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ObservatoryNANO

Energy Sector Economic Report

Nanotechnology for Fuel Cells

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Executive Summary

A fuel cell is an electrochemical cell that converts a hydrogen fuel into an electrical current, heat and water, and is a promising technology for future power production. Fuel cells may be used to power production in portable, stationary and transportation applications like consumer electronics, residential units and specialty vehicles. The majority of the fuel cell industry is still supply-driven and supported by government R&D funding and demonstration programmes. However, a growing number of applications are moving to a demand-driven direction and commercialization phase. The number of fuel cell units sold increased in 2009 despite the economic downturn.

Over 100 European companies indicated that they are working with fuel cell related materials, components and products now or in the near future. Small and medium size companies were predominant and almost half of all the studied companies focused exclusively on fuel cells. 40% of European companies are located in Germany and 14% in the United Kingdom. 43% of the companies are located on the value chain as a material, component or fuel cell/stack producer, half are system integrators, and the remainder are distributors.

Nanotechnology has great potential for materials, component and fuel cell/stack producers. It may improve material properties, the functionality and performance of components, and decrease price. The high price of fuel cells and a lack of infrastructure have been the biggest barriers to commercialization and therefore nanotechnology might be a key for speeding up the commercialization of fuel cell applications.

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1. Definitions and Methodology

1.1. What is nanotechnology?

The umbrella terms of nanoscience and nanotechnology are still not precisely defined, however, one thing which is clear, and which all definitions share, is the ambition to understand and control the fundamental structure and behaviour of matter at the atomic and molecular level. The realm of nanotechnology is generally agreed to lie within the range of 1 and 100 nanometres. A further restriction of the definition of nanoscience and nanotechnology is that new functionalities are made available by manipulation of matter at this scale or through specificities of the nano dimensions, where the physical, chemical and biological properties of materials differ from those of the bulk matter. Nanotechnology promises advances in controlling and manipulating matter and with this promise a vision of novel ways of creating and developing a new generation of products with original features, performances and functionalities.

1.2. Methodology for preparating the report

The content of this report is based on available market data, information from companies' internet pages, interviews and questionnaires. A list of European companies having fuel cell related activities was carried out by online research. Companies included in the list indicated that they work with fuel cell related materials, components or products now or in the near future. The component category includes producers of fuel cell components such as catalysts, membranes, bipolar plates, and interconnections.

2. Fuel cells short application description

Future power production technologies have strict requirements; they have to be clean, efficient, highly reliable and competitively priced. Fuel cells may provide an answer for future power production; it combines hydrogen fuel and oxygen from the air to produce electricity. The only by-products are heat and water when hydrogen is used as a fuel. However more research and development is needed, particularly to decrease the price level and speed up commercialisation of the applications.

Fuel cells might be as a power source in various applications like in portable (laptops, mobile phones etc.), transportation and specialty vehicles (forklifts, cars, busses) as well as stationary solutions (distributed heat and energy production). Fuel cell construction is showed in Figure 1, where main parts membrane, two electrodes (anode and cathode) and a catalyst is marked with green. Further the fuel cells can be combined to form a fuel cell stack and fuel cell units[1]. More detailed technological description is in the ObservatoryNano Fuel Cells and Hydrogen production and storage report[2].

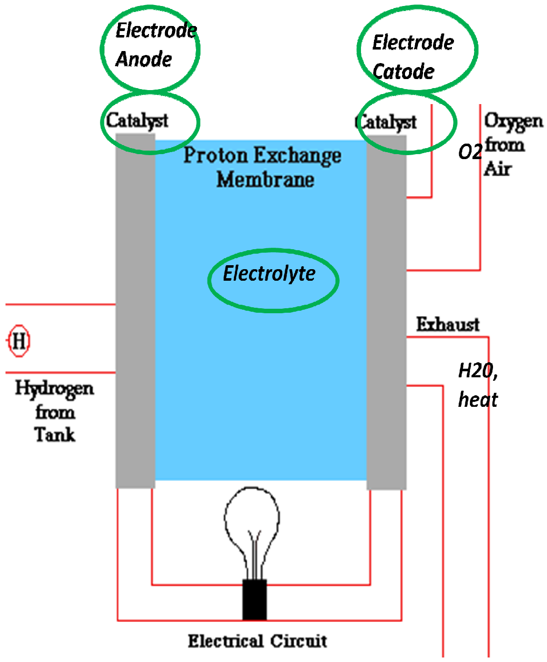

Figure 1. *Nanotechnology may be applied on the fuel cell parts marked in green to operating principal of the PEM-fuel cell -picture.* [3]**.**

2.1. Drivers and Barriers

Fuel cells have many benefits when compared to existing power sources, although they are not taken the market in large scale. Fuel cells costs and infrastructure are the most pressing barriers to be resolved[4,5,6].

