Fuel Cells – A Complement and an Alternative to Batteries on the Path to Application

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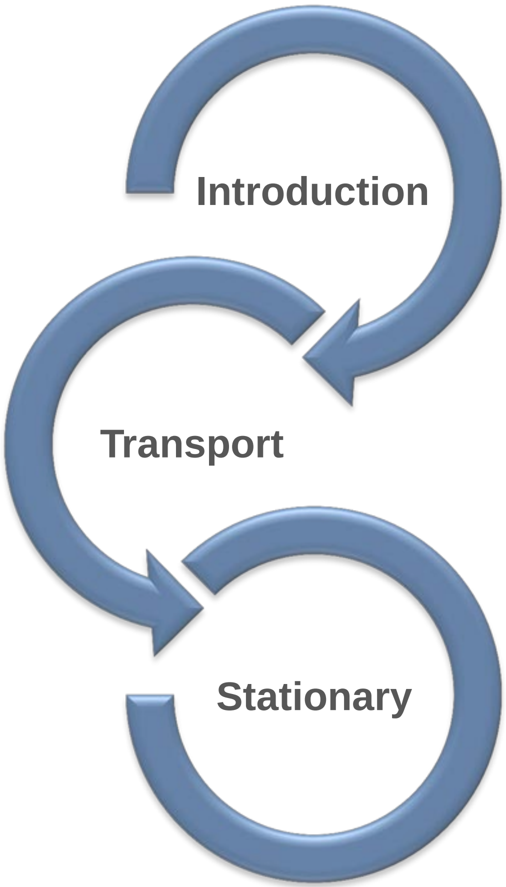
Content



- Importance of battery and fuel cells
- Challenges
- Principle and design of fuel cells

- Transport requirements
- Lowering noble metal content
- Hybrid systems

- Status of residential application
- Japan
- Germany

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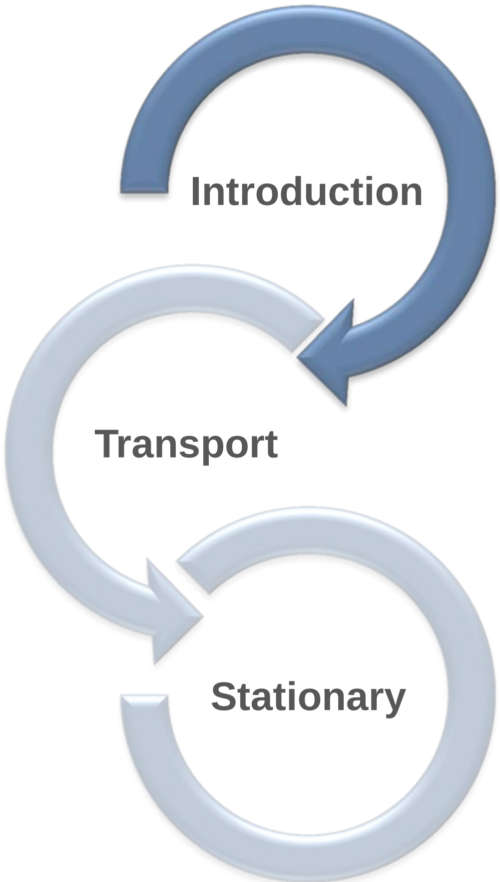

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Recent International Intitiatives

COP 21 and 22 in 2015 and 2016

- COP 21 achieved a legally binding and universal agreement on climate change
- Limit the world's rise in average temperature to "well below" 2 °C
- Dynamic commitments which are reviewed
- Ratified by more than 120 countries

Hydrogen Council 2017 in Davos

- Thirteen leading energy, transport and industry companies have today launched a global initiative for hydrogen to foster the energy transition.
- Investments currently amount to an estimated total value of €1.4 Bn/year

Importance of Fuel Cells and Hydrogen Technology

Transportation / mobility
- Fuel cell vehicles (FCV)
- Range extender

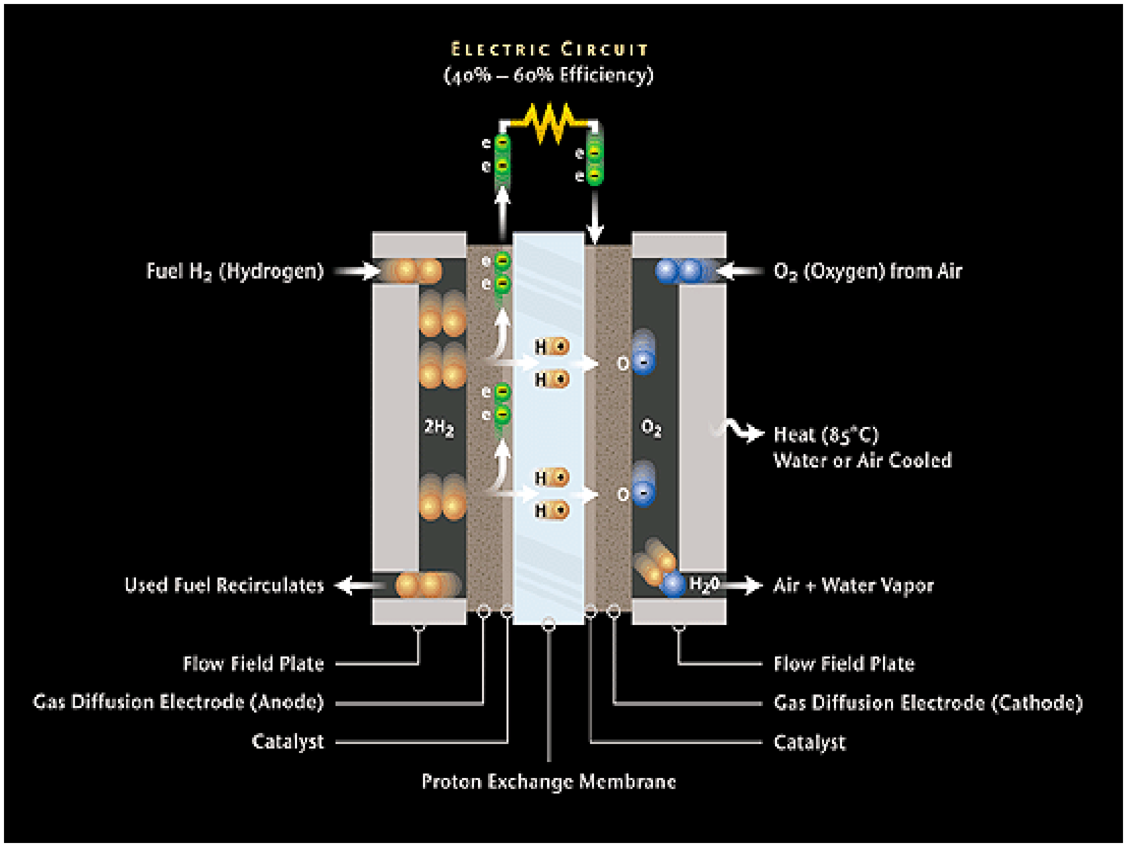
Energy / stationary application
- Residential power (micro-CHP)
- Distributed flexible power plants

Hydrogen:
- Long-term storage (power to gas)
- Use in chemical industry
- Synthetic fuels
- Load management

Toyota Mirai

How Does a Fuel Cell Work?

chemical energy → **electrical energy**



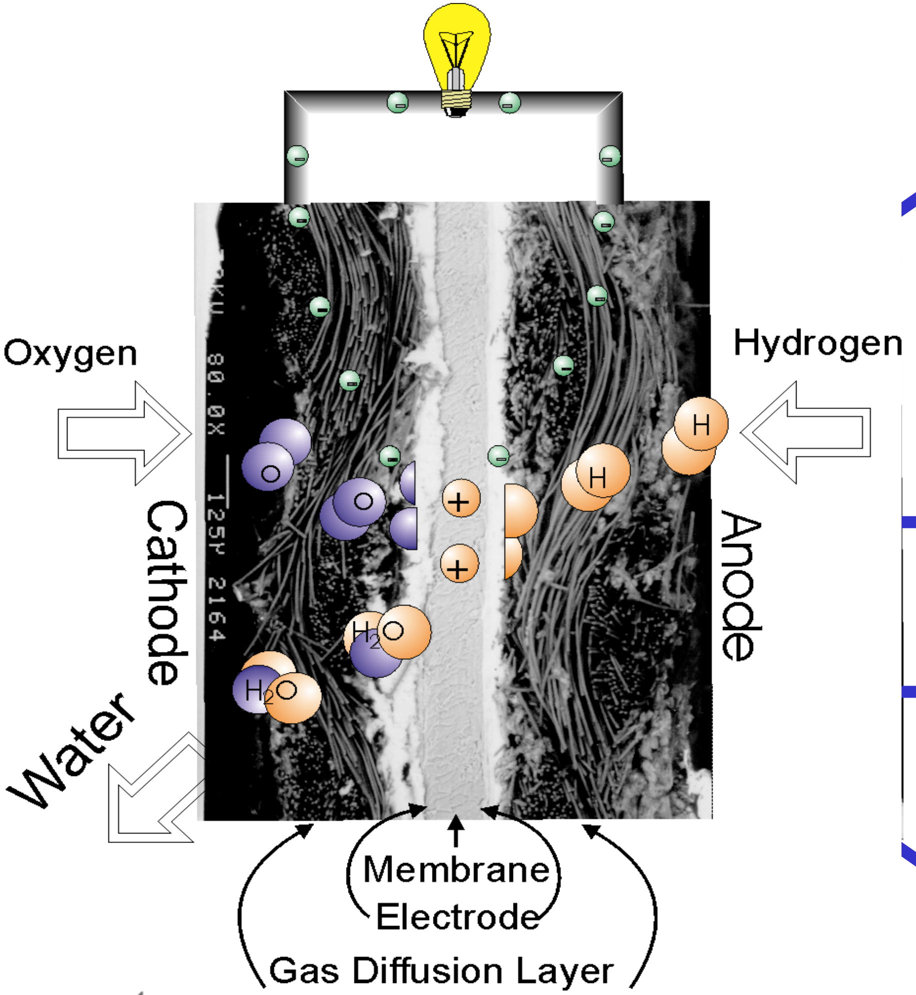
Example: Proton Exchange Membrane Fuel Cell (PEMFC)

