Why Hydrogen?

Introduction

- In order to limit Climate Change, it's now clear that the world needs to stop burning fossil fuels and convert to renewable energy, primarily wind & solar
- A third of all Green House Gases (GHG's), responsible for Climate Change, come from the transportation sector
  - But transportation needs large amounts of portable, storable energy. How do we convert, store and transfer the energy from wind and solar to vehicles?
- Vehicles can run on renewable electricity by using electric motors instead of Internal Combustion Engines (ICE's)
  - There are TWO types of Electric Vehicles
    - Battery EV's
    - Fuel Cell EV's
  - Battery and Fuel Cell EV's have complementary characteristics
    Both are needed to entice all users away from ICE to electric vehicles
- Battery EV's
  - The most efficient and therefore the lowest cost per mile to operate
  - Great as a passenger car "every day driver" around town
  - Just plug them in to charge
  - But Battery EV's have limited range; long recharge times; lose range at cold and hot temperatures; plus battery bulk, weight and cost become prohibitive for larger vehicles and towing trailers
- Fuel Cell EV's
  - Offer the same performance as ICE vehicles, are suitable for any size vehicle (even locomotives and ships), great for long trips and unaffected by cold and hot weather
  - But Fuel Cell EV's need hydrogen fuel which can be made from renewable electricity

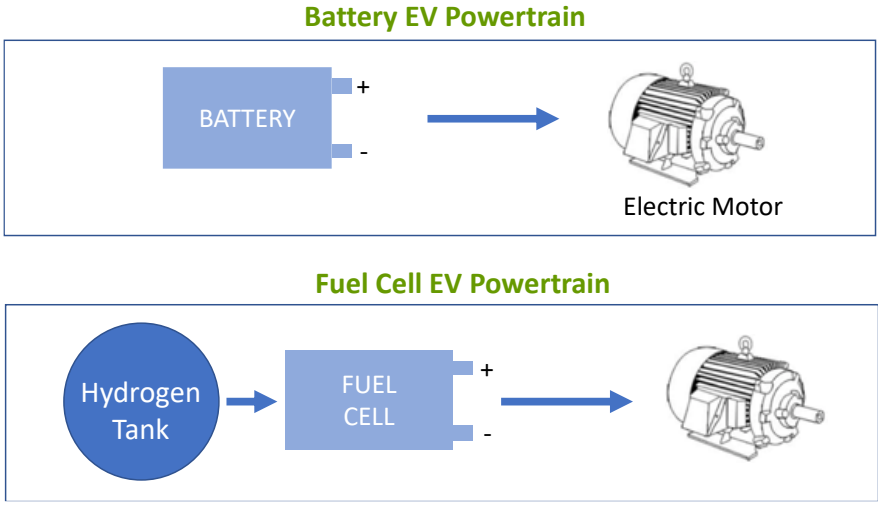
Table 1 – Comparison of the Two Types of EV's

Characteristic	Battery EV	Fuel Cell EV
Range	100 to 300 miles	Unlimited via refueling
Refueling Time	30 minutes to 40 hours	3 Minutes
Refueling Temperature	Only when battery above 32° F	Any Temperature
Cold temperature range	Reduced 30% to 50% (Colo AAA study)	Unaffected
Fuel cost per mile	4¢	11¢ (same as gasoline)
Power Source Lifespan	~100K miles (battery)	>250K miles
Suitability for buses, trucks, large pickups, SUV's & RV's	Battery cost, weight and bulk become impractical	Unlimited
Range when Towing	Decreases battery range	Decreased fuel efficiency

Fuel Cell EV's

- Fuel Cell EV's and Battery EV's are basically the same except for the power source

Figure 1 – Electric Vehicle Differences



- Fuel Cell EV's combine the best of ICE vehicles (fast fueling, long range, unlimited cargo and towing capacity, cold and hot weather performance) and the best of electric vehicles (rapid acceleration, zero-emissions)

Figure 2 – Some of the Fuel Cell Vehicles Available Today

Hyundai Tucson | Honda Clarity | Toyota Mirai | Hyundai Nexo

Class-6 Trucks
GM 6500XCD

Buses
ENC, New Flyer, Van Hool, more

Class-8 Trucks
Toyota, Nikola, Hyundai, Hyzon

- So why isn't everyone driving a Fuel Cell EV?
  - Fuel Cell EV's need hydrogen fuel
- The hydrogen fueling stalemate
  - How can anyone buy a Fuel Cell EV without hydrogen fuel stations?
  - Why would investors build fuel stations without the vehicles to buy the fuel?
- Clearly, both the fuel stations and vehicles need to be deployed *simultaneously*
  - Sponsorship is needed

