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“Idrogeno:….il domani è già cominciato?”

25 ottobre 2018

c/o Palazzo Turati - *Camera di Commercio di Milano-MonzaBrianza-Lodi*

Sala Consiglio – I° Piano - via Meravigli 9/B, Milano

Investimenti nelle tecnologie a idrogeno e possibili scenari. Prospettive di mercato e costi

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Regione Lombardia

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Il contributo dell'idrogeno e delle celle a combustibile (1/3)

- L'**idrogeno** è l'elemento più comune in natura ed è largamente utilizzato nel settore industriale come gas tecnico.
- Come vettore energetico, grazie all'utilizzo in celle a combustibile (*fuel cell*), può produrre elettricità senza emettere inquinanti ma acqua, risultato della reazione chimica con l'ossigeno.
- Le **celle a combustibile (*fuel cell*)** sono sistemi elettrochimici che convertono l'energia chimica di un combustibile direttamente in energia elettrica, senza che avvenga alcun processo di combustione termica, ottenendo quindi rendimenti di conversione più elevati rispetto a quelli tipici delle macchine termiche.
- Una **cella a combustibile** funziona in modo analogo a una **batteria**, producendo energia elettrica attraverso un processo elettrochimico ma, a differenza della pila, consuma sostanze provenienti dall'esterno e può funzionare senza interruzioni, finché al sistema è fornito il combustibile e l'ossidante (ossigeno/aria). Diversi sono i tipi di fuel cell esistenti.
- Nel caso di ***fuel cell* PEM** (Proton Exchange Membrane) il combustibile è l'idrogeno. Anche la fuel cell PEM può essere utilizzata in *reverse mode* (ovvero in modalità invertita), in questo caso fornendo elettricità ed acqua al sistema questo è in grado di separare l'acqua in idrogeno ed ossigeno.

Il contributo dell'idrogeno e delle celle a combustibile (2/3)

- **Nell'ultimo mezzo secolo** l'idrogeno ha aumentato la sua diffusione ed è stato efficacemente impiegato in importanti applicazioni speciali e di frontiera e, più di recente, in alcuni prodotti per l'industria e beni durevoli che hanno raggiunto l'economicità ed hanno avviato la commercializzazione.

- **Nell'esplorazione spaziale**: la NASA ha utilizzato l'idrogeno in *fuel cell* PEM e AFC per generare elettricità a bordo dei veicoli spaziali dal 1965 (con la Gemini 5), nei programmi Gemini, Apollo e Space Shuttle.

- **In marina**: il German Submarine Consortium ha avviato nel 1994 un programma per la produzione di sottomarini con propulsione a idrogeno e *fuel cell* PEM e ha varato 25 battelli per le Marine di Germania, Italia, Grecia, Sud Corea, Portogallo e Israele

Il contributo dell'idrogeno e delle celle a combustibile (3/3)
La situazione attuale (1/4)

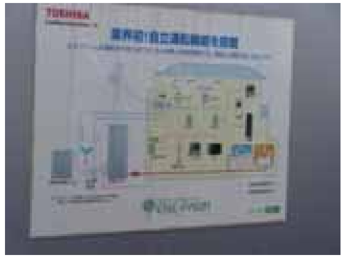
- In merito alle applicazioni che hanno già raggiunto una economicità tale da consentire la commercializzazione, **i più recenti dati di diffusione sono forniti dall'IPHE** e si riferiscono ai prodotti per l'industria (*fork lift),* ai veicoli (vetture e bus), alle stazioni di rifornimento di idrogeno, agli impianti stazionari di cogenerazione relativi ai principali Paesi partecipanti.

Country	# of Cars	# of Buses	# of Fork Lifts	# of Stations	# of Stationary Units
China	60	**150**	2	10	-
France	200	-	**~100**	18	>50
Germany	**~500**	146	100	43	**~1,900**
Japan	**~2,450**	6	77	**122**	**~235,000**
Korea	~100	Demo only		17	**177MW**
United States	**~4,500**	25	**~16,000**	>80	**235MW**

- Fonte: Tim Karlsson, IPHE, "International Trends", June 2018 https://docs.wixstatic.com/ugd/45185a_a122c8e014ff414e97371ad499b4c7a9.pdf

La situazione attuale (2/4)

- **Commercial H_2 and FC industry is even more emerging and, in the coming years, have the potential to be a disruptive low-carbon solution.**
- **FC Stationary System.** In Japan, from 2009 to **March 2018 more than 235,000** ENE-FARM PEM-FC systems were sold & installed.



