New Emission Free Power Trains for Modern Vehicles

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in der Helmholtz-Gemeinschaft

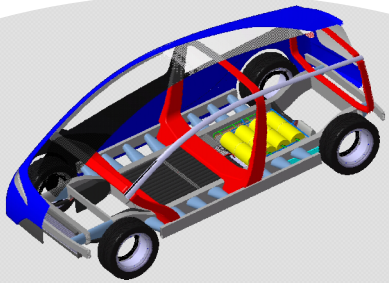
Content of the Presentation

- Motivation for the Development of new Vehicle Power Trains
- Fuel Cell Technologies and their Functional Principles
- Architecture of Vehicle-Integrated Fuel Cell Power Trains
- Process Engineering Concept of a Fuel Cell System
- Availability of Fuel Cell Systems
- PEFC System Package in Vehicles
- Hydrogen Combustion Engines and Conventional Power Trains
- Hydrogen Storage Technologies for Vehicles
- Short Summary

Vision

Sustainable, Secure and Financeable

„Individual Mobility“



Innovative Vehicle Concepts
for Road and Railway

- Significant **Improved Useage of Energy Potentials** for Vehicle and Transport Tystems
- Breakthrough at **Emission- / CO_2-Free or -Neutral Power Train Technologies**
- Increasing **Energy Efficiency of Transport**

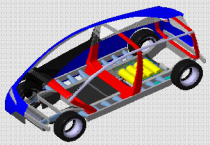
The Fields of Research of the DLR-Institute FK

Vehicle System & Technology Assessment — 1

Vehicle Drive Train Concepts — 2

Alternative Energy Converter — 3

Lightweight- & Hybrid-Design — 4



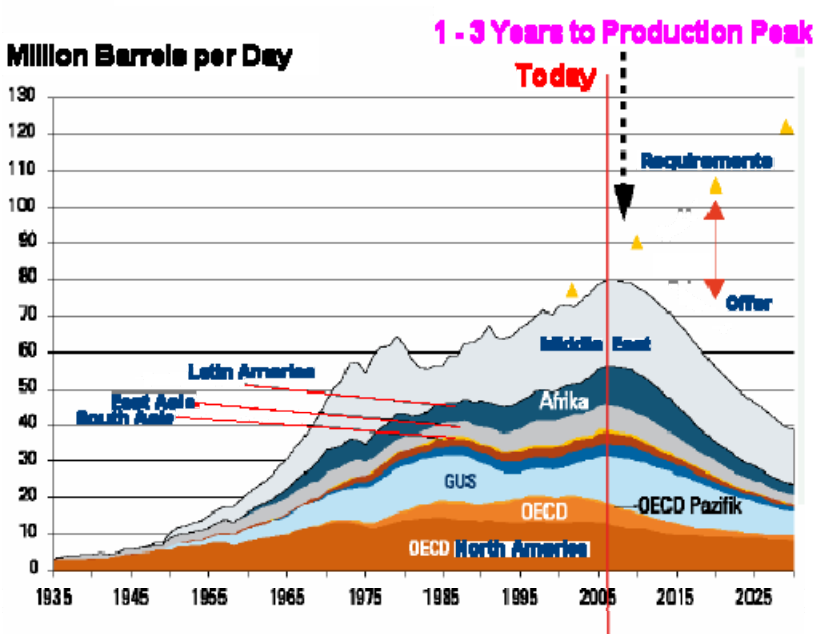
Innovative Vehicle Concepts for Road and Rail

FK **designs** and **demonstrates** innovations for vehicle concepts and technologies of new transportation concepts adopted to the needs

Motivation for the Development of new Vehicle Concepts and Drive Trains

Our fossile fuel based energy system is not sustainable
The two decisive reasons therefore are:

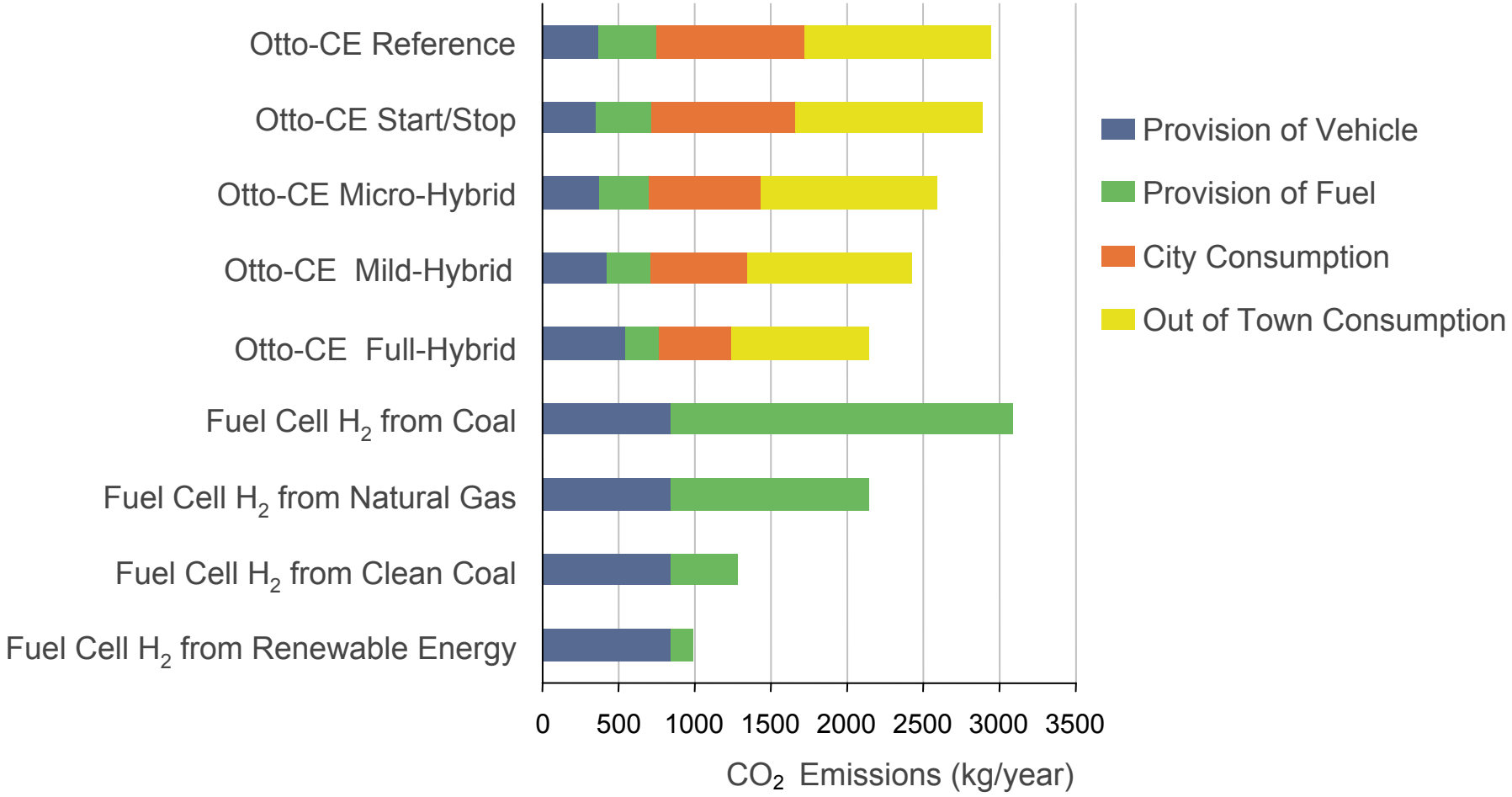
Depletion of Resources



Protection of the Global Climate

Source: Dr. Schmidtchen, DWV, F-cell Sept. 2007

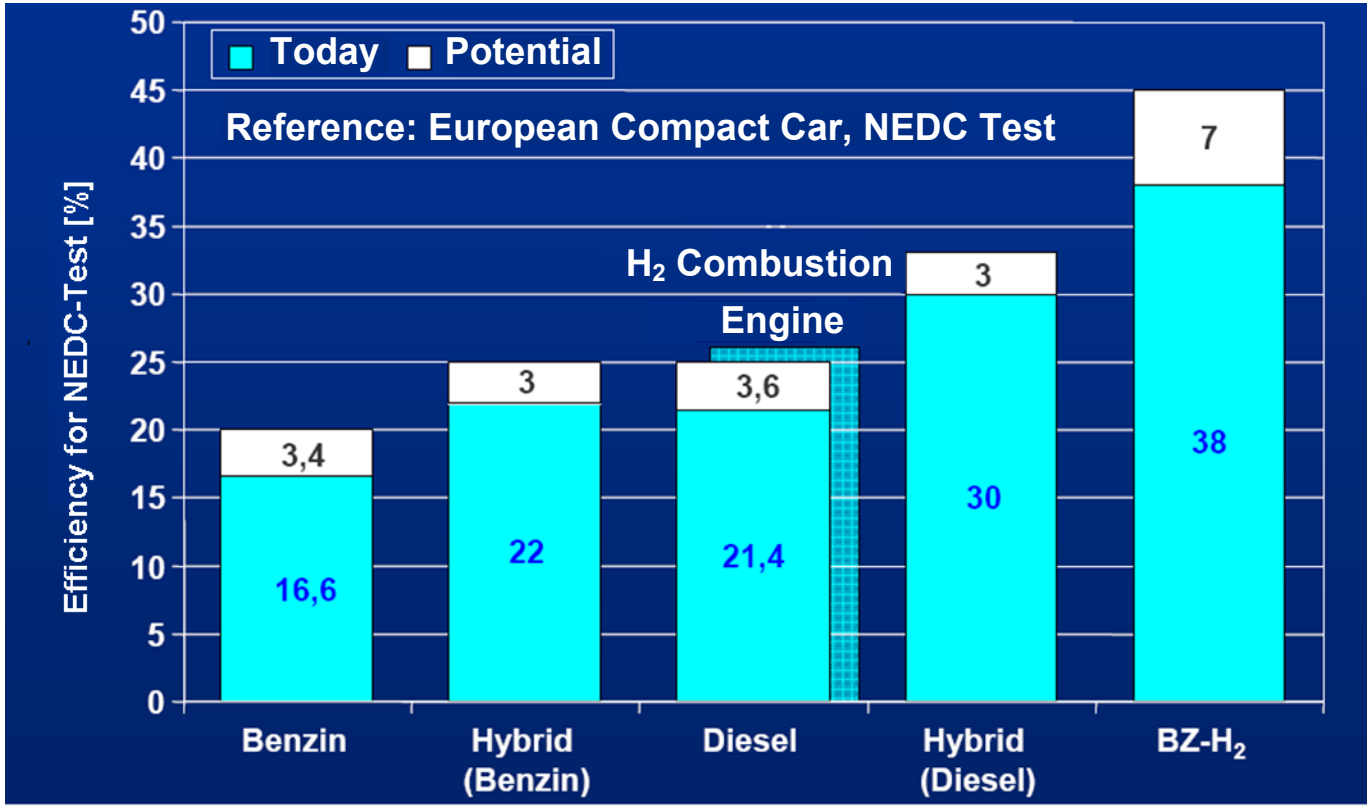
CO_2 – Emissions of Hybride Drive Train Concepts compared to Fuel Cell Power Trains



CE: Combustion Engine

Sources: DLR. R. Edwards, Well-To-Wheel Analysis, 2003. UBA-H2, Entwicklung einer Gesamtstrategie zur Einf. alternat. Kraftstoffe. Pehnt, Ganzheitliche Bilanzierung, 2002. Schweimer, Sachbilanz des Golf A4, Wolfsburg.

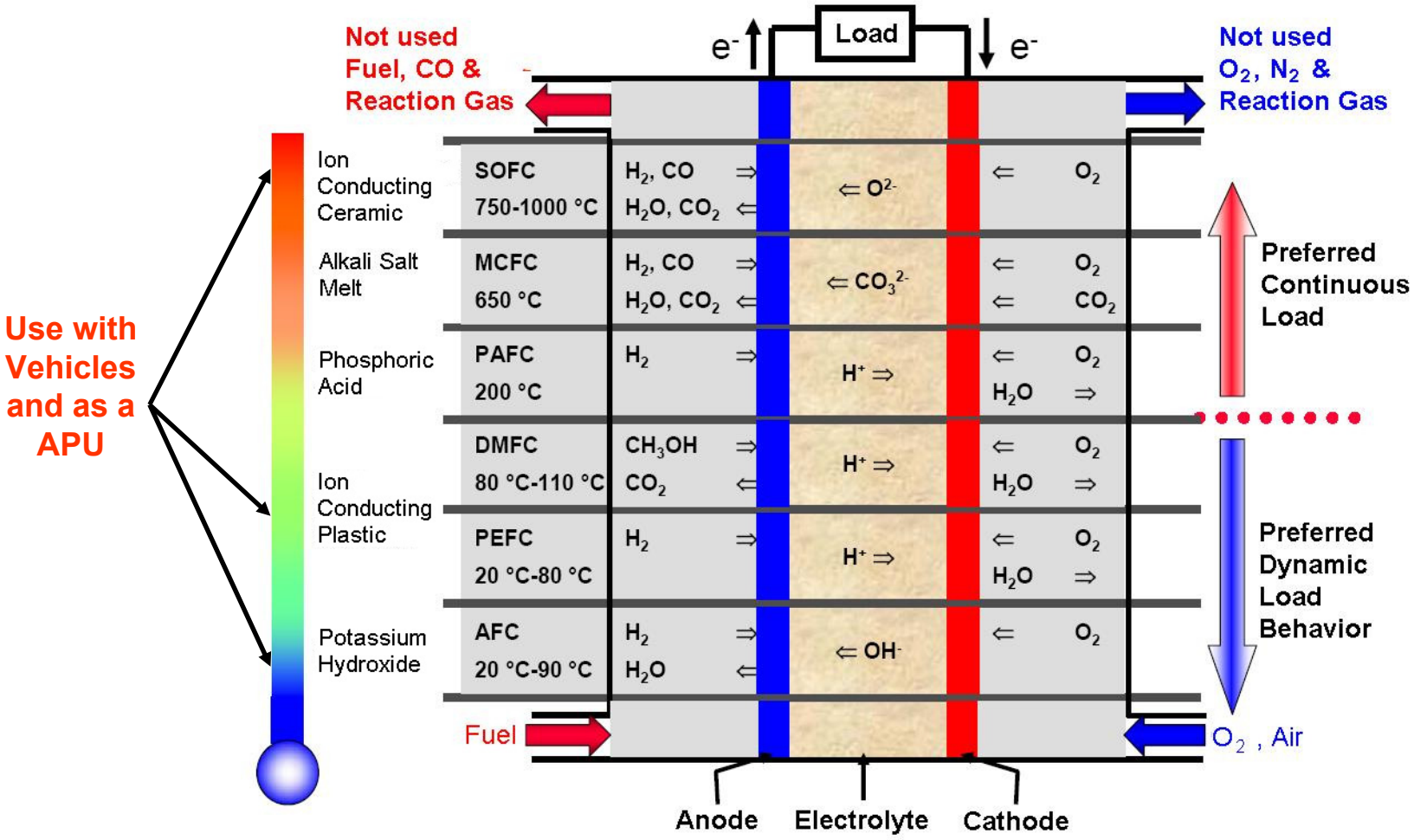
Comparison of of Power Trains Efficiencies and its Development Potentials with a Tank-To-Wheel-Look



High Efficiency: Low Usage of Primary Energy Sources Over Compensation of Energy Losses during Hydrogen Production by High Fuel Cell System Efficiency

Source: Dr. Wind, Daimler, F-cell Sept. 2007

Classification of Fuel Cell Technologies



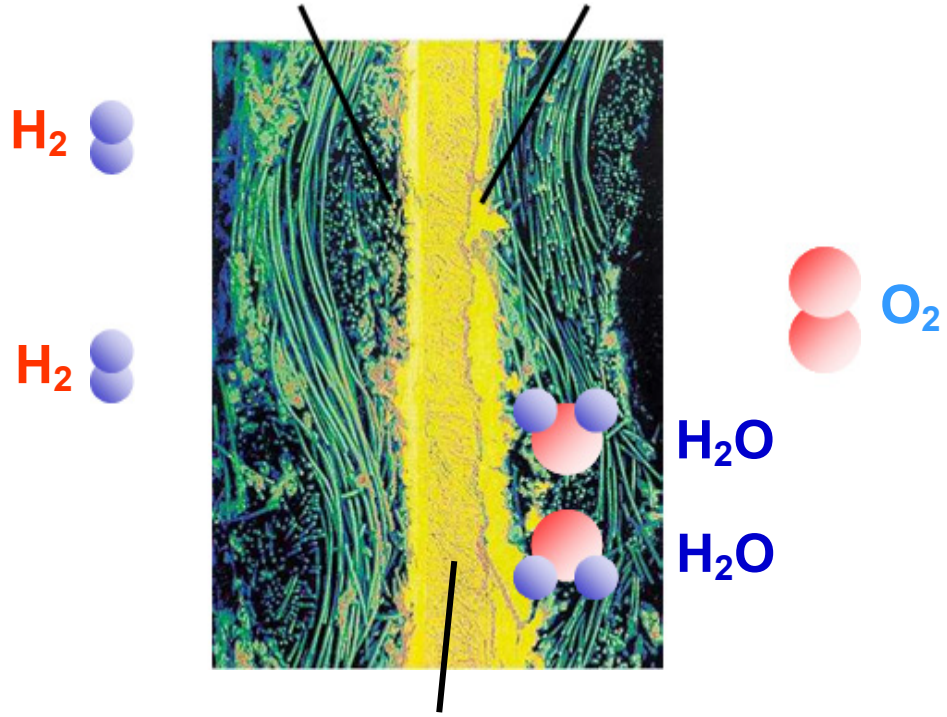
Source: „Grundlagen Brennstoffzellen“, T. Aigle, WBZU, 2006

