CONSIDERATION ABOUT THE HYDROGEN FUEL CELL POWERTRAIN LCOE

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1. Overnight Costs and Levelized Costs of Generating Electricity

Investment costs are probably the most important element in any investment decision. They vary greatly from technology, from time and from geographic area. **Overnight cost** is a common unit of measure of power investments, it is the cost of a construction project if no interest was incurred during construction, as if the project was completed "overnight." The unit of measure typically used for Overnight cost is USD/kW.

The notion of **Levelized Costs of Generating Electricity** (LCOE) is a handy tool for comparing the unit costs of different power generation technologies. The LCOE approach is a financial model used for the analysis of generation costs. Focus of estimated average LCOE is the entire operating life of the power plants for a given technology. In LCOE financial model, different cost components are taken into account: capital costs, fuel costs, operations and maintenance costs (O&M). These costs are an average over the life of a project and for a specific technology, based on a specific and particular set of assumptions. The costs cash-flow is discounted to the present (date of commissioning) using assumed specific discount rates. The resultant LCOE values, one for each generation option, are the main driver for choice technology. The unit of measure typically used for LCOE is USD/MWh.

Currently, with different frequency, public and private institution released analyses[1] regarding present and future LCOE generation focused on broad or specific power generation technologies. Each of these LCOE analyses adopts little difference with regard to definition (*i.e.* elements included in formula) and assumptions adopted (as: year of reference, discount rate, currency, geographic area, cost of fuel and so on). Analyzing these studies a wide dispersion of data is evident and there is no technology that has a clear overall advantage globally or regionally. Results are particularly sensitive to fuel and electricity price assumptions and discount rate level is another key element. Results vary from analysis to analysis, from time to time, from country to country, and even within the same region, there are significant variations in the cost for the same technologies.

2. Fuel Cells and Hydrogen

A Fuel Cell is a device that uses a fuel and oxygen to create electricity by an electrochemical process, without combustion. A single Fuel Cell[2] consists of an electrolyte and two electrodes (anode and cathode). Fuel Cells are classified primarily by the kind of electrolyte they employ:

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1 - See, among other:
European Commission (EC), 2008: *"Energy Sources, Production Costs and Performance of Technologies for Power Generation, Heating and Transport"*, European Commission SEC(2008)2872, Brussels, Nov. 2008, < http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2008:2872:FIN:EN:PDF >.
IPCC, 2011: *"IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation"* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA < http://srren.ipcc-wg3.de/report/IPCC_SRREN_Full_Report >.
Lazard Ltd, 2008, 2009 and 2010: *"Levelized Cost of Energy Analysis"* Lazard Ltd, New York, NY, USA.
Organization for Economic Co-operation and Development (OECD) / International Energy Agency (IEA) – Nuclear Energy Agency (NEA), 2010: *"Projected Costs of Generating Electricity"* 2010 Edition, Paris, France < http://www.iea.org/w/bookshop/add.aspx?id=403 >.
U.S. Energy Information Administration (EIA), 2010 and 2011: "*Levelized Cost of New Generation Resources from the Annual Energy Outlook"* EIA Washington, DC, USA (See infra).
World Economic Forum (WEF) in collaboration with Bloomberg New Energy Finance, 2009, 2010 and 2011: "Green Investing" World Economic Forum USA Inc. New York, NY, USA. 2009 *"Green Investing: Towards a Clean Energy Infrastructure"* < http://www3.weforum.org/docs/WEF_IV_GreenInvesting_Report_2009.pdf >; *"Green Investing 2010: Policy Mechanisms to Bridge the Financing Gap"* < http://www3.weforum.org/docs/WEF_IV_GreenInvesting_Report_2010.pdf > and "*The Green Investing 2011: Reducing the Cost of Financing"* < http://www3.weforum.org/docs/WEF_IV_GreenInvesting_Report_2011.pdf >.
2 - For detail see: < http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/basics.html > and <http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_types.html >.

Phosphoric Acid Fuel Cells (PAFC), **Alkaline Fuel Cells** (AFC), **Molten Carbonate Fuel Cells** (MCFC), **Solid Oxide Fuel Cells** (SOFC)**, Direct Methanol Fuel Cells** (DMFC) **and Polymer Electrolyte Membrane Fuel Cells** (PEFC) also called Proton Exchange Membrane Fuel Cells (PEM). PEM Fuel Cells use hydrogen as fuel and have emissions only of water.

Today Fuel Cells are present in a wide range of prototype and products: portable applications, micro CHP system, recreation products, vehicles, niche and professional application, military items. In presence of such a wide context of application, I chose to consider in my analysis the Hydrogen Fuel Cell (PEM) Powertrain (H2FC Powertrain) as "Power Generation Plant" because, if the current U.S. Hydrogen and Fuel Cell Vehicle Program is able to meet all the 2015/2017[3] technological targets, in the subsequent year, the high volume associated with the H2FC vehicles mass production (up to 500.000 units sold per year) will permit to reduce dramatically the Fuel Cell system manufacturing costs, in order to be competitive with current gasoline ICE systems.

3. The Vehicle-to-Grid Concept

Every day more than 90% of vehicles are parked, even during peak traffic hours. In this situation the vehicle power generation system H2FC powertrain, if properly equipped, could become a new power generation source, supplying electricity to homes and to the grid like a new type of distributed generation: **Vehicle-to-Grid** (V2G).

Academics, public and private operators well know the V2G concept[4]. V2G could be realized indifferently with Electric Vehicles and Fuel Cell Vehicles (FCV), but only in the case of FCV we are in presence of a real new power generation capacity GHG emission free: the H2FC powertrains[5]. FCV in a V2G mode may profitably provide power to the grid when they are parked and connected to an electrical outlet. In this perspective, literature analyzed also the economic aspects[6]. FCV have significant potential revenue streams from V2G, on peak power production, but it is possible to obtain higher return offering a series of high-value ancillary services to the grid.

4. This Study

If FCV, properly equipped and parked in V2G mode, become a new power generation source supplying electricity to homes and to the grid, it could be useful to begin to analyze the H2FC powertrain relevance in the power generation sector. But, in my opinion, in the mass production

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3 - The ***"Energy Policy Act of 2005"*** fixed the U.S. Hydrogen and Fuel Cell Vehicle Program goals in Sec. 805. In particular: *"(b) GOAL.—The goal of the program shall be to demonstrate and commercialize the use of hydrogen for transportation (in light-duty vehicles and heavy-duty vehicles), utility, industrial, commercial, and residential applications."; "(f) PROGRAM GOALS.— (1) VEHICLES.— **For vehicles, the goals of the program are** — (A) **to enable a commitment by automakers no later than year 2015** to offer safe, affordable, and technically viable hydrogen fuel cell vehicles in the mass consumer market; and (B) to enable production, delivery, and acceptance by consumers of model year 2020 hydrogen fuel cell and other hydrogen-powered vehicles that will have, when compared to light duty vehicles in model year 2005— (i) fuel economy that is substantially higher; (ii) substantially lower emissions of air pollutants; and (iii) equivalent or improved vehicle fuel system crash integrity and occupant protection."* <http://www.hydrogen.energy.gov/pdfs/epact_05.pdf >.
Surprisingly, in autumn 2011, the U.S.DOE published on the web the final version of ***"The Department of Energy Hydrogen and Fuel Cells Program Plan - An Integrated Strategic Plan for the Research, Development, and Demonstration of Hydrogen and Fuel Cell Technologies"*** (September 2011) in which *"While the Program has broadened its focus beyond the 2015 technology readiness milestone for fuel cell electric vehicles (FCEVs), it continues to pursue technology advancements needed for their commercialization. **The milestone for automotive fuel cells has shifted from 2015 to 2017**, and a key milestone for hydrogen production has already been met—enabling hydrogen to be produced (at high volumes and widespread deployment of stations) from natural gas at fueling stations for approximately $3 per gallon gasoline equivalent"* (Appendix A: About This Document) < http://www.hydrogen.energy.gov/pdfs/program_plan2011.pdf >.
In the U.S. DOE ***"The Department of Energy Hydrogen and Fuel Cells Program Plan - An Integrated Strategic Plan for the Research, Development, and Demonstration of Hydrogen and Fuel Cell Technologies"*** **(2010, Draft version)** all automotive milestones were fixed in year 2015, < http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/program_plan2010.pdf > accessed on web from Nov. 2010 to Oct. 2011.

4 - The concept of 'Vehicle-to-Grid' was first proposed in 1997 by W. Kempton "*Electric vehicles as a new power source for electric utilities"*, Transportation Research Part D 2 (3), 1997, p157–175 < http://www.udel.edu/V2G/docs/Kempton-Letendre-97.pdf >; Interesting documents to see are: "*Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California"*, 2001, Institute of Transportation Studies, University of California, Davis, CA, USA < http://pubs.its.ucdavis.edu/publication_detail.php?id=360 > and W. Kempton, J. Tomić *"Vehicle to Grid Power Implementation: from stabilizing the grid to supporting large-scale renewable energy"*, 2005, Journal of Power Sources Volume 144 < http://www.spinnovation.com/sn/Articles_on_V2G/Vehicle-to-grid_power_implementation_From_stabilizing_the.pdf >.

