Industry (METI)

Simulation of NU Competitiveness under RE Integration

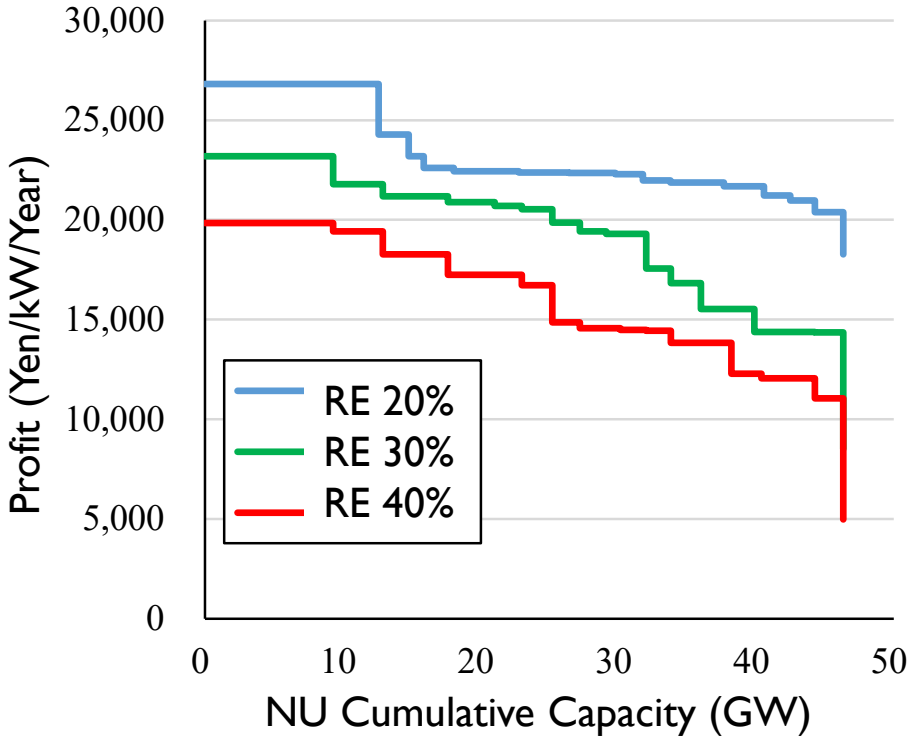
- Analysis by Optimal Power Grid Model*
  - Cost Min. Model, 352 buses & 441 lines, Hourly Resolution over 8,760 hrs

    * Komiyama, R., Fujii, Y., ***Renewable Energy***, Vol.139, August 2019, pp.1012-1028, 2019.
- NU Profit in Wholesale Market decreases under Massive RE Integration

Topology of Power Grid Model in Japan

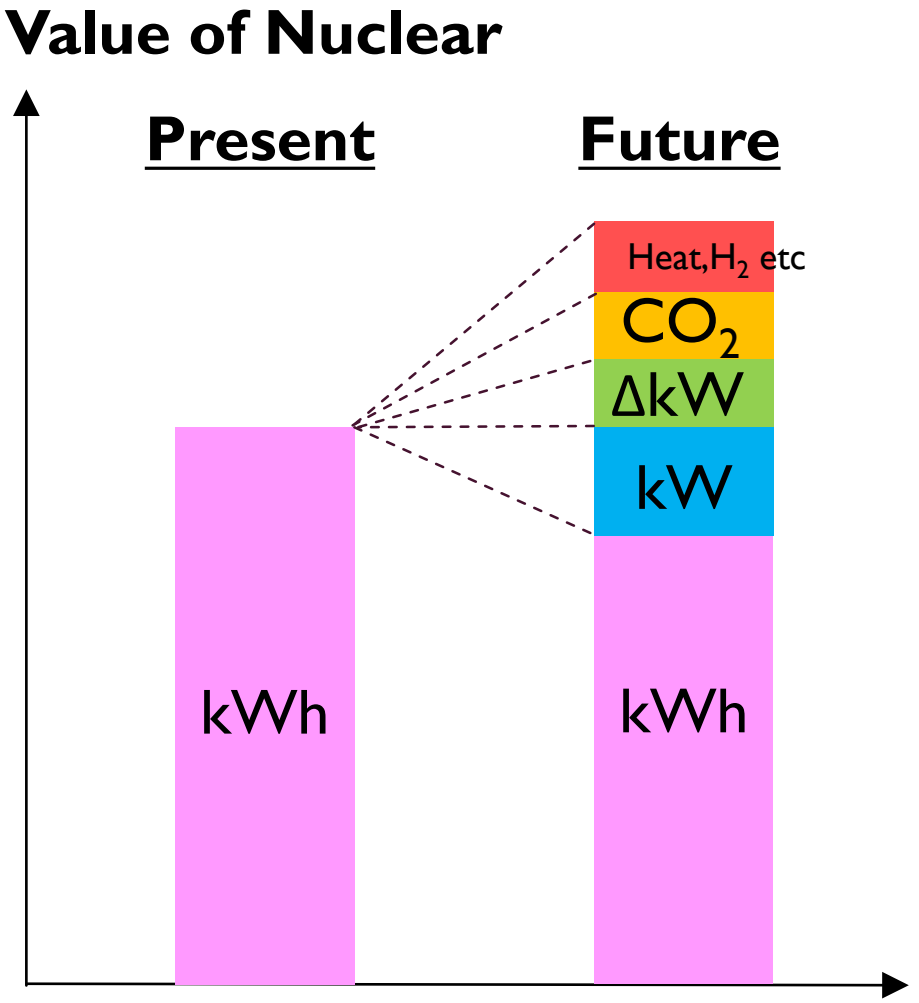


NU Profit from Wholesale Market under RE Integration



Revision of Nuclear Strategy in Energy Market

- Nuclear holds multiple market values, other than baseload power (kWh-value)
  - Power Supply Security (kW-value)
  - Ramp Capability (ΔkW-value)
  - Non-fossil-value (Zero CO_2-value)
  - Multiple NU Energy Usage (Heat, H_2)
- Utilization of Multiple NU Technical Function
  → Enhancement of NU Competitiveness



Wrap-up

NU & RE are a pair of wheels for decarbonization, and NU & RE harmonization is important

→Development of New Nuclear "Baseloadability", compatible with massive RE Integration

- Cross-industrial Usage of Multiple Energy Carrier produced by NU & RE
- FPO in Nuclear Reactor → "Baseloadability" + Flexibility
- Development of Advanced Nuclear Reactor
  - Nuclear Reactor with more Safety, Economics, Sustainability and Non-proliferation feature, based on the Lesson of Fukushima Accident & LWR
  - Safety and Public Acceptance
- New NPP Construction
  - Succession of Nuclear Technology, Human Resource Development, Enhancement of NU Technology with Building-up NPP Construction Experience

Thanks for your kind attention.

Ryoichi Komiyama

The University of Tokyo

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