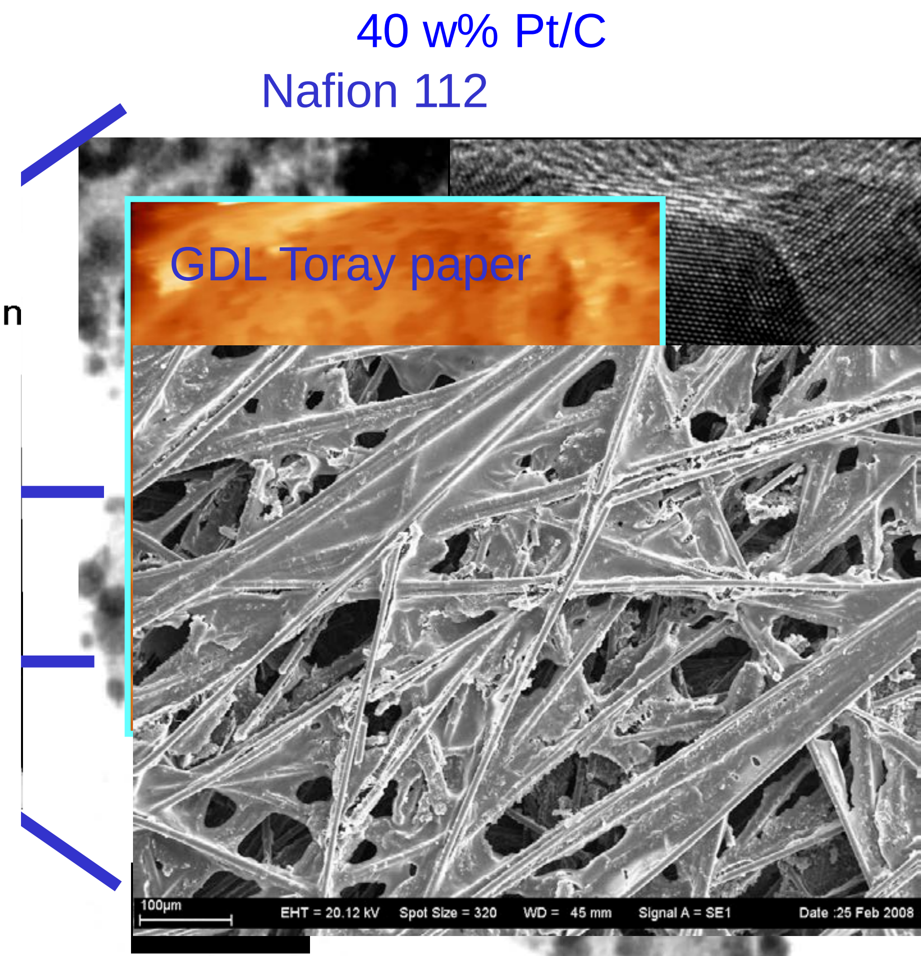
- Electrolyte: polymer membrane
- Charge carriers: H^+ ions
- H^+ ions react at cathode to water
- Reaction anode:

  $H_2 \rightarrow 2H^+ + 2e^-$
- Reaction cathode:

  $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$
- Temperature: 60 - 80° C

Components of Polymer Electrolyte Fuel Cells





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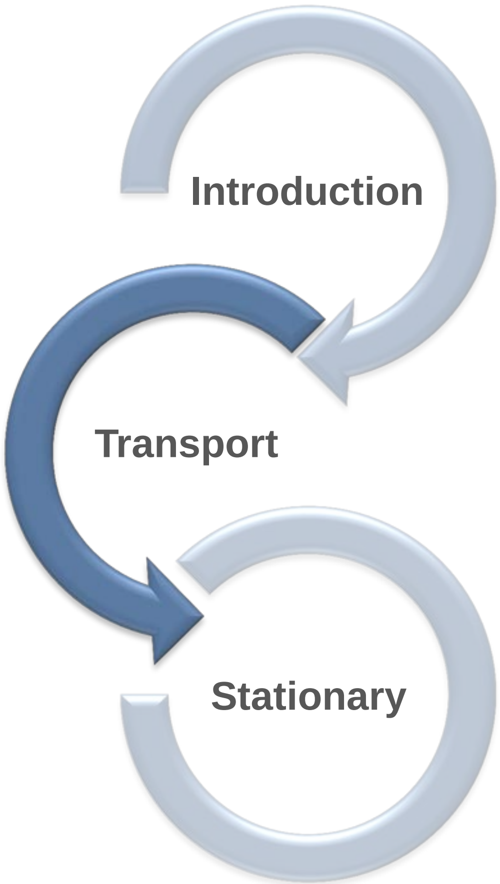

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Comparison of Battery and Fuel Cell Vehicles

Battery Vehicle

+ Locally emission-free
+ Highest efficiency
+ Standardized e-fuel
+ Private charging infrastructure
+ Model choice improving

- High cost
- Public charging infrastructure
- Charging currently time consuming
- Driving range
- CO_2 reduction dependent on % RE

Fuel Cell Vehicle

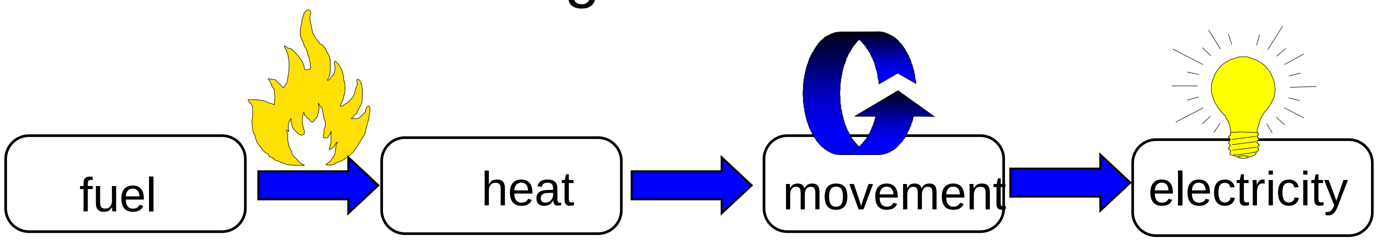
+ Locally emission-free
+ high efficiency
+ Charging / fueling $\cong$ 3 min.
+ Driving range > 400 km
+ Fast CO_2 reduction possible
+ Simplified heat management

- High cost
- Missing H_2 fueling infrastructure
- Reliability
- No model choices

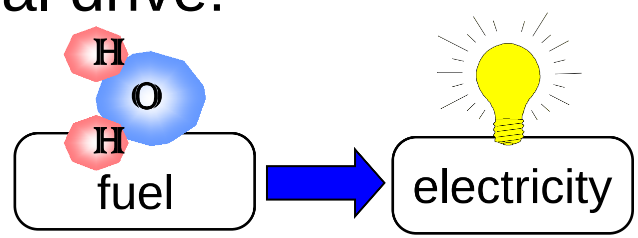
Efficiencies

Typical car efficiency (Tank to Wheel):

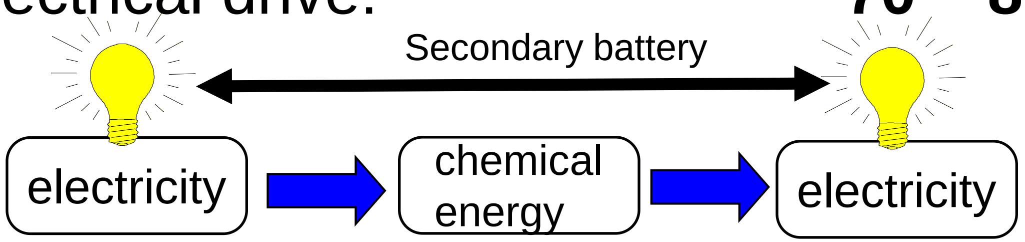
- Internal combustion engine: **20 – 25 %**