5 - In fact, in the case of Plug-In Hybrid Electric Vehicles or Electric Vehicles, we are only in presence of a new, and useful, energy storage capacity.

6 - See: T. Lipman, J. Edwards, D. Kammen, *"Economic Implications of Net Metering for Stationary and Motor Vehicle Fuel Cell Systems in California"*, 2002 < http://www.ucei.berkeley.edu/PDF/pwp092.pdf > and W. Kempton, J. Tomić, *"Vehicle-to-grid power fundamentals: Calculating capacity and net revenue"*, Journal of Power Sources, Volume 144, 2005 < http://www.spinnovation.com/sn/Articles_on_V2G/Vehicle-to-grid_power_fundamentals_Calculating_capacity.pdf >.

perspective (above mentioned) H2FC Powertrain will be so cost competitive to be useful adopted also for stationary power generation application.

In my *Considering Hydrogen Fuel Cells Powertrain as Power Generation Plant*[7] (EVS25, Shenzhen, China 2010), I considered first the H2FC Powertrain as "Power Generation Plant"[8]. In *Hydrogen Fuel Cell Powertrain Levelized Cost of Electricity*[9] (30th USAEE/IAEE North American Conference, Washington, U.S. 2011), I updated the analysis with focus on the U.S. context. In this study I updated the U.S. analysis and I elaborated some consideration about the possible economic utilization of these technologies in Japan.

5. The U.S. EIA LCOE Data

In the mid 70's U.S. EIA began publishing the *Annual Energy Outlook (AEO)*[10] in which, annually, presents a forecast and analysis of U.S. energy supply, demand, and prices. Since 1996 *AEO* considers and realizes forecast about the **Overnight costs**[11] and the **Levelized Costs**[12] of Electricity. In January 2010 the LCOE data for Central Production Power Plant are published in a separated document: *2016 Levelized Cost of New Generation Resources from the Annual Energy Outlook 2010*[13]. LCOE data are revisited in *Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011* in December 2010[14] (based on the *AEO Early Release*) and in April 2011[15]. **Fuel Cells technologies** were mentioned and included in EIA documents since 1994[16].

Table 1 (next page) is the re-elaboration of EIA Overnight cost and LCOE data (U.S. national averages).

6. Hydrogen Fuel Cell Powertrain LCOE

In order to calculate the H2FC Powertrain specific LCOE I need some H2FC Powertrain data: the system cost and efficiency, the expected system lifetime, the fuel cost (*i.e.* the H2 cost).

Current Status 2010 – 2011 (DOE[17] public data, based on projected high volume production): Overnight cost 49 USD/kW; 53%-59% System Efficiency; Lifetime 2500 - 2521 hours; and 3 UDS/GGE H2 cost (based on natural gas steam reforming).

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7 - M. V. Romeri *"Considering Hydrogen Fuel Cells Powertrain as Power Generation Plant",* World Electric Vehicles Symposium EVS25 "Sustainable Mobility Revolution". Shenzhen, China 2010, < http://www.evs25.org/event/2009ddc-en/index.html >, accessed 7 March 2011.

8 - My EVS25 study was updated in *"Possible Hydrogen Fuel Cell Vehicles Powertrain Roles in the Copenhagen Accord Perspective" 2011* Fuel Cell & Hydrogen Energy Conference organized by Fuel Cell & Hydrogen Energy Association. Washington DC Area, USA.

9 - M. V. Romeri *"Hydrogen Fuel Cell Powertrain Levelized Cost of Electricity",* 30th USAEE/IAEE North American Conference, "Redefining the Energy Economy: Changing Roles of Industry, Government and Research". Washington, DC, U.S., 2011, <http://www.usaee.org/usaee2011/submissions/OnlineProceedings/Romeri_H2FCP_LCOE.pdf >.

10 - EIA, *"Annual Energy Outlook 2011"* (AEO2011) < http://www.eia.gov/forecasts/archive/aeo11/ >; AEO Archive, <http://www.eia.gov/oiaf/archive.html >.

11 - Overnight costs are in *Table 8.2 "Cost and performance characteristics of new central station electricity generating technologies" (Electricity Generating Technologies),* EIA, *"Assumptions to the Annual Energy Outlook 2011"* (AAEO), <http://www.eia.gov/forecasts/aeo/assumptions/index.cfm > or < http://www.eia.gov/forecasts/aeo/assumptions/pdf/0554(2011).pdf >.

12 - Levelized costs are presented in different parts, figures and footnotes of each annual AEO edition (with exclusion of year 1999, 2000 and 2001). In particular many AEO footnotes refer to specific National Energy Modeling System runs. EIA, *Annual Energy Outlook, Cit.*

13 - EIA "*2016 Levelized Cost of New Generation Resources from the Annual Energy Outlook 2010",* Jan. 2010, <http://www.eia.gov/oiaf/archive/aeo10/pdf/2016levelized_costs_aeo2010.pdf >.

14 - EIA *"Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011", Dec. 2010,* <http://www.eia.doe.gov/oiaf/aeo/pdf/2016levelized_costs_aeo2011.pdf >

15 - EIA *"Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011",* April 2011 version, based on the AEO 2011, <http://www.eia.gov/forecasts/aeo/electricity_generation.cfm >.

16 - In *"2016 Levelized Cost of New Generation Resources from the Annual Energy Outlook 2010"* (Cit.) Fuel Cells are not included in the final Table published in the web but is considered in the AAEO Tables (In AAEO 2010 see Table 8.1 -Molten Carbonate Fuel Cell- and 8.2 -Fuel Cells- <http://www.eia.gov/oiaf/aeo/assumption/pdf/0554(2010).pdf >) and spreadsheet (EIA *"Generation costs & characteristics"* -Fuel Cells- <http://www.eia.gov/oiaf/aeo/excel/aeo2010%20tab8%202.xls >). The *"Updated Capital Cost Estimates for Electricity Generation Plants"* provides a summary of the current cost estimates for utility-scale electric generating plants (EIA commissioned an external consultant to develop current cost estimates for utility-scale electric generating plants November 2010 < http://www.eia.gov/oiaf/beck_plantcosts/pdf/updatedplantcosts.pdf >). A Fuel Cell Facility is considered and it utilizes multiple Phosphoric Acid Fuel Cell (PAFC) units (Chapter 15. Phosphoric Acid Fuel Cell units with a power output of 400 kW, total Plant output of 10 MW). In *"Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011" (*Dec. 2010 cit. and Apr. 2011 version cit.) Fuel Cells are not included in the final Table published in the web but are considered in the AAEO Tables (Table 8.1 - MCFC - and 8.2 -Fuel Cells-).

17 - S. Satyapal, *"The DOE Fuel Cell Technologies Program: Driving Progress through a Balanced Portfolio",* Fuel Cell Seminar**,** Orlando, FL, Nov. 2011, < http://www.fuelcellseminar.com/media/9362/plenary-%20sunita%20satyapal.pdf >, p. 6. S. Satyapal *"Hydrogen and Fuel Cell Technologies Update" Fuel Cells & Hydrogen Joint Undertaking Stakeholders General Assembly November 2010, Brussels*

Table 1 - 2016 Levelized Cost of New Generation Resources from the Annual Energy Outlook 2010 and 2011 (EIA, Jan. 2010 and Apr. 2011)										
US			LCOE 2010 (USD/MWh)					LCOE 2011 (USD/MWh)		
Plant Type	Plant Size (MW 2009)	Final Overnight Cost (USD/kW 2009)	Levelized Capital Costs	O&M + Other + Fuel Cost (USD/MWh)	Total System Levelized Cost	Plant Size (MW 2010)	Final Overnight Cost (USD/kW 2010)	Levelized Capital Costs	O&M + Other + Fuel Cost (USD/MWh)	Total System Levelized Cost
Conventional Coal	600	2223	69.2	31.3	**100.5**	1300	2809	65.5	29.6	**95.1**
Advanced Coal	550	2569	81.2	29.3	**110.5**	1200	3182	74.7	35.0	**109.7**
Advanced Coal with CCS	380	3776	92.6	36.6	**129.2**	520	5287	92.9	43.7	**136.5**
Conventional Gas Combined Cycle	250	984	22.9	60.2	**83.1**	540	967	17.5	47.7	**65.1**
Advanced Gas Combined Cycle	400	968	22.4	56.9	**79.3**	400	991	17.9	44.3	**62.2**
Advanced Gas Combined Cycle with CCS	400	1932	43.8	69.5	**113.3**	340	2036	34.7	53.7	**88.4**
Conventional Combustion Gas Turbine	160	685	41.1	98.4	**139.5**	85	961	45.8	77.1	**123.0**
Advanced Combustion Gas Turbine	230	648	38.5	84.9	**123.4**	210	658	31.7	70.3	**102.1**
Advanced Nuclear	1350	3820	94.9	24.1	**119.0**	2236	5275	90.2	23.8	**114.0**
Fuel Cells	10	5478				10	6752			
Wind	50	1966	130.5	18.8	**149.3**	100	2409	83.3	12.9	**96.1**
Wind - Offshore	100	3937	159.9	31.2	**191.1**	400	6056	209.7	34.0	**243.7**
Solar PV	5	6171	376.8	19.4	**396.2**	150	4697	194.9	16.1	**211.0**
Solar Thermal	100	5132	224.4	32.2	**256.6**	100	4636	259.8	52.4	**312.2**
Geothermal	50	1749	88.0	27.7	**115.7**	50	2482	77.4	22.4	**99.8**
Biomass	80	3849	73.3	37.8	**111.1**	50	3724	55.4	57.3	**112.6**
Hydro	500	2291	103.7	16.3	**120.0**	500	2221	78.5	12.0	**90.5**

Table 2 summarizes the DOE Projected Transportation Fuel Cell System Cost.

