Future Smart Energy - Fuel Cell and Hydrogen Technology

Summer School 2014, Aalborg, Denmark

August 5, 2014

Samuel Simon Araya
ssa@et.aau.dk

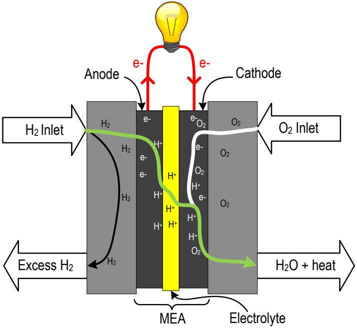
Department of Energy Technology
Aalborg University
Denmark

AALBORG UNIVERSITY
DENMARK

Layout

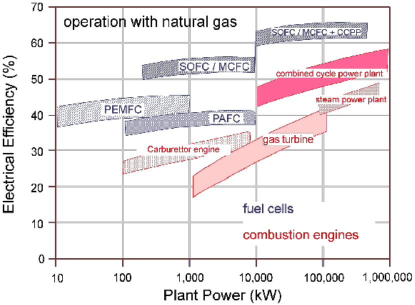
Introduction to fuel cells

Definition A fuel cell is an electrochemical device that converts the internal energy of gases into electrical energy, directly and continuously through chemical reactions.



- **1839** William Grove makes the first H_2-O_2 fuel cell
- **1950's** PEM fuel cell is invented at GE
- **1960's** NASA uses fuel cells for space missions
- **2007** Fuel cells begin to be sold commercially for APUs and stationary backup power
- **2008** Honda FCX clarity
- **2015** Toyota FCV available for sale

"Nature favors the prepared mind" -Louis Pasteur

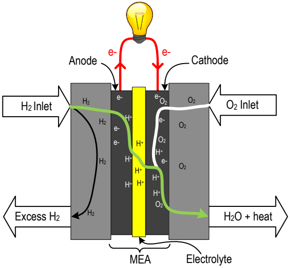


- No emissions
- Higher efficiency
- No moving parts
- Fuel flexibility

Low temperature FC	High temperature FC
▶ Proton Exchange Membrane Fuel Cells (PEMFC) ▶ Direct Methanol Fuel Cells (DMFC) ▶ Alkaline Fuel Cells (AFC) ▶ Phosphoric Acid Fuel Cells (PAFC)	▶ Solid Oxide Fuel Cells (SOFC) ▶ Molten Carbonate Fuel Cells (MCFC)

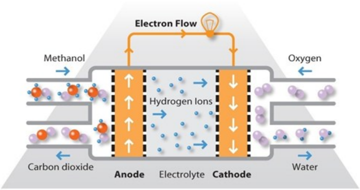
Introduction to fuel cells
Proton Exchange Membrane Fuel Cell (PEMFC)

Electrolyte	Proton exchange membrane - Nafion, PBI
Temperature	LT: 50-100 °C HT: 120-200 °C
Power	100 W - 250 kW
Applications	Backup power, portable power, μCHP, transportation



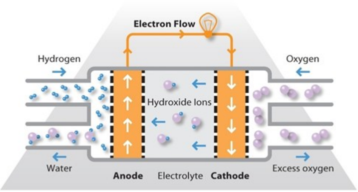
Pros	Cons
Compact, less corrision problems, insensitivity to orientation in space, high power density	Water management problems, expensive platinum catalyst, sensitive to CO

Dept. of Energy Technology
Aalborg University
Denmark



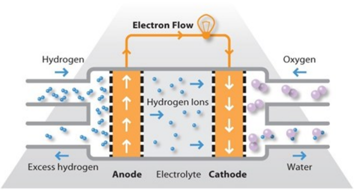
Electrolyte	Proton exchange membrane
Temperature	LT: 25-90 °C HT: 100-150 °C
Power	1 W - 100 W
Applications	Portable power, mobile electronic devices

Pros	Cons
Methanol is more energy dense and easier to transport than hydrogen	Low efficiency, expensive platinum catalyst



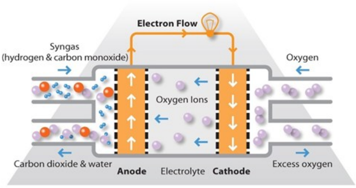
Electrolyte	Alkaline solution, generally KOH
Temperature	LT: 23-70 °C HT: 100-250 °C
Power	100 W - 100 kW
Applications	Military, space

