Renewables and Clean Energy for Industries –Japanese Case for Variable Renewable Energy Highly Penetrated Energy System and for Replacement of Fossil-fuel Fired Boilers-

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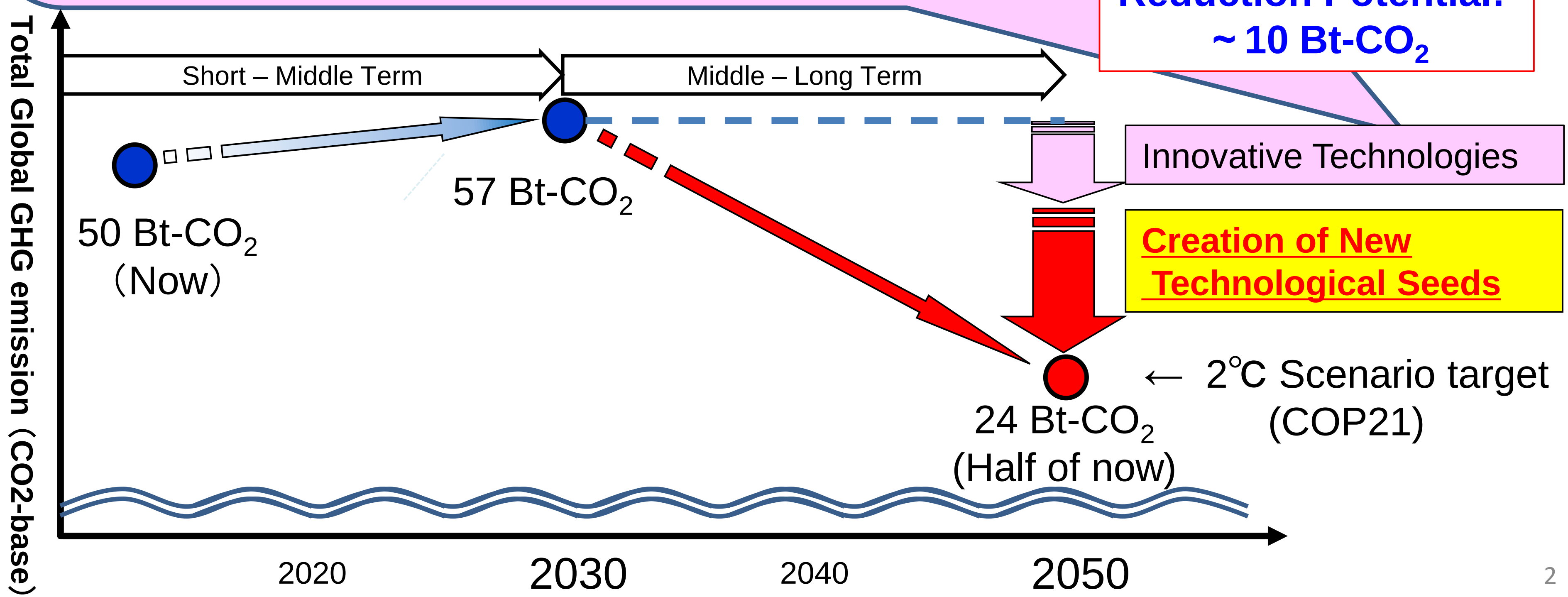
Energy System Integration Technologies with Core Technologies
(IoT, AI, Big Data, Power Electronics, Sensors, Superconductivity)

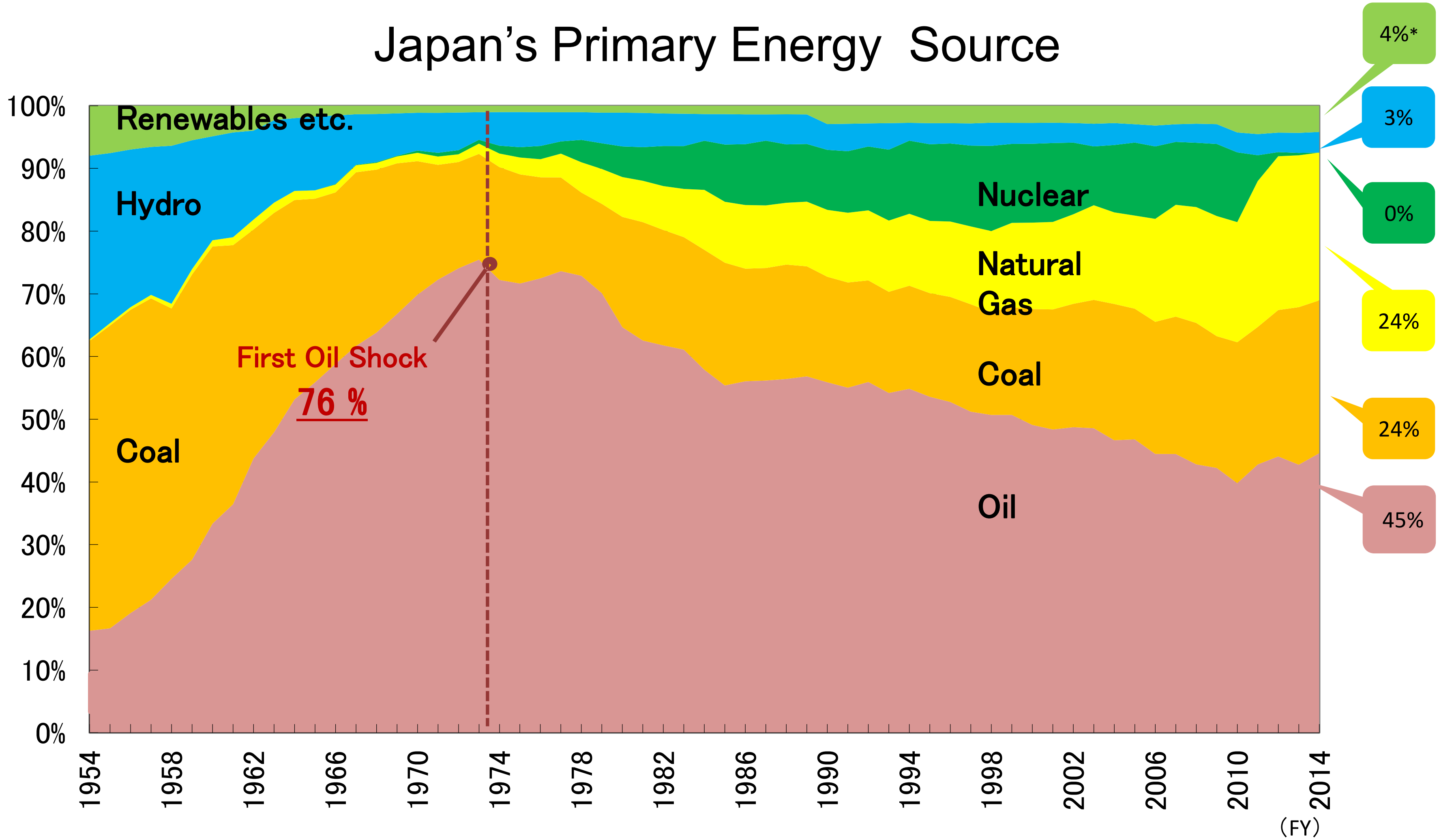
- Innovative Production Processes (Membrane Separation)
- Ultralight Materials
- Use of Hydrogen
- Next-Generation Geothermal Power Generation
- Next-Generation Storage Batteries
- Next-Generation Solar Power Generation
- **Capture and Effective Usage of CO_2**