Table 2 - DOE Projected Transportation Fuel Cell System Cost (USD/kW Nominal, Unadjusted)^							
80 kW net	2002	2006	2007	2008	2009	2010	2011
Fuel Cell System Cost	275	108	94	73	61	51	49
Of which: Stack		65	50	34	27	25	22
Of which: Balance of Plant		43	44	39	34	26	27

^ Projected to high volume (500,000 units per year)

2015/2017 DOE technical targets (based on projected high volume production): Overnight cost 30 USD/kW; 60% System Efficiency; Lifetime 5000 hours; and H2 cost 2 – 4 UDS/GGE[18].

Table 3 shows the H2FC Powertrain Levelized Cost of Electricity.

Table 3 - H2FC Powertrain Levelised Cost of Electricity (USD)								
H2FC Powertrain Efficiency	H2FC Powertrain Hours LIFE	Hydrogen Cost USD/GGE°	Capital Overnight OVN Cost (USD/kW)^	Levelized Capital Cost LCC (USD/MWh)	O&M + Others (Assumed Equal to 10% LCC, USD/MWh)	Fuel Cost (USD/MWh)	Levelized Cost (USD/MWh)	
53%	**2500**	**3,0**	**49,0**	19,6	2,0	169,8	**191,4**	DOE Current status
59%	**2500**	**3,0**	**49,0**	19,6	2,0	152,5	**174,1**	DOE Current status
53%	**2521**	**3,0**	**49,0**	19,4	1,9	169,8	**191,2**	DOE Current status
59%	**2521**	**3,0**	**49,0**	19,4	1,9	152,5	**173,9**	DOE Current status
60%	**5000**	**4,0**	**30,0**	6,0	0,6	200,0	**206,6**	2015/2017 DOE Targets
60%	**5000**	**3,0**	**30,0**	6,0	0,6	150,0	**156,6**	2015/2017 DOE Targets
60%	**5000**	**2,0**	**30,0**	6,0	0,6	100,0	**106,6**	2015/2017 DOE Targets

^ Projected, high-volume manufacturing cost of automotive H2FC systems
° Distributed Natural Gas Reforming status and targets assume station capacities of 1500 kg/day, with 500 stations built per year

<http://ec.europa.eu/research/fch/pdf/sunita_satyapal.pdf#view=fit&pagemode=none >, p. 5-8. K. Wipke *"Controlled Hydrogen Fleet and Infrastructure Analysis"*, US DOE NREL, Annual Merit Review, Washington, 2010, <http://www.hydrogen.energy.gov/pdfs/review10/tv001_wipke_2010_o_web.pdf >, p. 13 and 25. U.S. DOE *"The Department of Energy Hydrogen and Fuel Cells Program Plan - An Integrated Strategic Plan for the Research, Development, and Demonstration of Hydrogen and Fuel Cell Technologies"*, Sep. 2011, Appendix A: About This Document (A2), cit. Other references and assumptions in M. V. Romeri *"Considering Hydrogen Fuel Cells Powertrain as Power Generation Plant"*, World Electric Vehicles Symposium EVS25 "Sustainable Mobility Revolution". Shenzhen, China 2010, cit.

18 - Using the EIA *"The Impact of Increased Use of Hydrogen on Petroleum Consumption and Carbon Dioxide Emissions"* H_2 production costs (after a check of row material 2008 price assumption coherence with current price) the low value of this range could be reduced from 2.0 USD/GGE (see Table 2.1 Estimated Hydrogen Production Costs). Thanks to the fact that expected system life is shorter than one year (also in 2015/2017) it is not necessary to consider any financial aspect. Also, in a conservative perspective, I do not take in consideration the possibility to recover the heat co-produced during the electricity generation (like in a CHP power plant).

Based on the above mentioned assumption the LCOE H2FC Powertrain range value is today 174 -191 USD/MWh and 107-207 USD/MWh for 2015/2017.

If the current U.S. Hydrogen and Fuel Cell Vehicle Program is able to meet all the 2015/2017 technological targets the high volume associated with the H2FC vehicles mass production will permit to reduce dramatically the Fuel Cell system manufacturing costs and the H2FC Powertrain will be so cost competitive to be useful adopted also for stationary power generation application.

Using the 2015/2017 DOE H2FC Powertrain data target the LCOE would be in a range of USD 107-207 for MWh and, in the U.S. context, the lower value of this range appears competitive with many of the power generation technologies considered.

7. Energy in Japan

Japan has few domestic energy resources and is only 16% energy self-sufficient[19]. Japan is the world's largest importer of LNG and coal and the third largest net importer of oil.

In Japan[20] oil accounts for about 47% of the primary energy supplied and, in the transport sector, the degree of dependence on oil is almost 100%. Energy consumption in Japan has increased in the commercial, residential and transport sector with changes in lifestyle and higher rate of vehicle ownership. In the industrial sector, energy consumed has been progressively saved. When the first oil crises occurred, in 1973, to promote energy conservation and to stabilize its energy supply, Japan endeavored to reduce its oil dependence through the introduction of nuclear power and natural gas. After the second oil crisis in 1979, Japan accelerated the process of introduction of nuclear power and the development and introduction of new energy.

With regards of Japan electricity sector **Table 4** and **5** describe, based on ANRE-METI[21] data, the Japan trend in terms of generation plant and power generated by type of fuel.

Table 4 - Trend of Eletrical Generation Facilities' Capacity by Type of Fuel

FY	1973	2008
Oil	60,8%	19,5%
Coal	6,6%	15,7%
Natural Gas	3,1%	25,1%
Nuclear Power	2,8%	20,1%
Pumping Hydro-Power	6,4%	10,7%
Hydro / Geothermal / New Energy	20,2%	8,9%
TOTAL (GW)	80,39	238,90

Table 5 - Trend in Eletric Power Generated by Type of Fuel

FY	1973	1979	1985	1990	1995	2000	2005	2008
Oil	73,0%	53,0%	27,0%	29,0%	19,0%	11,0%	11,0%	12,0%
Coal	5,0%	4,0%	10,0%	10,0%	14,0%	18,0%	26,0%	25,0%
Natural Gas	2,0%	14,0%	22,0%	22,0%	22,0%	26,0%	24,0%	28,0%
Nuclear Power	3,0%	14,0%	27,0%	27,0%	34,0%	34,0%	31,0%	26,0%
Pumping Hydro-Power	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%
Hydro / Geothermal / New Energy	16,0%	15,0%	13,0%	11,0%	9,0%	9,0%	8,0%	8,0%
TOTAL (TWh)	379,00	491,80	584,00	737,60	855,70	936,60	988,90	991,50

The 2002 ***Basic Act on Energy Policy***[22] outlined the general guideline for Japan's energy policy and identified three main principles: securing of stable supply, environmental suitability, and utilization of market mechanisms. In 2003, the government decided a *Basic Energy Plan*[23], establishing long-term energy demand and supply related policies. After the coming into effect of the Kyoto Protocol, METI published the *New National Energy Strategy*[24] based on new international energy supply-demand structure and, consequently, in 2007 the government revised the *Basic Energy Plan*[25] that depicted Japan as a nation based on atomic energy.

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19 - U.S. EIA "*Japan, Country Analysis Briefs"*, Mar. 2011 < http://www.eia.gov/countries/cab.cfm?fips=JA >.

20 - Agency for Natural Resources and Energy (ANRE), *"Energy in Japan 2010"*, <http://www.enecho.meti.go.jp/topics/energy-in-japan/english2010.pdf >, p. 3-9.

21 - ANRE *"Energy in Japan 2010"*, cit. p 9-10.

22 - *"Basic Act on Energy Policy"*, 2002, < http://www.japaneselawtranslation.go.jp/law/detail/?id=123&vm=04&re=02&new=1>. The government shall review the *Basic Energy Plan* at least once every three years by taking into consideration the changes in the situation concerning energy.

23 - Ministry of Economy, Trade and Industry (METI) "エネルギー基本計画 平成１５年１０月" - *"Basic Energy Plan"*, Oct. 2003, <http://www.meti.go.jp/report/downloadfiles/g31006b1j.pdf >.

