# High pressure PEM-elektrolysis:

## Maximizing “well-to-wheel“ efficiency for hydrogen-powered vehicles



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Biovest GmbH

# Biovest‘s activities

- market studies, project development with a focus on hydrogen and renewable energies.
- Participation in interdisciplinary research and demonstration projects, e.g.:
  - HyLog by Fronius
  - „The renewable Hydrogen fuelling station of the future“ by Joanneum at the HyCentA
- Design of energy strategies for power utilities and political entities
- Biovest is the Austrian distributor of PEM electrolyzers built by Proton Energy Systems

# Hydrogen mobility:
## Hydrogen as a range extender

- hydrogen has the highest energy density per mass unit
- Hybrid vehicles combining a battery with a fuel cell profit from a longer range
- Example: Fronius Hylog project:
- http://www.fronius.com/cps/rde/xbcr/SID-838CEE98-8C78BFBB/fronius_usa/4000062925EN_PRO_0208_hylog_referenz_en.pdf
  http://www.fronius.com/cps/rde/xbcr/SID-F151EC24-DE2D003E/fronius_usa/Poster_HyLog-low.pdf

# Ranges of 2011 Generation of BEVs



- Renault Kangoo 2008: 90 km (http://www.elektro-auto.net/index.php?option=com_content&task=view&id=82&Itemid=57)
- CITROËN C-ZERO 2011: 130 km (http://www.c-zero.citroen.com/#/at/news/vorstellungskraft-teil2)
- Renault/Nissan Leaf 2011: 160 km (http://kurier.at/freizeit/motor/2030841.php)
- Other brands: http://www.faz.net/s/Rub1DABC609A05048D997A5F315BF55A001/Doc~E5170E852FE2D41EEBE5F454E40C061FB~ATpl~Ecommon~Scontent.html

BEVs: battery electric vehicles

# ...and in the winter ?

- „Next to driving most energy is lost with heating and cooling.“
- Electric heating drastically reduces range
- Matthias Küsell, Head of R&D for BEV and PHEV systems at Bosch (http://kurier.at/freizeit/motor/2018582.php)

# Current range of FCEVs

Fuel Cell:

- 50 % efficiency, remainder dissipated as heat
- Hydrogen has the highest energy density per mass unit
- Also a climate-friendly approach: less CO2 if hydrogen is produced by renewable electricity

Honda FCX Clarity fuel cell hybrid:

- First assembly-line produced FCEV
- range 386 km (with 700 bar hydrogen approx.580 km)
- 350 bar, 3.92 kg hydrogen
- Complete with electric heating and all customary servo drives: http://automobiles.honda.com/fcx-clarity/specifications.aspx

FCEV: Fuel cell electric vehicles

# Market Forecast on Battery Electric, Plug-in Hybrid and Fuel Cell Electric Vehicles


Source: http://www.zeroemissionvehicles.eu/

**The following companies and organisations participated in this study:**

***Car manufacturers***
BMW AG, Daimler AG, Ford, General Motors LLC, Honda R&D, Hyundai Motor Company, Kia Motors Corporation, Nissan, Renault, Toyota Motor Corporation, Volkswagen

***Oil and gas***
ENI Refining and Marketing, Galp Energia, OMV Refining and Marketing GmbH, Shell Downstream Services International B.V., Total Raffinage Marketing

***Utilities***
EnBW Baden-Wuerttemberg AG, Vattenfall

***Industrial gas companies***
Air Liquide, Air Products, The Linde Group

***Equipment car manufacturers***
Intelligent Energy Holdings plc, Powertech

***Wind***
Nordex

***Electrolyser companies***
ELT Elektrolyse Technik, Hydrogenics, Hydrogen Technologies, Proton Energy Systems

***Non-governmental organisations***
European Climate Foundation

***Governmental organisations***
European Fuel Cells and Hydrogen Joint Undertaking, NOW GmbH

## All conclusions are based on proprietary industry data

This study represents the most accurate to date,[26] as conclusions are based not on informed speculation, but on confidential, granular and proprietary data, provided by key industry players. This has allowed a true comparison of the power-trains, with all underlying assumptions clearly stated (see Methodology section, pages 15-25).