Reduction Potential: ~10 Bt-CO_2



Japan's Energy Supply Structure

Ministry of Economy, Trade and Industry
Agency for Natural Resources and Energy

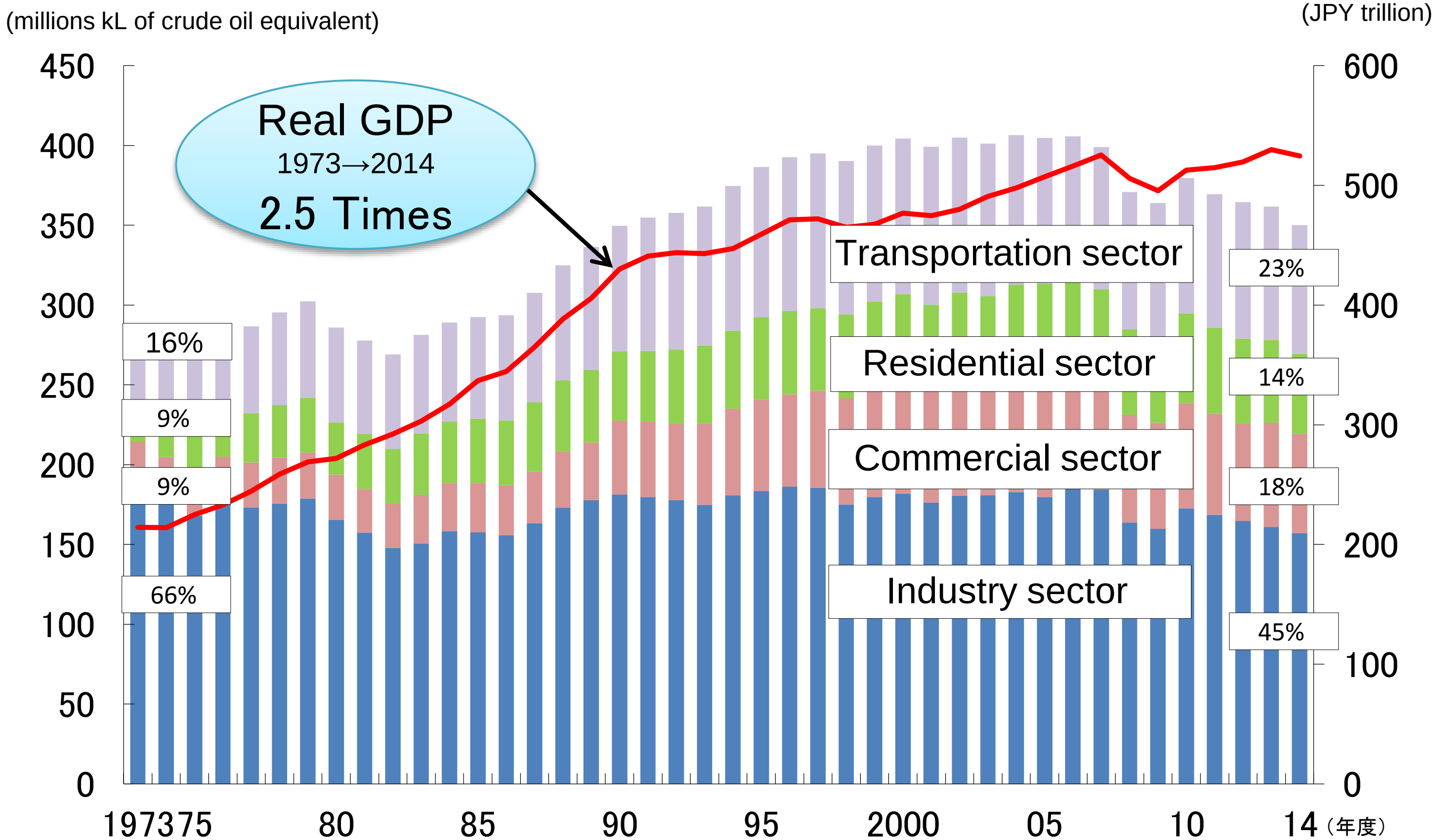


* "Renewables etc." consists of solar power (0.2%), wind power (0.2%), geothermal heat (0.1%), and biomass (1.8%), effective recovery use of wasted energy(1.9%).

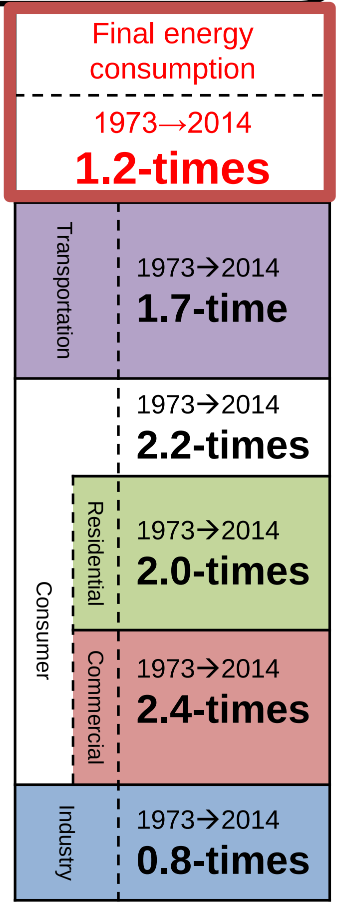
Source: Prepared based on "Comprehensive Energy Statistics 2015" issued by the Agency for Natural Resources and Energy.

Trends in Final Energy Consumption in Japan

- The final energy consumption of Japan has basically consistently increased, except for periods immediately following the two oil crises and the recent economic downturn.
- Until 2014 the GDP continued increasing to about 2.5 times the 1973 level and the consumption of energy for individual sectors significantly increased with the Consumer sector increasing to **about 2.2 times**, while the transportation sector increased to **about 1.7 times**, whereas the industrial sector decreased to **about 0.8 times**.

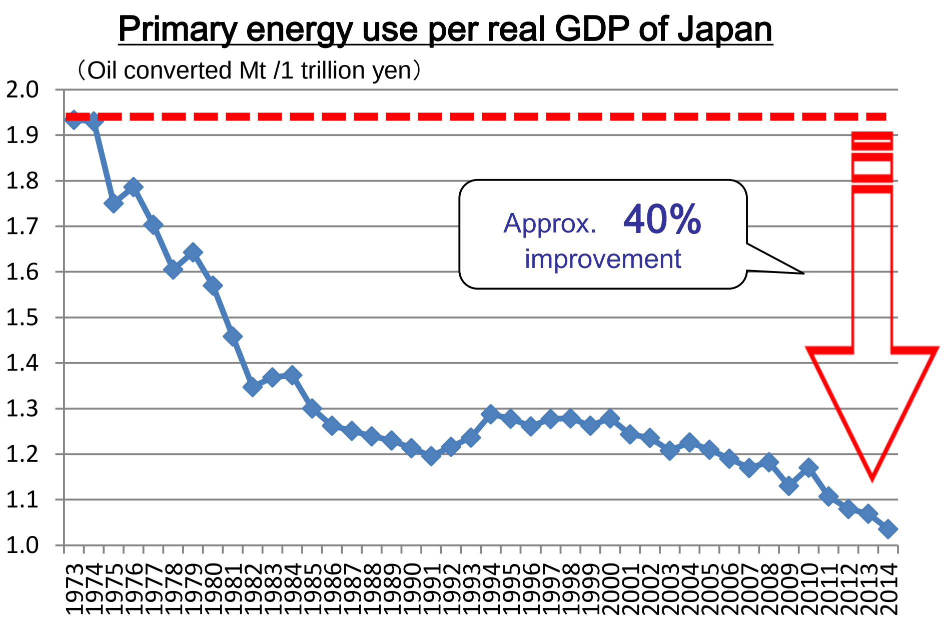


Sources: "Comprehensive Energy Statistics" and "Annual Report on National Accounts."

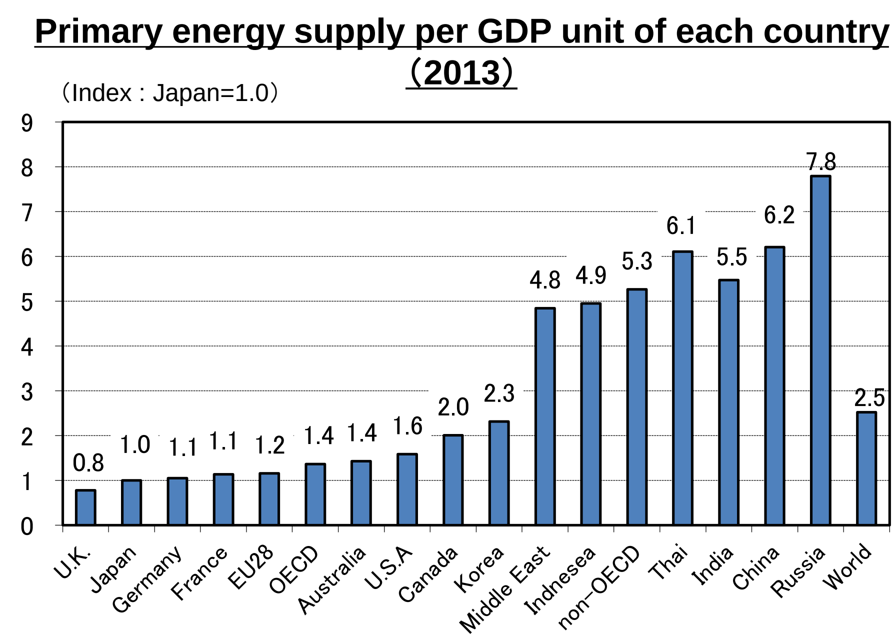


Japan's Energy Efficiency Efforts after the Oil Crises

- Japan has improved energy efficiency by approx. 40% after the oil crises in the 1970s as a result of positive actions by both public and private industrial sectors.
- Japan intensively introduced "Energy Management System based on the Act on the Rational Use of Energy", then achieved the lowest level of energy consumption per GDP in the world.