24 - METI "新 国家エネルギー戦略 ２００６年５月" - *"New National Energy Strategy"*, 2006, <http://www.meti.go.jp/press/20060531004/senryaku-houkokusho-set.pdf >. The *New National Energy Strategy* is focused on three main objects: establishment of energy security measures; establishment of the foundation for sustainable development through a comprehensive approach for energy issues and environmental issues all together; and commitment to assist Asian and world nations in addressing energy problems. The New Strategy also promoted the future implementation of four plan: *Energy Conservation Frontrunner Plan* (Target: At least another 30% improvement in energy efficiency by 2030); *Transport Energy for the Next Generation Plan* (Target: Reduction of oil dependence to around 80% by 2030); *New Energy Innovation Plan* (Target: Reduction of solar energy power generation cost, and improvement of the self-sufficiency ratio of the energy supply); and *Nuclear Power National Plan* (Target: The ratio of nuclear power to all power production will be maintained or increased at the level of 30% to 40% or more up to 2030 or later). METI *"New National Energy Strategy"* Press Release May 2006, <http://www.meti.go.jp/english/information/downloadfiles/PressRelease/NewEnergyStrategy.pdf >.

25 - METI "エネルギー基本計画 平成１９年3 月" - *"Basic Energy Plan"*, 2007, < http://www.meti.go.jp/press/20070309003/energy-plan-.pdf >.

8. Japan's Role in World Energy

Japan is one of the major exporters of energy sector-capital equipment and has a strong energy research and development program that is supported by the government, which pursues energy efficiency measures domestically in order to increase the country's energy security and reduce CO_2 emissions[26].

Japan is actively engaged in the international policy-making process[27] and is committed to guiding the world's economies along a sustainable and secure energy pathway.

In May 2007, Japan launched its ***Cool Earth 50*** strategy, aimed at lowering global greenhouse gas emissions and encouraging international participation[28]. In January 2008, at the World Economic Forum in Davos Japan presented its *Cool Earth Promotion Programme*[29], which focuses on how to implement the strategy. A committee made up of executives from private companies along with the director of Japan's R&D institute was set up to identify key technologies, develop road-maps for their development and consider the direction to promote international technology co-operation further. The conclusions were published in the *Cool Earth – Innovative Energy Technology Program*[30] in March 2008.

Japan held the **G8 presidency** in 2008 and placed international efforts to fight climate change at the top of the G8 Summit agenda in Hokkaido Toyako. Under the theme of environment, Japan urged leaders to focus on concrete goals and means to address the imminent challenge of climate change. Prime Minister Fukuda led discussions based on the *Cool Earth* initiatives and, at the end of Summit, Leaders announced their intention of seeking to share with all parties of the UNFCCC the vision to consider and adopt the goal of at least a 50% reduction of global emissions by 2050.[31]

The Japan G8 presidency and Prime Minister ***Hatoyama Initiative***[32] paved the way for subsequent international climate change agreements since Durban.[33]

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26 - U.S. EIA *"Japan, Country Analysis Briefs"*, cit.

27 - International Energy Agency (IEA) *"JAPAN 2008 Review"*: *"the second-largest economy in the IEA, Japan is a world leader in progressing energy and environmental policy. (…) With a gross domestic product (GDP) of almost USD 4.4 trillion in 2006, Japan's economy is the second-largest in the world and about one-third the size of the United States' economy. The economy is driven by its manufacturing sector – particularly electronics and vehicles – which makes up over a fifth of the total."* P. 9 and 17, < http://www.iea.org/textbase/nppdf/free/2008/Japan2008.pdf >.

28 - The 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report has providing the most comprehensive assessment of the science and encourages the continuation of the science-based approach that should guide the climate protection efforts. The IPCC has concluded that global CO_2 emissions must be reduced by 50% to 80% by 2050 (445-490 ppm) if the long-term mean global temperature rise is to be limited to between 2 and 2.4°C. "*Fourth Assessment Report of the Intergovernmental Panel on Climate Change"*, UN IPCC 2007, < http://www.ipcc.ch/ >.

29 - IEA "*JAPAN 2008 Review"*, cit. p. 33-34. The *Cool Earth Promotion Programme* has three pillars: *A post-Kyoto Protocol framework; International environment co-operation and Innovation.* In order to halve greenhouse gas emissions by 2050, it will be critical to have breakthroughs in technological innovation. Japan proposes the formulation of an international framework through which the world can collaborate closely with international agencies such as the IEA to accelerate technology development and share the fruits of such efforts. Japan will undertake a fundamental rethinking of all its societal systems in order to shift Japan to a low-carbon society.

30 - METI, March 2008, Press Release: *"Establishment of the Cool Earth Energy Innovative Technology Plan"* <http://www.meti.go.jp/english/newtopics/data/nBackIssue20080305_04.html >, accessed Mar. 2012. *"Cool Earth-Innovative Energy Technology Program"*, <http://www.meti.go.jp/english/newtopics/data/pdf/031320CoolEarth.pdf >, *"Technology Development Roadmap"*, <http://www.meti.go.jp/english/newtopics/data/pdf/CE_RoadMap.pdf >.

31 - ***"G8 Hokkaido Toyako** Summit - Leaders Declaration"*, N. 23, < http://www.mofa.go.jp/policy/economy/summit/2008/doc/doc080714__en.html >. Also, Leaders: *"added that making progress towards the shared vision, and a long-term global goal will require mid-term goals and national plans to achieve them; stressed that this global challenge can only be met by a global response and this will require both accelerating the deployment of existing technologies and the development and deployment of new low-carbon technologies; agreed that "sectoral approaches" can be useful tools to improve energy efficiency and reduce GHG emissions through dissemination of existing and new technologies; asked IEA to develop global technology roadmaps to support low-carbon technologies introduction"*. Idem, N. 25.

32 - Prime Minister proposed to the international community an "Hatoyama Initiative" based on four points that was included in the Copenhagen Accord: *"Japan deems the following four principles essential in assisting developing countries: First, the developed countries, including Japan, must contribute through substantial, new and additional public and private financing. Second, we must develop rules that will facilitate international recognition of developing countries' emissions reductions, in particular those achieved through financial assistance, in a measurable, reportable and verifiable manner. Third, on assistance to developing countries, consideration should be given to innovative mechanisms to be implemented in a predictable manner. And an international system should be established under the auspices of the UN climate change regime. This system should facilitate one-stop provision of information on and matching of available bilateral and multilateral financing, while securing transparency and effective utilization of assistance. Fourth, Japan proposes to establish a framework to promote the transfer of low-carbon technologies which ensures the protection of intellectual property rights."* Statement by Prime Minister Hatoyama at UN Summit on Climate Change, September 2009, <http://www.kantei.go.jp/foreign/hatoyama/statement/200909/ehat_0922_e.html >.

33 - In December 2009 the UN-COP15 "takes note" of the **Copenhagen Accord**, a political, and not legally-binding, agreement in which the Leaders of delegations present: 1) agreed that climate change is one of the greatest challenges of our time. 2) Agreed that deep cuts in global emissions are required according to science, and as documented by the IPCC AR4 with a view to reduce global emissions so as to hold the increase in global temperature below 2° C, and call for an assessment of the implementation of this Accord to be completed by 2015, including consideration of strengthening the long-term goal (in relation to temperature rises of 1.5° C). 3) Agreed that developed countries shall provide adequate, predictable

9. Most Recent Events

Since bubble economy collapsed in the early 1990s, Japan has been suffering from long-term sluggish economy, decreased growth potentials as well as further deteriorated fiscal balance[34]. With population decreasing and aging, the Japanese socioeconomic system did not seem able to provide appropriate solutions. The global financial crisis of 2008 delivered a direct blow to the Japanese economy, which was overly dependent on external demand, and pushed the country into recession.

In December 2009, new government approved the *Emergency Economic Countermeasures* and ***The New Growth Strategy***[35] aiming to create demand and new jobs through the pursuit of a "problem-solving" national strategy, focused on key challenges, mainly global warming (energy) and population ageing, which can be turned into sources of growth: "green innovation"[36] and "life innovation".

In June 2010 government formulated *The New Growth Strategy*[37] and, consistently, made **second Revision of the *Basic Energy Plan***[38]. At the three basic principles, two new points were added: the *"energy-based economic growth"* and the *"reform of the energy industrial structure"*. Japan will fundamentally change its energy supply and demand system by 2030. Ambitious target[39] were set and specific measures[40] were identified including relevant plans[41] to expand the nuclear component of the country's energy mix and to build next-generation energy and social systems.

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and sustainable financial resources, technology and capacity-building to support the implementation of adaptation action in developing countries; decided to pursue various approaches, including opportunities to use markets, to enhance the cost-effectiveness of, and to promote mitigation actions; decided to establish a Technology Mechanism to accelerate technology development and transfer in support of action on adaptation and mitigation that will be guided by a country-driven approach and be based on national circumstances and priorities (The collective commitment by developed countries is to provide new and additional resources approaching USD 30 billion for the period 2010–2012 and a goal of mobilizing jointly USD 100 billion dollars a year by 2020). 4) Annex I Parties commit to implement individually or jointly the quantified economy wide emissions targets for 2020 and Non-Annex I Parties to the Convention will implement mitigation actions (…) in the context of sustainable development. *"The Copenhagen Accord"*, 2009, <http://unfccc.int/meetings/copenhagen_dec_2009/items/5262.php >.

