Stephen Davis
19-9-4

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Hydrogen for Energy Storage

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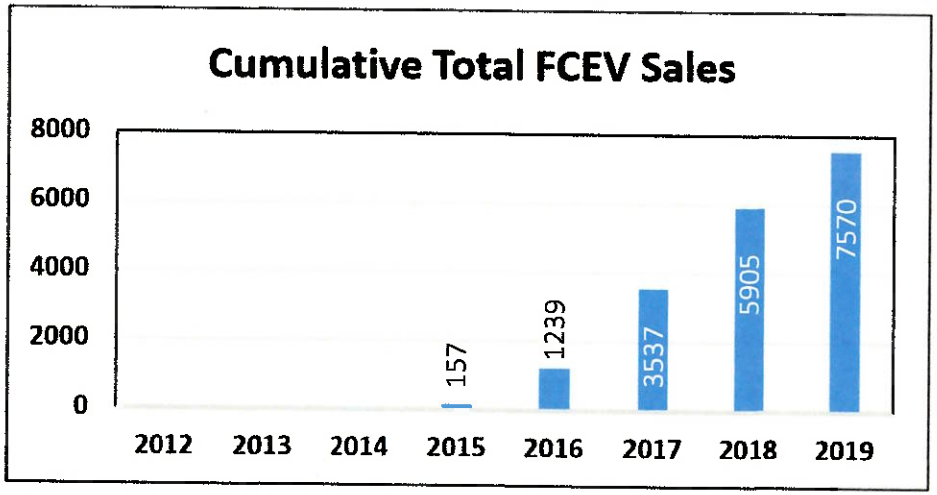
Market for FCEV

Open - Retail	41
Open - Non-Retail	0
Commissioning	7
Under Construction	2
Approval to Build	3
Planning Approval	6
Permit in Process	2
Pre-Permit Application	2
Establishing Site Control	0

Hydrogen Stations in California.
Updated Sept 24th 2019
www.cafcp.org.



Sales of FCEV in California. Data for 2019 updated to October 1st.
Data from Baum and Associates. www.cafcp.org.

Toyota Mirai

Honda Clarity

Hyundai Nexo

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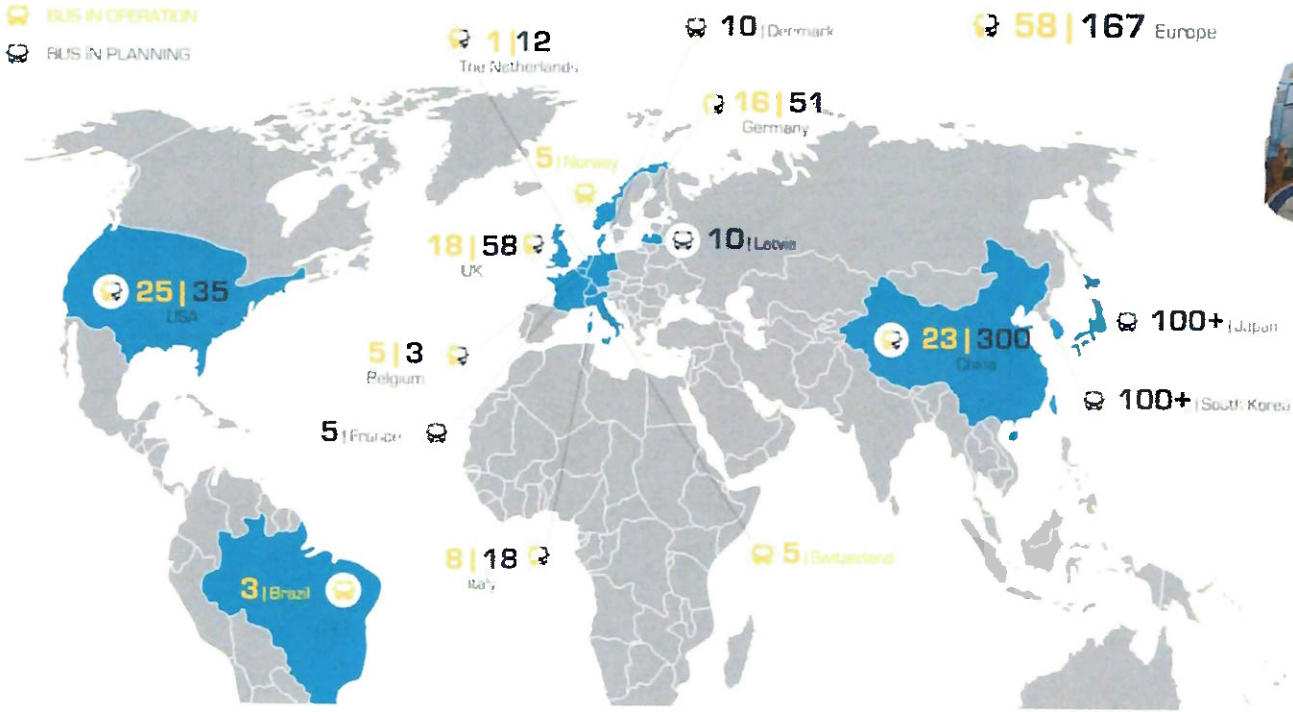
The case for buses