The Basic Principle of a Low Temperature Fuel Cell

PEFC (Polymer Electrolyte Membrane Fuel Cell)

$2H_2 \rightarrow 4H^+ + 4e^-$ Anode

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ Cathode



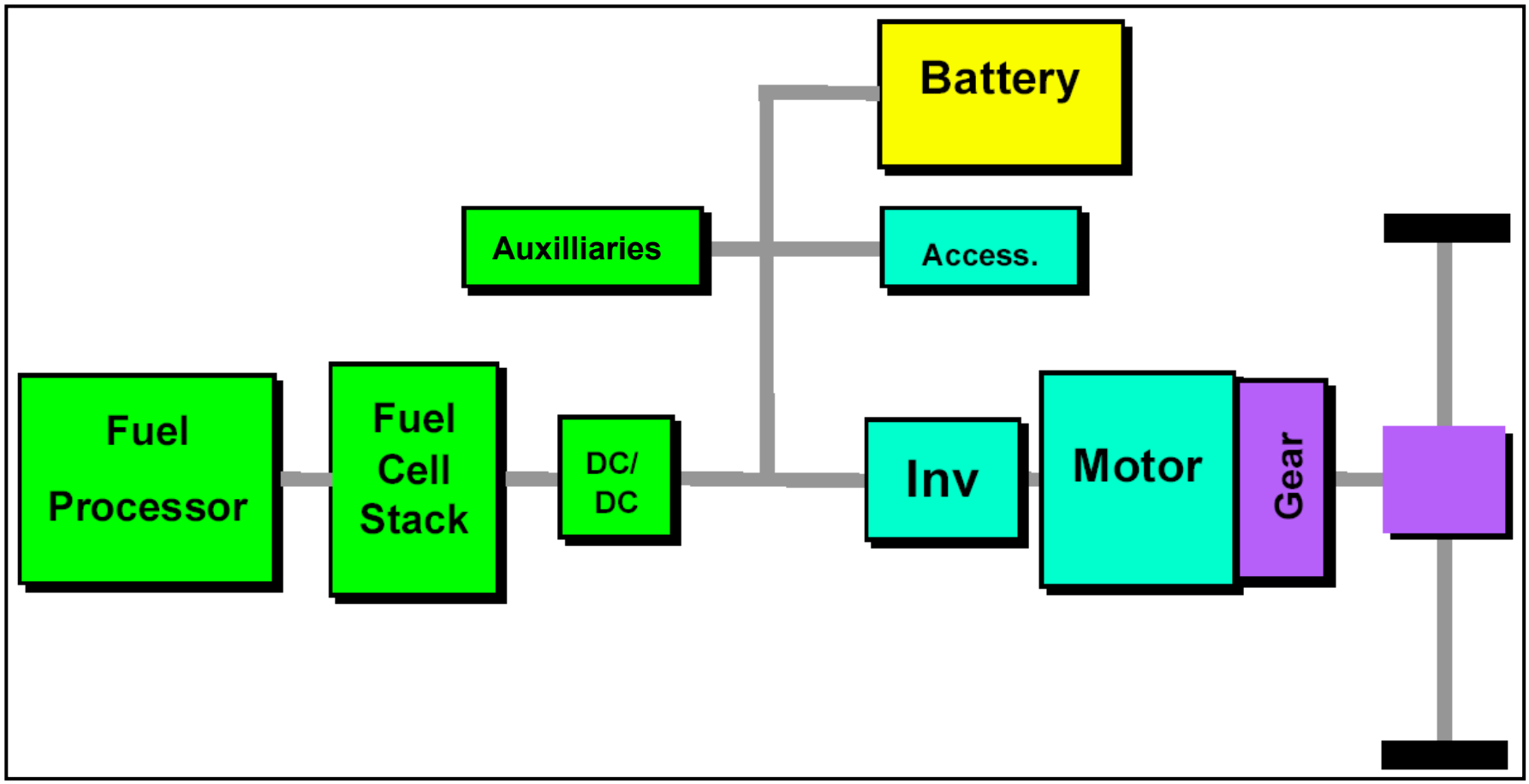
Polymer Electrolyte Membrane

- **Anode:** Hydrogen (H_2) is oxydised (delivers Elektrones)
- **Electrolyte Membrane** Conducts Protons but is an Electrical Isolator
- **Cathode**: Oygen (O_2) is reduced (receives Elektronee)
- **Typical Electrical Values Load-connected**