# FCEVs are comparable to ICEs on driving performance and range

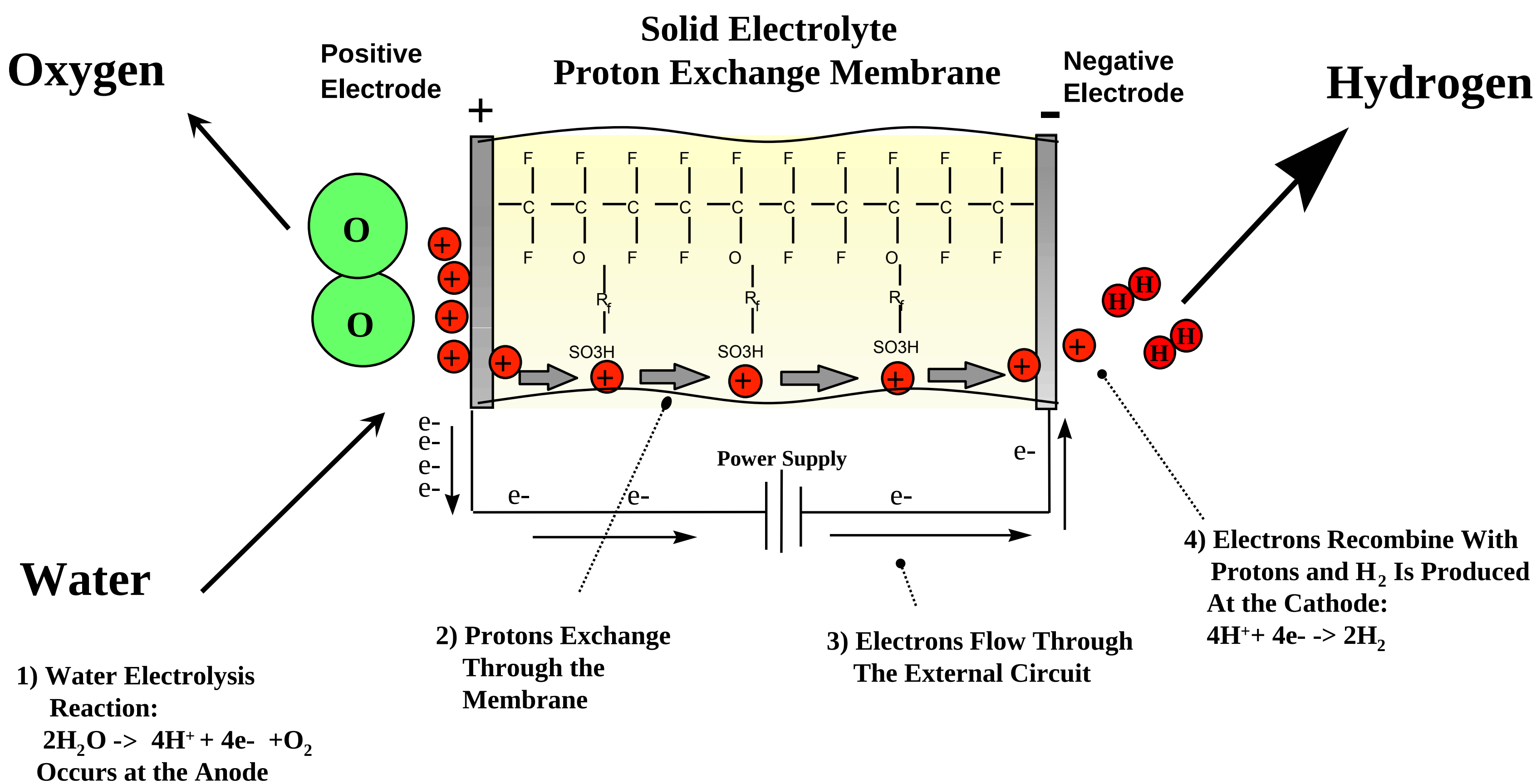

1 Bars represent range of performance across reference segments
2 Fast charging; implies higher infrastructure costs, reduced battery lifetime and lower battery load
3 The gas tank of a PHEV has the same refueling time as a conventional vehicle

Source: http://www.zeroemissionvehicles.eu/

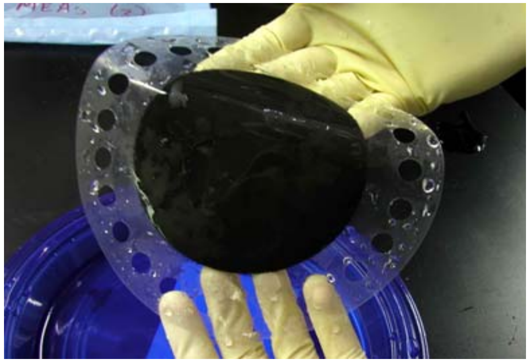
# Elektrolysis: hydrogen production using (renewable) electricity and water

- Alkaline (KOH) Electrolysis
- „Polymer-Electrolyte-Membrane“ (PEM) or „proton exchange membrane“ (PEM) Electrolysis

# How PEM Electrolysis Works



# The inside of an electrolyzer



Membrane Exchange Assembly (MEA)


Cell stack

$H_2$ Generator

# PEM-Electrolyzer HOGEN S 40 has the size of a washing machine

Courtesy of Fronius

# Why High pressure electrolysis ?

- Pressurization during electrolysis occurs via true isothermal electrochemical compression and is based on the Nernst equation
- Electrochemical compression is more efficient than mechanical compression and reduces need for service-intensive mechanical compressors:
- Electrolysis at 165 bar:
  no two- or three-stage compression system required;
  only booster compressor necessary.
  much longer service intervals of compressor
- Electrolysis at 350 bar: no or only small booster necessary
- >350 bar: Electrolysis inefficient; booster compressor needed

# Why High pressure electrolysis ?

- Greatly simplifies design of hydrogen fueling station
- Greatly reduces reduces size and cost of fueling station
- Estimates of efficiency gains “well-to-wheel” range from 5 to 15 %
- Storage of renewable energy (wind, solar) as hydrogen becomes economical

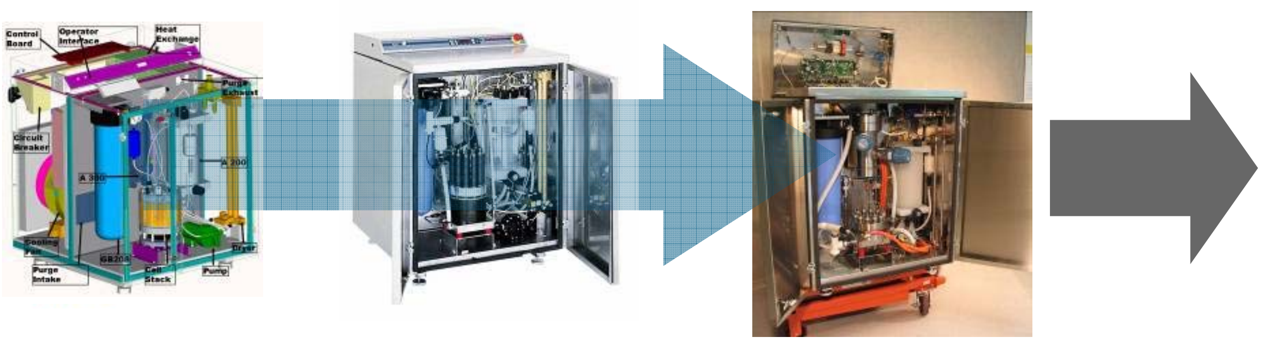
# Development of a high pressure $H_2$ generator for Home Fueling

Product Requirements:

- Small-scale generation
- Safe system, easy to operate
- ≥ 5,000 psi (350 bar) generation pressure
- Potential integration with renewables
- Simple, low cost
- Applicable Codes & Standards
    - ISO 22734-2, “Hydrogen Generators Using Water Electrolysis Process – Part 2: Residential Applications”

# Small High Pressure $H_2$ Generator

- 2,400 psi (165 bar) differential pressure
- 0,6-2,2 kg $H_2$/Tag
- Field demonstrations with select customers underway
- Over 20,000 hr of continuous operation
- Stack & system durability demonstrated
- Outdoor version recently completed
- 350 bar cells already in continuous testing, first field testing in two years

