Considering Hydrogen Fuel Cells Powertrain as Power Generation Plant - 2017 review.[1]

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PAPER

Worldwide Hydrogen energy vector and Fuel Cells technologies seem to be a Cinderella low-carbon solution in the current energy and transport debate. But in the coming years, hydrogen and fuel cells have the potential to be a disruptive low-carbon solution.
The electricity produced by a Hydrogen Fuel Cell can be used both for stationary and transport application and the traditional model to link transport to energy sector is the Vehicle-to-Grid (V2G) approach.
I think that it is time to consider the link between the transport sector and the energy sector not only in a V2G approach but in another perspective, more direct, relevant and disruptive. In fact the Hydrogen Fuel Cell Powertrain (H_2FCPowertrain) or, in other words, the propulsion system of a Fuel Cell Vehicle (FCV), is a small power generation plant (typically the H_2FCPowertrain size is around 100 kW). In the coming years the high volume associated with the possible FCVs mass production will permit to reduce dramatically the FC system manufacturing costs, in order to be competitive with gasoline in hybrid-electric vehicles.
In a mass production perspective, H2FCPowertrain will be so cost competitive to be useful adopted also for stationary power generation application, also in LCOE perspective.

2017 Review

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

From 2010 I wrote, presented and published different studies where I compared the H_2FCPowertrain LCOE, based on the U.S. Department of Energy (DOE) public data, with the traditional power generation technologies LCOE with very promising results, in the U.S. context and in many other contexts around the world. In this 2017 review, for the H_2 production costs, I used also the International Energy Agency (IEA) data.

1. General Consideration

1.1 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.

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 for Overnight cost is USD/kW.

The **Levelized Costs of Generating Electricity (LCOE)** is often cited as a handy tool for the analysis of generation costs and to compare the unit costs and the overall competiveness of different generating technologies. Focus of estimated average LCOE is the entire operating life of the power plants for a given technology. In LCOE model, different cost components are taken into account: capital costs, fuel costs, operations and maintenance costs (O&M), decommissioning costs. 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.

1.2 Fuel Cells

Fuel Cell is a device that uses a fuel and oxygen to create electricity by an electrochemical process, without combustion. A single Fuel Cell consists of an electrolyte and two electrodes (anode and cathode). Fuel Cells are classified primarily by the kind of electrolyte they employ and PEM Fuel Cells (PEMFC) use hydrogen as fuel and have emissions only of water. Today Fuel Cells are present in a wide range of products and prototypes and I chose to consider in my analysis the Hydrogen Fuel Cell Powertrain (H_2FCPowertrain) as "Power Generation Plant" because the high volume associated with the FCVs mass production (from 10k to 500k and more units/year) will permit to reduce dramatically the Fuel Cell system manufacturing costs, in order to be competitive with gasoline in Hybrid-Electric Vehicles (HEVs).

In my opinion, in this perspective, H_2FCPowertrain will be so cost competitive to be useful adopted also for stationary power generation application as a power generation plant.

1.3 Beyond the Vehicle-to-Grid Concept: Considering H_2FCPowertrain as Power Generation Plant

Every day more than 90% of vehicles are parked, even during peak traffic hours. In this situation the vehicle power generation system H_2FCPowertrain, if properly equipped, could become a new power generation source, supplying electricity to homes and to

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the grid like a new type of distributed generation: **Vehicle-to-Grid** (V2G). Academics, public and private operators well know the V2G concept V2G could be realized indifferently with Electric Vehicles and FCVs, but only in the case of FCV we are in presence of a real new power generation capacity greenhouse gas (GHG) emission free: the H2FC Powertrains. 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. 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.

In my opinion, in the coming years, hydrogen and fuel cells have the potential to be a disruptive low-carbon solution. The electricity produced by a Hydrogen Fuel Cell can be used both for stationary and transport application and I think that it is time to consider the link between the transport sector and the energy sector not only in a V2G approach but in another perspective, more direct, relevant and disruptive. In fact the H_2FCPowertrain or, in other words, the propulsion system of a FC Vehicle (FCV), is a small power generation plant (typically the H_2FCPowertrain size is around 100 kW). In the coming years the high volume associated with the possible FCVs mass production will permit to reduce dramatically the FC system manufacturing costs, in order to be competitive with gasoline in hybrid-electric vehicles.