- **FC Fork Lift.**

La situazione attuale (3/4)

- **FC Vehicles.** Commercialization starting date: **Hyundai *"ix35 Tucson" FC*** in June 2014; **Toyota *"Mirai" FC*** in December 2014 in Japan; **Honda *"Clarity" FC*** in March 2016 in Japan.


- Brussels,September 2017, **4 European carmakers exhibited FCVs prototypes.**


Symbio


Daimler


Audi


BMW

La situazione attuale (4/4)

- **FC Buses.**

- **Hydrogen Refuelling Station.**

Le prospettive possibili

- **Diversi sono gli scenari di previsione disponibili, realizzati sia a livello internazionale che nazionale e sviluppati sia in termini sintetici che in dettagliate *roadmaps*. Tra i più recenti ricordiamo:**
- 2017 novembre, **Hydrogen Council – Hydrogen scaling up**
- 2017 dicembre, **IEA Hydrogen – Global Trends and Outlook for Hydrogen**
- 2018 agosto, **CSIRO Australia – National Hydrogen Roadmap**
- 2018 settembre, **IRENA – Hydrogen from Renewable Power .** Technology Outlook for the Energy Transition
- 2018 settembre, **Hydrogen Council – Hydrogen Meets Digital.** New opportunities for the energy and mobility system

- **Recenti iniziative che hanno visto coinvolta l'Italia:**
- 23 maggio**,** Malmö Svezia, **Mission Innovation, IC#8 Renewable and Clean Hydrogen Challenge**
- 18 settembre, Linz Austria, **Meeting informale dei ministri dell'energia, firma della The Hydrogen Initiative**
- 23 ottobre, Tokyo Giappone, **Hydrogen Energy Ministerial Meeting 2018**

Le prospettive possibili
Trasporti (dati IEA)

National FCEV targets

	2020	2023	2025	2028	2030
US	13 000	40 000			
Japan	40 000		200 000		800 000
France		5 000		20 000-50 000	
China	5 000		50 000		1 000 000
Netherlands	2 000				
Korea	10 000		100 000		630 000

National hydrogen fuelling station targets

	2020	2023	2025	2028	2030
US	80	100			
Japan	160		320		
France		100		400-1 000	
China	100		300		500
Germany	100		400		1 000
Korea	100		210		520