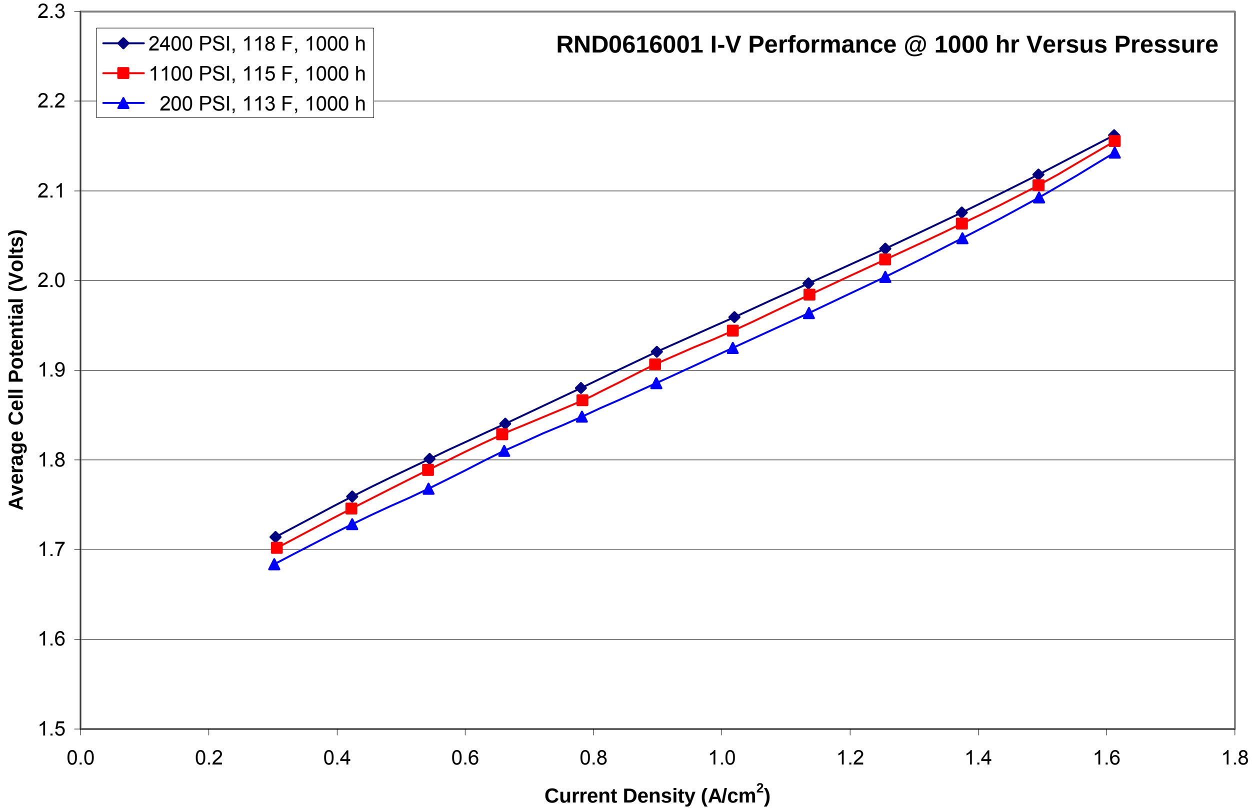




Sitron
RND0721101

# Effect of Pressure

- Small voltage penalty



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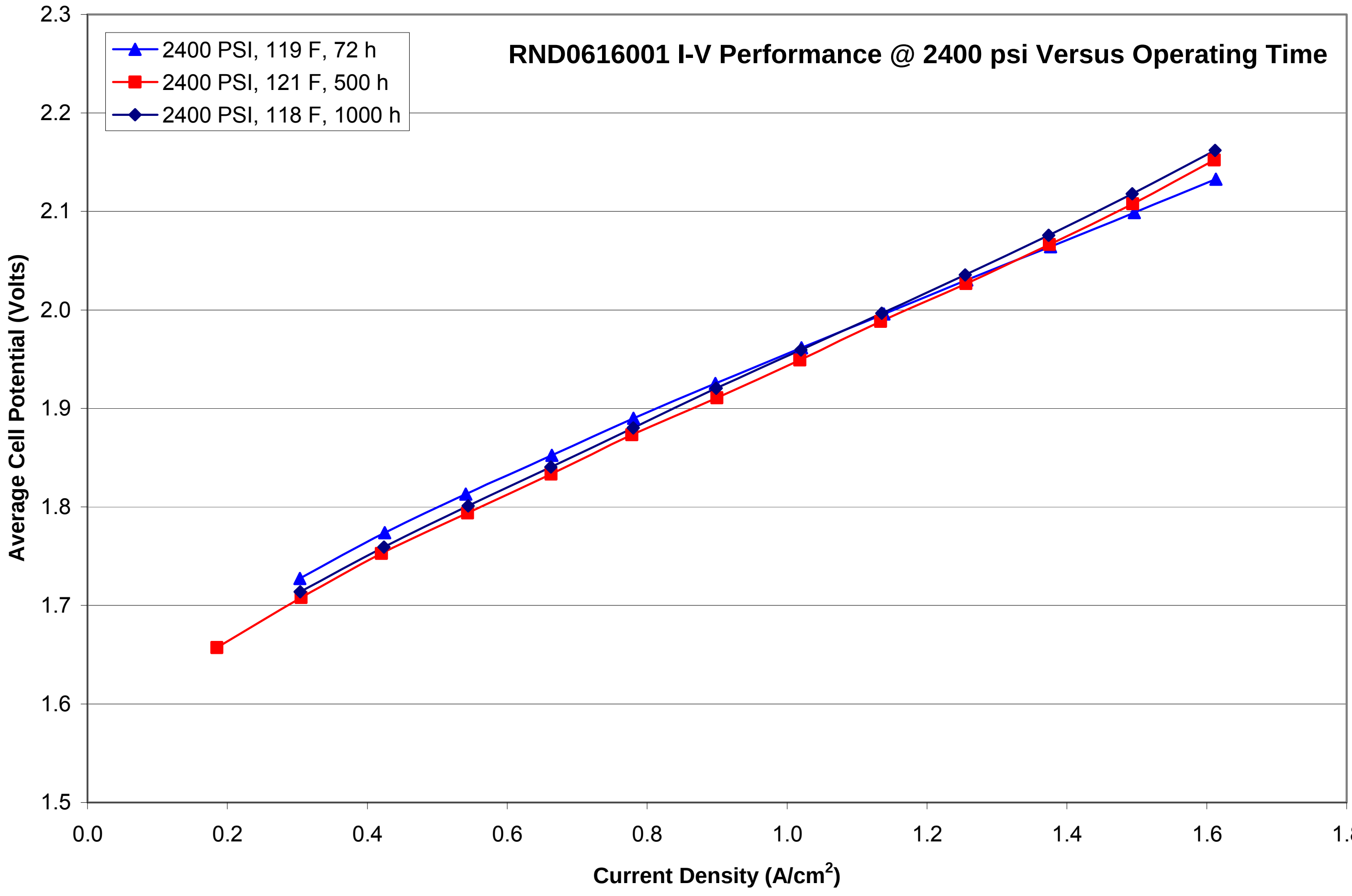
# Performance vs. Time