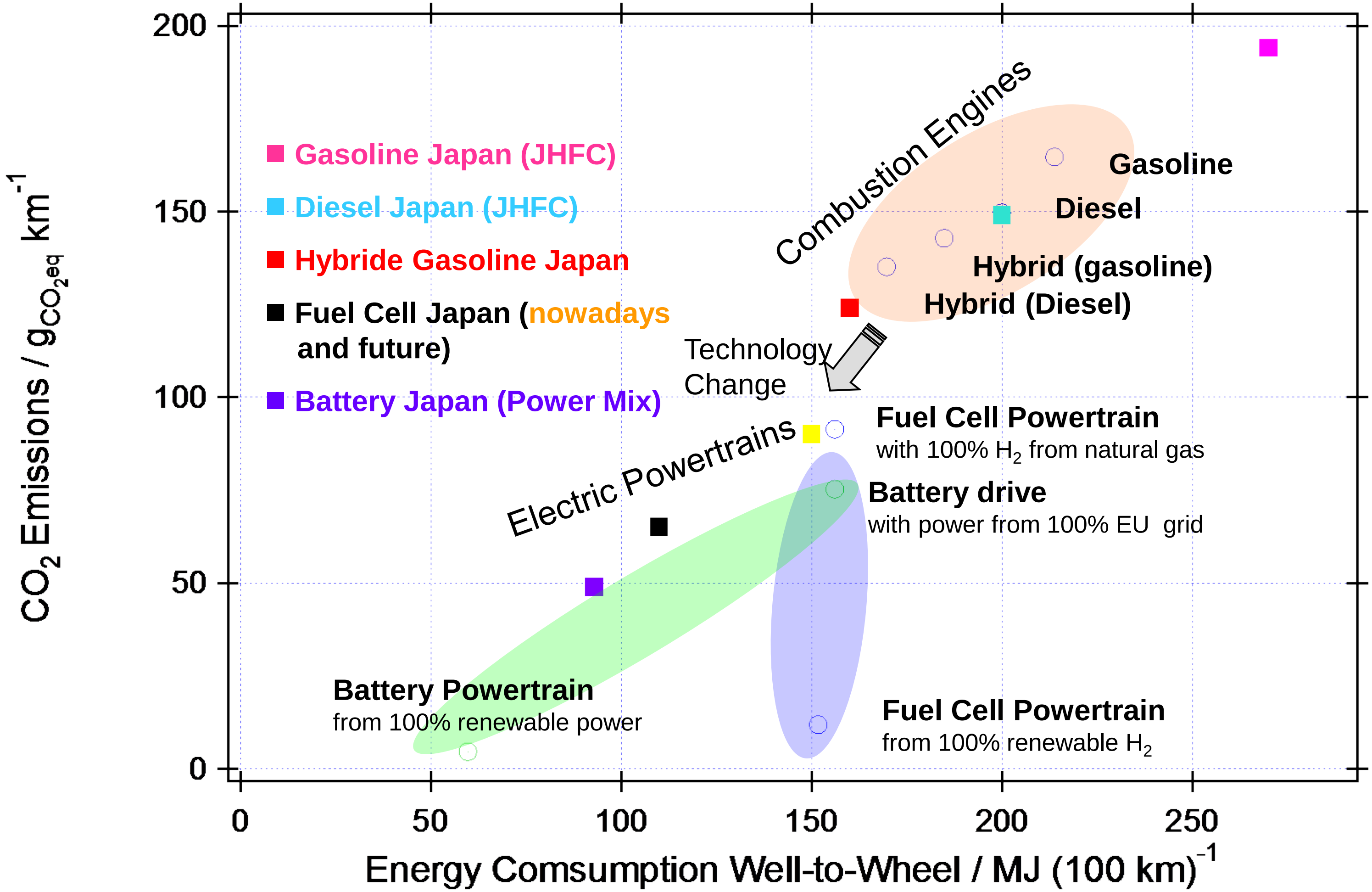
- Fuel cell electrical drive: **40 – 50 %**



- Battery electrical drive: **70 – 80 %**



Efficiency Comparison of Automotive Power Trains



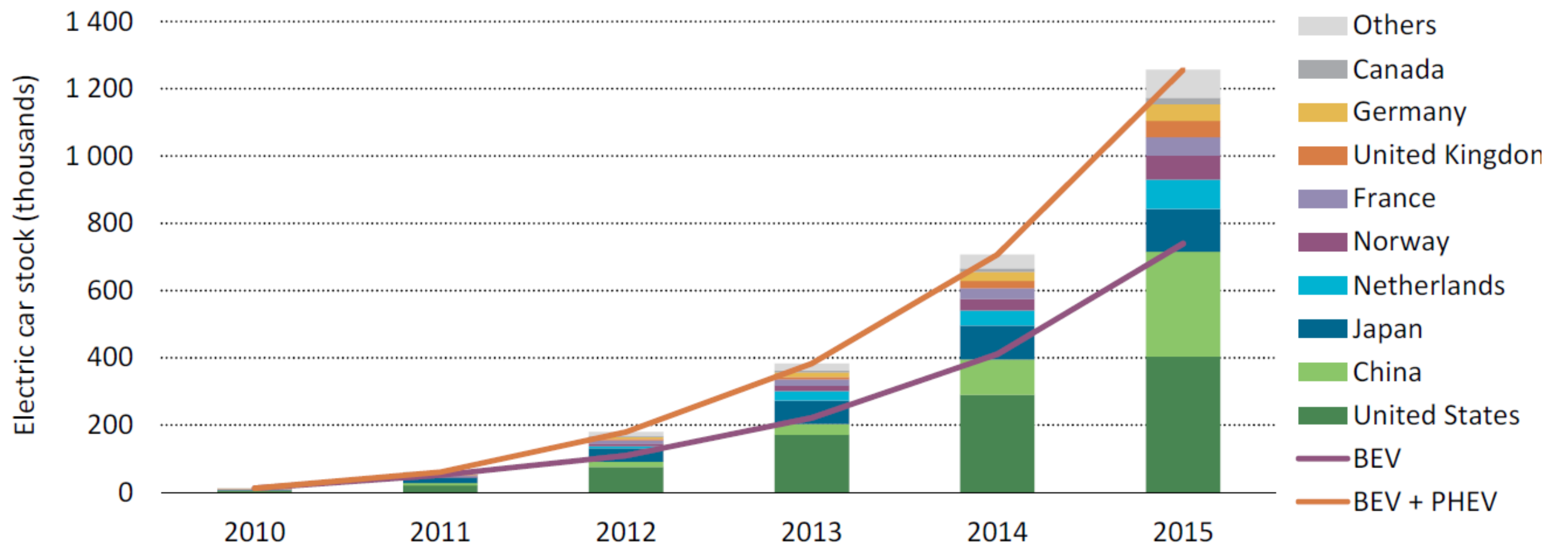
Based on Well-to-Wheel studies of European and Japanese Sources: Concawe, EUCAR, JRC und JHFC

Status of Electromobility (I)

More than 1 Mio battery electric vehicles

About 90% of drivers in germany travel less than 100 km per day

Figure 1 ● Evolution of the global electric car stock, 2010-15



Note: the EV stock shown here is primarily estimated on the basis of cumulative sales since 2005.

Source: Global EV Outlook 2016

International Energy Agency
Secure Sustainable Together

CLEAN ENERGY MINISTERIAL
Accelerating the Global Clean Energy Transition

Electric Vehicles Initiative

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Status of Electromobility (II)

Few thousands of fuel cell vehicles – no degression of cost by mass fabrication yet

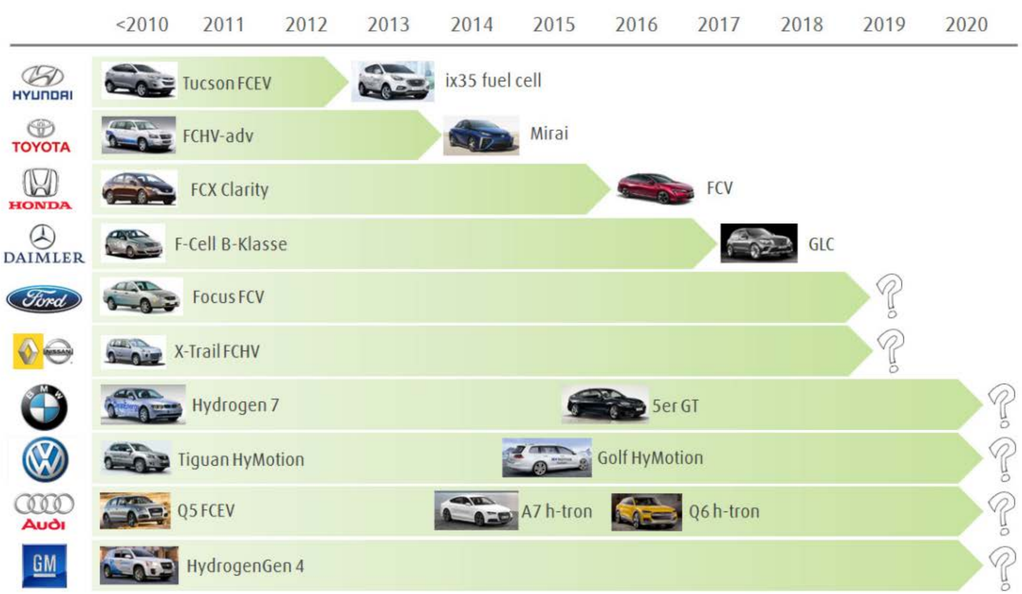

Abbildung 2: Zeitleiste der Markteinführung von FCEVs wesentlicher Automobilhersteller

2017 FCV models:

FCX Honda Clarity

Mercedes GLC f-cell

Plug-in hybrid SUV
9 kWh Li-ion battery (50 km)
4 kg H_2 @ 700 bar (500 km)

