FIT-4-AMANDA

Future European Fuel Cell Technology: Fit for Automatic Manufacturing and Assembly

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Abbreviations

AFC	Alkaline fuel cells
AM	Anode Module
BPP	Bipolar Plate
CCM	Catalyst Coated Membrane → ionomere membrane with attached catalyst layers
DMFC	Direct methanol fuel cell
EP	End Plate
FCEV	Fuel cell electric vehicle
GDL	Gas Diffusion Layer
ICE	Internal combustion engine
MEA	Membrane Electrode Assembly → a CCM between two GDLs
PEM	Proton exchange membrane
PEMFC	Proton exchange membrane fuel cells
SOFC	Solid Oxide

1 Publishable Executive Summary

Fit-4-AMandA focusses on the industrialisation of stack production and delivering affordable fuel cell systems in larger quantities to saturate the emerging market demand. The first step in the project is the formulation of the specifications of requirements for the automatic machine that will be producing stacks, which is the centrepiece of the fuel cell systems. Such requirements are the demands on the technology for the product manufacturing and also the product-side requirements for the processes of storage, supplying, assembling and handling. Furthermore, the requirements for the planned production system have to be defined in the same step, such as output cycle time and the kind of manufacturing und automation level, the general machine design, quality assurance system and special infrastructure requirements. This document is the result of collection of all the specifications related to the FC stack product, the machine design, the machine parameters and processing steps, as well as the quality control measures. It describes the concept - how and in what limits an automated PEMFC stack manufacturing plant could work and produce the targeted quality and quantity.

2 Introduction

Target of this document is a business study in the fields of fuel cell technologies in the transport sectors, depending on governmental requirements (latest pollution laws and so on) and especially the technical points.

Fuel cells efficiently convert diverse fuels directly into electricity without combustion, and they are key elements of a broad portfolio for building a competitive, secure, and sustainable clean energy economy. They offer a broad range of benefits, including reduced greenhouse gas emissions; reduced oil consumption; expanded use of renewable power (through the use of hydrogen derived from renewable resources as a transportation fuel as well as for energy storage and transmission); highly efficient energy conversion; fuel flexibility (use of diverse, domestic fuels, including hydrogen, natural gas, biogas, and methanol); reduced air pollution, criteria pollutants, water use; and highly reliable grid support. Fuel cells also have numerous advantages that make them appealing for end users, including quiet operation, low maintenance needs, and high reliability. Because of their broad applicability and diverse uses, fuel cells can address critical challenges in all energy sectors: commercial, residential, industrial, and transportation[1].

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[1] https://energy.gov/, 2017

3 Requirements

3.1 Technology

The Fuel Cells EU-programs focuses on R&D to address challenges facing **fuel cells for automotive applications** with potential spillover benefits for near-term applications such as distributed power (primary and backup), material handling equipment, specialty vehicles, and APUs, which will help drive manufacturing volume. These near-term applications will generate market traction for the adoption of longer term applications such as **light-duty vehicles, which have the greatest potential impact for fuel cell technologies** on national energy goals and associated metrics, as well as other transportation systems such as APUs that could be applicable for truck, marine, or aircraft applications, and they would also provide substantial environmental and energy-security benefits.

Fuel cell R&D emphasizes activities aimed at achieving high efficiency and durability along with low material and manufacturing costs for the fuel cell stack. R&D activities include developing lower cost, better performing system balance of plant (BOP) components such as air compressors, fuel processors, sensors, and water and heat management systems. The sub-program also supports the development of experimental diagnostics and theoretical models to gain a foundational understanding of reaction mechanisms and to optimize material structures and technology configurations. Each application—light-duty vehicle and bus transportation, stationary power, material handling equipment, specialty vehicles, APUs for heavy-duty vehicles, and portable power for consumer electronics—has specific market-driven requirements for technology development.

Polymer Electrolyte Fuel Cell (PEMFC) (as seen in Fig 1-1) are being considered for applications that require faster start-up times and frequent starts and stops, such as automotive applications, material handling equipment, and backup power. For PEMFCs, continuing advancements are needed to minimize or eliminate precious metal loading, improve component durability, and manage water transport within the cell. Additionally, membranes that are capable of operation at higher temperatures (up to 120°C for automotive applications and above 120°C for stationary applications) are needed for better thermal management. R&D is required to reduce cost and increase durability of the membrane electrode assembly (MEA) as well as optimize the integration of advanced cell components into the MEA.