  0,7 V Voltage

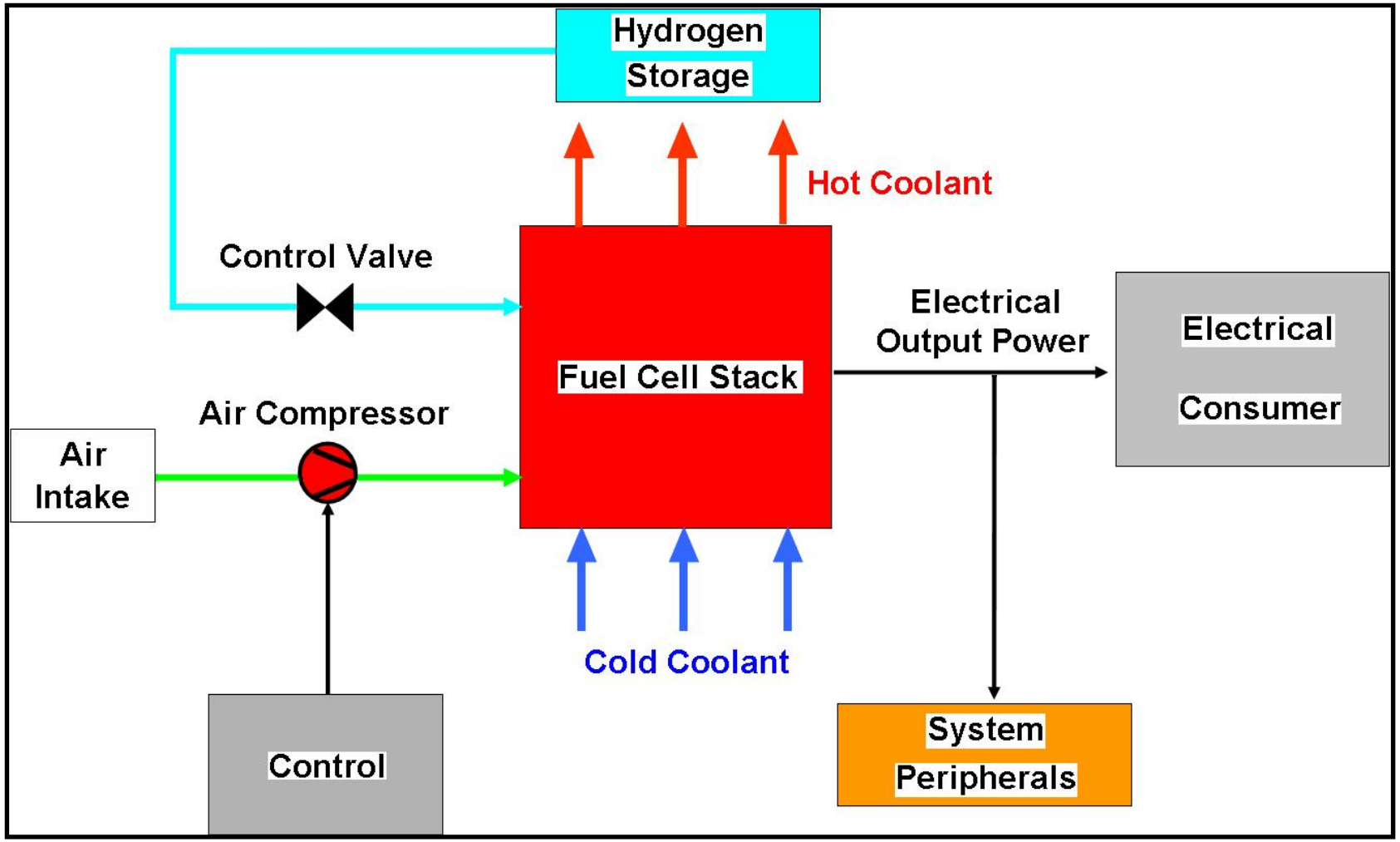
  0,75 A/cm² Current

Hybrid Power Train with Fuel Cell

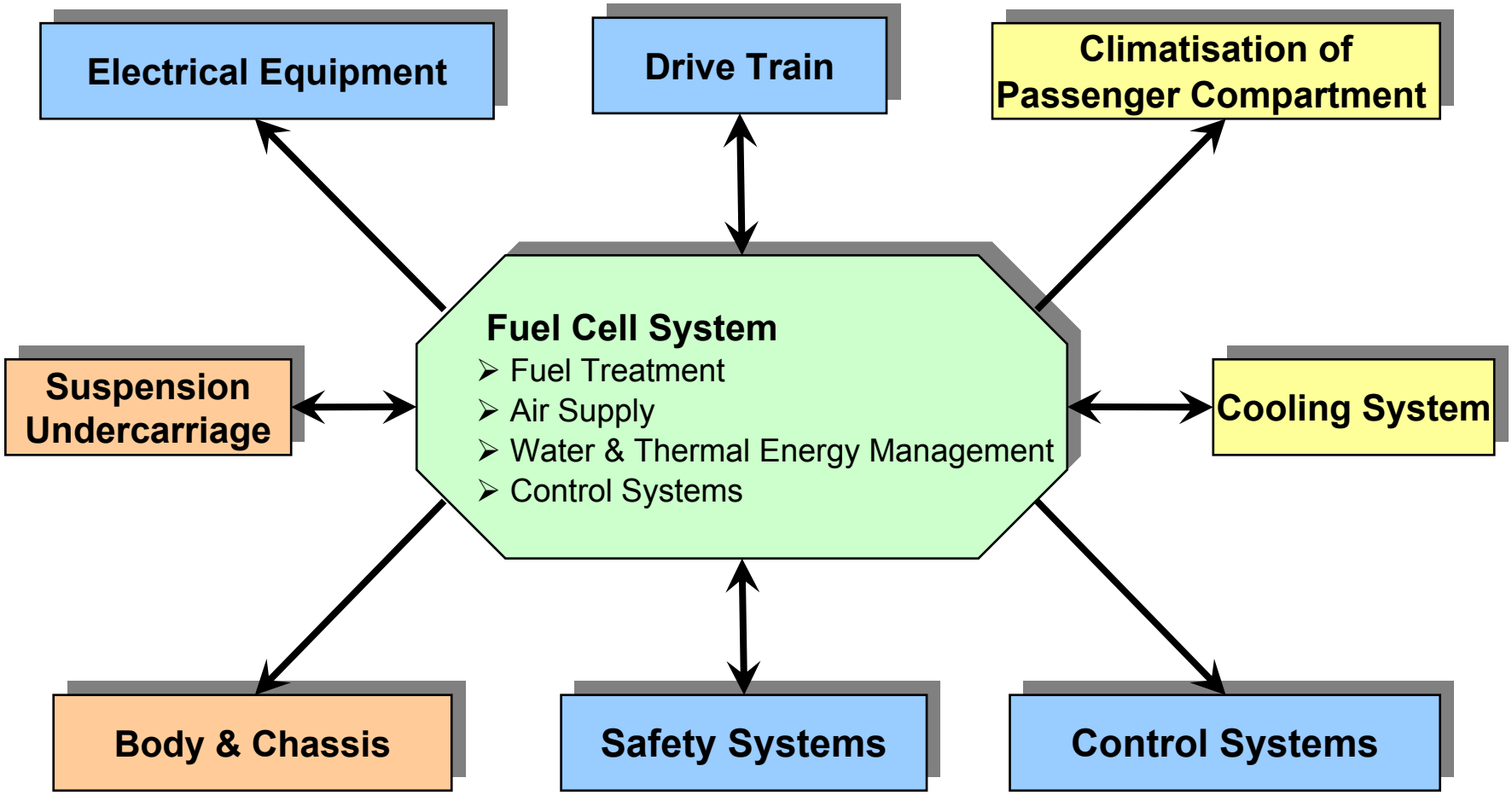


Source: „GM Well to Wheel Analysis... – A European Study“, GM Adam Opel AG, 2002

Basic Process Concept of a Fuel Cell System

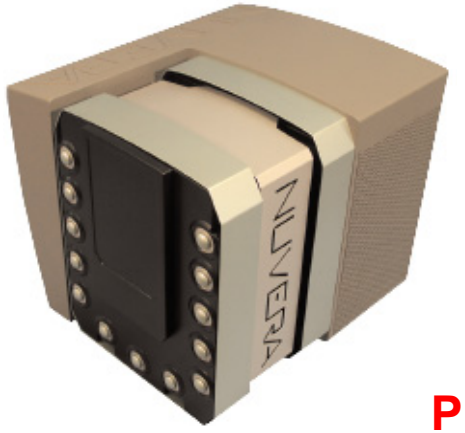


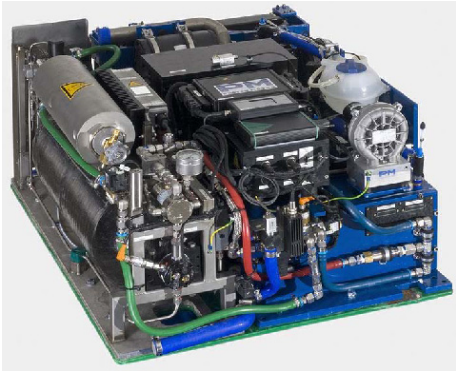
Subsystems and Interaction of a Fuel Cell Vehicle



Examples of deliverable Fuel Cell Modules from different Manufacturers (no claim to completeness)

Nuvera – Powerflow, 5kW





Nedstack – PS6-100, 6-100kW

Proton Motors – MH30, 18-38kW

Nuvera – Andromeda, 50kW

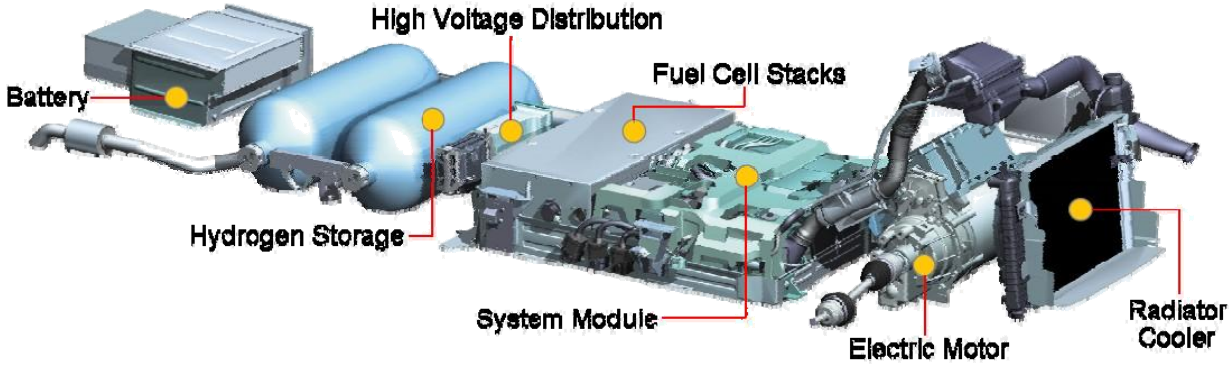
Hydrogenics – HyPM HD65, 65kW

Ballard – Mark902, 85kW

Package Concept of the PEFC Power Train in the Underbody of a Mercedes B-Class F-cell