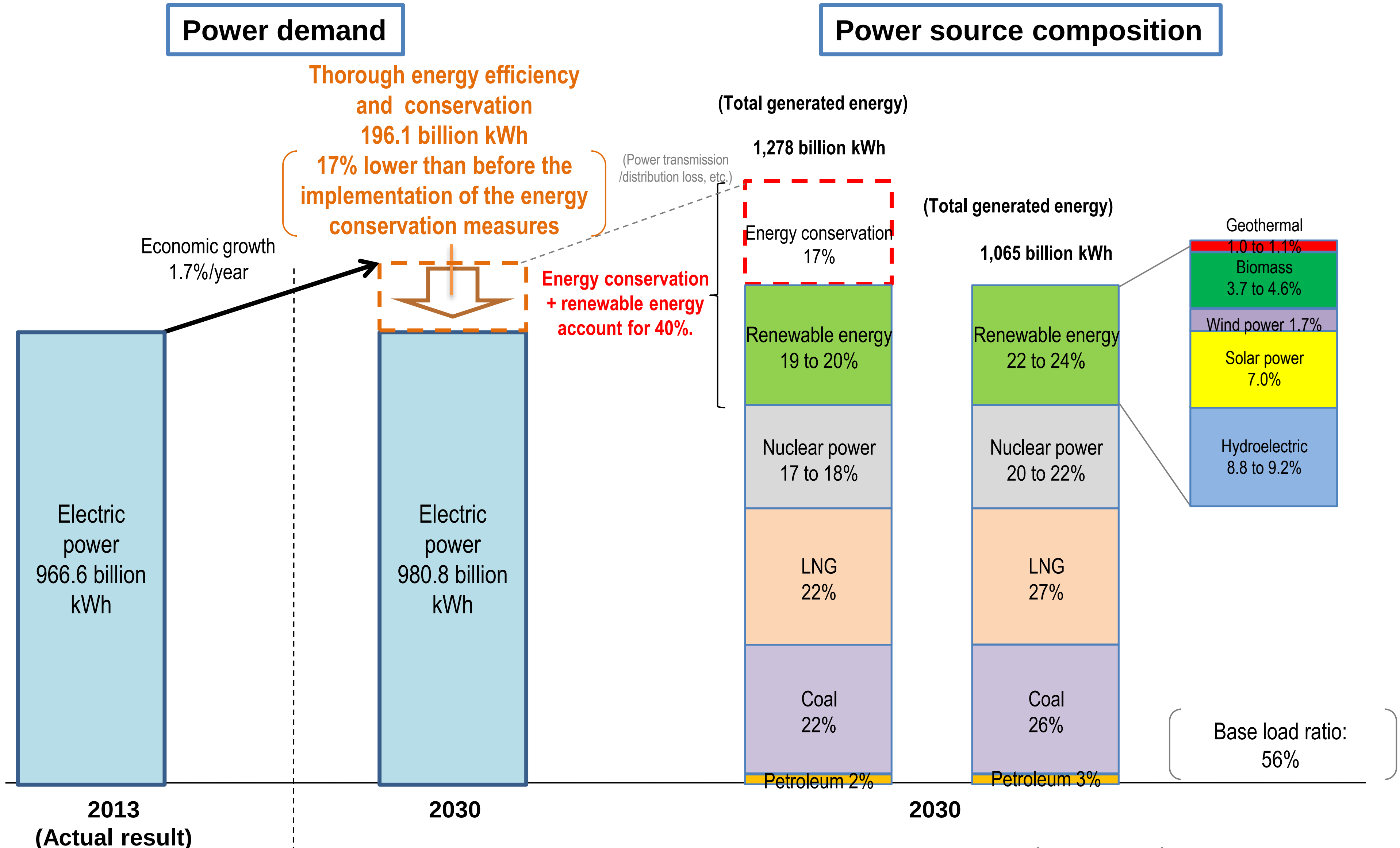


Source) Total Energy Statistics by ANRE/METI



Calculated according to IEA statistics

The Energy Mix (Power demand and power source composition）



* Values are approximate.

Energy Efficiency Measures

Ministry of Economy, Trade and Industry
Agency for Natural

Industrial Sector <approx. -10.42 million kL>

- Major 4 industries (steel, chemical, cement, and paper/pulp)
  ⇒ Promotion of commitment to a low-carbon society

- Strengthened energy management in factories
  ⇒ Improvement of energy efficiency by making production lines observable

- Development and introduction of innovative technology
  ⇒ Introduction of environment-conscious iron manufacturing process (COURSE50)
  (CO_2 reduction by approx. 30% by hydrogen reduction of iron ore and CO_2 separation from blast furnace gas)
  Introduction of technologies to use CO_2 as raw material etc.
  (CO_2 and water are used with solar energy to produce major chemicals.)

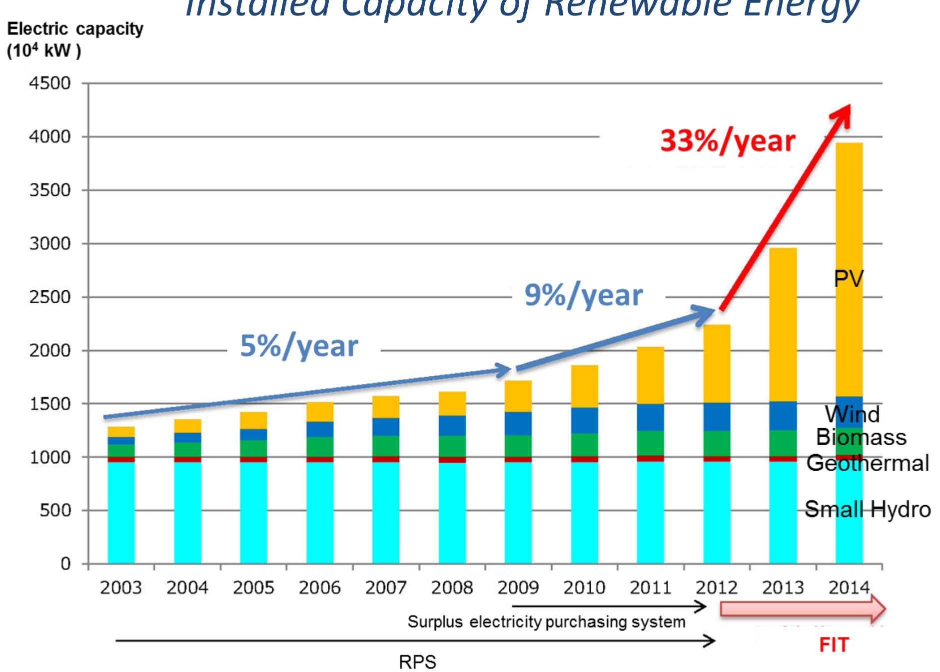
- Introduction of highly efficient facilities across several types of industries
  ⇒ Low-carbon industrial furnace, high-performance boiler, cogeneration, etc.