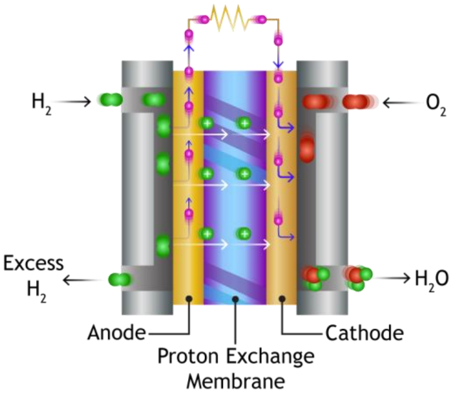

Figure 3-1 Polymer electrolyte membrane fuel cell (PEMFC) schematic [2]

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[2] https://web.stanford.edu

Direct methanol fuel cells (DMFCs) are well suited for early market applications as sources of portable and backup power in consumer electronic devices and similar applications where the power requirements are low and the cost targets and infrastructure requirements are not as stringent as for transportation applications. A higher energy density alternative to existing technologies is required to fill the increasing gap between energy demand and energy storage capacity in these low power applications. Challenges for DMFCs include reducing Pt loading, reducing methanol crossover to increase efficiency, and simplifying the BOP to increase energy and power density, improve reliability, and reduce cost.

Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electricity and water onboard spacecraft. One advantage of AFCs is that they can use a variety of nonprecious metal catalysts at the anode and cathode. The initial AFCs used aqueous potassium hydroxide (KOH) solutions as the electrolyte. To address some of the issues dealing with these liquid electrolytes, novel AFCs that use a polymer membrane as the electrolyte have been developed. These fuel cells are closely related to conventional PEMFCs except that they use an alkaline membrane instead of an acid membrane, and they are commonly referred to as AMFCs. Challenges for AMFCs include tolerance to carbon dioxide, membrane conductivity and durability, higher temperature operation, water management, power density, and anode electrocatalysis.

Medium-temperature (phosphoric acid) and **high-temperature** (solid oxide and molten carbonate) fuel cells are more applicable for systems that run for extended periods of time without frequent start and stop cycles. These systems also have benefits for CHP generation, and they offer simplified operation on fossil and renewable fuels. The high-temperature systems can also be utilized in tri-generation mode to produce electrical power, heat, and hydrogen. R&D needs for phosphoric acid-based fuel cells (PAFCs) include methods to decrease or eliminate anion adsorption on the cathode, lower cost materials for the cell stack and BOP components, and durable electrode catalyst and support materials. Polymer-phosphoric acid-based systems including polybenzimidazole-phosphoric acid type (PBI-type) have applications similar to PAFC. For high-temperature MCFCs, R&D is needed to limit electrolyte loss and prevent microstructural changes in the electrolyte support that lead to early stack failure. R&D is also needed to develop more robust cathode materials. For SOFCs, challenges include stack survivability during repeated thermal cycling, decreasing long start-up times, and potential mechanical and chemical compatibility/reactivity issues between the various stack and cell components due to high-temperature operation. For all of these systems, improved fuel processing and cleanup, especially for fuel-flexible operation and operation on biofuels, are needed to improve durability and reduce system costs. Table 1-1 describes the different fuel cell types discussed here.

Table 3-1 Types of fuel cells

Fuel Cell Type	**Temperature** **Common Electrolyte/ Charge Carrier**	**Applications**
Polymer Electrolyte Membrane (PEMFC)	<120°C Perfluorosulfonic acid / H+	Backup power, Portable power, Distributed generation, Transportation, Specialty vehicles
Direct Methanol (DMFC)	<100°C Perfluorosulfonic acid / H+	Early market applications
Alkaline (AFC), Alkaline Membrane Fuel Cell (AMFC)	<100°C aqueous KOH, alkaline polymer / OH-	Military, Space, Backup power, Transportation
Phosphoric Acid (PAFC) and Polymer Phosphoric Acid	150–200°C H3PO4, Polymer/H3PO4, H+	Distributed generation
Molten Carbonate (MCFC)	600–700°C (Li,K,Na)2CO3 / CO32	Electric utility, Distributed generation
Solid Oxide (SOFC)	500–1,000°C Yttria–Stabilized Zirconia (Zr.92Y.08O2) / O2	Electric utility, Distributed generation, APUs

3.2 Market

The fuel cell industry had revenues of approximately 1.8 billion € in 2014, an increase of approx. 1 billion € over revenues in 2013. In transportation applications, manufacturers have begun to commercialize fuel cell electric vehicles (FCEVs). *Hyundai and Toyota have recently introduced their FCEVs in the marketplace, and Honda is set to launch its new FCEV in the market in 2016. Others, including Daimler, reportedly are set to begin commercialization in 2017.*[3] *The largest markets for fuel cells today are in stationary power, portable power, auxiliary power units, backup power, and material handling equipment. Approximately 155,000 fuel cells were shipped worldwide in the four-year period from 2010 through 2013, accounting for 510–583 MW of fuel cell capacity.*[4] *In 2014 alone, more than 50,000 fuel cells accounting for over 180 MW of capacity were shipped.*[5]