Pros	Cons
High performance, non-noble-metal catalyst	Electrolyte sensitive to CO_2



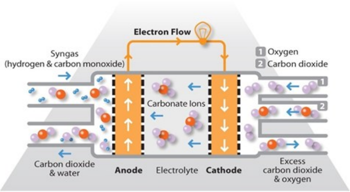
Electrolyte	Liquid phosphoric acid
Temperature	150-200 °C
Power	150 kW - 11 MW
Applications	μCHP

Pros	Cons
Mature technology, no-noble metals	Low power density, continuous operation



Electrolyte	Solid Oxide
Temperature	600-850 °C
Power	1 kW - 3 MW
Applications	μCHP

Pros	Cons
High efficiency, long-term stability, fuel flexibility	Significant ohmic losses, high thermal stress



Electrolyte	Molten carbonate salt
Temperature	600-700 °C
Power	1 kW - 1 MW
Applications	μCHP

Pros	Cons
High efficiency, fuel flexibility	The carbonate ions are consumed, high thermal stress

Dept. of Energy Technology
Aalborg University
Denmark

Characteristics of hydrogen

- Hydrogen is an energy carrier, not an energy source. Hydrogen can store and deliver usable energy, but it doesn't typically exist by itself in nature; it must be produced from compounds that contain it.
- Production of hydrogen requires feedstock and energy input.
- Hydrogen has high energy content per weight, however energy density per volume is quite low.

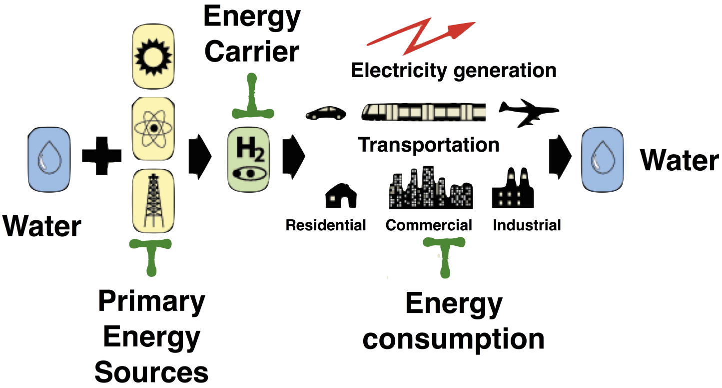
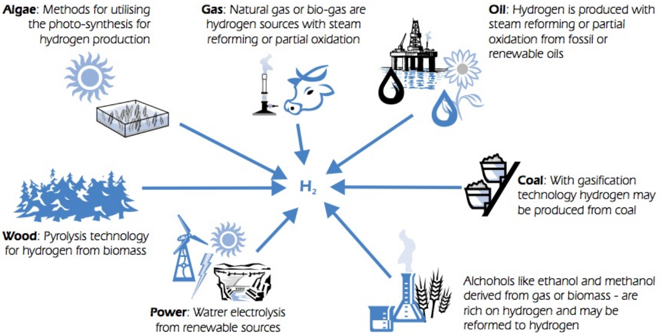
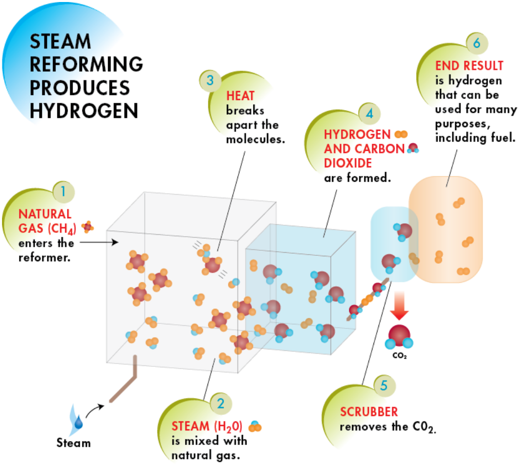


Figure: Hydrogen energy system



Source: Hydro.