California October 1st 2019

FCEBs in operation..... 31
FCEBs in development.... 21
FC Shuttles in dev..... 4



China has committed to have:

- 600 buses by the end of 2019
- 1000 buses by the end of 2020

FCE Buses vs BE Buses

- More range
- More payload
- Less time to refill
- Can refill once per route
- Longer life (batteries degrade)
- Less cost of maintenance

Source: Ballard / California: AC Transit, Orange County Transportation Authority (OCTA), SunLine Transit, UC Irvine

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The case for trucks inCalifornia

Tesla Model 3 Battery
75kWh / 480 kg

Mirai's Hydrogen Tanks
5 kg H2 / 100kWh / 93 kg

Nikola FC Truck – Estimated 500 to 750 miles

Toyota FC Truck – Estimated 250 miles

Kenworth FC-B Truck – Estimated 100 miles

US Hybrid FC Truck – Estimated 200 miles

Hydrogen is best for trucks

- Hydrogen trucks are being developed
- Long haul requires a larger network of hydrogen stations
- Price of renewable hydrogen must also come down

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Production

Steam Methane Reforming

$CH_4 + H_2O + heat \rightarrow CO + 3H_2$

$CO + H_2O \rightarrow CO_2 + H_2 + heat$

Electrolysis

$2H_2O \rightarrow O_2 + 2H_2$

An. $2H_2O \rightarrow 2H^+ + \frac{1}{2}O_2 + 2e^-$
Ca. $2H^+ + 2e^- \rightarrow H_2$

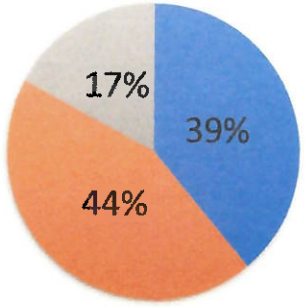
- PEM
- Alkaline

An. $2OH^- \rightarrow H_2O + \frac{1}{2}O_2 + 2e^-$
Ca. $2H^+ + 2e^- \rightarrow H_2$

Biomass (different alternatives)

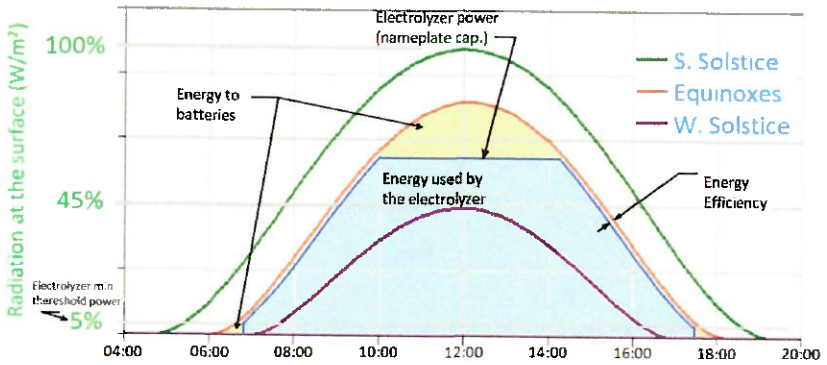
$Biomass + O_2 \rightarrow CO + H_2 + CO_2 + heat$

% in the $/kg of hydrogen produced (electrolysis)