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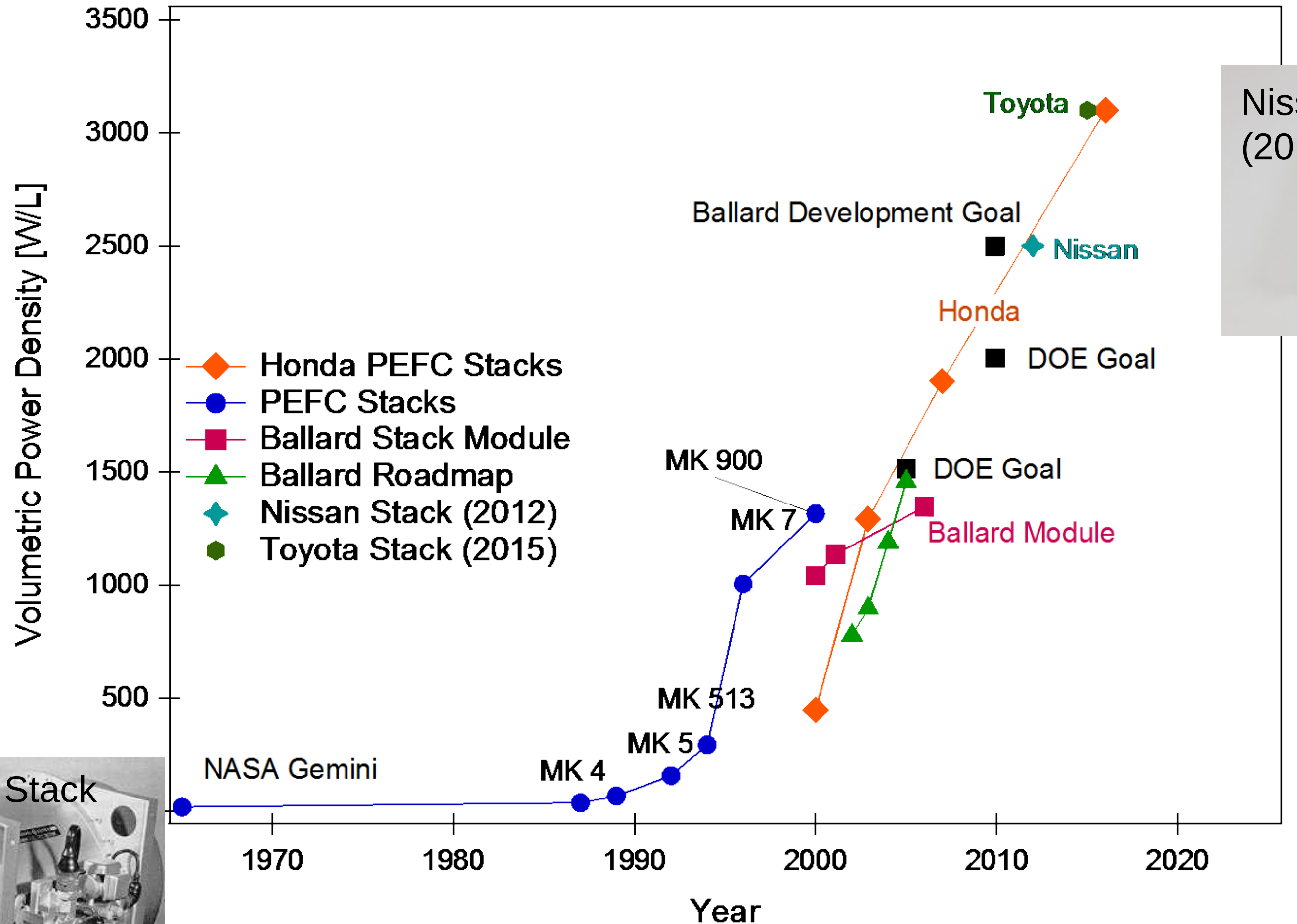
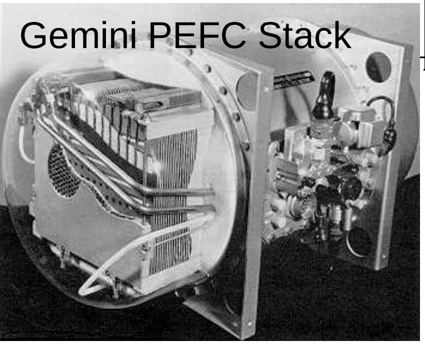
Development Success





Pt loading (mg/cm^2): 1960s ca. 11
1990s ca. 1 - 3
2000s ca. 0.4 - 0.6
2016 ca. 0.2 - 0.3

Advantages of Fuel Cell Vehicles

Driving range acceptable for countries with wide infrastructure gaps (e.g. Argentina, Brazil …)

Congestion in tropical megacities (Shanghai, Mexico…) with air conditioning requirements

Gas infrastructure is demonstrated (LNG in Argentina)

Infrastructure for Fuel Cell Vehicles

Plug-in Cars:
Public charging station: ca. 12 vehicles cost: ca. 8000 €

H_2 fueling station: ca. 2000 – 2500 vehicles, cost: ca. 1 Mio €

Cost for 1 Mio vehicles Battery: 0.67 billion €
Fuel cells: 0.5 billion €

- Investments for H_2 Infrastructure until 2030 accumulate to 10 - 21 bill. Euro in a moderate scenario (7 Mio. fuel cell vehicles)*
  - Comparative values:
    - Road infrastructure in Germany in 2005: 5 bill. Euro
    - EEG (RE) compensation 2013: 8.5 bill. Euro Photovoltaics
      20.38 bill. Euro total
    - Income toll system in Germany 2015: 3 bill. Euro

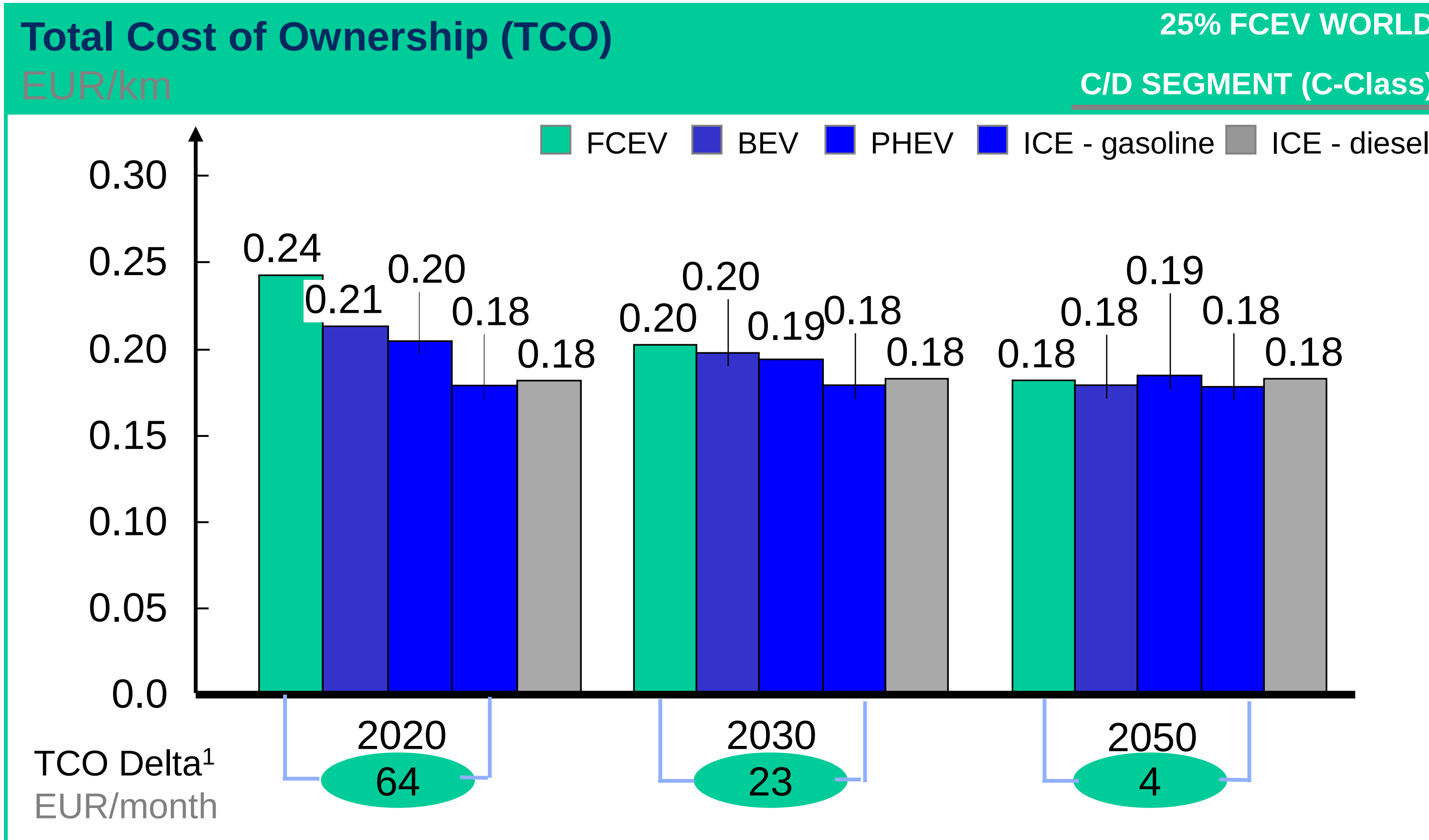
*GermanHy 2009, Joest et al.

Importance of Pt Expenditure for Automotive PEMFCS

- High-cost of precious-metal catalyst, Pt (~35 € / g) contributes significantly of the total system cost*
- 3-5 times higher PGM content compared to ICE
- South Africa is the top producer of platinum, with an almost 77% share, followed by Russia at 13% (40 years reserves at the present rate)
- Platinum is considered a bottleneck towards the widespread diffusion of this technology
- Pt loading for commercial automotive MEA in present demonstration cars is around 0.45 mg/cm² leading to roughly **0.5 g/kW**

* E.J. Carlson, P. Kopf, J. Sinha, S. Sriramulu, and Y. Yang *Cost Analysis of PEM Fuel Cell Systems for Transportation* December 2005, TIAX LLC