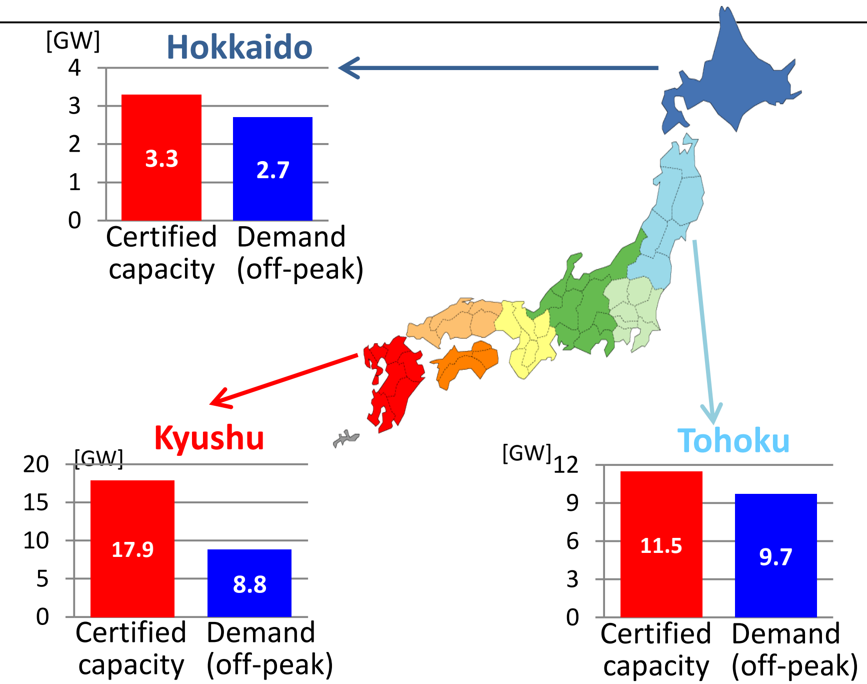
Japanese Energy Situation Sept.2016, Agency for Natural Resources and Energy

Curtailment on Renewable Energy of PV in Japan

- PVs have penetrated rapidly after the introduction of Feed in Tariff (FIT) in July 2012. Installed capacity of PVs have surpassed 20GW at the end of FY2014 and is expected over 60GW in 2030.
- PVs account for 95% of certified capacity under FIT and are concentrated in specific areas such as Kyushu, Hokkaido and Tohoku. Certified capacity under FIT is greater than off-peak demand in these regions.

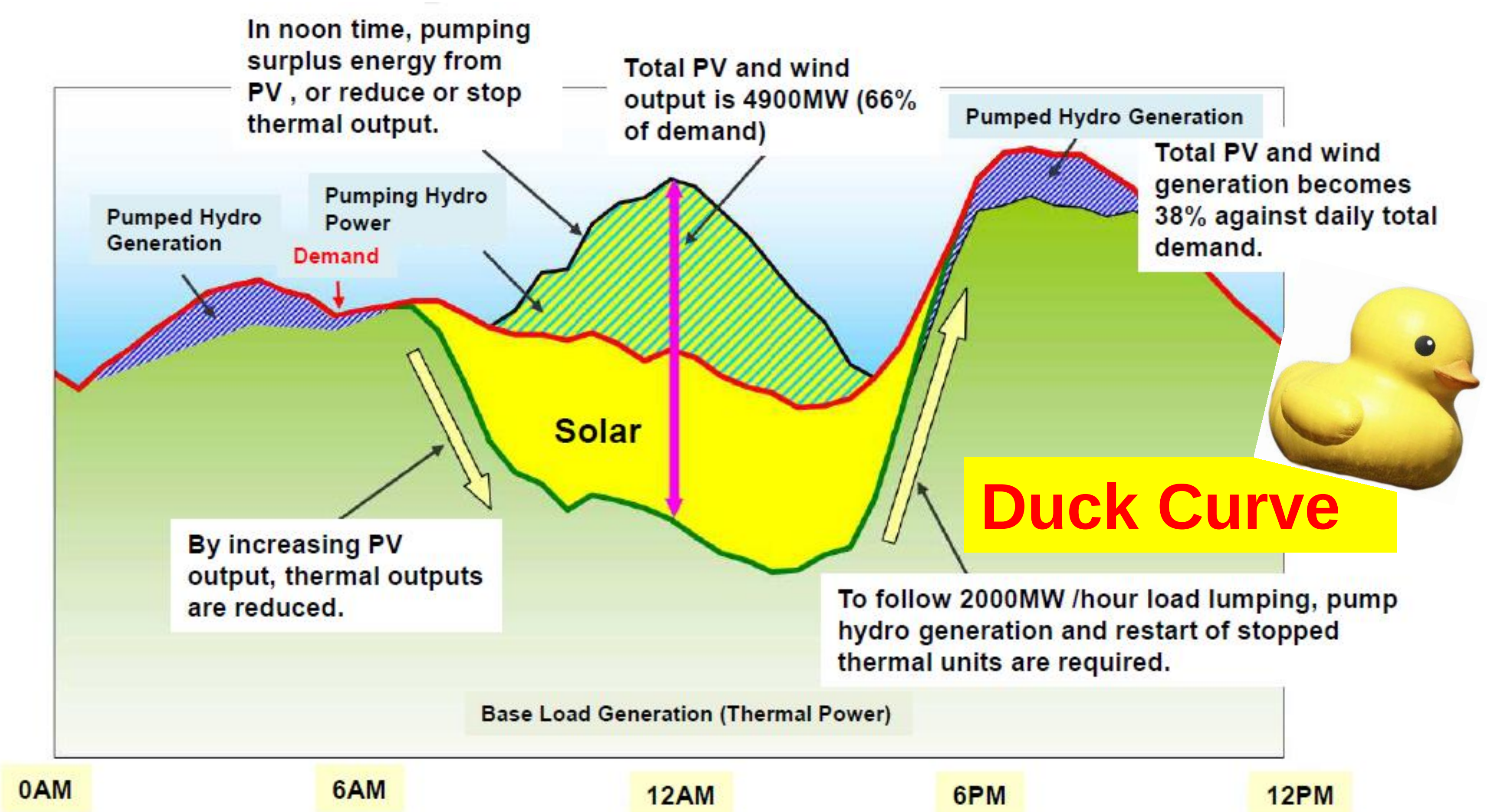
Installed Capacity of Renewable Energy





Supply & Demand in Kyushu Electric Area

- In this figure, supply & demand curve in Kyushu area on May. 4th ,2016 (Japanese holiday week) is shown.
- Is was required to follow 2000MW/hour load lumping, pumped hydro generation and restart of stopped thermal units.



Source: Kyusyu Electric Company

Estimated Curtailment Ratio in 2030

- The curtailment of PV and wind power generations increased to about 15% at about 2 times penetration of the PV and wind prospect in 2030 based on the Long-term Energy Demand and Supply Prospects published in 2015.