Cut through Mercedes B-Class F-Cell

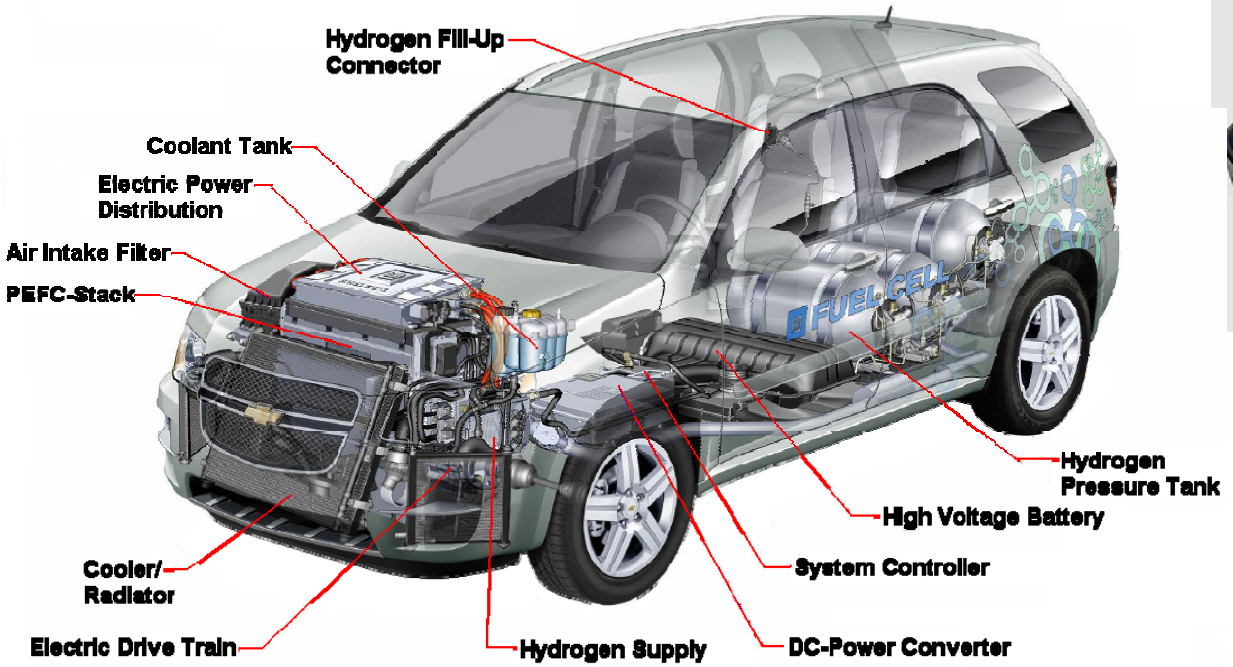
Package Example of a Fuel Cell System into the F-Cell Double Bottom



Source: Dr. Wind, DC / Brennstoffzellenfahrzeuge bei DaimlerChrysler F-cell 2007

Package Concept of a Fuel Cell Power Train for the Engine Compartments of GM- and Opel-Fuel Cell Vehicles

Chevrolet Equinox Fuel Cell



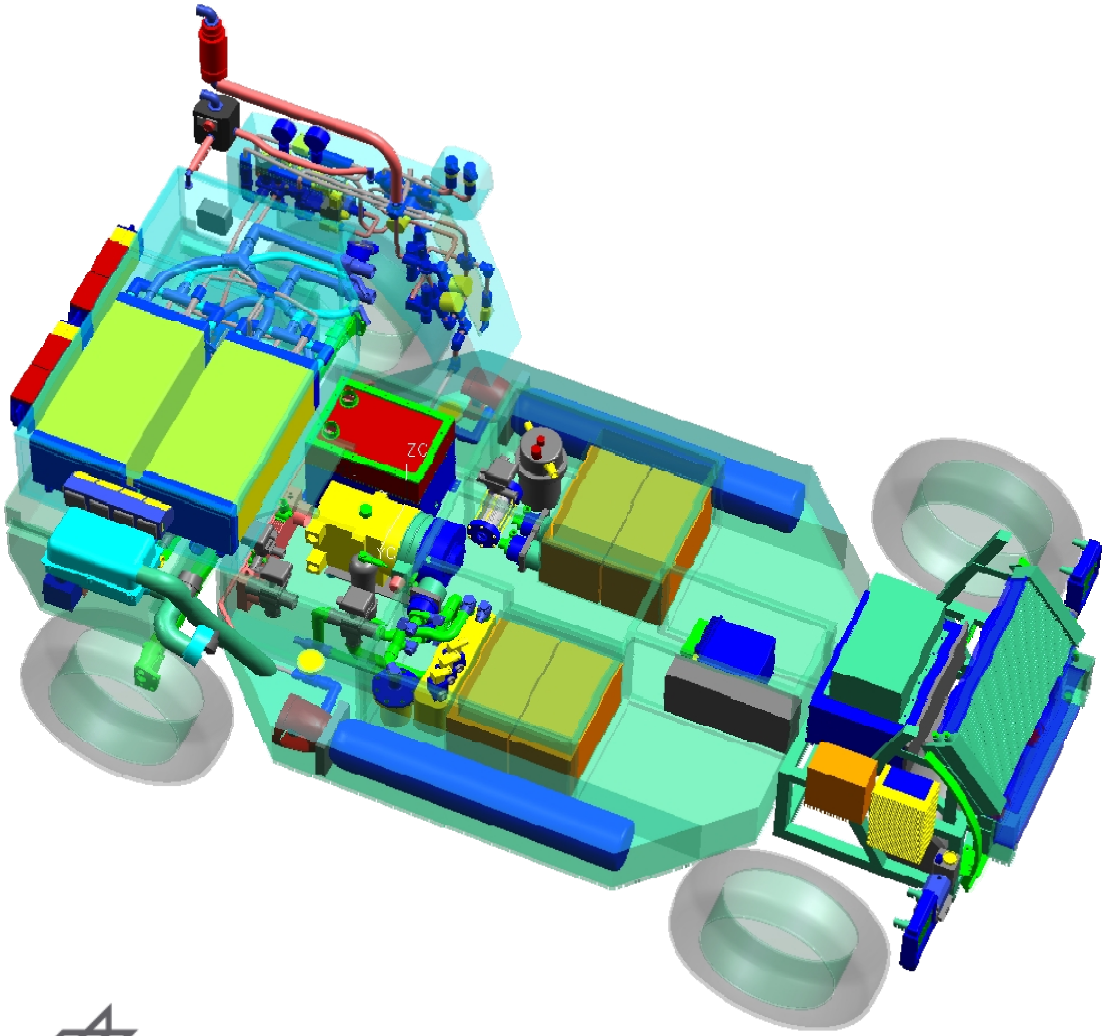
Opel / GM HydroGen 1

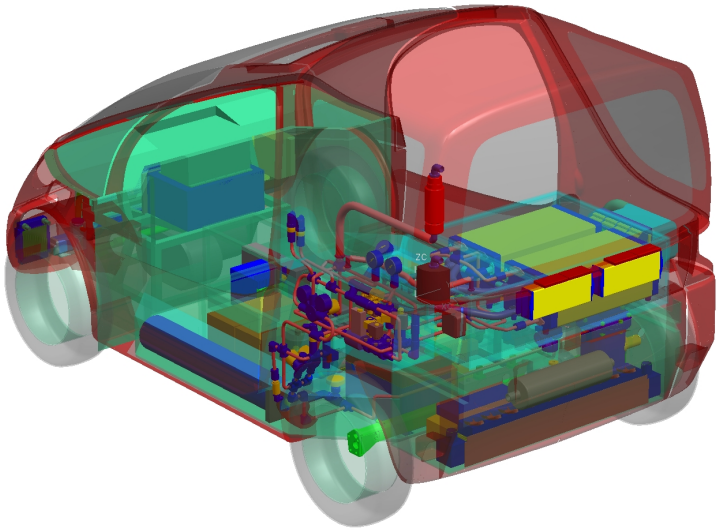
Source: Dr. Eberle GM / Opel Fuel Cell Activities, F-cell 2007