In a mass production perspective, H_2FCPowertrain will be so cost competitive to be useful adopted also for stationary power generation application, also in LCOE perspective.

2. H_2FCPowertrain LCOE

In order to calculate the H_2FCPowertrain LCOE it is necessary to know some specific data: system cost and efficiency, expected system lifetime, fuel cost (i.e. H_2 production cost).

2.1 2015 H_2FCPowertrain LCOE Data

According to my ***"Hydrogen and Fuel Cell: A Cinderella or a Disruptive Low-Carbon Solution?"** – presented at 2015 Fuel Cell Seminar & Energy Exposition, Los Angeles CA, USA, and published in ECS Transaction 2016 (details in references)* – based on 2015 DOE public data, I found:

Current Status (2014): Overnight cost, 55 USD/kW (at 500k units/year, 66 USD/kW at 100k units/year, 280 USD/kW low volume); 54% System Efficiency; Lifetime, 2500 hours; H_2 cost, 3 UDS/Kg-GGE (based on natural gas steam reforming).

2020 Targets: Overnight cost, 40 USD/kW (at 500k units/year); 60% System Efficiency; Lifetime, 5000 hours; H_2 cost, 2–4 UDS/kg-GGE.

H_2FC Powertrain Levelised Cost of Electricity (USD/MWh)								
Efficiency	Hours LIFE	Hydrogen Cost USD/GGE°	Capital Overnight Cost (USD/kW)^	Levelized Capital Cost LCC (USD/MWh)	O&M + Others (Assumed Equal to 10% LCC, USD/MWh)	Fuel Cost (USD/MWh)	LCOE (USD/MWh)	
54%	**2500**	**3,0**	**55,0**	22,0	2,2	166,7	**190,9**	DOE 2014 Status
60%	**5000**	**4,0**	**40,0**	8,0	0,8	200,0	**208,8**	2020 DOE Targets
60%	**5000**	**3,0**	**40,0**	8,0	0,8	150,0	**158,8**	2020 DOE Targets
60%	**5000**	**2,0**	**40,0**	8,0	0,8	100,0	**108,8**	2020 DOE Targets

The H_2FCPowertrain LCOE, using these data referred to high projected production volume, would be USD 191 for MWh. Using the 2020 targets the LCOE range moved to USD 109-209 for MWh and, for the lower value of this range, it appeared competitive with many of the U.S. power generation technologies analyzed by the U.S. Energy Information Administration (EIA) that annually realizes forecast about the U.S. Overnight Costs and LCOE (*table of 2012-2017 data*).