In December 2010 the UN–COP16 in Cancun, Mexico, ended with the adoption of a balanced package of decisions that set all governments more firmly on the path towards a low-emissions future and support enhanced action on climate change in the developing world. In particular the **Cancun Agreements** include: 1) Industrialised country targets (provided under the Copenhagen Accord) are officially recognised under the multilateral process and these countries are to develop low-carbon development plans and strategies and assess how best to meet them, including through market mechanisms, and to report their inventories annually. 2) Developing country actions to reduce emissions (in 2020 timeframe) are officially recognised under the multilateral process. Cancun Conference, Nov. - Dec. 2010, < http://unfccc.int/meetings/cancun_nov_2010/meeting/6266.php >.

In December 2011, Countries meeting in **Durban**, South Africa, at UN-COP 17 agreed to define a roadmap to a new legally binding global agreement. Countries have delivered a breakthrough on the future of the international community's response to climate change, whilst recognizing the urgent need to raise their collective level of ambition to reduce greenhouse gas emissions to keep the average global temperature rise below two degrees Celsius. Governments, including 35 industrialised countries, agreed a second commitment period of the Kyoto Protocol from 1 January 2013. During 2012, countries have to agree on the length of the commitment period. Countries that will participate in the second commitment period will turn their economy-wide targets into quantified emission limitation or reduction objectives under the Kyoto Protocol and submit them for review by 1 May 2012. At Durban, Countries agreed to negotiate a universal legal agreement under which all countries will mitigate their emissions in the long run. These negotiations will take place under a new body in the Climate Convention (the Durban Platform). Governments decided to adopt a universal legal agreement on climate change as soon as possible, but not later than 2015. They have also set the deadline of 2020 for the entry into force of this new agreement. Durban Conference, Nov. - Dec. 2011, <http://unfccc.int/meetings/durban_nov_2011/meeting/6245.php >.

34 - According to *"Strategy for Rebirth of Japan"*, December 2011, < http://www.npu.go.jp/policy/pdf/20120127/20120127_en1.pdf >.

35 - *"New Growth Strategy (Basic Policies) Toward a Radiant Japan"*, Dec. 2009, <http://www.npu.go.jp/en/policy/pdf/1230sinseichousenryaku_e.pdf >. And "*Emergency Economic Countermeasures for Future Growth and Security"*, December 2009, < http://www.npu.go.jp/en/policy/policy04/pdf/20091208/091228_emergency_economic.pdf >.

36 - *"New Growth Strategy (Basic Policies) Toward a Radiant Japan"*, cit. Targets to reach by 2020 from "green innovation": create over JPY50 trillion in new environment-related markets and 1,4 million new environment sector jobs and reduce worldwide greenhouse gas emissions by at least 1,3 billion tons of CO_2 equivalent (equivalent to the total emissions of Japan) using Japanese private-sector technology.

37 - *The New Growth Strategy* identified 7 areas for economic growth and 21 National Strategic Project. Areas for growth: green innovation; life innovation; the Asian economy; tourism and the regions; science and technology and information and communications technology; employment and human resources; financial sector. The National Strategic Projects related to "green innovation" are: Rapidly Increase Renewable Energy by Introducing a Feed-in Tariff System; Future City initiative; and Forest and Forestry Revitalization Plan. *"The New Growth Strategy Blueprint for Revitalizing Japan"*, 18 June 2010, < http://www.npu.go.jp/en/policy/policy04/pdf/20100706/20100706_newgrowstrategy.pdf >.

38 - METI "エネルギー基本計画 平成22 年6 月" - *"Basic Energy Plan"*, June 2010 < http://www.meti.go.jp/press/20100618004/20100618004-2.pdf > and *"The Strategic Energy Plan of Japan (Summary)"* < http://www.meti.go.jp/english/press/data/pdf/20100618_08a.pdf >.

39 - Idem. **Targets**: Double the energy self-sufficiency ratio in energy supply and the self-developed fossil fuel; Raise the zero-emission power source ratio from current 34% to about 70%; Half CO_2 emissions from the residential sector; Maintain and enhance energy efficiency in the industrial sector at the highest level in the world; Maintain or obtain top-class shares of global markets for energy related products and systems; Domestic energy related CO_2 emissions will be reduced by 30% or more in 2030 compared to the1990 level.

40 - Idem. **Establishment of an independent and environmental-friendly energy supply structure**: expanding the introduction of renewable energy through the feed-in tariff system; advanced utilization of fossil fuels; accelerating the CCS technology development. **Establishment of a low carbon energy demand structure:** in industrial sector (enhancing energy efficiency and conservation, and commercializing innovative technologies); in residential sector (through net-zero-energy houses, new compulsory energy-saving standards, replacing lights with highly-efficient LED); in commercial sectors (enhancing support and regulatory measures to diffuse energy-saving consumer electronics, energy-saving information

On Friday 11 March 2011 the 9,0 magnitude **Great East Japan Earthquake** struck off the coast of Sendai, Japan, triggering a large tsunami, and caused more than 19 thousand victims[42]. The Great East Japan Earthquake led to the Fukushima Daiichi nuclear accident[43] that caused broad concerns regarding energy issues among the public and has thrown the long-term role of Japan nuclear power into doubt[44].

The Great East Japan Earthquake was a *"crisis in the midst of a crisis"*[45] and the Government decided that the *New Growth Strategy* should be reexamined taking into account the impact of the earthquake. The Council[46] identified the formulation of the ***Innovative Strategy for Energy and Environment*** as the most significant issue to be considered in light of the nuclear incident and subsequent electricity restrictions.*"For the mid- to long-term, the Government will develop a new best mix of energy sources centered on a reduced dependence on nuclear energy and the acceleration of Green Innovation, with the aim of developing distributed energy systems supported by new technologies"* [47].

The Council set up the Energy and Environment Council[48] to develop, in the summer 2012[49], the *Innovative Strategy for Energy and the Environment*[50] as pillars of Japan's revitalization based on new technology framework. As the basis for developing the new strategy, the EEC's Cost Review Committee has reviewed power generation cost data[51] to examine energy mix.

Table 6 (next page) describes Japan cost of selected generation plant technologies in 2004, 2010 and 2030 based on Cost Review Committee[52] data.

10. Hydrogen and Fuel Cells in Japan

Japan has a long tradition in Hydrogen and Fuel Cells with many subjects[53] involved.

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technology equipment, heat pump water heaters, fuel cells, hybrid construction machines and other highly efficient equipment); in transportation sector (raising next-generation vehicles' share of new vehicle sales to up to 50% by 2020).

41 - Idem. **Nuclear**: In 2010, Japan was the world's third-largest producer of electricity by nuclear power. The second Revision of *Basic Energy Plan* set an ambitious plan to expand the nuclear component of the country's energy mix (more than half of its power generation in 2030), building nine new or additional nuclear plants (with the overall plant capacity utilization rate at about 85%) by 2020 and another five by 2030. **Next-Generation Energy:** Realizing the smart grid and smart communities; Promoting the development, installation of smart meters and energy management systems; Diffusing fixed fuel cells and developing a hydrogen supply infrastructure, including hydrogen stations for fuel cell vehicles.

42 - According to *"March 11, One Year On: By the Numbers"* The Wall Street Journal, 10 March 2012, <http://blogs.wsj.com/japanrealtime/2012/03/10/march-11-one-year-on-by-the-numbers/tab/print/ >.

43 - According to IEA *World Energy Outlook 2011* resulted in the immediate loss of 9.7 GW of nuclear capacity, which was automatically shut down. Earthquake also led to the temporary loss of 12 GW of coal, gas and oil-fired capacity. In total, this amounted to about 8% of the country's total power production capacity. IEA *"World Energy Outlook 2011"*, p. 453 - 454. < http://www.iea.org/w/bookshop/add.aspx?id=428 >.

44 - As of 27 January 2012 only 3 of 54 existing nuclear power plants in Japan were in operation. K. Ogata "*Outlook of Energy Resources in Japanese Power Sector and Application Technologies after Earthquake of 11th March"*, p. 5, The 3rd IAEE Asian Conference, Kyoto, February 2012, < http://eneken.ieej.or.jp/3rd_IAEE_Asia/pdf/plenary/09_MHI_Ogata.pdf >.

45 - *"Interim Report on Strategies to Revitalize Japan"*, Aug. 2011, < http://www.npu.go.jp/en/policy/policy04/pdf/20110701/20110701_01.pdf >.

46 - Idem. Council on the Realization of the New Growth Strategy (Council).

47 - Idem, p. 6.

48 - The Energy and Environment Council (EEC) is a subcommittee under the Council on National Strategy and Policy (National Policy Unit - NPU). EEC is assigned to formulate innovative energy strategies in collaboration with METI (responsible for the Japanese energy policy).

49 - *"The Strategy for Rebirth of Japan"*, December 2011, p. 4, < http://www.npu.go.jp/policy/pdf/20120127/20120127_en1.pdf >.

50 - According to the *Interim Report on Strategies to Revitalize Japan* composed of the *"Basic Energy Plan"* (a new best mix of energy sources), a *"Strategy for the Energy and Environment Industries"*, and the *"Green Innovation Strategy"*. Cit. p. 9.

