International Energy Agency (IEA) Advanced Fuel Cells

Implementing Agreement

ANNUAL REPORT 2013

July 2014

iea Energy Technology Network

This Annual Report has been prepared by the National Member, Operating Agents and the Secretariat of the Executive Committee, who also acted as Editor.

Copies can be obtained from the programme's web site at **www.ieafuelcell.com** or from:

Dr Louise Evans
Secretary, IEA Advanced Fuel Cells Executive Committee
The Gemini Building
Fermi Avenue
Harwell
Didcot, OX11 0QR
United Kingdom

Table 1 Contributing Authors

Name	Organisation	Country
Prof Dr Viktor Hacker	Graz University of Technology	Austria
Mr Lennart Andersen	Danish Energy Agency	Denmark
Dr Jari Kiviaho	VITO Technical Research (VTT)	Finland
Mr Thierry Priem	Alternative Energies and Atomic Energy Commission (CEA)	France
Professor Dr Detlef Stolten	Forschungszentrum Jülich	Germany
Dr Martin Müller	Forschungszentrum Jülich	Germany
Dr R Can Samsun	Forschungszentrum Jülich	Germany
Dr Igor Derzy	Ministry of Energy and Water	Israel
Dr Ing Stephen McPhail	National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)	Italy
Mr Hiroyuki Kanesaka	New Energy and Industrial Technology Development Organization (NEDO)	Japan
Dr Tae-Hoon Lim	Korea Institute of Science and Technology	Korea
Dr Ulises Cano Castillo	Electrical Research Institute	Mexico
Mr Bengt Ridell	Grontmij AG	Sweden
Dr Stefan Oberholzer	Swiss Federal Office of Energy	Switzerland
Dr Xiaoping Wang	Argonne National Laboratory	USA
Dr Di-Jia Liu	Argonne National Laboratory	USA
Dr Rajesh Ahluwalia	Argonne National Laboratory	USA
Dr Nancy Garland	Department of Energy	USA

Contents

1. Chairman's Welcome

Welcome to the Annual Report of the Advanced Fuel Cells Implementing Agreement (AFC IA), a technology platform of the International Energy Agency (IEA).

Fuel cells are distinguished by:

- **High efficiencies** – conversion of fuel to electrical energy is generally significantly more efficient than with conventional technologies.
- **Low levels of pollutants** – lower than conventional technologies for power generation and transportation (NO_x, SO_x, fine particulates, etc). In the case of fuel switching to hydrogen for transportation, emissions of pollutants are zero at the point of use.
- **Reduction of CO_2 emissions** – using hydrogen for transportation leads to zero CO_2 emissions at the point of use.

Focusing on the transport sector, fuel cells are the only technology offering an uncompromising transformation of passenger road transportation that can be free of greenhouse gas emissions. Major car companies such as Hyundai and Toyota are promoting fuel cells now over other electric technologies. Longstanding stakeholders including Daimler, Ford and Honda, as well as Hyundai and Toyota, are working towards market introduction between 2015 and 2018. Other world players such as Volkswagen and BMW have stepped up their fuel cell development efforts.

As successful progress towards market-ready fuel cell cars is achieved, the challenge turns towards the fuel infrastructure (for example hydrogen infrastructure including mass storage) and the attention this needs in terms of concepts and programs to achieve implementation in the respective countries. Notable hydrogen infrastructure projects are under way in Japan, Scandinavia, Germany and California in the USA. Regulatory procedures as well as codes and standards will need to be adapted, harmonised and created where necessary. The reliability of the fuelling infrastructure will be subject to enhancement during the initial implementation period.

Any company or institution of a member country is invited to join our Annexes, in which the technical work to develop and understand fuel cells is being done.

Interested companies or institutions from non-member countries are welcome to contact us to consider membership. Moreover, we are happy to welcome companies and organisations to Executive Committee meetings on a sponsorship basis, providing direct access to the most current international technical discussions on fuel cells and the opportunity to expand an international network.

For further information, please see our website **IEA Advanced Fuel Cells** or contact us directly via email at: **Secretariat-AFCIA@ricardo-aea.com**.

Prof Dr Detlef Stolten
Chairman of the Advanced Fuel Cells Implementing Agreement

Detlef Stolten took over as Chairman of AFC IA in 2011 after previously serving as Vice Chairman.

Since 1998, Professor Stolten has been the Director of the Institute for Energy and Climate Research – Electrochemical Process Engineering at Research Centre Jülich, Germany. His research focus is the electrochemistry, chemical engineering and systems analysis for the DMFC, HT-PEFC and SOFC technology, particularly the reforming of middle distillates.

2. Introduction

The aim of the Advanced Fuel Cells Implementing Agreement (AFC IA) is to contribute to the research and development (R&D) of fuel cell technologies, deployment of fuel cell technologies and dissemination thereof for all our member countries and organisations.

The international collaboration that we create in the AFC IA aids R&D efforts by focussing on key areas by countries, research institutions and companies, through sharing information and new developments directly and rapidly. The collaboration between countries facilitates the creation of demonstration programmes, as well as identifying and working to lower the barriers for market introduction of fuel cell applications.

The AFC IA is in a unique position to provide an overview of the status of fuel cell technology, deployment, and the opportunities and barriers faced within our member countries. Our focus is to work together to improve and advance fuel cell technology.

Key Messages – Facts

Advanced Fuel Cells Implementing Agreement

- The technology for fuel cell electric vehicles is ready for market introduction. Hydrogen infrastructure remains an obstacle, but developments are addressing this. Two car manufactures already have semi-automated production of fuel cell vehicles.
- One third of all molten carbonate fuel cell (MCFC) systems in operation in the world are running on biogas.
- Catalysts – platinum alloys have higher performance and durability than straight platinum, producing very high performing materials.
- Catalysts – core shell catalysts are a rapidly developing area, and the first such example has been licensed to a Japanese company.
- Materials-based hydrogen storage has proved to be very challenging to achieve

Key Messages – Opinion

Advanced Fuel Cells Implementing Agreement

- Future solutions for transportation will very likely encompass a notable share of fuel cell vehicles, because of their high efficiency, high cruising range and the option to easily and rapidly refuel.
- Fuel cells have achieved significant ramp-up of unit production and deployment over the last few years. What is needed now is the market, visibility and policy support. Policy support can be technology neutral, but it is needed.
- Several US original equipment manufacturers (OEMs) of the fuel cell companies have reported that the companies are near break-even in 2013 [1].
- The efficiency and electrochemistry of solid oxide fuel cell (SOFC) stacks are essentially solved – state-of-the-art SOFC show reasonable efficiencies and stable electrochemical performance. The problems remaining with SOFC systems are mechanical.

2.1 NATIONAL OVERVIEW

Here we provide a brief summary of each member country's position with regard to fuel cells in 2013, which is often related to their national priorities within the energy arena. At the end of each country profile there is a table summarising the developments and state of play of fuel cell technologies within the country.

2.1.1 Austria

The major energy policy goals of Austria are to stabilise energy consumption at 1,100PJ by 2020 and to reduce greenhouse gas emissions by 16% (base year: 2005) by 2020. Renewable energy in Austria contributes 26% and

[1] Plug Gains on US Funding to Boost Range of Electric Trucks, January 7th, 2014, Bloomberg.com, www.bloomberg.com/news/2014-01-07/plug-power-rises-on-u-s-funding-to-double-electric-truck-range.html

by 2020 this figure should be 34%. The R&D programmes strategically cover fuel cell topics to support the development of innovative companies in this field. EUR 2 million to EUR 4 million is spent yearly on national fuel cell and hydrogen projects.

Fuel cell projects in the mobility sector are focused on competitiveness and solutions to modernise and 'green' the transport system. In total, about 500 projects with public funding of EUR 118 million have been supported over the last few years. The new programme, 'Mobility of the Future (2012–2020)', provides an annual budget of EUR 14 to EUR 19 million for R&D in the transport sector.

The option to use fuel cells domestically in Austria fell out of favour, but has recently returned with newly released building codes. By 2014/15 a major demonstration programme including 30 micro combined heat and power (m-CHP) fuel cell systems will take place. It is under negotiation between the Austrian utility companies, manufacturers and ministries.

Table 2 Summary of Austrian Fuel Cell Information

Fuel cell	Infrastructure
Hydrogen filling stations operational	One public station in Vienna, two non-public stations in Graz and Sattledt.

2.1.2 Denmark

The Danish Government's long-term goal for the country's energy policy is to be 100% independent of fossil fuels by the year 2050. According to the Energy Political Agreement of March 2012, the key goals for 2020 are:

- More than 35% renewable energy in final energy consumption.
- Approximately 50% of electricity consumption to be supplied by wind power.
- 7.6% reduction in gross energy consumption in relation to 2010.
- 34% reduction in greenhouse gas emissions in relation to 1990.

Consequently, in the longer term, hydrogen and fuel cell technologies can be part of the solution to convert and store the energy and thereby contribute to the integration of fluctuating renewable energy in the Danish energy system.

Table 3 Summary of Danish Fuel Cell Information

Fuel cells		Details/ comments
MW installed and operational	912kW	Danish companies have installed an additional 2,046MW abroad
Number of domestic stationary units	62 units	Danish companies have installed an additional 60 units abroad
Number of other stationary units (large scale)	250 units	Danish companies have installed an additional 652 units abroad
Number of operational fuel cell vehicles	9 vehicles	An additional 12 Danish vehicles are abroad Additionally, Hyundai are operating 17 i35 cars in Denmark
Hydrogen filling stations operational	3 stations in operation	

2.1.3 Finland

The Finnish Fuel Cell Programme aims to speed the development and application of innovative fuel cell and hydrogen technologies for growing global markets. The specific goals in Finland are to increase the share of renewable energy to 38% by 2020 and to create national pilot and demonstration projects in new energy technologies, including fuel cells. In research and development activities, the target is to put the emphasis on new renewable energy sources such as fuel cells.

