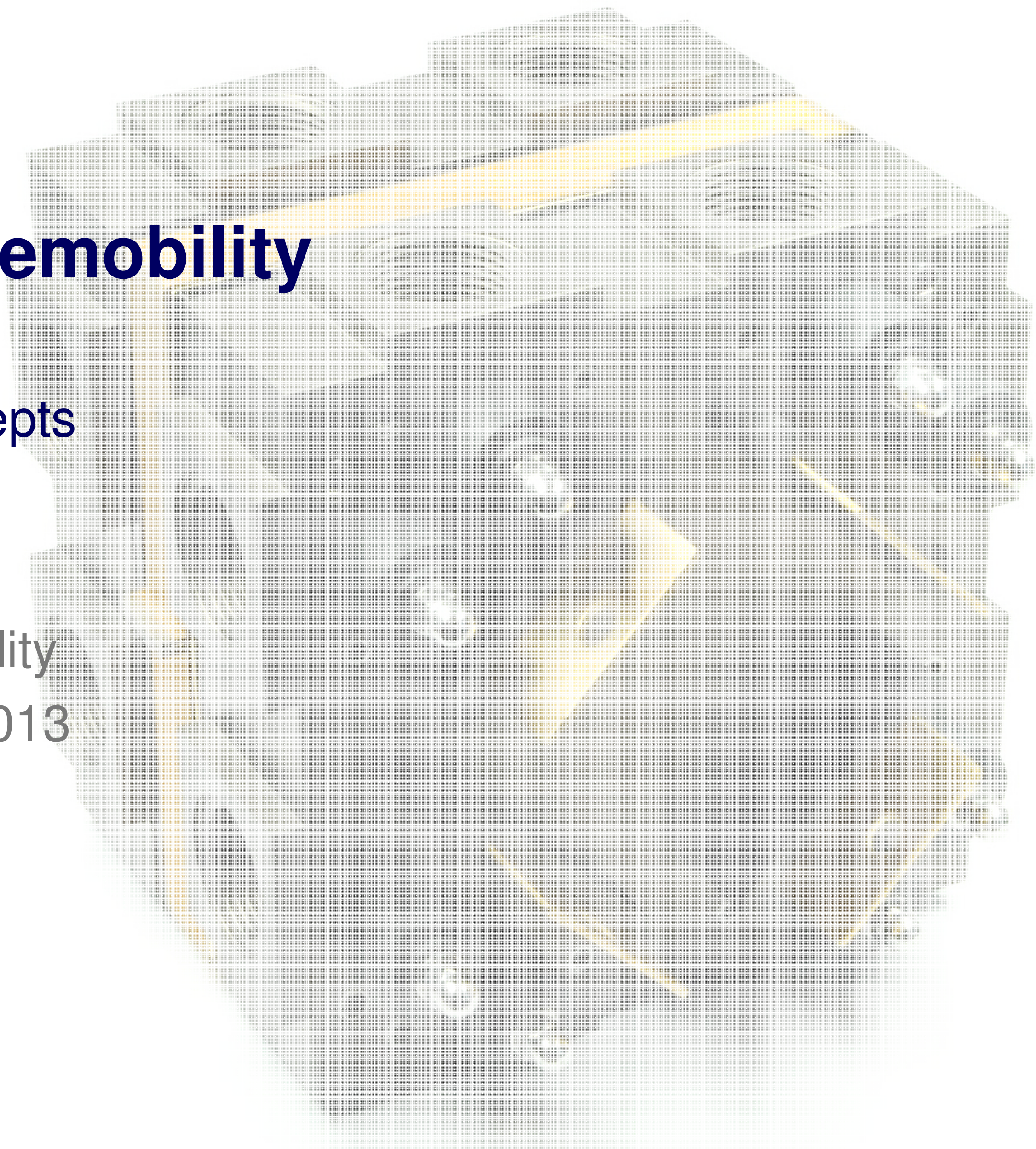
Fuel cells for long distance emobility

Development status and powertrain concepts



Dr.-Ing. Jörg Karstedt, Coordinator Emobility

Hydrogen & Fuel Cells Energy Summit 2013

Berlin, 5.12.2013

Fuel cells for long distance emobility: Content

- ZBT – A brief introduction
- Motivation for alternative powertrains
- Automotive fuel cell systems:
  - Status and future development
  - Powertrain concepts
- Conclusion

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Zentrum für BrennstoffzellenTechnik GmbH: The fuel cell research center

The fuel cell research center:

- Research and development of fuel cells, hydrogen and battery technology
- Focus on industry demand
- Independent service provider
- 100 full time employees + 40 students

Infrastructure:

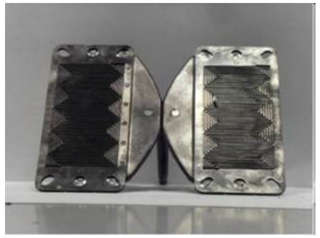
- 1200 m² laboratory
- 4 confidential laboratories with 220 m²
- Flexible testbenches with advanced measurement and analytics
- 3 climatic chambers incl. vibration testing
- First accredited testing laboratory for fuel cells
- 120 m² injection molding/compound laboratory
- Prototype production line

Project supported by the European Funds for Regional Development and the Region of North Rhine-Westphalia, Germany

Zentrum für BrennstoffzellenTechnik GmbH: R&D / service portfolio – main topics

Fuel Processing (stationary / portable)

- Natural gas reformer
- Multi fuel options
- For LT & HT PEM
- For SOFC
- From reactors to systems
- Patented & licensed



Bipolar plates

- Compound based
- Materials & plates
- For LT & HT PEM
- Different production methods
- Licensed / (patented)

Prüflabor Brennstoffzellen Technik

System testing

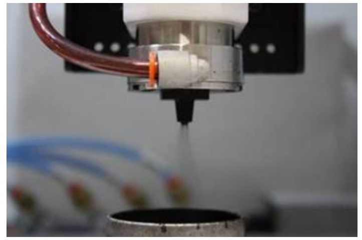
- Sub- / complete systems
- Material qualification
- Validation of specification
- environmental testing
- Accredited Fuel Cell Testing Laboratory PBT

Production & QS

- Development of production processes
- Quality control
- Traceability

MEA technologies

- Qualification (membranes, electrodes, GDL)
- Manufacturing
- LT, MT-PEM

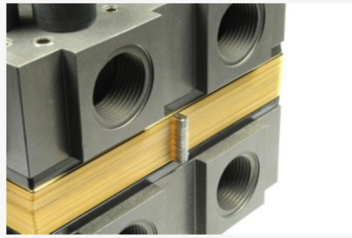


Infrastructure

- Studies / energy analysis
- Safety / modeling
- Assessment
- Marketing
- Testing

