EVS26
Los Angeles, California, May 6-9, 2012

Considering Hydrogen Fuel Cells Powertrain as Power Generation Plant in the Copenhagen Accord and Cancun Agreements Perspective

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Abstract

Copenhagen Accord's and Cancun Agreements' general perspective does not include any low-carbon technologies consideration and Hydrogen Fuel Cell (H2FC) Vehicles is still not considered as a relevant solution in the energy debate. I presented different analyses in which I argued that it's time to do so.

In this analysis I considered the "H2FC Powertrain" as power generation plant and the Levelized cost of electricity (LCOE) was compared to costs of traditional power generation technologies.

Using the U.S. DOE "H2FC Powertrain" data (referred to high projected production volume) the present LCOE would be in a range of USD 174 -191 for MWh. Using 2015 data target the lower value of the LCOE cost range moves down and it appears competitive with almost all power generation technologies analyzed.

This analysis, based on U.S. data, confirms the possible relevant "H2FC Powertrain" role in Copenhagen Accord's, Cancun and Durban Agreements' perspective both in transport and power generation sectors.

Keywords: PEM fuel cell (proton exchange membrane), Hydrogen, Powertrain, V2G (vehicle to grid), United States of America

1 Introduction

Over recent years, global energy demand growth, environmental conservation, fight against climate change and global financial and economic crisis have taken an increasing importance in national and international policy debate.

In this context of great uncertainty, financing low-carbon technology projects seem to be a good investment, especially during difficult economic times.

1.1 The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report

The 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (1) 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 CO2 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.

1.2 The Copenhagen Accord

In December 2009 UN-COP 15 produced no international agreement but it is clear that it was no failure. In fact UN-COP15 “takes note” of the Copenhagen Accord (2), a political, and not legally-binding, agreement in which the Leaders of delegations present:

(a) Agreed that climate change is one of the greatest challenges of our time.

(b) 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).

(c) Agreed that developed countries shall provide adequate, predictable and sustainable financial resources, technology and capacity-building to support the implementation of adaptation action in developing countries, the collective commitment by developed countries is to provide new and additional resources, approaching USD 30 billion for the period 2010–2012 and USD 100 billion dollars a year by 2020.

(d) 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. States may undertake actions voluntarily and on the basis of support.

International community welcomed the Copenhagen Accord as a first step towards a low-emission future. In fact analysts observed that with these Accord pledges, the global temperature increase is estimated around or above 3° C in long term.

1.3 The Cancun Agreements

In December 2010 the UN – COP 16 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 elements of the Cancun Agreements (3) include:

(a) 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.

(b) Developing country actions to reduce emissions (in 2020 timeframe) are officially recognised under the multilateral process. A registry is to be set up to record and match developing country mitigation actions to finance and technology support from by industrialised countries. Developing countries are to publish progress reports every two years.

Copenhagen Accord’s and Cancun Agreements’ general perspective does not include any low-carbon technologies consideration and Hydrogen Fuel Cell Vehicles (HFCV) is still not considered as a relevant solution in the debate regarding the instruments to be considered in this perspective.

1.4 More Recent Events

1.4.1 President Obama Speech

In 2011 State of Union address, President Obama said: *“By 2035, 80 percent of America’s electricity will come from clean energy sources. Some folks want wind and solar. Others want nuclear, clean coal and natural gas. To meet this goal, we will need them all”* (4).

1.4.2 International Energy Agency, World Energy Outlook 2011

According to IEA WEO 2011: *“if stringent new action is not forthcoming by 2017, the energy-related infrastructure then in place will generate all the CO_2 emissions allowed* (in the long-term target Scenario of limiting the global average temperature increase to 2°C) *up to 2035, leaving no room for additional power plants, factories and other infrastructure unless they are zero-carbon”* (5).

1.4.3 The Durban Agreement

In December 2011, Countries meeting in Durban, South Africa, at UN Climate Change Conference 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 January 1, 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 May 1, 2012.

Kyoto Protocol only covers 10-15% of global emissions, and governments know efforts must go way beyond that. So they also confirmed further immediate mitigation action outside of the Protocol. Under the Copenhagen Accord and the Cancun Agreements all industrialised countries plus 49 developing countries have made the mitigation pledges covering the time period from now until 2020. These pledges cover 80% of global emissions and were affirmed in Durban. But mitigation outside of the protocol will take place outside of a firm legal framework.

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 so-called Durban Platform). Governments decided to adopt a universal legal agreement on climate change as soon as possible, but not later than 2015. Work will begin on this immediately. They have also set the deadline of 2020 for the entry into force of this new agreement (6).

2 A Possible Original Proposal to Energy Debate

It is longtime that I underlined the possible relevant implication of Hydrogen Fuel Cell use in stationary and transport applications (7) and, in recent years I presented different works in which I argued that it's time to consider HFCV as a relevant possible solution in energy debate.