Capex Energy Other Opex

Energy at 40$/MWh / Capex Based on standard prices for PEM electrolysis equipment (2019) and includes compression, storage and dispensing / Costs for labor estimated for California



Adapting the production of the electrolyzer to the available solar energy can be challenging (sunrise, sunset, clouds, etc)

Hydrogen costs

- Electrolytic hydrogen ~ 5 $/kg
- SMR clean ~ 2-3 $/kg
- SMR basic ~ 1.5 $/kg
- Liquefaction ~ 3 $/kg
- Compression to 500 bar ~ 0.07 $/kg

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Distribution

Hydrogen Supply pros and cons

- Liquid – Larger storage
- Gas – Cheaper processing
- H2 Pipeline – Scarce
- On Site – Price of electricity

Iwatani Hydrogen Station – Liquid supply

ITM Hydrogen Station – On Site Production

True Zero Hydrogen Station – Gaseous supply

Shell Hydrogen Station – H2 pipeline supply

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The HRS

Low pressure storage

Compression

High pressure storage

Dispenser

Chiller

Standard costs estimated (average HRS 150 kg/day)

- Transport to HRS ~ 1.5 $/kg
- Energy ~ 0.5 $/kg
- Rent ~ 0.55 $/kg
- Overhead ~ 1.1 $/kg
- Capex ~ 1.22 $/kg (based on about 1.3 M investment / 15 years)
- Total ~ 4.9 $/kg (Not included financing)

Typical Hydrogen Refueling Station

- Receives the hydrogen and stores it
- Compresses the gas up to around 900 bar
- Dispenses the gas at 700 bar into cars / 350 bar into buses

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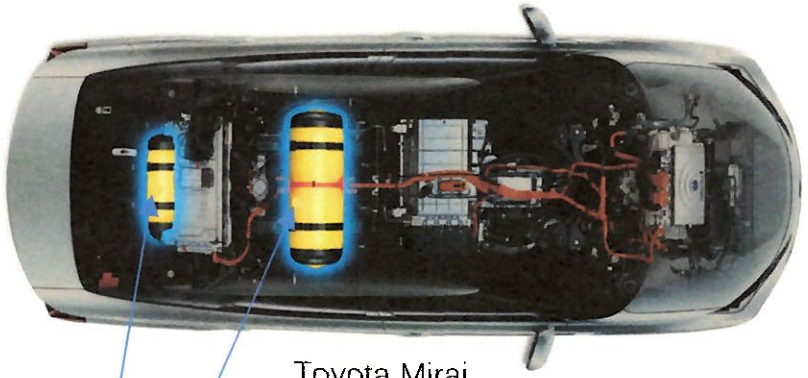
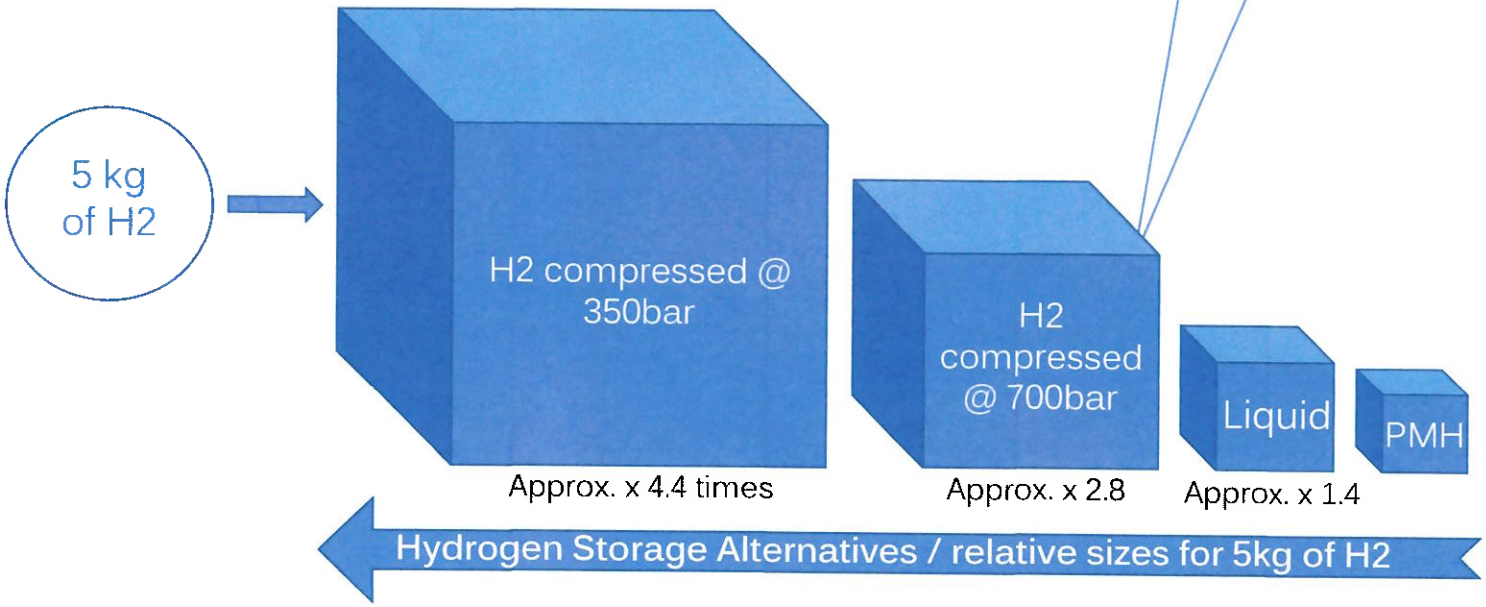
Storage as Metal Hydrides