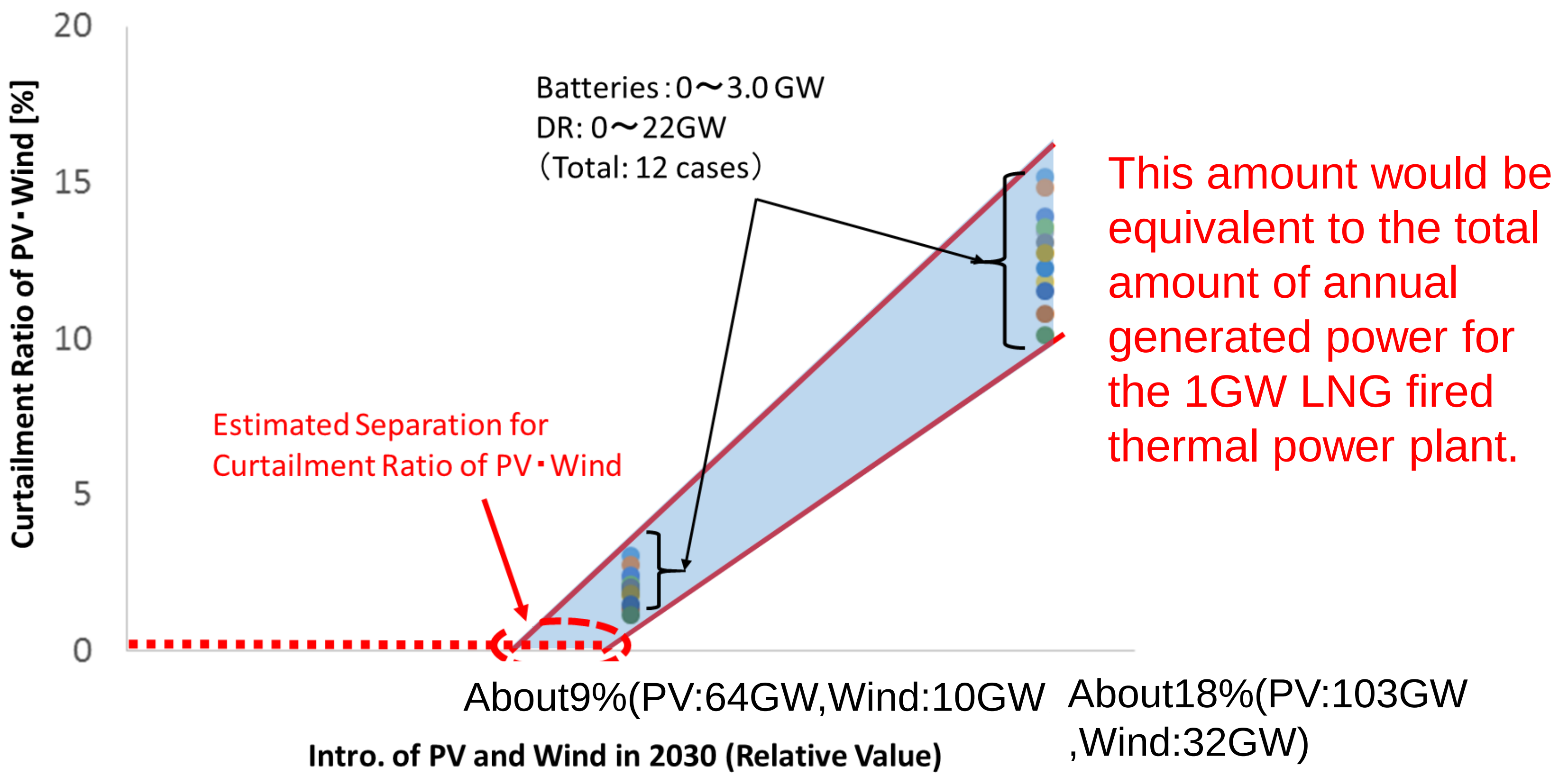
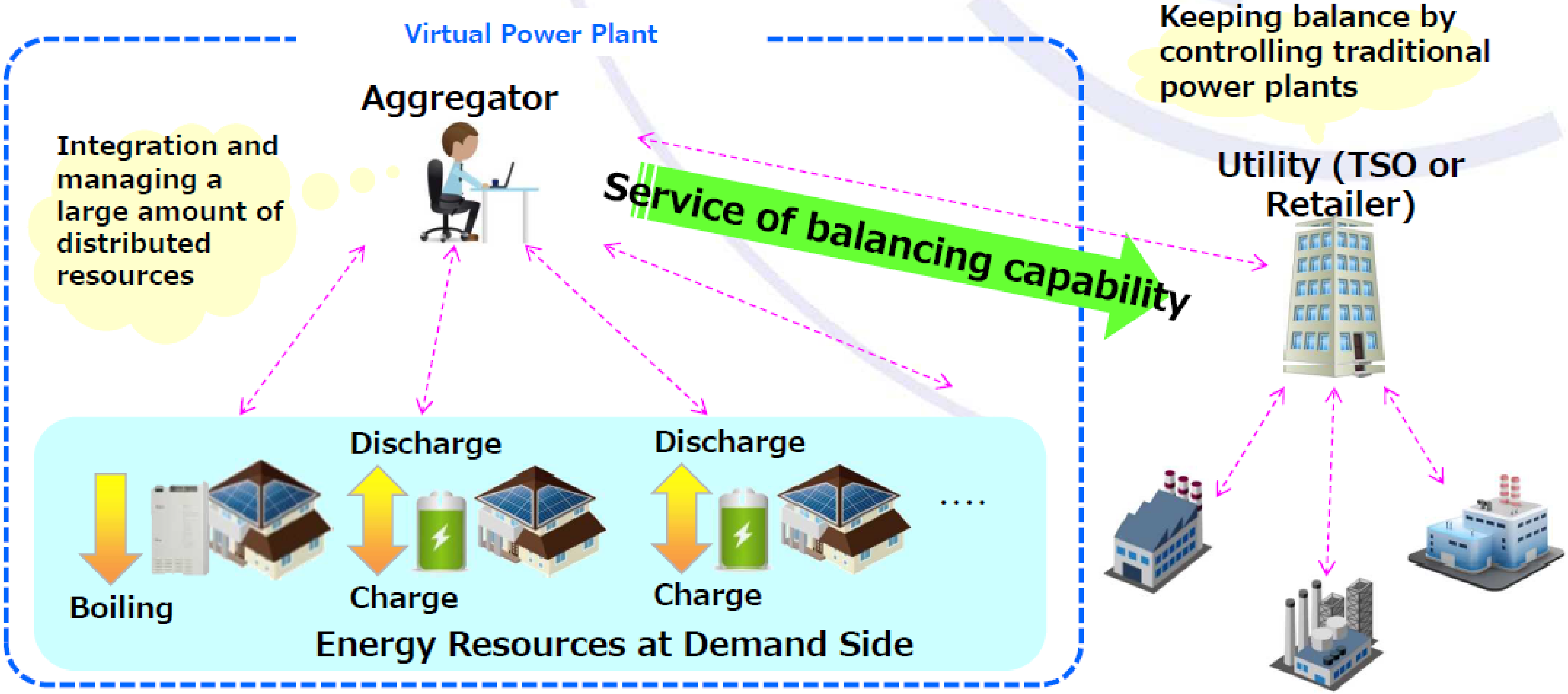


Fig. Estimated curtailment ratio of PV and wind.

VPP(Virtual power Plant) Project started from 2016

METI Project
Virtual Power Plant Demonstration Project

Japan started Virtual Power Plant demonstration. Unfortunately, there are not so many available fossil fuel distributed generator which can send electricity to grid. So, Japanese project is especially focusing aggregating battery storage and sleeping generators.



Virtual Power Plant (VPP) for Air-Conditioning of Factories

One Virtual Power Plant Project has been started at 2016 for air-conditioning and for the thermal management of factories and large scale of buildings by use of Demand Response.
This is 5 years' Japanese National Project under METI and the technology utilizing thermal storage tank of water would be utilized for not only the Nega-Watt Demand Response but also the Posi-Watt Demand Response.

Utilization of Surplus PV power for the thermal management and air-conditioning of factories and large scale of buildings
⇒Operating the Compressor of Heat Pump for generating and storing the Cooled Water
Reducing the Power of Compressor for corresponding the decrease of PV power generation ⇒ Stop the Compressor of Heat Pump and deliver the cooled and heated water for continuing the thermal management and air-conditioning of factories

Demand Response for Industrial and Business Sector

Nega-watt DR for Industrial and Business Sector

- DR for Highly Distributed Energy System
  - For Industrial use, For Business use air conditioner ~ ZEB

Posi-watt DR for Industrial and Business Sector

- In a future electric power system with high penetration PV, the surplus power may occur during the daytime in the middle season of low electricity demand.
- To avoid PV output suppression control, electric storage or Posi-watt DR would be one of the measures for absorbing the surplus power.
- **Manufacturing Companies Utilizing Electric Furnaces** (Metal Refinery ,Industrial Electric Oven) would able to utilize the renewable energy of PV.
  - [Now] Electric Furnace is in operation mainly at night while the electricity price had been low (in Japan).
  - [Future] Electric Furnace will be in operation mainly in the daytime and more in the low demand seasons while the electricity price would be low enough because of surplus power from large amount of RE in low electricity demand season.==> Operational Formation Change would be necessary