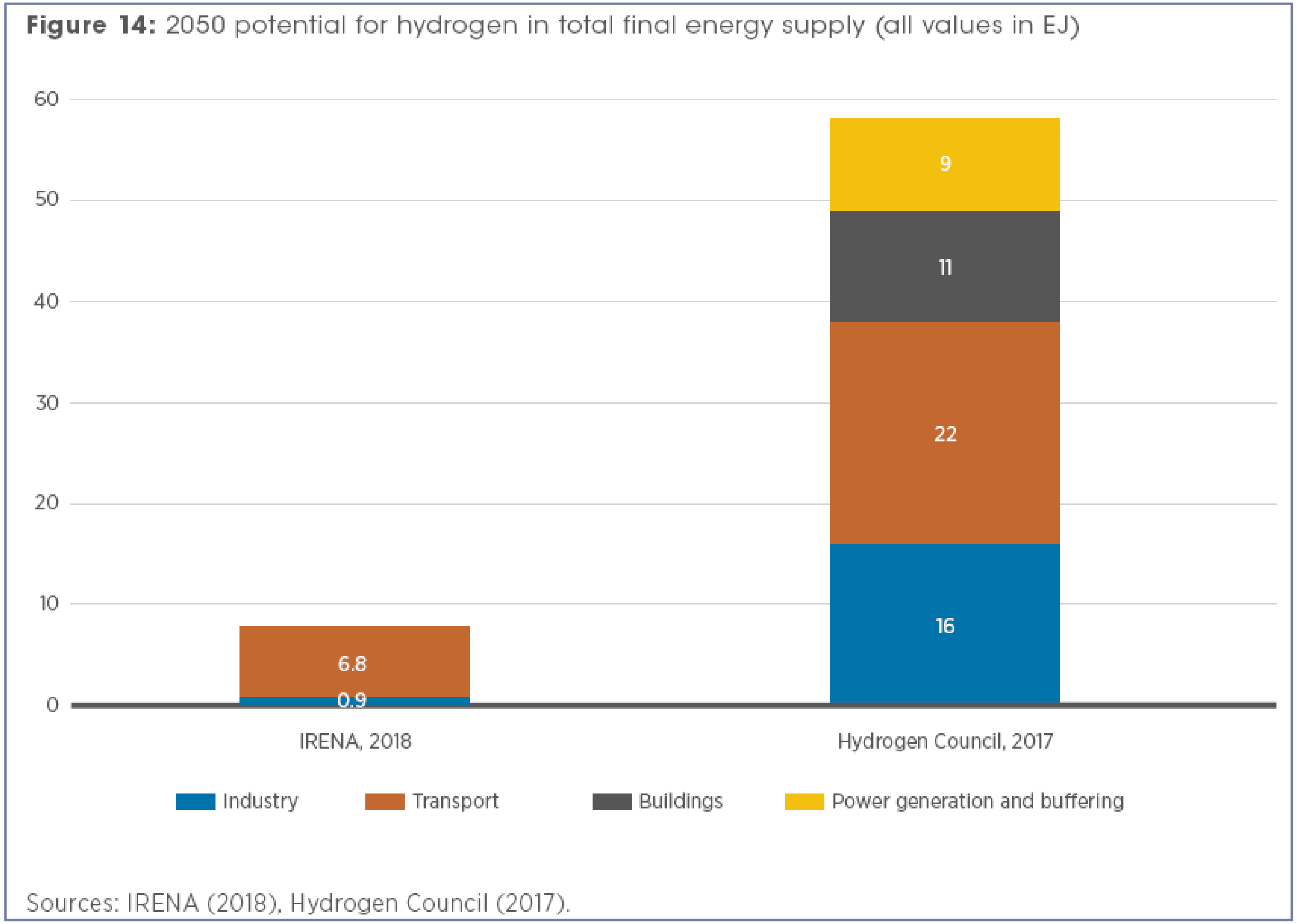
Fonte: **IEA,** Hydrogen Tracking Clean Energy Progress https://www.iea.org/tcep/energyintegration/hydrogen/ (sito visitato 24 ottobre 2018)

Le prospettive possibili
Generazione distribuita (target del Giappone)

Stationary	Target Number	Current Status	Partnerships, Strategic Approach	Policy Support
Small	1.4 mil by 2020 5.3 mil by 2030	235,276 (as of March 2018)	• Establishing ENE-FARM partners (manufacturers, gas companies and constructors)	• Subsidy for purchase (national government initiative)
Medium	No target	21: SOFC 50: PAFC (as of March 2018)	• Commercializing fuel cells for industrial application by 2017' (Strategic Roadmap, METI)	• Subsidy for R&D, demonstration (national government initiative)

Fonte: **IPHE, "**IPHE Country Update May 2018: Japan" https://docs.wixstatic.com/ugd/45185a_c3cea35640664a33bfb54f56ec310539.pdf

Le prospettive possibili
Il punto di vista di IRENA e quello dell'Hydrogen Council