Toyota Mirai



Standard Metal Hydrides

Pros

- Low pressure
- No risk of explosion

Cons

- Slow absorption / release
- Small density of H2

Porous Metal Hydrides

Pros

- Low pressure
- No risk of explosion
- Fast absorption / release
- Highest density of H2

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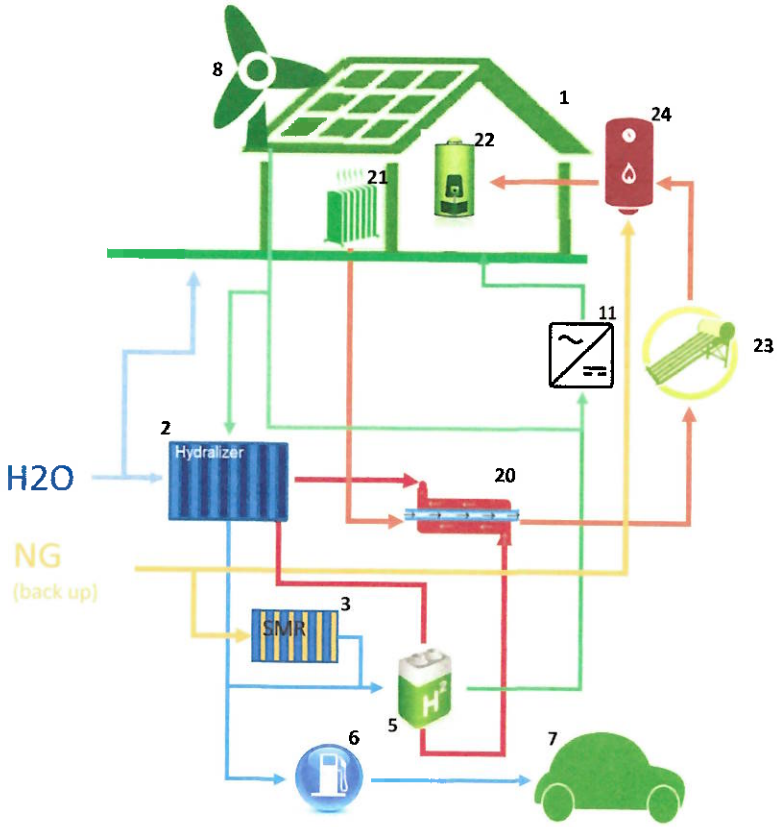
Application of the Hydrapak (PMH)



Electrolysis + Hydrapak (PMH)

ELECTRIC/H2 SUBSYSTEM
01-House with PV[III] panels
02-Hydralizer
(Electrolyzer + PMH)
03-Back Up - SMR
05-Fuel Cell
06-H2 Dispenser
07-FCEV[II]
08-Wind turbine
11-Inverter

HOT WATER SUBSYSTEM
20-Heat exchanger / Pre-heater
21-Heating system
22-DHW[I] heat exchanger
23-Sun/water heat exch.
24-Back-Up gas/fuel DHW[I] boiler

