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HYDROGEN AND ELECTRICITY SUPPLY FOR FUTURE VEHICLES BY EXCESS ELECTRICITY FROM SOLAR AND WIND POWER

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SUMMARY: This paper reports on hydrogen and electricity supply for EV (Electric vehicle) and FCV (Fuel cell vehicle) around 2050. The electricity will be supplied mainly with renewables, such as solar, wind, hydro, geothermal and biomass in Japan. Electricity from fluctuating renewables causes excess more than demand. We analyzed the scale of necessary systems to supply the excess electricity to hydrogen for FCV and electricity for EV by dynamic simulation.

Keywords: renewable energy, electric vehicle, fuel cell vehicle, hydrogen energy, excess electricity

INTRODUCTION

Renewable energy is expected to be safe, self-sufficient and sustainable without carbon emission. So there are attentions on renewable rich energy future. When we study future energy system with renewables dominated, it is anticipated that the electricity generations by renewable energy are fluctuating and cause lack and excess to energy demand. Lack of electricity is supported by backup and storage. Excess electricity is expected to be used for some useful purposes. We analyzed the case that the electricity will be fully supplied by renewables and the excess electricity will be supplied to the other energy end use, such as energy for vehicles.

FUTURE ELECTRICITY DEMAND

The official reports of Japanese population forecast for 2050 is 74% (A scenario) and 78% (B Scenario) and the energy demand for 2050 is 63% (A Scenario) and 57% (B Scenario) of the year 2000 level. [1] The population decrease will inevitably cause the decline of energy demand. GDP growth rate is forecasted officially as 1% for 2020-2030. The society will shift to more service oriented, less material production.

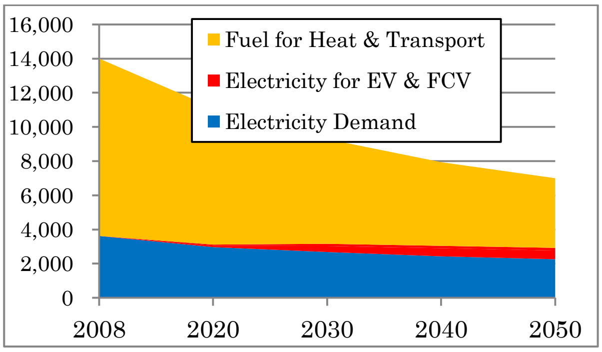

Fig.1 End use energy demand toward 2050 (PJ)

Electricity demand around 2050 will be decreased much more by efficient technologies. So we assume the annual electricity demand in 2050 will be 65% of the year 2008 level. [2][3] Fig.1 shows the end use energy demand to the year 2050. We discuss on electricity demand and electricity for EV and hydrogen for FCV. But we do not discuss the fuel demand for heat in industry, commercial and household sector and fuel for transport in this paper.

There are ten electric power companies in Japan. They are connected with grid except Okinawa area, because it is remote. So we do not treat the electricity supply of Okinawa area in this study. Nine companies supply 963TWh in 2008. The mutual connection grid lines among the nine power grids are not so large. We treat the nine grid areas as a single integrated grid in this study.

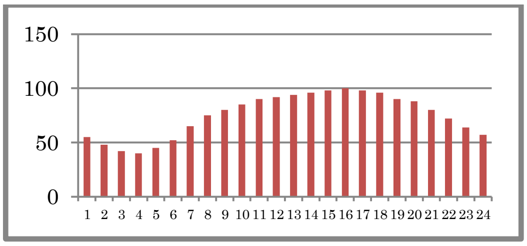

Fig.2 Hourly electricity load pattern for a day.

The hourly electricity load pattern for a day is estimated as shown in Fig.2. The load is low in early morning and rises toward noon and becomes maxim around late afternoon, and slowly decreases to midnight.