Table 1. *Fuel cell applications, drivers and barriers[7, 8].*

	Portable	Stationary	Transportation
Product group examples	• Consumer electronics • Chargers & generators [0,5-2 kW]	• Residential units [0,5-5kW] • DG/central power plants; [5kW-10 MW]	• Light duty vehicles (car etc.) • Specialty vehicles (forklifts, scoters etc.) • APU [1->500kW]
Drivers	• Demand of larger power units • Products short life time • Alternative fuels	• Off-grid energy production • Emission reduction • Alternative fuels	• Emission reduction • Lack of legislation • Increased efficiency • Reliability • Quiet operation
Barriers	• Miniaturization • Shortage/lack of standards • Consumer acceptance • DMFC, PEMFC durability, lifetime • Fuel cell, BoP components price • Fuel supply chain	• Fuel cell system price • SOFC durability & lifetime • DMFC lifetime • Shortage/lack of standards	• Fuel cell system price • Fuel (H_2) infrastructure • PEMFC durability, lifetime • Shortage/lack of safety codes, standards

2.2. Functional requirements and impact of Nanotechnology

Nanotechnology will impact the fuel cell, fuel cell system and fuel processing as well storage applications. Specific characteristics of different fuel cell applications may be improved with nanotechnology, as seen in Table 2:

Table 2. *The most important characteristics of different fuel cell application, and the potential impact of nanotechnology*[2,8]*.*

	Portable	Stationary	Transportation
Main characteristics	• Miniaturization • Performance, moisture control • Fuel storage	• Performance • Durability • Bio fuel processing	• Cost reduction • Performance • Fuel processing • Fuel storing
Some nano-technology solution	• Improved catalysts for DMFC, RMFC • Methanol impermeable membranes • Lighter electrodes by carbon nanotubes	• Increase of durability by coatings and new materials • Performance and efficiency improvement with electrolyte nanostructure materials	• Lower catalyst loadings, recyclable catalysts • Cheaper and more durable membranes • Component coating (anode and cathode) • Nano wires for fuel storing

Catalysts, membranes, electrodes and bipolar plates are the main focus areas of nanotechnology in fuel cells. With nanotechnology it is possible to decrease the weight of electrodes as well as to increase the conductivity and electrochemically active surface of catalysts. Expensive Platinum (Pt) used on catalysts could be replaced with less expensive alternatives[9]. The mechanical properties, conductivity and corrosion resistance of interconnect and bipolar plates could also be improved with nanocoatings. On a membrane, which mostly depends on the type of fuel cell, it is possible to increase the area of active surface, cyclability and lifetime.[2]

The adoption and market potential of fuel cell related nanosolutions for materials and components were evaluated by questionnaires and interviews that were carried out by the author of this report. The results illustrated that it was difficult to pick specific nanotechnologies to be the most important solution. Eight of the companies estimated that they will have a fuel cell related material or component like catalyst, electrolyte, membrane, interconnection or bipolar plate on a market in five year or sooner. The average time for the market penetration was about two years. The highest adoption potential was seen for catalysts and electrodes.

Dr Gaby J.M. Janssen from Energy research Centre of the Netherlands (ECN) estimates that, "In general in my field of PEMFC nanotechnology can become very important for developing more durable and cost-effective electrodes. However, functionality as well as durability of nano solutions has to be proven and there is long way to market, maybe 5-10 year. As regards the membrane, any nanostructuring that would improve proton conductivity at low relative humidity while not compromising on durability is needed. Depending on the type of modification, it might take at least 2-5 year for the innovation go to the market."

Professor Göran Lindbergh from Department of Chemical Engineering and TechnologyApplied Electrochemistry Royal Institute of Technology, KTH summarises: "My general opinion is that nano is a key in fuel cell research and development, but it is impossible to pick the wining concepts or directions today".