Between 2007 and 2013, the Finnish Fuel Cell programme has facilitated more than 70 successful projects, with more than 60 companies involved. Finnish organisations have benefited from having taking part in 17 Fuel Cells and Hydrogen Joint Undertaking (FCH JU) funded projects with a total value of EUR 61 million. Highlights from these projects include:

- The first commercial applications of fuel cell back-up power for telecommunications base stations and portable back-up power.
- Finland's first commercial hydrogen refuelling station.
- Significant advances in CHP based on SOFC. The first 20kW unit was demonstrated for more than 6,000 hours in Vaasa using landfill gas.
- Finnish SOFC research is now recognised as state of the art worldwide.
- Companies from industries such as energy, metals, electronics, chemicals, mechanical engineering and many others have worked together in thematic workshops and helped to form value proposition analyses for fuel cells.

At present, the competiveness of the Finnish industry is in peril. New innovative products are urgently needed to improve the industrial competiveness. Therefore, it would be worthwhile for the Finnish industry to invest in fuel cell and hydrogen applications, where the international industry base is still modest but advancing. The potential in this area is huge because the variety of possible applications is enormous and there is much space for technical advances, areas were the Finnish industry is traditionally strong.

2.1.4 France

The French National Road Map on Hydrogen and Fuel Cells is organised into four focus areas, with agreed timescales and budgets:

1. Hydrogen/Renewable Energy convergence - Hydrogen from Renewable Energy, Hydrogen for Renewable Energy, five to seven years,150-200 million EUR with three R&D projects and three demonstration projects expected.
2. Towards a new generation of electro-mobility - Broadening the EV Markets, ten years, 200 million EUR with two R&D projects, three demonstration projects and one industrial pre-deployment expected.
3. H2FC for a sustainable city - H2FC as a component of eco-districts and smart grids, ten years, 150-360 million EUR with one R&D project and six demonstration projects expected.
4. H2FC, driver of national and international growth - Exporting tomorrow's energy technologies, five years, 105-180 million EUR , with one demonstration project and four industrial pre-deployment projects expected.

Table 4 Summary of French Fuel Cell Information

Fuel cells		Details
Number of non-domestic stationary units (large scale)	1 (360 kW): H_2 and fuel cell system coupled with a PV plant for peak shaving on electric grid	Myrte Project (Corsica) led by AREVA
Operational FC vehicles	F-City H2: 5 kW range extender system	FAM Automobiles/ Michelin
	HyKangoo: 5 kW range extender system	SymbioFCell, Renault, Solvay
	GreenGT H2: 300 kW Fuel Cell racing car to be engaged for real in the Le Mans race in June 2013	GreenGT, SymbioFCell
	Forklift fleet testing (9 units) on Air Liquide plant	Hypulsion (GV Axane/Plugpower)

2.1.5 Germany

In Germany, hydrogen and fuel cell technology play an essential role in the anticipated future of mobility and energy supply. In 2006, to guarantee the further development of these technologies, the Government, industry and science began a strategic alliance called the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) to speed up the process of market preparation of products. The total budget of NIP, invested over a period of 10 years up to 2016, amounts to EUR 1.4 billion.

The targets established by NIP are:

- Accelerating market development through targeted support and promotion of hydrogen and fuel cell sectors in mobile, stationary and portable areas.
- Strengthening value chains and added value in Germany.
- Securing technological leadership and implementing the technology in Germany.
- The focus is large-scale demonstration projects and R&D projects. Specific programme areas within NIP are Transport and Hydrogen Infrastructure, Hydrogen Provision, Stationary Energy Supply and Special Markets.

Table 5 Summary of German Fuel Cell Information

		Details/ comments
MW installed and operational	2.35MW [3]	
Number of domestic stationary units	400 units	Only Callux, as of 12.02.2014: 2,900,000 hours operation, 1,700,000kWh electricity produced [4]
New in 2013	Approximately 100 units	
Number of operational fuel cell vehicles	112 cars and 15 buses	Information as of 2007
Number of operational fuel cell vehicles	Special markets: 5,400 systems produced in 2013 [1]	Clean Energy Partnership (CEP) fleet [5]
Portable units	24,000	Number of units sold by SFC, German company (Press Release from 05/2012)
Hydrogen filling stations operational	27 stations in Clean Energy Partnership (CEP) 15 available to the public	

[3] Information from VDMA Fuel Cells Association, Konjunkturspiegel für die Brennstoffzellen-Industrie 2013
[4] Information from the Callux Project: www.callux.net
[5] Information from the CEP: www.cleanenergypartnership.de/

2.1.6 Israel

The development of fuel cells and hydrogen technologies in Israel is driven by private companies, academic research and the Government, individually and in collaboration. In 2010, the Government launched a national programme establishing Israel as a centre of knowledge and industry in the field of fuel alternatives for transportation, with fuel cells promoted as a viable option.

There are fuel cell research groups in seven universities, and several highly advanced industrial fuel cell enterprises conducting R&D and demonstration programs. The programs span a broad range of applications including stationary and automotive, based on SOFC and Alkaline Fuel Cell (AFC) technologies and using methanol, hydrogen and other alternatives as the fuel.

R&D programmes support the development of fuel cells and their applications, including the Transportation Electric Power Solutions group (TEPS), begun in 2011 as a unique collaboration between industry, academia and Government, to promote advanced fuel cell technologies and solutions. The Government supports innovative research in this area; invests in and encourages private companies; supports national infrastructure and supports international cooperation and collaboration. In 2012, the total of Governmental support to these programmes was about USD 10 million.

2.1.7 Italy

In 2013, the National Energy Strategy to 2020 for Italy was published with its focus being to reduce the cost [6] and dependence on energy imports [7] for Italy whilst maintaining the environmental targets [8]. These objectives should be achieved through increasing energy efficiency [9] and the use of renewables [10], across seven flagship approaches:

1. Fostering across-the-board energy efficiency.
2. Promoting a competitive gas market (with the aim of turning Italy into a main Southern European hub for natural gas).
3. Strengthened support for Renewables (including storage systems).
4. A domestic electricity market fully integrated with the European market.
5. Restructuring the refining industry.
6. Sustainable raising of domestic hydrocarbon production.
7. Modernising the governance system of the energy sector.

The Energy Strategy requires current technologies to be widely deployed by 2020, including hydrogen and fuel cell technologies. Italian stakeholders are developing a political platform for the definition and implementation of a specific Italian Hydrogen and Fuel Cell Roadmap. There is little focus on fuel cell and hydrogen technologies centrally, but local activities are active at the forefront of European deployment of all scales of fuel cell technologies.

A significant development in 2013 has been the scaling up of SOFC power’s manufacturing facilities, from a few tens of kW per year to 2MW/year of SOFC stack roll-out, increasing the area of its factory by a factor of four. SOFCpower’s main focus is the residential-scale CHP market, but their units can also be used with biogas and in waste-to-energy (WTE) applications.

[6] A €14 billion reduction

[7] Reduction from 84% to 67%

[8] Environmental targets are to reduce GHG emissions by 19% compared to 1990

[9] Energy efficiency should lead to a reduction of 24% of primary energy consumption

[10] Renewables will be up to 20% of total energy consumption, becoming the main source for electricity generation with 36–38% (from 23% in 2010) of total make-up of electricity generation

The second major, independent, industrial player in Italy is Electro Power Systems (EPS), which deploys back-up power systems (either fed by hydrogen or incorporating the complete cycle from renewable-assisted water electrolysis back to hydrogen oxidation in the same unit), with over 3,000 units worldwide.

The INGRID project, which aims to provide effective balancing support to the local electricity grid by means of a 39MWh energy storage facility that will combine a 1.2MW electrolyser with a 1 ton hydrogen storage facility, utilising renewable energy from solar and wind farms in the Puglia region, is still continuing. The hydrogen generated will be utilised by fuel cells either for grid energy or for transport purposes.

Italy has one new large-scale combined cooling, heat and power (CCHP) fuel cell installation underway, with funding agreed for a 400kW molten carbonate fuel cell (MCFC) system at ENEA in Portici. The final negotiations are underway. There are several other large scale installations that may progress in the near future [11].

Table 6 Summary of Italian Fuel Cell Information

		Details/ comments
MW installed and operational	More than 1MW, over 500 systems	installation of first large-scale systems (400kW) under negotiation
Number of domestic stationary units New in 2013	35 25	A further 125 are being installed
Number of other stationary units (large scale)	350	Remote systems for telecom repeater stations, EPS
Number of operational FC vehicles	5	Milano and Bolzano
Hydrogen filling stations operational	10 stations, although not all are active	

2.1.8 Japan

Japan is a leading country in the field of fuel cells, both for residential applications and for passenger cars.

Commercialisation of ENE-FARM micro-CHP residential fuel cell products has been particularly successful. The first of these products were launched in early 2009, and the total number of installed systems was over 57,000 by the end of October 2013. A further subsidy round for ENE-FARM was announced in December 2013 with 20 billion JPY made available for 50,000 units (200 million USD, 140 million EUR). This funding will provide a subsidy of 0.37M JPY for each PEFC unit (3,700 USD, 2,600 EUR) and 0.43M JPY for each SOFC unit (4,300 USD, 3,100 EUR), respectively.

[11] Proposed MCFC installations, all to be supplied by Fuel Cell Energy Solutions (Germany):
- 400kW MCFC system at INFN, Frascati. Funding not yet requested.
- Two 400 kW systems fed with biogas from anaerobic digestion of the organic fraction of MSW from Ariccia, south of Rome.
- A private commission for one or two 400kW CHP systems fed with natural gas; negotiations are ongoing.
- The waste management agency of Terni is in its first stages of contact with suppliers for a system fed with biogas.
- Three municipalities near Milan (Rho, Pero and Settimo Milanese) are concluding negotiations with suppliers for a biogas fed system.

The government subsidy for ENE-FARM products will cease in 2015, with the assumption that the price for a domestic fuel cell system will have decreased to around 700,000 – 800,000 JPY by 2016. The target sales price by 2020-2030 is 500,000 – 600,000 JPY in the NEDO (government) scenario. In April 2013 Panasonic released a new ENE-FARM model priced at just less than 2 million JPY (approx. $20,000, €14,000). To date the price of ENE-FARM products has dropped in line with expectations.

Japan has a number of car manufacturers that are developing fuel cell systems for transport. Toyota announced they would jointly develop FCEVs with BMW on January 24, 2013. Nissan, together with Daimler and Ford, announced the joint development of FCEV technology on January 28, 2013. Meanwhile, Honda announced the joint development of FCEV technology with GM on July 2, 2013.