ENERGY DEMAND FOR VEHICLES

Passenger vehicles are 55.5 million in 2010 and will be decreasing to 49 million in 2050. Table 1 shows the energy demand for passenger vehicles around 2050. We assumed half of them is FCV and the other half is EV. The annual driving distance is 10,000km and the fuel economy is 195Wh/km.

Table1. Electricity demand for future vehicles

Electricity Demand	Unit	FCV	EV
Driving Load/km (A)	Wh	195	195
Rooftop PV/km (B)	Wh	39	39
Net demand/km (A-B)	Wh	156	156
Charge efficiency	%		90
H2 production efficiency	%	85	
FC Generation efficiency	%	60	
Annual Driving Distance	km	10,000	10,000
Annual Electric Demand/vehicle	kWh	3059	1733
Number of Vehicles	million	24.5	24.5
Annual Electric Demand	TWh	74.9	42.5

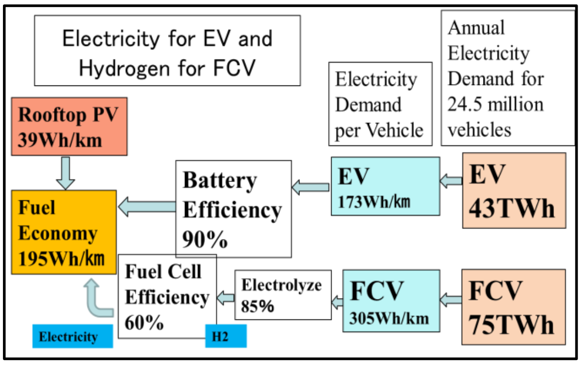

Fig.3 Energy flow for EV and FCV

Fig.3 shows the energy flow for EV and FCV. Electricity for EV is supplied with 90% battery efficiency. Electricity for FCV is supplied with 85% electrolyser efficiency and with 60% efficiency of fuel cell.

Fig.4 shows the concept of future vehicle with 600W photovoltaics at roof top area 3m^2. It has regenerative brake and recovers electricity from rotation energy of wheel with 50% efficiency. In case of FCV there is a hydrogen sub tank, which is used for storage of hydrogen produced on board.

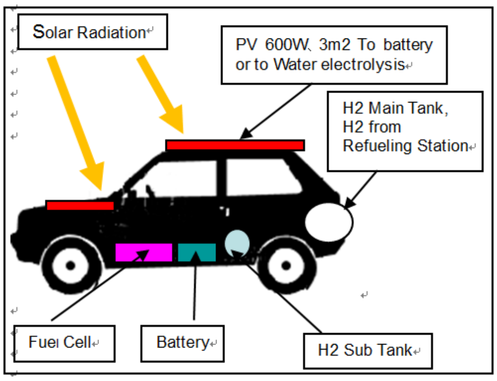

Fig.4 EV and FCV with rooftop PV

Photovoltaic panel on vehicle's rooftop is assumed to supply 20% of driving demand, 39Wh/km annually for each vehicle. [4] The hydrogen demand for FCV and electricity demand for EV are estimated using conversion efficiency as shown in Table 1.

Hydrogen production is assumed to electrolyze water with efficiency 85%. Annual electric demand per EV is 1733kWh and that per FCV is 3059kWh.

If PV cost shall decrease along with learning curve, it will be a realistic option. Especially it will be effective in the areas with rich solar radiation.

RENEWABLE ENERGY RESOURCES

There are several studies on renewable energy resources in Japan. Table 2 shows the renewable energy capacity of present, max potential and this study.

The capacity of hydro power is 20.7GW now. We assumed it will be 33.6GW in 2050. The geothermal plant is 520MW now and will be14.2GW in 2050.

