CCUS and Hydrogen in Rich Renewable Energy Systems
脱炭素社会の**CCUS**と水素




International Symposium on
CCUS and Hydrogen

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Haruki Tsuchiya
槌屋治紀
Research Institute for
Systems Technology
システム技術研究所

Massive Renewable Energy Supply

Target

- Safety
- Security
- Energy Independence
- Zero CO_2 emission
- Sustainable
- Less nuclear proliferation

Problems

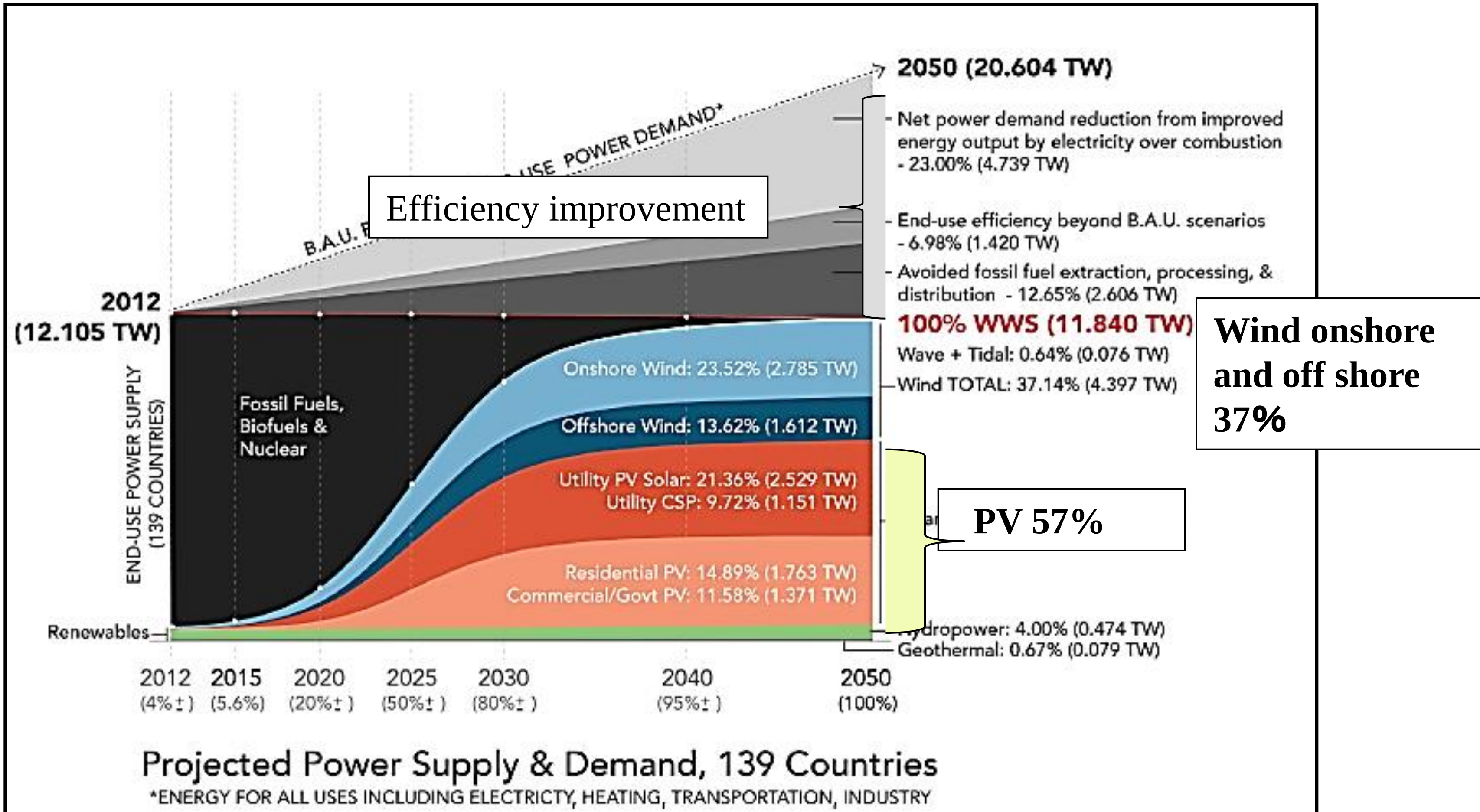
- Is it stable supply?

  (Solar and wind are variable)
- Are domestic resources enough?
- Large energy storage?
- Large cost?

Global Renewable Energy Scenarios for 2050

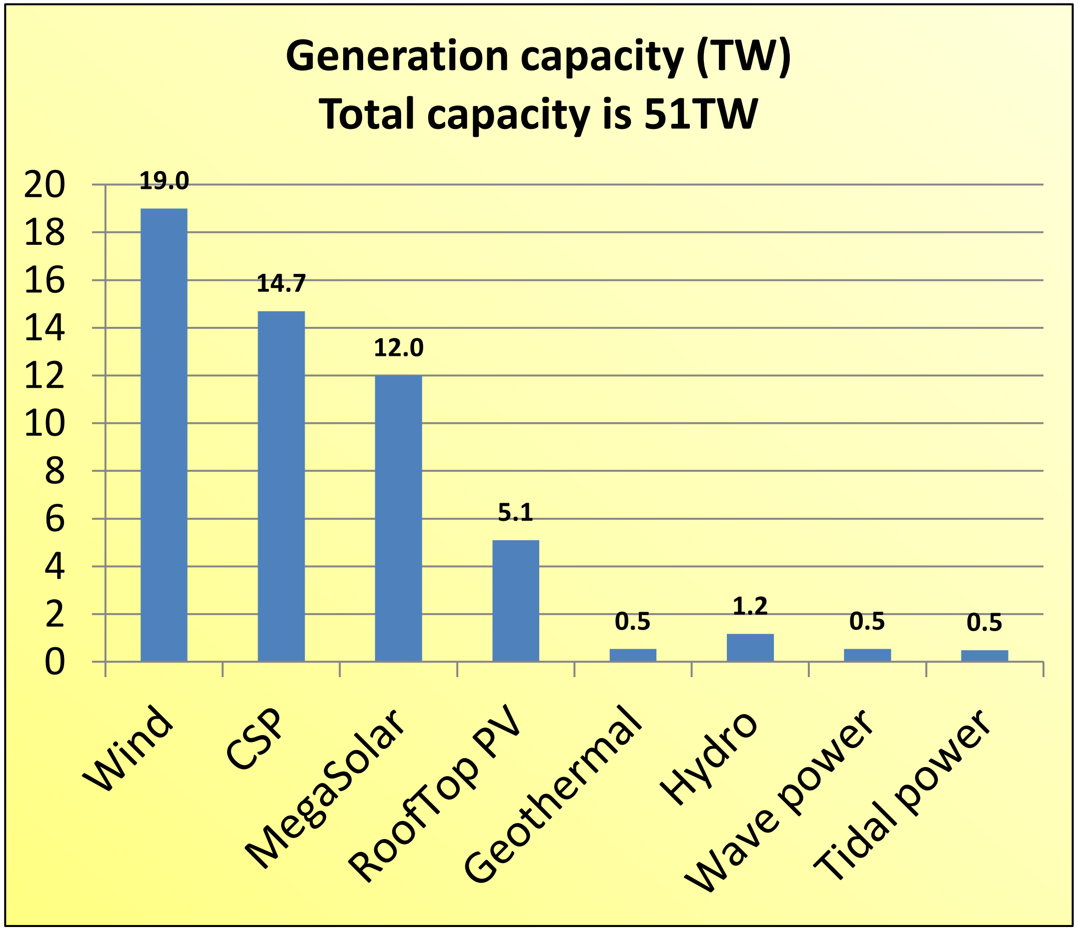
1) **Study by Stanford University**
2) **Study by Lappeenranta University of Technology (Finland)**

WWS scenario（Water, Wind and Solar) 2011
World will be 100%Renewable （Jacobson, Stanford University)



Energy demand in 139 countries: 12,105TW（2012）→11,840TW（2050）
Supply share: PV 57%、Wind 37% and Hydro 4%.

Global energy scenario with 100% renewables by Jacobson (Stanford University)



WWS systems（Water, Wind, Solar）2011

Global energy demand will be supplied by 51 TW electricity plant.
It requires only 1.16% of global land area.
Necessary material: cement and steel are enough.
Rare metals for EV and wind machines: enough
Platinum for FCV: recycled.
70 million cars produced every year. 50 kW for a car, it is the production scale of 3.5TW electricity plant every year.

Lappeenranta University of Technology: Global Energy Systems Capacity (left) and Generation(right) in Northeast Asia in 2050

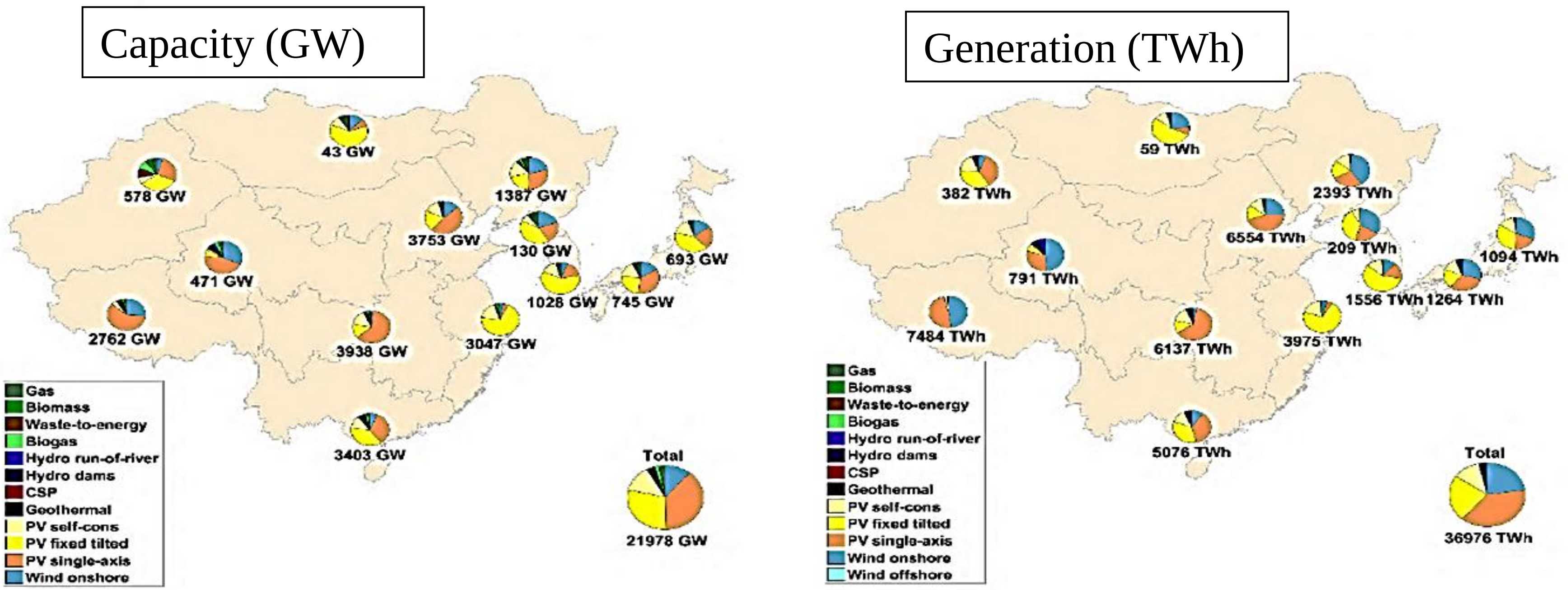


Figure 3.7-25: Northeast Asia – Regional electricity generation capacities (left) and electricity generation (right) in 2050.