Goals to Market

- Develop a 65% peak-efficient, direct hydrogen fuel cell power system for transportation that can achieve 5,000-hour durability (ultimate 8,000 hours) and be mass produced at a cost 35 €/kW by 2020 (ultimate 25 €/kW).
- Develop distributed generation and micro-CHP fuel cell systems (5 kW) operating on natural gas that achieve 45% electrical efficiency and 60,000-hour durability at an equipment cost of 1.300 €/kW by 2020.
- Develop medium-scale CHP systems (100 kW–3 MW) by 2020 that achieve 50% electrical efficiency, 90% CHP efficiency and 80,000-hour durability at a cost of 1.300 €/kW for operation on natural gas and 1.800 €/kW when configured for operation on biogas.

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[3] http://energy.gov/sites/prod/files/2015/10/f27/fcto_2014_market_report.pdf.

[4] E4Tech, The Fuel Cell Industry in Review 2015 (London, U.K.: 2015), www.FuelCellIndustryReview.com.

[5] Daimler, AG, Ready to Start Up (Stuttgart, Germany: 2015), https://www.daimler.com/documents/company/other/daimler-corporateprofile-en-2015.pdf.

3.2.1 Market for Light-Duty Vehicles

Fig 1-2 shows that durability and cost are the primary challenges to fuel cell commercialization in light-duty vehicle transportation applications. The cost of fuel cell stacks and systems must be reduced before they can be competitive with conventional vehicle technologies (gasoline internal combustion engines). The DOE system cost target for 2020 is 30 €/kW (~ $40/kW), which is believed to be the point where fuel cell vehicles would be competitive on a life-cycle cost basis with incumbent and future competing technologies. Long-term competitiveness with alternative powertrains, including future advanced gasoline engines, is expected to require further cost reduction to 25 €/kW, which represents the sub-program's ultimate cost target.[6]

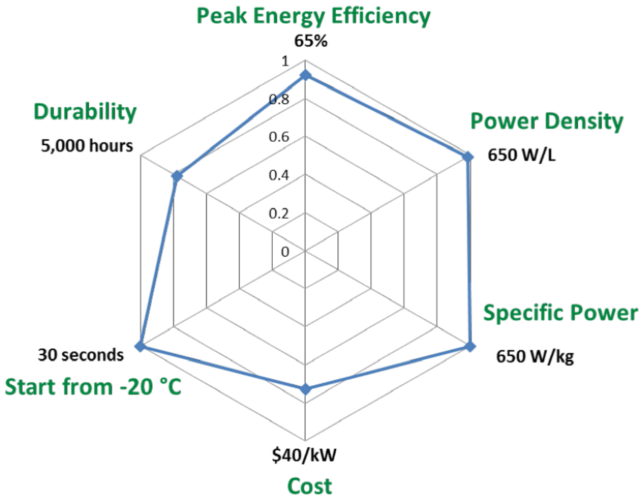

Figure 3-2 Fuel cell power system 2020 targets versus 2015 status (blue) for 2020.

2015 modeled cost estimates place the cost of an 80-kWnet automotive polymer electrolyte membrane (PEM) fuel cell system based on next-generation laboratory technology and operating on direct hydrogen to be 45 **€/kW** when manufactured at a **volume of 500,000 units/year** and 50 €/kW at a volume of 100,000 units/year. A significant fraction of the cost of a PEM fuel cell comes from the PGM catalysts that are currently used on the anode and cathode for the electrochemical reactions. Other key cost factors include the membrane, cell hardware, and BOP components. It should be noted that the projected cost status is based on an analysis of state-of-the-art components that have been developed and demonstrated through the Fuel Cells sub-program at the laboratory scale. Additional efforts would be needed for the integration of components into a complete automotive system that meets durability requirements in real-world conditions. *Table 1-2 shows estimated PEM cost €/kW for Light-Duty Vehicles Class. The expected cost of automotive PEM fuel cell systems based on current technology, planned for commercialization in the 2016 time frame, is approximately 240 €/kW when manufactured at a volume of 20,000 units / year.* [7]

Table 3-2 Estimated PEM cost €/kW for Light-Duty Vehicles Class

€/kW	based on unit/year	Technology level
45	500.000	next-generation
50	100.000	next-generation
240	20.000	current technology

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[6] https://energy.gov

[7] DOE Hydrogen and Fuel Cells Program Record, 15015: Fuel Cell System Cost—2015, September 30, 2015

3.2.2 Market for Buses and Heavy-Duty Vehicles Market[8]

Transit bus applications represent a promising mid-term market for fuel cell technology. Central fueling of transit bus fleets facilitates the introduction of hydrogen fuel in the transportation market, and the less stringent cost, weight, and volume criteria of heavier vehicles make the implementation of fuel cell propulsion systems less challenging in transit buses than in other transportation applications. However, cost and durability are still challenges for fuel cells in bus applications.