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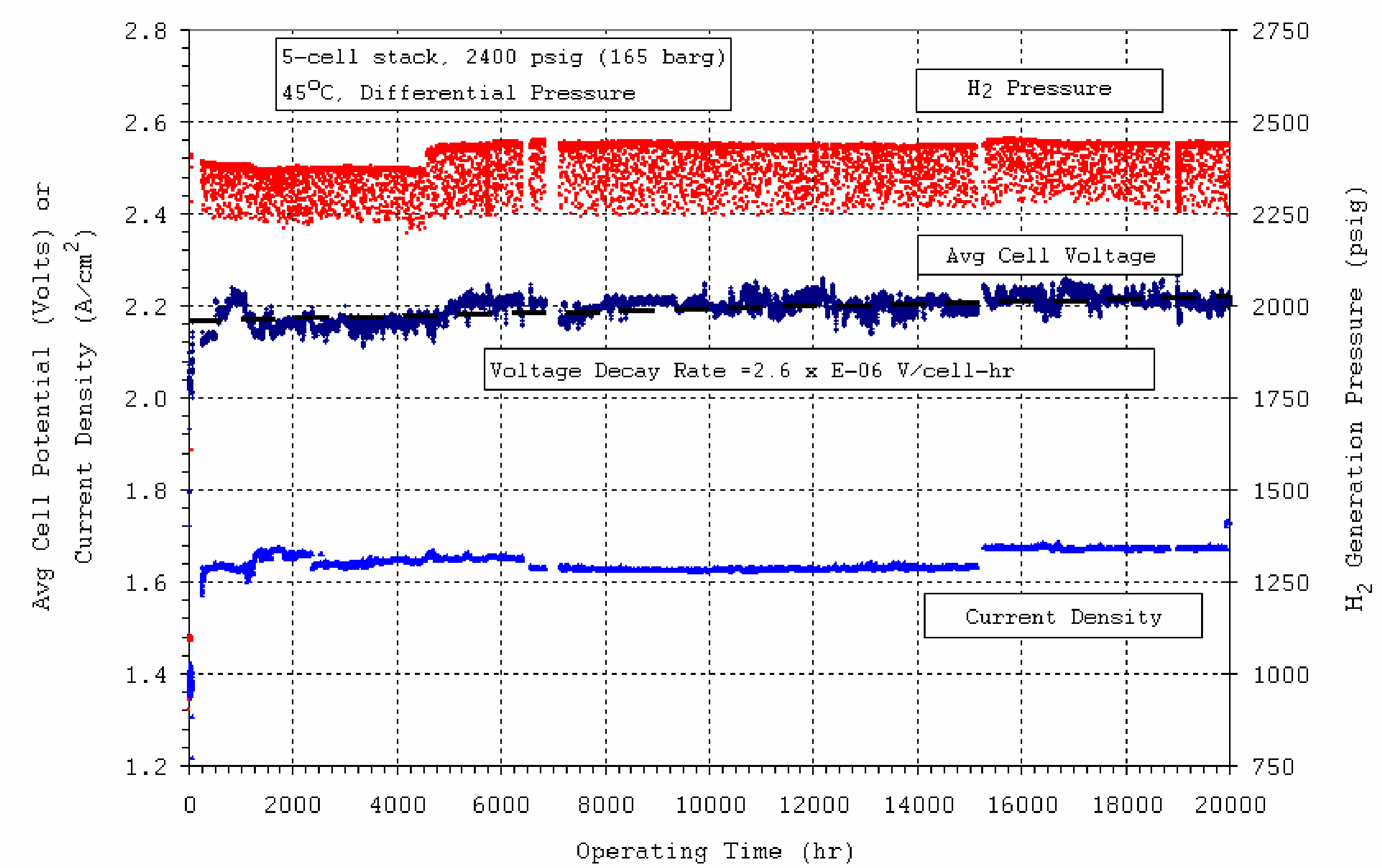
# High Pressure Durability

- 5-cell stack, ~1.6 A/cm$^2$, 2400 psi**d** $H_2$ (165 bar)
- 0.25 kg/hr (5 slpm)
- +18,000 hr at pressure



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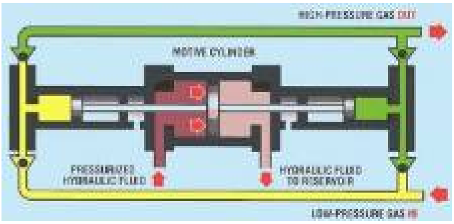
High pressure
electrolyzer
2 kg $H_2$/day
Outdoor rated

Medium Pressure
Storage
(165 bar)

Single stage boost
compressor




Simple
dispensing
interface


Packaged system boundary

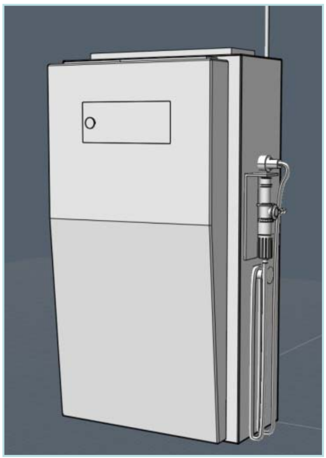
Vehicle Fill

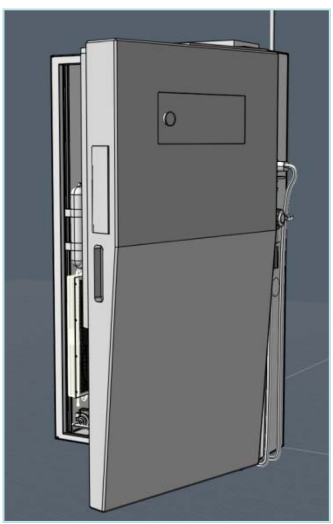
≤5 kg at up to
(700 bar)

