Deliverable D1.3

Report on Selected Stack Concepts
public summary

Grant Agreement number:	245142
Project acronym:	Autostack
Project title:	Automotive Fuel Cell Stack Cluster Initiative for Europe
Funding Scheme:	Support Action
Project start:	01/01/2010
Project duration:	18 months

Period covered: from January 2010
to September 2011

Project co-funded by the Fuel Cells and Hydrogen Joint Undertaking within the Seventh Framework Programme		
Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the FCH JU)	
RE	Restricted to a group specified by the consortium (including the FCH JU)	
CO	Confidential, only for members of the consortium (including the FCH JU)	
EU restricted	Classified with the mention of the classification level restricted "EU Restricted"	
EU confidential	Classified with the mention of the classification level confidential " EU Confidential"	
EU secret	Classified with the mention of the classification level secret "EU Secret "	

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1 Objective of this deliverable

The aim of this work package is to provide guidance for automotive stack development. As a result, development efforts can be streamlined and the variety of stack concepts can be reduced. Ultimately, a common stack platform concept shall be identified with the potential of widespread market introduction in the automotive field and in related applications. This will simultaneously reduce the complexity of the task, limit development costs and enable economies of scale.
The stack concept selection is based on today's state of the art stack technology. One key enabler is the robustness of the stack: the more tolerant and the more insensitive a stack design is towards varying operating conditions, the higher the chances are to define a common stack platform with maximum compatibility to various system requirements. The common stack concept will help enhancing the technical progress and improve the economies of scale but still leave room for differentiation on the system and vehicle level, thus fostering productive competition.

2 OEM Stack Platform

2.1 *System Requirements*

The fuel cell stack platform was developed in a top down approach, i.e. the requirements of state-of-the-art passenger vehicles were broken down and translated into specific fuel cell stack requirements. Simultaneously, these requirements were mirrored versus state-of-the-art stack technology as specifically reported in section **Fehler! Verweisquelle konnte nicht gefunden werden.** of this report. This approach was chosen to ensure that the suggested system specification and stack design have a high degree of maturity and can directly be utilized for mid-term industrial product development. Particular attention was paid to the stack target cost, which is seen as the major remaining hurdle for widespread market introduction of fuel cell technology in automotive markets.

Whereas the internal combustion engine today covers all drive cycles and ranges, hybrid and battery electric vehicles have their particular strengths and weaknesses and therefore fit specific segments and requirements, only. The fuel cell propulsion system though is closest to the ICE in terms of its universal fit to a variety of vehicles and driving profiles.

Figure 1 below displays the typical segments for each propulsion system based on these characteristics.

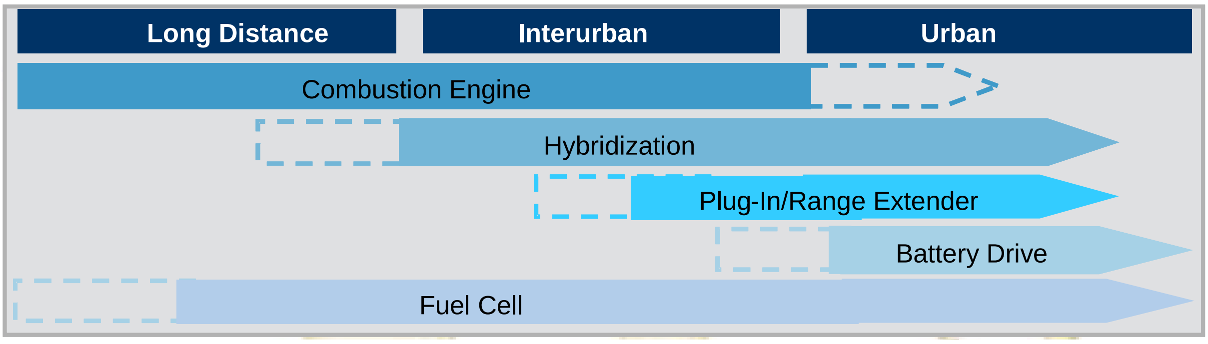

Figure 1: **Range of driving profiles of various power trains**

Based on the segmentation in Figure 1, corresponding target vehicle types were selected which are suitable for state-of-the-art fuel cell propulsion. The OEMs agreed on a compact class vehicle (Golf, VW) as the reference case for this project. It should however be noted, that ongoing developments aim at more powerful and larger cars for longer ranges, too. Figure 2 below provides an overview of the analyzed and targeted vehicle categories for state-of-the-art fuel cell application.