	Capacity GW	**Generation TWh**
East Japan	693	1094
West Japan	745	1264
Total	1438	2358

World is in 9 areas with 146 sub areas. They are supplied by fully renewable energy in 2050. Japan is shown as one of the northeast Asia country. Published in 2019.

Long-term Scenarios for Decarbonizing Japan by WWF Japan

Long-term Scenarios 2050 for WWF Japan

Activity Level Decrease
Energy Efficiency Improvement

→ Decrease Energy demand

Two scenarios,
1) 'Bridge Scenario'
(GHG 80% decrease)
2) '100% Renewable'

→ Decrease CO_2 Emission in 2050

We studied two scenarios, 'Bridge scenario' and '100% Renewable Energy Scenario'. If we can decrease energy demand, the problems for renewable energy supply become smaller, and we can decrease CO_2 emission smoothly.

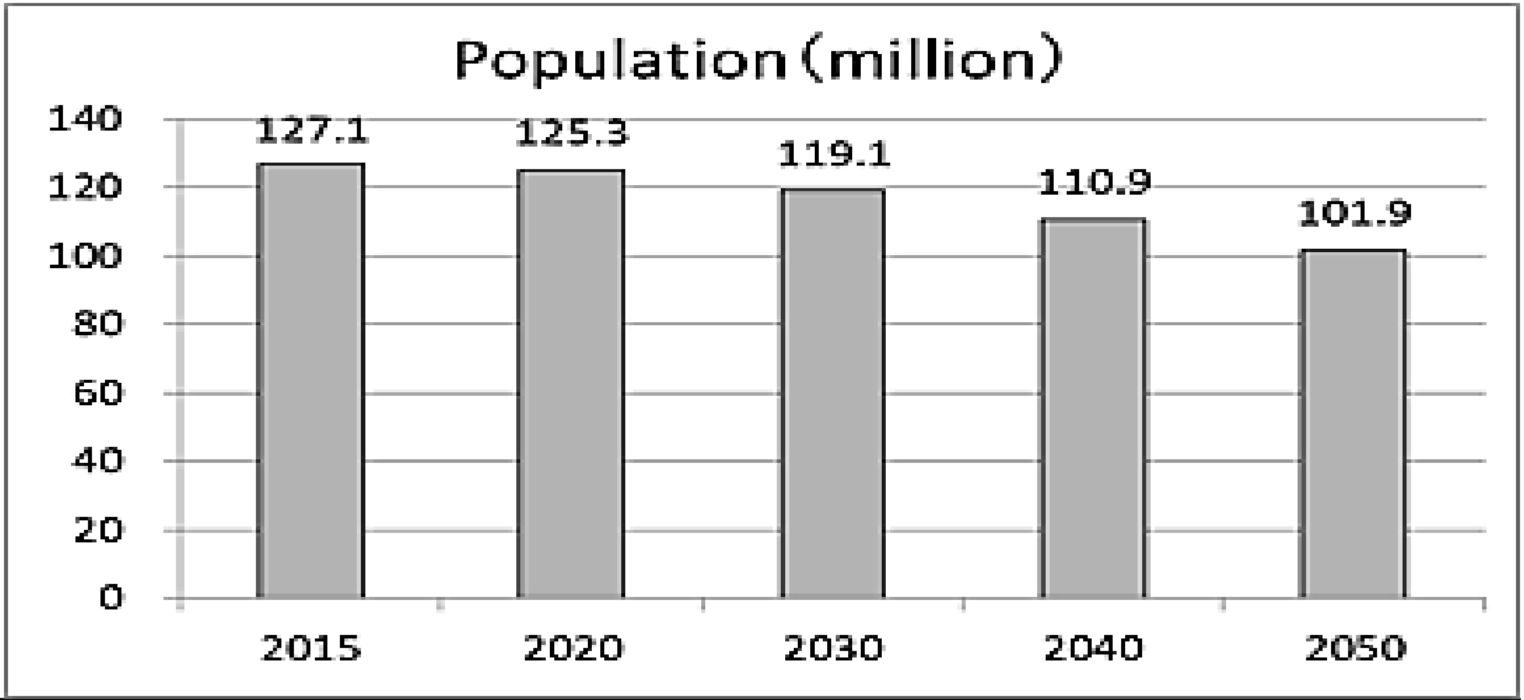
Estimate of future energy demand

Future energy demand	=	Energy demand in base year	×	Activity level Population, GDP, macro economics index etc.	×	Efficiency improvement EV, FCV, LED light, Heat pump

Future energy demand is estimated by demand in base year, future activity level and efficiency improvement.

Activity level: population decrease is very large.
Efficiency improvement: new technology widespread

Population will decrease toward 2050



The population will decrease by 20% from 127 million in 2015 to 102 million in 2050.

The 2017 Report of National Institute of Population and Social Security Research.

Renewable supply scenario

Supply

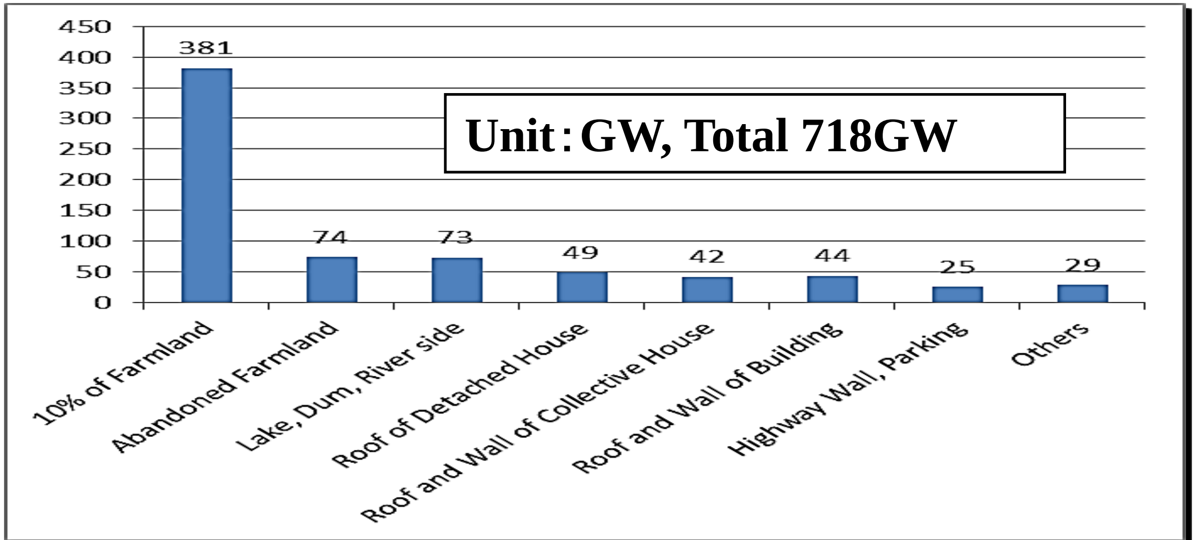
- Electricity
  Hydro, Solar PV, Wind, Geothermal, Biomass
- Excess electricity
  Solar PV and Wind
- Solar heat, Biomass, PV on Car-Top

Demand

Electricity demand: Lighting, Motor, Pump, Air conditioner, Electronics, Computer

Thermal demand: EV, FCV hydrogen, Air Craft, Industrial Heat, Heat pump

Potential and install prospects of Photovoltaics



PV potential (NEDO White paper of renewable energy 2014）

Capacity (GW)	2015	2020	2030	2050	2115
Photovoltaic Systems	34	70	100	250	700

PV Outlook 2030, JPEA (Japan Photovoltaic Energy Assc. 2015

Prospects (GW)	2020 High	2030 High	2050 High
Detached House	17	31	170
Collective Huose, Office Building	22	44	103
Mega Solar Systems	25	34	
Total	63	109	273

Survey of Renewable distributed energy systems in 2050, Ministry of Environment 2014