In *"Hydrogen and Fuel Cells Vehicles in the Post Kyoto Perspective"* (8), presented at the National Hydrogen Association XXI Annual Hydrogen Conference & Expo "green energy. green jobs. green planet." (Long Beach CA USA, May 2010), I argued that the U.S. and EU energy and transport policies support the HFCV introduction into the market in the 2015-2020 timeframe. In 2020 the U.S. and EU, HFCV car fleet penetration seems to remain at a low level (around 1%) and the relevance in road transport sector CO2 emission reduction is limited. But, considering HFCV, properly equipped and parked in Vehicle To Grid (V2G) mode as a new power generation source, the new V2G power generation capacity installed on HFCV on the road by 2020 in the U.S. and EU is in a range between 20 and 30% of the present installed generation capacity in these regions, or in a range between 34% and 78% of the new generating capacity foreseen to be installed in these areas until 2030. In this perspective the relevance is considerable in 2020

In *"Considering Hydrogen Fuel Cells Powertrain as Power Generation Plant"* (9), presented at the World Electric Vehicles Symposium EVS25 "Sustainable Mobility Revolution" (Shenzhen China, November 2010), I considered the "Hydrogen Fuel Cells Powertrain" (PEMFC) as power generation plant and the Levelized cost of electricity (LCOE) production was compared to costs of traditional power generation technologies published in the most authoritative analyses. Using 2015 DOE data target (referred to high projected production volume), the "Hydrogen Fuel Cells Powertrain" LCOE production cost range, in most of the contexts, it appeared competitive with all the power generation technologies.

In *"Possible Hydrogen Fuel Cell Vehicles Powertrain Roles in the Copenhagen Accord Perspective"* (10), presented at the Fuel Cell and Hydrogen Energy 2011 Conference and Expo (Washington DC Area USA, February 2011), I concluded: "In my opinion, observing these economic data it will be necessary to think the HFCV link to energy sector not only in the V2G perspective but also considering Hydrogen Fuel Cell Powertrain as Power Generation Plant with relevant and positive consequences for a rapid development of these low-carbon technologies in transport and power generation sectors, in Copenhagen Accord's perspective".

In this paper I present an updated analysis using the most recent US data and it is confirmed the possible relevant HFCV powertrain roles in the Copenhagen Accord's and Cancun Agreements' perspective also in the US transport and power generation sectors.

3 Investment Costs in Energy Sector

Investment costs are probably the most important element in any investment decision. They vary greatly from technology to technology, from time to time and from country to country.

3.1 Overnight Cost

Overnight cost is a common unit of measure of power investments. Overnight cost 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 is USD/kW.

3.2 Levelized Costs of Electricity (LCOE)

The notion of Levelized Costs of 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. The unit of measure typically used is USD/MWh.

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.

Currently, with different frequency, public and private institution released analyses 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.

3.3 The U.S. EIA LCOE Data

In the mid 70's U.S. EIA began publishing the Annual Energy Outlook (AEO) in which, annually, presents a forecast and analysis of U.S. energy supply, demand, and prices (11). Since 1996 AEO considers and realizes forecast about overnight costs and LCOE. 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"* (12). LCOE data are revisited in *"Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011"* in December 2010 (based on the AEO Early Release, Ref. 13) and in April 2011 (14).
Fuel Cells technologies were mentioned and included in EIA documents since 1994, but EIA never provided data about the Fuel Cells LCOE.

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

4 The U.S. Hydrogen and Fuel Cell Vehicle Program Goals

The "Energy Policy Act of 2005" fixed the U.S. Hydrogen and Fuel Cell Vehicle Program goals in Sec. 805 (15).
In particular: "*The goal of the program shall be to demonstrate and commercialize the use of hydrogen for transportation (in light-duty vehicles*

Table 1 - 2016 Levelized Cost of New Generation Resources from the Annual Energy Outlook 2010 and 2011 (EIA, Jan. 2010 and Apr. 2011)

US		Final	LCOE 2010 (USD/MWh)				Final	LCOE 2011 (USD/MWh)		
Plant Type	Plant Size (MW 2009)	Overnight Cost (USD/kW 2009)	Levelized Capital Costs	O&M + Other + Fuel Cost (USD/MWh)	Total System Levelized Cost	Plant Size (MW 2010)	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**

and heavy-duty vehicles), utility, industrial, commercial, and residential applications." And, *"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."*

Surprisingly, in autumn 2011, the U.S. DOE published 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"* (16) 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"*.

In the 2010 Draft version of the Program Plan (17), all automotive milestones were still fixed in year 2015.

5 The Hydrogen Fuel Cell Powertrain LCOE

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 this analysis I chose to consider 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 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.

Academics, public and private operators well know the V2G concept (18). V2G could be realized indifferently with Electric Vehicles (EV) and HFCV but only in the case of HFCV we are in presence of a real new power generation capacity GHG emission free: the "H2FC Powertrains". HFCV 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 (19).

In my opinion, in mass production perspective, H2FC Powertrain will be so cost competitive to be useful adopted also for stationary power generation application and not considered only in a V2G perspective.
In order to calculate the H2FC Powertrain specific LCOE it is necessary to know some H2FC Powertrain data: The system cost and efficiency, the expected system lifetime, the fuel cost (i.e. the H2 cost).

5.1 Current Status Data (2010 – 2011)

DOE (20) 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).

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

5.2 2015/2017 Targets

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.
Thanks to the fact that expected system life is

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) 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).

5.3 Main Results

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.

Table 3 shows the H2FC Powertrain Levelized Cost of Electricity.

6 Conclusions

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, for the lower value of this range it appears competitive with many of the power generation technologies considered.

In my opinion, in 2017, the H2FC Powertrain could be one of the relevant zero-carbon technologies helpful to overcome the IEA WEO 2011 constrain.
Also, observing these H2FC Powertrain data, it will be necessary to think the Hydrogen FCV 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, in Copenhagen Accord's and Cancun Agreements' perspective.

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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

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