PEMFC technology is the primary fuel cell type considered in fuel cell- or battery-dominant hybrid systems operating on hydrogen. Fuel cell bus development and demonstration activities have been primarily funded by the U.S. Department of Transportation's Federal Transit Administration. While not focusing directly on bus applications, the Office continues to fund research on fuel cell materials that are relevant to bus applications.

Fuel cell bus power plants are offered with a 12,000-hour or 5-year warranty, including air, fuel, and water management systems. A recent fuel cell bus demonstration has surpassed 20,000 operating hours in real-world service with the original cell stacks and no cell replacement.[9] Remaining fuel cell durability issues are difficult to identify and understand through field data. The development and implementation of accelerated stress tests (ASTs) are needed to shorten the time required to address durability issues for all drive cycles and hybridization strategies. Because BOP components, power electronics, and power plant integration issues cause more forced shutdowns than the fuel cell system does, the development of fuel cell-powered buses should be done at the overall system level. Of course, the hybridization strategy chosen has a major effect on system design and technical requirements.

Although fuel cell durability increases have been realized and costs have been reduced for bus applications, the efficiency, durability, and cost targets (manufacturing, capital, operations, and maintenance) for fuel cells have not yet been met. Initial capital cost is a particularly important target.

Medium- and heavy-duty trucks are an emerging application for fuel cells. Medium- and heavy-duty vehicles accounted for 6 quads of petroleum use in 2012.[10] *Emissions from these vehicles are also a concern because they were the source of over 400 MMT of CO_2 emissions in 2012, and diesel-powered vehicles and equipment account for nearly half of NOx and more than two-thirds of all particulate matter emissions from U.S. transportation sources.*[11] Fuel cells offer the opportunity for reduced emissions and petroleum usage while increasing efficiency in this sector. Central fueling of fleets for some heavy- and medium-duty trucks facilitates the introduction of hydrogen fuel in this market, especially if fleets are collocated with material handling equipment utilizing hydrogen. However, fuel cells still need to be demonstrated in these applications. See the Market Transformation section for information on the application of fuel cells in medium- and heavy-duty trucks. Truck technical targets are currently under development.

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[8] https://energy.gov

[9] L. Eudy, M. Post, and C. Gikakis, *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2015* (Technical Report NREL/TP-5400-64974) (Golden, CO: National Renewable Energy Laboratory, 2015), http://www.nrel.gov/docs/fy16osti/64974.pdf.

[10] DOE, Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities, Table 9.1.1 (Washington, D.C.: September 2015)

[11] S.C. Davis, S.W. Diegel, and R.G. Boundy, Transportation Energy Data Book: Edition 33 (Technical Report ORNL-6990) (Oak Ridge, TN: Oak Ridge National Laboratory).

3.2.3 Market for Stationary Power Systems[12]

The stationary fuel cell market accounts for the majority of the current global fuel cell market in terms of megawatts shipped.[13] Stationary fuel cells can be used in a broad range of commercial, industrial, and residential applications, from multi-megawatt systems for large centralized power generation to small units (e.g., 1 kW) for backup power or micro- CHP systems. Even though the specific performance requirements differ between the stationary applications and are different from those for transportation applications, the main challenges are the same: reducing cost and increasing durability. While the acceptable price point for stationary fuel cell systems is considerably higher than that for transportation systems, current costs are still too high to be competitive with conventional/incumbent technology for most applications. ***Recent studies have indicated that prices range from ~3.400 €/kW for large prime power systems to over ~ 17.000 €/kW for small prime power (<11 kW)****, values that are considerably higher than DOE targets.*[14] Additionally, the durability of stationary fuel cell systems in most instances does not match that of the incumbent technology. More specifics related to the challenges for particular stationary application segments are described below.

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[12] https://energy.gov

[13] DOE Fuel Cell Technologies Office, 2014 Fuel Cells Technology Market Report (Technical Report) (Washington, D.C.: October 2015)

[14] Aggregated Price Data by Application, at Low Volume Production Levels," NREL, April 2015

3.3 Targets

3.3.1 Technical Targets

Following tables (1-3 and 1-4) show the performance objectives considered of a example design. They provide details on the fuel cell stack design for the PEM systems and on the fuel cell stack design for the SOFC system. Details regarding typical and representative specifications and requirements. [15]

The overall efficiency associated with the PEM system assumes that waste heat is recovered at a useable temperature of ~80°C to 100°C. This temperature is higher than would be achieved in direct hydrogen system because some high quality heat is recovered from the fuel processing system. The extended lifetime target of 50,000 hours results in stacks that are operated more conservatively (e.g. 0.4 amps/cm^2) than automotive or materials handing installations. Based on conversation with PEM stack manufacturers, they suggest that this current density is appropriate for reformate versus hydrogen as the fuel.