Toyota's new-generation sedan-type FCEV (FCV CONCEPT) was unveiled in 2013 at the Tokyo Motor Show, with Honda unveiling their new FCEV concept at the Los Angeles Motor Show in 2013. Both Toyota and Honda announced that sales of sedan-type FCEVs will start around 2015.

In 2011 10 Japanese energy companies and three automakers made a joint statement committing to 100 hydrogen refuelling stations in 2015 based around four main urban areas, to coincide with the market introduction of FCEVs from Toyota, Honda and Nissan. The key issue for FCEVs, to enable full commercialisation in 2025-2030, remains cost reduction of the fuel cell system itself.

A new research focus of triple combined power that uses SOFC systems in conjunction with a gas-turbine and a steam-turbine, was begun in 2012, with the emphasis on elemental technology development. Two new NEDO programmes have begun in 2013; one targets technology development for SOFC for commercialisation and has a budget of 1.24 billion JPY in 2013, and will run to 2017; the second will target technology development for hydrogen utilisation, and with a budget of 2 billion JPY in 2013, and will run to 2017.

Table 7 Summary of Japanese Fuel Cell Information

		Details/ comments
MW installed and operational	Approximately 40MW [12]	Ene-Farm as of Oct 2013
	1.6MW	PAFC technology (estimation)
Number of domestic stationary units	57,000 units	Ene-Farm
New in 2013	13,000 units	From April to October 2013
Number of other stationary units (large scale)	10	PAFC technology, 100kW those shipped in 2012 only
Number of operational fuel cell vehicles	55 cars and buses	
Hydrogen filling stations operational	17 stations	

[12] Assuming each unit is 700W. Some units are 750W.

2.1.9 Korea

The national programme of fuel cells in Korea is driven mainly by the Ministry of Trade, Industry & Energy (MOTIE), which works for the commercial adoption of fuel cell as a strategic technology for future hydrogen infrastructure, and promotes innovative technology that will reduce the price and enhance performance and durability of fuel cells. The budget in 2012 was KRW 46 billion (approximately USD 43 million, Government funding only). Total electricity production from fuel cells in 2012 was 389GWh.

The RPS (Renewable Portfolio Standard) was introduced in 2012 and applies to stationary fuel cells as a renewable energy technology. RPS mandates the portion of renewable electricity to be generated to every power company with a capacity of 500MW or larger. The required portion will increase from 2% in 2012 to 10% in 2022.

In 2010, the 'Dissemination of Green Home Program' began, with the target of constructing one million green homes by 2020. Fuel cells are included in the list of power sources with the Korean Government subsidising 80% of the installation costs of fuel cells in 2012. The subsidy available will be reduced gradually to 30% by 2020.

Fuel cell vehicle commercialisation is underway with the second phase of the demonstration programme running from 2010 to 2013. One hundred fuel cell vehicles are in operation providing data on durability, operational cost and the effect on the environment. There are 14 hydrogen fueling stations in operation and the Government target is to increase this number to 48 by 2015 and 500 by 2030. The focus will be on both onsite hydrogen reforming and hydrogen delivery (by truck) for refuelling stations.

Table 8 Summary of Korean Fuel Cell Information

		Details/ comments
MW installed and operational	MCFC : 113MW PAFC : 4.8MW PEFC : 1,97MW	MCFC : 1.2MW/2.4MW POSCO Energy Products PAFC : 400kW UTC Products PEFC : 1kW FCP, GS Fuel Cell Products
Number of domestic stationary units New in 2013	1,970 units 260 1kW units	(2006–2013, 1kw residential use)
Number of other stationary units (large scale) New in 2013	MCFC: 43 units PAFC: 12 units 58.8MW	MCFC
Number of operational FC vehicles	120 passenger cars, 6 buses	SUV equipped with 100kW stack, 70MPa (700 bar) Tank (6kg H_2[13]) Bus equipped with 200kW stack, 70MPa (700 bar) (30kg H_2)
Hydrogen filling stations operational	14 stations (2 under construction)	

[13] H2 denotes Hydrogen.

2.1.10 Mexico

Mexico enjoys very favourable conditions to adopt fuel cells in such applications as utility transportation and back-up power. Such conditions arise from several positive situations: its favourable geographical location (Ballard has established a manufacturing facility in Mexico near the US border) and Mexico being one of the largest automobile manufacturers in the world with a well-developed related industry and very keen on new technology products. According to a global firm [14], Mexico is, for some industries like electronic goods, the most competitive country in the world in terms of manufacturing costs, stating that these are approximately 25% lower than in the United States and even lower than in the BRIC countries.

In recent months an Energy Reform allowing more private participation in this sector was approved by Congress, which should facilitate the introduction of emerging energy technologies. Scientists have made efforts, together with visionary congressmen, to introduce a hydrogen initiative to enact hydrogen technologies into the newly reformed energy sector vision. Although Mexico has not included fuel cell technologies specifically in its present energy roadmap, the energy reforms introduced by the present Government facilitate the introduction of clean technologies in a more market-driven atmosphere, where final users should be presented with more than fossil-fuelled options for electricity generation.

Table 9 Summary of Mexican Fuel Cell Information

		Details/comments
MW installed and operational	0.28MW [15]	From a recent finance report
Portable units	Approximately 40kW	Several low power (0.5 – 2kW) FC (PEM) are on test in different R&D organisations.

2.1.11 Sweden

The hydrogen and fuel cell activities in Sweden are driven from the bottom-up, by developing companies, academic research and experts. The aim of the Swedish Government is to observe the market and to support industry and universities with national activities focused on a new research programme on PEFC and SOFC (about EUR 600,000 per year) and participation in IEA and EU activities (about EUR 70,000 per year). Another programme to cover the international business development is under preparation and will begin in 2014. The new programme has a focus on transport applications, but it is still under development.

[14] Alix Partners, cited in the Electronics Trade and Investments Reports by ProMexico

[15] Considering that Ballard units come in 2.5 and 5kW, installed capacity might be larger, as it has been reported that 114 units of Ballard's ElectraGenTM-ME have been installed in Mexico. Other units commercialised by Microm should also add up to this number

Table 10 Summary of Swedish Fuel Cell Information

		Details/comments
MW installed and operational	Less than 1MW	Some back-up power units are installed most for test or demonstrations
Number of domestic stationary units	Less than 10	A few PEFC units running but not really as residential fuel cells
Number of operational fuel cell vehicles	2 Hyundai FCV cars in Malmö as part of an EU-project	The two Hyundai cars as a part of the EU Next Move project. The region, Skåne, is sharing the project with the City of Copenhagen
Portable units	A fast growing number of myFC Powertrekk, with PEM technology. A portable charger for mobile phones, GPS or similar USB connected units	myFC a Swedish company has commercialised the Powertrekk unit. It is now sold at large home electronics stores [16]
Hydrogen filling stations (HRS) operational	One movable HRS in Arjeplog mainly for winter testing. There are two HRS in the city of Malmö, one new 70MPa (700 bar) moveable station that is placed there temporary during the NextMove project. The old HRS from 2003 is mothballed but has been tested with good results. Today it can deliver hydrogen up to 35 MPa (350 bar)	

2.1.12 Switzerland

Switzerland is focusing on reducing domestic emissions, through an incentive fee on thermal fossil fuels to encourage energy efficiency and renewable energy renovations, and emission caps for passenger cars at average CO_2 emissions of 130g of CO_2/km starting in 2015.

Table 11 Summary of Swiss Fuel Cell Information

		Details/comments
MW installed and operational	0.26MW	1 MCFC plant with 240kW, a few domestic SOFC systems (1-3kW), a few 1-2kW systems for UPS (Telecom)
Number of domestic stationary units	Approximately 15	Some are not in the field, but with the developers (Hexis)
Number of other stationary units	Approximately 10	One big MCFC plant, the others are small units for Uninterruptible Power Supply (UPS)
Number of operational fuel cell vehicles	5 buses and 5 other vehicles	5 buses from Daimler on regular services, a few other pilot and demonstration vehicles (municipal vehicle Hy.muve, a few passenger cars)
Hydrogen filling stations operational	Two, with a further one planned: • First one opened in spring 2012, using alkaline electrolysis producing 130kg H_2/day at 35MPa (350 bar). • Second at Belenos Clean Power Holding AG (not public, for R&D). • Third one in planning at EMPA (research), PV combined with electrolysis.	

[16] For more information on myFC see www.siba.se/product/15329724/powertrekk

2.1.13 USA

"As part of an all-of-the-above energy approach, fuel cell technologies are paving the way to competitiveness in the global clean energy market and to new jobs and business creation across the country."
Secretary Moniz, US Department of Energy, December 2013

The US Department of Energy's Fuel Cell Technologies Office aims to enable the widespread commercialisation of a portfolio of hydrogen and fuel cell technologies through applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges. The appropriation for FY12 was USD 103,624,000 and USD 95,844,000 for FY13. The key targets that many other countries also reference are:

Fuel cells:

- By 2015, develop a fuel cell system for portable power (less than 250W) with an energy density of 900Wh/litre.
- By 2017, develop a direct-hydrogen fuel cell power system for transportation with a peak efficiency of 60% and 5,000-hour durability, that costs USD 30/kW at high volume.
- By 2020, develop distributed generation and micro-CHP fuel cell systems (5kW) with an electrical efficiency of 45% and 60,000 hour durability that operate on natural gas or LPG and cost USD 1,500/kW.
- By 2020, develop medium-scale CHP fuel cell systems (100kW–3MW) with electrical efficiency of 50%, CHP efficiency of 90% ,and operate for 80,000 hours at a cost of USD 1,500/kW for operation on natural gas and USD 2,100/kW when configured for operation on biogas.
- By 2020, develop a fuel cell system for auxiliary power units (1–10kW) with a specific power of 45W/kg and a power density of 40W/litre at a cost of USD 1,000/kW.

Hydrogen storage:

- By 2017, develop and verify on-board hydrogen storage systems with specific energy of 1.8kWh/kg (5.5 wt%) and energy density of 1.3kWh/litre (0.040kg hydrogen/litre).
- Ultimate full-fleet target of 2.5kWh/kg system (7.5 wt% hydrogen) and 2.3kWh/litre (0.070kg hydrogen/litre).