2.3. Product and company examples

Here is few examples of European companies having nanotechnology-based fuel cell components already on the market. More companies utilizing nanotechnology in fuel cells may be found, for example, from the Hydrogen & Fuel Cell Investor web-pages: Link:
http://www.h2fc.com/reframe.php?top=/global/indust.shtml&bot=/industry/components/index.shtml

Acta SpA, Italy has introduces high performance, low cost **catalysts** for fuel cells. HYPERMEC catalysts use a patented manufacturing process to enable them to be platinum free.
Link: http://www.acta-nanotech.com/

QuantumSphere Inc. (QSI) develops and manufactures advanced materials including high-performance **nanoscale catalysts**. The catalysts use lower cost metals, engineered at the nano scale, to replace platinum. Thus, QSI's nano scale palladium catalysts and MEA designs are less expensive and lead to better performance at the same time.

Link: http://www.qsinano.com/about_company.php

FuMA-Tech GmbH focuses on functional membranes and plant technology**.** Particular significance is given to direct methanol fuel cells for portable applications in the low-performance range. The new fluorine-free hydrocarbon **membranes** are based on inorganic-organic nano-particles in multi-matrix technology and are characterised by low water and methanol transport at marginal membrane thickness.

Link:http://www.h2fc.com/reframe.php?top=/global/indust.shtml&bot=/industry/components/index.shtml

3. Fuel cell market

3.1. Market penetration

The majority of the fuel cell industry is still supply-driven and supported by government R&D funding and demonstration programmes, but a growing number of companies are moving to a demand-driven direction and commercialisation phase. At this stage there is typically industry rationalisation, as an increased number of companies enter bankruptcy or merge with competitors.[10] However, there has been a 50% increase in fuel cell system shipments to customers in 2008 and increasing trend continued in 2009 as Fuel Cell Today's Industry Reviews indicated (Table 3). Nanotechnology has great potential in the fuel cell sector. Dr. Kauranen and Prof. Jumppanen estimate that at the moment nanotechnology can cover about 10-15 % of the fuel cell market size and investment in nanotechnology R&D accounts for about 3-5% of the organisations' fuel cell activities[8].

Table 3. *Global fuel cell market growth* [8,10,11,12,13,14]

Year	2013	2009	2008	2007	2006
Amount of fuel cell units shipped	200 000	24 000	18000 (Mostly DMFC, PEM)	12 000 (mostly DMFC)	7 500
Market size	1,9-5 billion USD (estimation)	0,8 billion USD (estimation)	570 milj.USD	450 milj. USD	387 milj. USD
R&D, H_2&FC (public)	2-3 billion, private funding 5-10 times higher than public (estimation[8])	2 billion USD (estimation)	1,2 billion USD	1,0 billion USD	

Prof. Jumppanen summarises the future prospects; "Fuel cell R&D is predicted to continue at its current level in 2010 due to existing extensive national development programs and partnership projects. After 3-5 years there will be a significant need to increase the amount of private funding to get competitive products to the market. The commitment of large corporations and OEM´s will be also crucial to make major market breakthroughs and get fuel cells to mass products."

3.2. Fuel cell activities geographically

As of 2007, most of the fuel cell activities are headquartered in North America, followed by Japan and Germany, as indicated in Table 4. The location of fuel cell manufacturing and R&D activities were about the same. In addition, activities were noted in the UK, The Netherlands, Finland, Denmark, Sweden, Belgium, France, Ireland, Italy, Switzerland and Spain. 60% of reporting companies had been involved in fuel cell related activities for ten years or less, which shows the youth of the fuel cell sector.[11]

Table 4. *Location of the fuel cell activities headquarters 2007*[11].

Region	%
North America	59
Japan	12
Germany	11
Other countries	18

The Table 5 indicates that North America had the greatest manufacturing capacity in 2008 and Europe the largest amount of units shipped. In Europe Germany might have the highest future potential, because of national funding and subsidies[8]. On the other hand competition from Asia is growing. The largest increase in market potential in future is seen in India, Middle East and the Latin America nations by the Fuel Cell Industry Review 2009[11]. Canada has already a strong position on the market, with many large international companies located there.