Potential of Industrial Sector DR resources in Japan

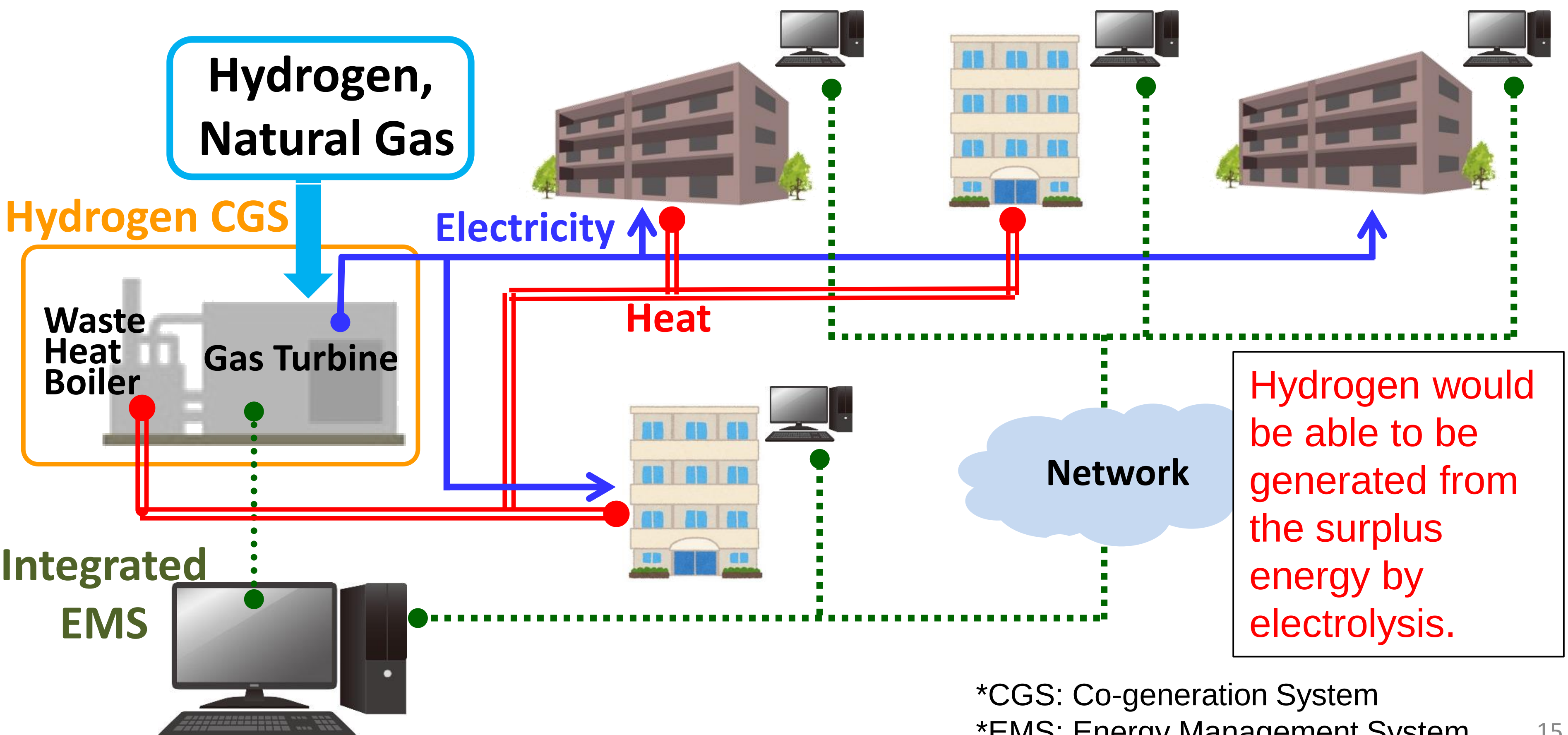
- Not only Nega-watt but also Posi-watt Demand Response would become to be strongly requested due to a large amount of variable renewable energy
- The potential of Posi-watt DR now is as follows;
  - High-Voltage customers (air conditioners etc.): 5.4GW

High-Voltage customers	Water thermal storage type air conditioning (Heat pump) [P/N]	Industrial electric oven [P/N]	Others [P/N]	Total
(A) Number of machines	0.08M	-	-	-
(B) Storing power[GW]	10.7 ((A)×1336kW)	-	-	-
(C) DR resources ： (B)×1/3[GW]	3.7	1.1	0.56	5.4

P: Posi-watt N:Nega-watt

Smart Community with Hydrogen Energy (FS)

- *"<u>Hydrogen CGS</u>", which is composed of hydrogen gas turbine(s) and waste heat boiler(s), could be one of the promising energy system for effective energy utilization at a community. Feasibility study of this system is now ongoing.*



Hydrogen would be able to be generated from the surplus energy by electrolysis.

*CGS: Co-generation System
*EMS: Energy Management System

Energy Conservation

Thermal energy (e. g. industrial exhaust heat) can be utilized to increase the amount of heat generation and converted to chemical energy.

Methanol → Combustion → **H_2O & CO_2**
Combustion heat

↓

Dissociative energy
(C-H bond: ca 100kcal/mol)

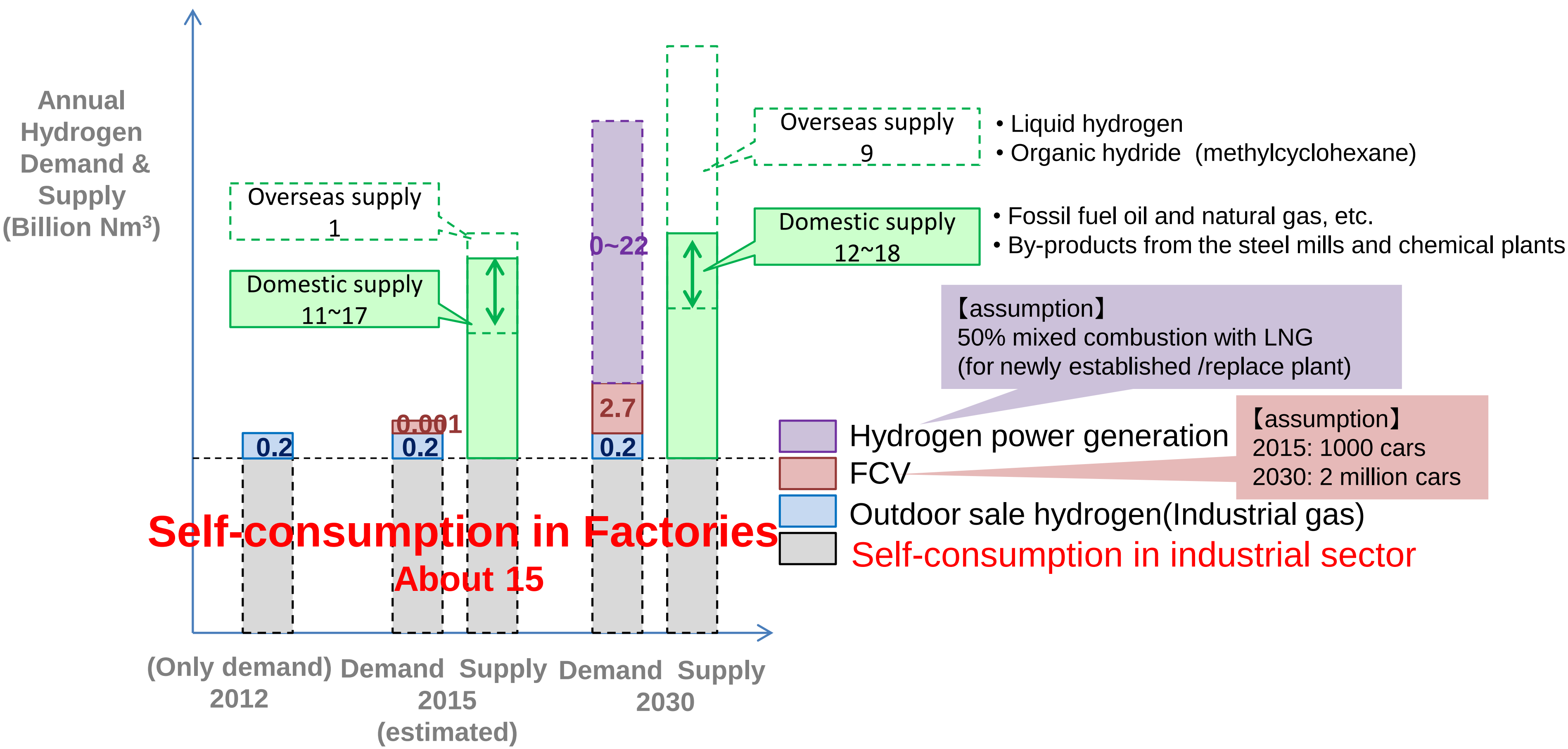
Industrial exhaust heat
(thermal energy)

↓

Methanol → Steam reforming → **Hydrogen** (chemical energy) **& CO_2**

Combustion → **Combustion heat**
…20 % higher than methanol

Hydrogen Demand and Supply



Surplus Supply of Variable Renewable Energy would be able to be converted to Hydrogen by Electrolysis for the large amount of use in Factories(Industrial Sector).