Electric powertrains can become cost competitive with ICE over the next decades



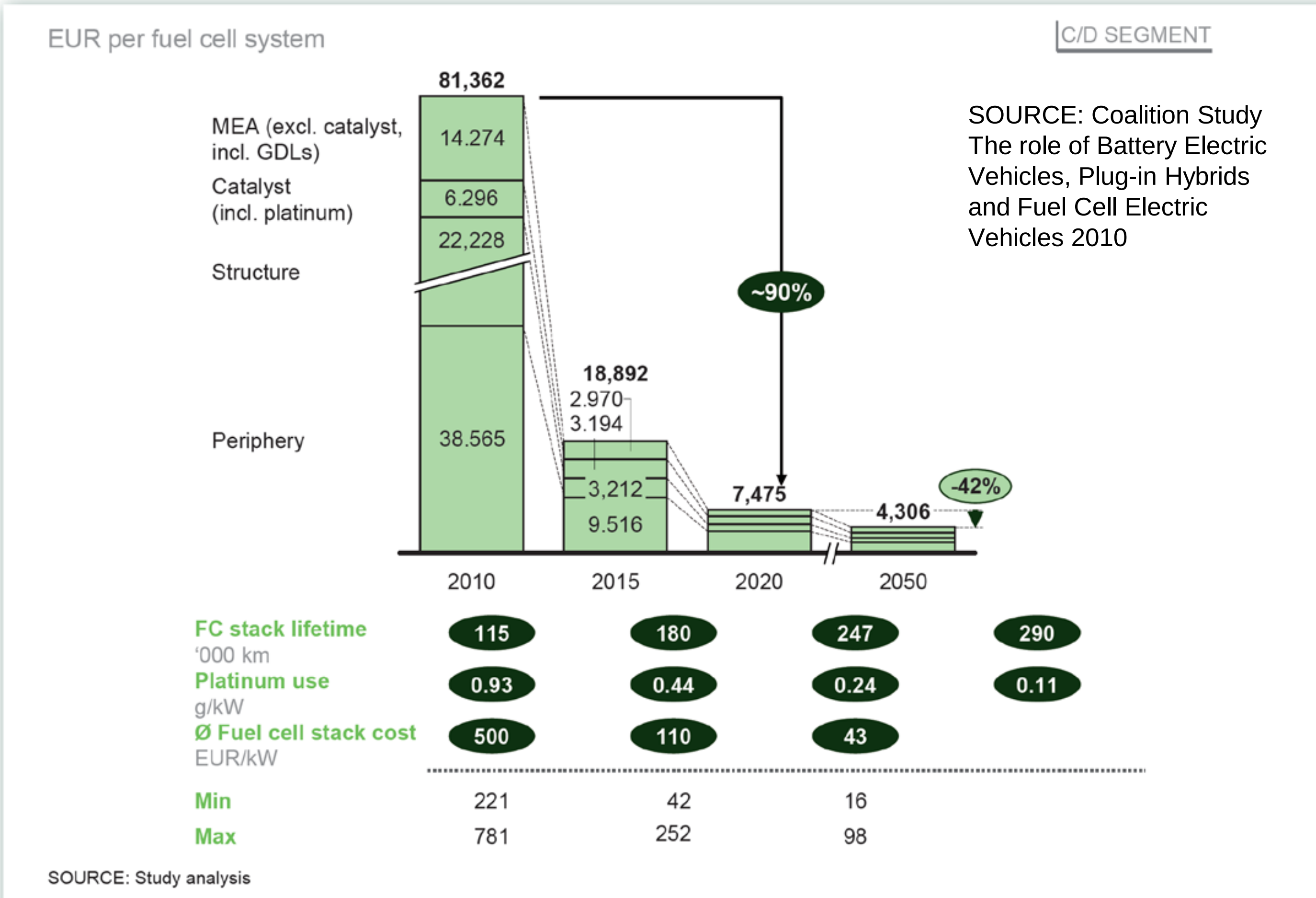
• TCO: purchase price + operation costs
• Purchase price: component costs (66%), asembly costs (13%), SG&A (14%), profit (7%)
• Operation costs: maintainance, fuel costs and infrastructure costs
• Duration: 15 years; 12.000 km per year (180.000km overall)

1 Delta between FCEV TCO and ICE gasoline TCO calculated in EUR/month/vehicle

SOURCE: Clean team sanitized data, coalition workshops, Working team analysis

Assumption: Dramatic Fuel Cell System Cost Reduction (90 %!) with efficient Pt use

By 2020, the cost of a fuel cell system falls by 90%, BEV components by 80%



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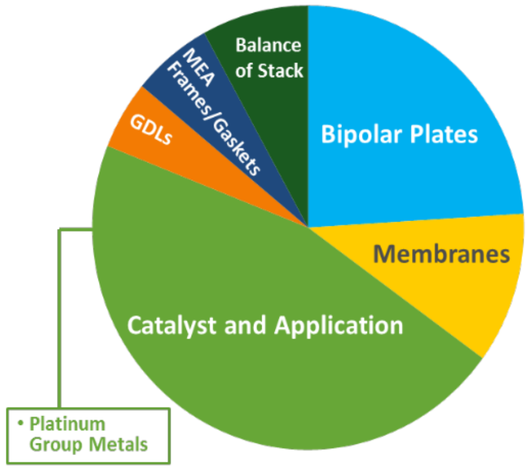
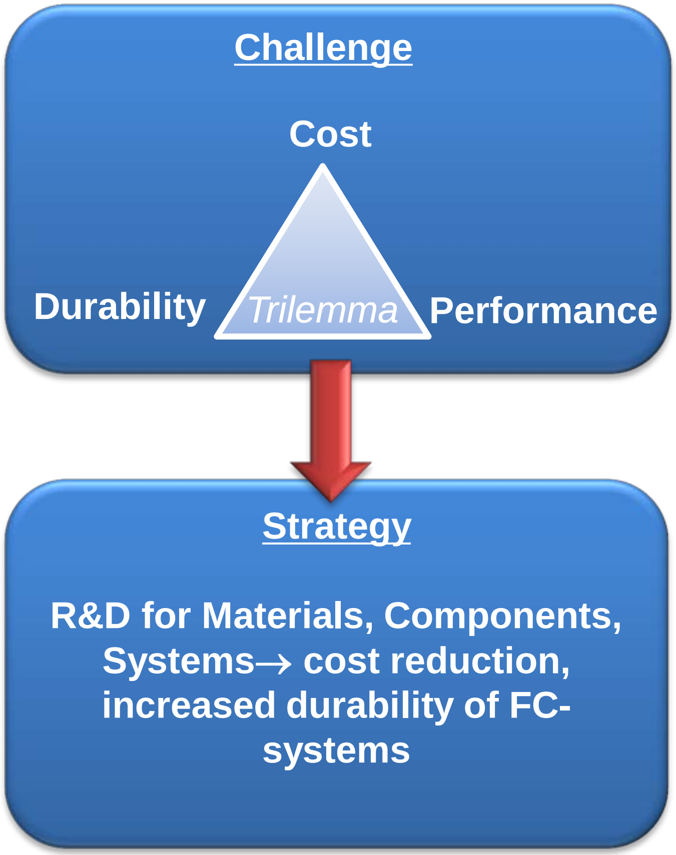
Reduction of stack cost

- Reduction of manufacturing cost at increased durability in order to compete with conventional technologies



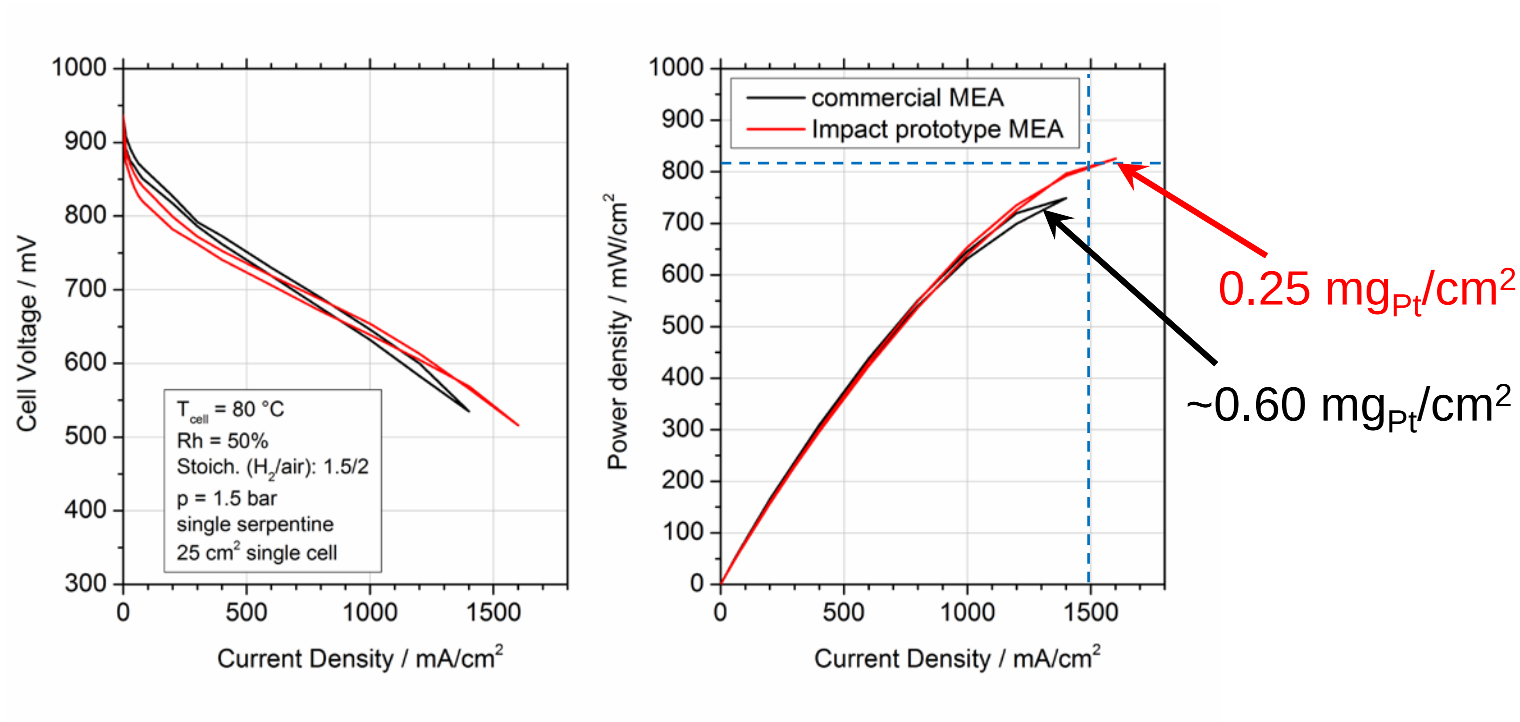
[U.S. DOE 2015 Annual Merit Review]

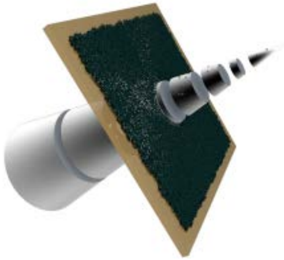


- Most promising regarding cost reduction: catalyst layer (45 % of stack cost)
  - **Low loadings**
  - Alternative catalysts

Reduction of Pt content EU (Impact project)