STEAM REFORMING PRODUCES HYDROGEN
1
NATURAL GAS (CH_4) enters the reformer.
2
STEAM (H_2O) is mixed with natural gas.
3
HEAT breaks apart the molecules.
4
HYDROGEN AND CARBON DIOXIDE are formed.
5
SCRUBBER removes the CO_2.
6
END RESULT is hydrogen that can be used for many purposes, including fuel.
Steam
CO_2

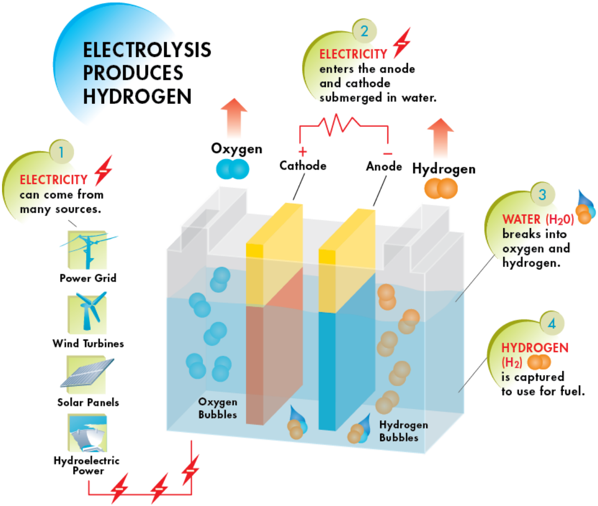
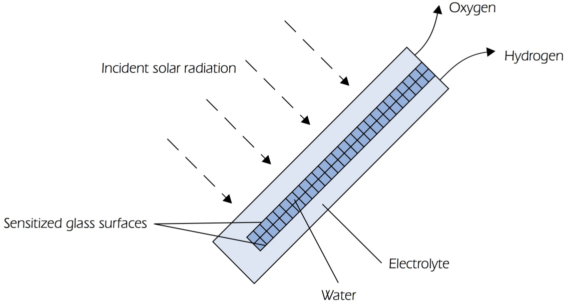

ELECTROLYSIS PRODUCES HYDROGEN
1
ELECTRICITY can come from many sources.
Power Grid
Wind Turbines
Solar Panels
Hydroelectric Power
2
ELECTRICITY enters the anode and cathode submerged in water.
Oxygen
+
Cathode
−
Anode
Hydrogen
Oxygen Bubbles
Hydrogen Bubbles
3
WATER (H2O) breaks into oxygen and hydrogen.
4
HYDROGEN (H2) is captured to use for fuel.

Photo-electrolysis



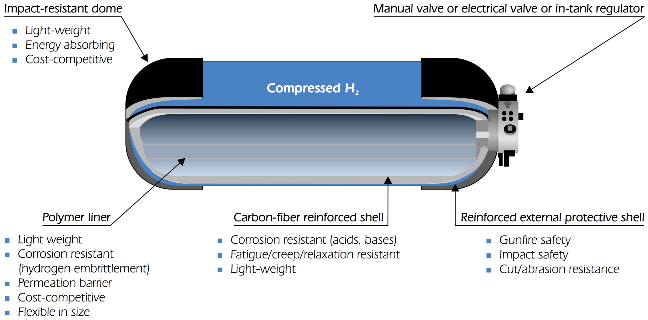
Requirements

Hydrogen has the lowest storage density of all fuels

- Low cost materials and components, low cost and high volume manufacturing methods
- Compact and lightweight materials and components
- Storage efficiency
- Durability
- Fast refueling time
- Codes and standards (safety and reliability)

Compressed gas storage

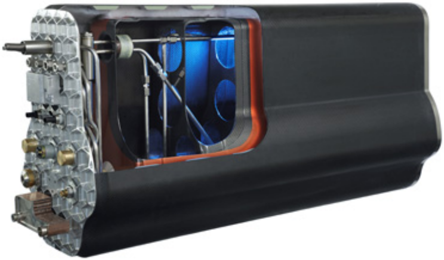
Physical storage of compressed hydrogen gas in high pressure tanks (up to 700 bar)



10% of the HHV needed to pressurize from 0-700 bar

Cryogenic liquid storage

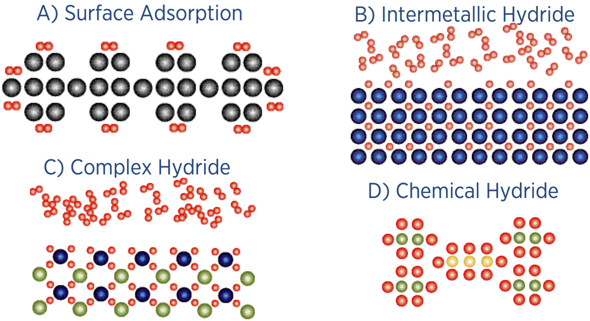
The most common way to store hydrogen in a liquid form is to cool it down to cryogenic temperatures (−253 °C).