Table 12 Summary of US Information

		Details/comments
MW installed and operational	249MW (total from 2008–2013)	A total of 13,605 units An additional 27MW (1,558 units) were exported

2.2 THE INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) is an autonomous agency that was established in 1974. The IEA carries out a comprehensive programme of energy co-operation among 28 advanced economies, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The aims of the IEA are to:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

To attain these goals, increased co-operation between industries, businesses and Government funded energy technology research is indispensable. The public and private sectors must work together, share burdens and resources, while at the same time multiplying results and outcomes.

The multilateral technology initiatives (Implementing Agreements) supported by the IEA are a flexible and effective framework for IEA member and non-member countries, businesses, industries, international organisations and non-government organisations to research breakthrough technologies, to fill existing research gaps, to build pilot plants, to carry out deployment or demonstration programmes – in short to encourage technology-related activities that support energy security, economic growth and environmental protection.

More than 6,000 specialists carry out a vast body of research through these various initiatives. To date, more than 1,000 projects have been completed. There are 41 Implementing Agreements (IA) working in the areas of:

- Cross-Cutting Activities (information exchange, modelling, technology transfer).
- End-Use (buildings, electricity, industry, transport).
- Fossil Fuels (greenhouse gas mitigation, supply, transformation).
- Fusion Power (international experiments).
- Renewable Energies and Hydrogen (technologies and deployment).

The IAs are at the core of a network of senior experts consisting of the Committee on Energy Research and Technology (CERT), four working parties and three expert groups. A key role of the CERT is to provide leadership by guiding the IAs to shape work programmes that address current energy issues productively, by regularly reviewing their accomplishments, and suggesting reinforced efforts where needed. For further information on the IEA, CERT and the IAs, please consult www.iea.org.

2.3 THE ADVANCED FUEL CELLS IMPLEMENTING AGREEMENT

The scope of the Implementing Agreement for a Programme of Research, Development and Demonstration on Advanced Fuel Cells (AFC IA) is to advance the state of understanding of all Contracting Parties in the field of advanced fuel cells. It achieves this through a co-ordinated programme of information exchange on the research and technology development underway internationally, as well as performing systems analysis. The focus is the technologies most likely to achieve widespread deployment – molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC) and polymer electrolyte fuel cells (PEFC) – and applications of fuel cells, specifically stationary power generation, portable power and transport. There is a strong emphasis on information exchange through Annex meetings, workshops and reports. The work is undertaken on a task-sharing basis with each participating country providing an agreed level of effort over the period of the Annex.

The current period of the AFC IA is February 2009 to February 2014. The AFC IA applied to CERT, via the IEA Working Party on End-Use Technologies (EUWP), for a new period in September 2013, which will run from 2014 to 2019.

This report gives an overview of the status, progress and future plans of the programme, summarising the activities and decisions of the Executive Committee, as well as of each of the Annexes during 2013.

The scope of the AFC IA Programme for 2009 to 2014 is shown in Table 13.

Table 13: Scope of the Programme 2009-2014

Information Management Internal and external network	**Implementation and Application Issues** Reduction of barriers	**Technology Development** Stationary, Mobile, Portable
		MCFC, SOFC, PEFC
	Systems Analysis	**Systems Analysis**
Co-ordination within the Implementing Agreement Co-ordination with other Implementing Agreements Public awareness and education Direct input into CERT, EUWP and IEA activities in general.	Market issues Environmental issues Non-technical barriers (e.g. standards, regulations) User requirements and evaluation of demonstrations.	Cell and stack • cost and performance • endurance • materials • modelling • test procedures Balance of Plant • tools • availability • data base Fuel processing Power conditioning Safety analysis

2.4 CURRENT ANNEXES

Seven Annexes were active in 2013:

Annex	Title
Annex 22	Polymer Electrolyte Fuel Cells (PEFC).
Annex 23	Molten Carbonate Fuel Cells (MCFC).
Annex 24	Solid Oxide Fuel Cells (SOFC).
Annex 25	Fuel Cells Fuel Cells for Stationary Applications
Annex 26	Fuel Cells for Transportation
Annex 27	Fuel Cells for Portable Applications
Annex 28	Systems Analysis

Together, these seven annexes form an integrated programme of work from February 2009 to February 2014, comprising three technology-based annexes (MCFC, SOFC and PEFC) and three application-based annexes (stationary, transportation and portable applications), with the Systems Analysis Annex encompassing all these areas as shown in Figure 1.

2.5 HOW TO JOIN THE AFC IA

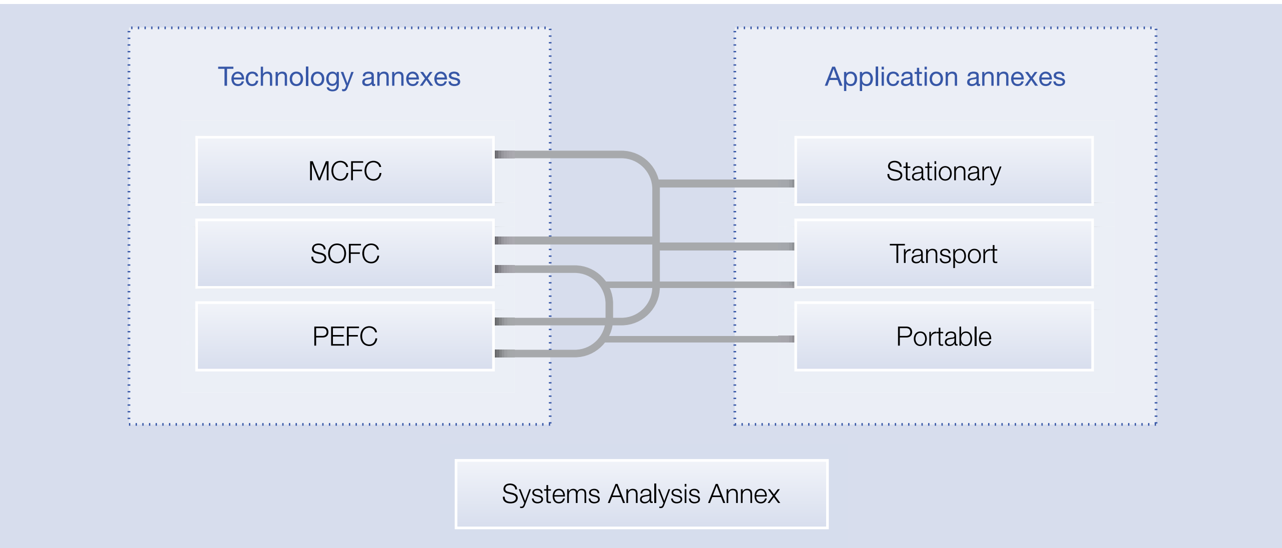
The IEA Advanced Fuel Cells programme welcomes new participants from IEA and non-IEA countries. It is a task-sharing activity, so we welcome countries with a significant programme of fuel cell research, development and commercialisation of this technology to become member countries.

Any company or institution of a member country is invited to join our Annexes, in which the technical work to develop and understand fuel cell development is carried out.

We also welcome individual companies, government agencies and industrial or academic organisations that work in this field to join as Sponsoring Organisations, which allows groups to join Annex meetings as well as to the Executive Committee meetings, providing direct access to the most current international technical discussions on fuel cells and the opportunity to further develop an international network.

If you are interested in joining the AFC IA, please contact the Secretary, Dr Louise Evans (Secretariat-AFCIA@ricardo-aea.com).

Figure 1: Active Annexes within the AFC IA Programme



3. Executive Committee Report

3.1 ACTIVITIES

Two Executive Committee (ExCo) meetings were held in 2013, the first in Salzburg, Austria and the second in Jerusalem, Israel.

Table 14 Executive Committee Meetings 2013

Meeting	Date and place that meetings were held
ExCo46	22 – 23 May 2013, Salzburg, Austria
ExCo47	18 – 19 November 2013, Jerusalem, Israel

After discussion within the Annexes and the Executive Committee, and preparation of the formal documentation, the AFC IA requested a new term at the EUWP Meeting on the 19th September 2013, for a period of five years, to run from February 2014 – February 2019. In December 2013 it was confirmed that the request had been granted by CERT without condition.

In 2012, the design of the Annual Report was updated to include Key Messages from the Annexes, and this approach has been further refined in 2013, with the aim to provide useful and accurate information to experts and policy makers alike via this route. The Implementing Agreement produces two newsletters a year, introducing the work of the group to a wide audience, and making these available through our website, aswell as a set of summary Key Messages, taken from the Annual Report. Annex 24 produced the report 'Yellow Pages of SOFC' which gives a clear summary of the status of SOFC technology and companies internationally, and is available through the IA website.

The production of a book from the activities of Annex 28: Systems Analysis continues, with the intention to produce a completed and published work in 2014. Additionally, in 2013, it was agreed that a further publication would be produced by the group, focusing on the roadmaps and plans underway in each Member Country to bring clarity and summary to this topic. The intention is to publish this work in 2014.

The web site of the IA (www.ieafuelcell.com) was actively maintained and updated, providing a resource for the members of the Implementing Agreement, a repository of on-going activity and a source of fuel cell information with the reports.

In 2013 the AFC IA voted to take forward the suggestions for two new Annexes, Modelling and Electrolysis. Preliminary work programmes were developed, with the appointment of Operating Agents and specific activities due to commence in 2014.

3.2 MEMBERSHIP

In 2013, the Advanced Fuel Cells Implementing Agreement welcomed Israel as a new full member to the Implementing Agreement. Full membership started in January 2013. The Executive Committee Members are Dr Igor Derzy of the Ministry for Energy and Water, and Dr Ela Strauss from the Ministry of Science and Technology.

Interest in joining was again expressed by China, and initial outreach was also undertaken with Brazil and Portugal.

The following re-elections were made in 2013 by unanimous agreement: Professor Detlef Stolten (Germany) appointed as Chairman and Dr Angelo Moreno (Italy) and Dr Nancy Garland (USA) as Vice-Chairs. Also, Alex Körner replaced François Cuenot as the IEA Desk Officer for the AFC IA.