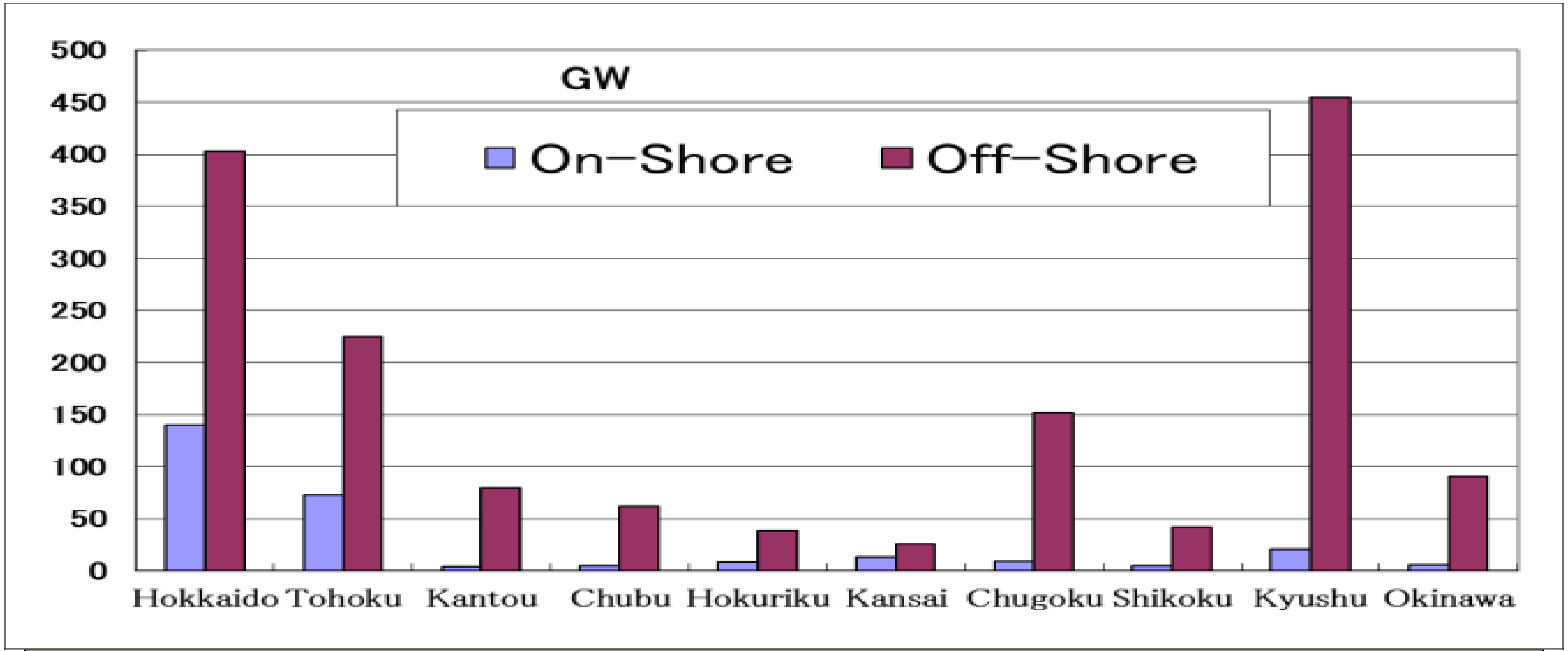
Potential & prospects of photovoltaics .

NEDO : 718GW of PV potential including roof and wall of buildings, river side, abandoned farm land.

JPEA Prospect: 250GW in 2050, 700GW in 2115.

Ministry of Environ. Prospect: 272.5GW in 2050.

Wind Energy Potentials (GW)



The potential wind power resources study by Ministry of Environment. The total wind potential: 1856GW. 283GW on-shore,1573GW off-shore. The off-shore potential is six times larger than that of on-shore wind. Japan has long coast lines. The largest on-shore potential is 140GW in Hokkaido. The largest off-shore potential is 454GW in Kyushu.

Renewable Energy in Japan

Energy Source	2015	Max Potential	Prospect for 2050	Bridge Scenario	100% RE Scenario
Hydro power	21 GW	46 GW	46 GW	46 GW	46 GW
Photovoltaic	33 GW	718 GW	279 GW	241 GW	445 GW
Wind Power	3 GW	1698 GW	75 GW	78 GW	104 GW
Geothermal	0.54 GW	31GW	8 GW	10 GW	10 GW
Wave power	0	18 GW	14GW	10 GW	10 GW
Biomass	66PJ	-	973PJ(*)	1640PJ	2200PJ

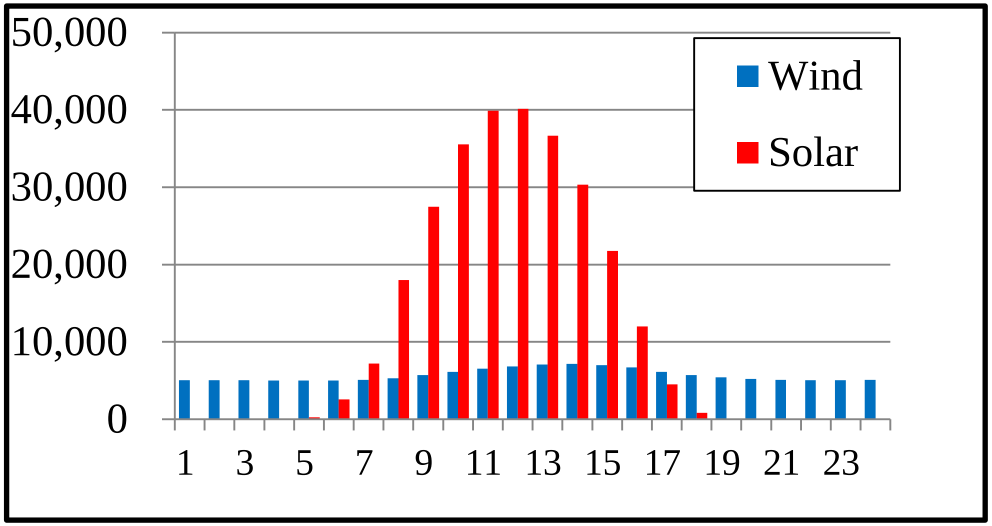
Maximum potentials: Survey 2014 on Distributed Renewable Energy for 2050 (Ministry of Environment)
PV potential (Photovoltaic Roadmap: PV2030+, NEDO, 2014)
*) shows prospect for 2030. Biomass peaked 270PJ in 1940.

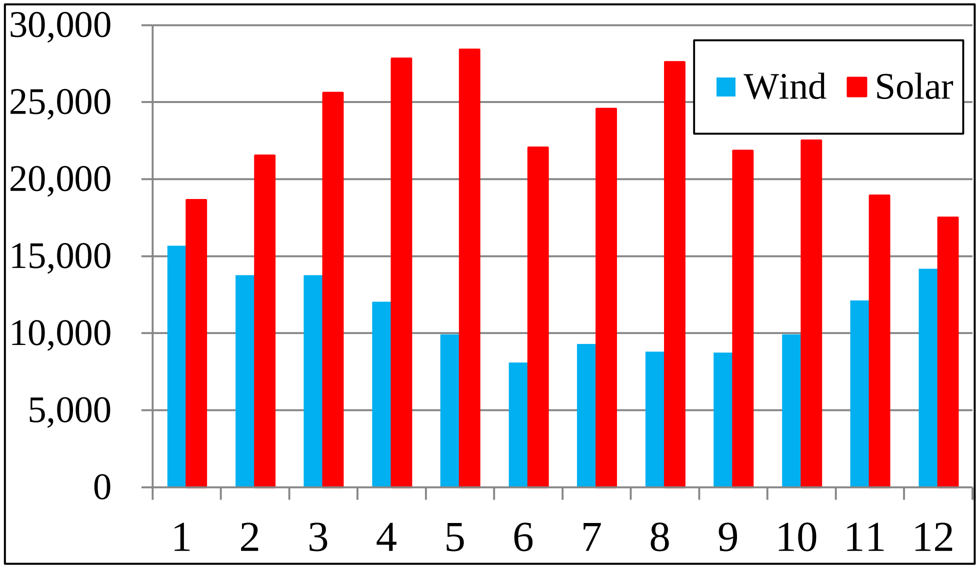
Photovoltaics and Wind in WWF study

Renewable Energy	Number of Sites Capacity factor(CF)	Installation
Photovoltaics	842 sites CF=12.6%	Unit 10kW, South oriented, Tilt angle =latitude－5 degree
Wind Turbine	99 sites with CF>18% among 842 sites, Average CF=27.6%	2MW, Diameter =80m, Hub hight=56m, Cut-in speed=3m/s, Cut-out speed=25m/s

Weather data of Expanded AMEDAS 2000 has solar radiation and wind speed of 842 sites in Japan.

Hourly and monthly generations of PV and wind (GWh)

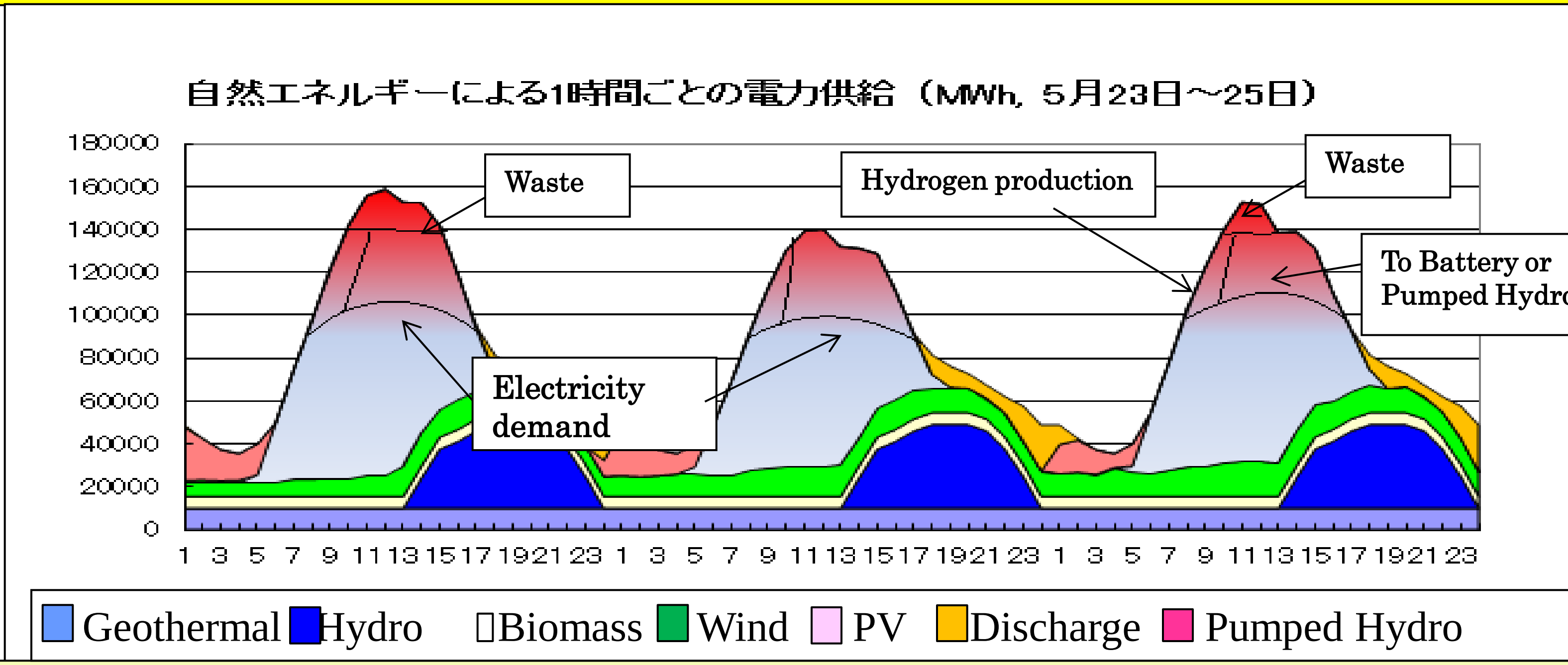




Hourly and monthly electricity generations of PV and wind.