30 % of the HHV consumed in the liquefaction process

Materials-based storage

Within the structure or on the surface of certain materials, as well as in the form of chemical compounds that undergo a chemical reaction to release hydrogen



	Hydrogen	Gasoline Vapor	Natural Gas
Flammability Limits (in air)	4-74%	1.4-7.6%	5.3-15%
Explosion Limits (in air)	18.3-59.0%	1.1-3.3%	5.7-14%
Ignition Energy (mJ)	0.02	0.20	0.29
Flame Temp. in air (°C)	2045	2197	1875
Stoichiometric Mixture (most easily ignited in air)	29%	2%	9%

Characteristics of H_2

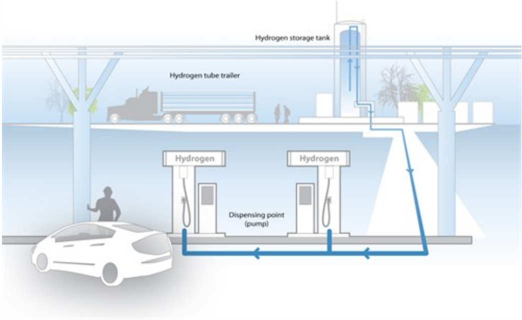
- Odorless, colorless and tasteless
- Lighter than air and diffuses rapidly
- Buoyant

Dept. of Energy Technology
Aalborg University
Denmark

Some of hydrogen's differences provide safety benefits compared to gasoline or other fuels

Figure: FCV Left & ICE Right at 3 Seconds, 60 Seconds, and 90 Seconds

Dept. of Energy Technology
Aalborg University
Denmark



H_2 distribution today

- Pipeline
- High-Pressure Tube Trailers (trucks)
- Liquefied Hydrogen Tankers (Barge)

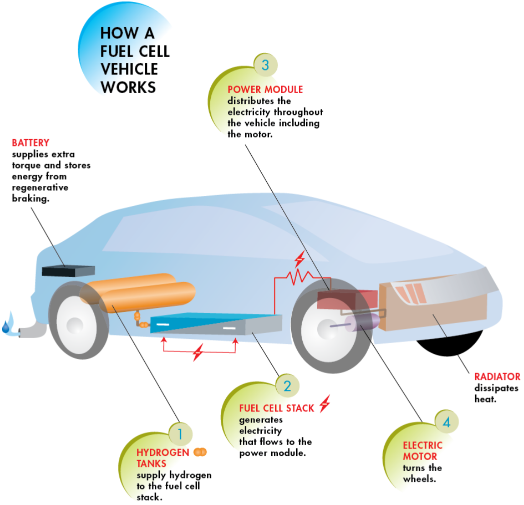
Dept. of Energy Technology
Aalborg University
Denmark

Figure: Current hydrogen fuel stations in blue, hydrogen stations in development in orange

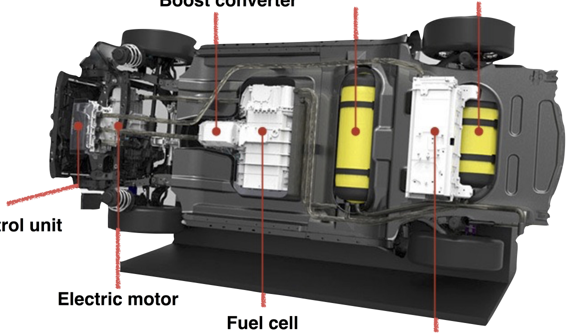
Dept. of Energy Technology
Aalborg University
Denmark

Applications

Transportation: Fuel Cell Electric Vehicle (FCEV)