NOTES:
I – Domestic Hot Water
II – Fuel Cell Electric Vehicle
III – Photo Voltaic
IV – Polymer Electrolyte
(Proton Exchange)
Membrane

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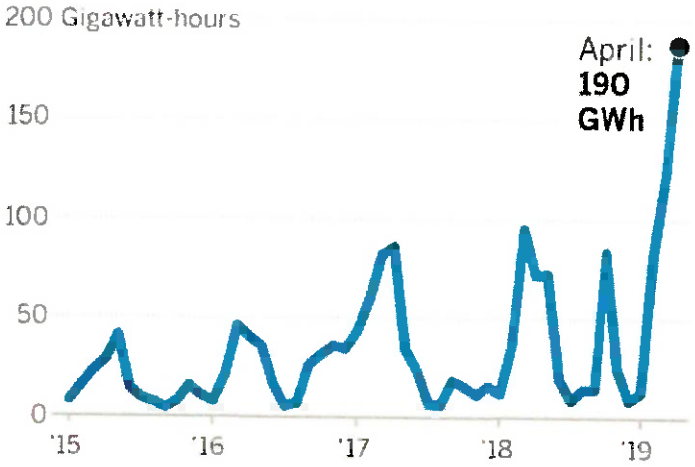
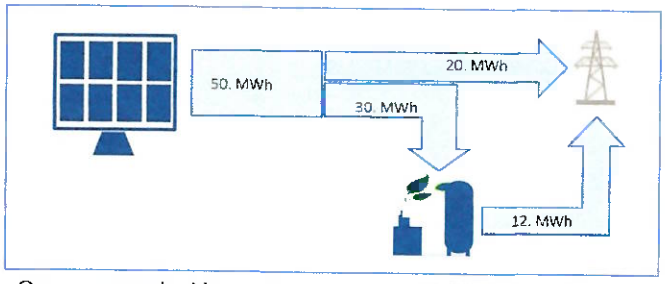
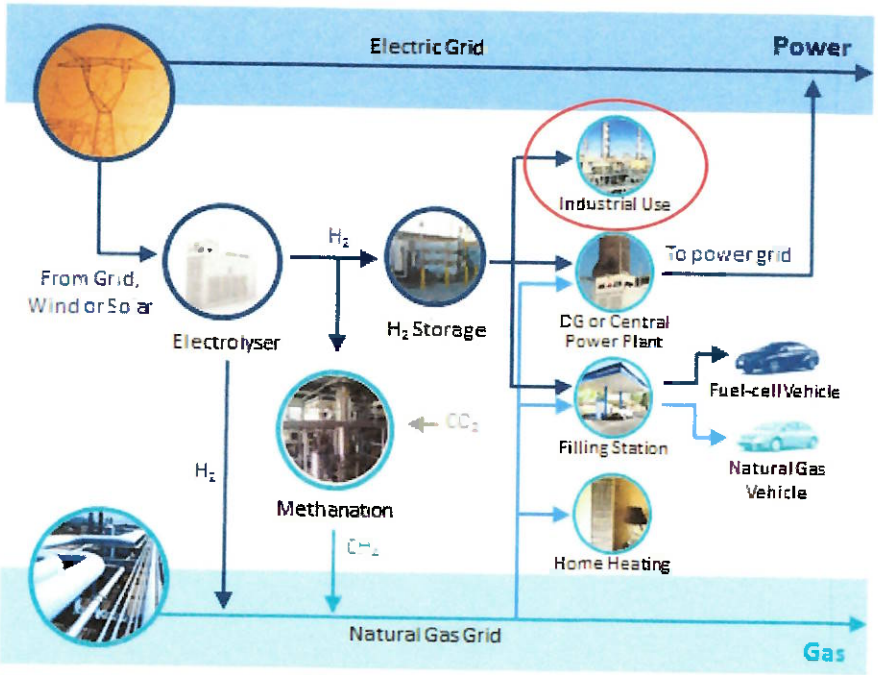


Total wind and solar curtailed in California
Source: CalSO
Graph by: Shaffer Grubb / Los Angeles Times



Gross example. No compression loses accounted for

Other ways of using RH2



Power to gas – injecting to the grid
Source: SoCalGas / Matt Gregory

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Thanks

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