Table 3-3 PEM Fuel Cell Design Parameters

Parameter	100 kW	200 kW
Power Density (W/cm^2)	0,27	0,27
Full Load Current Density (A/cm^2)	0,4	0,4
Full Load Cell Voltage (VDC	0,68	0,68
Active Area Per Cell (cm^2)	780	780
System Net Power (kW)	100	250
System Gross Power (kW)	120	300
Number and Size of Stacks per System	2 x 60 kW	6 x 50 kW
Number of Cells per stack (#)	283	236
Nominal Stack Open Circuit Voltage (VDC)	283	236
Full Load Stack Voltage (VDC)	192	160

Table 3-4 SOFC Fuel Cell Design Parameters

Parameter	100 kW	200 kW
Power Density (W/cm^2)	0,28	0,28
Full Load Current Density (A/cm^2)	0,4	0,4
Full Load Cell Voltage (VDC	0,7	0,7
Active Area Per Cell (cm^2)	414	414
System Net Power (kW)	100	250
System Gross Power (kW)	120	300
Number and Size of Stacks per System	4 x 30 kW	10 x 30 kW
Number of Cells per stack (#)	259	259
Nominal Stack Open Circuit Voltage (VDC)	285	285
Full Load Stack Voltage (VDC)	181	181

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[15] Manufacturing Cost Analysis of 100 and 250 kW Fuel Cell Systems for Primary Power and Combined Heat and Power Applications, 2016

3.3.2 Emission targets

The manufacturers with a large share in markets in Europe are affected by the goals of climate control and the limits on fleet emissions defined by EU agencies. A similar development can be seen in the US, especially in individual states like California. *Figure 1-3 shows an overview of the planned emission regulations in selected regions. In this context, the manipulations of exhaust emission and fuel consumption measurements with diesel and petrol engines at Volkswagen become even more scandalous. It is in the focus not only in Germany and the US, but also in the rest of the world. Air pollution in megacities in Asia is increasing the pressure to introduce new zero-emission drive systems. It is, therefore, not only political pressure that urges the car industry to act, but also trends in society.*[16]

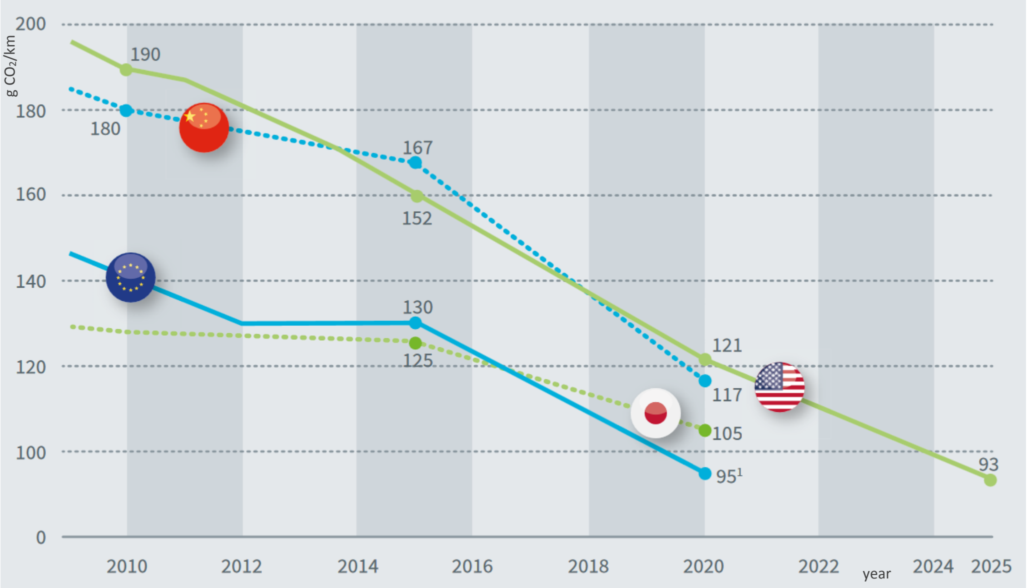

Figure 3-2 Planned emission standards in select regions (g CO_2/km)

As seen in figure 1-4 car makers therefore are faced with the challenge of lowering their fleet emission levels, while maintaining their competitiveness. The scale of this challenge becomes clear when looking at the EU emission limits. Based on current rules, OEMs will have to reduce the overall CO2 emissions of their fleets by 28 percent on average.