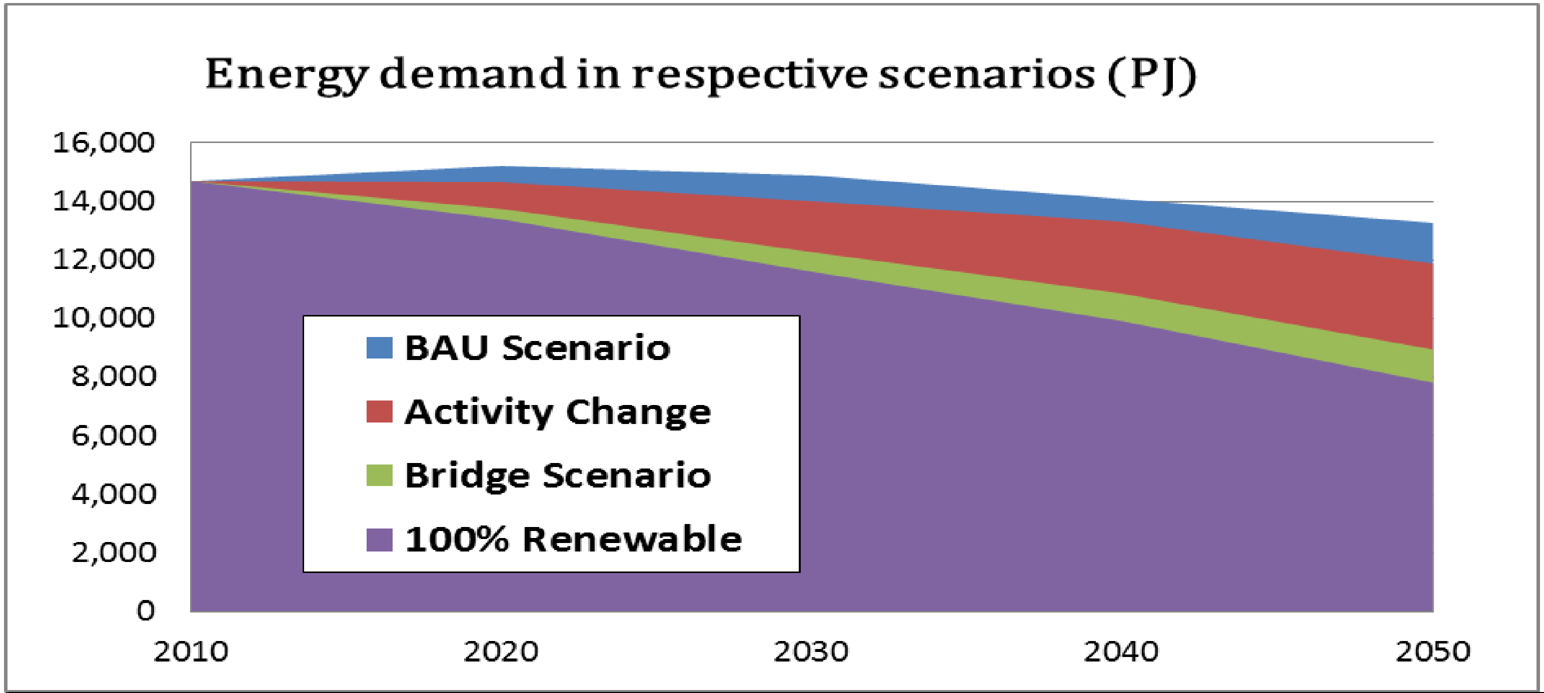
PV: Bell shape during daytime. Wind: Almost flat for 24 hours,
Wind: low in summer and high in winter, PV is reverse.
Solar and wind are mutually complementary throughout a year

Dynamic Simulation of Electricity Supply in 2050
(Based on 842 sites of AMEDAS weather data 2000)



Dynamic simulation of hourly renewable electricity for three days. Variable nature of photovoltaics and wind power is compensated by pumped hydro and battery systems. Hydro power is used in the evening. Geothermal power keeps constant supply. The excess electricity is used for EV, hydrogen production for FCV and heat pump for low temperature demand.

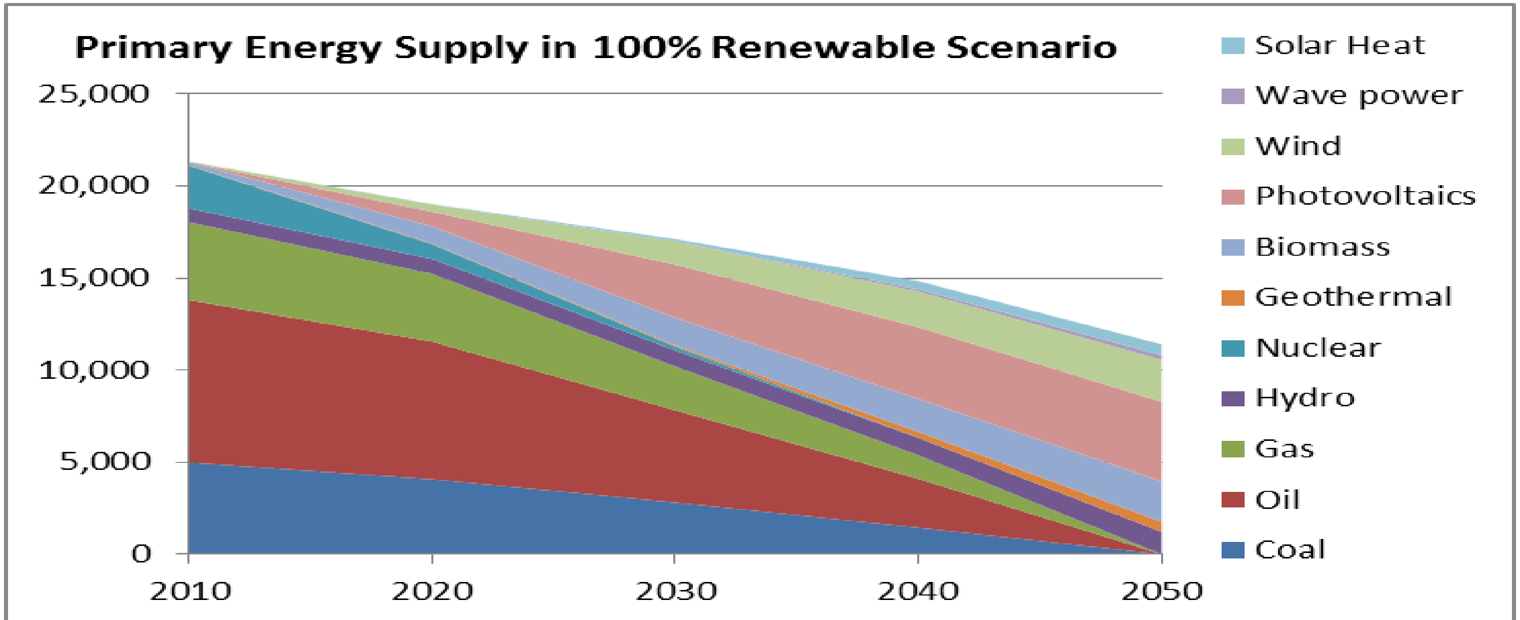
End use energy demand in scenarios



Unit:PJ	2010	2020	2030	2040	2050	2050/2010
BAU Scenario	14,698	15,215	14,892	14,084	13,272	90.3
Activity Change	14,698	14,660	14,008	13,312	11,884	80.9
Bridge Scenario	14,698	13,749	12,272	10,856	8,950	60.9
100% Renewable	14,698	13,396	11,604	9,917	7,821	53.2

End use energy demand in 2050 is 61% (Bridge Scenario) and 53% (100% Renewable energy Scenario) compared to 2010 level.

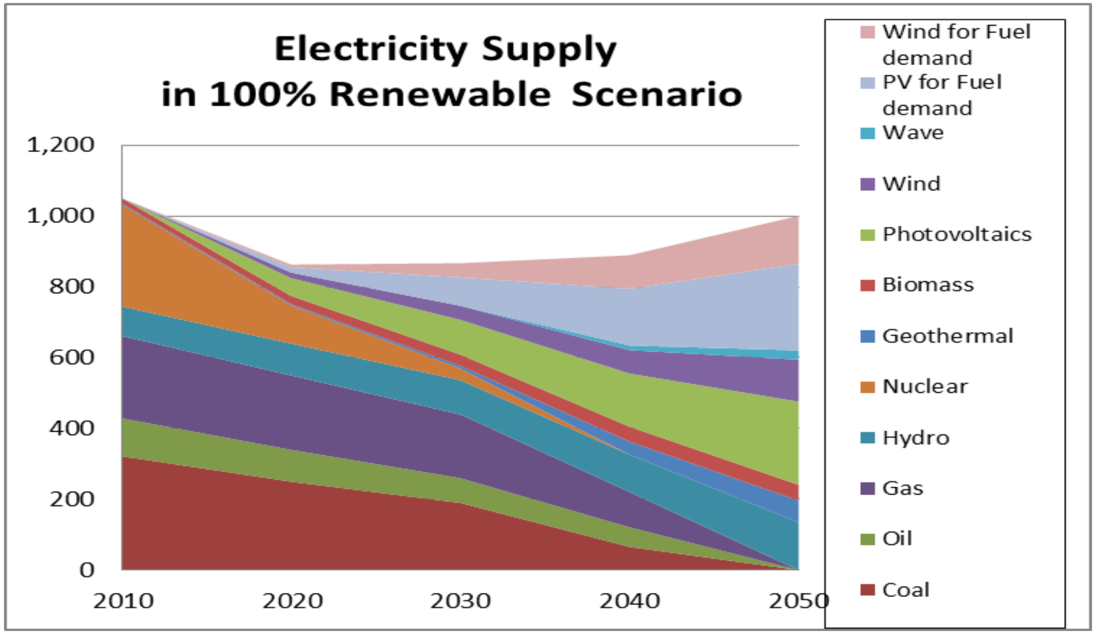
Primary energy supply structure in '100% Renewable Scenario'



	100% Renewable Scenario				
PJ	2010	2020	2030	2040	2050
Coal	4,981	4,076	2,814	1,443	0
Oil	8,819	7,474	5,009	2,657	0
Gas	4,243	3,682	2,380	1,278	0
Hydro	747	810	873	949	1,215
Nuclear	2,322	801	207	0	0
Geothermal	28	33	66	331	552
Biomass	153	938	1,500	1,778	2,200
Photovoltaics	20	794	2,890	3,900	4,316
Wind	29	397	1,260	1,946	2,286
Wave power	0	0	2	118	237
Solar Heat	0	20	120	444	600
Total	22,157	19,025	17,122	14,844	11,406

Fossil fuel supply in 2050 will be zero in '100% renewable scenario'.