Hydrogen Fueling

- Unlike petroleum, hydrogen is a gas, so it needs a different fuel station infrastructure
- Hydrogen can be created at the point-of-use by splitting water molecules with *renewable electricity* (see the next section *Electrolyzer and Fuel Cell Technology*)
  - Avoids trucking hydrogen
- Hydrogen can be generated at the utilities' convenience
  - Off-peak hours or when wind & solar output exceeds demand
  - Utility can turn electrolyzer on and off to help level electricity demand
- Battery EV's need to charge at the users' convenience, possibly overloading the grid

Figure 3 - A Modular Hydrogen Fueling Station

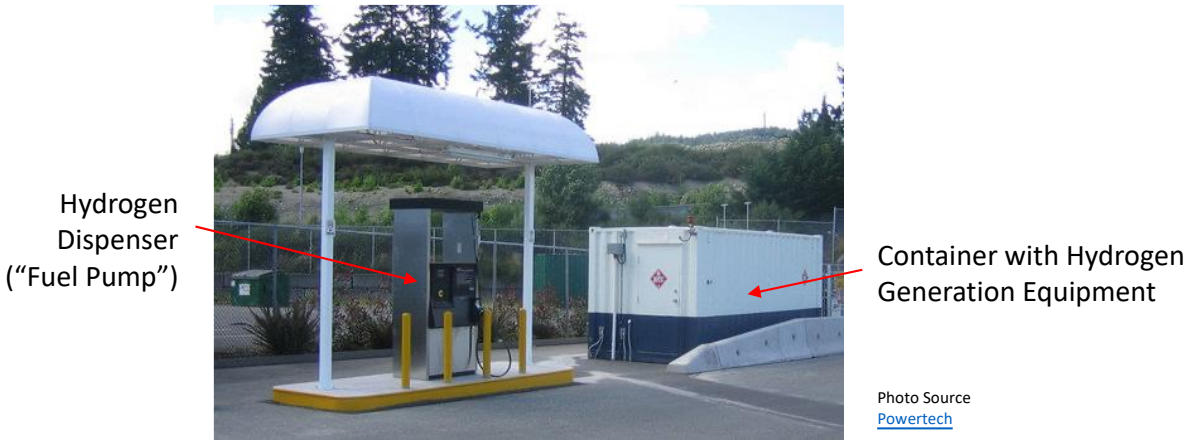
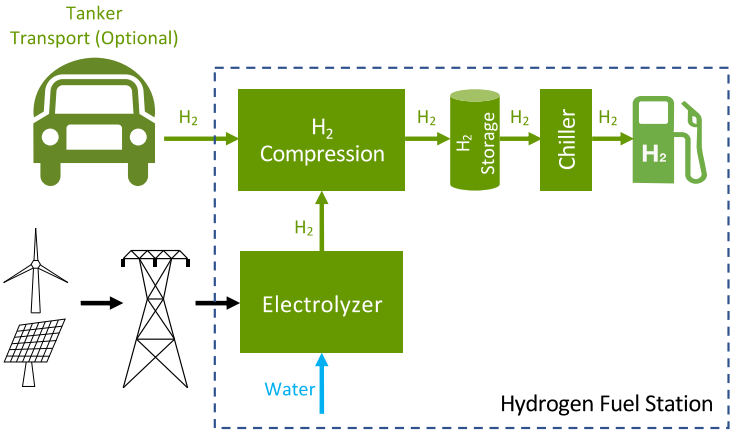


Figure 4 – Schematic of a Hydrogen Fuel Station



Electrolyzer and Fuel Cell Technology

- Both Electrolyzers and fuel cells use the same technology to perform complementary functions
- An electrolyzer uses electricity to split water molecules into hydrogen and oxygen
  - The hydrogen is captured and compressed for storage and distribution
- A fuel cell reverses this by using hydrogen and oxygen (from the air) to make electricity