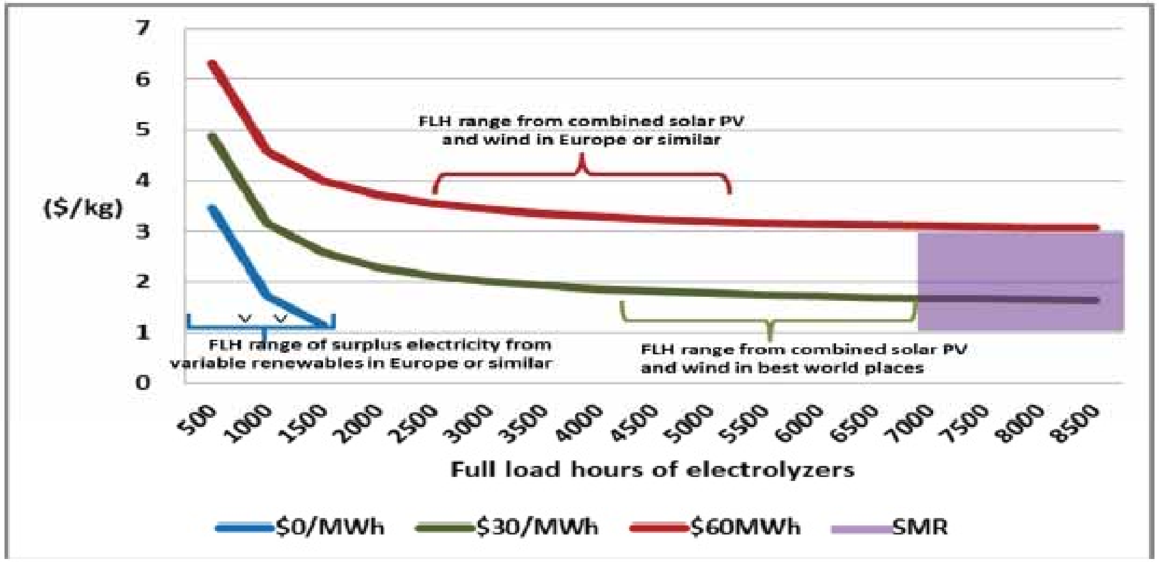


Fonte: **IRENA,** Hydrogen from Renewable Power Technology Outlook for the Energy Transition, pagina 32
http://irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf

Alcune considerazioni sui costi: dell'idrogeno (1/3) – dati IEA

- According to **IEA** (2017) **"Producing ammonia and fertilizers: new opportunities from renewable"** (NH_3): *"Thanks to the recent cost reductions of solar and wind technologies, ammonia production in large-scale plants based on electrolysis of water can compete with ammonia production based on natural gas, in areas with world-best combined solar and wind resources"* and *"similar H_2 prices could be reached in countries with lower-quality renewable resources if "surplus" electricity is considered free"*.

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.

Fonte: **IEA**, Cédric Philibert, 2017: *"Producing ammonia and fertilizers: new opportunities from renewable"*, pagina 2, https://www.iea.org/media/news/2017/Fertilizer_manufacturing_Renewables_01102017.pdf

Alcune considerazioni sui costi: dell'idrogeno (2/3) – dati US DOE, Distributed Water Electrolysis

Technical Targets: Distributed Forecourt Water Electrolysis Hydrogen Production[a,b,c]

Characteristics	Units	2011 Status	2015 Target	2020 Target
Hydrogen levelized cost[d] (production only)	$/kg	4.20[d]	3.90[d]	2.30[d]
Electrolyzer system capital cost	$/kg	0.70	0.50	0.50
	$/kW	430[e,f]	300[f]	300[f]
System energy efficiency[g]	% (LHV)	67	72	75
	kWh/kg	50	46	44
Stack energy efficiency[h]	% (LHV	74	76	77
	kWh/kg	45	44	43
Electricity price	$/kWh	From AEO 2009[i]	From AEO 2009[i]	0.037[j]

Distributed Electrolysis H2A Example Cost Contributions[a,b,c]

Characteristics		Units	2011 Status	2015	2020
Electrolysis system	Cost contribution[a,b,e]	$/kg H_2	0.70	0.50	0.50
	Production equipment availability[c]	%	98	98	98
Electricity	Cost contribution	$/kg H_2	3.00[i]	3.10[i]	1.60[j]
Production fixed O&M	Cost contribution	$/kg H_2	0.30	0.20	0.20
Production other variable costs	Cost contribution	$/kg H_2	0.10	0.10	<0.10
Hydrogen production	Cost contribution	$/kg H_2	4.10	3.90	2.30
Compression, storage, and dispensing[k]	Cost contribution	$/kg H_2	2.50	1.70	1.70
Total hydrogen levelized cost (dispensed)		$/kg H_2	6.60	5.60	4.00