The U.S. LCOE of New Generation Resources from the EIA Annual Energy Outlook 2012-2017 *(2016-2017 Data for Plants Entering in Service in 2022)*														
	2012		2013		2014 n.s.			2015 n.s.			2016 n.s.			2017 n.s.
Plant Type	Total LCOE *(USD/MWh)*	Overnight Cost in 2012 *(USD/kW 2011)*	Total LCOE *(USD/MWh)*	Overnight Cost in 2013 *(USD/kW 2012)*	Total LCOE *(USD/MWh)*	Overnight Cost in 2014 *(USD/kW 2013)*	2015 Capacity Factor (%)	Total LCOE *(USD/MWh)*	Overnight Cost in 2015 *(USD/kW 2014)*	2016 Capacity Factor (%)	Total LCOE *(USD/MWh)*	Overnight Cost in 2016 *(USD/kW 2016)*	2017 Capacity Factor (%)	Total LCOE *(USD/MWh)*
Conventional Coal	**97,7**	2883	**100,1**	2925	**95,7**	2726	85	**95,1**						
Advanced Coal IGCC	**110,9**	3718	**123,0**	3771	**115,9**	3483	85	**115,7**						
Advanced Coal IGCC with CCS	**138,8**	5138	**135,5**	6567	**147,4**	5891	85	**144,4**	5098	85	**139,5**	4586-5072	85	**123-140**
Conventional Gas Combined Cycle	**66,1**	901	**67,1**	915	**66,3**	869	87	**75,2**	956	87	**58,1**	923	87	**57,3**
Advanced Gas Combined Cycle	**63,1**	1006	**65,6**	1021	**64,4**	942	87	**72,6**	1080	87	**57,2**	1013	87	**56,5**
Advanced Gas Combined Cycle with CCS	**90,1**	2059	**93,4**	2084	**91,3**	1845	87	**100,2**	2132	87	**84,8**	1917	87	**82,4**
Conventional Combustion Gas Turbine	**127,9**	956	**130,3**	971	**128,4**	922	30	**141,5**	922	30	**110,8**	1040	30	**109,4**
Advanced Combustion Gas Turbine	**101,8**	664	**104,6**	673	**103,7**	639	30	**113,5**	664	30	**94,7**	640	30	**94,7**
Advanced Nuclear	**111,4**	5429	**108,4**	5501	**96,1**	4646	90	**95,2**	6108	90	**102,8**	5091	90	**99,1**
Geothermal	**98,2**	2567	**89,6**	2494	**47,8**	2331	92	**47,8**	2331	91	**45,0**	2331	91	**46,5**
Biomass	**115,4**	4041	**111,0**	3919	**102,6**	3399	83	**100,5**	3498	83	**96,1**	3540	83	**102,4**
Fuel Cells		*6382*		*7044*		*6042*			*7181*			*6252*		
Wind	**96,0**	2175	**86,6**	2205	**80,3**	1850	36	**73,6**	1536	40	**64,5**	1576	39	**63,7**
Wind - Offshore		6121	**221,5**	6192	**204,0**	4476	38	**196,9**	4605	45	**158,1**	4648	45	**157,4**
Solar PV	**152,7**	3805	**144,3**	3564	**130,0**	3787	25	**125,3**	2362	25	**84,7**	2169	24	**85,0**
Solar Thermal	**242,0**	4979	**261,5**	5045	**243,1**	3123	20	**239,7**	3895	20	**235,9**	3908	20	**242,0**
Hydro	**88,9**	2397	**90,3**	2435	**84,5**	2651	54	**83,5**	2191	58	**67,8**	2220	59	**66,2**

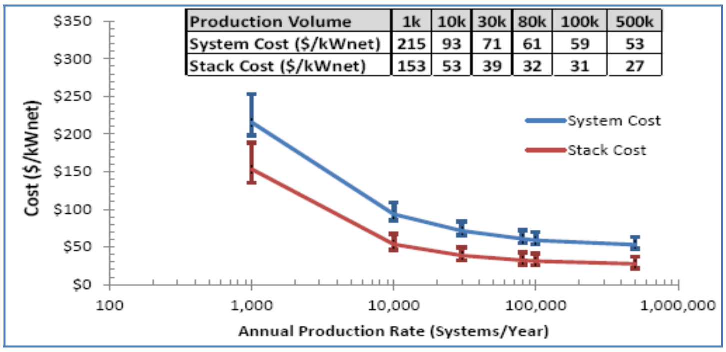
In 2015, I considered these U.S. H_2FCPowertrain LCOE data also in the EU context, having in mind the difference in natural gas prices present in these two areas and considering that, in EU, there are other cheap ways to produce H_2 like from: brown coal (with CO_2 capture, use and sequestration CCUS), nuclear power and all the situations of electricity overproduction. In 2020 perspective, based on our elaboration of the OECD-IEA-NEA Projected Costs of Generating Electricity 2015 Edition LCOE data, for the lower value of target range (109 USD/MWh) the H_2FCPowertrain technology appeared competitive with many of the power generation technologies also considering the three different discount rate (3%, 7% and 10%) used in this OECD-IEA-NEA edition. *More details in the published 2015 study.*

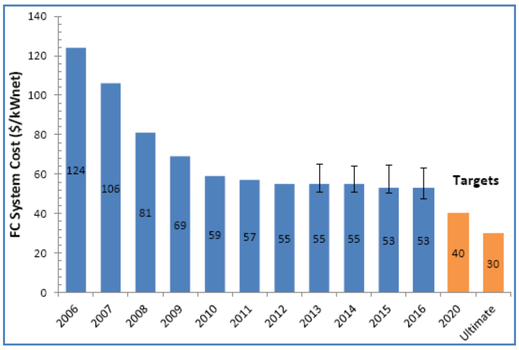
2.2 2017 Review

This analysis is based on DOE and IEA public data.