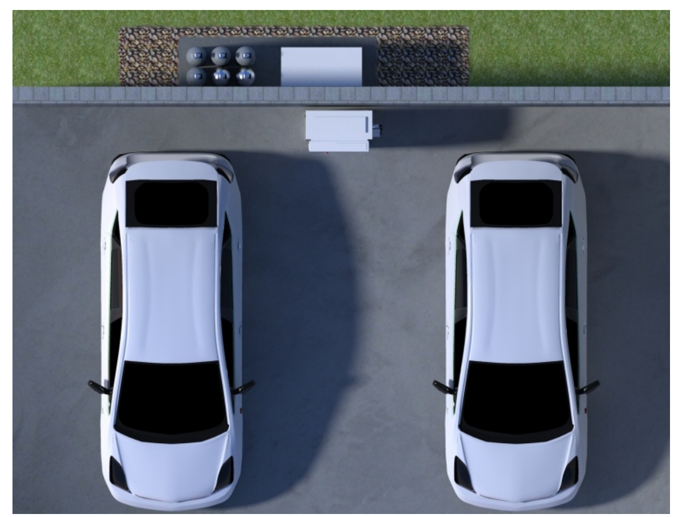
Slow fill

# Home fueling station for one vehicle

# Home fueling station concept design







# Home fueling station at Volkswagen in the Isenbüttel Technology Center

- Hydrogen generator Hogen S40 by Proton Energy Systems
- fed by 50 $m^2$ photovoltaics system
- Generates about 25 $Nm^3$ $H_2$ per day
- Enough to drive an FCEV 200 km

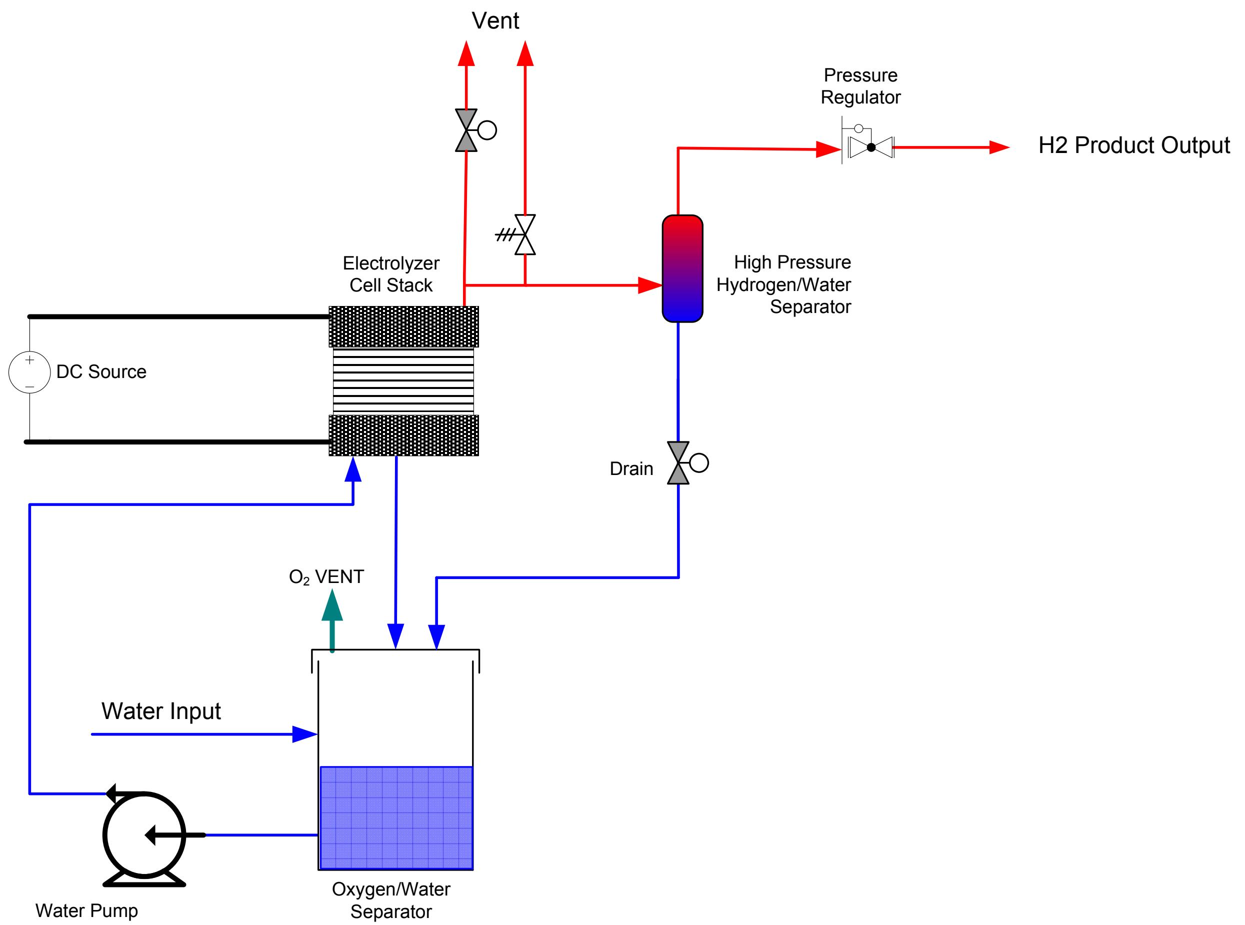
# Thank you for your attention !

