Prospects and Challenges for Fuel Cell Cars for Tomorrow's mobility

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DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

DLR - sites and employees

The DLR - German Aerospace Research Center

5.100 employees working in 27 research institutes and facilities

- ■ at 8 sites
- ● in 7 field offices.

Offices in Brussels, Paris and Washington.

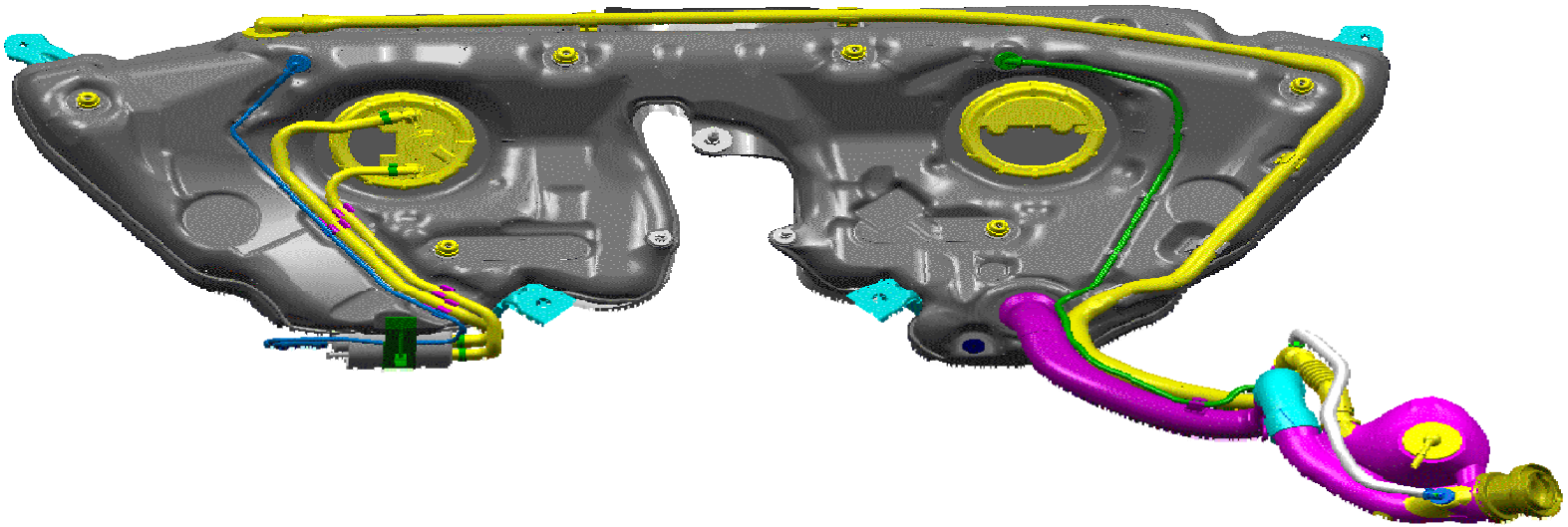
fields of research:

aeronautics, space, transport, energy

Outline

- Bench mark liquid fuel
- Tomorrow's vehicle concepts ?
  - Fuel consumption
  - Development routes
- Tomorrow's fuels ?
- Fuel cell cars and hydrogen storages
  - Operation conditions
  - Safety
  - Cost
- Summary

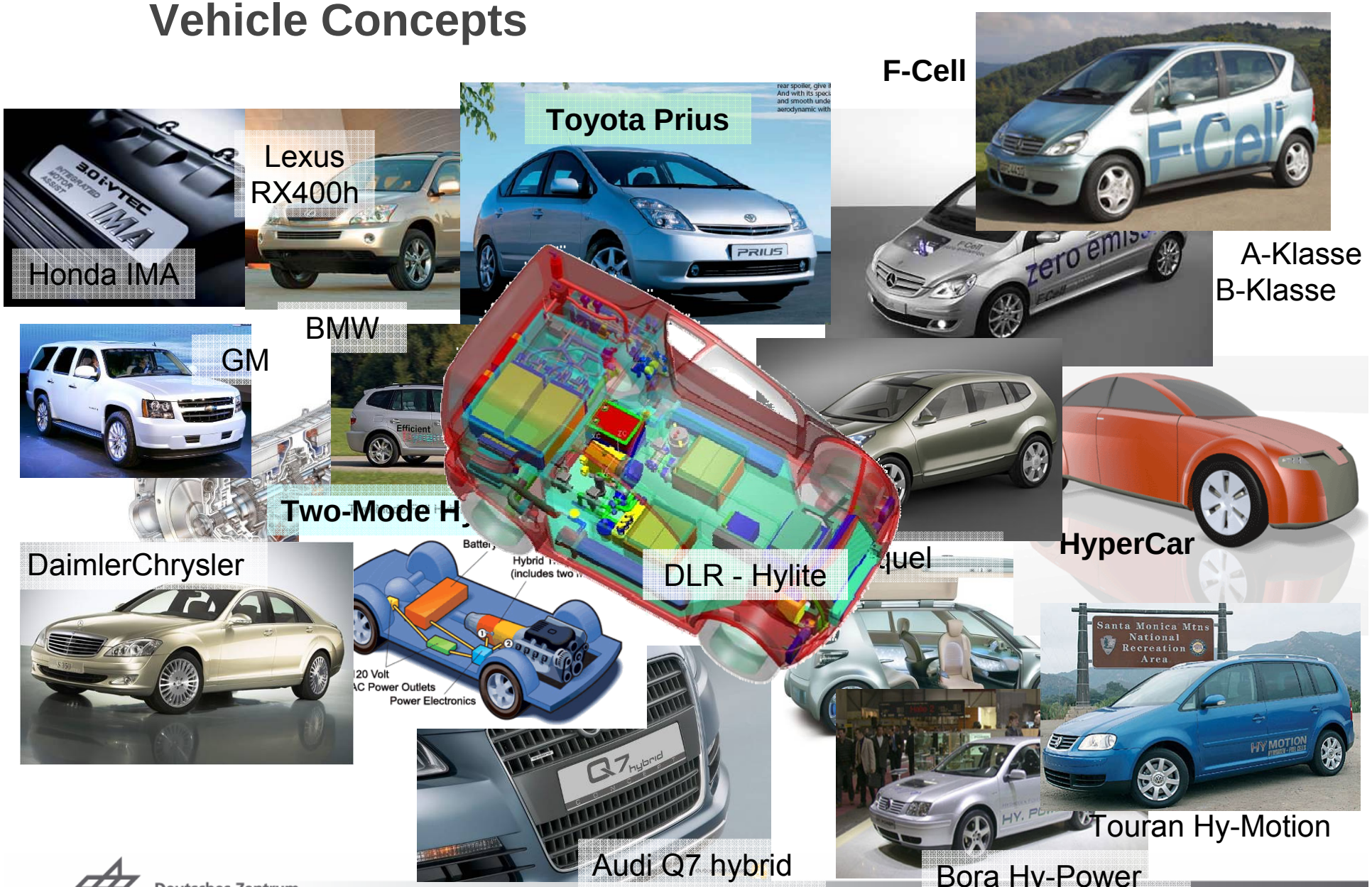
Bench mark – Storage of conventional liquid fuels