2.2.1 The U.S. DOE Data

Current Status (2016): Overnight cost, 53 USD/kW (at 500k units/year; 59 USD/kW at 100k units/year; 215 USD/kW low volume – *details down, in left table*); 52% System Efficiency; Lifetime, 4100 hours; H_2 cost, 5 UDS/kg-GGE (based on natural gas steam reforming, high volume projection; including: production, delivery & dispensing; *in 2014 including only production & delivery*).





2020 targets: Overnight cost, 40 USD/kW (at 500k units/year – *annual data up, in right table*); 60% System Efficiency; Lifetime, 8000 hours (*in 2014, 5000 hours*); H_2 cost, 4 UDS/kg-GGE (with the same assumptions of current status).

The **2017 H_2FCPowertrain LCOE**, using these DOE data & assumptions referred to high projected production volume, would be USD 303 for MWh, using the 2016 data and 206 USD for MWh using the 2020 targets (**2017 data, bold in table**; *2015 study data, italics in table*).

H_2FC Powertrain Levelised Cost of Electricity (USD/MWh)								
Efficiency	Hours LIFE	DOE Hydrogen Cost USD/GGE	Capital Overnight Cost (USD/kW)	Levelized Capital Cost LCC (USD/MWh)	O&M + Others (Assumed Equal to 10% LCC, USD/MWh)	Fuel Cost (USD/ MWh)	LCOE (USD/ MWh)	ASSUMPTIONS
54%	*2500*	*3,0 ^*	*55,0*	*22,0*	*2,2*	*166,7*	*190,9*	*2014 DOE Status*
52%	**4100**	**5,0 ***	**53,0**	**12,9**	**1,3**	**288,5**	**302,7**	**2016 DOE Status**
60%	*5000*	*4,0 ^*	*40,0*	*8,0*	*0,8*	*200,0*	*208,8*	*2020 DOE Targets (2015)*
60%	*5000*	*3,0 ^*	*40,0*	*8,0*	*0,8*	*150,0*	*158,8*	*2020 DOE Targets (2015)*
60%	*5000*	*2,0 ^*	*40,0*	*8,0*	*0,8*	*100,0*	*108,8*	*2020 DOE Targets (2015)*
60%	**8000**	**4,0 ***	**40,0**	**5,0**	**0,5**	**200,0**	**205,5**	**2020 DOE Targets (2016)**

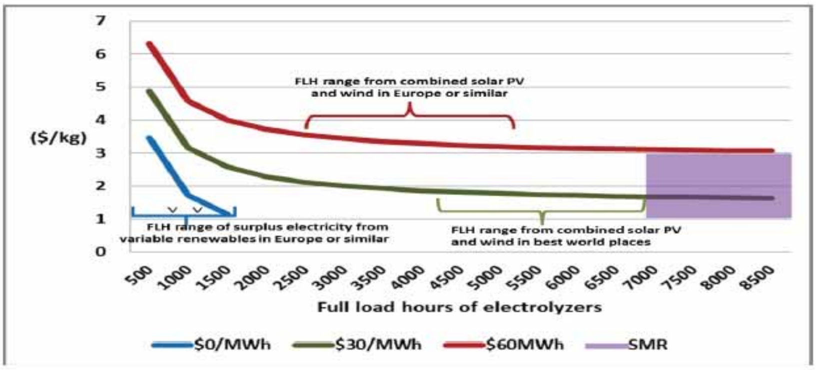
^ Costs of producing and delivering hydrogen (from natural gas)

*** Projected costs of hydrogen production, delivery and dispensing (from natural gas)**

2.2.2 The IEA Data of H_2 Production Costs

Considering the fact that current DOE data regarding H_2 projected costs including "*production, delivery & dispensing*" *costs* and not only the *"production & delivery" costs* as in the past, I decided to use in this analysis the IEA H_2 production costs presented in two recent publications (2017): *"Producing industrial hydrogen from renewable energy"* and *"Producing ammonia and fertilizers: new opportunities from renewable" (main data in next table, detail in references).*

Cost of hydrogen from electrolysers at USD 450/kW Capex for different electricity costs and load factors.