In 2013 Laurent Antoni replaced Thierry Priem as the Member for France, with Thierry Priem remaining as the Alternate Member. Kristina Difs from the Swedish Energy Agency became the full Member for Sweden, with Bengt Ridell remaining as the Alternate Member, and for Finland Heikki Kotila retired with Jari Kiviaho become the full Member in the interim.

The following thirteen IEA member countries participated in this Implementing Agreement during 2013.

Table 15 Advanced Fuel Cells Implementing Agreement Member Countries

Country	Signatory Party	Date of Signature	ExCo Participants
Austria	Austrian Energy Agency (EVA)	September 2004	Dr Günter Simader Prof Dr Viktor Hacker
Denmark	Riso National Laboratory	September 2004	Mr Lennart Andersen Mrs Inger Pihl Byriel
Finland	Finnish National Technology Agency (TEKES)	May 2002	Mr Heikki Kotila Dr Jari Kiviaho
France	Commissariat à l'Energie Atomique (CEA)	May 2005	Dr Ing Laurent Antoni Mr Thierry Priem
Germany	Forschungszentrum Jülich	December 1992	Prof Dr Detlef Stolten Dr R Can Samsun
Israel	Ministry of Energy and Water Resources	December 2012	Dr Igor Derzy Dr Ela Strauss
Italy	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA)	April 1990	Dr Ing Angelo Moreno
Japan	New Energy and Industrial Technology Development Organisation (NEDO)	April 1990	Mr Kenji Horiuchi Mr Hiroyuki Kanesaka
Korea	The Korea Electric Power Corporation (KEPCO)	April 1998	Dr Tae Hoon Lim Dr Jonghee Han
Mexico	Electrical Research Institute	June 2006	Dr Jorge M Huacuz Dr Ulises Cano Castillo
Sweden	The Swedish Energy Agency (from December 1998, previously NUTEK)	April 1990	Dr Kristina Difs Mr Bengt Ridell
Switzerland	Office Féderale de l'Energie (OFEN)	April 1990	Dr Stefan Oberholzer
USA	Department of Energy	May 1995	Dr Nancy Garland Dr Shailesh Vora

3.3 FINANCING AND PROCEDURES

All activities under the Annexes of the Implementing Agreement are task shared. The only cost shared activity is the Common Fund, which provides funding for the Executive Committee Secretariat. The new funding arrangements were introduced in 2011, whereby there are three tiers of Common Fund contributions; the level of payment is led by a country's level of GDP. This funding arrangement was maintained in 2013.

3.4 KEY DECISIONS IN 2013

- It was decided by unanimous vote that Detlef Stolten (Germany) will remain as Chairman, with Nancy Garland (USA) and Angelo Moreno (Italy) as Vice Chairwoman/man for the next two years.
- Dissemination and information gathering activities for ExCo members have been agreed, to give a harmonised approach for all members to achieve. The new newsletter was highly commended and a standardised process for its distribution by members agreed.
- The AFC IA decided to contribute to the modelling work of the IEA as far as possible, by sharing the data from Annex 28: Systems Analysis as it becomes available.
- The AFC IA decided by unanimous vote to request a further term to 2019, and an extended scope to encompass Electrolysis and Modelling of fuel cell systems.
- The AFC IA will go ahead with a summary of roadmap activities across members and wider, with the intention of publishing a book in 2014.
- Unanimous vote to update the AFC IA procedures to set time requirements for the documentation required around meetings.
- Adopted the draft guide for Operating Agents, setting out role, requirements, timescales and reiterating our existing procedures.
- Unanimous vote to proceed with the Electrolysis Annex.
- Unanimous vote to proceed with the Modelling Annex.

3.5 FUTURE PLANS

Information exchange with other Implementing Agreements continues to be encouraged, building on links already in place with the Hydrogen and Hybrid Electric Vehicle Implementing Agreements.

Two Executive Committee meetings will be held in 2014. The 48th meeting will be held in Korea on the 13 and 14 June 2014, and the 49th meeting will be held in Grenoble, France on the 4-5th December 2014.

Continued implementation of the approved work programme for the seven current Annexes is planned together with commencing the two new Annexes.

The objective of this annex is to contribute to the development of techniques to reduce the cost and improve the performance and durability of polymer electrolyte fuel cells, direct fuel polymer electrolyte fuel cells, and corresponding fuel cell systems.

4. Annex Reports

4.1 ANNEX 22 REPORT

POLYMER ELECTROLYTE FUEL CELLS (PEFC)

Key Messages – Facts
Polymer Electrolyte Fuel Cells

- Commercialisation of fuel cell vehicles for mass-transportation comes closer to realisation with the planned launch of passenger FCV sedans by Toyota and Honda in 2015 and the innovative leasing programme by Hyundai in 2014.
- Worldwide governmental and industrial commitments to fuel cell research and commercialisation remain strong.
- Developments in new fuel cell materials, such as platinum-based bimetallic catalysts, non-precious metal based catalysts and high temperature membranes have made significant advancements in 2013.
- Studies in components and systems, such as graphite coated bipolar plates, online fuel cell performance monitoring and system modelling and simulation have made significant progresses in 2013.
- Technologies for the direct conversion of fuels by fuel cells, such as boron-hydride, methanol and dimethyl ether (DME) at higher cell temperatures are advancing.

Key Messages – Opinion
Polymer Electrolyte Fuel Cells

- With the anticipated launch of commercial fuel cell vehicles, we expect that fuel cell materials, stack components and stack systems will see accelerated development in the near future.
- Reducing cost and improving durability still remain the top priorities in the R&D of fuel cell materials and systems.
- Major technology breakthroughs, such as high temperature membranes, low-cost catalysts, etc., will accelerate the implementation of fuel cells, not only in the transportation, but also in the stationary power generation sectors.
- New ideas and 'out-of-box' thinking are essential for fuel cell technology breakthroughs, therefore should be incentivised and encouraged.

The objective of Annex 22 is to contribute to the identification and development of techniques and materials to reduce the cost and improve the performance and durability of polymer electrolyte fuel cells (PEFC), direct fuel polymer electrolyte fuel cells (DF-PEFC) and corresponding fuel cell systems. Major applications are in the automotive, portable power, auxiliary power, stationary power, and combined heat and power (CHP) sectors. The R&D activities in Annex 22 cover all aspects of these two types of fuel cells, from individual component materials to whole stack systems.

The Annex has been in operation since February 2009 and will run until February 2014. The Operating Agent for this Annex was Dr Xiaoping Wang of Argonne National Laboratory, United States Department of Energy until November 2013. Dr Di-Jia Liu of Argonne National Laboratory assumed the role of Operating Agent for this Annex in December 2013.

Table 16: List of Participating Organisations in Annex 22

Country Participant	Associated Institution
Austria	Graz University of Technology
Denmark	IRD Fuel Cell Technology Research Centre A/S Danish Power Systems (DPS)
Finland	VTT Technical Research Centre of Finland Spinverse Oy
France	Atomic Energy Commission (CEA)
Germany	Forschungszentrum Jülich Fraunhofer ICT
Italy	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
Japan	Toyota Motor Company
Korea	Korea Institute of Energy Research (KIER) Korea Institute of Science and Technology (KIST)
Mexico	Instituto de Eléctricas (IEE)
Sweden	KTH - Royal Institute of Technology
USA	Argonne National Laboratory (ANL)

The low-cost and long-term stability of PEFC are critical to the successful commercialisation of the technology. The results shared within Annex 22 identify balanced approaches in materials, components, systems and alternative fuel research in the member countries. In the catalyst area, the progresses in improving platinum (Pt) catalysts through bimetallic alloying and researching platinum-free alternatives are equally encouraging. High temperature membranes and low-cost bipolar plates could both be game-changing technologies in expanding fuel cell applications. New online monitoring and modelling approaches are essential to system implementation. Fuel cells with alternative fuels such as methanol, etc., could potentially find early market entry in small appliance applications.

4.1.1 Activities

The 9th workshop of the Annex 22 Working Group was held on May 16–17, 2013 in Stockholm, Sweden. Fourteen representatives from Austria, Denmark, Finland, Germany, Japan, Sweden, and USA attended this two-day workshop.

The 10th workshop of the Annex 22 Working Group was held on December 11–12, 2013 in Tokyo, Japan, in conjunction with a fuel cell symposium held at FC-Cubic of Japan. Eleven representatives and local hosts from Austria, Denmark, Japan, Korea, Mexico and USA participated in the meeting.

4.1.2 Technical Developments

Annex 22 has three active subtasks. The work and results are reported for each subtask below.

Subtask 1 – New Stack Materials

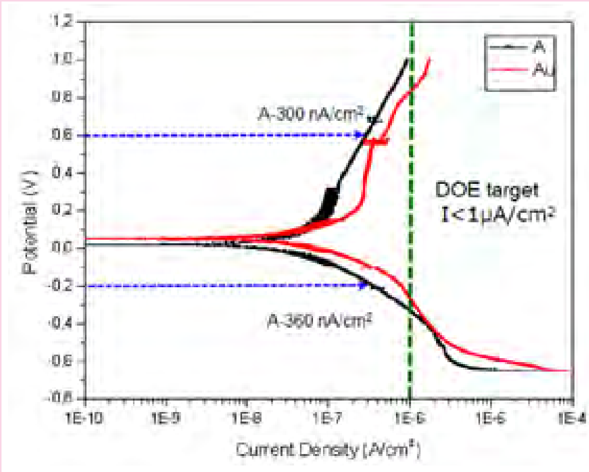
Information exchange in this subtask focuses on research aiming to develop improved, lower-cost membranes, electrode catalysts and structures, membrane-electrode assemblies (MEA), bipolar plates, and other stack materials and designs.

High temperature PEFC (HT-PEFC) can offer both improved PEFC performance and system efficiency for combined heat and power (CHP) generation. Development of high performance catalysts that are stable at the operating temperature of the HT-PEFC (160°C) is essential.

Graz University of Technology has continued the investigation for platinum-transition metal catalysts for high temperature PEFC. As identified last year, the ratio of Platinum (Pt) and Cobalt 1:5 exhibited the most promising results as highly active oxygen reduction reaction catalysts. However, the catalyst has stability comparable to that of a commercial Pt catalyst. To stabilise the catalysts, different post-preparation treatments were investigated, including acid leaching with and without thermal treatment. It was found that by acid leaching the catalyst followed by annealing at 200°C, the catalyst stability was significantly improved, to twice the performance of commercial Pt-Cobalt catalysts. Future work aims to further improve the catalyst activity by increasing the alloying metal content without sacrificing catalyst stability.