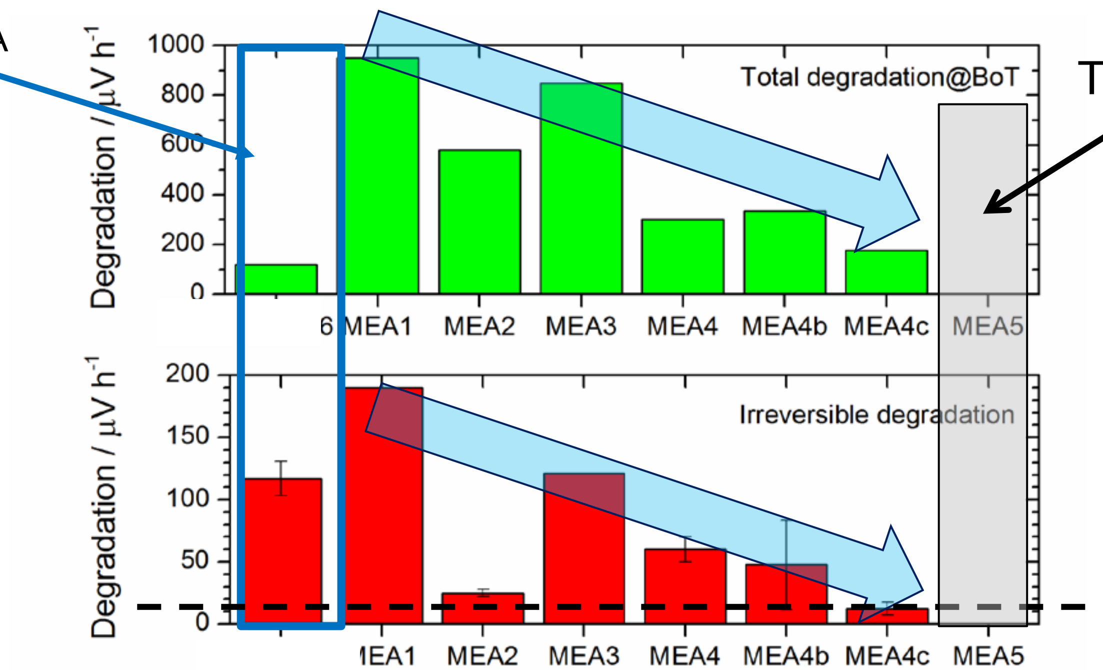
Performance improvement at low loadings:





Reduction of Pt content: Durability EU (Impact project)

Durability improvement (1 A/cm²):

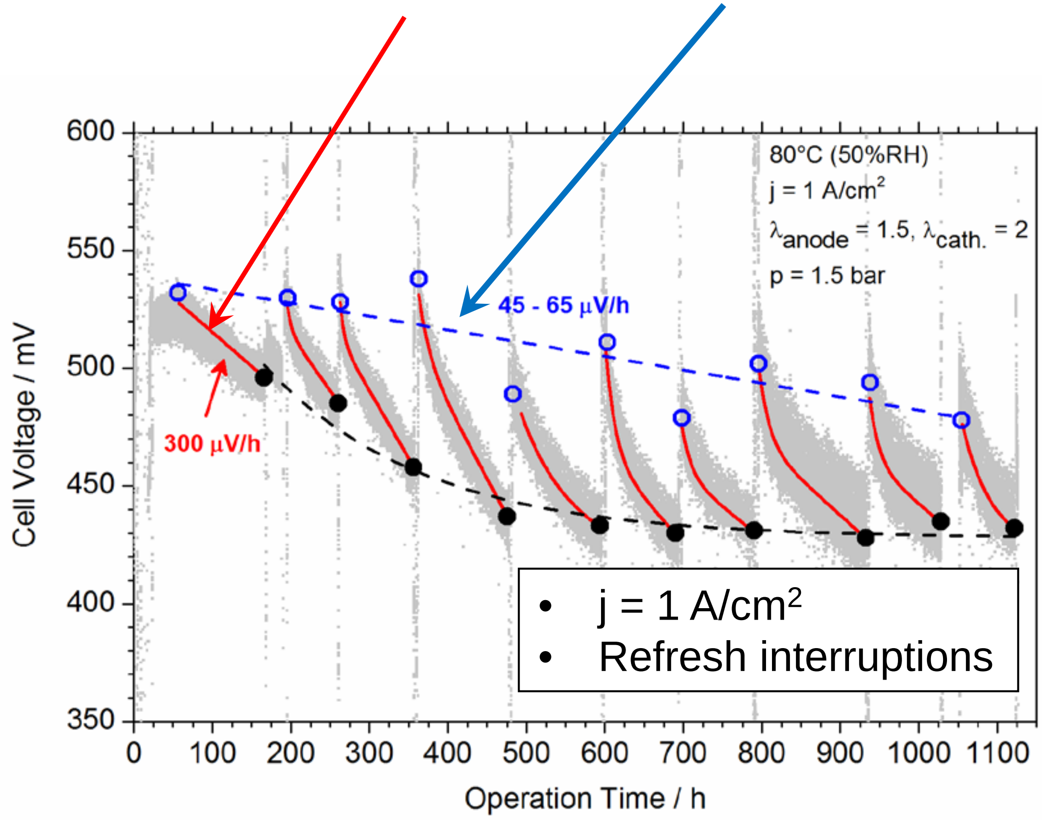


- Reduced durability at reduced Pt- loading

Determination of Degradation Rates

Problem: No common procedure to determine degradation rates

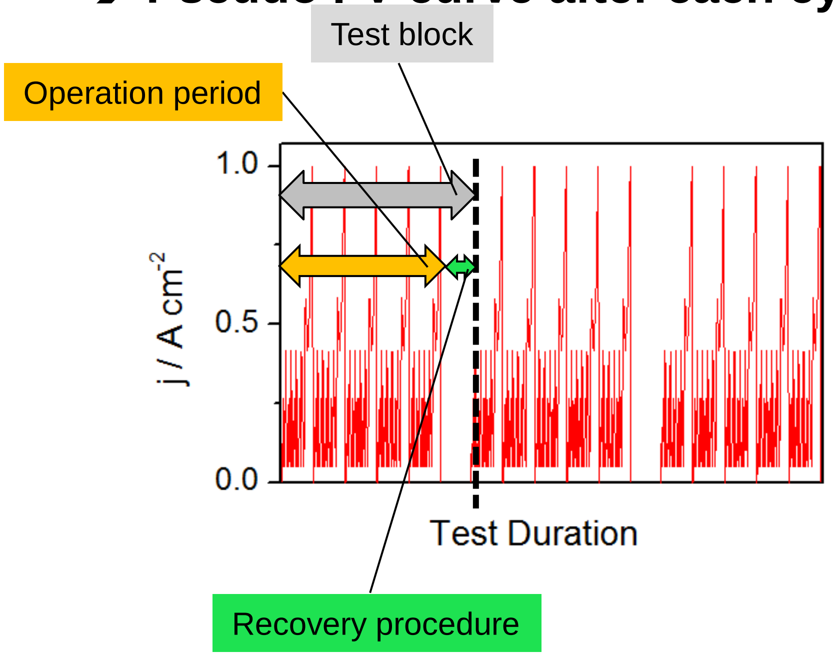
Determination between **reversible** and **irreversible** degradation

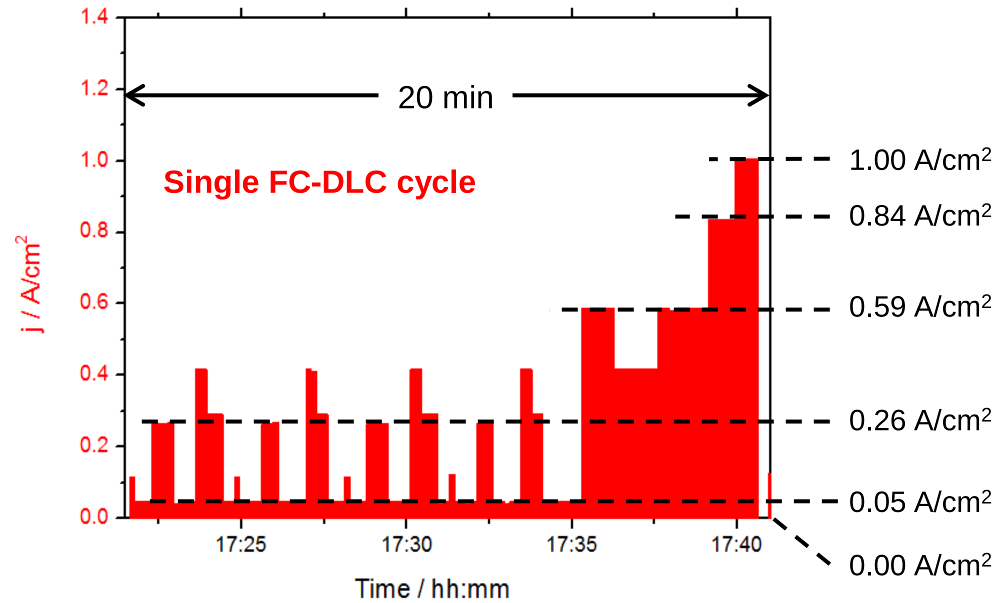


Determination of Degradation Rates

FC dynamic load cycle (FC-DLC) according to FCH-JU StackTest Project

➔ Pseudo I-V curve after each cycle





Durability test:

➢ Sequence of test blocks consisting of an operation and a recovery period

Determination of Degradation Rates

FC dynamic load cycle (FC-DLC) according to FCH-JU StackTest Project
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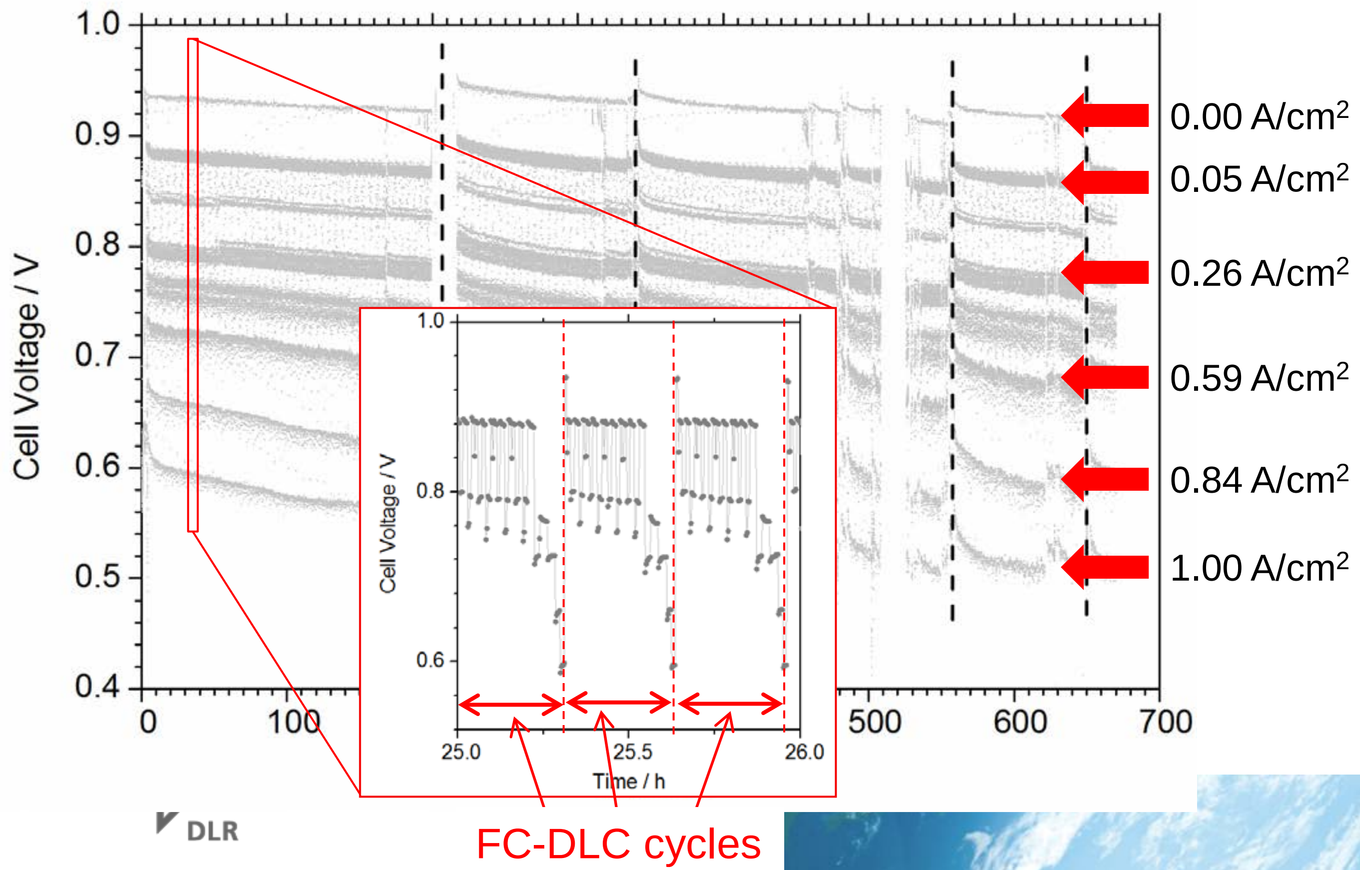


Degradation and Performance vs. Pt-loading

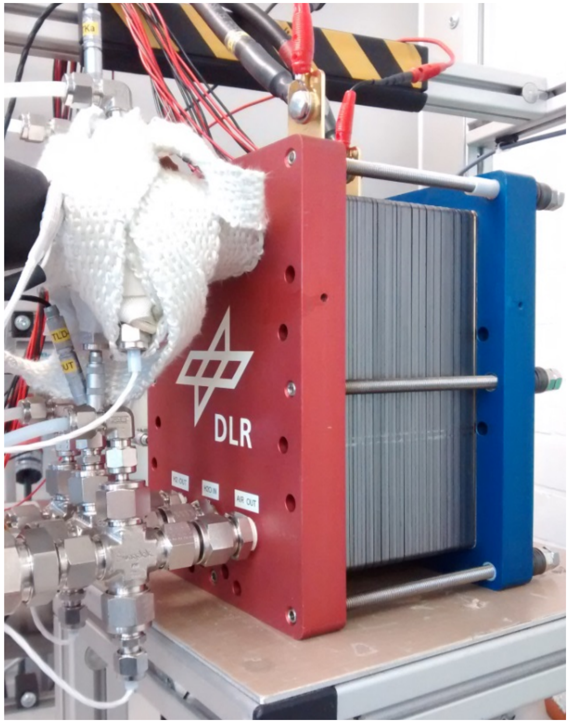
Pt-loadings at anode/cathode in mg_{Pt}/cm^2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
MEA0476	MEA0476	MEA0476	0.05/0.20	0.05/0.30	0.05/0.40	0.05/0.15	0.10/0.40	0.20/0.40	MEA0476	0.05/0.20	0.05/0.30	0.05/0.40	0.05/0.15	0.10/0.40	0.20/0.40	MEA0476	MEA0476	MEA0476

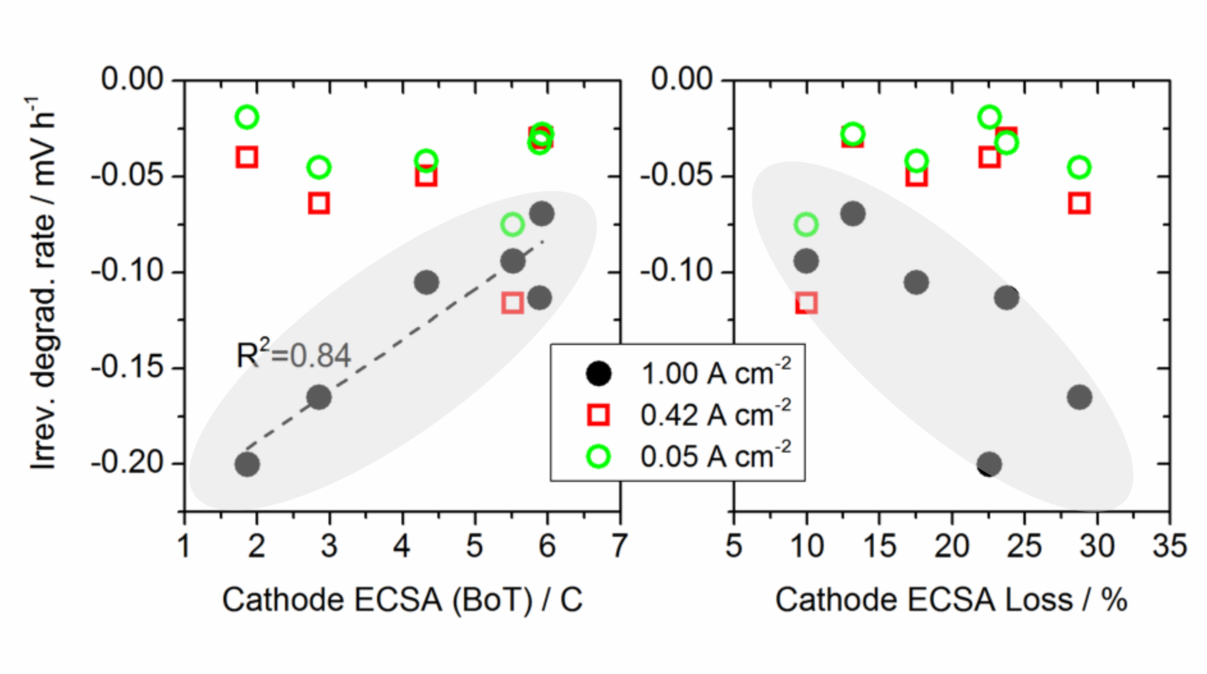
1st set (cells 4–9)

2nd set (cells 11–16)

DLR Rainbow-Stack



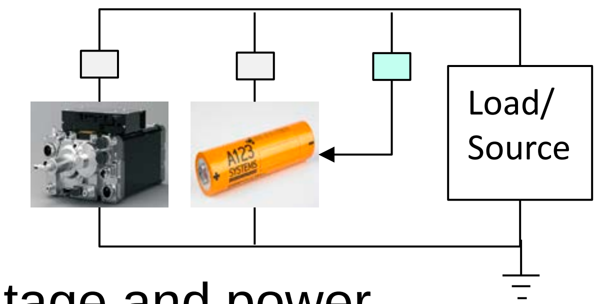
Degradation and Performance Vs Pt-loading



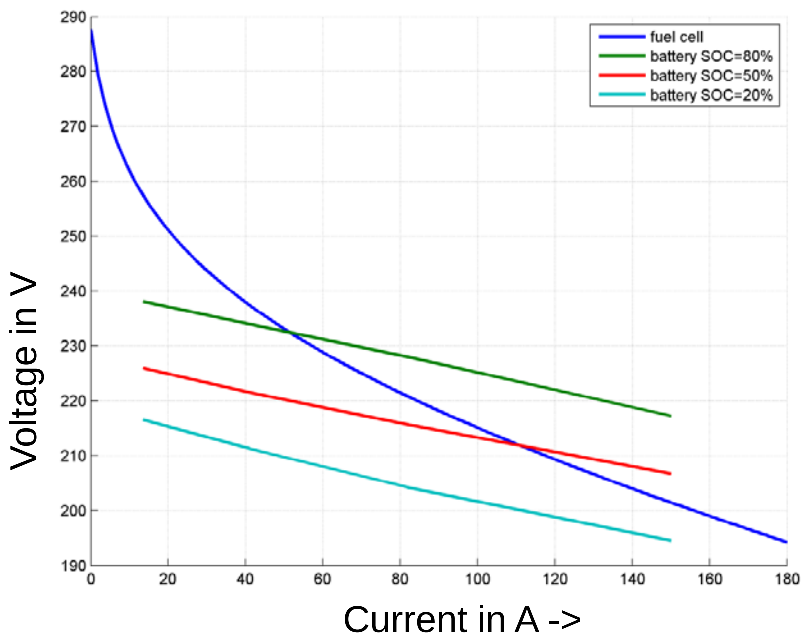
- Irreversible degradation increases with decreasing cathode ECSA (BoL)
- Slightly increased ECSA loss observed for high degradation rates
- No correlation observed for anode ECSA loss