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[16] International Benchmarking on the Status Quo of Electromobility in Germany 2015

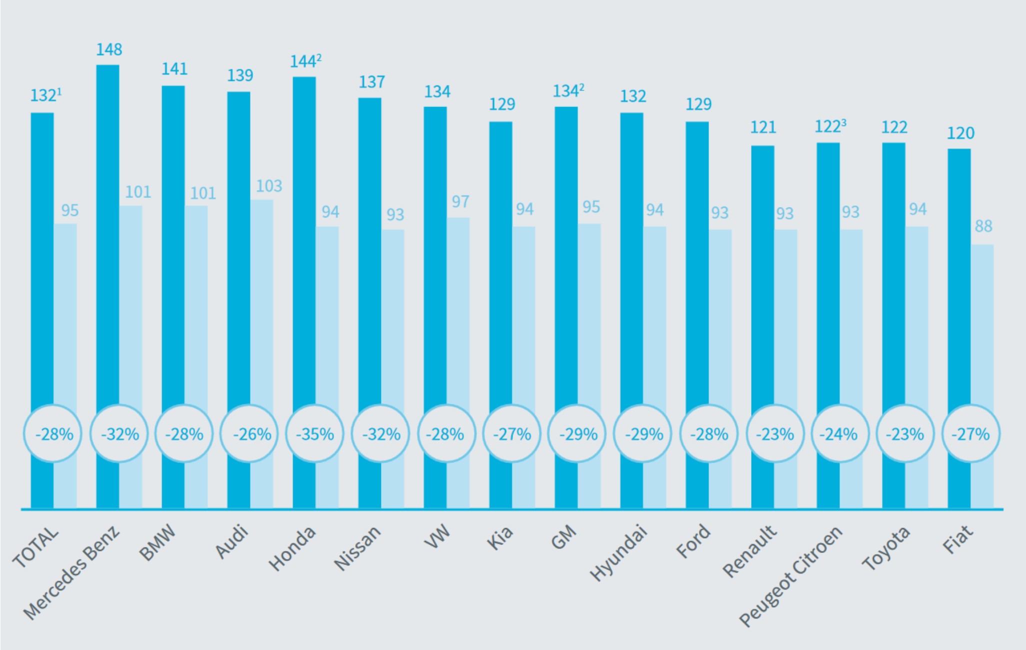

Figure 3-3 CO_2-emmisions of selected OEMs and brands 2012 in Europe (NEDC) compared to 2020 goal

The disruptive potential of e-mobility is confirmed without any doubt, even though uncertainties concerning the development of different types of alternative drives continue to exist. This finding, in combination with future scenarios regarding CO_2 regulation, further strengthens the assumption that some types of electrified drive systems will eventually supplant and almost completely replace total the traditional internal combustion engine (ICE) until 2050 (Fig 1-5) with an market potenial of ~ 40% by fuel cell cars.

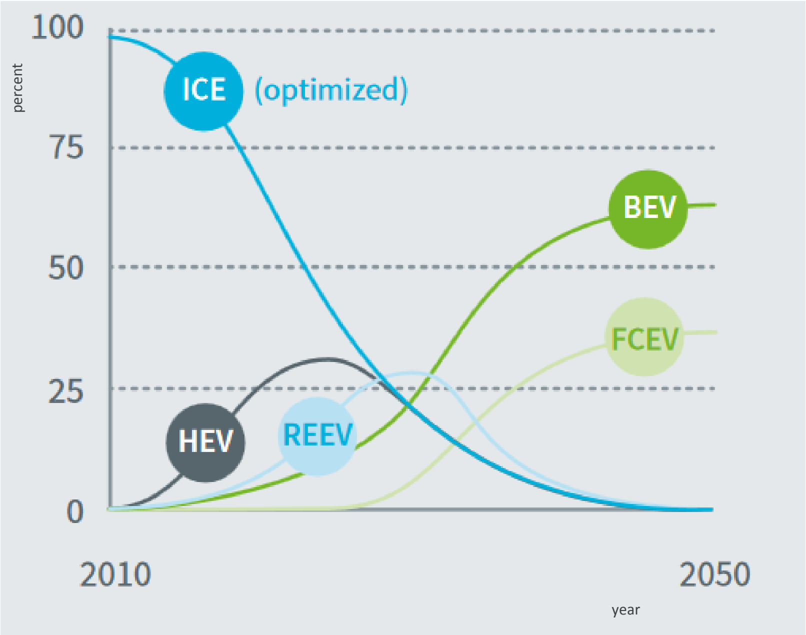

Figure 3-4 Today valid regulation leads to BEV and FCEV world [17]