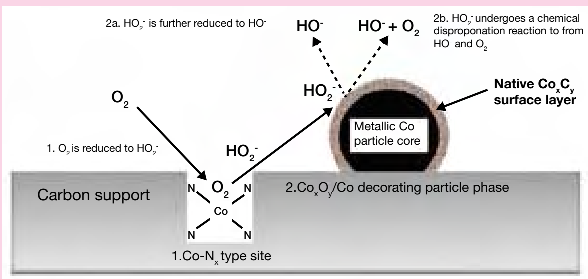
- Sandvik Materials Technology (SMT) in Sweden has been developing coatings on suitable substrates such as graphite and stainless steel for bipolar plate applications, aiming to improve the lifetime of PEFC by preventing passive layer formation and promoting low contact resistance. A thin stainless strip with thin graphite like carbon (GLC) coating was developed, which yielded a material suitable for mass production and possessed corrosion current well below the Department of Energy's (DOE) 2015 target. The performance will be verified under real fuel cell operation conditions.

Figure 2: Corrosion test shows a GLC coated thin steel strip has lower corrosion current than the gold coated substrate



- Korea Institute of Science & Technology (KIST) has developed a Cobalt-Nitrogen-Carbon (Co-N-C) based non-platinum group metal (PGM) catalyst using electrospinning method and investigated its activity towards the oxygen reduction reaction. The formation mechanism of the ORR active site was modelled, with the calculated binding energy shift of the metal-pyridinic N-bond identified as consistent with that observed in N-XPS study. They also introduced an interesting conversion mechanism and clarified the potential pathways for pyridinic N-formation during the organic nitrogen conversion.

Figure 3: The ORR mechanism over Co-N-C catalyst proposed by KIST

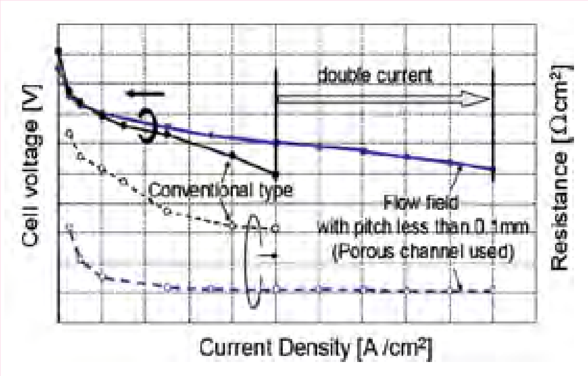


Subtask 2 – Systems, Component, and Balance of Plant

This subtask addresses system-level and balance-of plant issues in PEFC systems. Great emphasis is placed on the durability investigation of PEFC under varied stressed operating conditions, as this reveals insights into fuel cell degradation mechanisms.

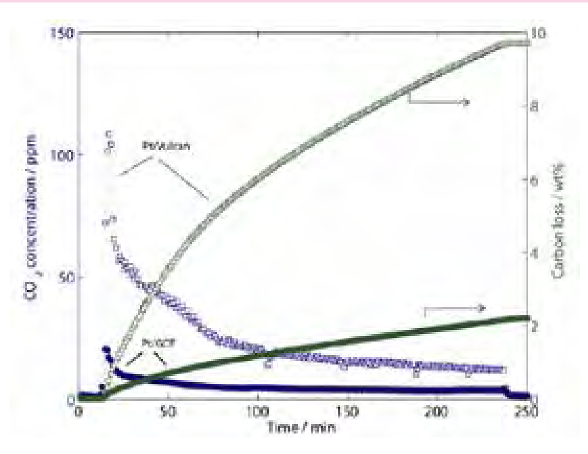
- Danish Power System (DPS) in Denmark is developing MEAs for high temperature operation (160°C). The standard products at DPS include both Dapozol® membranes and Dapozol® MEA. The Dapozol® MEA showed great carbon monoxide (CO) tolerance in the presence of 2.3% CO and no humidification system needed. The MEA also demonstrated great durability, indicated by the longer than 8,000-hour operation with a degradation rate of 9μV/hour at $200mAcm^{-2}$ over 4,000-hour operation. The future goal of the company is to achieve 90% cost reduction in the MEA production from today's EUR $1/cm^2$ to EUR $0.1/cm^2$ in 2015 through high-volume and automated production.
- VTT in Finland is carrying out various projects developing PEFC systems using low grade hydrogen at low temperature. This technology would be applied in industrial working machines and will use by-product hydrogen from industry. CO oxidation, accumulation at the catalyst and optimal air bleed levels have been studied by analysing the exit gas. Preliminary results show that more air (oxygen) is needed at higher temperature to mitigate same level of CO in fuel.
- Toyota Motor Corporation in Japan recently focused on FC performance improvement by optimising the flow channel and rib width. Through the evaluation of oxygen pressure, water distribution, and conductance as a function of rib width or channel width, a new design of flow channels with a porous structure was adopted, which resulted in better materials transfer. This lead to about twice the current compared to a conventional cell design. As a result, the power density of Toyota's new FC stack was doubled, achieving the world's highest level of volumetric density – 3.0kW/litre.

Figure 4: Approximately a doubling of the current was obtained by Toyota from the use of porous channels compared to the conventional structure



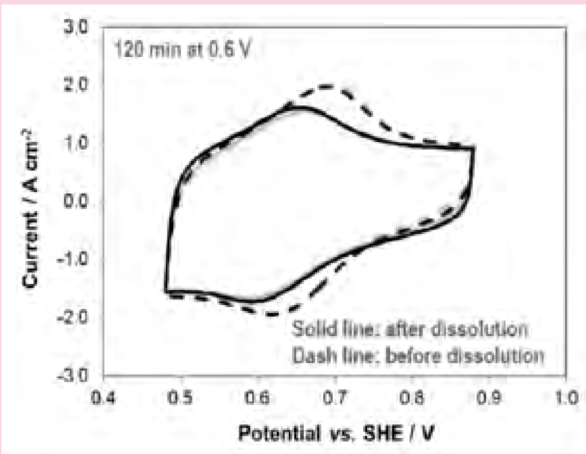
A deep analysis on materials and strategies to mitigate carbon corrosion during start up and shut down has been carried out at KTH in Sweden with the aim of achieving a cost of USD 30/kW and a durability of 5,000 hours, up from the current 2,500 hours. High voltages during start up and shut down damage the porous structure of the cathode reducing durability. KTH has investigated the use of alternative support materials that are more resistant to corrosion, such as inorganic oxide/carbide support, graphitised carbon fibre (GCF). The Pt/GCF cathode showed a corrosion rate five times lower than Pt/Vulcan with no change in single cell performance or in electrode morphology (Figure 5). However, the initial performance is lower than when using Pt/Vulcan due to challenges of depositing platinum on low surface area carbon. Methods to protect the cathode during shut-down have also been investigated and H_2 (hydrogen) purging of the cathode has been identified as giving the most promising results. Therefore, it is proposed that a mild graphitisation of the support, without compromising platinum deposition, in combination with the hydrogen purge strategy, could solve the degradation issues due to start-ups and shut-downs for Pt/C cathodes.

Figure 5: Carbon corrosion test – potential cycling 0.6–1.5V versus RHE, 300 cycles. Pt/GCF cathode shows a corrosion rate five times lower than Pt/Vulcan.



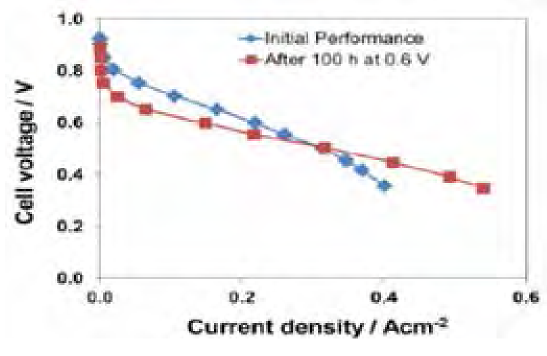
- Instituto de Investigaciones Eléctricas (IIE) is working on hydrogen PEFC-hybrid utility electric vehicle. The start point was the design of energy management strategies for a vehicle with a maximum speed of 40km/hour to 50km/hour and a travel range of 50km to – 60km. The practical considerations included cost and productivity. The dynamic features of a PEFC in real life applications was also investigated, particularly related to voltage undershoot as well as overshoot and hysteresis. Different fuel cell polarisation scenarios were included. The water redistribution in PEFC and in ionomer, reactants concentration gradients, thermal non-uniformities and instantaneous voltage responses were also analysed.
- Argonne National Laboratory in the US has studied the stability of iron (Fe) species in the 900 C heat-treated polyaniline-iron-carbon (PANI-Fe-C) PEFC cathode catalyst. The knowledge gained will be beneficial for the development of less expensive and durable non-precious metal catalysts for PEFC. It was found that the rate and extent of iron lost from the catalyst in the electrochemical environment was dependent on the potential and type of electrolyte, with the result that cathode kinetic performance decreased but mass transportation improved. Figure 6 shows the decreased anodic and cathodic currents reflecting a loss of electroactive material, which is consistent with the loss of iron; the dashed line represent the currents before dissolution while the solid line represent the currents after dissolutions.

Figure 6: Decrease of anodic and cathodic currents reflecting a loss of electroactive material



MEA performances at 0.4V and 0.6V have also been tested within this work. No degradation at 0.4V was observed but great loss in performance was seen at 0.6V. Iron content decreased to 78% and 84% after 200 hours at 0.6V and 0.4V due to the larger loss of metallic, organometallic, sulfide, and carbide-like coordination environments.

Figure 7: Cell voltage (V) versus current density (Acm-²) at initial conditions (blue line) and after 100 hours at 0.6V (red line)



Subtask 3 – Direct Fuel Polymer Electrolyte Fuel Cells

The objective of this subtask is to improve the performance and lifetime of direct fuel polymer electrolyte fuel cells, including direct methanol, direct ethanol, and direct sodium borohydride fuel cells.