Source: „Technische Daten des „HydroGen 1“, GM Adam Opel AG, 2002

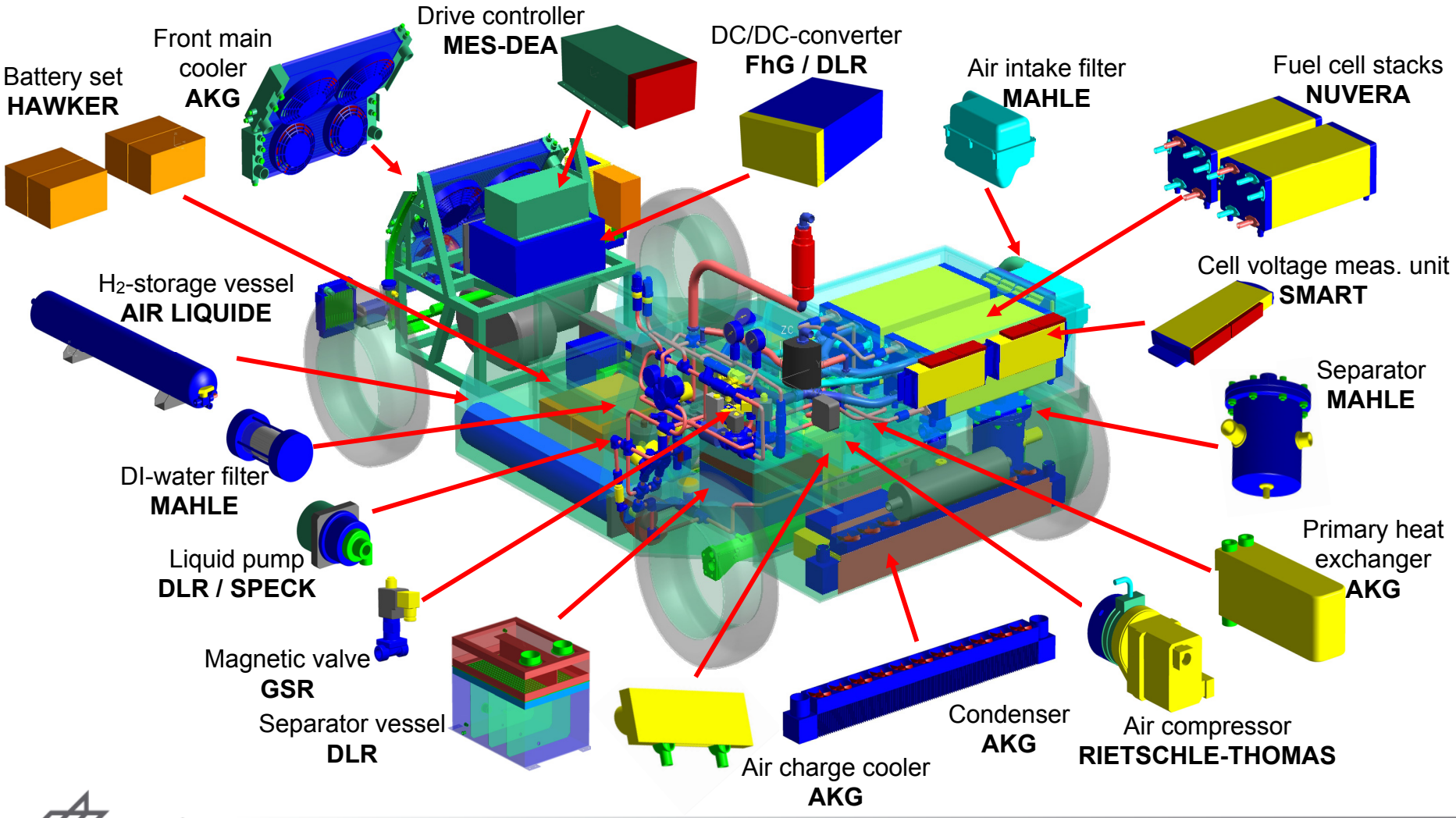
Fuel Cell System Package in the DLR Test Vehicle HyLite

Overview about the System Package

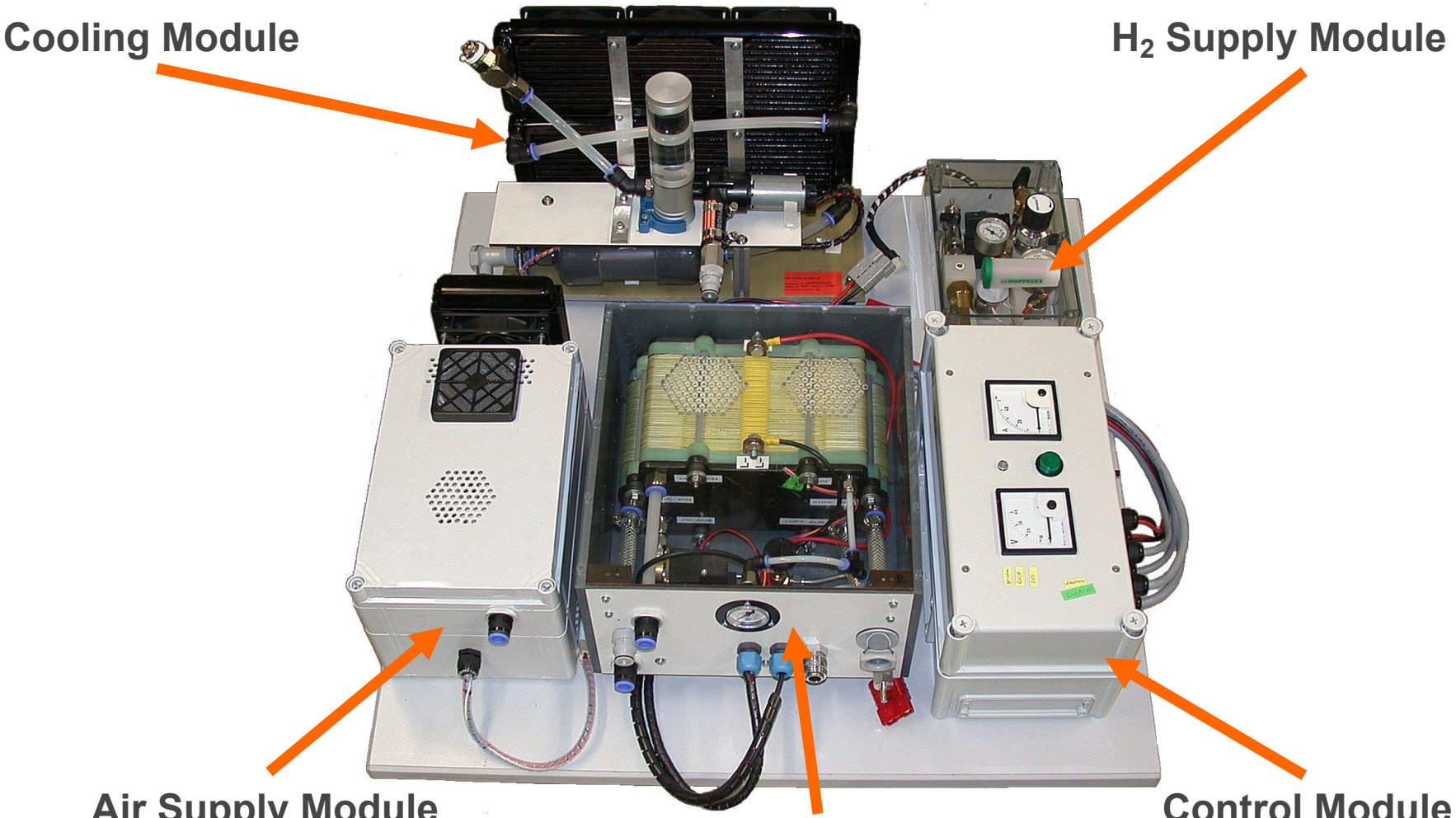




HyLite Fuel Cell System Component Development Efforts



Modular DLR- PEFC-System Concept with High Degree of Package Freedom for the Vehicle Integration