Fuel cell systems

- Hydrogen powered
- from stack to application
- 100 – 1.000 W
- Uninterrupted power supply, APU, special applications



Stack development

- Design, Manufacturing
- Testing
- LT, MT, HT-PEM

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Motivation for alternative powertrains: Global trends 2050

- World population will increase by 35 % from 6.8 bn. (2009) to 9.2 bn.[1]
- Urbanization will rise by 38 % from 51 % (2010) to 70 %[2]
- Global energy demand will grow by 84 % from 2007 to 2050[3]
- The number of passenger vehicles will increase by 250 % from 840 mio. (2010) to 2.1 bn.[4]
- Based on current trends the worldwide transport related CO_2 emissions will rise by 75% until 2050[4]

Challenges:

- **Availability of primary energy carriers**
- **Energy security**
- **GHG emissions**

1: UN, 2009; 2: UNHABITAT, 2010; 3: International Energy Agency, 2010; 4: International Energy Agency, 2012

Electricity and Hydrogen: Renewable energy carriers for transport applications

Economy

- Energy carriers with national value chain
  - Crude oil imports Germany 2012: 60 bn. €
- No import dependency
- Supply security

Mobility

- Performance
- Range
- Refuelling time

Quelle: CEP

Sustainability

- Production from renewable sources
- No CO_2 emissions
- Storage of fluctuating renewable energy
- Integration of transport sector in renewable energy concept

Quality of life

- No exhaust emissions
- Noise reduction
- „Clean“ infrastructure

Powertrain options for electric vehicles: Battery electric vehicles, fuel cell / battery hybrids and fuel cell range extenders

source: Toyota

source: Toyota

	Battery Electric Vehicle	Fuel Cell/Battery Hybrid
Battery System Fuel Cell System	High energy, > 15 kWh -	High power, ~ 1.5 kWh High performance, > 80 kW
Emission free Low Noise Energy Diversity	✔	✔
Advantages	▪ Highest TTW efficiency ▪ Low operating cost ▪ Private charging	▪ State of the art range, comfort, refuelling time ▪ High continuous power
Challenges	▪ Limitations range, charging time, comfort ▪ Public charging	▪ High density H_2 infrastructure ▪ Increased operating cost
Design criteria Battery Fuel Cell System	 ▪ Range ▪ -	 ▪ Peak power ▪ Performance
Applications	▪ Urban traffic	▪ High performance long distance (>120km/h, SUVs)

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Automotive fuel cell systems: Technology status and future development

Achievements and technology status

- 500 FCVs, > 15 Mio. km, > 90.000 refuellings (Portfolio of Powertrains, 2010)
- Customer expectations are met
  - Driving Performance and comfort (low noise)
  - High efficiency/low fuel consumption
  - Short refuelling time
  - Technology proven in hot and cold weather conditions, on- and offroad operation
  - Sufficient range
  - No local emissions
  - Automotive safety standards

Current development focus

- Package / weight optimization
- Range / storage optimization
- Durability
- Hydrogen infrastructure
- Cost: series production, suppliers and technology

Automotive fuel cell systems:
Package / weight: Comparison of different powertrain options

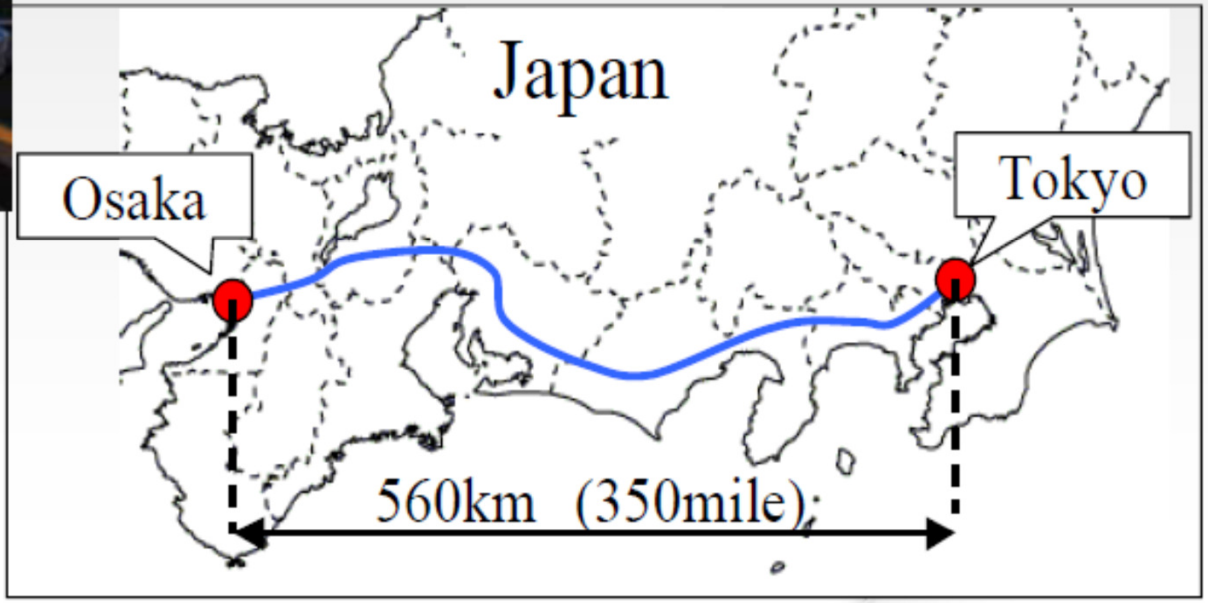
Powertrain mass and volume of different vehicle technologies for a 500 km vehicle range:

	Diesel	Plug-In Hybrid	BEV [2)]	FCV [3)]
Packaging				
Energy storage (type & weight)	Tank 45 kg	Tank, Battery (14,6 kWh) } 180 kg E-Range 70 km	Tank, Battery (100 kWh) } 830 kg E-Range 500 km	H_2-Tank, Battery (1,4 kWh) } 131 kg E-Range 500 km
Energy conversion (type & weight)	ICE Transmission } 215 kg	E-Motor, Inverter, Transmission ICE, Generator Inverter } 275 kg	E-Motor, Inverter, Transmission } 147 kg	E-Motor, Inverter, Transmission, HV DC/DC, FC System } 276 kg
Powertrain weight	260 kg	455 kg	977 kg	407 kg
Powertrain volume	125 l	319 l	760 l	480 l

source: Daimler

Automotive fuel cell systems:
Development focus range / storage: Practical driving range