	Micro-Kompakt	Kompakt-Klasse	Mittel-Klasse	Luxus- & Familien-Fzge	City-Bus	Überland-Bus	Klein-laster	Mittlerer LKW	Schwerer LKW
FC-EV	🟡	🟢	🟡	🟡	🟢	🔴	🟢	🟡	🔴
B-EV	🟢	🟡	🔴	🔴	🔴	🔴	🟡	🔴	🔴

🟢 possible 🟡 Possible with restrictions 🔴 Today not possible

Figure 2: **Suitability of Battery / Fuel Cell Drive Train for Various Vehicles**

The vehicle requirements then were cascaded into fuel cell system requirements. The basic requirements on system level were agreed as follows:

- Performance, dynamics
- Gravimetric and volumetric power density
- Durability, robustness, degradation
- Cold start, cold start time
- Limitation to one fuel
- Cost

Generally, comparable to ICE

These need to be complemented by:

- High efficiency
- Sustainability of fuel concept

Superior to ICE and Hybrids

Based on the system requirements, the common system architecture had to be established. The objective was to enable a joint stack platform concept while at the same time allow sufficient flexibility for different system architectures and operation strategies of individual OEMs.

The OEMs therefore agreed on the following essential system properties and components only:

- Net power output of 80 kW
- Scalability of the stack for different power levels
- Agreement on system architecture limited to:
    - Air compressor without expander
    - Gas-to-gas humidifier (cathode out ⇒ cathode in)
    - H_2 - recirculation pump (active ⇒ blower or passive ⇒ jet pump).

The simplified flow diagram of the system is displayed in Figure 3 highlighting the gas-to-gas humidification via a membrane humidifier and the hydrogen loop.

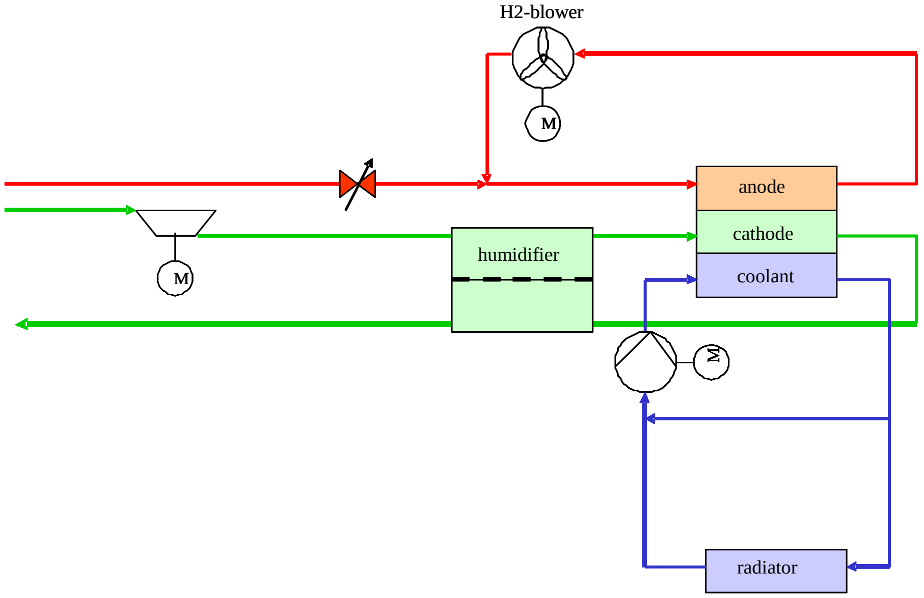

Figure 3: **Simplified schematic of the automotive fuel cell system**

2.2 System Packaging

The OEMs agreed that front packaging will be required to provide sufficient flexibility for the integration of different propulsion systems in the same vehicle platform, at least until 2025. The analysis of the associated packaging constraints of individual OEM vehicles made clear that high stack power density in terms of performance, volume and geometry establishes the most critical technical requirement for the common stack platform. As result of the packaging analysis, a joint geometry was determined for the fuel cell stack and subsequently for the single cell shape. The actual motor compartments for front packaging of representative actual OEM vehicles (Daimler: E-class, Fiat: Panda, VW: Jetta) are displayed in Figure 4 – below.

The packaging constraints are forcing high power density with a performance of at least 1 W/cm2 under typical automotive operating conditions. The automotive fuel cell stack has to combine high power density with low cost, high reliability, high efficiency and sufficient durability.