- Fraunhofer ICT in Germany has developed a demonstration unit for direct ethylene glycol fuel cell (DEFC) which was presented at the Tokyo Expo 2012. A new demonstration design for the investigation of ethanol oxidation at high temperature (120˚C–160˚C) is currently under development. The aim is to improve performance and efficiency of HT-DEFC.

- DPS of Denmark has prepared fuel cells with its high temperature membrane and applied various fuels such as pure hydrogen, methanol, and LPG, targeted for APU application.

4.1.3 Work Plan for Next Year

During 2013, the active research and development (R&D) within the Annex addressed all the critical technical barriers and issues that hinder PEFC and direct fuel-PEFC technologies from achieving widespread commercialisation. For both technologies, the R&D focused on cell and stack materials and components and system, with improved MEA, reduced catalyst and system costs, improved catalyst and support durability, and enhanced system design and analyses. There is still a need for further advancement, thus, it is expected that these topic areas will continue to be active for R&D in future years.

It was the intention of this Annex that the set of Key Messages will be updated and released annually for this Annex.

The next Annex 22 meeting will take place in June 2014, in Seoul, South Korea, and will be held in conjunction with the Executive Committee Meeting taking place at this time and the WHEC2014 Conference.

The objective of this annex is to provide for further international collaboration in the research and development of certain aspects of Molten Carbonate Fuel Cells technology, in order to realise commercialisation of the system.

4.2 ANNEX 23 REPORT

MOLTEN CARBONATE FUEL CELLS (MCFC)

Key Messages – Facts
Molten Carbonate Fuel Cells

- An 11.2MW (four 2.8MW DFC-3000) fuel cell park was installed at Daegu city in Korea and a 14.9MW fuel cell park is now under construction in Connecticut, USA.
- The world's largest fuel cell park, a 59MW facility composed of 21 DFC-3000 power plants is under construction in Hwasung City, South Korea.
- MCFC research groups are focused on achieving improved fuel processing, such as lower cost systems to clean impurities from natural gas or biogas, and fuel processing systems for alternative fuels, including liquid fuels.

Key Messages – Opinions
Molten Carbonate Fuel Cells

- Annex 23 believes the new golden age of gas will be a big opportunity for fuel cells, particularly MCFC.

The objective of the Molten Carbonate Fuel Cell (MCFC) Annex is to provide international collaboration in the R&D of certain aspects of MCFC technology, to realise commercialisation of the MCFC system. The aspects include:

- Improvement of performance, endurance, and cost-effectiveness, for stacks and balance of plant (BoP).
- Development and standardisation of effective test-procedures for materials, cells and stacks.
- Identification of present and envisaged problems to be solved for commercialisation.

Annex 23 has three subtasks:

- Subtask A: Research and development (R&D) issues for longer life, higher performance and lower cost.
- Subtask B: Lessons learned from demonstrations and early products.
- Subtask C: Standardisation of stack and balance of plant (BoP).

This Annex has been in operation since February 2009 and will run until February 2014. The Operating Agent for this Annex is Dr Tae Hoon Lim from the Korean Institute of Science and Technology (KIST).

Table 17: List of Participating Organisations in Annex 23

Country Participant	Associated Institution
Germany	Forschungszentrum Jülich GmbH through Motoren und Turbinen Union Friedrichshafen GmbH (MTU)
Italy	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
Korea	Ministry of Knowledge Economy (MKE) through Korea Institute of Science and Technology (KIST)
USA	US Department of Energy (DOE) through Fuel Cell Energy (FCE)
Japan (Obsever)	Central Research Institute of Electric Power Industry (CRIEPI)

MCFCs are high temperature fuel cells, operating at 600°C and above, and offer the advantage of being able to use non-precious metals as the catalyst as well as having internal reforming due to the high temperature operation. A further advantage is the use of MCFC within CHP systems, taking advantage of the high operating temperatures and the heat generated. MCFC offer the advantage of being able to make use of a variety of fuel sources, including natural gas, industrial and municipal wastewater treatment gas, propane and coal gas.

Field experiences of MCFC systems operations over the world show the importance of lifetime extension and cost reduction to achieve market comparability with competing technologies. Many institutions and research activities focus on these technical hurdles, particularly focusing on corrosion prevention and electrolyte management.

4.2.1 Activities

The fifth meeting of Annex 23 was held in Columbus, Ohio in October 2013, and was held in conjunction with Fuel Cell Seminar 2013.

4.2.2 Technical Developments

Fuel Cell Energy, an American company specialising in large MCFC stationary power units, had seen its product sales and revenues increasing by 94% over the fiscal year ended in October 2011, and further increasing by a small amount in 2012. The increase in revenues is partially attributable to large overseas orders from POSCO Power (South Korea) which ordered 70MW in 2011, and a subsequent 121.8MW order in late 2012, together with a licensing agreement. In 2012, Fuel Cell Energy had delivered 180MWe of MCFC and has a backlog of another 120MWe. A further 100MW+ contract was signed at the end of 2012 with Korea for deliveries up to 2016.

Fuel Cell Energy Solutions (FCES) is a new company jointly owned by Fuel Cell Energy and the Fraunhofer institute in Dresden Germany. FCES began manufacturing activities in Germany in 2012, and will develop and manufacture MCFC units for the European market with stack components from Fuel Cell Energy. The old manufacturing plant of MTU in Ottobrunn will be used for FCES's manufacturing. This new company has received its first order from BAM Deutschland AG for a 250kWe plant to be installed in the Government's new Federal Ministry of Education and Research complex in Berlin.

Market Perspectives

In Korea the RPS (Renewable Portfolio Standard) has existed since 2012, with fuel cells eligible for the same level of support (and classified as) as renewable energy. The RPS mandates a portion of renewable electricity to every power company with a capacity of 500MW or larger. The forced portion will increase from 2% in 2012 to 10% in 2022. It is estimated that 350MW/year of additional renewable energy is required from 2012 through 2016 and 700MW/year through to 2022. The total market size will be around USD 54 billion through to 2022. The competence of fuel cells against other renewables will decide the size of the fuel cell market.

Figure 8: Daegu, 11.2MW MCFC installation in Korea

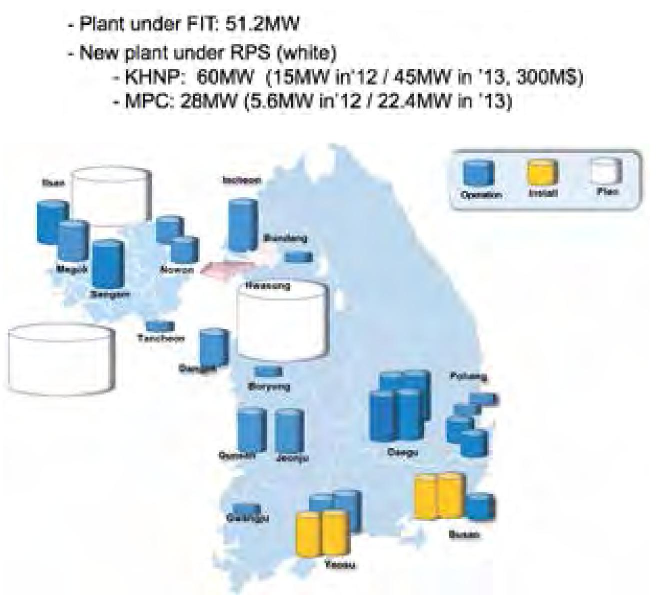
POSCO had 51.2MW of installed capacity of MCFC over a total of sixteen sites in Korea at the end of 2012, and has commercialised products available at 300kW, 1.4MW and 2.8MW, demonstrating the market readiness of this product area. Also, a light-weighted & down-scaled 100kW class MCFC system has been developed with FCE and operated at two sites in Seoul City. To cope with pollutant regulation & revitalisation of the national shipbuilding industry, POSCO began participating in the national project for vessel application, which is designing an MCFC system to run on diesel fuels suitable for large marine applications.

Doosan Heavy Industry finished the development of a 300kW MCFC system in 2011, with development into MW systems planned in 2012/13. The intention is to achieve high efficiency (greater than 48%) and long-term operation (higher than 40,000 hours). Doosan Heavy Industry is looking for new applications for MCFC, such as CO_2 capture, desalination, and higher efficiency system combined with turbines.

In USA there are 33 states and the District of Columbia that have instituted RPS mandates; five states that have adopted non-binding renewable energy goals and nine of these states specifically list fuel cells as eligible technologies. Further technologies that can be used in conjunction with fuel cells are widespread, such as CHP, biomass and landfill gas [17]. In total these markets represent the potential for an estimated 76,750MW of renewable power by 2025 according to the Union for Concerned Scientists. Fuel cells using biogas fuels qualify as renewable power generation technology in all of the US RPS states, with nine states specifying that fuel cells operating on natural gas are also eligible.

Figure 9: MCFC Installations in South Korea

Site	Operation	Capacity
Namdong Power (Bundang)	'06.11	250kW
POSCON (Pohang)	'08.3	300kW
POSCO Power (Pohang)	'08.8	2.4MW
HS Holdings (Jeonju)	'08.9	2.4MW
Naturi Power (Gunsan)	'08.9	2.4MW
Jungbu Power (Boryong)	'08.9	300kW
SH (Seoul)	'09.5	2.4MW
Meya Yulchon (Yeosu)	'09.10	4.8MW
GS EPS (Dangjin)	'09.10	2.4MW
Dongseo Power (Ilsan)	'09.10	2.4MW
POSCO Power (Incheon)	'09.11	2.4MW
Byuksan (Busan)	'10.5	1.2MW
SH (Samgam)	'10.9	2.4MW
TCS1 (Daegu)	'10.9	5.6MW
Dongseo Power (Ilsan)	'11.4	2.8MW
TCS1 (Daegu)	'11.6	5.6MW
Cobalt Sky (Busan)	Under Install	5.6MW
Meya Yulchon (Yeosu)		5.6MW



[17] Source 2009: www.epa.gov/chp/state-policy/renewable_fs.html

The cost to manufacture an MCFC plant in the USA is today approximately USD 2,000/kWe with the aim to further decrease the costs to USD 1,500/kWe in the near future.