The cruising range has been significantly improved by increasing hydrogen tank pressure (35 MPa => 70 MPa) and system efficiency. (about 300 km => 500 km with practical driving cycle)



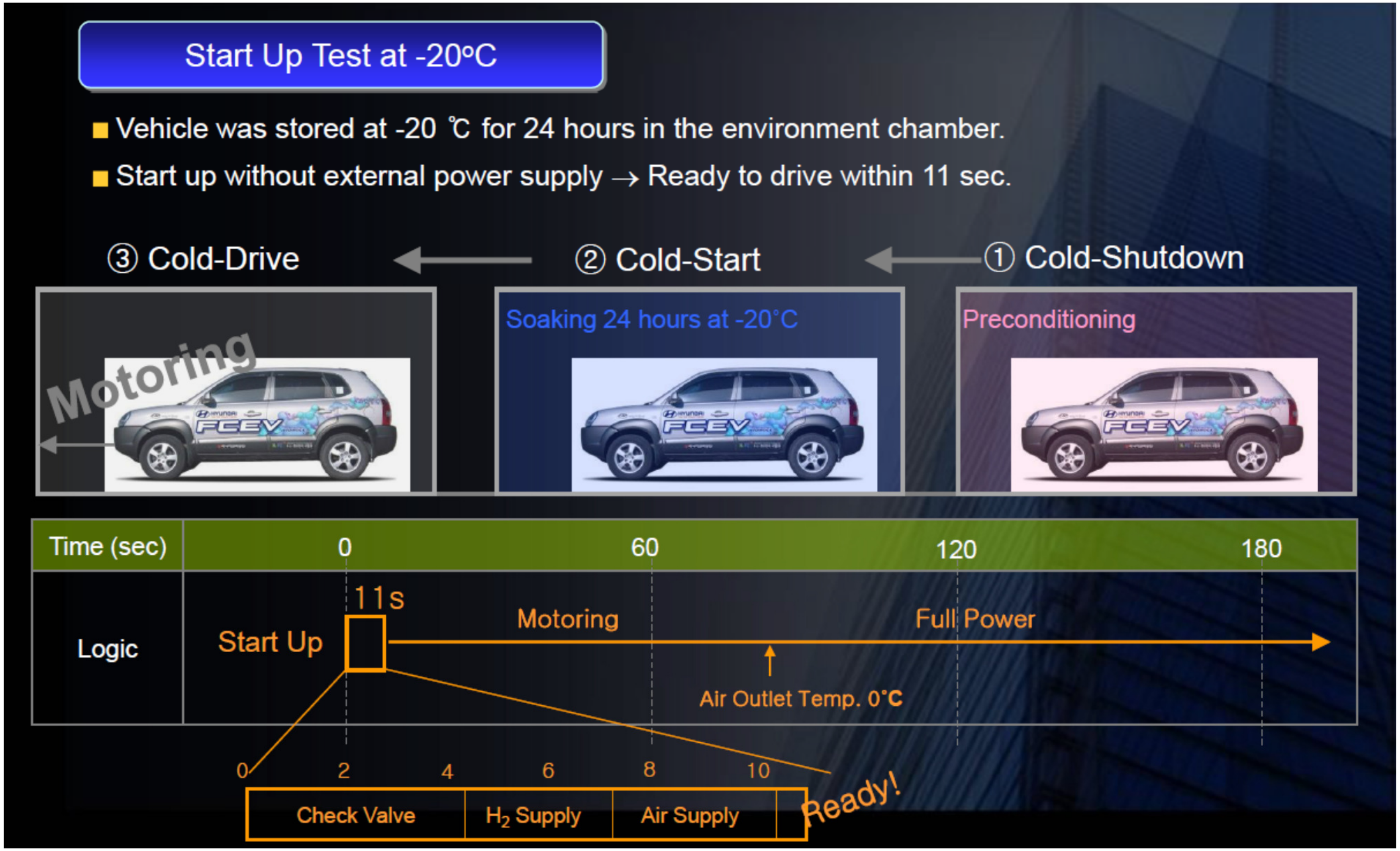
Cruising range	
LA#4	790 km
10-15	830 km

Toyota in-house test

With single refueling, FCHV-adv successfully traveled between Osaka and Tokyo (560 km) under real-use conditions (air conditioner on, etc.) with enough reserve capacity.

source: Toyota

Automotive fuel cell systems: Cold start performance of current FCEVs

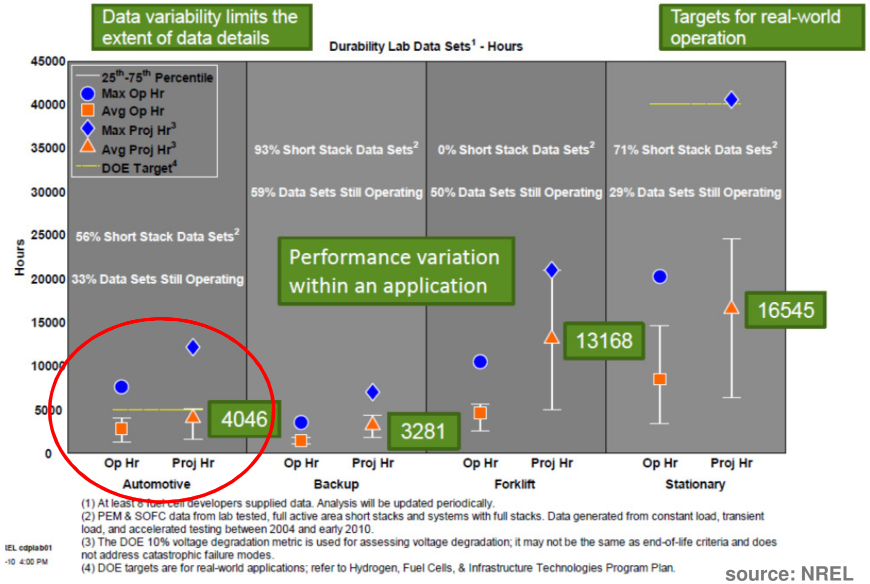


sources: Hyundai

Automotive fuel cell systems: Development focus durability

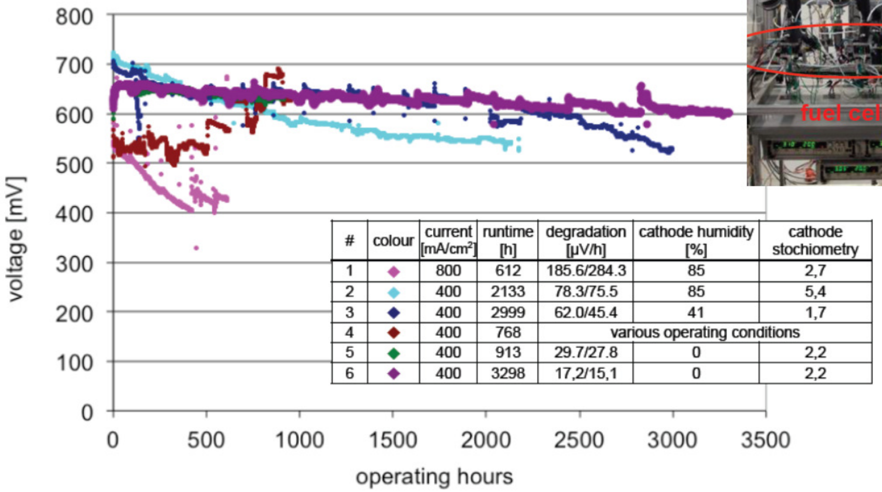
Increase of fuel cell system durability:

- MEA optimization (membrane polymer, catalyst)
- Optimized coatings for metallic BPP
- Material selection stack and system
- Optimized operating and startup-/ shutdown strategies
- Regeneration procedures
- Accelerated testing and real world performance

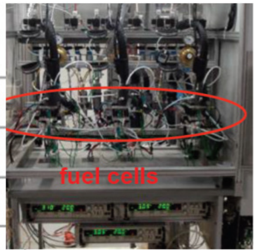


source: NREL

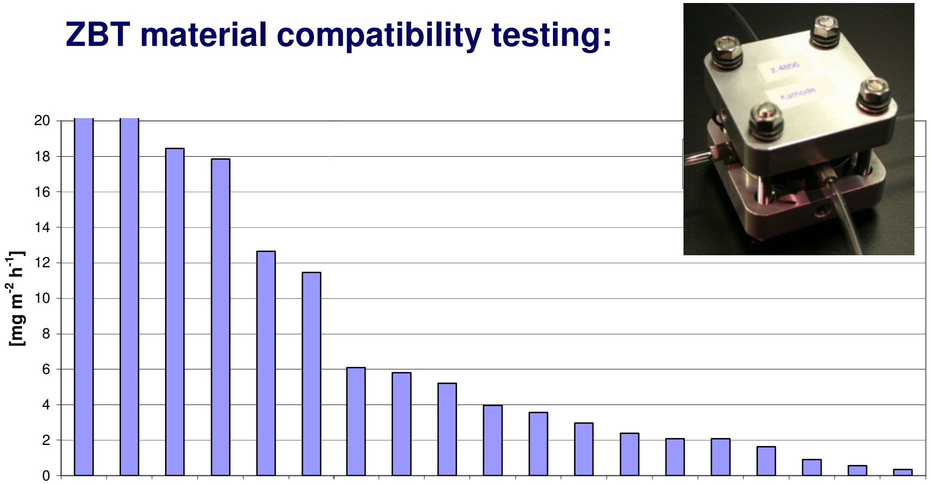
ZBT durability testing:



#	colour	current [mA/cm²]	runtime [h]	degradation [µV/h]	cathode humidity [%]	cathode stochiometry
1	◆ (pink)	800	612	185.6/284.3	85	2,7
2	◆ (light blue)	400	2133	78.3/75.5	85	5,4
3	◆ (dark blue)	400	2999	62.0/45.4	41	1,7
4	◆ (dark red)	400	768	various operating conditions		
5	◆ (green)	400	913	29.7/27.8	0	2,2
6	◆ (purple)	400	3298	17,2/15,1	0	2,2



ZBT material compatibility testing:



Automotive fuel cell systems: Development focus hydrogen infrastructure

Hydrogen Infrastructure

Production / Distribution:

- 22 bn. Nm^3 annual industrial hydrogen production in Germany (equates to the demand of 15 mio. FCVs)
- Cost for 1 mio. FCVs: ~ 2 bn. €, scaleable[1]

Retail stations:

- Cost for 1 mio. FCVs: ~ 1 bn. €, upfront[1]
- Infrastructure cost for FCVs comparable with charging infrastructure cost for battery electric vehicles (BEVs) or plug-ins (PHEVs):
  - FCVs: 1,5 ct/km[1]
  - BEVs / PHEVs: 1,5-2,5 ct/km[1]

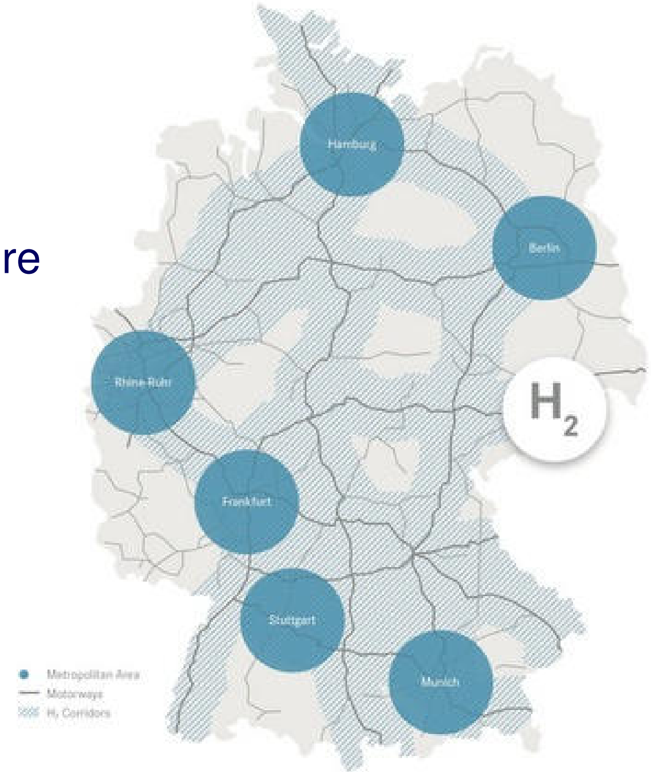
H_2 Mobility Initiative

Action plan for the construction of a hydrogen refuelling network in Germany by 2023

~400
Stations
will Germany's public hydrogen refuelling network cover by 2023.