The most critical analysis in that context circled around the issue of MEA Pt-loading. In essence, precious metal loading is frequently used as a descriptive parameter to achieve the ultimate stack target cost which is needed for commercialization, i.e. $ 35 – 40/kW. This cost target is typically tied with the assumption that MEAs should contain less than 0.15 mg Platinum per cm^2 active area to achieve this cost target (see DoE[1] and others).

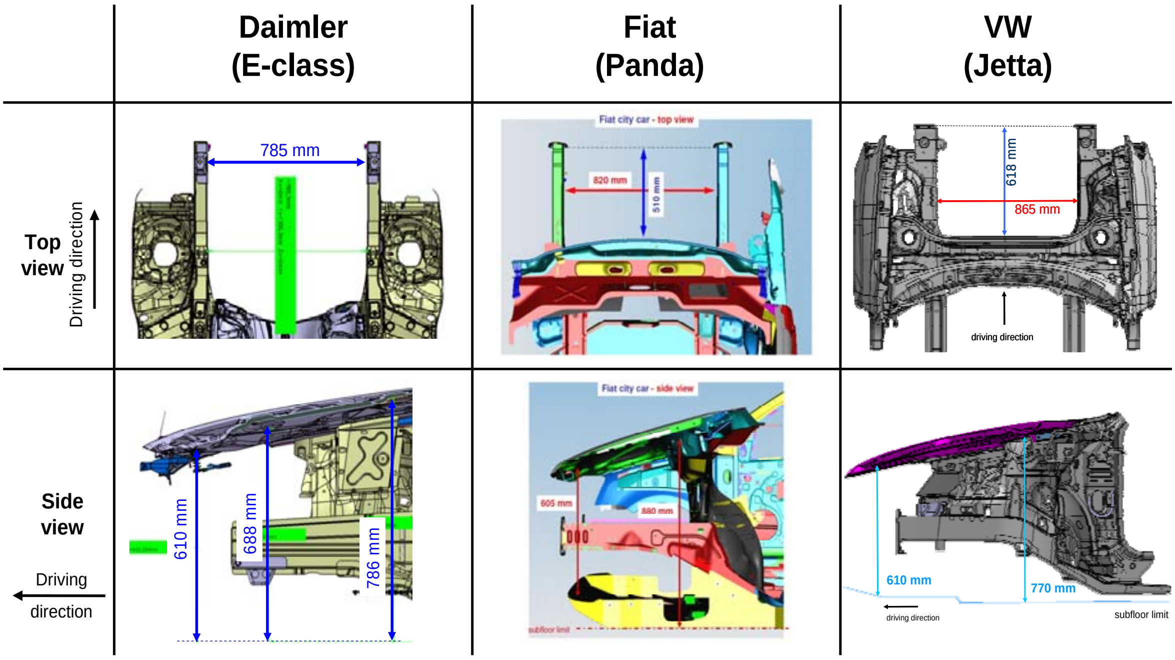

Figure 4: Comparison of front package volumes for selected OEM vehicles

The supply chain assessment and more specific analysis of the associated issues however suggested that simultaneous achievement of ultra-low Pt-loadings and the targeted power density (1 W/cm2) at the requested efficiency (>670 mV per cell) constitutes an enormous challenge. The target is even more critical in the kinetic stack region at low current density, where the catalyst layer is already fully used with the higher Pt-loadings today. Any further reduction of Platinum will therefore directly impact stack efficiency which is considered a no go for automotive operation.

Based on experimental data, a logarithmic correlation between Pt - loading and power density is assumed for all MEA technologies. The graph below shows the resulting stack costs in €/kW for the 2015-MEA at different price constellations. It appears that besides technical limitations of current MEA-technology, the optimum Pt-loading under cost aspects may be in the region of 0.4mg/cm² as this would allow the best balance between all conflicting requirements and provides the best trade-off between the cost of the Platinum and area cost of the stack.

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[1] http://www.annualmeritreview.energy.gov/

In effect, automotive ready MEA-technology foreseeable in the 2015 to 2020 timeframe will therefore most likely require a Pt-loading of at least 0.5-0.6 g/kW. It is assumed that such Pt-loading represents the technical limit of current MEA-technology while still fulfilling technical application targets. It should however be recognized that even this target still needs to be proven under automotive operating conditions.
The graph in Figure 5 below displays the balance of power density and Pt-loading under different area specific cost assumptions (i.e. membrane and bipolar plates) using a Pt-price of € 30/g.