Table 5. *Fuel cell industry manufacturing capacity and unit shipped during the year 2008* [11].

Region	Manufacturing capacity, %	Unit shipped, %
North America	69	21
Europe	11	53
Asia	20	21

World commercial fuel cell demand in 2008 was quite evenly divided into Western Europe, United States, Japan & other regions, as seen from Table 6. In the future product sales are expected to grow, especially in China and other developing countries, but four-fifths of all commercial demand in 2018 is still calculated to come from the US, Western Europe, Japan, Canada and South Korea[14].

Table 6. *World commercial fuel cell demand on 2008* [14].

Region	Fuel Cell demand %
Western Europe	29
United States	25
Japan	20
Other Regions & Countries	26

3.3. Fuel cell business on Europe

About one hundred European companies indicated in their webpages that they work with fuel cells and related material, components or products, either now or in the near future. Companies in the component category worked with fuel cell catalysts, membranes, bipolar plates and other corresponding components. These figures are based on ObservatoryNano research carried out at the beginning of 2010. According to this study, half of the companies are located in the value chain as a system integrator. 43% of companies were producing material, components or fuel cells and stacks, as shown in **Figure 2**. The companies located in the early part of the value chain are potential users of nanotechnology, but its benefits affect the whole value chain and results can be seen finally by system integrators and distributors with better end product performance and lower price. Naturally the share of companies solely focusing the distribution of fuel cells or fuel cell applications is still small, as this is a phase in which products are just entering to the market. About 25% of the companies indicated that they would not have a fuel cell product on the market in the near future.

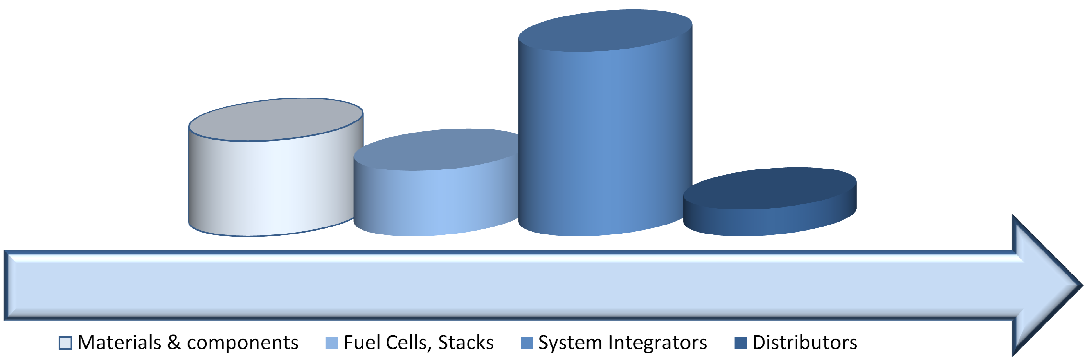

Figure 2. *European companies (103 in total) that work with fuel cells and fuel cell related materials, components and products now or in the near future. Companies are located in several places on the value chain: Materials & components (26%), Fuel Cells/stacks (18%), System integrators (50%), and Distributors only (7%). These figures are based on ObservatoryNano research carried out in 2010.*

38% of European fuel cell companies are headquartered in Germany and 14% in the United Kingdom. Several fuel cell-related companies are located also in Finland, Italy, Sweden, Switzerland and Denmark, as seen from Figure 3. Small and medium size companies were predominant with about 66% share from all the studied companies. 48% of all the companies focused only the fuel cell related business. The equivalent figure for small and medium sized companies was 65% and 14% for large companies. A more detailed list of companies is presented in appendix 1.