Fonte: **DOE,** Technical Targets for Hydrogen Production from Electrolysis
https://www.energy.gov/eere/fuelcells/doe-technical-targets-hydrogen-production-electrolysis (sito visitato 24 ottobre 2018)

Alcune considerazioni sui costi: dell'idrogeno (3/3) – dati US DOE, Central Water Electrolysis

Technical Targets: Central Water Electrolysis[a,b]

Characteristics	Units	2011 Status[c]	2015 Target[d]	2020 Target[e]
Hydrogen levelized cost (plant gate)[f]	$/kg H_2	4.10	3.00	2.00
Total capital investment[b]	$ million	68	51	40
System energy efficiency[g]	%	67	73	75
	kWh/kg H_2	50	46	44.7
Stack energy efficiency[h]	%	74	76	78
	kWh/kg H_2	45	44	43
Electricity price[i]	$/kWh	From AEO '09	$0.049	$0.031

Central Water Electrolysis H2A Example Cost Contributions[a,b]

Characteristics	Units	2011 Status[c]	2015[d]	2020[e]
Capital cost contribution	$/kg	0.60	0.50	0.40
Feedstock cost contribution	$/kg	3.20	2.30	1.40
Fixed O&M cost contribution	$/kg	0.20	0.10	0.10
Other variable cost contribution	$/kg	0.10	0.10	0.10
Total hydrogen levelized cost (plant gate)	$/kg	4.10	3.20	2.00

Fonte: **DOE,** Technical Targets for Hydrogen Production from Electrolysis
https://www.energy.gov/eere/fuelcells/doe-technical-targets-hydrogen-production-electrolysis (sito visitato 24 ottobre 2018)

Alcune considerazioni sui costi: delle *fuel cell* – dati US DOE

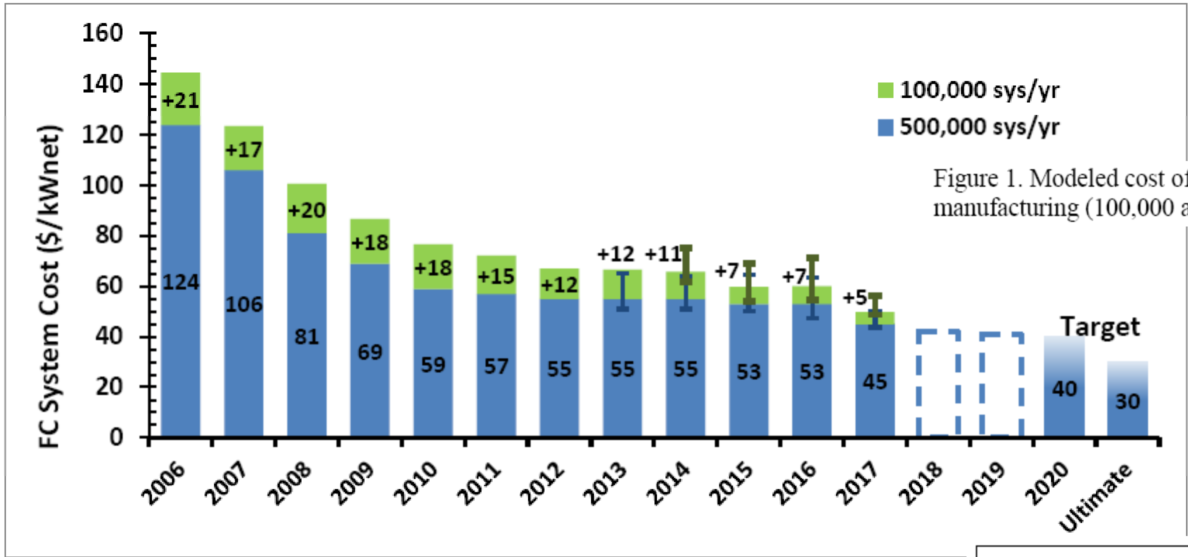


Figure 1. Modeled cost of an 80-kW_{net} PEM fuel cell system based on projection to high-volume manufacturing (100,000 and 500,000 units/year).