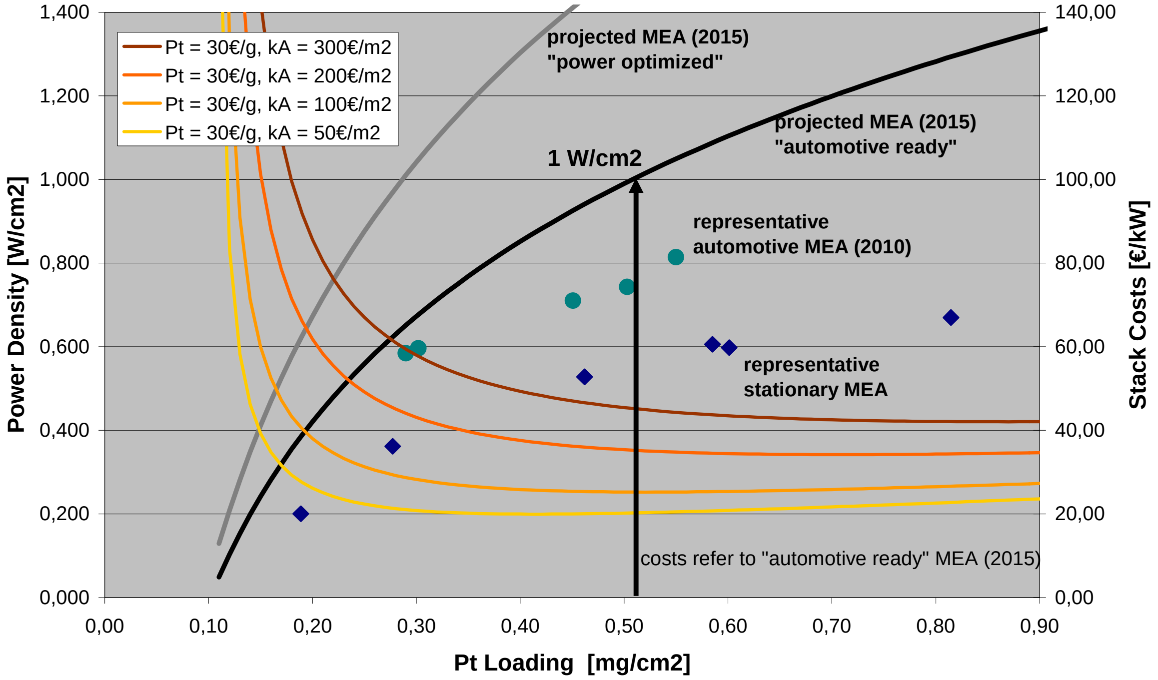

Figure 5: Balance of power density and Pt-loading and their relative cost impact

2.3 Functional and Validation Testing

During vehicle life, the stack will be faced with all kinds of different driving, climate and other environmental conditions. In order to prove the design concept and specific properties of the stack, a set of typical automotive tests were determined and agreed between the OEMs with degradation testing being the core of it. Since stack degradation does not simply scale with mileage and calendar age but is primarily determined by the load spectrum, i.e. the frequency of detrimental operation modes, critical operating conditions were identified and respective tests determined.

Durability testing does include and selectively stress those adverse conditions such as:

- Hot operation
- Start/Stop
- H_2 depletion
- Reactant impurity effect (SO_2, NH_3, CO, NO_x).
- Pressure Swing
- Freeze Start…

In Figure 6 below, critical stack operating conditions, so called “stress factors” of the drive cycle, with impact on stack durability and degradation are displayed.