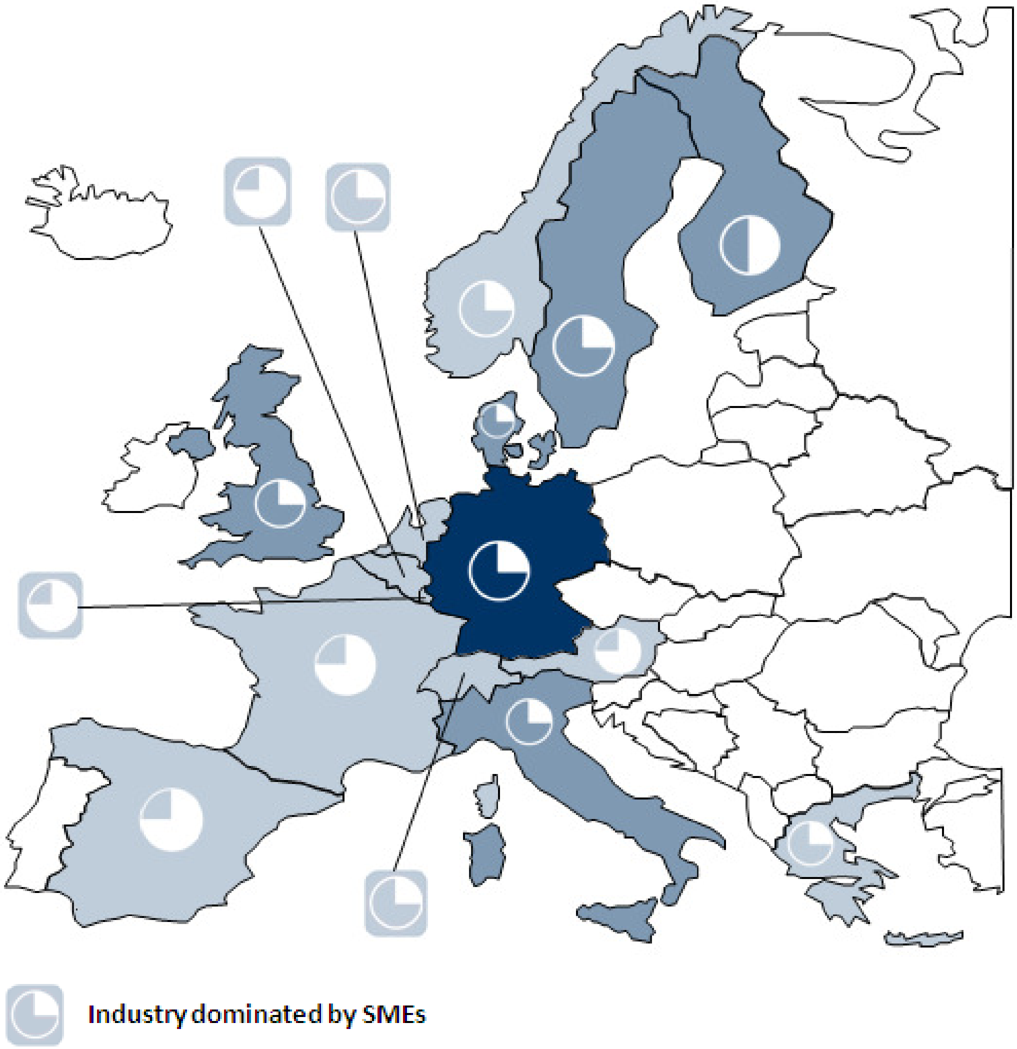

Figure 3. *European fuel cell companies. The darker blue indicates more companies are located in the country. (SME: under 250 employees) Amount of companies is based on research carried out by the ObservatoryNano-project in 2010.*

3.4. Market share of the fuel cell applications

Especially stationary, back-up power and material handling fuel cell applications sales increased in 2009 [13]. In 2008 the fuel cell market size increased in all of the main application sectors, but fuel cell transport applications took the biggest share of the market, measured by the number of shipments denoted FuelCell Today´s report (2009). In Europe the release of the FCH JU (Fuel Cell and Hydrogen Joint Undertaking) funding was estimated to affect transport sector market growth positively in future, especially if a large scale bus demonstration projects starts. In addition interest in fuel cell marine applications has risen in Europe in 2008, after marine shipping was included in the EU Emissions Trading Scheme. Forklifts also belong to a group of growing potential. PEM and DMFC electrolyte types were and will be dominated by transport applications. [10]

Leisure applications (boats, caravans) were the biggest product group in the portable fuel cell sector in 2008, with a market size of $80.1 million [15]. Portable fuel cells applications will have the greatest potential in future and are moving from a supply-driven to a demand-driven model by 2010. [10] It is expected that the market for portable fuel cell applications will reach $4.4 billion by 2015[15]. The World Fuel Cells Report projected that in 2018 portable fuel cell products will account for 98% of total fuel cell sales (approximately 9,95 million units).[14] Market growth was projected to begin in Asia with mobile phones as the first commercial high volume products. Market growth outside of Asia will begin at the end of 2013. DMFC is estimated to be dominant electrolyte type in mobile phones and fuel cell toys, and will be developed also for military use. Military and emergency services are moving towards SOFC by 2013. [10]