Table 2 The renewable energy resources (GW)

Sources	2012	Max Potential	This Study
Hydro power	20.7	33.6	33.6
Geothermal	0.54	33.1	14.2
Photovoltaics	9.1	700	218
Wind Power	2.66	1856	67
Biomass Electricity	4	11.2	8

Pumped Hydro and Back up

There is 26GW pumped hydro which has been constructed for storage of excess electricity of nuclear power as their output is constant. Pumped hydro is used for charging in early morning and for discharging in late afternoon. We applied this storage system to store the excess electricity generated by solar and wind in this study. There is loss of 30% for lifting water by pump system. The storage capacity is assumed as 260GWh with 10 hours of maximum working time. We did not assume battery systems, but assumed natural gas plant for back up.

Solar power

Solar photovoltaic was introduced by subsidies in 1990s and is rapidly increasing by the government decision of feed-in-tariff system in 2011 and nearly 9GW was introduced cumulatively until 2013.

The price of photovoltaic system is analyzed by Learning curve and the past price records show that the price decreased to 82 % every time when the cumulative production doubled in Japan. [5]

"Photovoltaic Road map: Photovoltaic 2030+" is an updated version of future possible scale of photovoltaic by NEDO in 2010. It reports solar will be used not only 200GW in household sector, but also 150~200GW in commercial sector, 150 GW in industries, and 150~200GW for electric vehicles in transport sector. [6]

Extended AMEDAS has hourly weather data of 842 sites nationwide in Japan. [7] We used this data to calculate solar and wind power.

The calculation method for solar power is to split horizontal radiation into direct beam and scattered irradiance and to combine both sun lights on the panel oriented at south with tilt angle. [8] The optimum tilt angle to get maximum annual generation is set at "latitude -5" degree at each construction site as is known experimentally. The inverter of 94% efficiency is included with partial load factor curve. The solar capacity factor is approximately 12%. [9]

Wind Power

There are 2,660MW wind machines already introduced until 2013. Potential study showed very large resources 283GW on shore and 1572GW off shore.[10] Japan is surrounded by sea and has long coast lines. Off shore wind power will be great supply sources in the future.

In this study, 2MW wind machine with horizontal axis and three blades is used to calculate the wind power in respective sites. The blades start to rotate at cut-in wind speed 3m/s, and stop at cut-out wind speed 25m/s. The conversion efficiency is assumed 40%. The diameter of rotor is 80m and hub height is 56m. Wind speed of meteorological data is extended by power factor law to calculate the wind speed at hub height. [11]

As we excluded the wind power sites having capacity factor less than 18%, finally 99 sites are selected for wind sites among 842 sites. The site selection of wind power resulted in the average capacity factor 27%. The wind data sites include remote islands. They are used for this study as wind machines are already built on shallow coast lines and they will be built off shore in the future.

At first the hourly generation amount by single unit of 100kW solar system and 2MW wind machine for respective site are calculated. The necessary unit numbers of solar 100kW and wind machine 2MW are allocated by considering annual electricity demand of respective areas. These unit numbers of solar and wind machines are multiplied with hourly generation to calculate electricity supply throughout dynamic simulation.

DYNAMIC SIMULATION

Computer simulation is performed to calculate hourly renewable powers corresponding to electricity demand with daily load curve around 2050.[12][13] The simulation summary is shown in Table 3. The total electricity supply 782TWh is 125% of the pure electricity demand 627TWh. The excess 22.7% (142.6TWh) is supplied to future vehicles. The difference is loss at pumped hydro plant. Natural gas backup supplies 18.8% of the demand.

The ratios of electricity supply are solar 38%, wind 25% of electricity demand. The capacity of solar is 218 GW and wind is 67GW. The pumped hydro capacity is 260GWh (26GWx10hours). Other renewables are hydro 33GW, geothermal 14GW and biomass 8GW. Natural gas is used for backup power.