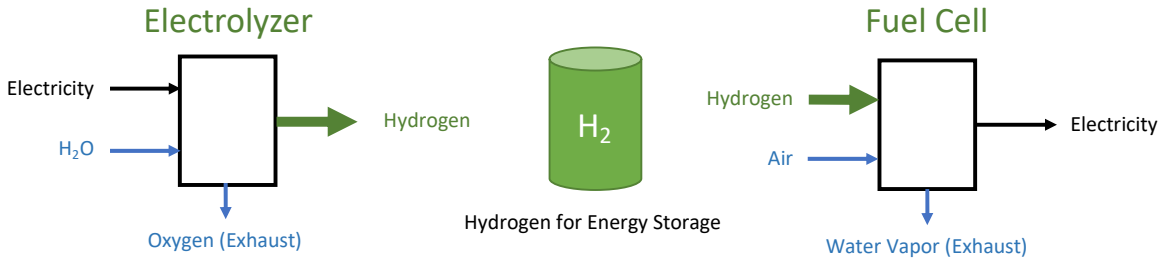
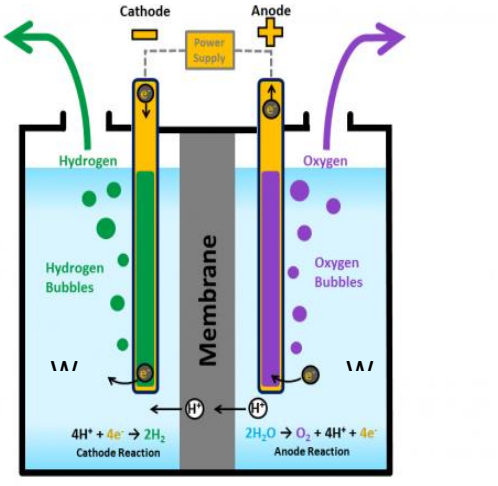
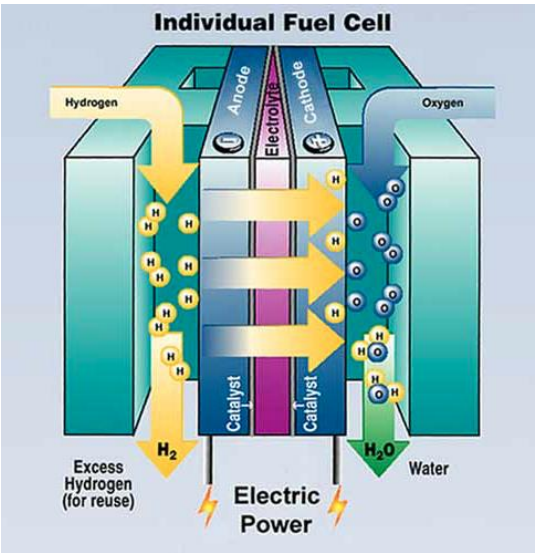


Figure 5 – Schematic Diagram of an Electrolyzer



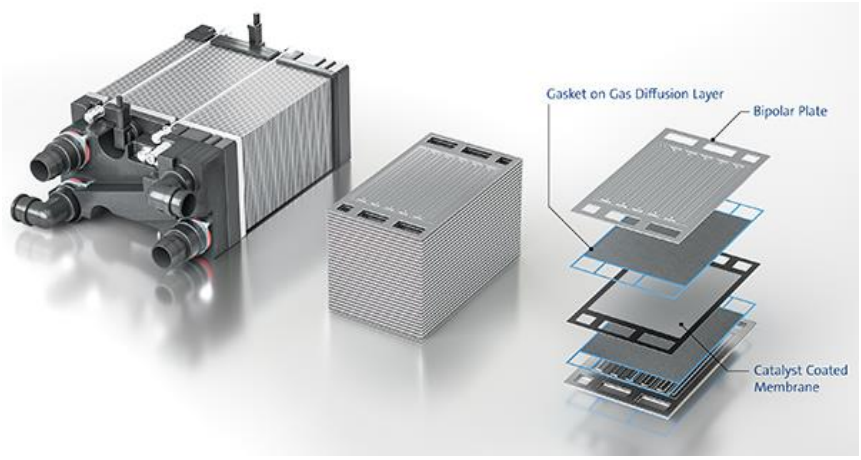
Source:
www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis

Figure 6 – Schematic Diagram of a Fuel Cell



Source:
http://www.geni.org/globalenergy/library/articles-renewable-energy-transmission/h2-fuel-cell.shtml