~90
Kilometers
lie between the H_2 filling stations on the motorways around the metropolitan areas by 2023

>10
H_2 filling stations
will be available in each metropolitan area from 2023



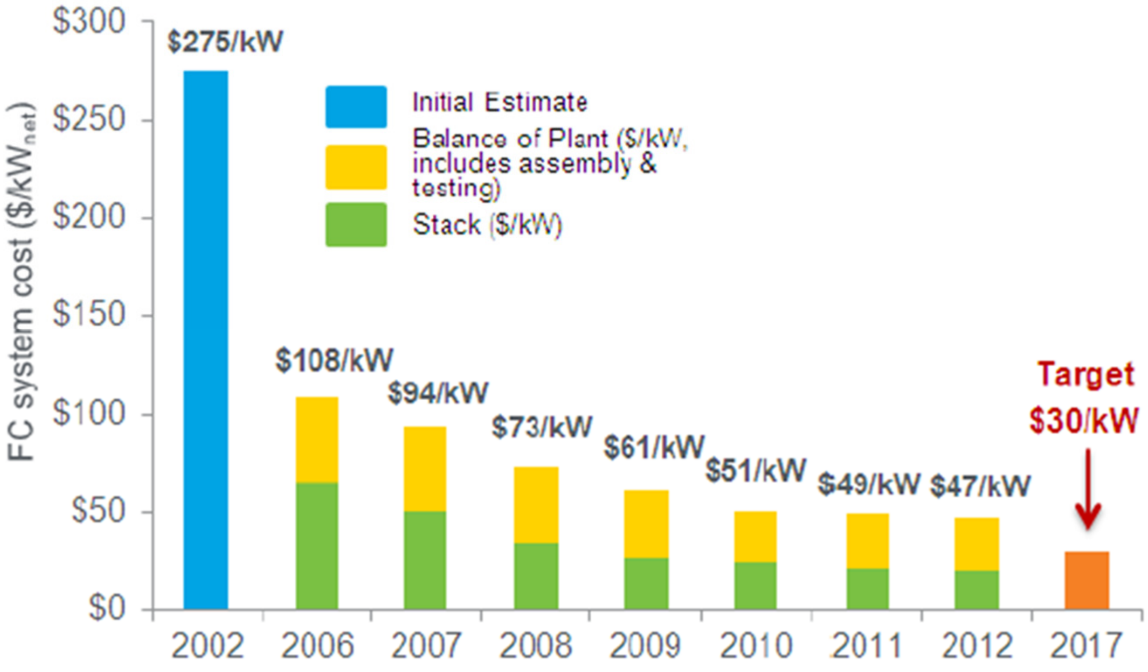
AIR LIQUIDE DAIMLER THE LINDE GROUP NOW OMV H2 Mobility Action plan

source: 1: BMW, Daimler, Ford, GM, Honda, Hyundai, Kia, Nissan, Renault, Toyota, VW, McKinsey 2010

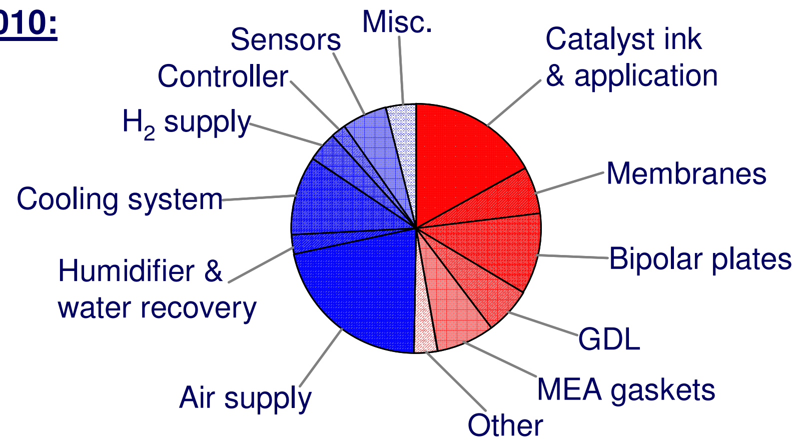
Automotive fuel cell systems: Development focus cost reduction

Focus cost reduction:

- Increase of power density
- Reduction of platinum loading (Tradeoff durability/robustness)
- BOP component cost optimization
- Materials selection
- System integration
- Automation
- Conventional powertrain tech transfer
- Volume/Synergies
- Supply landscape



2010:



sources: DTI 2010/2011, DOE 2012 500.000 units/year

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Experiences National Fuel Cell Vehicle Learning Demonstration: System Operation

Program:

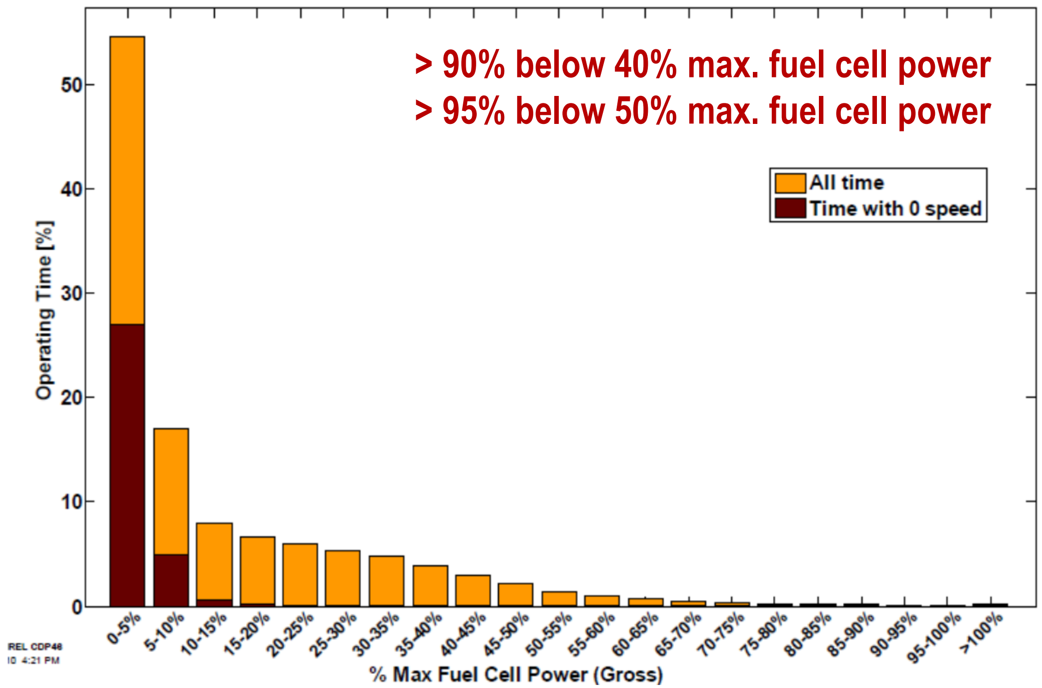
- 7 year duration
- 4 OEMs, 183 fuel cell vehicles, 2 fuel cell system generations
- 5.8 mio. km, 500.000 individual trips
- 25 fuelling stations, > 150.000kg H_2