Electricity supply in '100% Renewable Scenario'



Power Source (TWh)	2010	2020	2030	2040	2050
Coal	322	250	190	66	0
Oil	107	90	70	55	0
Gas	233	210	180	100	0
Hydro	83	90	97	105	135
Nuclear	288	108	33	0	0
Geothermal	3	4	7	37	61
Biomass	15	23	32	42	45
Photovoltaics	0.0	50	98	150	235
Wind	0	16	40	66	118
Wave	0	0	0	13	26
Total to Pure electricity	1,051	840	747	635	621
PV for Fuel demand	0	15	80	160	245
Wind for Fuel demand	0	8	40	95	136
Electricity Total	1,051	863	867	889	1,001

The electricity supply will decrease at first. but gradually increase to almost 1000TWh in 2050. It is because of the rise of demand for excess electricity. It is mainly from solar and wind.
It will be used for FCV, hydrogen and low temperature heat demand by heat pump.

Electricity supply in ‘100% renewable scenario in 2050’

	Capacity	Generation	Share
Supply Source	GW	GWh/year	%
Photovoltaic system	444.7	486,696	78.51
Wind power	104	242,027	39.04
Hydro power	46	135,241	21.81
Geothermal	10	60,997	9.84
Wave Power	10	25,999	4.19
Gas power	0	0	0
Biomass power	10	49,056	7.91
Total		1,000,016	161.30

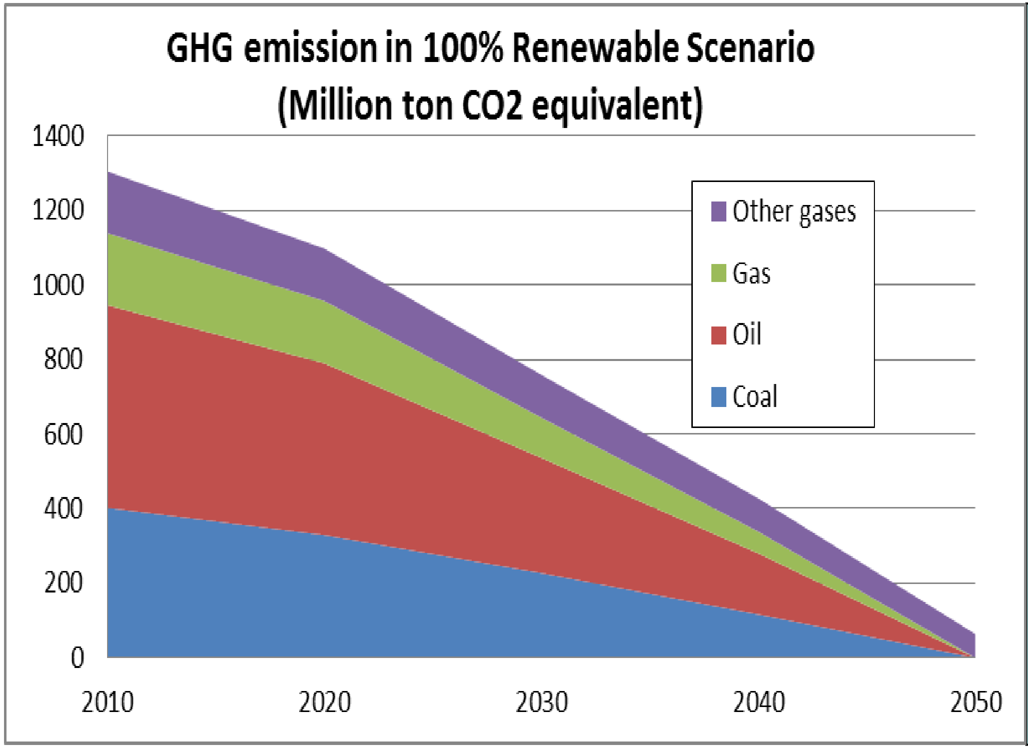
	GW	Unit area (W/m2)	Area (km2)	Share in national land (%)
PV	445	100W/m2	4450	1.18
Wind	104	20MW/100ha (*)	5200	1.38

(*) Eurus Energy in Hokkaido

Solar PV is 445GW , Wind power is 104GW in 2050. The electricity demand is 620 TWh. Excess Electricity is 59% of electricity demand.

Shares in national land: 1.18% for PV and 1.38% for wind.
Present shares:forest 66%, agriculture 13%, residential 5%, road 3%.

GHG emission in '100% renewable energy scenario'

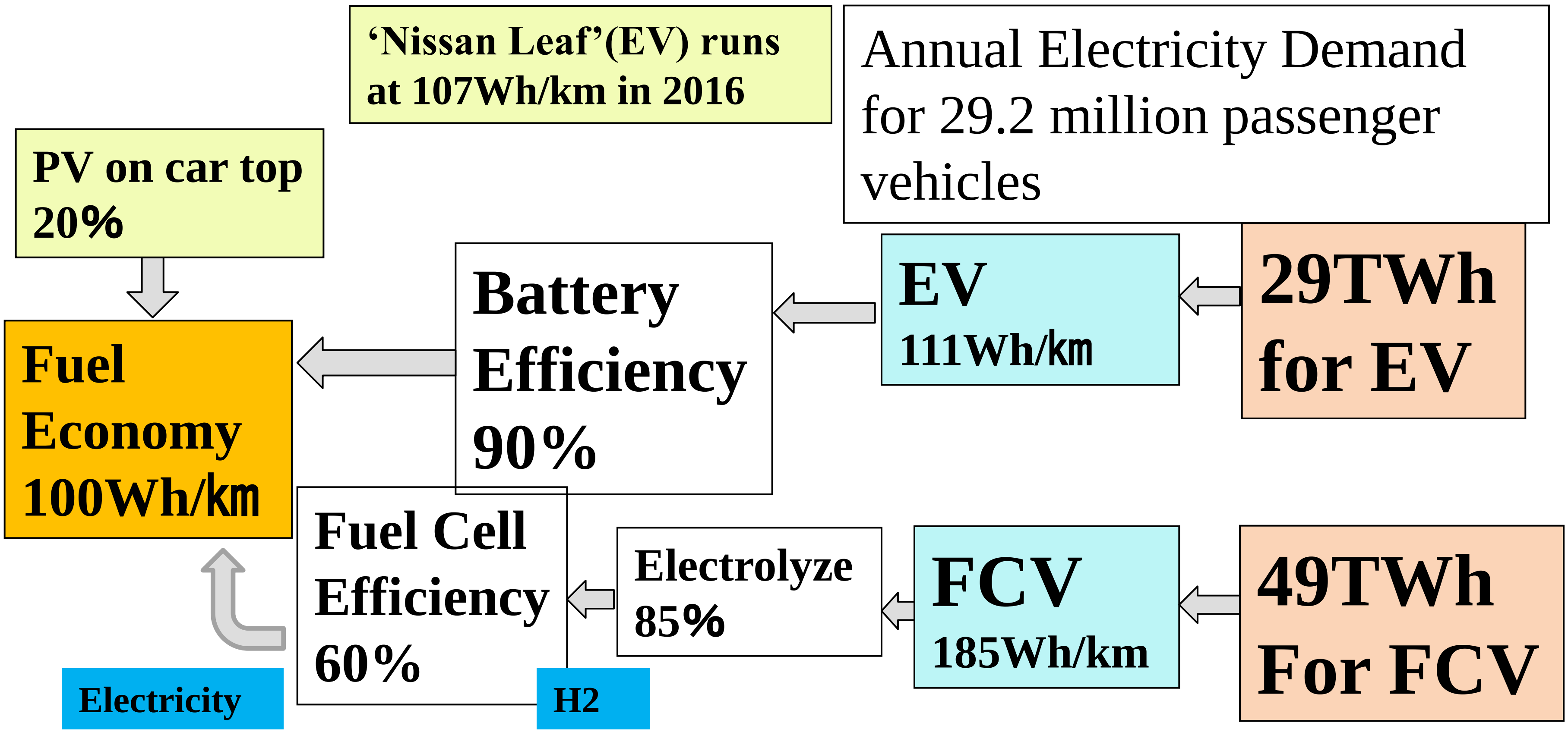


CO_2 emission in 2050 will be zero, but CO_2 equivalent emission from 'the other gas' will remain, as 64 million ton in 2050., which is 5% of 1990 CO_2 emission level

GHG (Million ton CO2)	2010	2020	2030	2040	2050
100% Renewable	1304	1098	759	428	64
Coal	402	329	227	117	0
Oil	544	461	309	164	0
Gas	193	167	108	58	0
Other gases	166	140	115	89	64