Figure 7 – Photo of a Fuel Cell "Stack"



A Fuel Cell, Electrolyzers Look Very Similar

Source: https://www.designworldonline.com/wp-content/uploads/FST_PP_Brennstoffzelle_EN_Lowres_1360px_RGB.jpg

Hydrogen Fueling Business Case

In order to entice all users of petroleum vehicles to switch to electric vehicles, the electric vehicle solution must:

- Make business sense – cost the same or less than alternatives
- Offer the same features and performance (highlighted in the introduction)

Electric Vehicle Cost

As with all new technologies, initial products are rather expensive until the design costs are recovered and cost-savings innovations are implemented. Consider the original product pricing in Figure 8.

Figure 8 – Original Product Prices in 2020 Dollars

Motorola DynaTAC 1983
$11,200

Sony Hi-Def TV 1998
$15,500

GE Monitor Top Refrigerator 1927
$7,436

Compaq Desk Pro 386 1988
$18k to $30K

Fuel Cell EV's are expected to match the cost of comparable petroleum vehicles based on the manufacturing costs. Although battery costs have dropped significantly, battery vehicles may always cost more than comparable petroleum vehicles. Also a factor, is that batteries last only half as long as internal combustion engines, so need to be replaced half-way through the life of the vehicle. Although both these costs are mostly offset by the cost of fuel – the fuel is paid for in small increments over a long period of time, while a battery replacement is a large ($10,000+) immediate expense.

Operating Cost

As discussed in the introduction, the "fuel" cost per mile of Battery EV's is significantly less than either ICE or Fuel Cell EV's (See Table 1). This is where Battery EV's stand out.

Hydrogen for Fuel Cell EV's is dependent on the cost of electricity to generate the hydrogen. In Colorado, there are electric rates offered for EV's which allow generating hydrogen at a cost which provides a margin to pay for the fuel station infrastructure and still sell hydrogen at parity with gasoline or diesel. This is aided by the fact that Fuel Cell EV's are over 2.5 times as efficient as ICE vehicles.

Effects of Electric Vehicles on the Electrical Grid

As the world stops using petroleum for transportation, that energy for EV's – whether they are Battery or Fuel Cell – is going to come from the electrical grid. While there's no question the grid is going to have to grow, there is a difference in how Battery and Fuel Cell EV's place demands on the grid.

- Battery EV's need to charge at the *users'* convenience
- Hydrogen for Fuel Cell EV's can be generated at the *utilities'* convenience

This is an issue of timing. What this means is that when a battery vehicle needs "fuel", it has to draw electricity *now*. However, hydrogen can be made at any time and stored. Therefore, you could fuel your EV this morning with hydrogen that was made last night or last year. This is important for the electrical grid where the supply of electric has to match the system demands second-to-second. The electric utilities struggle today to match changing demands. This will be many times more of an issue in the future when electrical supply from wind and solar are frequently varying completely out of sync from electrical demands.

Hydrogen generation, controlled by the utilities, can actually help balance the electrical grid. Hydrogen can be generated when there is an abundance of power available, and completely shut off during times of peak loads. In the future, electrical generation and hydrogen generation will work hand-in-hand to support a 100% renewable energy grid.

Hydrogen Safety

All energy sources carry a certain amount of risk. This is as true for batteries as it is for fuels. Consider Figure 9 showing car fires for hydrogen, gasoline and batteries.

Figure 9 – Car Fires Showing a Battery, Hydrogen and Gasoline Vehicle

Hydrogen Car Fire **Gasoline Car Fire**

One Minute After Ignition

Source: Fuel Cell and Hydrogen Energy Association: www.fchea.org

Hydrogen can be considered as safe (if not safer) than petroleum or battery vehicles for the following reasons:

- Hydrogen is lighter than air, diffuses quickly, and is non-toxic if inhaled
- Gasoline and diesel pool on the ground where they continue to burn
- Since diesel is an oil it clings to objects as it burns
- Hydrogen generates much less radiant-heat than gasoline, greatly reducing the risk of a secondary fire
- Lithium-Ion batteries will burn violently if deformed or punctured or develop internal short circuits

Summary

Battery EV's and Fuel Cell EV's have complementary characteristics. Both are needed to entice *all* users of Internal Combustion Engine vehicles to switch to electric vehicles.