51 - According to The Institute of Energy Economics, Japan IEEJ *"The cost of nuclear power generation increased by 50% from the estimates made in 2004 as a result of incorporating social costs such as accident risk response. However, thermal power costs have also increased because of higher fossil fuel prices and introduction of measures to reduce CO_2 emissions. As a result, costs among base power sources have been brought to more or less the same range. Distributed power sources, such as cogeneration systems, and energy efficiency and conservation measures, such as LED lights and high efficiency air conditioners, were also identified to be viable contributor to the energy mix. The nuclear power generation cost is revised to at least JPY 8.9/kWh or an increase of 50%, reflecting inflated construction costs and additional safety costs (JPY 1.4/kWh), policy-related costs, including subsidies given to host communities of nuclear plants and R&D costs for the Nonju fast-breeder reactor (JPY 1.1/kWh), and damages identified at present for the Fukushima Daiichi accident (5.8 trillion JPY, or JPY 0.5/kWh). The accident risk funds, is currently estimated to be 5.8 trillion JPY per model plant (…). If damages amount to 10 trillion JPY, the generation cost is calculated to be JPY 9.3/kWh, and if 20 trillion JPY, this will be JPY 10.2/kWh. (…) Generation costs for large-scale base-load power plants fueled by coal and LNG are also revised upward incorporating CO_2 reduction costs and rising fuel prices, but still remain around JPY 9.5 to 11/kWh and within competitive ranges. Costs for oil-fired thermal power plants were estimate differently; these are JPY 25/kWh as a middle load power source operating at 50% load factor and considerably higher at JPY 39/kWh as a peak load power source operating at 10%. (…) taking account of the benefits of waste heat utilization, gas cogeneration costs are estimated to be in the range of JPY 10.6-11.5/kWh, which is comparable to large-scale thermal power plants. The generation cost of fuel cells, which have just emerged in the marketplace, is expected to fall significantly to reach JPY 11/kWh in 2030."* IEEJ *"Japan Energy Brief"* No.17, January 2012, < http://eneken.ieej.or.jp/en/jeb/1201.pdf >.

52 - Energy and Environment Council's Cost Review Committee "コスト等検証委員会報告書 平成23年12月19日" - *"Cost Review Committee Report"*, Dec. 2011, Table 36 - Electricity Generation Cost by Source, p. 62, < http://www.npu.go.jp/policy/policy09/pdf/20111221/hokoku.pdf > or "主な電源の発電コスト" - *"Electricity Generation Cost by Source"* < http://www.npu.go.jp/policy/policy09/pdf/20111221/hokoku_kosutohikaku.pdf >.

Table 6 - Japan Electricity Generation Cost by Source (Cost Review Committee, Dec. 2011 - JPY/kWh)							
	2004	2010	2030	2010^	2030^	Life (Years)	Utilization %
Nuclear	5,9	8,9～	8,9～			40	70
Coal	5,7	9,5	10,3			40	80
LNG	6,2	10,7	10,9			40	80
Oil	16,5					40	
Oil		36,0	38,9			40	10
Oil		22,1	25,1			40	50
Wind (On Shore)		9,9～17,3	8,8～17,3			20	20
Wind (Off Shore)		9,4～23,1	8,6～23,1			20	30
Geothermal		9,2～11,6	9,2～11,6			40	80
Solar (PV Mega)		30,1～45,8	12,1～26,4			20 (35)	12
Solar (PV Home)		33,4～38,3	9,9～20,0			20 (35)	12
Hydro (Large)		10,6	10,6			40	45
Hydro (Small)		19,1～22,0	19,1～22,0			40	60
Biomass (Firing)		17,4～32,2	17,4～32,2			40	80
Biomass (Co-Combustion)		9,5～9,6	9,5～9,7			40	80
CHP Gas		10,6	11,5	19,7	20,1	30	70
CHP Oil		17,1	19,6	22,6	26,0	30	50
Fuel Cell (ENE-FARM)		101,9	11,5	109,3	18,7	10 (15)	46

^Before Heat Value Deduction

The Hydrogen Energy Systems Society of Japan was established almost 35 years ago to promote the importance of hydrogen energy systems and NEDO was created in 1980 by the MITI. The development of Fuel Cells was introduced with the Moonlight Program in 1981 and WE-NET[54] project was focused on Hydrogen research. In 1999 the RD&D activities of PEM Fuel Cells were initiated by the METI's Policy Study Group on Fuel Cell Commercialization that, in 2001, released a national strategy[55] with ambitious goals. New Energy technologies and Fuel Cells were been positioned in priority areas of 2001 *Science and Technology Basic Plan*[56]. In 2002, Prime Minister Koizumi underlined in a policy speech to the Diet the role of Fuel Cell toward a Hydrogen economy[57] and Fuel Cells were considered in the 2003 *Basic Energy Plan*[58]. In 2004 Japan had one

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53 - Among other: Ministry of Economy, Trade and Industry (METI, formerly known as MITI), < http://www.meti.go.jp/english/ >; Agency of Natural Resources and Energy (ANRE, part of METI), < http://www.enecho.meti.go.jp/english/index.htm >; New Energy and Industrial Technology Development Organization (NEDO, an affiliate of METI), < http://www.nedo.go.jp/english/ >; Fuel Cell Commercialization Conference of Japan (FCCJ) < http://fccj.jp/eg/ >; Hydrogen Energy Systems Society of Japan (HESS), < http://www.hess.jp/hess_contents/index.english.html >; National Institute of Advanced Industrial Science and Technology (AIST, part of METI, formerly, Agency of Industrial Science and Technology) < http://www.aist.go.jp/index_en.html >; Japan Automobile Research Institute (JARI), < http://www.jari.or.jp/english/ >; New Energy Foundation (NEF) < http://www.nef.or.jp/english/index.html >; Japan Gas Association (JGA) < http://www.gas.or.jp/english/index.html >; Petroleum Energy Center (JPEC) < http://www.pecj.or.jp/english/index_e.html >; Institute of Applied Energy (IAE) < http://www.iae.or.jp/e/ >; Engineering Advancement Association of Japan (ENAA) < http://www.enaa.or.jp/EN/ >.

54 - The 1993-2002 "International Clean Energy System Technology Utilizing Hydrogen (World Energy NETwork)" WE-NET project was part of "New Sunshine Program" that aimed to develop innovative technologies for sustainable growth. < http://www.enaa.or.jp/WE-NET/contents_e.html >.

55 - Policy Study Group for Fuel Cell Commercialization reports: "燃料電池実用化戦略研究会報告２００１年1 月２２日" - *"Study Group Report on Commercialization of Fuel Cell Technology"*, Jan. 2001, < http://www.meti.go.jp/report/downloadfiles/g10122bj.pdf > and "固体高分子形燃料電池／水素エネルギー利用 技術開発戦略 ２００１年8 月8 日" - *"Strategy for Technology R&D of PEM Fuel Cell and Hydrogen Utilization"*, Aug. 2001, <http://www.meti.go.jp/report/downloadfiles/g11221cj.pdf >. According to IEA *"Hydrogen & Fuel Cells – Review of National R&D Programs"* (p. 94) the *"three-stage commercialization plan through 2020, integrates the development of fuel cell, hydrogen production, and hydrogen transportation and storage technologies, concurrently with the implementation of demonstration programs, vehicle sales, construction of refueling infrastructure, establishment of codes and standards, and a general push to enlarge the consumer market for fuel cells and fuel cell vehicles. (…) 2002-2005 will focus on continued technology development, vehicle and stationary fuel cell demonstrations, development of soft infrastructure and codes & standards, and the establishment of fuel standards; 2005-2010 is to be the Introduction Stage, when the introduction of vehicles will be accelerated along with the gradual establishment of the fuel supply system. Finally, the Diffusion Stage will encompass initiatives taken forward from FY2011, particularly the establishment of fuel supply system and 'self-sustained growth' driven by private sector promotion and adoption"*. IEA *"Hydrogen & Fuel Cells – Review of National R&D Programs"*, Dec. 2004, < http://www.iea.org/textbase/nppdf/free/2004/hydrogen.pdf >, accessed Jan. 2006, or < http://www.amazon.com/Hydrogen-Fuel-Cells-National-Programs/dp/9264108831 >, accessed Mar. 2012.
Strategy goals. Commercialization: By the end of **Introduction Stage in 2010**: 50.000 Fuel Cell Vehicles and 2,1 GW of stationary Fuel Cell CHP systems; By the end of **Diffusion Stage in 2020**: 5.000.000 FCV and 10 GW of stationary Fuel Cell CHP systems. **Performance (2010): Durability:** Vehicles, system (stack and reformer) more than 5.000 hours; Stationary: system (stack and reformer) more than 40.000 hours. **Cost:** Vehicles, system below 5.000 JPY/kW (FC stack less than 4.000 JPY/kW; reformer less than 1.000 JPY/kW); Stationary: FC stack less than 80.000 JPY/kW; reformer less than 20.000 JPY/kW (Price system Home use below 300.000 JPY/system; Price Business use below 150.000 JPY/kW). **Refuel infrastructure**: in the near future 'Reports' suggested also the possible use of "clean gasoline" or GTL (Gas to Liquid).