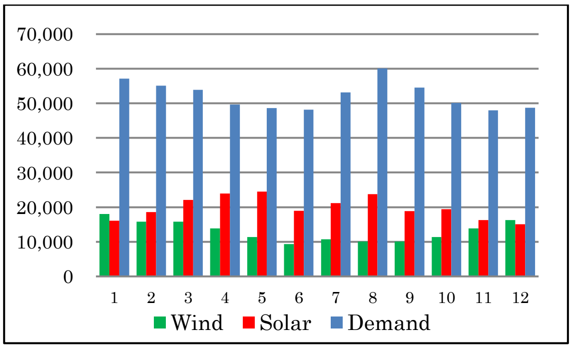

Fig.5 Monthly electricity demand, wind and solar generation (GWh)

Fig.5 shows monthly demand and renewable generations. There are large electricity demands in summer and winter with peak in August. Solar generation has large amount in April, May and August. Wind generations are larger in winter and smaller in summer.

Fig.6 is hourly supply of solar, wind, back-up, discharge, biomass, hydro, and geothermal for three days, 10-12 May. Geothermal and hydro powers are shown at the lower part. Solar photovoltaic shows big peak powers at daytime. Fig.6 does not include the charge to pumped hydro.

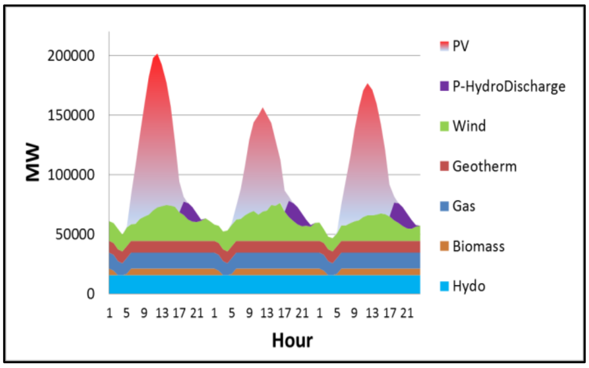

Fig. 6 Dynamic simulation (MWh, 10-12 May)

Table 3 Summary of simulation

Simulation Items	Unit	Total
Photovoltaics Capacity	MW	218,048
Wind Power Capacity	MW	67,384
Pumped Hydro Storage	GWh	260
Electricity Demand	GWh/year	626,945
Average Electricity Demand	MW	71,569
Peak Electricity Demand	MW	109,965
Total Electricity Generation	GWh/year	781,919
_Photovoltaics	GWh/year	238,638
_Wind Power	GWh/year	156,647
_Hydro Power	GWh/year	135,313
_Geothermal Power	GWh/year	87,325
_Natural Gas Power	GWh/year	117,783
_Biomass Power	GWh/year	46,214
Total Share of Generation	%	124.72
_Share of Photovoltaics	%	38.06
_Share of Wind Power	%	24.99
_Share of Hydro Power	%	21.58
_Share of Geothermal	%	13.93
_Share of Natural Gas Power	%	18.79
_Share ofBiomass Power	%	7.37
Pumped Hydro Charge	GWh/year	53,330
_Pumped Hydro Discharge	GWh/year	40,942
_Loss of Pumped Hydro	GWh/year	12,283
_Pumped Loss/Demand	%	1.96
_Max Charge Level	%	100
_Average Charge Level	%	73.2
Excess Electricity	GWh/year	142,592
_Excess Electricity/Demand	%	22.74
_Max Excess Power	MW	133,944

EXCESS ELECTRICITY

The excess electricity is difference between generation and demand. Fig.7 shows monthly excess electricity. It is expected to be flat, but the results show fluctuations, especially smaller in summer season.