Airport Aprone Area Pulling Tractor with Fuel Cell Hybrid Power Supply

PEFC-Emergency-Shutdown

H_2-in Air Measurement

Cooling System and Hydrogen Supply Interconnection

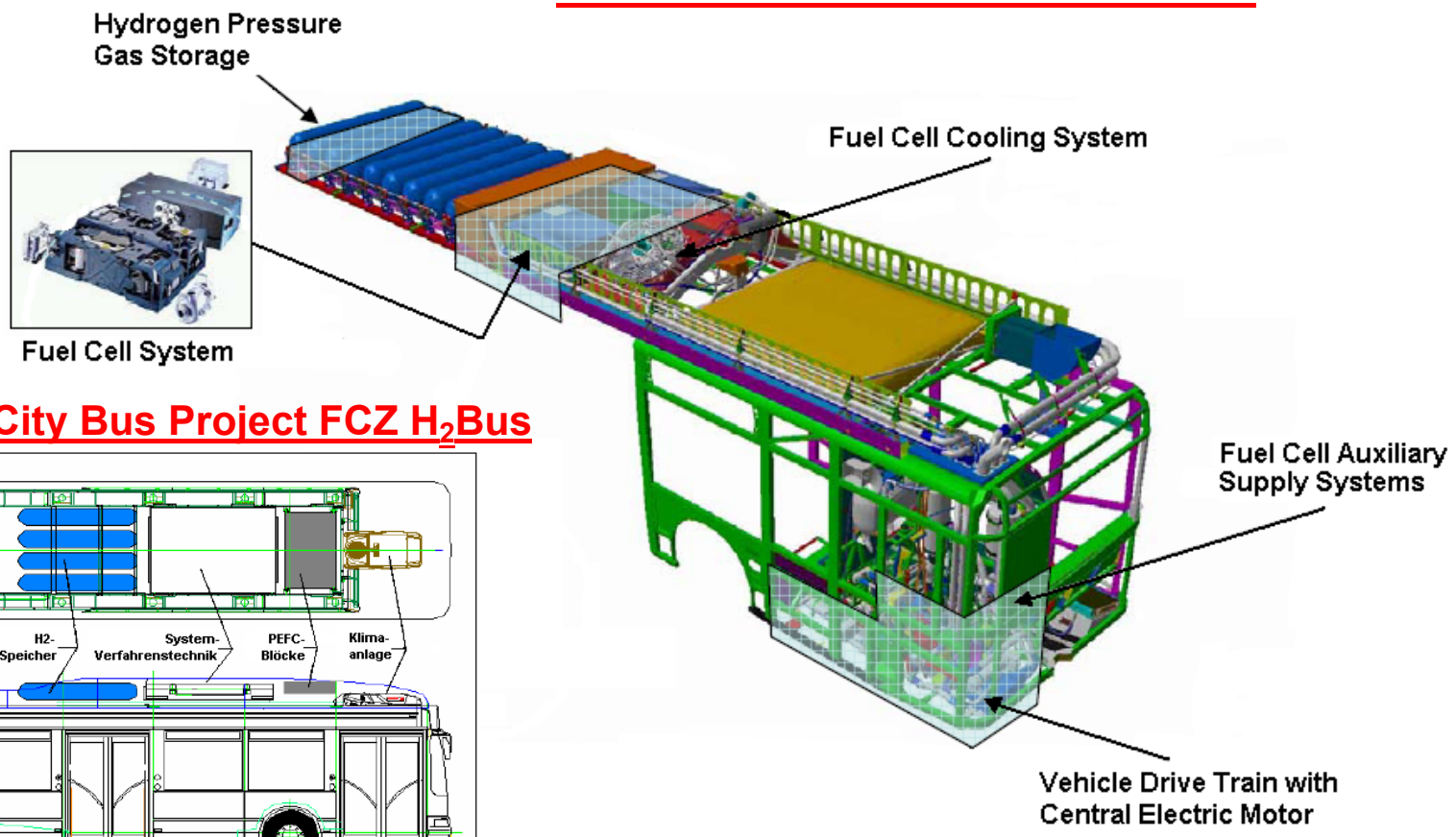
PEFC-System under the Driver Seat

Modulare 2,1kW$_N$ PEFC-System

Identical Concept between 1,2 and 2,4kW

Package Concepts of different PEFC-Power Supplies in Fuel Cell Busses

Mercedes Benz Citaro Fuel Cell Bus



Proton Motor FC City Bus Project FCZ H_2Bus

Source: „PEM Fuel Cells in Hybrid Configuration“, B. Eska, F-cell 2007

Source: „Brennstoffzellen im mobilen Einsatz“, F. Panik, F-cell 2007

Fuel Cell Locomotives for Hydrogen Powered Operation

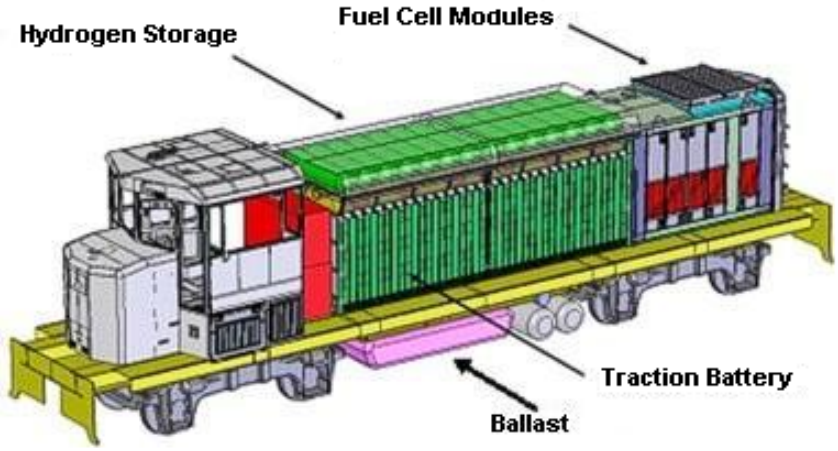
Concepts and Prototypes

20kW PEFC-Power

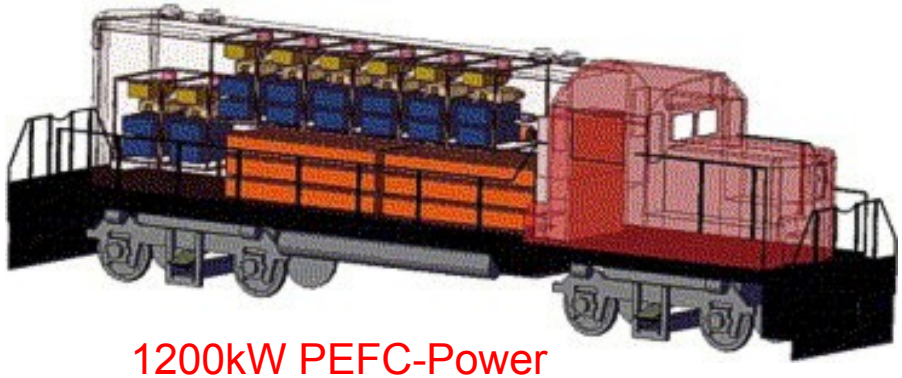
Fuelcell Locomotive Pulling 3 Fully Loaded 4 Ton Ore Cars

Source: Final Technical Report, Cooperative Agreement: DE-FC36-99GO10458, 1/28/2003