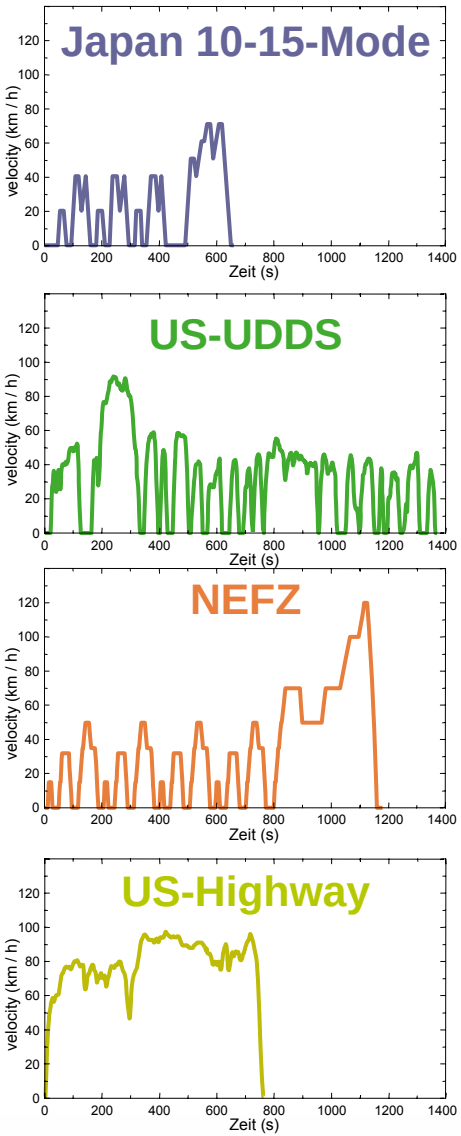
- Almost free shapable
- Volumetric efficiency (Volume of Storage / package space) ≈ 90 %
- Gravimetric efficiency (Mass of fuel / Mass of empty storage) ≈ 4,0
- Gravimetric energy density ≈ 9,5 $kWh/kg_{System\ weight}$