System operation:

- Low fuel cell power operation dominant
- Fuel cell systems rarely operated at max. power
- Small share of fuel cell energy generated at high fuel cell power
- But: Max. fuel cell power is THE cost driver for fuel cell systems

→ **Fuel cell downsizing enables significant cost reductions**

Fuel cell system operating power



source: National Fuel Cell Electric Vehicle Learning Demonstration Final Report, NREL 2012

Experiences National Fuel Cell Vehicle Learning Demonstration: Degradation

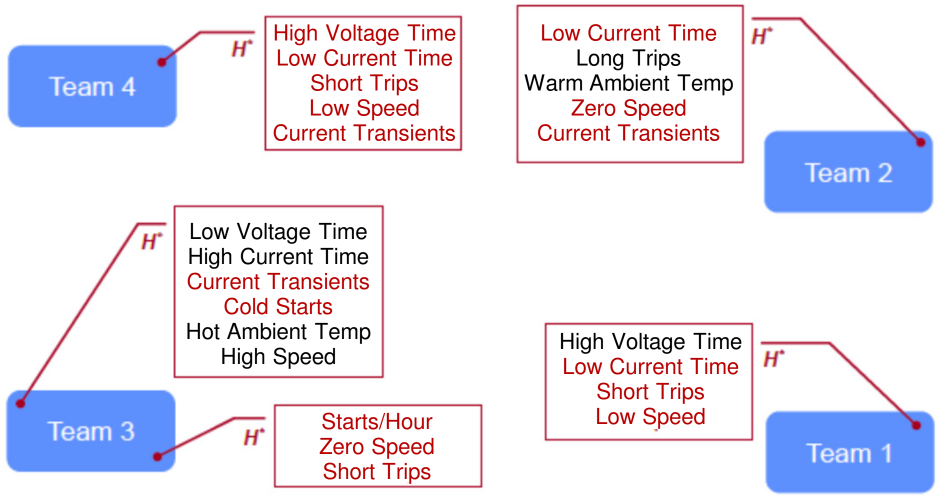
Important degradation parameters

- Current transients
- Low speed/zero speed
- Short trips
- High voltage time/Low current time
- Cold starts
- Starts/Hour

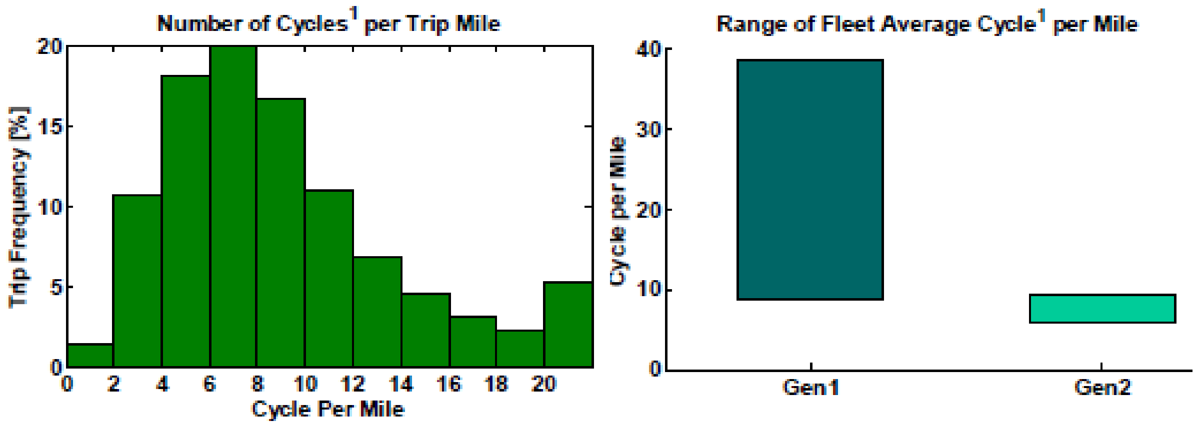
→ **Fuel cell range extender operating strategy can be optimized to minimize those degradation effects**

→ Load gradients of the fuel cell system have been significantly reduced in Gen 2 systems by hybridization / control strategy

Primary factors affecting fuel cell degradation



Fuel cell transient cycles by mile



source: National Fuel Cell Electric Vehicle Learning Demonstration Final Report, NREL 2012

Powertrain options for electric vehicles: Battery electric vehicles, fuel cell / battery hybrids and fuel cell range extenders