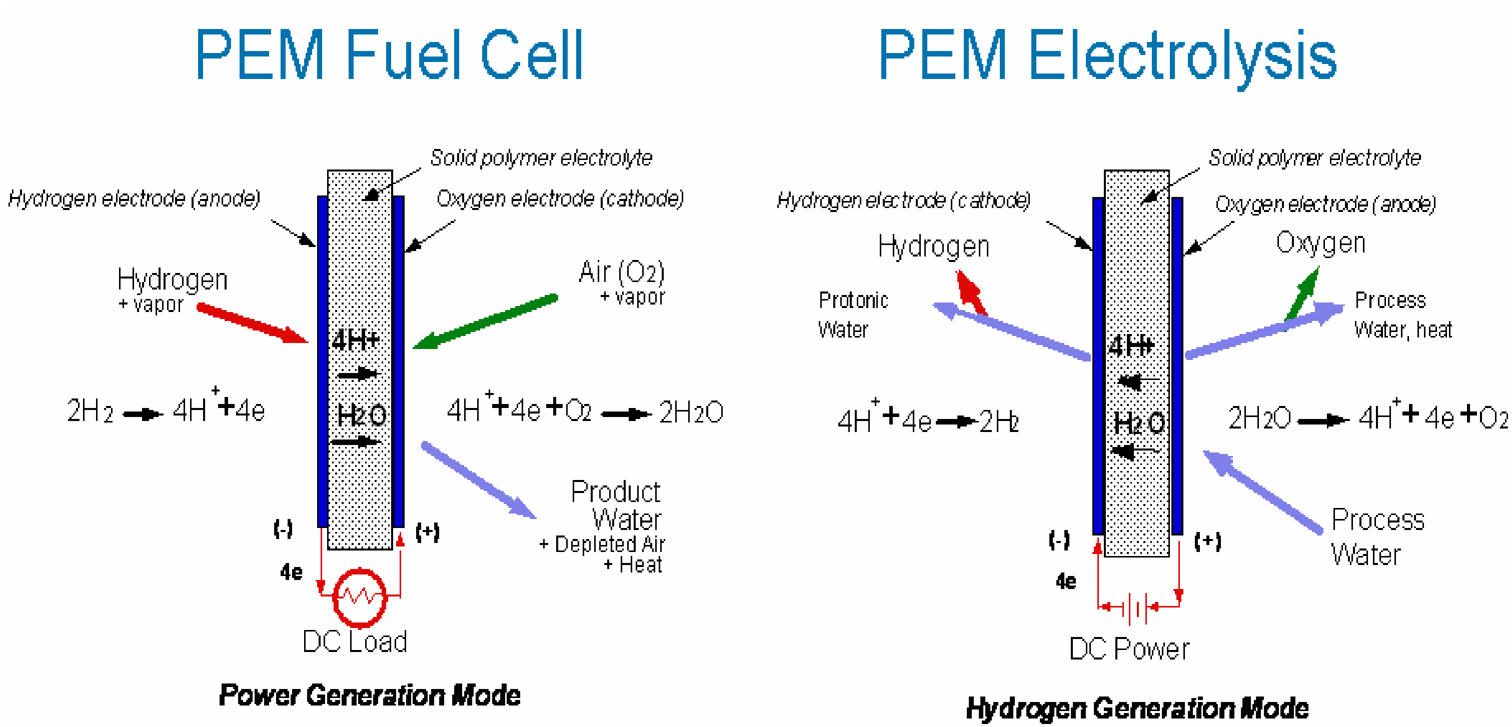
Biovest:
Project design and –management
for hydrogen projects

(franz.leichtfried@biovest.at)

# Extra slides for discussion

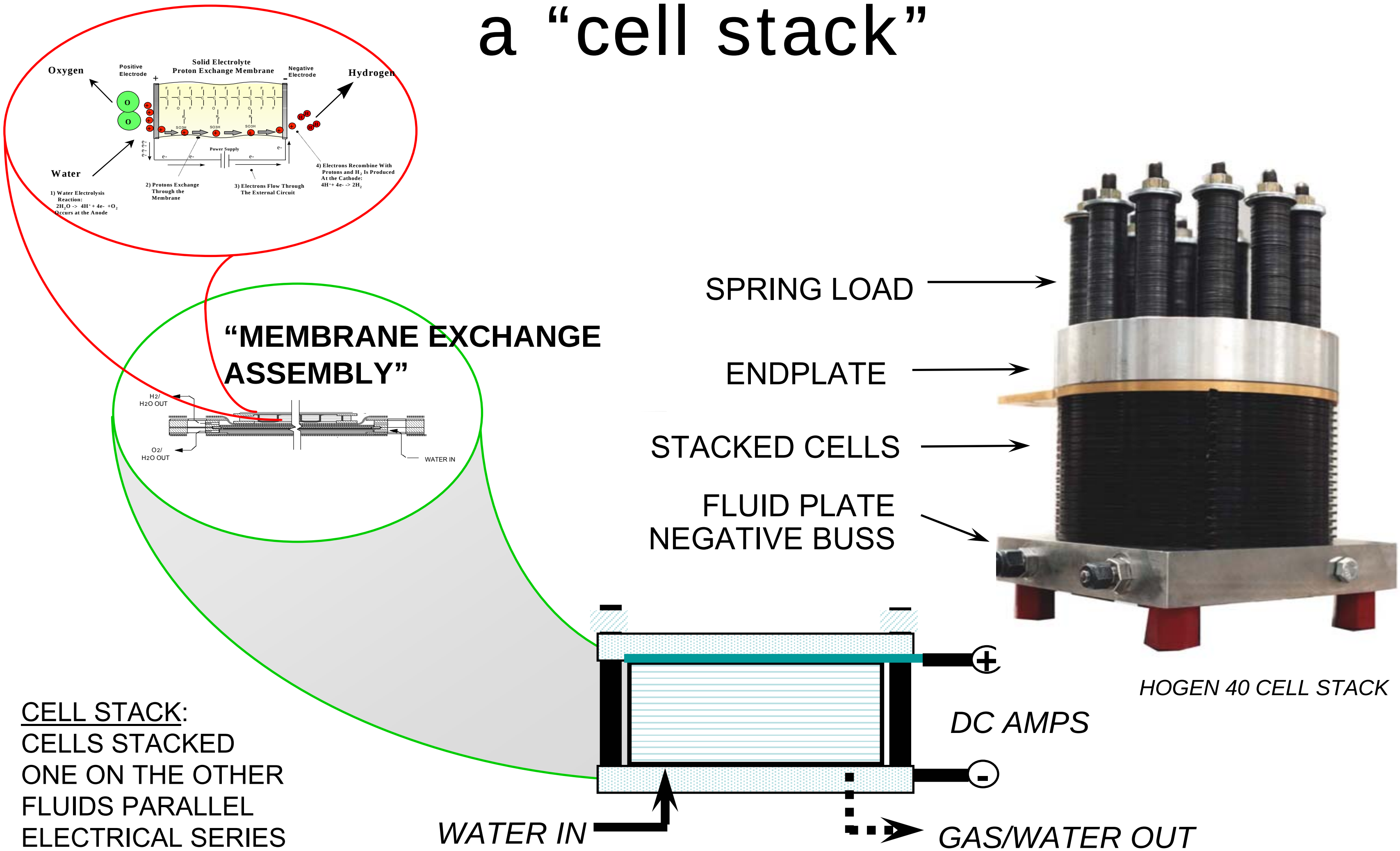
# High Differential Pressure PEM System






- Liquid water in contact with membrane
- Still have to consider 2-phase flow optimization in flow fields
- High (~2V) potential material compatibility
- High pressure differential (200 to >2400 psi) and high sealing loads
- Longer lifetime expectations (≥ 50,000 hours)