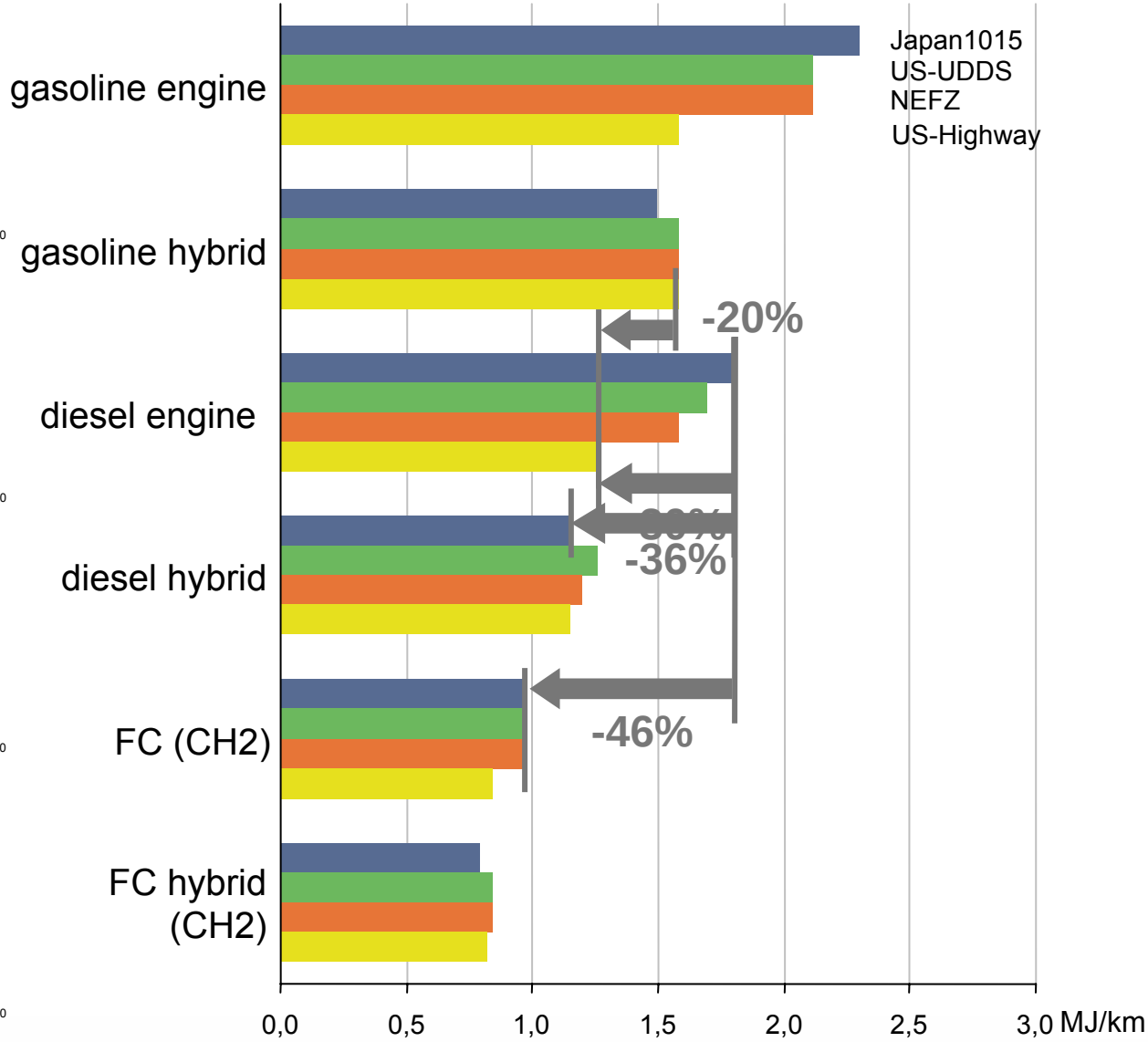
Picture: TI Automotive

Vehicle Concepts



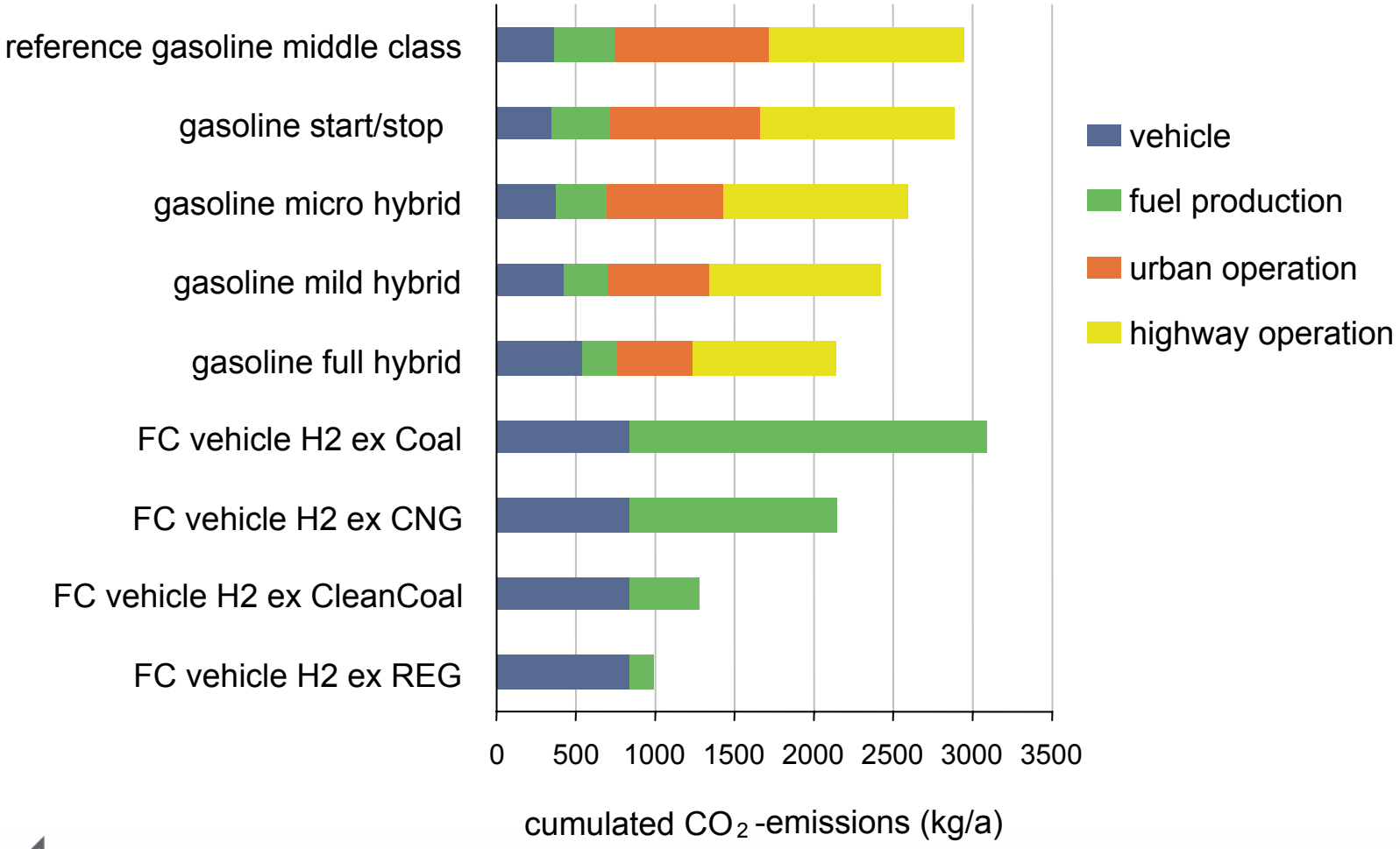
Fuel consumption





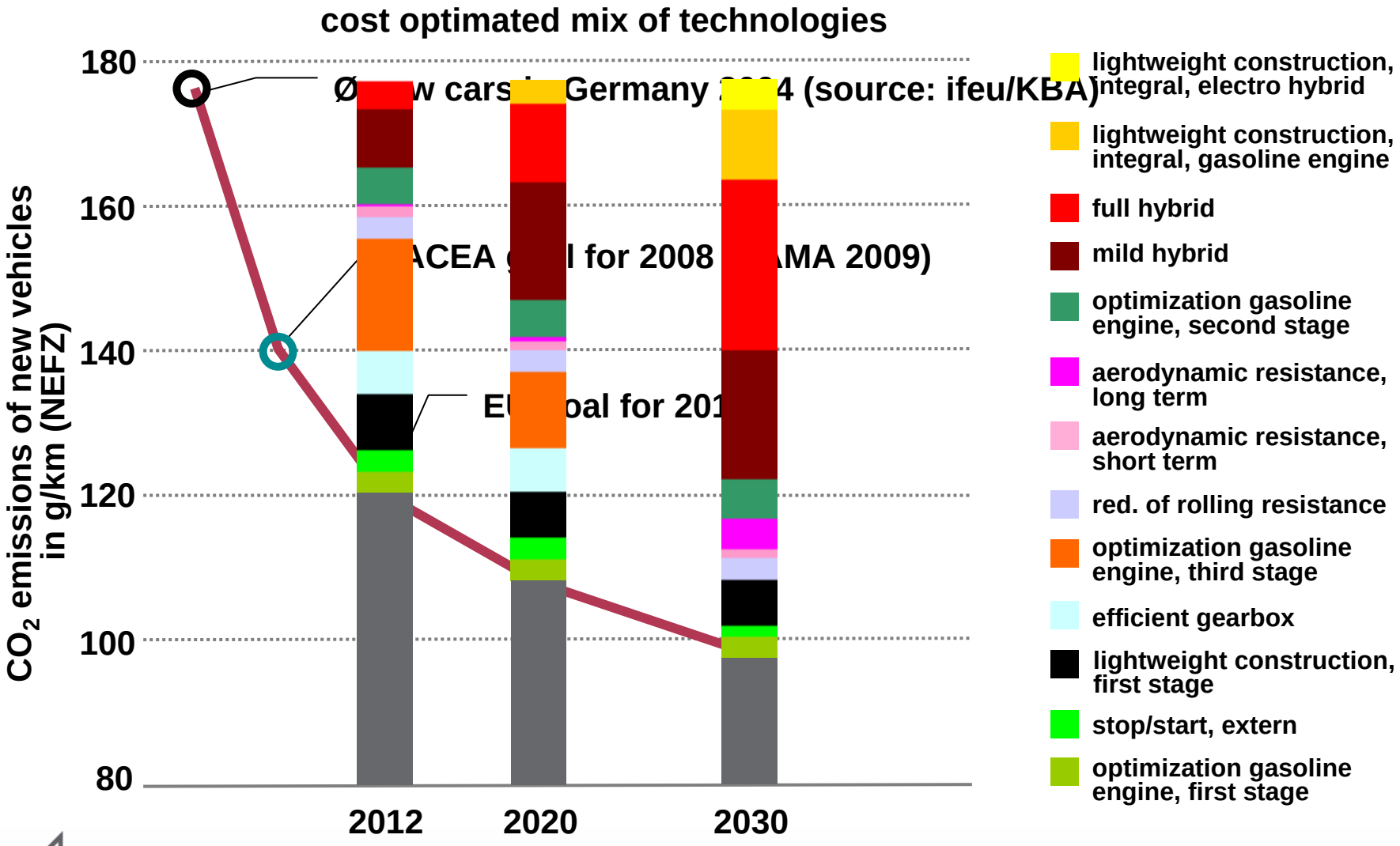
source: Y. Baba, H. Ishitani. Well to Wheel Efficiency of Advanced Technology Vehicles in Japanese. Electric Vehicle Symposium. Long Beach, 2003.