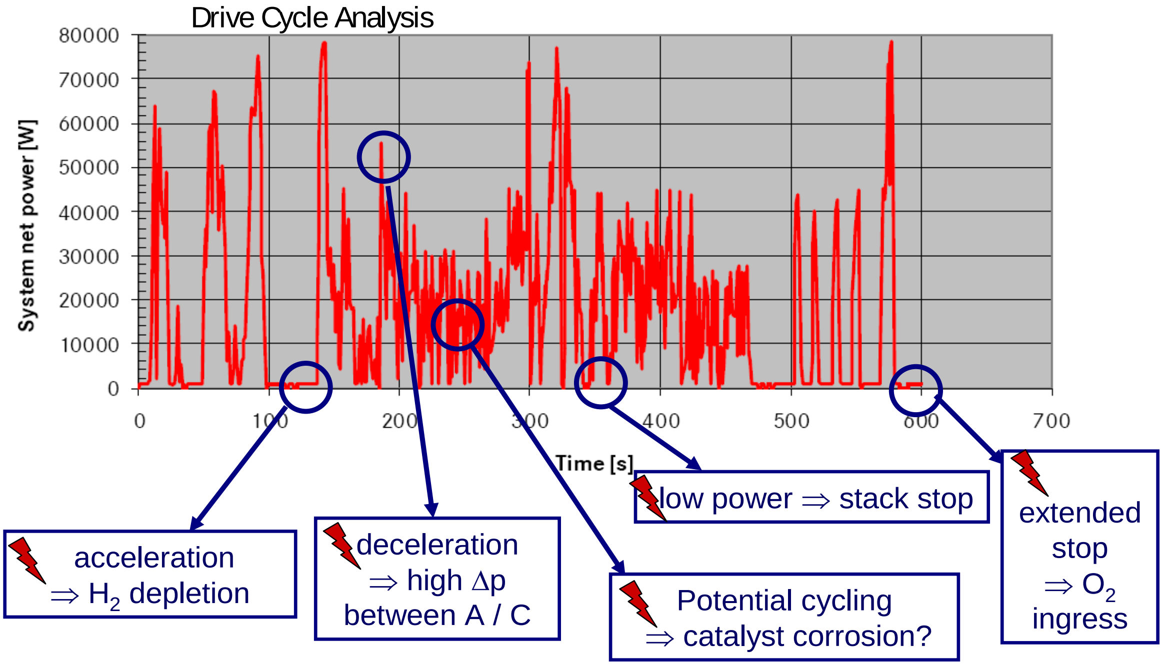

Figure 6: Stress factors in a “real” drive cycle

2.4 End of Life Criterium

The OEMs agreed a maximum power loss of 10% or end-of-life max power of 0.9 W/cm². However, degradation should not lead to increased heat release from the stack. The respective end-of-life cell voltage would be 0.637 V and the end-of-life current density 1.413 A/cm². This requirement compares to typical specifications for ICEs.

2.5 Cost Reduction Strategies

Stack power density has been identified as the main enabler for a fuel cell stack platform. Therefore, improvement of stack power density while maintaining efficiency shall have priority. Once established, a stack platform will trigger economies of scale. In the future, reduction of area specific noble-metal-loading while maintaining performance will broaden the base where the stack platform can be used and trigger a second level of economies of scale.

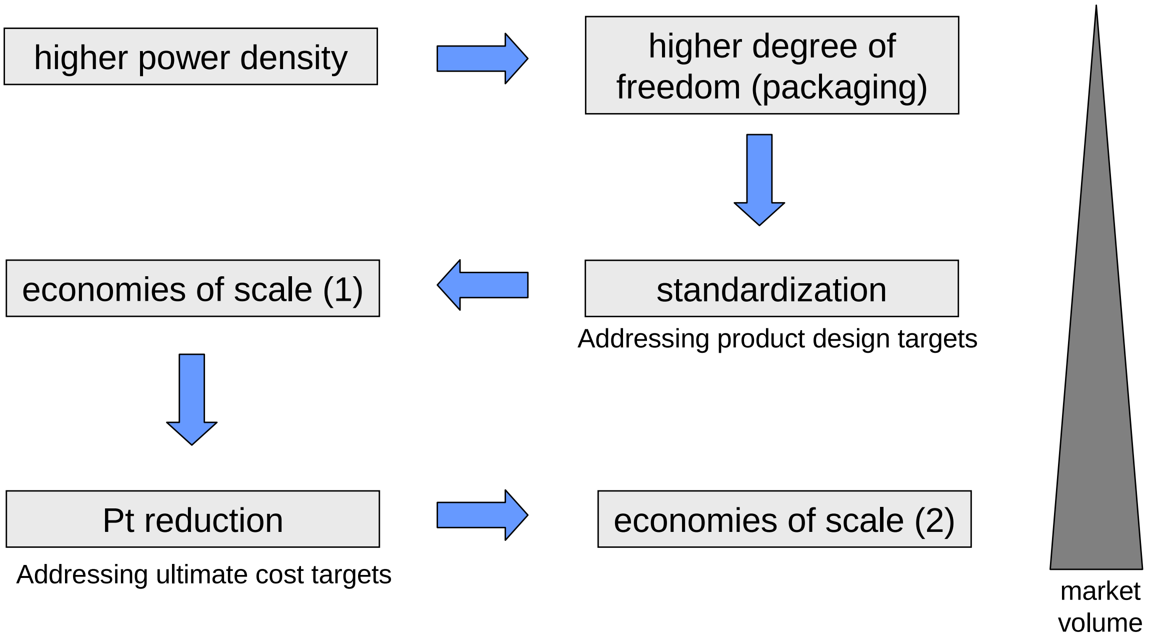

Figure 7: Cost reduction strategy for automotive stacks