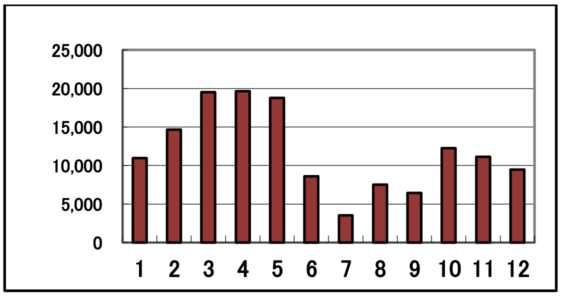

Fig.7 Monthly Excess Electricity (GWh)

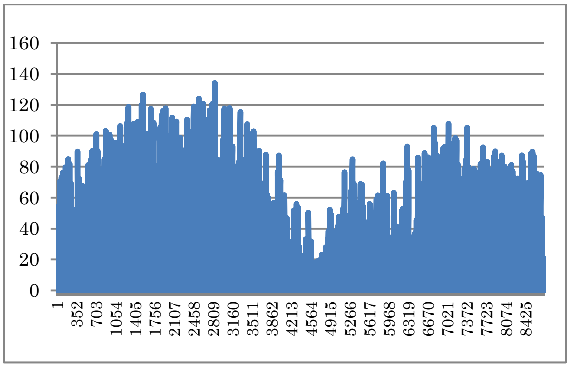

Fig.8 Hourly Excess Electricity for 8760 hours (GWh)

Fig.8 shows the hourly excess electricity. There are periods of very small excess electricity in July. This is because wind power is not large in summer and the peak of solar generation is not in summer, but in April and May.

It may be not enough to supply energy to EV and FCV in July. We are now trying to solve this problem with variety of design methods including energy storage systems.

Fig.9 shows the power duration curve of excess electricity. If we have the capacity 54GW of electric charger for EV and hydrogen production facilities for FCV, that is 40% of peak excess power 134GW, 82% of the excess electricity will be effectively recovered.

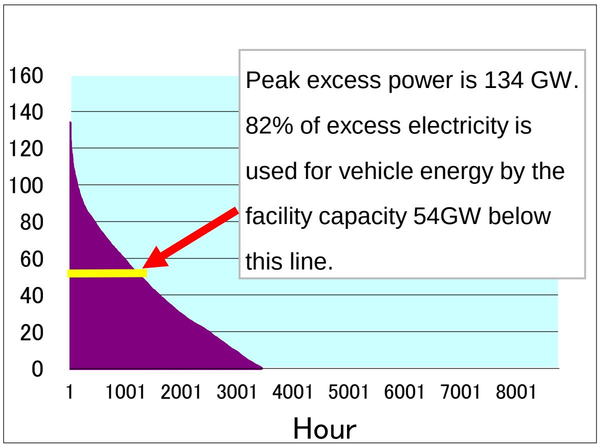

Fig.9 Power duration curve of excess electricity (GW)

Total electricity generation is 782TWh of which 627TWh is for pure electricity demand and 143TWh is for passenger vehicles, 43Twh for EV and 75TWh for FCV as shown in Table 4.

Table 4 Effective use of excess electricity

Electricity demand	Unit	in 2050
Total Generation	TWh	781.9
Pure elctricity use	TWh	626.9
Passenger vehicle	TWh	142.6
Electricity for EV	TWh	42.5
Hydrogen for FCV	TWh	74.9
Total	TWh	117.4
Loss	TWh	25.2
Electricity Charger	GW	19.5
Hydrogen producer	GW	34.5

The scale of electric charger for EV is 20GW and the capacity of hydrogen producer for FCV is 35GW.

There is loss of 25TWh which is not used. If we try to use full of excess electricity, it requires large capacity of electric charger and hydrogen production plant, which will not be used frequently. It is not economical because the capacity of facilities may be too large. The histogram curve shows that 82% of excess electricity can be recovered by capacity as large as 40% of peak excess electricity. The capacities are electric charger 19.5GW to EV and hydrogen producer 34.5GW for FCV.

CONCLUSION

Using weather data nationwide in Japan, we tried hourly dynamic simulation of annual renewable supply to electricity demand around 2050. The excess electricity generated by fluctuations of solar and wind is charged to EV and converted to hydrogen for FCV. The analysis of the simulation results show that the scale of energy supply facilities of excess electricity to EV and FCV will be 40% of peak excess electricity. It will supply 82%of excess electricity based on the histogram of excess electricity.

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