CO_2-emissions
different generic drive trains

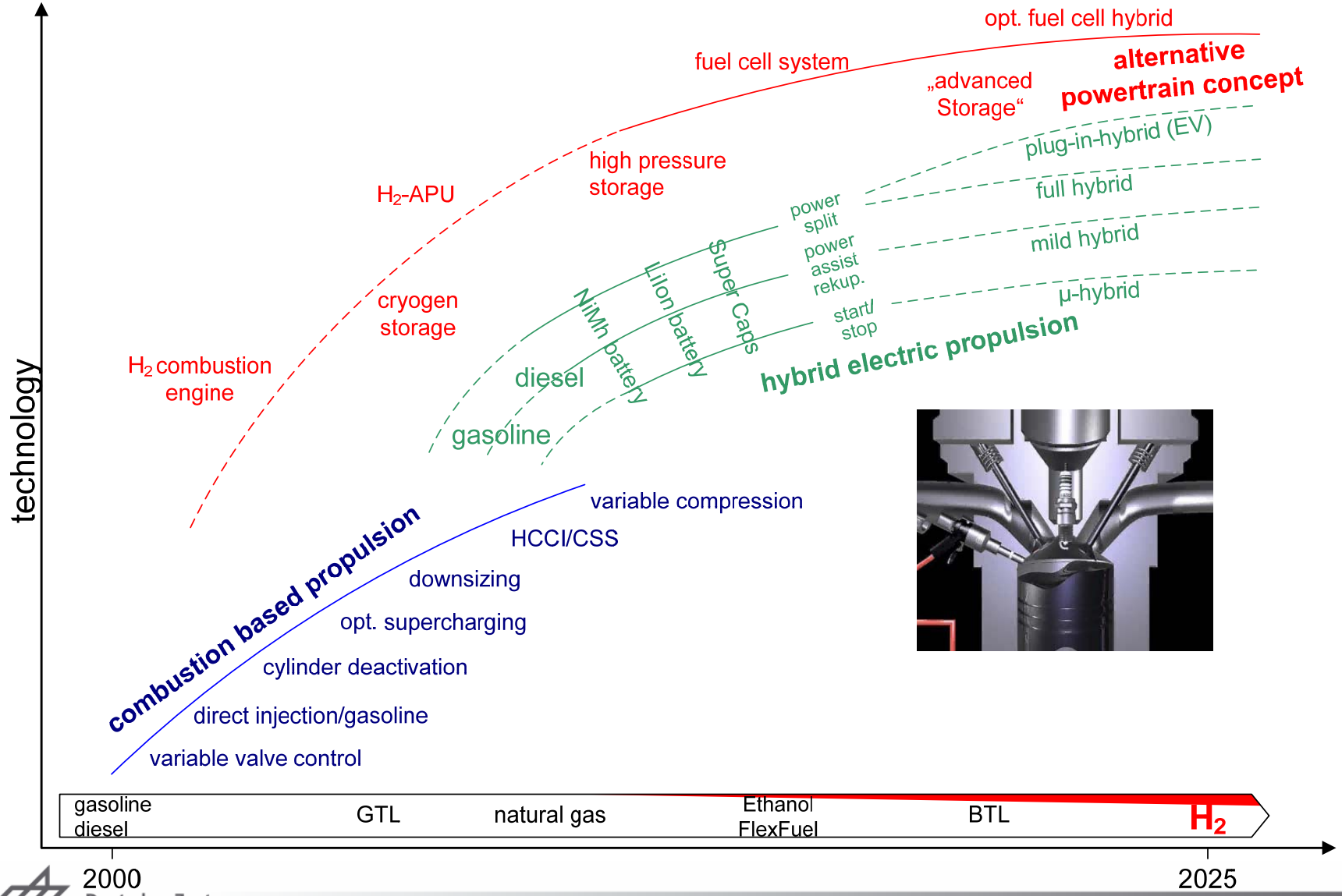


sources: DLR. R. Edwards, Well-To-Wheel Analysis, 2003. UBA-H2, Entwicklung einer Gesamtstrategie zur Einf. alternat. Kraftstoffe. Pehnt, Ganzheitliche Bilanzierung, 2002. Schweimer, Sachbilanz des Golf A4, Wolfsburg.

CO_2 reduction potentials

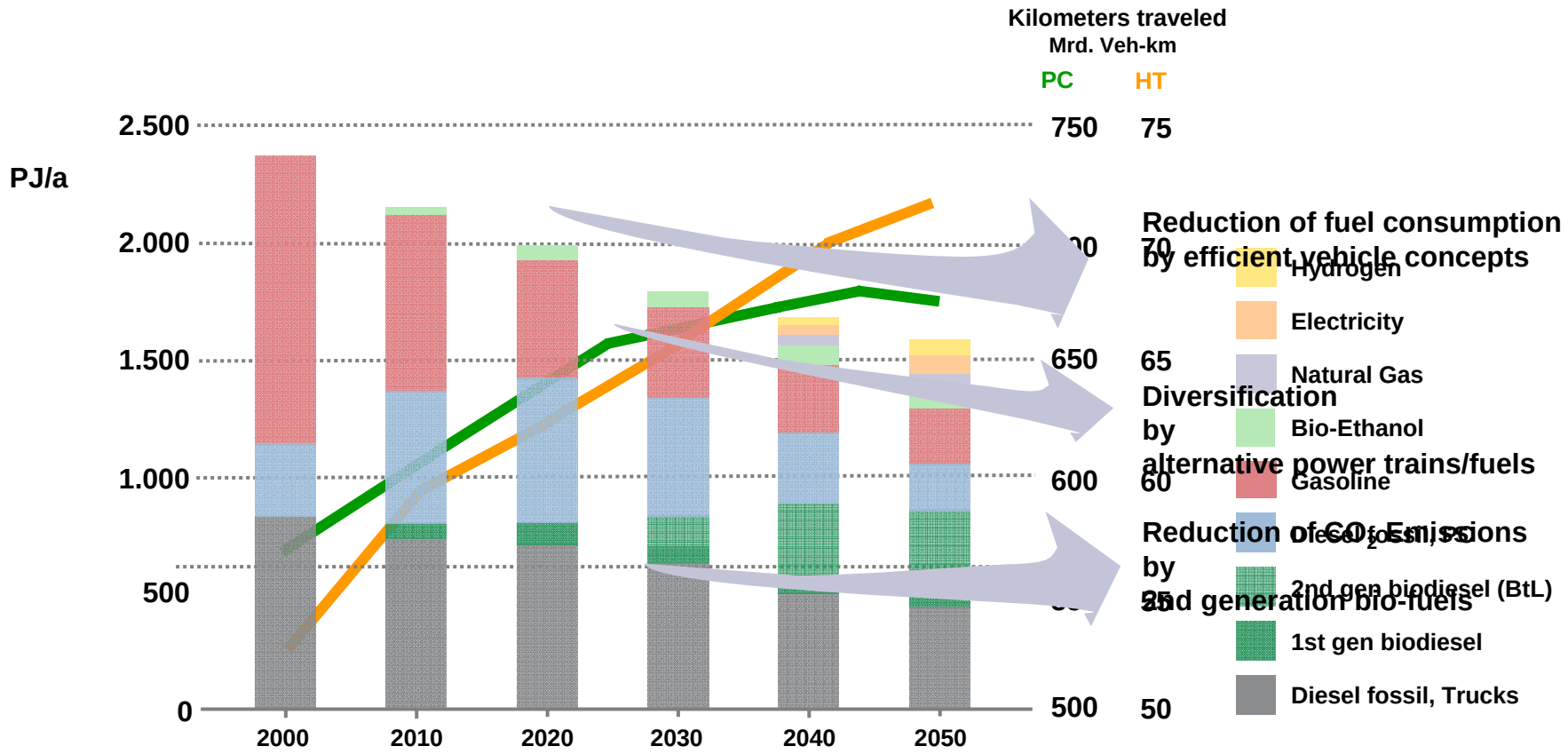


Roadmap towards sustainability



Fuel scenario for Germany

High-efficient vehicles & liquid bio fuels



Quelle: DLR

Fuel cell vehicle
Example Mercedes-Benz F-600 Hygenius

- Permanent excited Synchronous motor (85 kW, 350 Nm)
- Wasser-cooled Lithium-Ionen-Battery
- Fuel cell stack (60 kW)
- Compressed hydrogen (700 bar)
- Electrical compressor
- New Humidification device
- Range: 400 km
- Max speed: 170 km/h

- The following data is based on our estimation:
  - Fuel cell stack operation temperature: ~ 80 °C
  - ⇒ Challenge heat rejection (Have a look on front area of vehicle)
  - Hear more on that issue in presentation of VW