250kW PEFC-Power



Source: *A.R. Miller et al. /* Journal of Power Sources 173 (2007) 935–942

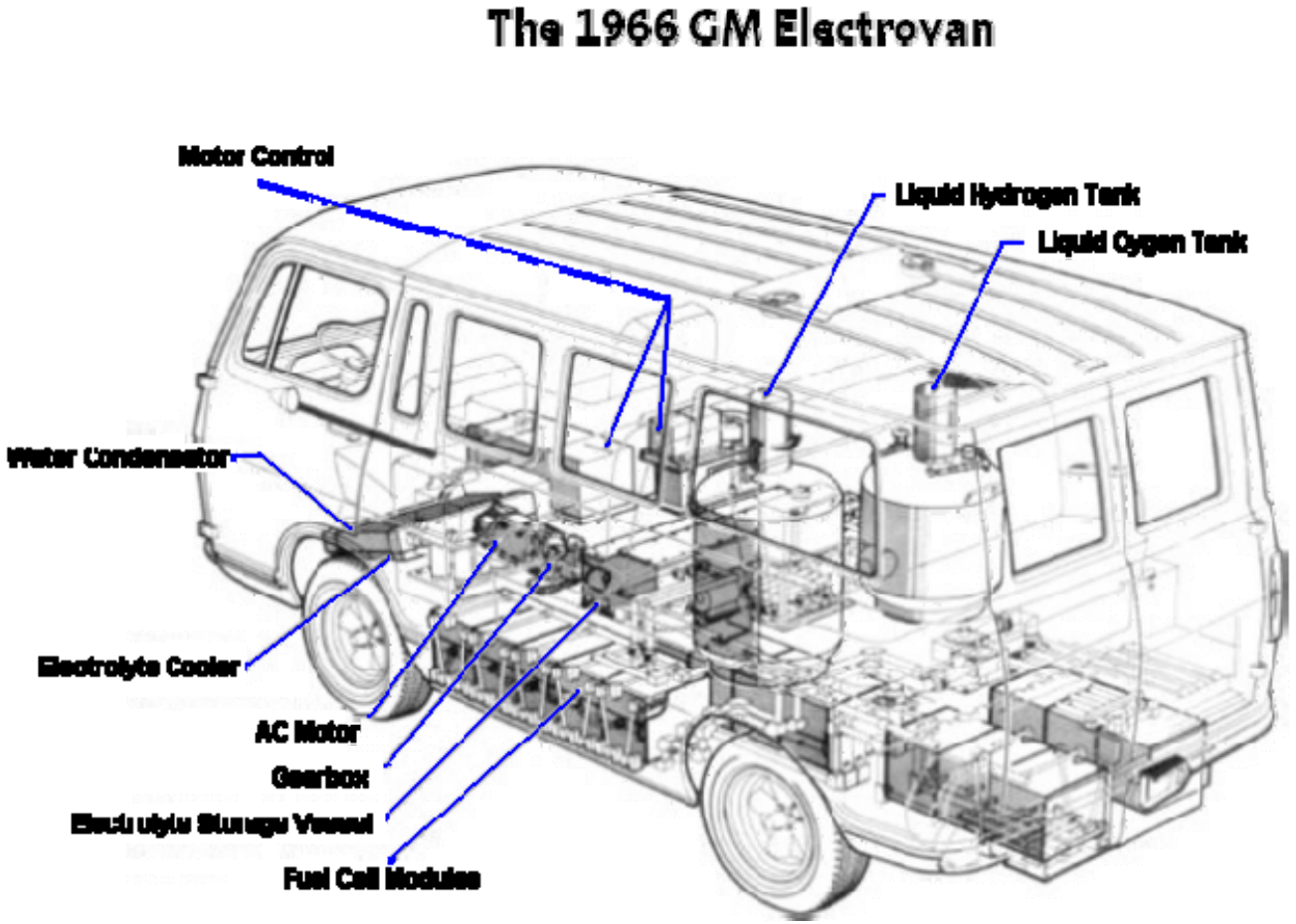


1200kW PEFC-Power

Source: *A.R. Miller et al. / Journal of Power Sources 157 (2006) 855–861*

Locomotive at Begin of Refitting

Fuel Cell is no new Development but needs long-term Development Effort



Source: *GM-FCA, F-Cell Conference 2007*

Vehicle Examples with Hydrogen Combustion Engine

Ford Focus C-MAX H2-ICE

2,3l, 82kW for H_2-Operation

Source: motortalk.de, Jul. 2004

BMW Hydrogen 7

6,0l, 191kW for bivalentic Operation

Source: Autopresse.de, Dez. 2006

Source: Claus Ableiter, 2008

Linde Gabelstapler 39x

2l, 43kW für H_2-Operation

Source: linde-mh.de.de, Mär. 2010

Mazda RX-8 Hydrogen RE

Source: hybrid-autos.info, 2006

MAN Busses with H_2-Internal Combustion Engines

MAN-Bus
Typ Lion's City H

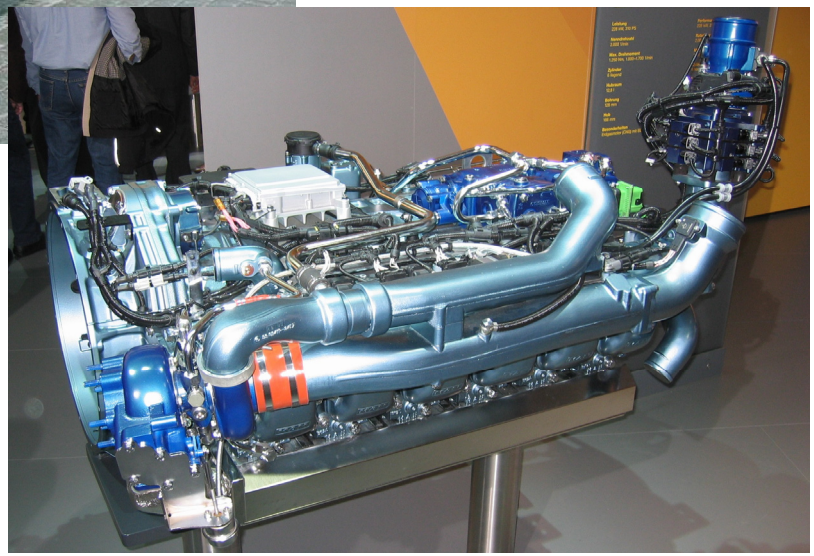
Source: TOTAL, Werner Weisflog, 2008

Wasserstoff-Combustion Engine
MAN Typ H 2876 UH

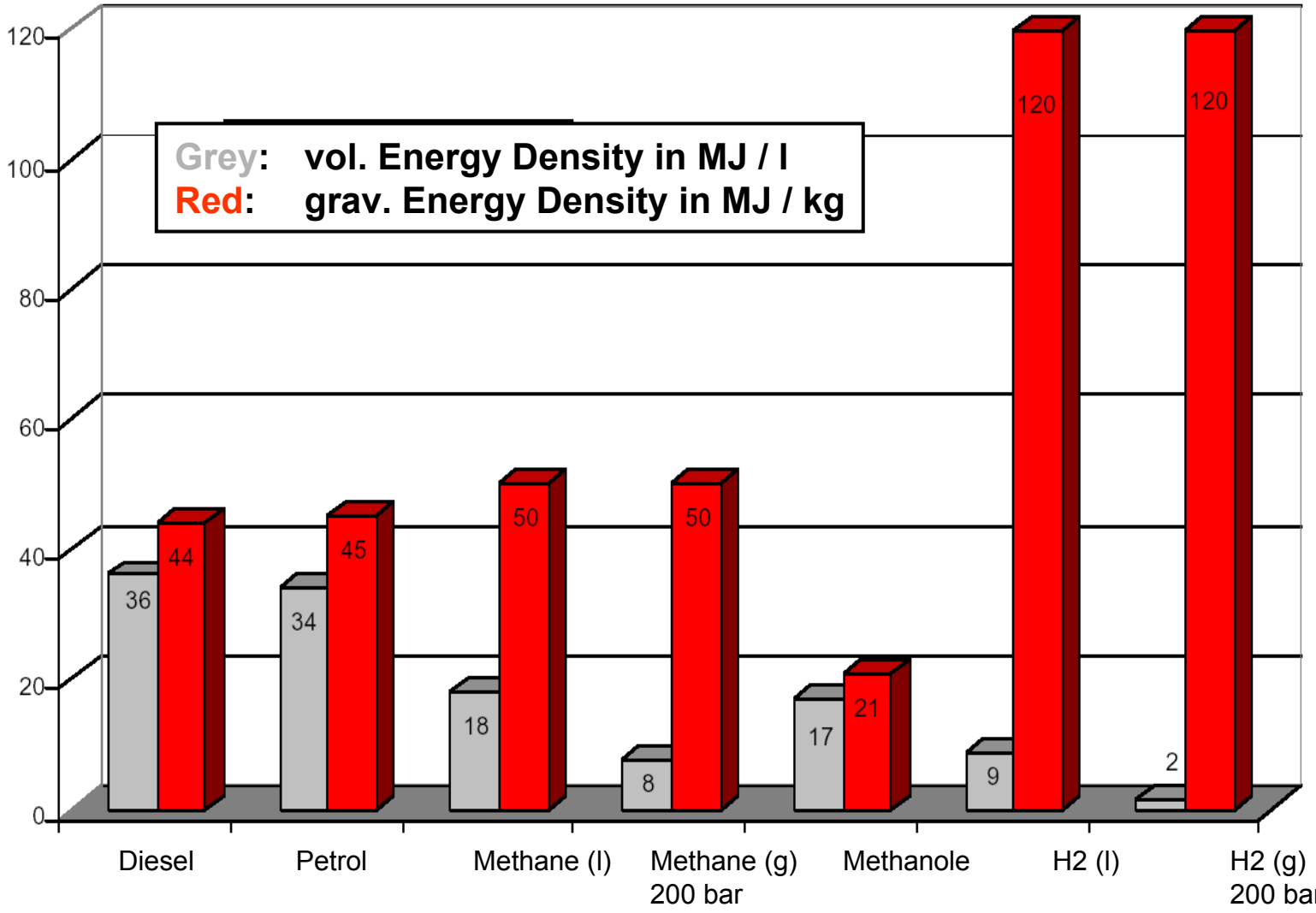
Motor Data:

H 2876 UH	H2876 LUH01
12,8l	12,8 l
150kW / 2200 1/min	200kW / 2200 1/min
760Nm / 1000 1/min	1000Nm / 1000 1/min

Source: The Knack, 2008



Gravimetric & Volumetric Energy Content of Different Fuels



Source: „Verkehr und Wasserstoffspeicherung“, Garche, Treffinger, FVS 2002

Hydrogen Storage Technologies & their Boundary Conditions of Operation

Liquid Hydrogen	Cryogenic Adsorption	Interstitial Metallic Hydride	Compressed Hydrogen	Alanate	Salt-like Metal Hydride	Water
LH_2	Activated carbon	Laves Phase Comp. / $FeTiH_x$ / $LaNi_5H_x$	CGH_2	$NaAlH_4$	MgH_2	H_2O
100 mat.wt.%	6.5 mat.wt.%	2 mat.wt.%	100 mat.wt.%	5.5 mat.wt.%	7.5 mat.wt.%	11 mat.wt.%

Storage Operating Temperature

-253°C	> -200°C	0 - 30°C	25°C	70 - 170°C	330°C	>> 1000°C

Corresponding Energy to Release Hydrogen in MJ per kg of H2

0.45	3.5	15	n/a	23	37	142

B. Bogdanovic, U. Eberle, M. Felderhoff, and F. Schüth / Scripta Materialia 56 (2007) 813-816
R. von Helmolt, U. Eberle / Journal of Power Sources 165 (2007) 833-843

Source: Dr. Eberle GM / Opel Fuel Cell Activities, F-cell 2007

Summary:

Limitations of Hydrogen as a Fuel and Secondary Energy Carrier

- **Hydrogen is no primary energy source but a secondary energy carrier. It has to be produced with additional energetic effort from a primary energy source/ converter.**

- **Hydrogen is a clean energy carrier but with a look on the total ecologic balance it can not be cleaner that the primary energy source.**

- **Hydrogen can not be cheaper than the primary energy source.**

- **Hydrogen and fuel cells have always to compete with other environmentally friendly and sustainable technologies. They are no wonder and no panacea.**

Source: Dr. Schmidtchen, DWV, F-cell 2007