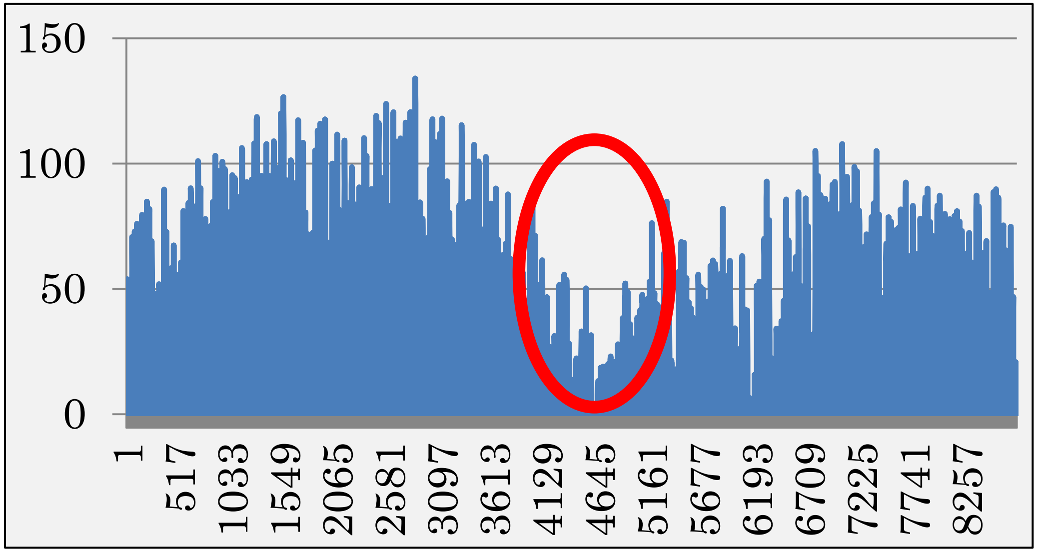
Hydrogen from Excess Electricity

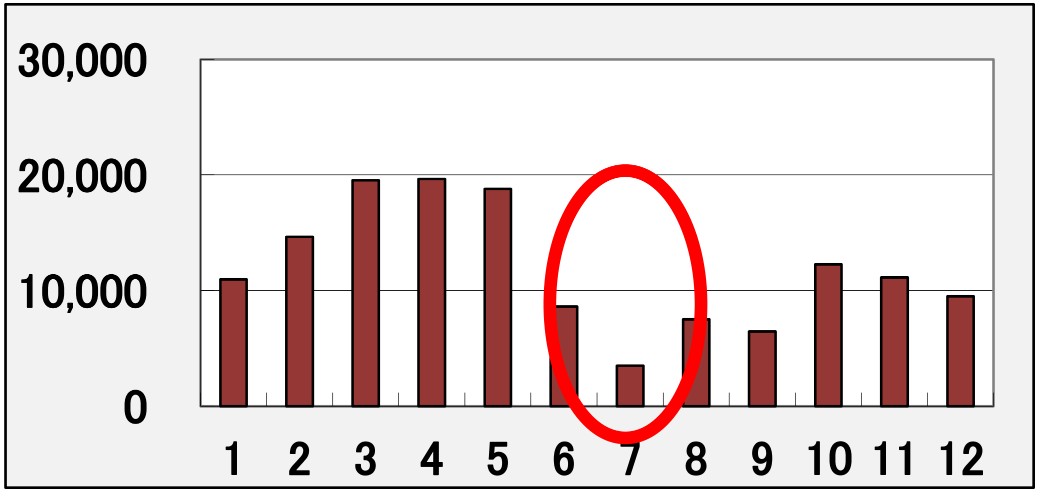
Electricity for EV and Hydrogen for FCV



We assumed 29.2 million passenger vehicles of EV and FCV respectively in 2050. Electricity demand is 29TWh for EV and 45TWh for FCV.

Hourly and monthly Excess Electricity for 8760 hours (GWh)

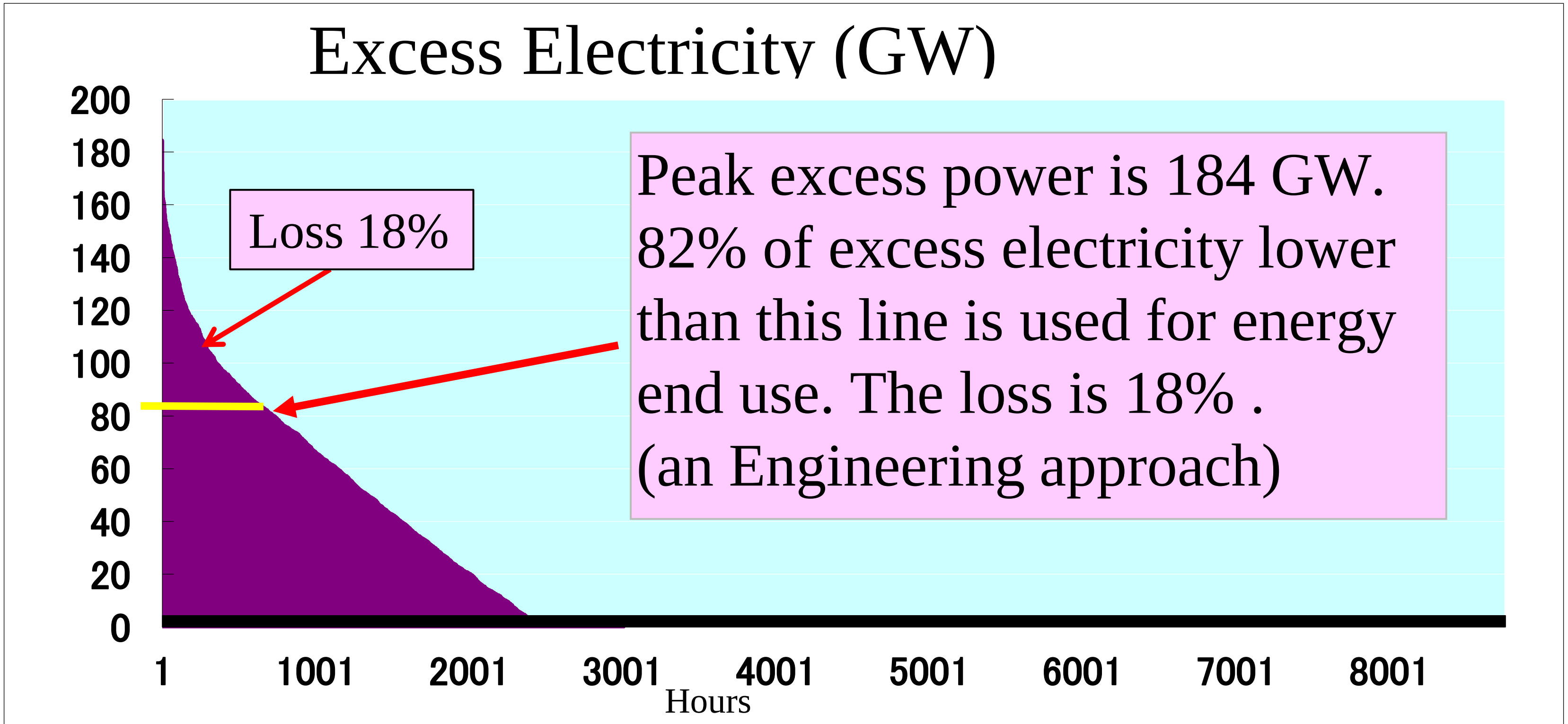




Small excess electricity happens in rainy season June and July.

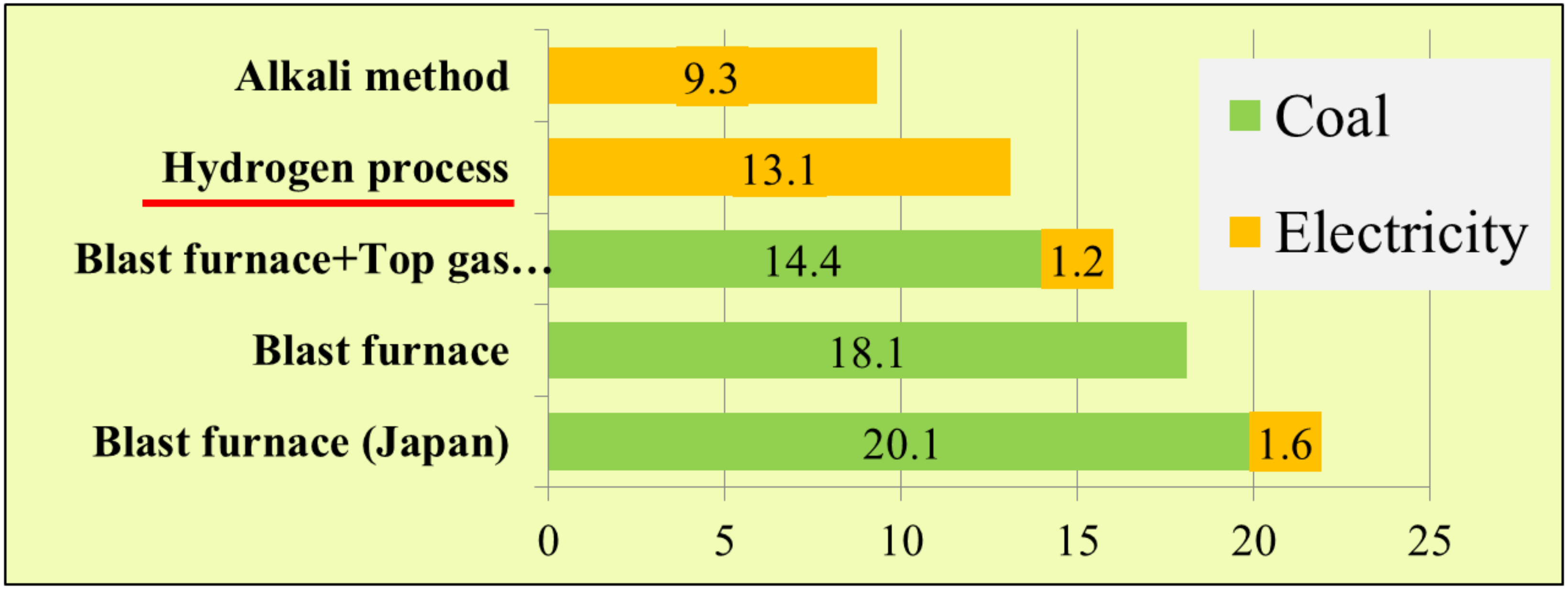
Simple solution to this problem is large energy storage.
But we have demand side approach: demand response and production scheduling against weather condition.

Time duration curve of excess electricity



If we use all of the excess electricity generated by wind and solar, it is not economical because the peak of excess power is very large. The time duration curve of excess electricity shows that we can effectively use 82% of excess electricity by plants having only 43% capacity of peak excess power.

Energy for steel production by hydrogen (GJ/crude steel ton)