Data of fuel cell stacks

Manufacturer	DaimlerChrysler	Ballard	Nuvera	GM	Honda	Toyota
Labeling		Mark 902	Andromeda II	St – 18		
Stack Type	PEM	PEM	PEM	PEM	PEM	PEM
Development date (approx.)	2006	2003	2004	2005	2003	-
Power	16,5 kW	85 kW	85kW	93 kW	43 kW	90 kW
Number of cells	100	440	384	440	-	-
Pressure (abs.)	ca. 1,6 bar	3 bar	1,6 bar	ca. 1,7 bar	-	-
Temperature	ca. 70-80°C	65 - 80 °C	70 – 85 °C	ca. 85 °C	max. 95 °C	-
BPP Material	Metal	Graphite	Metal	Metal	Metal	-
Dimensions	-	805x375x250 mm³ (75 l)	864x486x200 mm³ (84 l)	-	(33 l)	-
Weight	-	96 kg	140 kg	-	48 kg	-
spez. Weight	ca. 1 kW/kg	0,9 kW/kg	0,6 kW/kg	-	0,9 kW/kg	-
Installed in vehicle	DC F 600 HYgenius	DC F-Cell	Fiat Panda Hydrogen	GM Equinox	FCX (2003)	FCHV (7/2005)

Sources: Gathered from several sources, publications, web-sites, might be not consistent.

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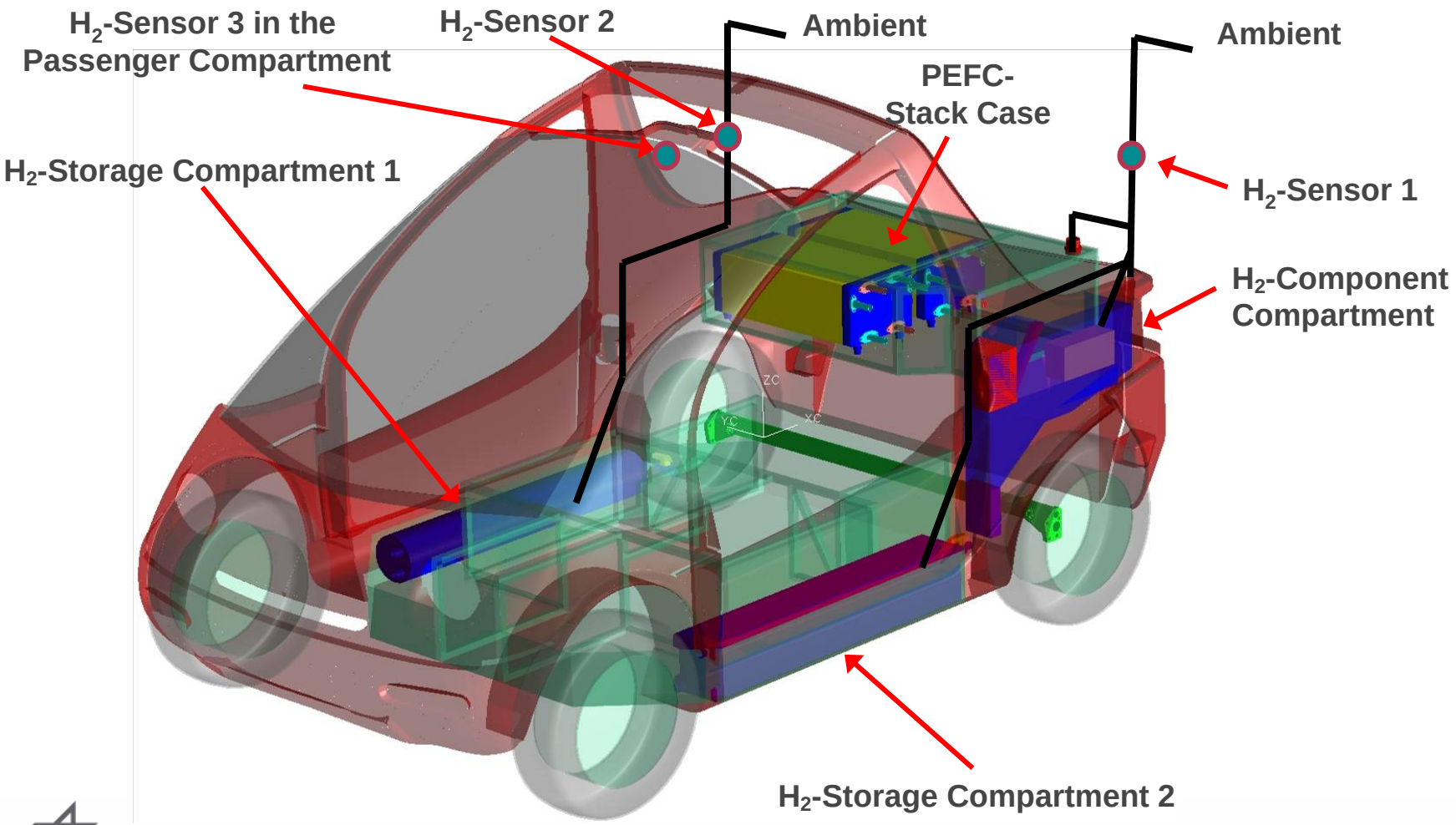
- Challenge desorption temperature:
- If the “HT-PEM” does not happen we would rely on a temperature level for desorption of approx. 90 °C

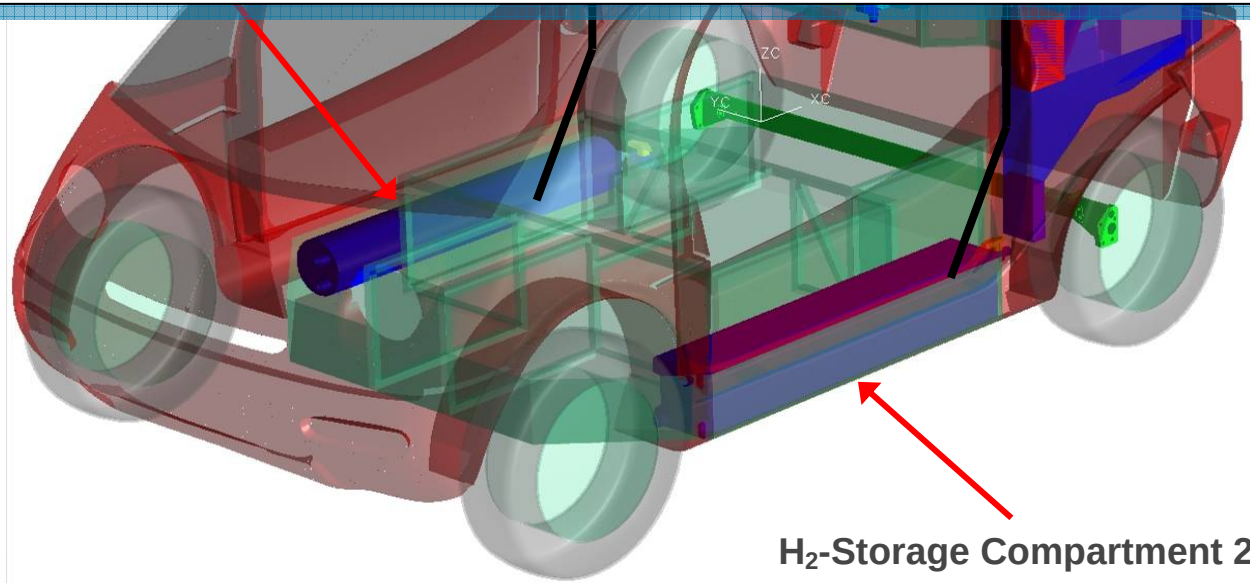
Sources: Gathered from several sources, publications, web-sites, might be not consistent.