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[17] McKinsey 2014

3.3.3 Production Cost Targets

Each stack consists of end plates, bipolar plates, seals and membrane electrode assemblies (MEA), which shows the manufacturing process in flow chart format. The four branches leading to stack assembly are:

- *End plate fabrication*
- *Bipolar plate fabrication*
- *Gasket/Seal fabrication*
- *MEA fabrication*

Total PEM stack manufacturing costs are summarized in Table 1-5 an based on following facts:[18]

The MEA is built up in layers starting with the hydrated membrane. The components of the catalyst ink are ball-milled into a uniform suspension. The anode layer is selective slot die coated directly on the hydrated membrane and dried. The cathode layer, meanwhile, is slot die coated onto a transfer substrate and dried. The coated membrane and transfer substrate layers are heated and roll pressed, then the transfer substrate is peeled away from the cathode layer following pressing. The catalyst loaded membrane is then hot pressed between two gas diffusion layers and die cut to final cell dimensions. The catalysts and gas diffusion layers are only applied to the active area. For all production volumes, the component reject rate was assumed to be 2.5% for catalyst production, 2.5% for catalyst application, 3.0% for decal transfer, 0.5% for hot pressing and 3.0% for die cutting.

Although the cells are identical for the 60 kW and 50 kW stacks, the higher volume production associated with the 50 kW stacks used for the 250 kW system (six stacks / system versus two) results in material and labor cost savings. Note that the membrane and gas diffusion layers dominate the cost at low volume, becoming much less important at high production rates, where catalyst cost becomes the dominant factor. Because of the precious metal content of the catalyst cost, it does not reduce as quickly with production volume as do those of the other materials. In fact, a potential concern is that the high production volumes, particularly for the larger systems, could cause increases in catalyst cost. While some recycling programs to reclaim the catalyst from retired fuel cells do exist, they still lack the availability and robustness of other precious metal programs, such as those in place for automotive catalytic converters. Additionally, due the to the nature of PEM fuel cell construction, recovering high value materials would likely be easier than is the case for catalytic converters.

The process selected to produce the end plates was near net shape sand casting of aluminum alloy followed by cell machining. Die casting the end plates was considered but was not recommended as acceptable manufacturing process due to the size and thickness of the plates. The process scrap rate was assumed to be 0.5%. The end plates are identical for either stack – the cost differences are again related to the greater number of plates needed for the 250 kW systems.

The stack contains 3 gaskets (cathode, anode and cooling) per cell plus 2 cathode gaskets on each end of the stack. To manufacture 1,000 systems consisting of two 60 kW stacks of 283 cells each requires a total of 566,000 each anode and cooling gaskets, and 570,000 cathode gaskets. The process to be used is normally injection molding of liquid silicon rubber. This is a standard process under non-automatic circumstances, but the automatization of this procedure needs high quality procedures to guarantee non-failure parts. Therefore the estimated costs within table 1-5 are to be supposed as a minimum.

The bipolar plates are a compression molded graphite/thermoset-polymer composite material. While the use of stainless steel bipolar plates is a common practice for many applications requiring low weight and cost per kW, such as automotive, industry feedback still supports the use of graphite material for applications focused on long

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[18] Manufacturing Cost Analysis of 100 and 250 kW Fuel Cell Systems for Primary Power and Combined Heat and Power Applications; Battelle Memorial Institute, 2016

lifetime expectations. The material is preformed into the approximate rectangular shape of the plate, then compressed into final shape in a 1000 ton press at 160°C for 230 seconds. Two plates are formed during each machine cycle. The anode plate includes the cooling channels (two sided plate) and is roughly twice as thick as the Cathode plate. However, processing time is considered to be equivalent for both plates. Following molding, the plates are removed from the molds and baked at 175°C for 15 minutes. The process scrap rate was assumed to be 2.5% - an accepted value for standard manufacturing processes today. Today scrap rates are still significant higher, which makes the real process more ineffective.

The following tables 1-5 and 1-6 summarize the cost for the stack components and manufacturing. [19]

Table 3-5 PEM Stack Component Cost Summary - 100 kW and 250 kW

	60 kW Stack - 100 kW System				**50 kW Stack - 250 kW System**			
	100	1000	10000	50000	100	1000	10000	50000
MEA	23.243 €	10.498 €	6.179 €	4.987 €	13.747 €	6.861 €	4.501 €	3.861 €
Anode / cooling Gasket	439 €	372 €	335 €	330 €	344 €	295 €	277 €	275 €
Cathode Gasket	226 €	167 €	147 €	144 €	148 €	132 €	122 €	119 €
Anode Bipolar Plate	2.115 €	1.352 €	1.242 €	1.238 €	1.139 €	1.055 €	1.032 €	1.031 €
Cathode Bipolar Plate	1.997 €	1.232 €	1.122 €	1.118 €	1.039 €	955 €	932 €	930 €
End plates	95 €	62 €	41 €	34 €	70 €	60 €	41 €	32 €
Assembly hardware	373 €	348 €	326 €	311 €	361 €	337 €	315 €	301 €
Assembly labor	159 €	141 €	140 €	139 €	123 €	118 €	117 €	117 €
Test and conditioning	1.221 €	196 €	136 €	135 €	460 €	144 €	130 €	129 €
Total Cost per Stack	29.869 €	14.370 €	9.669 €	8.436 €	17.431 €	9.956 €	7.467 €	6.795 €