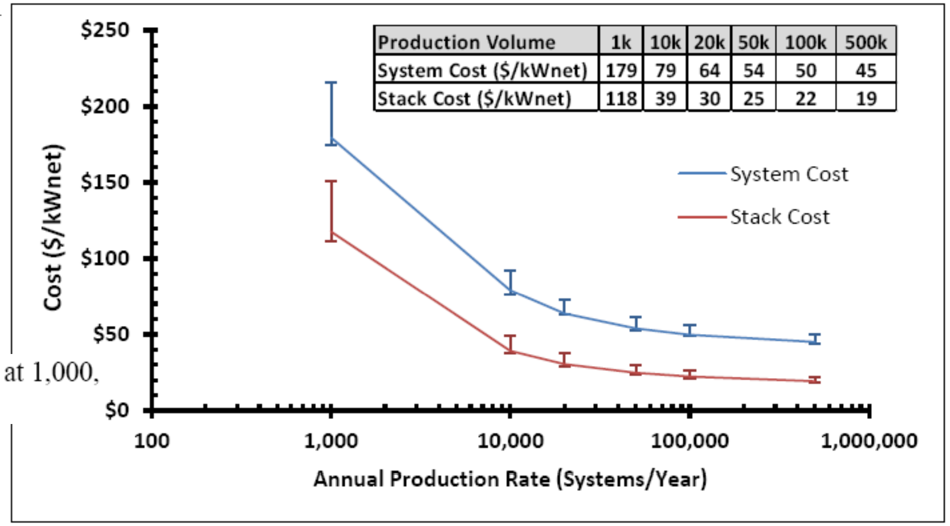


Figure 2. Projected cost of 2017 80-kW_{net} transportation fuel cell stacks and systems at 1,000, 10,000, 20,000, 50,000, 100,000, and 500,000 units/year.

Fonte: **DOE,** Hydrogen and Fuel Cells Program Record, Fuel Cell System Cost - 2017
https://www.hydrogen.energy.gov/pdfs/17007_fuel_cell_system_cost_2017.pdf

Alcune considerazioni sui costi: di un nuovo prodotto – Toyota MIRAI nel mercato USA (febbraio 2015) – Analisi del differenziale di prezzo con vettura equivalente

- **ORIGINAL. Vehicle costs are still high – the announced FCEVs sell at prices of USD 70,000 to USD 100,000.**
- **SUGGESTED.** Vehicle costs are still high **but today, in Japan, the FCEV Toyota MIRAI Manufacturer's Suggested Retail Price is 7,236,000 yen (or 60,300 USD) and, in the U.S., it will be 57,500 USD in next months.**
- **COMMENTS, REFERENCES, RATIONALES and NOTES.** Toyota MIRAI prices: for Japan see: Nov. 18, 2014 "Toyota Ushers in the Future with Launch of 'Mirai' Fuel Cell Sedan" <http://newsroom.toyota.co.jp/en/detail/4198334/>; for the U.S. see: "'Mirai' A Turning Point" <http://www.toyota.com/fuelcell/fcv.html>. Recent USD-JPY cross rate 120.

  Please read carefully the DOE Fuel Cell Tech. Office Record #14013, October 2014, **"Early Market Hydrogen Cost Target Calculation"** <http://www.hydrogen.energy.gov/pdfs/14013_hydrogen_early_market_cost_target.pdf> where "2014 Lexus GS 350 with standard options" is proposed "as a comparable vehicle to the Toyota FCEV" MIRAI (p. 4). Today the **Lexus GS 350 with standard options** Manufacturer's Suggested Retail Price (MSRP) is **48,625 USD** (See: <http://www.kbb.com/lexus/gs/2014-lexus-gs/gs-350/?vehicleid=392570&intent=buy-new>) and **57,500 USD** the **Toyota MIRAI** MSRP. For a high level luxury sedan **the present MSRP differential between FCEV and ICEV is 8,875 USD**.

  Assuming that the MSRP differential is referred all to fuel cell stack (114 kW), and not also to H2 tank cost, it is possible to calculate at around 78 USD/kW the additional cost of Toyota MIRAI fuel cell powertrain compared with ICE powertrain cost.