source: Toyota

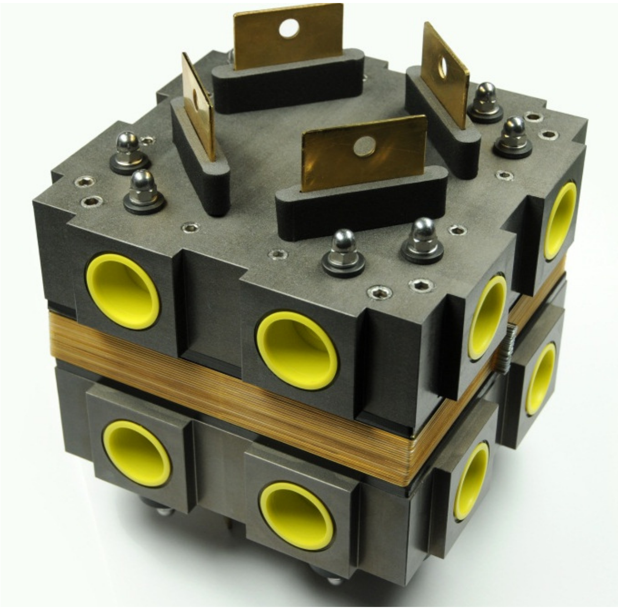
source: Toyota

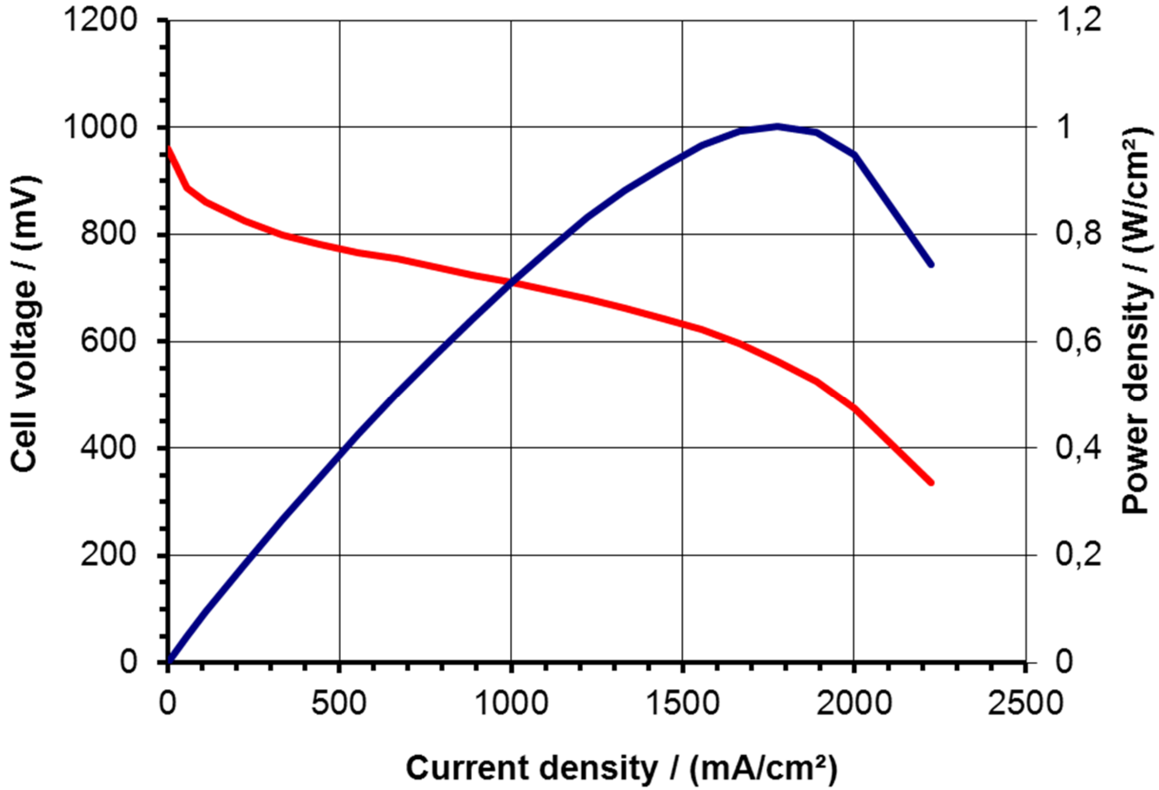
	Battery Electric Vehicle	Fuel Cell/Battery Hybrid	Fuel Cell Range Extender
Battery System Fuel Cell System	High energy, > 15 kWh -	High power, ~ 1.5 kWh High performance, > 80 kW	High energy, ~ 10 kWh Low cost, ~ 30 kW
Emission free Low Noise Energy Diversity	✓	✓	✓
Advantages	▪ Highest TTW efficiency ▪ Low operating cost ▪ Private charging	▪ State of the art range, comfort, refuelling time ▪ High continuous power	▪ State of the art range, comfort, refuelling time ▪ Low operating cost ▪ Private charging
Challenges	▪ Limitations range, charging time, comfort ▪ Public charging	▪ High density H_2 infrastructure ▪ Increased operating cost	▪ Medium density H_2 infrastructure ▪ Limited continuous power
Design criteria Battery Fuel Cell System	 ▪ Range ▪ -	 ▪ Peak power ▪ Performance	 ▪ Optimized TCO ▪ Average power demand
Applications	▪ Urban traffic	▪ High performance long distance (>120km/h, SUVs)	▪ Low-cost, emission free long distance emobility

Powertrain options for electric vehicles: ZBT's automotive stack development

Automotive stack development:

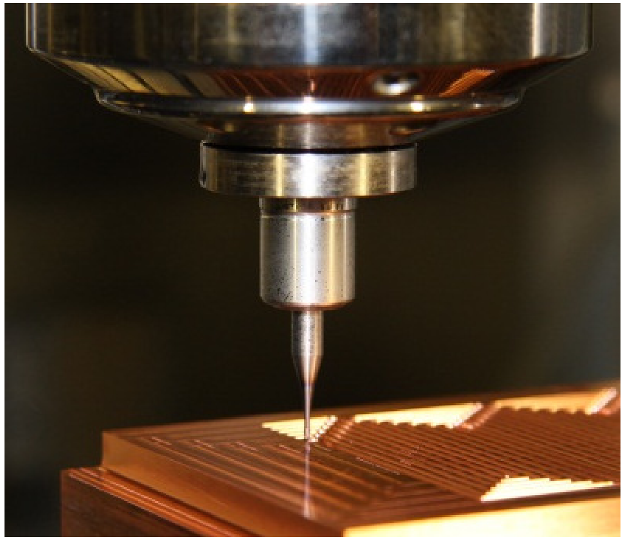
- Power density up to 1 W/cm²
- Pressurized operation up to 2.5 bar(a)
- Dry cathode
- Active area 100 cm² and 300 cm²
- Liquid cooling





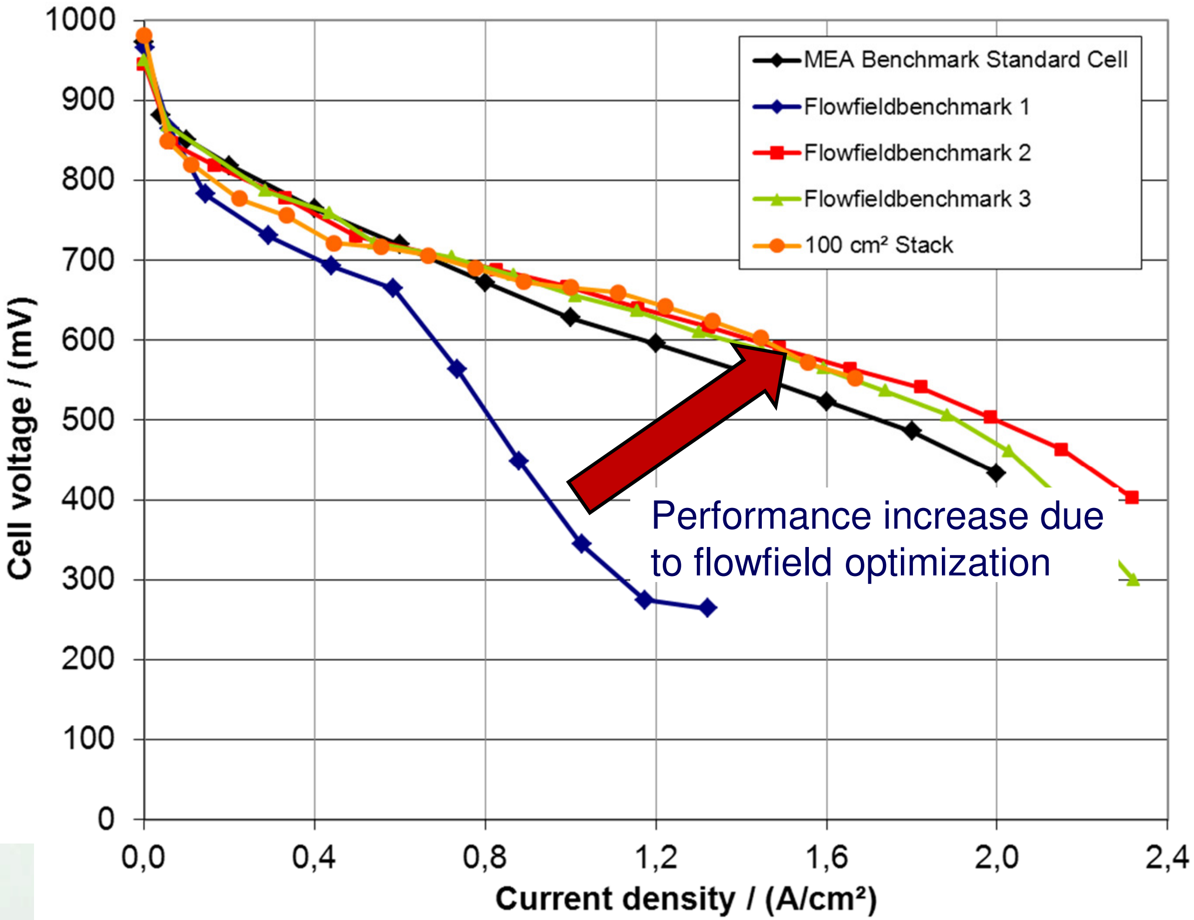
Stack development in cooperation with GRAEBENER MASCHINENTECHNIK