Table 3-6 PEM Stack Manufacturing Cost Summary - 100 kW and 250 kW

	60 kW Stack - 100 kW System				**50 kW Stack - 250 kW System**			
	100	1.000	10.000	100.000	100	1.000	10.000	100.000
Material	23.747 €	11.205 €	6.996 €	5.837 €	14.299 €	7.544 €	5.253 €	4.623 €
Labor	946 €	918 €	915 €	915 €	785 €	777 €	776 €	776 €
Machine	3.842 €	1.467 €	1.079 €	1.028 €	1.549 €	1.029 €	884 €	854 €
Scrap	530 €	268 €	193 €	173 €	309 €	191 €	151 €	140 €
Tooling	804 €	513 €	485 €	483 €	490 €	416 €	403 €	402 €
Part Total	29.869 €	14.370 €	9.669 €	8.436 €	17.431 €	9.956 €	7.467 €	6.795 €
Stacks/System	2	2	2	2	6	6	6	6
Total Cost per System	59.738 €	28.740 €	19.337 €	16.872 €	104.586 €	59.735 €	44.800 €	40.772 €

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[19] Manufacturing Cost Analysis of 100 and 250 kW Fuel Cell Systems for Primary Power and Combined Heat and Power Applications; Battelle Memorial Institute, 2016

4 Methods and results

This document lists the market potentials of fuel cell technologies by analysing literature, publications and conference papers, supported by further input of technical details and industrial requirements from TUC and EWII.

Although the fuel cell technologies are known since 1840, their potential as a clean alternative to internal combustion engines was not followed by developments and further investigations. Significant new developments started middle of 1990's, including research activities and first vehicles using fuel cell technologies in early 2000's.

In general a literature review has been done to figure out the valid standards and goals of fuel cell development. This happened under special view to government pollution laws and environmental targets. The results were collected and compered depending the used standards and possible markets.

5 Discussion and Conclusions

A number of discussions and action points arose during the compilation of the specification document. This section shows the most important discussion points and the decisions/conclusions drawn up to now.

- The yearly actualized potential market is going up/down depending on the valid laws.
    - Laws depending on elected national and European parties.
    - Market potentials depending on government decisions and support of introducing new technologies.
- OEM´s as producer depending on marketing strategies.
    - Strategies of all important OEM´s announces market entry of fuel cell cars until 2023.
    - Peripheries (like H_2 stations) have to be improved.
- Government decisions pro E-Mobility are necessary.
    - Norway, Netherland and Germany for example planning to complicate the selling of ICE-cars.
    - Decisions and regulations have to figure out clearer.
- The calculated system costs are still high.
    - New, more effective production technologies are necessary.
    - Number of scrap parts has to be reduced, not because single costs, but following cost during assembling.

6 Risk Register

The risks identified are connected to the market entrance of this technology. Other risks, especially technical risks will be found within the connected WP´s.

Risk No.	What is the risk	Probability of risk occurrence[20]	Effect of risk[21]	Solutions to overcome the risk
1	Economical risks: The unit-targets connected to the fuel cell technology are too progressive. → Stacks will be more expensive because oversized production lines	Medium	Medium	Market monitoring and modify the production lines to reduce the production costs
2	Political risks: The periphery of fuel cell technology is not ready at point of point of entrance. → Fuel cell cars available but H_2-Stations missing	Low	Medium	The building of H_2 stations has to be accelerated by government in advance of market entrance

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[20] Probability risk will occur: 1 = high, 2 = medium, 3 = Low

[21] Effect when risk occurs: 1 = high, 2 = medium, 3 = Low

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Project partners:

#	Partner	Partner Full Name
1	UNR	Uniresearch BV
2	PM	Proton Motor Fuel Cell GmbH
3	EWII	EWII Fuel Cells A/S
4	USK	USK Karl Utz Sondermaschinen GmbH
5	Fraunhofer	Fraunhofer gesellschaft zur foerderung der angewandten forschung E.V.
6	TUC	Technische Universitaet Chemnitz
7	UPS	UPS Europe SA

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