Example HyLite® fuel cell system package
Safety concept and hydrogen storage



Example HyLite® fuel cell system package
Safety concept and hydrogen storage

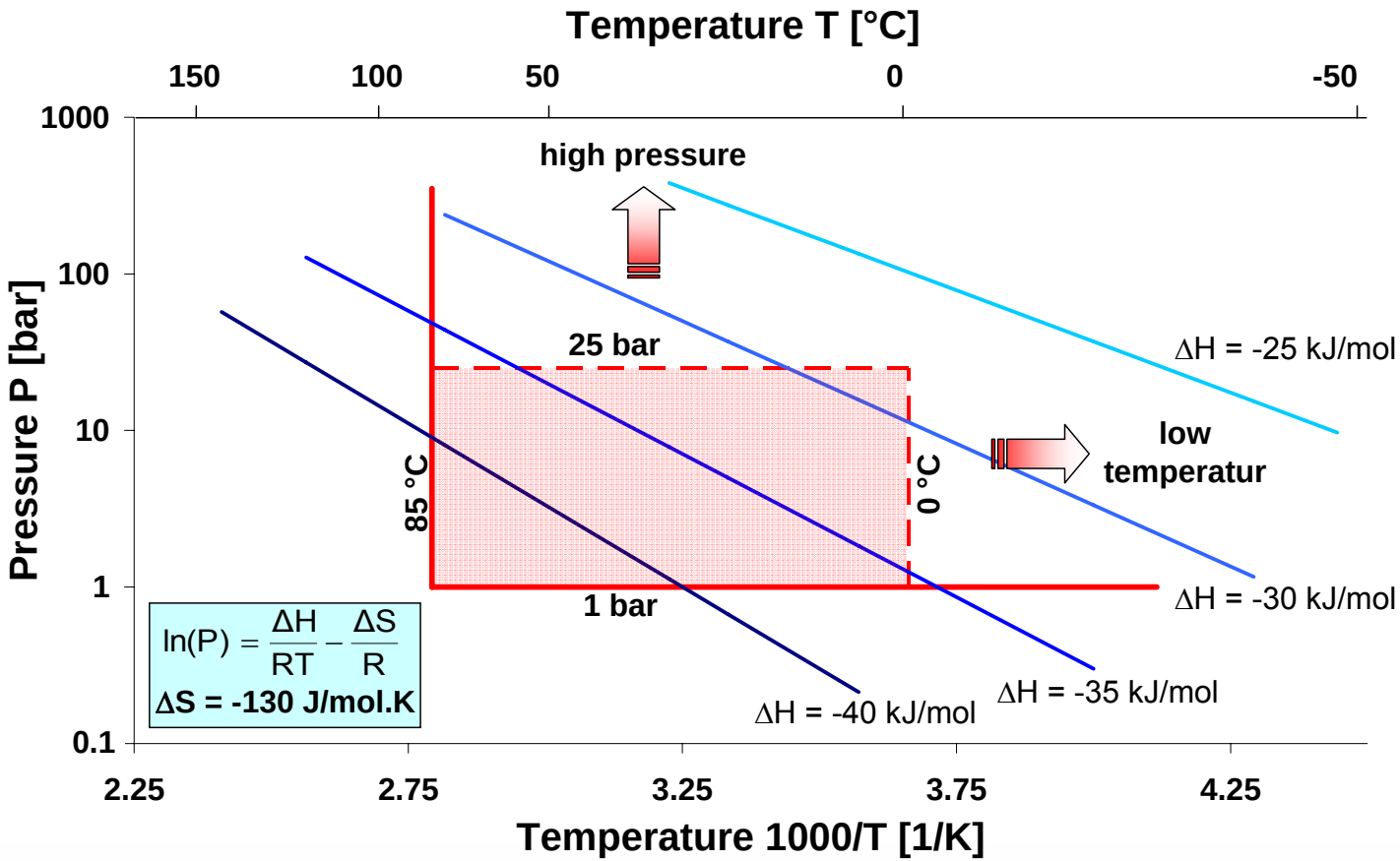
- Components/function needed
  - Storage (material + heat exchanger + vessel); storing hydrogen
  - Charging line with safety equipment; provide mass flow; operating pressure
  - Hydrogen supply line to fuel cell stack with safety equipment
  - Heating and cooling circuit for desorption and adsorption
  - Eventually: Cold start device
  - ⇒ System mass must consider all components required to fulfill the functions



H_2-Storage Compartment 2

Challenge charging of storage

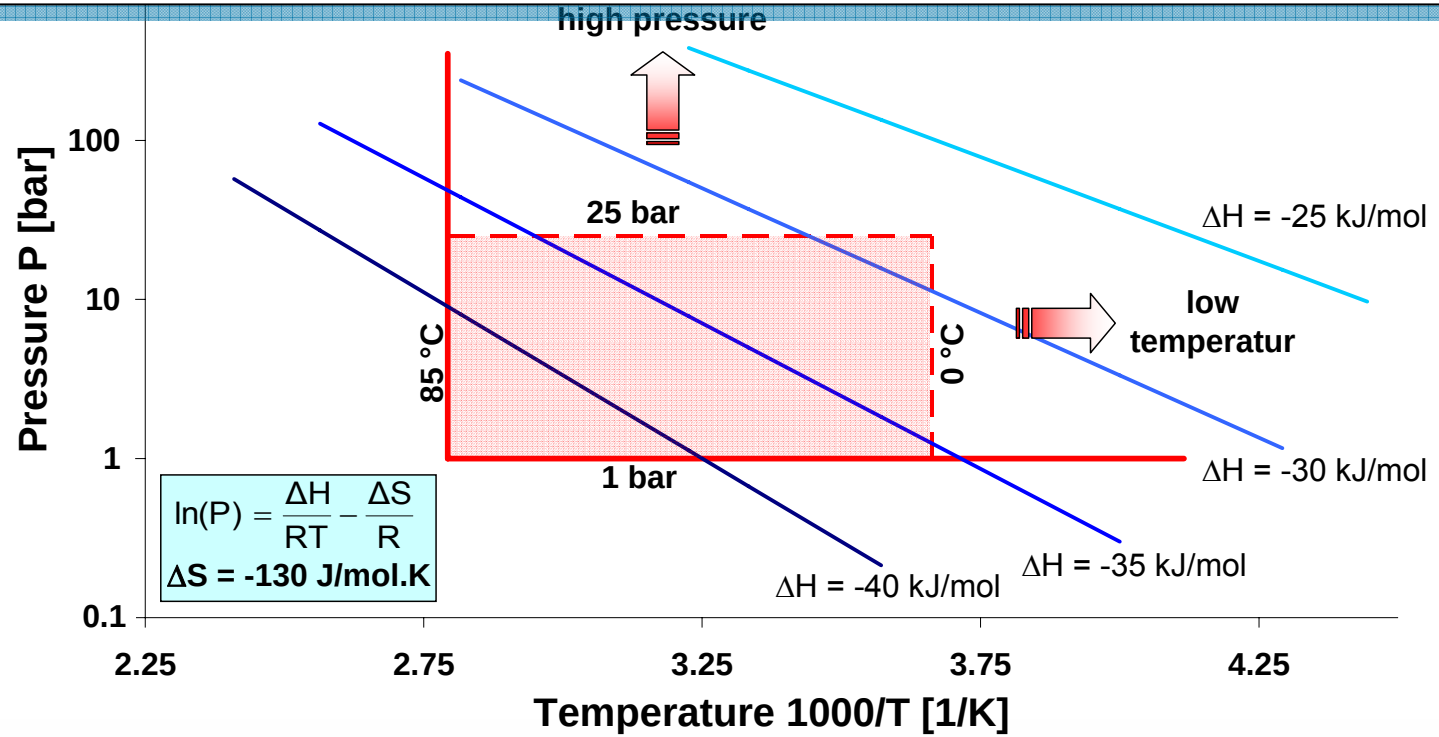
- 35 kJ/mol: 5 kg H_2 → 90 MJ
- 5 min: ca. 300 kW



Challenge charging of storage

- 35 kJ/mol: 5 kg H_2 → 90 MJ
- 5 min: ca. 300 kW

- The station should provide cooling power of several 100 kW
- I personally believe not on concepts replacing of storages; warranty!