In the stationary sector we have already seen market demand for large stationary CHP (combined heat and power), UPS, power plants and PEM micro-CHP (only in Japan). In Europe and the USA initial adoption of mCHP units' will be through governmental programmes. Electrical power generation applications of fuel cells will represent less than 1% of the total number of units sold in 2018, but in value terms it´s share is the largest[14]. PEM dominates in small stationary applications, whereas SOFC is on a late stage of testing and will be commercially available by 2013. However, the number of SOFC will increase later in Europe and Japan. Large stationary units mainly employ PAFC and MCFC electrolyte types. [10]

4. References

[1] Wikipedia/fuel cell, http://en.wikipedia.org/wiki/Fuel_cell, Accessed 10th of July 2009

[2] ObservatoryNano Fuel Cells and Hydrogen production and storage report http://www.observatorynano.eu/project/catalogue/2EN.FC/, Accessed 20th of May 2009

[3] Original picture by Marc Marshall, Schatz Energy Research Centre, http://americanhistory.si.edu/fuelcells/basics.htm#q2, Accessed 20th of May 2009

[4] http://ina.unizar.es/zeocell/default.htm, Accessed 15th of June 2009

[5] Fuel cell technology and application. B.J. Holland1, J.G. Zhu1, and L. Jamet, Faculty of Engineering, University of Technology, Sydney, P.O. Box 123 Broadway, NSW 2007 http://services.eng.uts.edu.au/cempe/subjects_JGZ/eet/AUPEC01_111.pdf

[6] U.S. DOE Fuel Cell Activities, Department of Energy (DOE), Fuel Cell Technologies Program, Presented at: Seminar on Fuel Cells for Power Production and Transport: Obstacles to Commercialization

May 28, 2009 Espoo, Finland. http://www.stvif.fi/dms/show/770, Accessed 15th of June 2009

[7] Fuel cell technology and application. B.J. Holland1, J.G. Zhu1, and L. Jamet, Faculty of Engineering, University of Technology, Sydney, P.O. Box 123 Broadway, NSW 2007 http://services.eng.uts.edu.au/cempe/subjects_JGZ/eet/AUPEC01_111.pdf

[8] Expert interviews in 2009: Prof. Jumppanen & Dr. Kauranen, Finland

[9] Nanomaterial Roadmap 2015 SWOT Analysis Concerning the Use of Nanomaterials in the Energy Sector. Sixth Framework Programme, funded by the European Commission, http://www.nanoroad.net/download/swot_e.pdf, Accessed 20th of May 2009

[10] Fuel Cells: Emerging Markets, Industry Review 2009. Fuel Cell Today

[11] Fuel Cell Today Worldwide, Fuel Cell Industry Survey 2007, Fuel Cell Council, Hydrogen and Fuel

Cells Canada, Fuel Cell Europe, Fuel Cell Commercialisation Conference Japan, PriceWaterHouseCoopers

[12] Global Fuel Cell Market to Reach $2.6 Billion in 2009, http://powerelectronics.com/news/fuel-cell-market/, Accessed 1st of September 2009

[13] 2009 Annual Report of The Hydrogen and Fuel Cell Technical Advisory Committee, The State of Hydrogen and Fuel Cell Commercialization and Technical Development http://www.hydrogen.energy.gov/pdfs/2009_htac_annual_report.pdf

[14] World Fuel Cells (Industry forecasts for 2013 & 2018) http://www.the-infoshop.com/report/fd87052-fuel-cells.html, http://www.freedoniagroup.com/brochure/25xx/2502smwe.pdf, Accessed 1st of September 2009

[15] http://www.qsinano.com/apps_fuelcell.php

Expert interviews

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Appendix 1: *List of European Companies indicating that they have a fuel cell related business now or in the future. (Research carried out at the beginning of 2010 by the ObservatoryNano-project.); http://www.observatorynano.eu/project/filesystem/files/EconomicAnalysis_FuelCells_Appendix1.pdf*