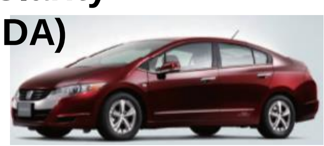
Development of H2 & FC's Technology in Japan

Micro-CHP "ENE-FARM"
(FC: PEFC/SOFC)
On Market: 2009

1st Hydrogen Station
July, 2014

Honda FCEV CONCEPT

FCX Clarity (HONDA)



FCHV-adv (TOYOTA)

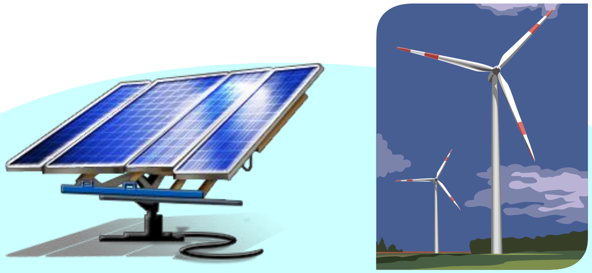
X-TRAIL FCV (NISSAN)

2002
2003
2008
2014 **TOYOTA : 1st commercial model**
2016 HONDA

Fuel Cell Vehicle
Toyota "MIRAI"
Debut: Dec 15, 2014

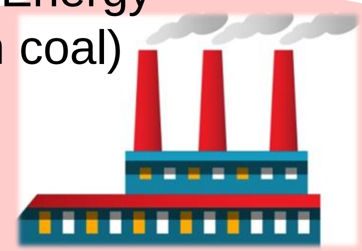
Large Scale Hydrogen Supply-Chain & Utilization

Feasibility Study has been conducted by several Chemical and Engineering Companies in Japan for utilizing the surplus renewable energy of the world.



Renewable Energy

Unutilized Energy
(ex. Brown coal)



+ CCS

- **Electrolysis**

Production

- **Reforming**

Storage & Transportation

Utilization

- **FCV**
- **Power generation**
  - **- Gas Turbines**
  - **- Stationary FCs**

- **Hydrogen Carriers**
  - **- Liquid H_2**
  - **- Methylcyclohexane**
  - **- NH_3 etc.**

Replacement of Fossil-fuel Fired Boiler for Industries

For reducing the global CO_2 emission largely in 2050, the fossil fuel fired boiler should be replaced by the clean energy or renewable energy.

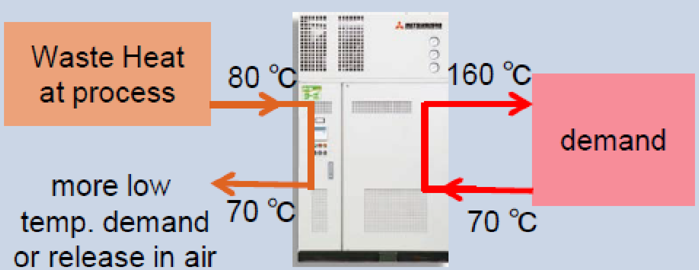
Some challenges has been conducted so far and some candidates for the replacement would be imagined.

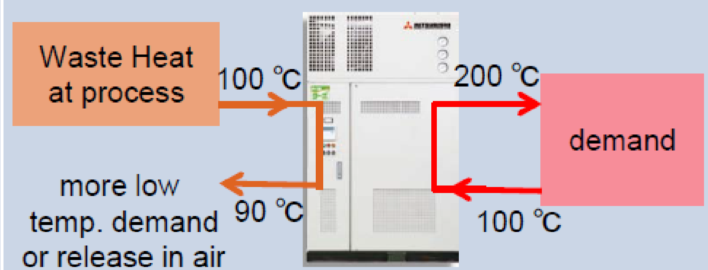
1. The thermal output of 200℃ High Performance Compression Type Heat Pump System has been challenged so far.(NEDO Project)
2. The Boilers Utilizing Wooden Biomass and methane fermentation have been promoted to develop for the regional community systems including industries.
3. The SOFC combined heat and power (CHP) would have the potential for providing the heat for boiler to generate the steam.
4. The concentrated solar heater would have the potential for producing the steam for industries.

2.3 ETW-SH (tentative): Specification

- High temperature heat pump and adaptable refrigerants have developed by the Ministry of Economy, Trade and Industry and NEDO since 2013
- Applications: Destination, Sterilization, Drying, Distillation, etc.

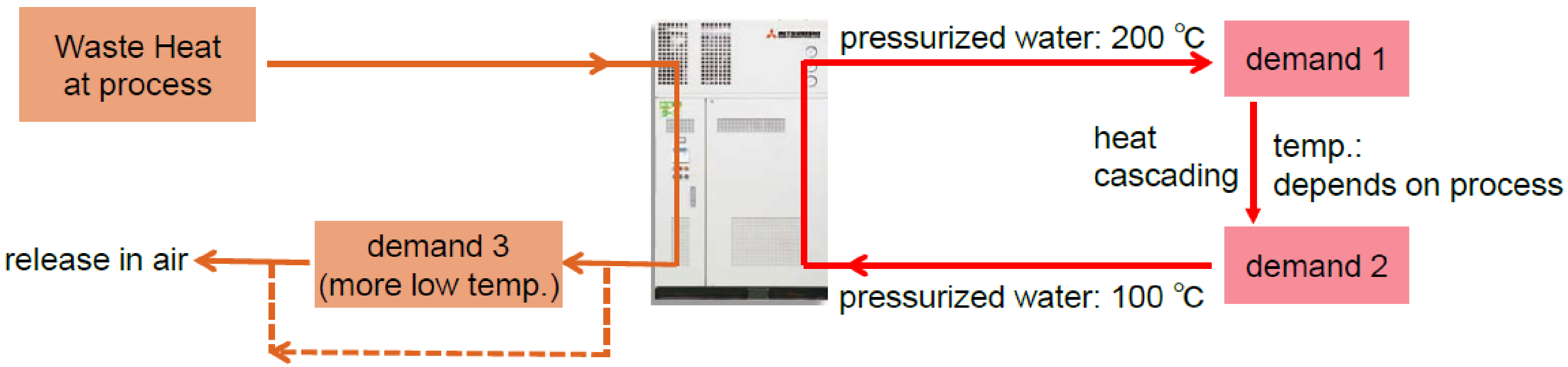
	Maximum 160	Maximum 200
Heating Capacity	600 kW	600 kW
COP (Hot Water)	3.5	3.5
Heating medium	Pressurized water (system design pressure: approx. 2.0 MPaG	
Pressurized Water	Entering 70 ℃ / Leaving 160 ℃	Entering 100 ℃ / Leaving 200 ℃
Heat Source Water	Entering 80 ℃ / Leaving 70 ℃	Entering 100 ℃ / Leaving 90 ℃
Refrigerant	Low GWP refrigerant (under development)	Low GWP refrigerant (under development)





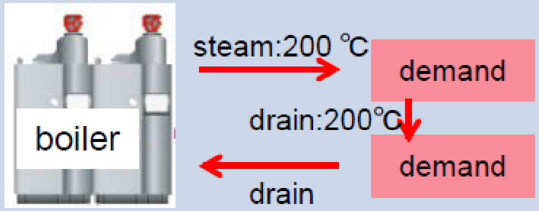
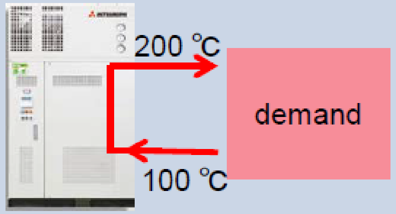
2.3 ETW-SH (tentative): Specification

- The larger the temperature difference between the output and the water supply, the more efficiency of the heat pump cycle
- The heat in the heat supply side cascade use, it is effective to return to the heat pump in a more state where the temperature is lower
- For waste heat temperature 90 ℃, it is better to waste recovering heat in a different process