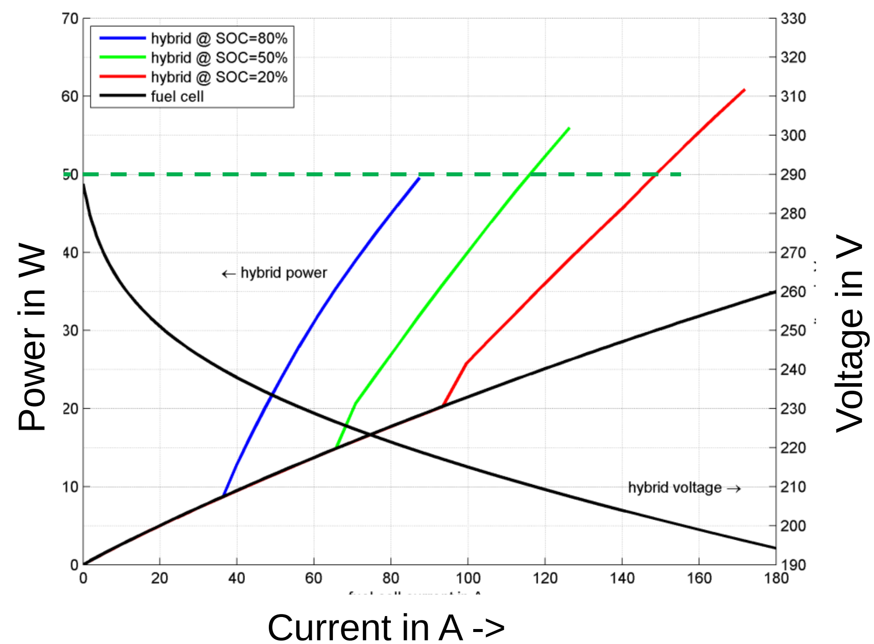
Fuel Cells with Batteries: Concept of Power Boost by Hybridization

Fuel cell + Li battery direct hybrid



Modeling of fuel cell and battery hybrid: voltage and power





Emission-free Aircraft

- Zero emission passenger flight with fuel cells
- HY4 combines high efficient power generation by fuel cell - battery hybrid with efficient drive train and economic fuselage.
- Air transport of up to 4 passengers with less than 350 g H_2 per 100 km at cruising speed of 160-200 km/h.
- Basis for future improvements regarding reliability, endurance and peak altitude.
- Future commercial emission-free passenger aircraft for up to 40-60 passengers seems possible with advanced fuel cell technology

DLR ulm university universität uulm HYDROGENICS Advanced Hydrogen Solutions Flughafen Stuttgart H2FLY PIPISTREL DLR

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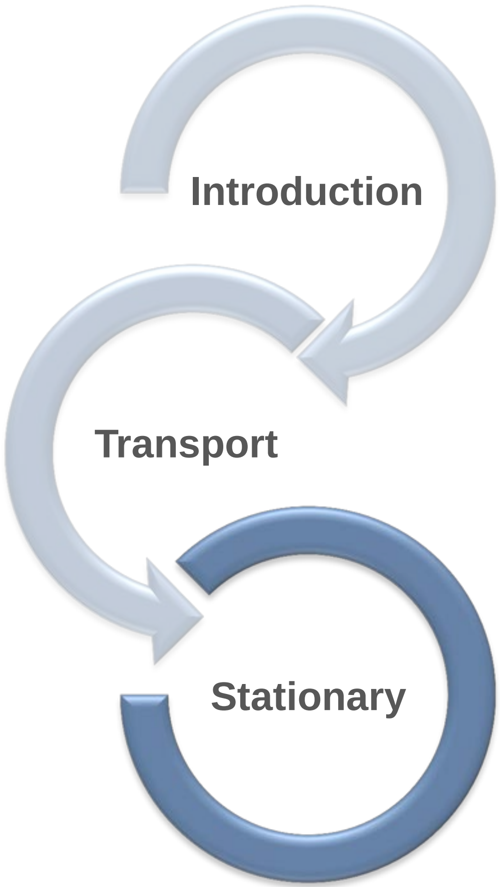

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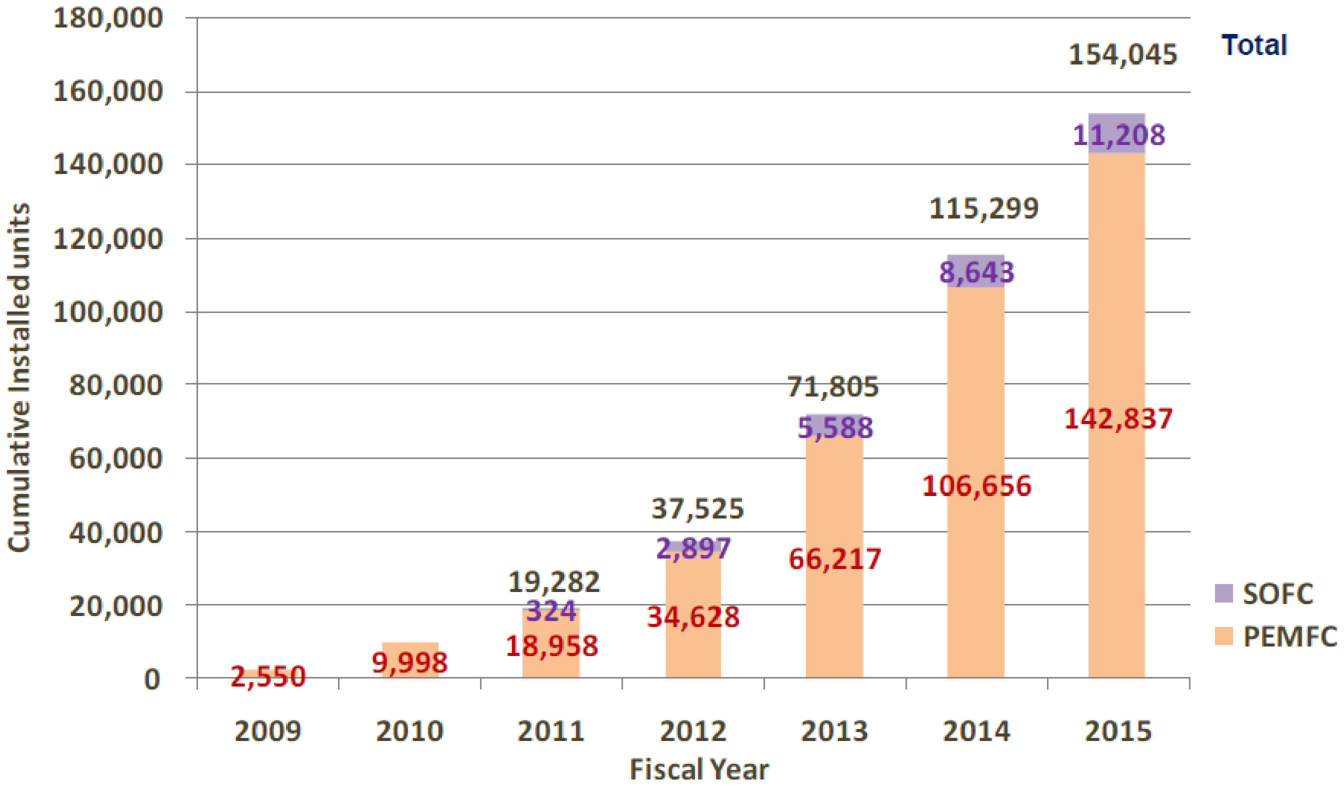
Stationary Application: Residential Application in Japan

	Toshiba	Panasonic	Aisin Seiki
Model			
Output	700 W (PEM)	700 W (PEM)	700 W (SOFC)
Size (mm)	W780 x D300 x H1000	H1750 x W400 x D400	W780 x D330x H1195
Weight	86 kg	88 kg	100 kg
Electrical Efficiency	39 %	39 %	52 % @700W
Hot water tank Capacity	200L	140L	28 Litters
Retail Price (list price) (excl. tax (8%))	¥ 1,630,000 (excl. installation)	¥ 1,600,000 - (excl. installation)	¥ 1,785,000 (excl. installation)

Source: Tokyo Gas, Osaka Gas

Stationary Application: Residential Application in Japan

- Accumulated volume: more than 150,000 units, achieved within 7 years.



Source: Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry

Residential Systems in Germany

- Technology introduction program (TEP) for stationary residental fuel cells in place in Germany
- Goal: Increase the number of installation up to 75 000 until 2023

Manufacturer	Micro-CHP brand name	Electrical power [kW]	Thermal power [kW]	Electrical efficiency [%]	Total efficiency [%]	Technology
Buderus	**Logapower FC10**	0.7	0.62	45	85	SOFC
Elcore	**Elcore 2400**	0.3	0.7	32	104	HT PEMFC
Hexis	**Galileo 1000 N**	1.0	1.8	35	95	SOFC
Junkers	**CeraPower FC**	0.7	0.62	45	85	SOFC
RBZ	**Inhouse 5000+**	5.0	7.5	34	92	PEMFC
SenerTec	**Dachs InnoGen**	0.7	0.96	37	93	PEMFC
SOLIDpower	**BlueGEN**	1.5	0.61	60	85	SOFC
	Engen-2500	2.5	2.0	50	90	SOFC
Viessmann	**Vitovalor 300-P**	0.75	1.0	37	90	PEMFC

Conclusions

- Fuel Cell and Batteries are important technologies for our future energy system
- Fuel Cells can help to overcome some of batteries present and future limitations
- Transport and stationary power can profit from hybrid system

THANK YOU FOR YOUR ATTENTION !

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