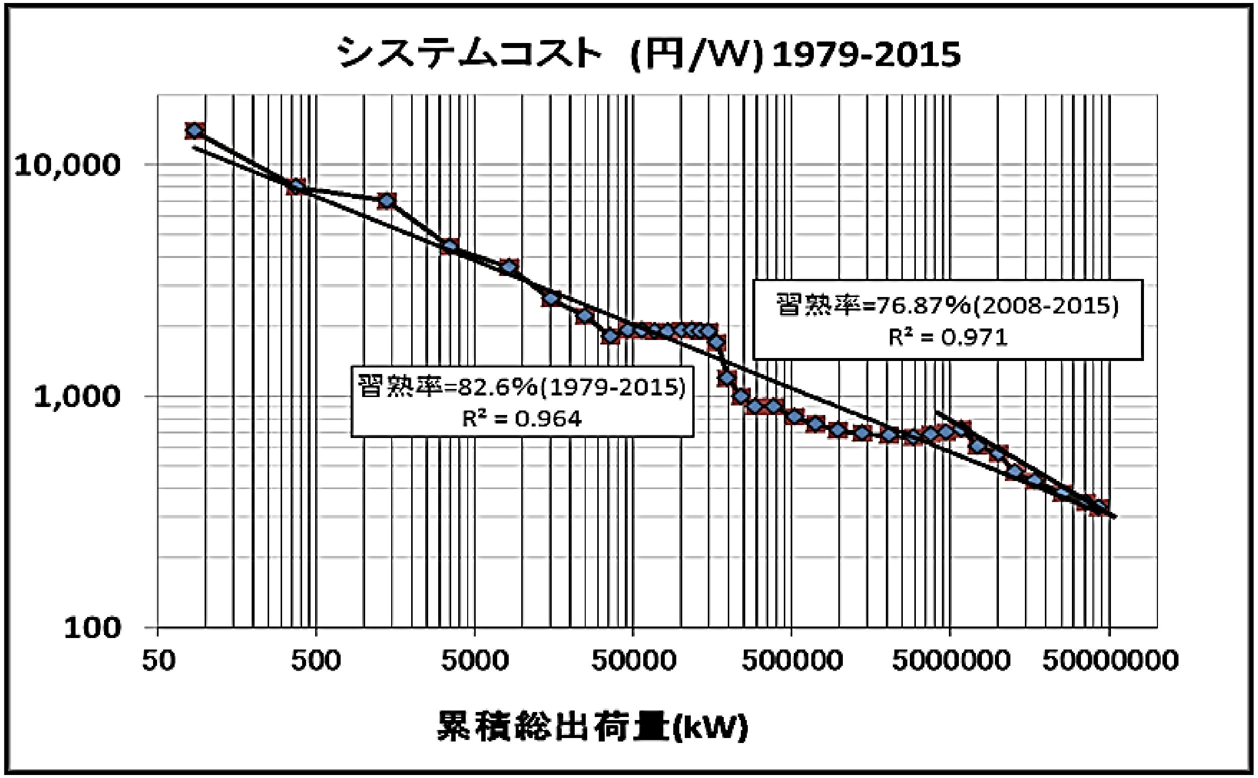


The bottom blast furnace case shows present Japanese case.
Other cases are studies by Wuppertal Institute. Electrolysis uses Alkali liquid method. Hydrogen process includes energy water electrolysis.

If the electricity is supplied by thermal power plant, the units of alkali and hydrogen reduction process is 2 or 3 times larger than the values above. But if electricity comes from renewables without loss, they are efficient.

Future Cost of Renewables

The cost down of photovoltaic systems

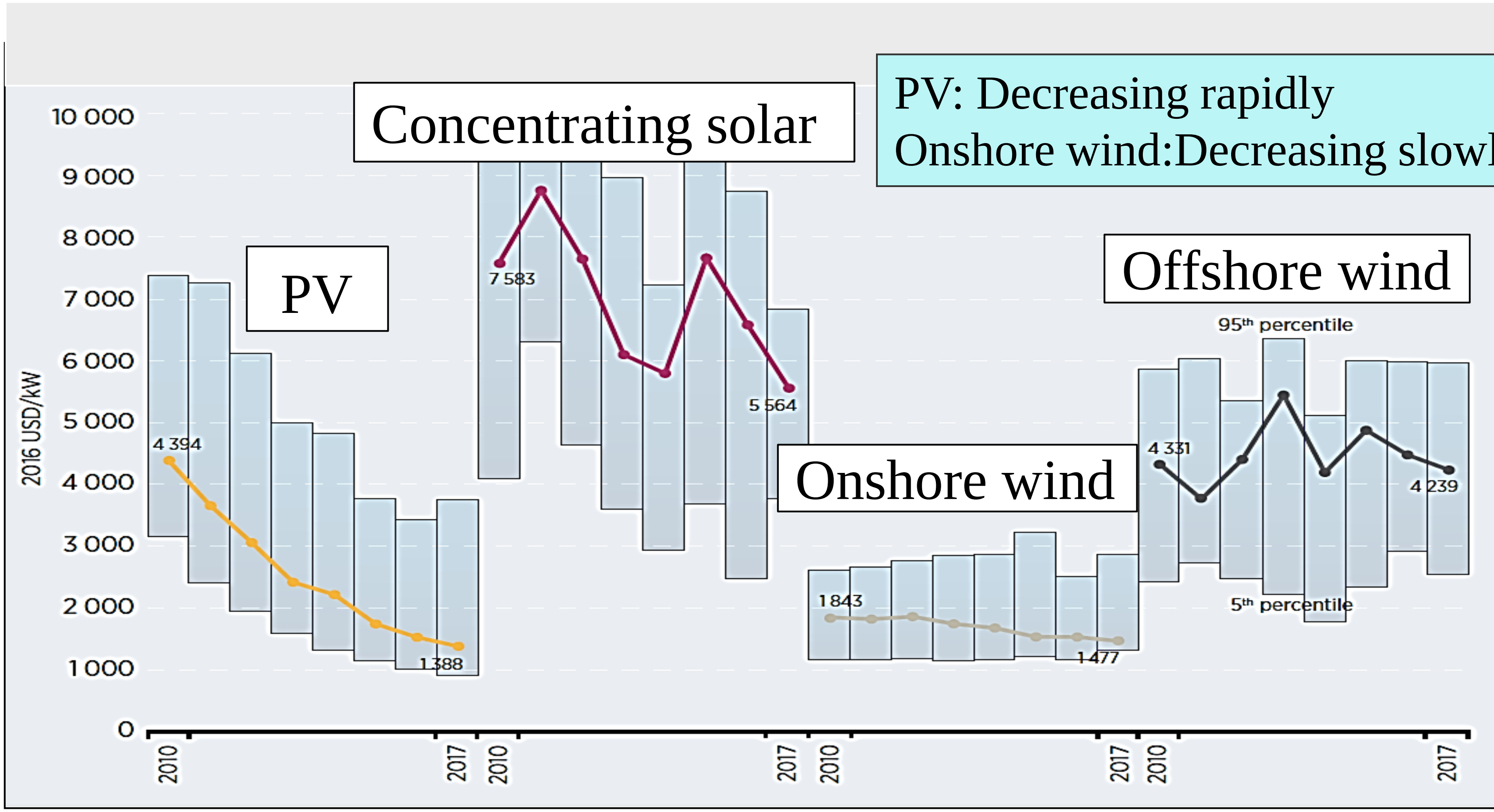


Cumulative production cost of photovoltaic systems in Japan.

(1990-2015)

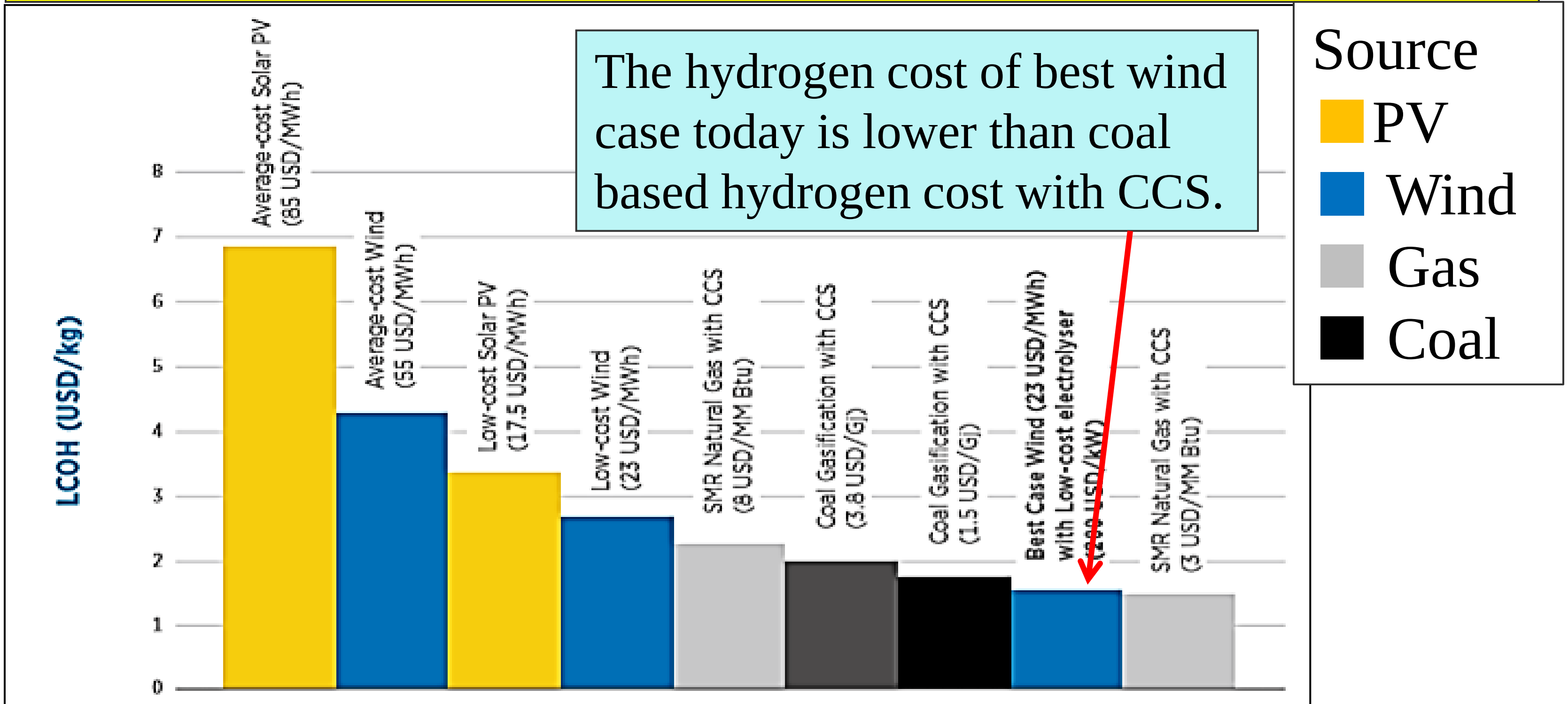
The photovoltaic system cost has been on the line of learning curve (1979-2015). The learning rate is 82.6% (1979-2015) and 76.9% (2008-2015). Learning rate: the reduction rate when the cumulative production doubled.