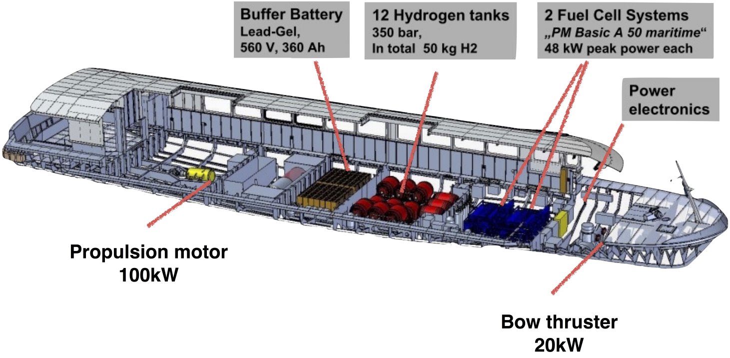
Applications
Transportation: Fuel Cell Electric Vehicle (FCEV)

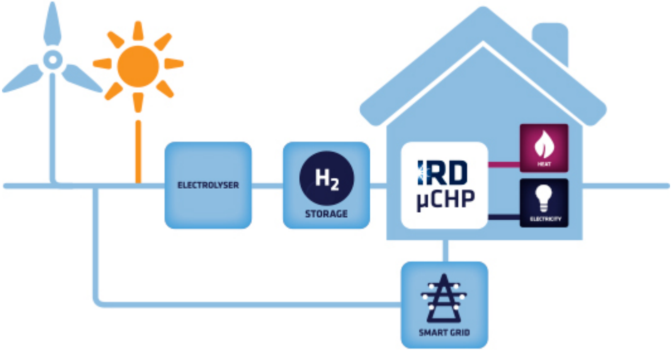


Toyota FCV teaser

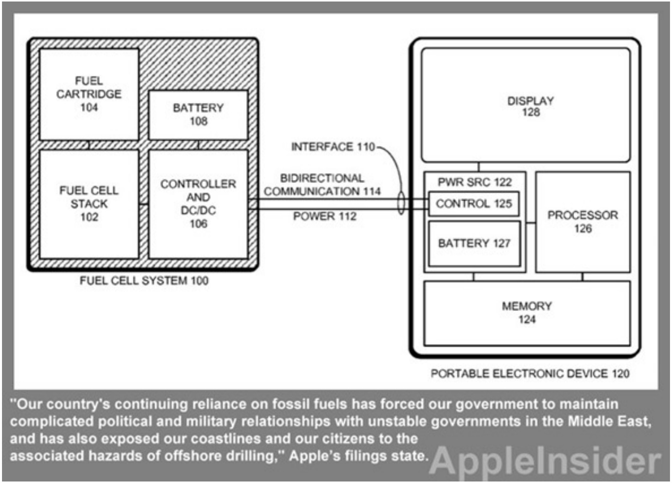
Applications

Transportation: Fuel Cell Ship





Over 45% electrical efficiency, and up to 98% total efficiency of fuel conversion if the heat is used


FUEL CARTRIDGE 104
BATTERY 108
FUEL CELL STACK 102
CONTROLLER AND DC/DC 106
FUEL CELL SYSTEM 100
INTERFACE 110
BIDIRECTIONAL COMMUNICATION 114
POWER 112
DISPLAY 128
PWR SRC 122
CONTROL 125
BATTERY 127
PROCESSOR 126
MEMORY 124
PORTABLE ELECTRONIC DEVICE 120
"Our country's continuing reliance on fossil fuels has forced our government to maintain complicated political and military relationships with unstable governments in the Middle East, and has also exposed our coastlines and our citizens to the associated hazards of offshore drilling," Apple's filings state.
AppleInsider

Concluding remark

Significance

"Given the number of advantages over conventional energy conversion devices that include higher efficiency, versatility and fuel flexibility, and considering also the urgency for shift in trend towards greener sources of energy, the role of fuel cells is crucial for a future global energy system that considers the environmental and socio-economic advantages to our societies."

Challenges: Cost, Durability, Infrastructure

Thank you for your attention

In case you have any questions or comments please do not hesitate to contact me. You can find my contact details below.

Samuel Simon Araya
ssa@et.aau.dk
Pontoppidanstræde 101
9220 Aalborg Øst

AALBORG UNIVERSITY
DENMARK