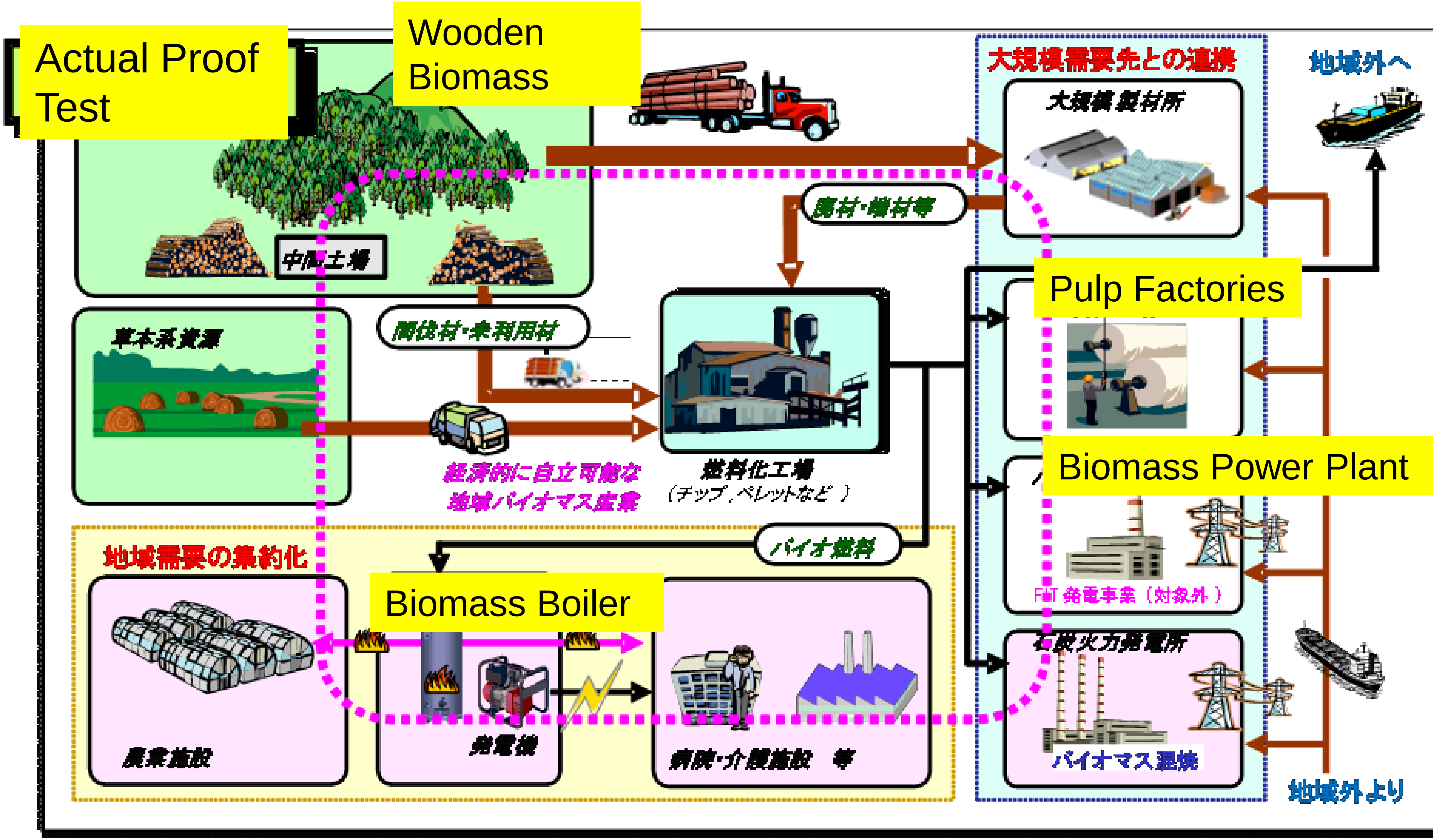
2.3 ETW-SH (tentative): Specification

- Primary energy consumption of the heat pump is about 1.5 times higher than that of the boiler

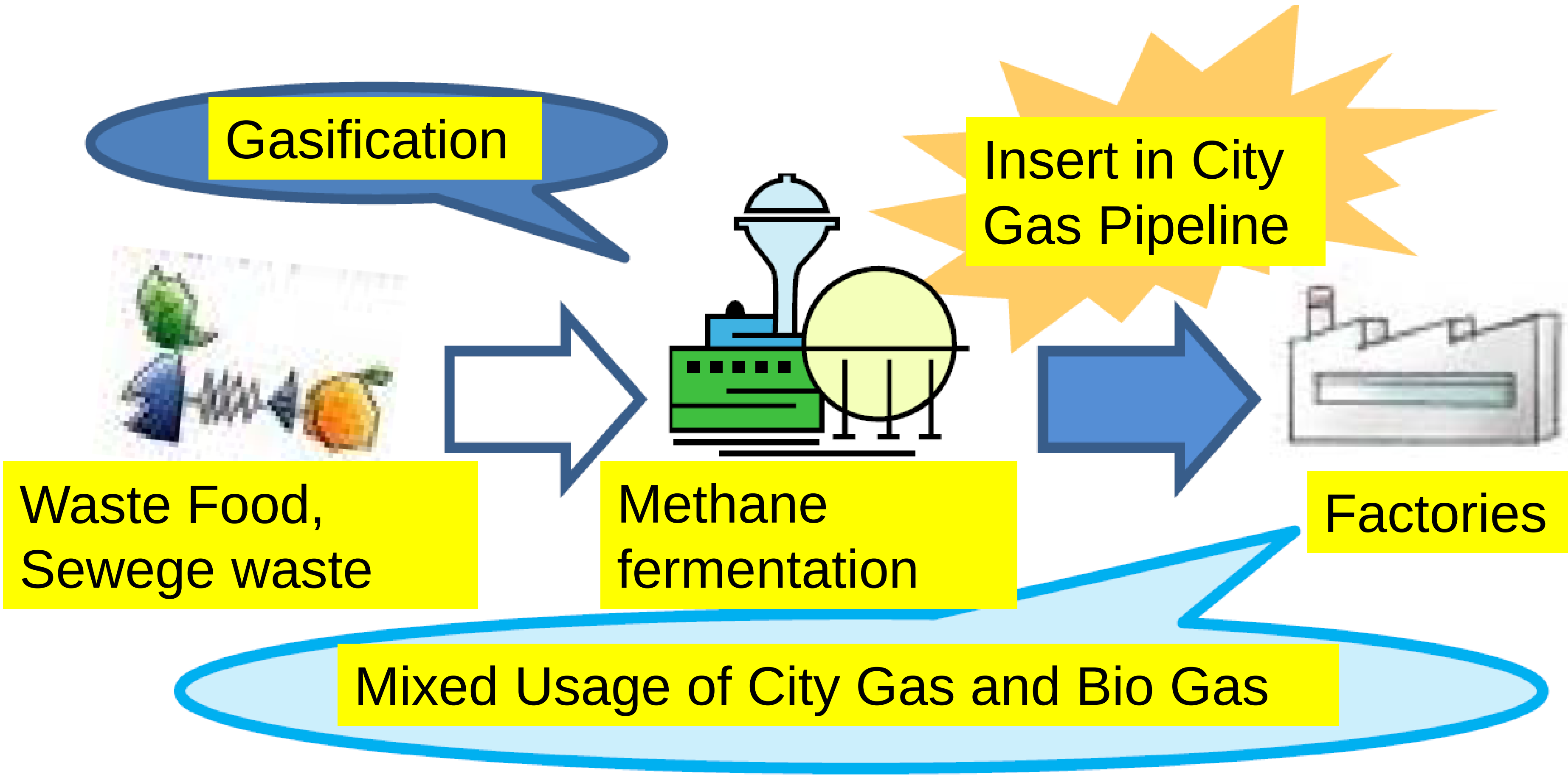
	Boiler	Heat Pump
Energy source	Natural gas	Electricity
Heat supply amount	Q [MJ/h]	Q [kW]
Efficiency	η_B=0.97 [-]	3.5 (COP)
Lower heating Value	LHV=40.6 [MJ/Nm^3]	-
secondary energy consumption	PG=Q/(η_B*LHV) [Nm^3/h]	PE=Q/COP [kW]
Primary energy conversion factor	CG1=45 [*1] [MJ/Nm^3]	CE1=9.76 [*2] [MJ/kWh]
Primary energy consumption	EG=PG*CG1 [MJ/h]	EE=PE*CE1 [MJ/h]
Primary energy efficiency	η_G=Q/EG= 0.875 [-]	η_E=(Q*3600/10^3)/EE= 1.29 [-]
CO2 emission factor	CG2=2.29 [*1] [kg-CO_2/Nm^3]	CE2=0.551 [*3] [kg-CO_2/kWh]
CO2 emission (with respect to the value of the boiler)	GG=PG*CG2 = 5.81*10^{-2} *Q [kg-CO_2] 1 [kg-CO_2]	GE=PE*CE2 = 4.37*10^{-2} *Q [kg-CO_2] 0.75 [kg-CO_2]
		

*1:TOKYO GAS Co., Ltd, *2:Act on the Rational Use of Energy (Japan), *3:Ministry of the Environment (Japan)

Regional Application of Biomass Energy



Regional Application of Biomass Energy



Summary and Conclusion

1. The energy conservation for the industrial sector has been challenged and promoted over 40 years in Japan to develop the high performance energy conservation equipment.

2. For many countries and the future figures of the world which have the **Variable Renewable Energy Highly Penetrated Energy System**, the surplus of energy supply based on the variable renewable energy would be occurred and then the various challenges utilizing the surplus energy for the use of industrial sector would be generated and promoted.

3. For reducing the global CO2 emission largely in 2050, the fossil fuel fired boiler should be replaced and various challenges including the development of 200℃ High Performance Compression Type Heat Pump and Boilers Utilizing Biomass for the regional community systems has been conducted.