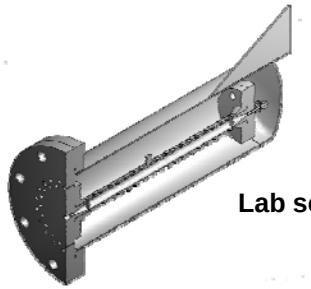
Experiments on charging of technical solid state storages

- Variety of storage tanks
  - 40 to 400 Nl H_2 capacity
  - Charge/discharge at constant pressure or constant mass flow
  - External cooling/heating system (2.25 kW)

- Lab scaled tank
  - 125 cm^3 geometric volume
  - Fulfilled with variety of low temperature metal hydride (AB_5, AB_2, etc…)
  - Temperature profile and pressure drop in the hydride bed

- Commercially available storage tank as bench mark
  - AB_5 with annular geometry (300 Nl H_2 capacity)
  - Storage of JSW compatible to HyLite vehicle

Storage test bench



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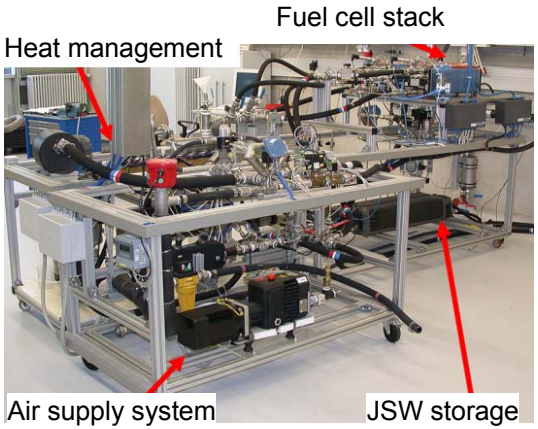

Fuel cell system test bench

Sources: DLR, Institute of Technical Thermodynamics, Institute of vehicle concepts

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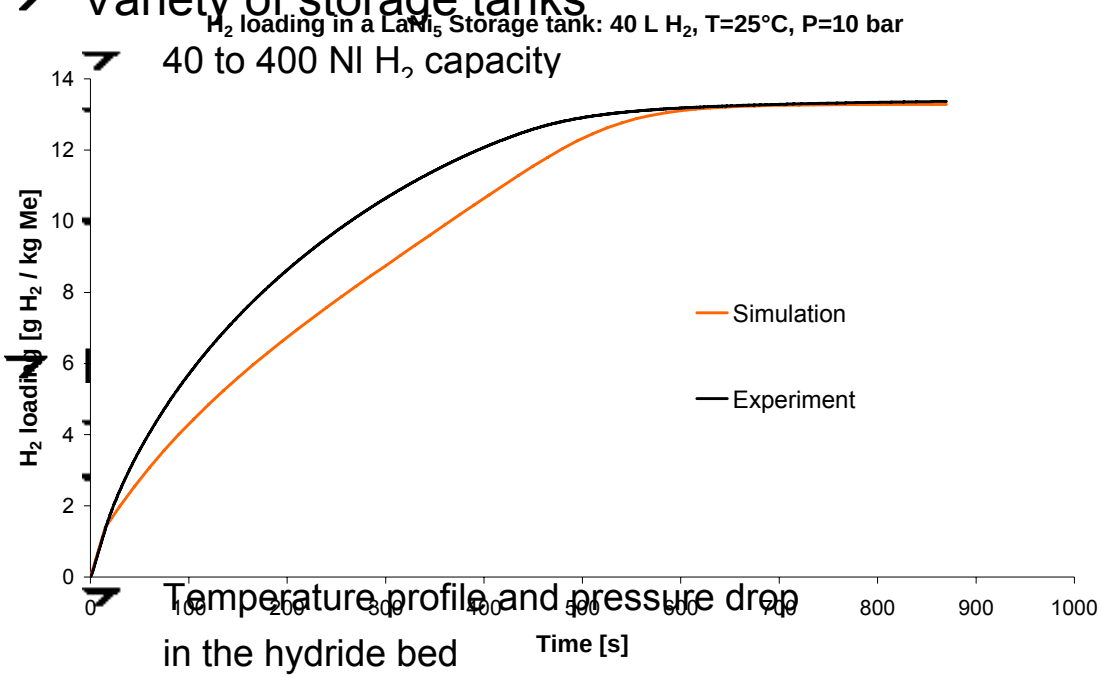

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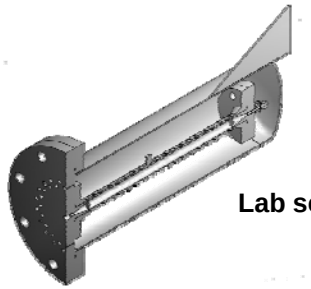

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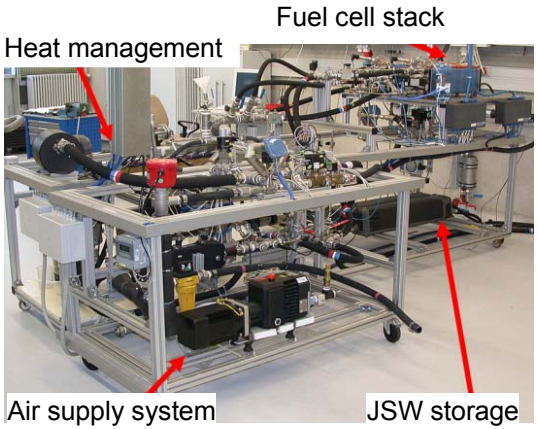