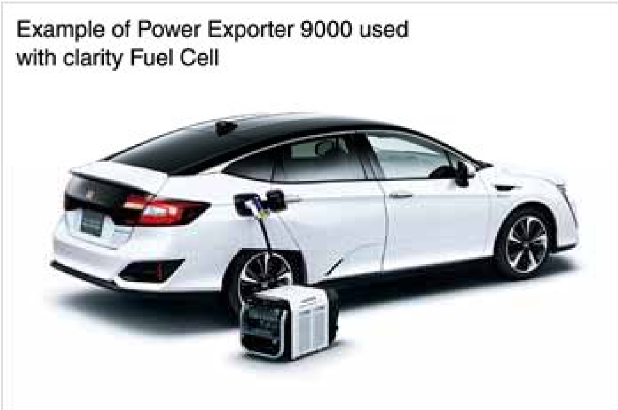
Fonte principale: **DOE 2014,** Hydrogen and Fuel Cells Technologies Office Record, Early Market Hydrogen Cost Target Calculation
https://www.hydrogen.energy.gov/pdfs/14013_hydrogen_early_market_cost_target.pdf

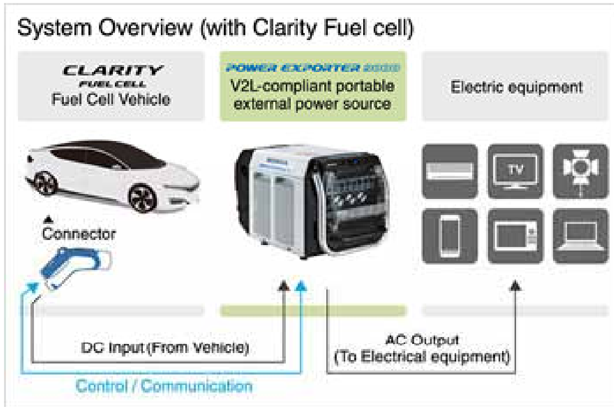
Saranno possibili nuovi business models… (1/3)
The Link Between Transport and Energy Sector (1/2)
The V2G Approach: From Labs to Market

- **The Vehicle-to-Grid (V2G) approach is the traditional model to link transport to energy sector.**

Japan, Kitakyushu (November 2013)

- In 2016 **Honda** released the **Power Exporter 9000** external power source at the same time as launch of the **Clarity FC**. The Power Exporter 9000 in combination with the Clarity FC, is enough to power an average household for approximately a week.





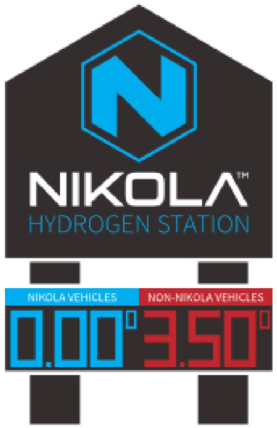
From: http://world.honda.com/powerproducts-technology/engineer-talk/PowerExporter9000/

Saranno possibili nuovi business models… (2/3)
The Link Between Transport and Energy Sector (2/2)
From V2G to "*Considering H_2FCPowertrain as Power Generation Plant*"

- **From 2010 I wrote, presented and published studies in which I suggested to 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 and relevant.**
- **In fact the Hydrogen PEM Fuel Cell Powertrain (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 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 (in LCOE perspective).**

China (2010-2014), USA (2011-2015), Japan (2012) Korea (2013)

Saranno possibili nuovi business models… (3/3)
Nikola: Hydrogen Trucks & Refueling Stations



Nikola's Hydrogen Fueling Network

Nikola trucks can refuel with hydrogen at any station within our planned fueling network. Nikola will provide free* hydrogen fuel for up to 1,000,000 miles. Nikola will also allow any non-Nikola hydrogen vehicle to fuel at their stations. Nikola believes in zero emission hydrogen and hopes to move America towards a clean fuel future.

Nikola will produce its own hydrogen on site via electrolysis. Vertical integration reduces market uncertainties, allowing Nikola to control fuel prices and keep them low for Nikola customers.

All From: https://nikolamotor.com/

Considerazioni conclusive

Grazie per la cortese attenzione

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