Assumptions: Capex of electrolysers $ 450/kW (NEL 2017), WACC 7%, lifetime 30 years, efficiency 70% (IEA 2015); cost of hydrogen from SMR $ 1 to 3/kg H_2.depending on natural gas prices.

The IEA H_2 production costs data-range is 1-4 UDS/kg-GGE and includes both H_2 from natural gas steam reforming and H_2 from electrolizers (for different electricity costs and load factors).

2.2.3 2017 Review – H_2FCPowertrain LCOE Based on DOE and IEA Data

Combining the 2016 DOE fuel cell data and the 2017 IEA H_2 production costs data-range (1-4 USD/kg-GGE) **the current H_2FCPowertrain LCOE value-range would be 72-245 USD/MWh and, for 2020, USD 56-206 USD/MWh.**

H_2FC Powertrain Levelised Cost of Electricity (USD/MWh)

Efficiency	Hours LIFE	IEA Hydrogen Cost USD/GGE^	Capital Overnight Cost (USD/kW)	Levelized Capital Cost LCC (USD/MWh)	O&M + Others (Assumed Equal to 10% LCC, USD/MWh)	Fuel Cost (USD/MWh)	LCOE (USD/MWh)	ASSUMPTIONS
52%	4100	4,0	53,0	12,9	1,3	230,8	**245,0**	2016 DOE Status & H_2 IEA (2017)
52%	4100	3,0	53,0	12,9	1,3	173,1	**187,3**	2016 DOE Status & H_2 IEA (2017)
52%	4100	2,0	53,0	12,9	1,3	115,4	**129,6**	2016 DOE Status & H_2 IEA (2017)
52%	4100	1,0	53,0	12,9	1,3	57,7	**71,9**	2016 DOE Status & H_2 IEA (2017)
60%	8000	4,0	40,0	5,0	0,5	200,0	**205,5**	2020 DOE Targets (2016) & H_2 IEA (2017)
60%	8000	3,0	40,0	5,0	0,5	150,0	**155,5**	2020 DOE Targets (2016) & H_2 IEA (2017)
60%	8000	2,0	40,0	5,0	0,5	100,0	**105,5**	2020 DOE Targets (2016) & H_2 IEA (2017)
60%	8000	1,0	40,0	5,0	0,5	50,0	**55,5**	2020 DOE Targets (2016) & H_2 IEA (2017)

^ Production costs: H_2 from natural gas steam reforming and H_2 from electrolizers (for different electricity costs and load factors)

It is interesting to note that these values are mainly due to the H_2 production costs data-range that impact for 58-231 USD/MWh in the current LCOE and USD 50-200 USD/MWh in 2020 LCOE.

3. Conclusions

In this perspective, the H_2FCPowertrain technology appears competitive with many of the power generation technologies and, especially in favorable conditions of H_2 production costs, H_2FCPowertrain seems to be useful to be adopted also for stationary power generation application.

Observing these H_2FCPowertrain data it will be necessary to think the FCVs link to energy sector considering also the possibility to utilize H_2FCPowertrain as a power generation plant, smart grid connected, with relevant and positive consequences for a rapid development of this disruptive low-carbon solution.

In line with the spirit of the Holy Father Francis Encyclical Letter "LAUDATO SI'" and with the new goals of United Nations "Transforming our world: the 2030 Agenda for Sustainable Development", in 2015 the UNFCCC COP 21 Conference adopted the historic "*Paris Agreement*" that introduced a new paradigm to a durable global framework to reduce global greenhouse gas emissions. After the 2017 decision of the United States of America to withdraw from the *Paris Agreement*, in July in Hamburg, the Leaders of the other G20 members stated that the *Paris Agreement* is irreversible.

In this new and irreversible global framework it will be useful well explain the advantage to utilize H_2FCPowertrain as power generation plant to all the actors involved in order to offer a new and feasible path to implement the Paris Agreement and to accelerate even more the introduction of this break-through low-carbon solution.

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