56 - Government of Japan *"The Science and Technology Basic Plan (2001-2005)"*, Mar. 2001, < http://www8.cao.go.jp/cstp/english/basic/2nd-BasicPlan_01-05.pdf > and Council for Science and Technology Policy *"Promotion Strategy for 8 Prioritized Areas"*, Sep. 2001, <http://www8.cao.go.jp/cstp/english/basic/2nd-strategy_01-05.pdf >.

57 - *"The fuel cell is the key to opening the doors to an era in which hydrogen will be used as source of energy. We will aim to achieve its practical use as a power source for automobiles and a source of electric power for households within three years"*. Prime Minister J. Koizumi to the 154th Diet Session, Feb. 2002, < http://www.kantei.go.jp/foreign/koizumispeech/2002/02/04sisei_e.html >.

of the most ambitious and comprehensive initiatives in the world, with verification projects[59] and roadmaps[60].

These activities to verify and promote Hydrogen & Fuel Cell technologies recognized that they were still in the developing phase and need more time to be competitive in the market and, for this reason government asked industry to pay more attention to basic research. METI established two new national laboratories[61] and the demonstration projects continued[62]. Considering that these technologies can be very promising option for CO_2 reduction were included in 2006 *New National Energy Strategy*[63] and in *2007 Basic Energy Plan*[64] first revision. In 2008 Fuel Cell Vehicles, Stationary Fuel Cells and Hydrogen appeared among the 21 innovative energy technology proposed in the *Cool Earth Energy Innovative Technology Plan*[65] and were mentioned in a 2009 statement by Prime Minister Hatoyama[66].

In January 2009 six gas companies started of marketing ENE-FARM[67] **PEFC systems for residential use** under the joint slogan "*ENE-FARM – Helping to Establish an Environmentally Advanced Nation*" and, in May, three fuel cell systems mass-producers companies (Panasonic, ENEOS Celltech and Toshiba Fuel Cell Power Systems) launched the full-scale sales[68]. More than 21.000 PEFC systems are installed in Japan in November 2011[69].

The Japanese auto and related industries have been successful in the global market with their high technical capacity and served as Japan's leading industry to drive economy and employment. Increasing interest in environmental problems and natural resource constraints has compelled the auto industry to further improve fuel efficiency, reduce emissions, diversify fuel, and introduce Next-Generation Vehicles (NGVs) to the market on a full-scale basis. To address these issues, the METI *Next-Generation Vehicle Strategy 2010*[70] depicted a national strategy for medium- to long-

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58 - METI "エネルギー基本計画 平成１５年１０月" - *"Basic Energy Plan"*, Oct. 2003, cit. See Chapter 2: Section 3, Point 3 *"Development of new Energy Resources, Introduction and Utilization"* and Section 6, Point 3 *"Efforts Toward the Realization of a Hydrogen Energy Society"*.

59 - Projects implemented in perspective of the start, in 2005, of the introduction phase. **Stationary:** The first full-scale efforts to commercialize PEFCs were initiated under a sub-project of the "Millennium Project" (field test 2000-2004, sponsored by NEDO, operated by JGA) and "The Large-scale Stationary Fuel Cell Demonstration Project" started in 2005 (sponsored by NEDO, operated by NEF), see infra. **Vehicles**: The "Japan Hydrogen & Fuel Cell Demonstration Project" JHFC (subsidized by METI, operated by JARI – FCV and by ENAA – Hydrogen infrastructure), see infra.

60 - Based on METI policy toward construction of hydrogen energy society, **new 2030 targets** were released. Stationary Fuel Cells of 12,5 GW in total on a power generation scale. Vehicles: 15 million FCV on the Japanese road. H_2 price 450 JPY/Kg. FCCJ *"Roadmap for Polymer Electrolyte Fuel Cell (PEFC) Technologies Development"*, Dec. 2003, < http://fccj.jp/eg/pdf/k2_11.pdf > and ANRE "２０３０年を見通した、燃料電池/水素エネルギー社会の展望"- *"2030-Prospects for Hydrogen Energy Society / Fuel Cells"*, Mar. 2004, <http://www.meti.go.jp/report/downloadfiles/g40412b30j.pdf >.

61 - The Polymer Electrolyte Fuel Cell Cutting-Edge Research Center and the Laboratory for Hydrogen Material R&D.

62 - The **"Demonstration of Residential PEFC System for Market Creation"** project (2005-2008), also known as "The Large-scale Stationary Fuel Cell Demonstration Project", installed 3.307 residential PEFC CHP systems in houses nationwide and collected operation data on use. M. Akai, *"Stationary Fuel Cell Programme in Japan"*, Paris 2010, < http://www.iea.org/work/2010/transform/akai.pdf > and *"Progress Report on The Large-scale Stationary Fuel Cell Demonstration Project in Japan"*, NEF 2009, < http://ieahia.org/pdfs/Task18_Japan_Residential_FC_Report.pdf >.
The **Japan Hydrogen and Fuel Cell (JHFC) Demonstration Project** started in 2002. In Phase 1 (2002-2005) it clarified the high energy efficiency of FCVs (in terms of *Well to Wheel* efficiency) and demonstrated data of FCVs and hydrogen stations. The major achievements reported on Phase 2 (2006-2010) included the safe operating experience at 15 refueling stations and operation of FCVs. Phase 3 of the project (2011-2015) has been started recently with these major issues: 70 MPa refueling, cost reduction, more frequent operation of refueling stations and total system from H2 production to refueling. Japan Hydrogen and Fuel Cell (JHFC) Demonstration Project < http://www.jari.or.jp/jhfc/e/jhfc/index.html > and IEAHIA *"Japan Member Update"*, 2011, <http://ieahia.org/pdfs/Copenhagen/Japan_64ExCo_Copenhagen_June2011.pdf >.

63 - The *Transport Energy for the Next Generation Plan* (Target: Reduction of oil dependence to around 80% by 2030) included development and promotion of the dissemination of electric vehicles and fuel cell vehicles. See: METI *"New National Energy Strategy"* Press Release 31 May 2006, cit. and METI "新 国家エネルギー戦略２００６年5月" - *"New National Energy Strategy"*, cit. p. 38. Fuel Cell was also considered in *New Energy Innovation Plan* (Target: Reduction of solar energy power generation cost, and improvement of the self-sufficiency ratio of the energy supply), see: idem, p.41.

64 - METI "エネルギー基本計画 平成１９年3月" - *"Basic Energy Plan"* first revision, 2007, cit. See: *Fuel Cell Vehicles* (p. 31) and *Efforts Toward the Realization of a Hydrogen Energy Society* (p.40).

65 - The Cool Earth-Innovative Energy Technology Program (METI, Mar. 2008, cit., p.3) identified "21" innovative energy technologies with relative development roadmap through 2050 including: "Fuel Cell Vehicle", "Stationary Fuel Cell" and "Hydrogen Production, Transport and Storage".

66 - *"Needless to say, solar panels, fuel cells and various other types of green technology need to be mobilized. Hydrogen energy is also likely to become available in the future."* Press Conference by Prime Minister Hatoyama following the United Nations and the Pittsburgh G20 Summit, Sep. 2009, < http://www.kantei.go.jp/foreign/hatoyama/statement/200909/25naigai_e.html >.

67 - M. Akai, *"Stationary Fuel Cell Programme in Japan"*, Paris 2010, cit. S. Eguchi *"ENE-FARM Fuel Cell Systems for Residential Use"*, 2009, <http://www.igu.org/knowledge/publications/mag/oct-09/igu_october_2009_7_pages_186-217.pdf >.

68 - S. Eguchi *"ENE-FARM Fuel Cell Systems for Residential Use"*, 2009, cit. "*In 2009, the ENE-FARM systems sold by the six companies cost JPY 3,2-3,465 million (USD 33.000-35.800); the rated output of Panasonic unit is 1 kW and ENEOS Celltech unit is 750 W. The METI started a support programme which subsidises half the cost of equipment and installation, up to JPY 1,4 million (USD 14.460) per unit in FY 2009.*

69 - T. Ito *"NEDO's activities on Fuel Cells and Hydrogen in Japan"*, Nov. 2011, <http://webcast.ec.europa.eu/eutv/portal/pdfgenerator?id=13440 >.

70 - METI Study Group on Next-Generation Vehicle Strategy "次世代自動車戦略2010" – *"Next-Generation Vehicle Strategy 2010"*, Apr. 2010, <http://www.meti.go.jp/press/20100412002/20100412002-3.pdf >.

term actions and included government NGVs diffusion targets by 2020 and 2030[71]. FCVs are defined as one of the NGVs that should be promoted for their potential from the viewpoint of global warming countermeasures, energy security and maintenance of Japan's industrial competitiveness.

In January 2011 thirteen carmakers and hydrogen suppliers issued a **joint statement**[72] in which it was announced that **mass-produced FCVs will be put on sale in 2015.** Prior to this, around 100 refueling stations are expected to be installed primarily in the four metropolitan areas of Tokyo, Aichi, Osaka and Fukuoka by energy suppliers.