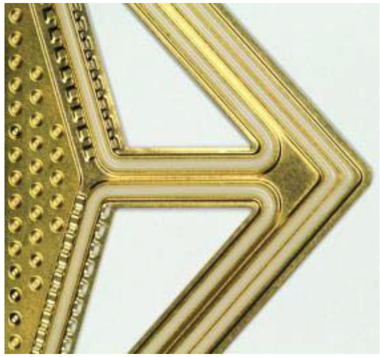
Powertrain options for electric vehicles: ZBT‘s automotive stack development (II)



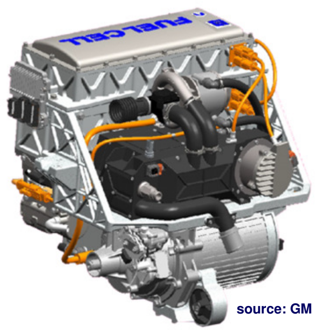
ZBT flowfield optimization:

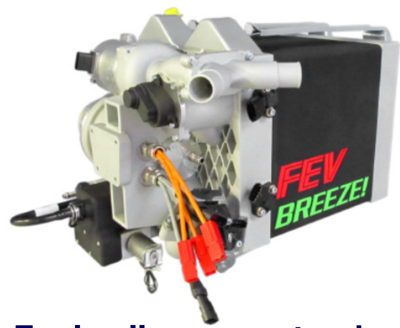
- CFD simulation
- RP manufacturing of flowfields
- Benchmark of RP-flowfields in standardized cell
- Reduction of tooling cost/ development time





Powertrain options for electric vehicles:
Comparison of „full power“ and „range extender“ fuel cell system



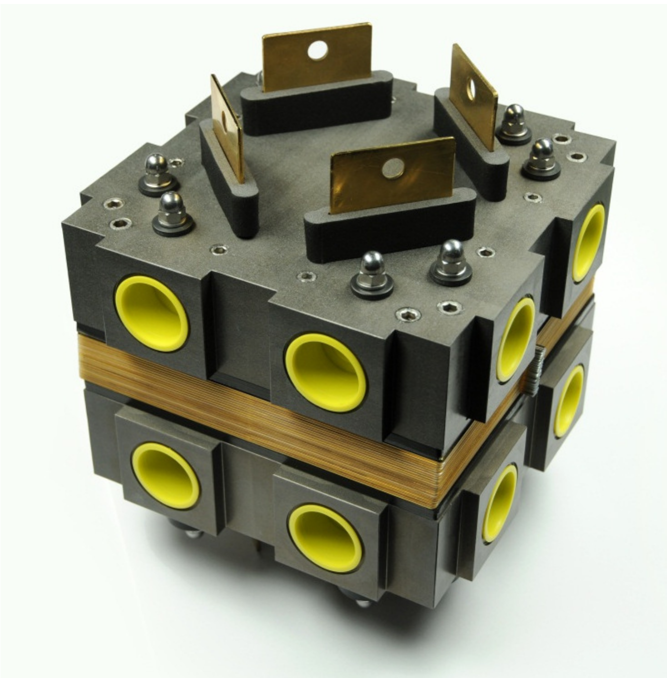


	Full power fuel cell system	Fuel cell range extender
Operating strategy	Highly dynamic	Steady state / limited power gradients
Durability requirement	5.000 h → higher platinum content/cost	2.000 h (reduced for REX operation) → lower platinum content/cost
Start-Up	~5 sec., frequent	> 30 sec., less frequent (REX strategy)
Cooling	Demanding for large stack and high power	Less demanding
Humidification	Complex water management	Less complex water management (limited power gradients)

Powertrain options for electric vehicles: Reference project
Fuel cell range extender for battery electric vehicles

BREEZE: Fuel Cell Range Extender (REX) for Battery Electric Vehicles

- Zero emissions during REM operation
- Significant NVH advantages compared to ICE REMs
- High efficiency
- Heat available for cabin heating
- Reduction of battery capacity
- Re-fueling possible in approx. 3 min.



Project Partners:

FEV

GRAEBENER MASCHINENTECHNIK

VKA RWTH AACHEN UNIVERSITY

ZBT

With financial support from:

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Investition in unsere Zukunft!
Europäischer Fonds für regionale Entwicklung

Ministerium für Wirtschaft, Energie, Bauen, Wohnen und Verkehr des Landes Nordrhein-Westfalen

Fuel cells for long distance emobility: Conclusion

- A portfolio of different powertrains is required to achieve significant CO_2 reductions in the future
- Emobility enables silent, emission free driving and a diversification of primary energy carriers that are used in the transport sector
- Fuel cells can increase applications and customer acceptance for emobility due to long-distance capability and short refuelling times
- Fuel cell range-extenders complement conventional „full-power“ fuel cell vehicles, they focus on optimized TCO and lower density refuelling infrastructure
- ZBT offers engineering services for emobility and fuel cell powertrains in cooperation with industrial partners

Thank you for your attention!

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