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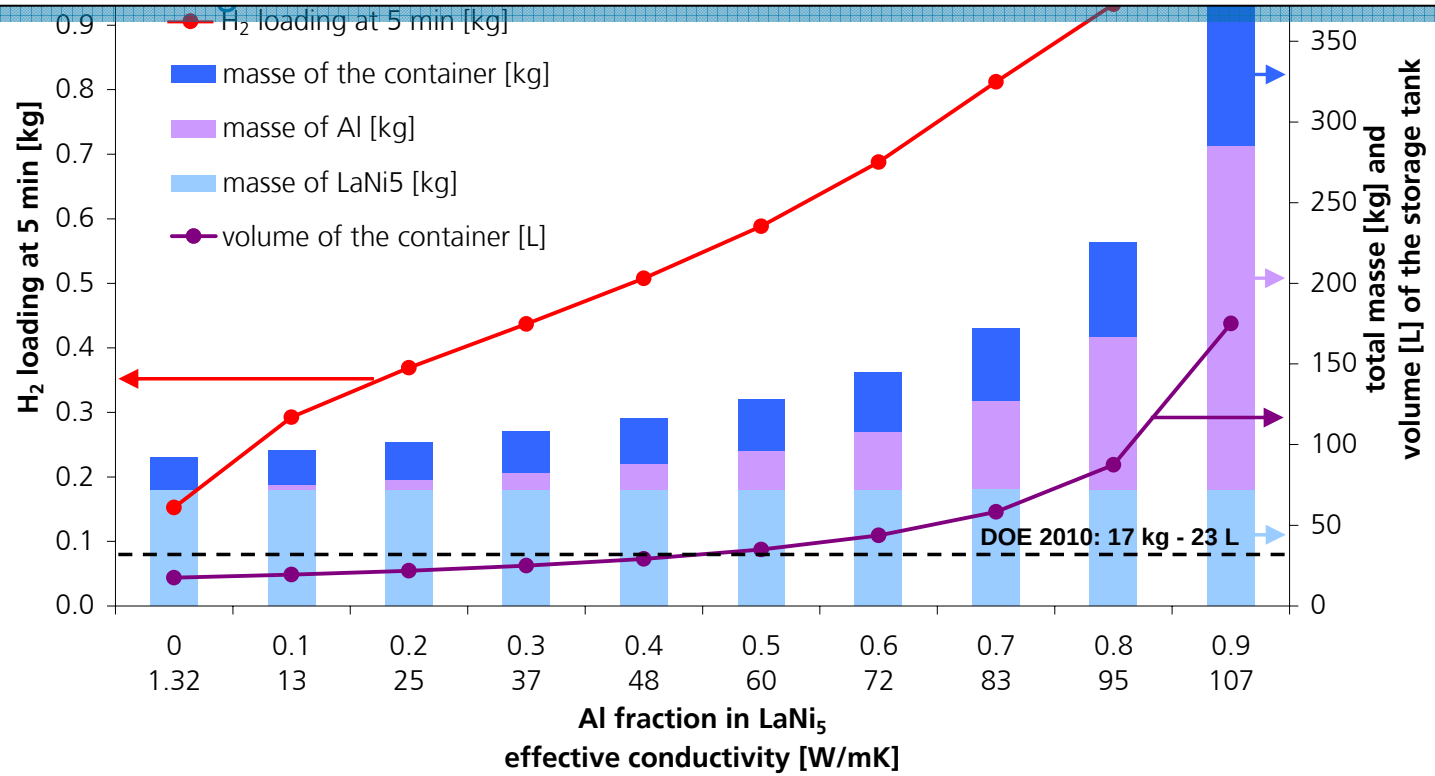
Challenge dynamic operation

- Dynamic operation
  - Understand heat and mass transfer
  - Develop effective heat and mass transfer employing light weight heat exchange devices



Source: DLR, Institute of Technical Thermodynamics

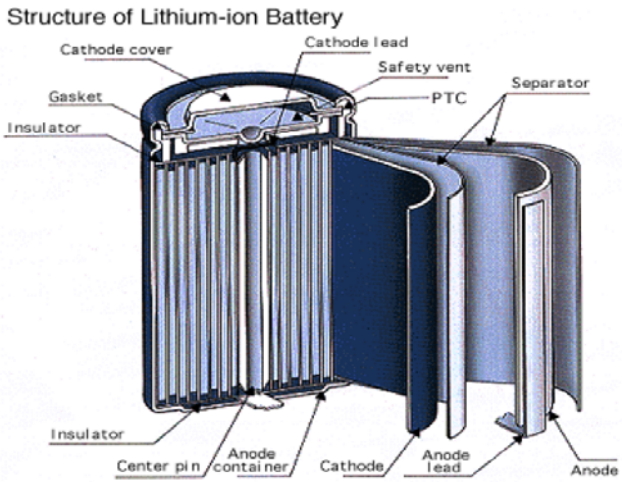
Challenge cost

	Carlson (2005) 500k stacks/a	DLR (2007) 10 stacks
Membrane	4.36 €	165.20 €
Electrodes	52.08 €	205.42 €
GDL´s	3.43 €	51.36 €
Bipolar plates	8.98 €	85.26 €
Gaskets	2.32 €	10.05 €
Summe	71.17 €	517.29 €

DLR cost investigation of fuel cell stacks
DLR (2007) cost consider material cost only

Zellebene						
High-Energy 1						
Bedarf				Technik	Kosten/Zelle $	
Komponente	Gewicht (kg)	Volumen (l)	Fläche (dm^2)	Spannung (V)	Masse	Nische
LiNi0,33Co0,33Mn0,33O2	0,143	0,062	45,071	3,9	2,46	**3,29**
Graphit	0,063	0,042	45,071	-0,22	1,26	**1,88**
Separator	0,005	0,015	99,156		0,32	**0,43**
PVdF (Kathode)	0,007	0,003			0,18	**0,26**
PVdF (Anode)	0,003	0,002			0,08	**0,11**
Acetylenschwarz	0,007	0,003			0,13	**0,18**
LiBF4	0,005	-			1,53	**1,91**
Dimethylcarbonat	0,054	0,050			0,06	**0,07**
Aluminium	0,009	0,003			0,16	**0,18**
Kupfer	0,020	0,002			0,40	**0,44**
Hülle	0,032		Kathodendicke		1,29	**1,52**
Sicherheit:	in Modulkosten berücksichtigt		150 µm		0,00	**0,00**
Gemeinkosten					0,00	**0,00**
Total	**0,348 kg**	**0,132 l**	**0,07 kWh**	**3,68 V**	**7,88**	**10,27**

DLR cost model for Li-Ion batteries



Challenge cost

- Cost issue of fuel cell
- Cost issue of traction batteries
- Cost issue of solid state storage ?

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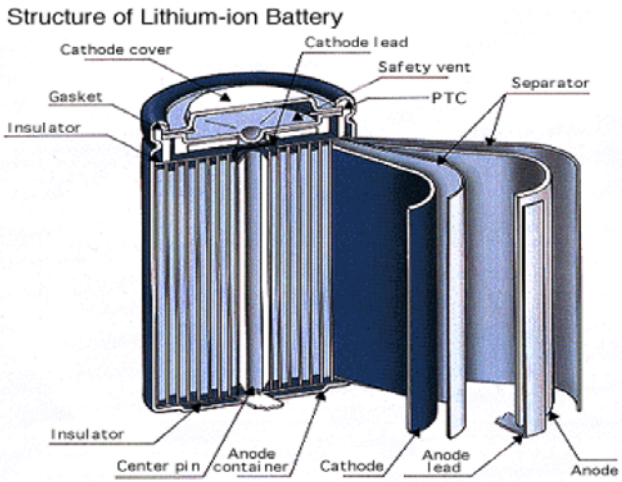

Summary

- Liquid fuel tank is tough bench mark
- Multiple power train technologies are in development the race is going on …
- Hydrogen competes with other fuels also in long term
  - Bio fuels
  - Electricity
- Solid state storage faces a lot of challenges
  - Reversible capacity of material
  - Cyclability
  - Adjustment to operation conditions of fuel cell system (T and p)
  - Refueling efforts
  - Is gravimetric energy density kept when considering all components needed in real operation
  - and finally what‘s about the cost ...

- We should discuss today and then go back to work immediately ...

Thank you very much for your attention!