# PEM Membranes ("cells" or "MEA's") form a "cell stack"




<u>CELL STACK</u>:
CELLS STACKED
ONE ON THE OTHER
FLUIDS PARALLEL
ELECTRICAL SERIES

# High-Purity Hydrogen made on-site using simple PEM Electrolyzers

- Manufactured by Proton Energy Systems
- 99,999 % $H_2$ purity
- Dew point: < - 65°C
- 15 – 165 bars pressure
- Input: electricity, deionized water, cooling water
- Modern, simple, easy-to-use polymer electrolyte or proton exchange membrane (PEM) electrolyzers without caustic hydroxides, asbestos or other hazardous materials
- Turnkey sytem; installed in one day

Analysis Report – Atlantic Analytical Laboratory
Sample of H2 gas @ 225 psi
generated by Proton's HOGEN® hydrogen generator

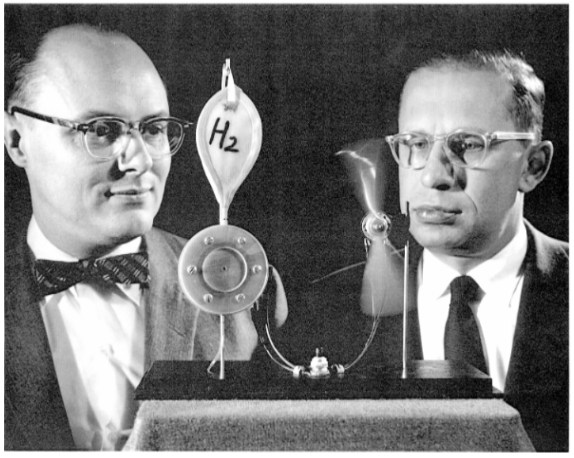
| Test Description/Units | Result | Report Detection Limit (D.L.) |
|---|---|---|
| Nitrogen (ppm vv/by MS) | nd | 4 |
| Oxygen (ppm v/v by MS) | nd | 4 |
| Carbon Dioxide (ppm v/v by MS) | nd | 4 |
| Argon (ppm v/v by MS) | nd | 4 |
| Helium (ppm v/v by MS) | nd | 10 |
| Hydrogen (% v/v by MS) | 99.9+ | 0.1 |
| Total hydrocarbons (ppm v/v as CH4) | — | 0.1 |
| Water Vapor (ppm v/v by EDP) | nd | 0.5 |

D.L. = report detection limit. nd = indicates the concentration is less than the report detection limit. — = test not performed. % = percent. ppm = parts per million. ppb = parts per billion. v/v = volume analyte/volume sample. w/w = weight analyte/weight sample. Unit conversions: 1 ppm v/v = 0.0001% v/v.

# High-Purity Hydrogen made on-site using simple PEM Electrolyzers

- Can be put anywhere without risk of explosions:
  Negligible oxygen diffusion through PEM-Membrane
  (oxygen side has ambient pressure)
- Range of operation: 0 – 100%;
  No need for „idle voltage" to counteract oxygen diffusion
  (alkaline elektrolysers continuously operate at 35 % of full load)
- PEM Elektrolysers automatically produce hydrogen on demand;
  react to demand in fractions of a second
- -> only sensible electrolyzer type for
  grid-independent PV or wind power systems
- Power consumption: 5.9 kWh/Nm$^3$ $H_2$

# PEM is Proven Technology




*PEM Inventors Grubb & Neidrach, 1955*


*HOGEN® 380 A Hydrogen Generator, 1998*

- PEM FC Invented at GE in 1953
  - **NASA Gemini 1963-65**
  - **PEM Water Electrolysis since 1973**
- Proven reliability
  - **US Navy commissioned first PEM electrolyzer in 1982 in a nuclear submarine.**
  - **Replaced dangerous, high maintenance KOH systems**
  - **Over 10 million cell hours proven in critical life support (US, UK Navy Submarines)**
  - **Zero downtime due to cell failure in Submarine Program**

# Proton Energy Systems

- **Manufacturer of Proton Exchange Membrane (PEM) hydrogen generation products using electrolysis**
- **Founded in 1996 in Wallingford, Connecticut.**
- **Over 1,200 systems operating in 60 different countries**