Global average install cost of renewables, 2010-2017



Renewable power generation costs in 2017, IRENA

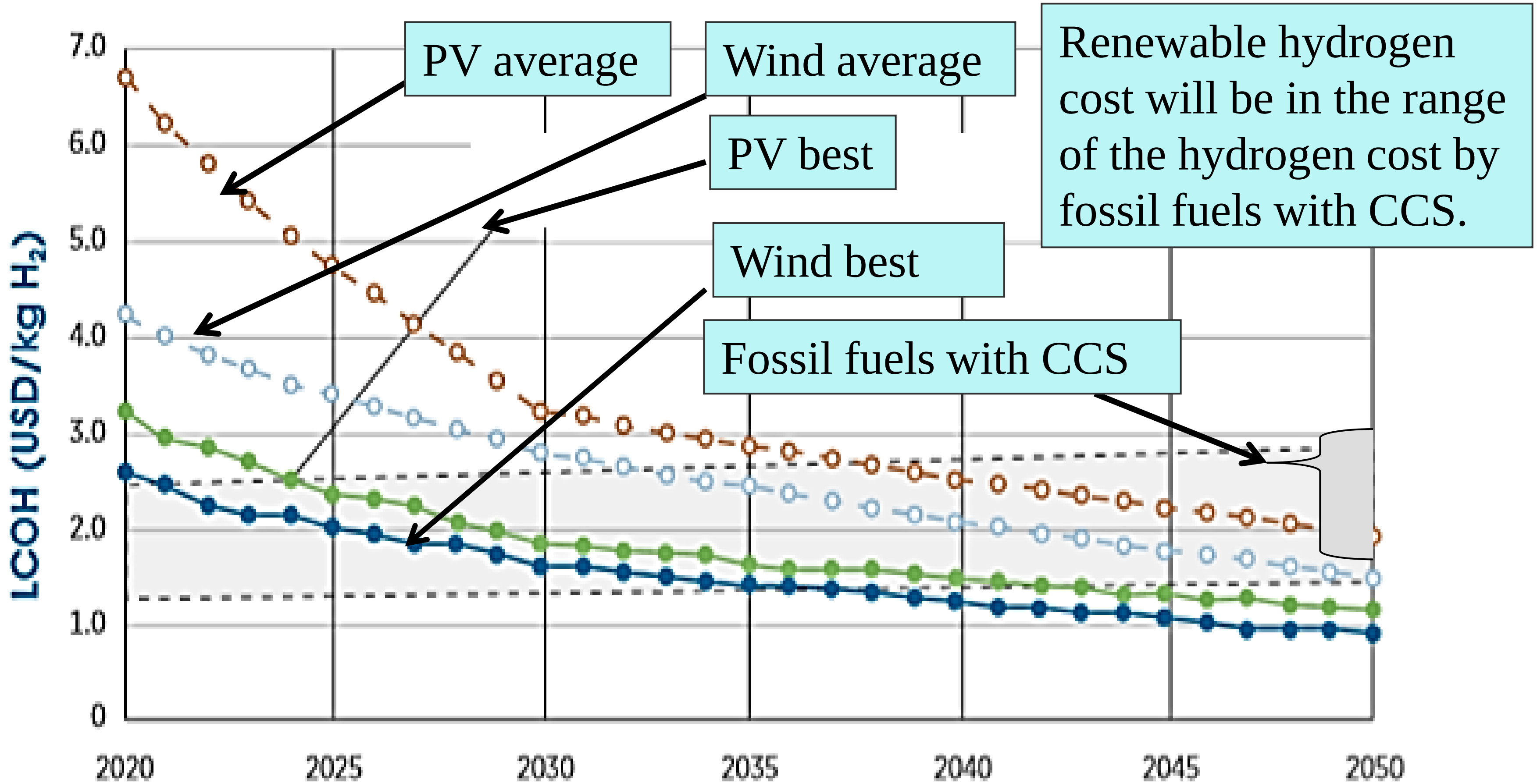
Hydrogen Cost from Renewables and Fossil Fuels today ($/kg$H_2$)



Notes: Electrolyser capex: USD 840/kW; Efficiency: 65%; Electrolyser load factor equals to either solar or wind reference capacity factors. For sake of simplicity, all reference capacity factors are set at 48% for wind farms and 26% for solar PV systems.
Source: IRENA analysis

Hydrogen: A Renewable Energy Perspective, IRENA 2019

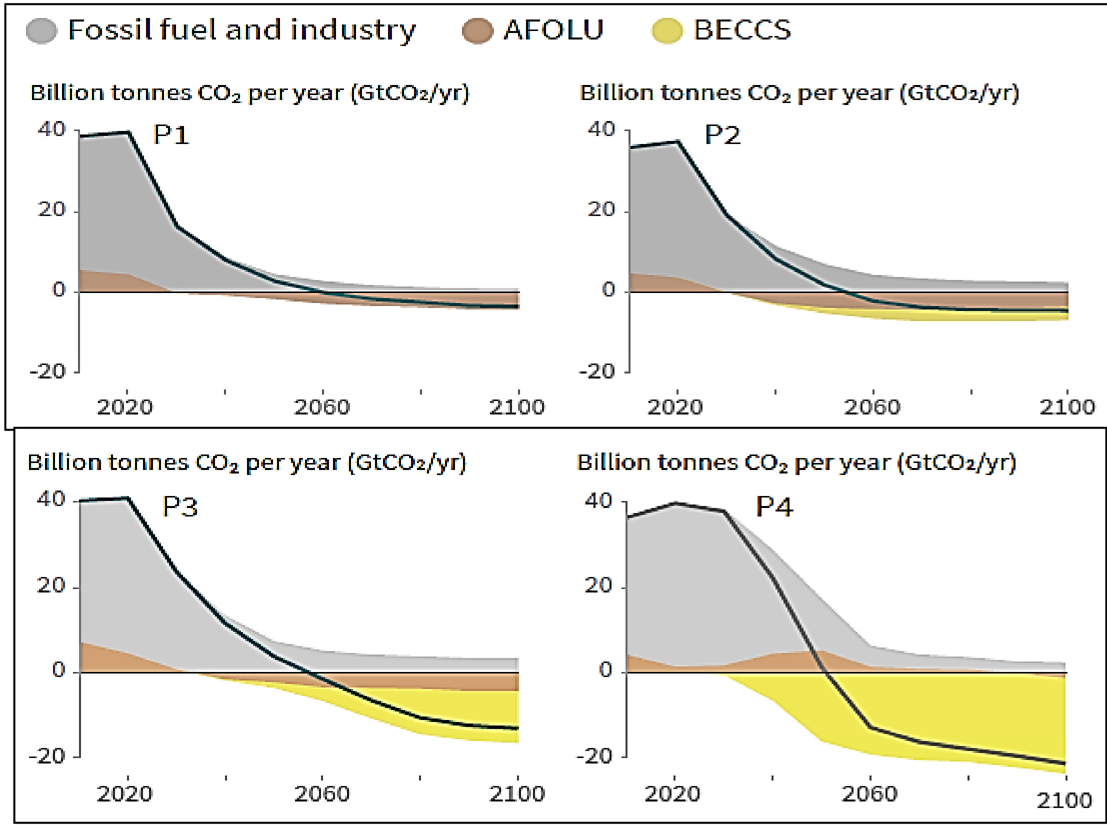
Future Hydrogen Cost ($/kg$H_2$) from Renewable vs. Fossil Fuels with CCS



Electrolyser Cost($/kW): 700(2020), 540(2030), 435(2040), 370(2050)
Hydrogen : A Renewable Energy Perspective, IRENA 2019

CCUS and Hydrogen

Global Warming of 1.5°C report shows CCS and/or BECCS are necessary. (IPCC report, 2018)



	Scenario	CCS	BECCS
P1	Low energy high renewable	0	0
P2	Sustainable society Human development	348	151
P3	Conventional way of life	878	687
P4	High growth Globalization	1137	1218
	(CO2 Gton till 2100)		

Report shows four scenarios to limit temperature rise less than 1.5C. But P4 requires very large CCS and BECCS.

BECCS or DAC

- Even if CO_2 emission will become zero in 2050, there still remains the accumulated CO_2 in the atmosphere.
- It is necessary to decrease it to eliminate climate risks.
- BECCS (Biomass energy with CCS) or DAC(Direct Air Capture) will be necessary.
- BECCS products will be used as construction materials for long time storage, but large land area is necessary.

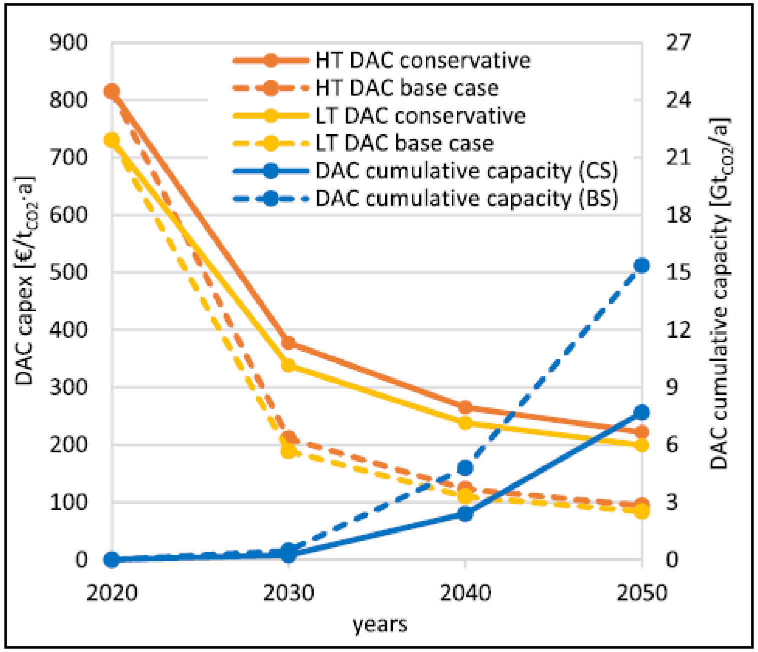
Carbon Engineering (Canada)

DAC cost was $600/$CO_2$ ton in 2010 by American Physics Society report. In 2018 Carbon Engineering expected €75-113/CO_2 ton at large scale. The cost is only for capture, not including storage cost.

DAC cost and CCUS with Hydrogen

Company	Sorbent	Regeneration Temperature (°C)	Target Cost €/ton CO2
Carbon Engineering	liquid	900 (HT)	73-178
ClimeWorks	Solid	100 (LT)	75
Global Thermostat	Solid	85-95 (LT)	113
Antecy	Solid	80-100 (LT)	-
Hydrocell	solid	70-80 (LT)	-

HT: high temperature, LT: low temperature
DAC cost estimate by Lappeenranta University of Technology, Finland (2019)



Climeworks (Zurich)

- If DAC can capture CO_2 at lower cost, hydrogen will be used to make aviation fuels and industrial materials.
- CO_2 (from DAC)+H_2 →Industrial materials, like plastics, cement, asphalt etc. A long time carbon storage (CCUS)

Conclusions

- Energy demand will decrease by population change and efficient technology in 2050 in Japan.
- Domestic renewable resources are possible to supply energy to the decreased energy demand.
- Dynamic nature of solar and wind shows the inevitable emergence of excess electricity, which can be used to produce hydrogen.
- The hydrogen will be used for FCV, aircraft, ship, steel production and thermal end use. Furthermore,
- Hydrogen and CO_2 from DAC will produce industrial materials for long term storage as CCUS.

Thank you