After Great East Japan Earthquake, the METI Study Group on Automobile Strategy for New Growth of Japanese Economy published the *Interim Report*[73], based on lessons learned from the disaster and the energy problems after earthquake, that provide new roles of NGVs: "*emergency power source*" in energy limited situation, and "*power supply-demand adjustment*" (based on V2G concept) in smart grid contexts. Also, *Interim Report* promoted the construction of hydrogen stations for the introduction of FCVs and included the 2010 FCVs roadmaps[74].

11. Consideration about the Hydrogen Fuel Cell Powertrain LCOE

Paragraph 6 shows, for the U.S. context and based on the mentioned assumption, a present H2FC Powertrain LCOE range value of 174-191 USD/MWh and of 107-207 USD/MWh in 2015/2017. The H2FC Powertrain overnight cost is today 49 USD/kW and 30 USD/kW in 2015/2017. Using a cross rate of 80 JPY for USD, these U.S. data in Japan context are: LCOE range value of 13.920-15.280 JPY/MWh (today) and of 8.560-16.560 JPY/MWh (in 2015/2017). Overnight cost is today 3.920 JPY/kW and 2.400 JPY/kW in 2015/2017.

If the current U.S. Hydrogen and Fuel Cell Vehicle Program is able to meet all the 2015/2017 technological targets the high volume associated with the H2FC vehicles mass production will permit to reduce dramatically the Fuel Cell system manufacturing costs (in order to be competitive with gasoline ICE systems) and the H2FC Powertrain will be so cost competitive to be useful adopted also for stationary power generation application. In mass production perspective H2FC Powertrain investments cost will be one of the lowest compared to other current power generation technologies overnight cost.

Using the U.S. data in Japan energy context confirm these considerations. In fact, with the 2015/2017 H2FC Powertrain data target, the LCOE would be in a range of JPY 8.560-16.560 for MWh (or 8,56-16,56 JPY/kWh) and the lower value of this range appears competitive with all the power generation technologies considered.

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71 - Idem. **Next-Generation Vehicles (NGV)**: Hybrid (HV), Electric (EV), Plug-in Hybrid (PHV), Fuel Cell (FCV), Clean Diesel (CDV), CNG. **Government Diffusion targets**: **By 2020** NGV account for up to 50% of new vehicle sales (in detail: HV 20-30%, EV+PHV 15-20%, CDV less than 5%, FCV less than 1%); advanced eco-friendly-vehicles (NGV + eco-friendly conventional vehicles) account for up to 80% in 2020. **By 2030** NGV account for up to 70% (50-70%) of new vehicle sales (in detail: HV 30-40%, EV+PHV 20-30%, CDV 5-10%, FCV less than 3%). To achieve this target, the government should provide effective incentives. Strategy identified other plans with regard: **Batteries** (to secure battery R&D and technology); **Rare metals** (to secure rare metals and build resource recycling systems); **Infrastructure** (to install 2 million normal chargers and 5,000 quick chargers); **Systems** (to connect vehicles with the systems - smart grid, etc.); and **International Standards** (to promote strategic International standardization). METI Press Release "*Announcement of the Next-Generation Vehicle Strategy 2010",* Apr. 2010, <http://www.meti.go.jp/english/press/data/20100412_02.html >

72 - METI Press Release "*Joint statement by private companies concerning the introduction of fuel cell vehicles onto the domestic market and the development of hydrogen supply infrastructure - Full launch of FCVs in the market slated for 2015!"*, Jan. 2011, <http://www.meti.go.jp/english/press/2011/0113_01.html >. Toyota Motor, Nissan Motor, Honda Motor, JX Nippon Oil & Energy, Idemitsu Kosan, Iwatani International, Osaka Gas, Cosmo Oil, Saibu, Showa Shell Sekiyu, Taiyo Nippon Sanso, Tokyo Gas, Toho Gas. T. Ito "*NEDO's activities on Fuel Cells and Hydrogen in Japan"*, Nov. 2011, cit.

73 - METI Study Group on Automobile Strategy for New Growth of Japanese Economy "中間とりまとめ 平成23年6月" – "*Interim Report"*, Jun. 2011, <http://www.meti.go.jp/press/2011/06/20110615002/20110615002-4.pdf >.

74 - **NEDO Technical Roadmap** is an analytic document with many technical goals and cost targets. Fuel Cell Vehicles outlook cost: towards the diffusion period, it is necessary to reduce to less than 500.000 yen manufacturing cost (that, for a 100 kW stack, it is about 50 JPY/kW) assuming a 500.000 units/year mass production (present system cost, more than 10 million JPY). Stationary PEFC system: cost of the entire system about 500 to 700.000 JPY (current cost about 1 million JPY) assuming a 100.000 units/year mass production (but further cost reduction will be feasible according to the diffusion of FCV). H_2 supply cost: about 40 to 60 JPY/m3. NEDO "NEDO燃料電池・水素技術開発ロードマップ2010 平成22 年6 月" - "NEDO 2010 Fuel Cell and Hydrogen Technology Development Roadmap", <http://app3.infoc.nedo.go.jp/informations/koubo/other/FF/nedoothernewsplace.2009-02-09.3960481985/nedoothernews.2010-07-14.2342472174/kaisetsu.pdf >, Jul. 2010. **FCCJ Roadmap**: To achieve the goal set by government to reduce 80% of CO_2 in the transportation sector by 2050, the scenario lays out a diffusion of 2 millions of FCV and construction of around 1.000 hydrogen stations in 2025. FCCJ "*Commercialization Scenario for FCVs and H2 Stations"*, Jul. 2010, < http://fccj.jp/pdf/22_cse.pdf >.

Observing these H2FC Powertrain data, it will be necessary to think the FCVs link to energy sector considering also the possibility to utilize the H2FC Powertrain as a Power Generation Plant, smart grid connected, with relevant and positive consequences for a rapid development of these low-carbon technologies.

The Energy and Environment Council underlined that *"it is not an easy task to create an 'Efficient,' 'Safe,' 'Environment-friendly,' and 'Energy-secured' energy structure"*[75] but in the current energy policy debate H2FC Powertrain utilization is still not considered in the range of feasible power generation options[76]. I suggest considering[77] this opportunity in Japan's *Innovative Strategy for Energy and Environment*, toward a *green economy*[78].

75 - EEC *"Interim Compilation of Discussion Points for the Formulation of Innovative Strategy for Energy and the Environment"*, Jul. 2011, <http://www.npu.go.jp/policy/policy09/pdf/20110908/20110908_02_en.pdf >, p. 8.

76 - Considering that installed capacity of Fukushima Daiichi was 4.696 MW and that of Fukushima Daini was 4.400 MW (Total of 9,1 GW) and 80 kWnet capacity of a single H2FC Powertrain (U.S. stack standard), 113.700 modules are necessary to replace all the Fukushima installed capacity. Using present overnight cost of 49 USD/kW, the cost to replace Fukushima installed capacity is USD 445,7 million (using the 2015/2017 cost of 30 USD/kW is USD 272,9 million). In Japan terms JPY 35,7 billion (using the 2015/2017 cost, JPY 21,8 billion). According to IEA WEO 2011 (cit. p. 451) at the end 2010, 49 GW of nuclear gross generation capacity was installed in 54 reactors in Japan.

77 - I suggest consider the opportunity to increase at less than 3% the present FCVs target by 2020 (today *Next-Generation Vehicle Strategy 2010* set the government target at less than 1% of new vehicles sales) and verified the possibility to install, annually, an equal number of H2FC Powertrain in the energy sector (in Japan or abroad). If so, it will be possible to achieve all the mass-production reduction costs by 2020. In fact, considering the present FCVs target and assuming new passenger car registration equal to 2001-2010 average (4.436.000 yearly, JAMA data) more than 40.000 FCVs will be sale in Japan by 2020. According to 2011 *Interim Report*, today there is a vehicles production capacity of 11 million units across the Japan. If we suppose full production capacity utilization by 2020, 1% of FCVs is equal to 110.000 units (of which 40.000 for domestic sales and 70.000 for export). If the 2020 target will be increased at less than 3% (considering an equivalent grow in export) and considering an equal number of H2FC Powertrain produced for the energy sector, it will be possible to produce more than 500.000 H2FC Powertrain per year with the consequent mass-production cost reduction. METI Study Group on Next-Generation Vehicle Strategy "次世代自動車戦略2010" – *"Next-Generation Vehicle Strategy 2010"*, Apr. 2010, cit., METI Study Group on Automobile Strategy for New Growth of Japanese Economy "中間とりまとめ 平成23年6月" – *"Interim Report"*, Jun. 2011, cit. and JAMA *"The Motor Industry of Japan 2011"*, May 2011, < http://www.jama-english.jp/publications/MIJ2011.pdf >.

78 - According to RIO+20 the concept of green economy focuses primarily on the intersection between environment and economy. This recalls the 1992 Rio Conference: the United Nations Conference on Environment and Development. See: RIO+20 Unite Nations Conference on Sustainable Development < http://www.uncsd2012.org/rio20/index.php?menu=62 >.