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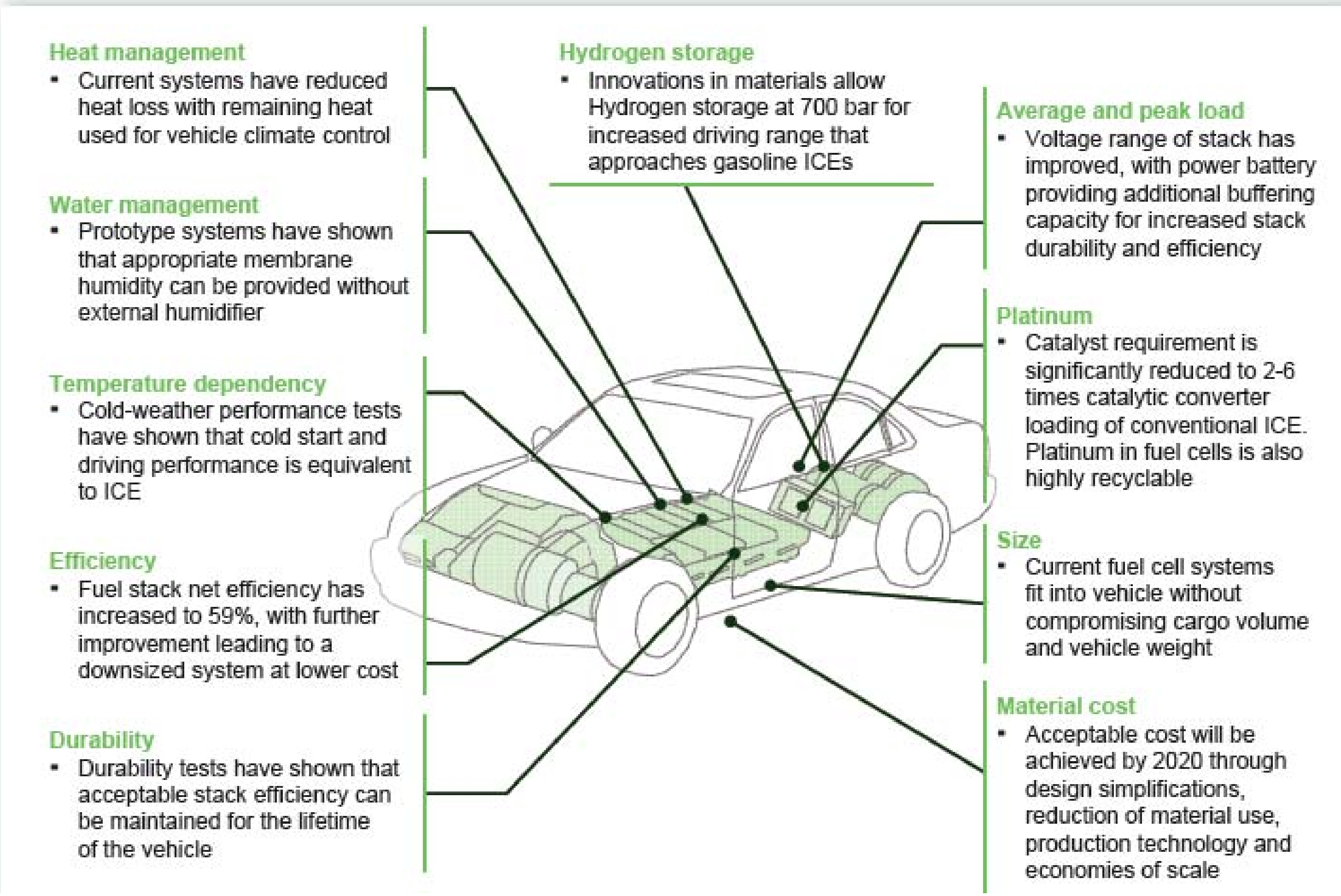
# Serial production of electrolyzers

PEM cell stacks

Turnkey systems

Models from 0.25 to 30 (soon 75) $Nm^3$ $H_2$/h

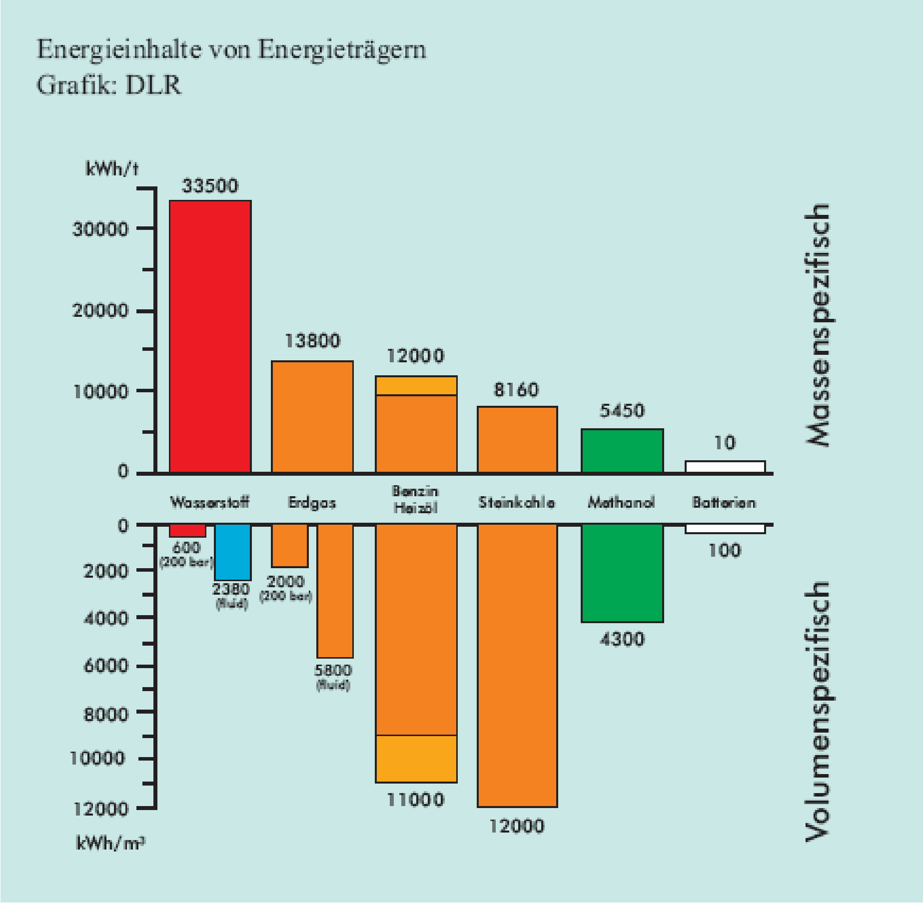
# Current status of FCEV vehicles




FCEV: Fuel cell electric vehicles

Source: http://www.zeroemissionvehicles.eu/

# Energy density of hydrogen



# Für Betrieb eines Wasserstoffautos erforderliche $H_2$-Produktion

- 12.000 km pro Jahr
- Verbrauch: 1,1 kg $H_2$/100 km
- Jahresverbrauch:
  132 kg $H_2$ oder 1.468 $Nm^3$
- Benötigte Tagesmenge (300 Tage /Jahr):
  0,45 kg $H_2$ oder 5 $Nm^3$
- 5 $Nm^3$ Tagesproduktion:
  PEM-Elektrolyseur Proton Energy HOGEN S40 (**siehe HyCentA in Graz**) mehr als ausreichend (1 $Nm^3$ pro Stunde)

# Elektrolyse Stromverbrauchsberechnung

- Benötigte Jahremenge:
  132 kg $H_2$ oder 1.468 $Nm^3$
- Stromverbrauch : 6 kWh/ $Nm^3$ $H_2$
- Jahresgesamtstromverbrauch (300 Tage Betrieb):
  8.808 kWh

# Erforderliche Kapazität – Photovoltaik oder Wind

Zur Erzeugung von jährlich 8.808 kWh:

- **53 m² (8,8 kWp) PV-Anlage** bei 20% Wirkungsgrad und PV-Jahresertrag von 1.000 kWh/$kW_p$
- **5 kW Windturbine**