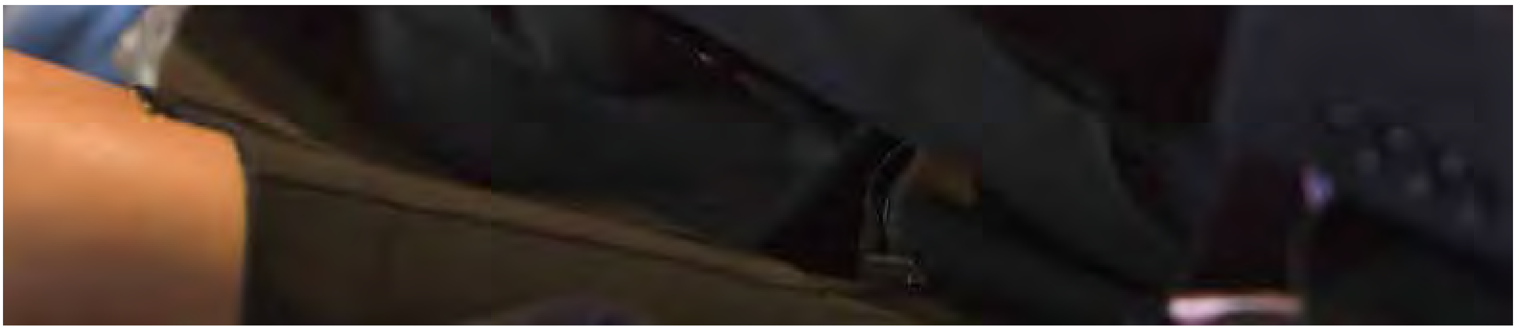
The EU project MCFC Fellowship is also focusing on large scale marine applications of MCFC technology, and has plans to install a 2.8MWe MCFC on board a ship.

Worldwide, there are large MCFC plants in operation at 64 sites with a total production of about 1.2TWh. It was recently announced that a new planned project has constructed a pilot plant using an MCFC running on ethanol from biomass on the Guadelope Islands and there are plans to extend this to a large 30MWe MCFC plant.

4.2.3 Work Plan for Next Year

Considerable experience from system operations demonstrates that life time enhancement and cost reduction are still needed to make MCFC systems compatible with the market.

The objective of this annex is to organise a series of annual workshops to discuss selected Solid Oxide Fuel Cells topics.



4.3 ANNEX 24 REPORT

SOLID OXIDE FUEL CELLS (SOFC)

Key Messages – Facts
Solid Oxide Fuel Cells

- The efficiency and electrochemistry issues of SOFC are essentially solved: the state of the art SOFC show reasonable efficiencies and stable electrochemical performance.
- Lifetimes over 50,000 hours reached for stack in laboratory environment.
- Electrical efficiency over 60% achieved for residential SOFC in a combined heat and power (CHP) system.
- Durability and cost still remain the major barriers to SOFC systems' commercialisation.

Key Messages – Opinion
Solid Oxide Fuel Cells

- SOFC for CHP and power only, for stationary industrial, commercial, residential and small applications are relatively mature and are at the threshold of the commercialisation process.
- With the advent of certain additional stack related development steps, a commercially feasible system for large scale projects with an investment cost (excluding stacks) of less than EUR 2,000/kW can be achieved.
- SOFC using metallic support is one promising emerging technology for Auxiliary Power Unit (APU) applications with lower material costs, higher robustness during fabrication and operation.

The aim of Annex 24 is the continuation and intensification of the open information exchange to accelerate the development of SOFC towards commercialisation. The mechanism used to achieve this is workshops, where representatives from the participating countries share and discuss the status of SOFC Research, Development and Demonstration in their respective countries, in addition to discussing a selected topic. The areas of particular focus and learning are the durability and costs of SOFC stacks and systems.

The Annex has been in operation since February 2009 and will run until February 2014. The Operating Agent for this Annex is Dr Jari Kiviaho from VTT Technical Research Centre in Finland.

Table 18: List of Participating Organisations in Annex 24

Country Participant	Associated Institution
Denmark	Risø National Laboratory
Finland	VTT Technical Research Centre of Finland (Processes)
France	The French Agency for the Environment and Energy Management (ADEME)
Germany	Forschungszentrum Jülich Gmbh
Italy	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
Japan	The New Energy and Industrial Technology Development Organisation (NEDO)
Korea	Korea Institute for Energy Research (KIER)
Sweden	Swedish National Energy Administration
Switzerland	Swiss Federal Office of Energy
USA	Department of Energy (DOE)

Theoretically, the power produced in an SOFC can reach up to 70% of the inlet fuel energy; in practice, within an end-user-ready system, these efficiencies are between 40% and 60%, depending on the power plant configuration. SOFC efficiency is unique in being practically independent of the system's scale, and one kilowatt power output systems have been demonstrated to have 60% net efficiency.

SOFC can serve a large variety of applications whilst maintaining their properties of fuel flexibility and high electrical efficiency. In particular, the most promising areas for their immediate utilisation are:

- Mobile, military and strategic (less than 1kWe)
- Auxiliary power units (APU) and back-up power (1kWe to 250kWe)
- Stationary small-scale combined heat and power (m-CHP) (1kWe to 5kWe)
- Stationary medium-to-large scale (0.1MWe to 10MWe).

4.3.1 Activities

The Annex meeting in 2013 was held in Okinawa, Japan, on 5 October 2013. The meeting was held in conjunction with SOFC XIII conference. 20 people from 11 countries participated to this meeting, all partner countries were represented.

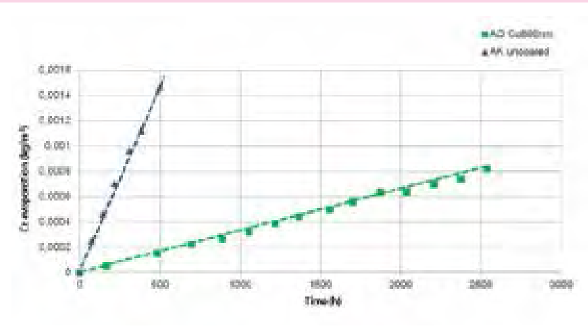
The IEA Annex 24 SOFC booklet: 'International Status of SOFC technology 2012–2013' was published in June 2013. The authors are Stephen J. McPhail, Luigi Leto and Carlos Boigues-Muñoz from ENEA, Italy. This booklet gives an excellent summary of the state of play of SOFC in 2013. It is aimed both at the SOFC expert and at the generalist, introducing technology, applications and company products to both. It is available online on the IA website.

4.3.2 Technical Developments

Covering residential and commercial applications, SOFC technology is an excellent choice for some markets; while in other markets, PEM technology is a viable option. However, both technologies require further progress to reduce costs, improve device performance and durability as well as to improve manufacturing processes. Research projects for SOFC are mainly focused on increasing durability, reducing production costs and developing new generation SOFC products, such as ceramic and metal supported SOFC tailored for anticipated application areas. SOFC based on ceramic supports is now a mature technology which has been comprehensively studied, while SOFC using metallic supports is a promising technology for APU applications with lower material costs and higher robustness during fabrication and operation. Some of the research projects carried out during 2013 are described in the following sections.

Sandvik is a Swedish company developing materials for interconnects (bipolar plates) for SOFC applications. Sandvik developed a ferritic steel interconnect which has similar thermal expansion to ceramic interconnects, good electrical conductivity, formability and lower costs. However, this material is affected by cathode poisoning. To address this problem, Sandvik has recently developed a new technology for SOFC interconnects which improves the cell lifetime through reducing chromium evaporation and corrosion. The new manufacturing technique uses a cobalt coating to reduce the evaporation of chromium from steel (Figure 10) and utilises a cerium coating to reduce the oxidation rate. Evaporation of chromium on a coated cathode is almost seven times lower than in an uncoated cathode during the same life time of 500 hours.

Figure 10: Cobalt coating results in significant reduction in chromium evaporation (Testing condition: 850°C in 20% O_2 and 3% H_2O)



Three research institutions in Germany (FZJ, IKTS and DLR) are developing cells and stacks and two of them (IKTS and FZJ) are also developing fuel cell systems. While DLR is focusing on metal substrate cells, IKTS is using electrolyte substrate cells and is closely co-operating with Plansee, using their interconnects. Plansee, together with AVL, is also developing systems in the 10kW range for stationary applications. For its part, FZJ is developing anode substrate cells and large stacks. In 2012, FZJ demonstrated a 20kW system based on four 5kW stacks operated in parallel (Figure 11).

Figure 11: 20kW SOFC system based on four 5kW stacks by Forschungszentrum Jülich

FUELMAT research group at EPFL in Switzerland, in collaboration with another three fuel cell companies (HTCeramix, Hexis and SOFCPower), is studying different aspects of SOFC and electrolysis. Their projects aim to understand the limiting mechanisms, modelling different fuel cell aspects such as thermo-mechanical and electrochemical behaviours, life time prediction and fluid dynamics. The research group has a 12 laboratory set-up for testing fuel cell components, single cells and stack testing, including electrolysis.

Over the past few years VTT in Finland has successfully collaborated with Elcogen, a cell manufacturing company specialising in SOFC. VTT focuses on R&D, stack design, modelling and post-test analysis to support cell and stack manufacturing process carried out by Elcogen. The result of this collaboration is single cells and stacks with low degradation and good performance which Elcogen has commercialised as a 500W stack and 1kW stack in 2013 (Figure 12).

Figure 12: Elcogen 1.5kWe commercial stack

VTT has also developed and tested a 10kW SOFC demonstration unit fuelled with natural gas and an anode gas recycle loop. The stack design and operation has been validated by experimental testing for a total operation time of more than 5,000 hours. Total system efficiency higher than 50% was achieved.

Technology Perspective and market overview

SOFC research and development has been highly supported and successful in Japan, where more than 3,000 SOFC CHP units had been installed by March 2013, an example of which is given in Figure 13. Ene-Farm products will receive a Government subsidy until 2015, while a new parallel project called 'Technology Deployment for promoting SOFC commercialisation' commenced in 2013. This four-year project has four main aims:

- To develop rapid evaluation method of cell stack durability to accelerate R&D.
- To demonstrate SOFC systems for business use.
- To develop technology for large scale power generation using SOFC.
- To develop new technologies such as electricity storage with low cost H_2 (hydrogen) production using reversible SOFC.

Figure 13: Osaka Gas/Aisin/Kyocera 700W SOFC CHP for Ene-Farm

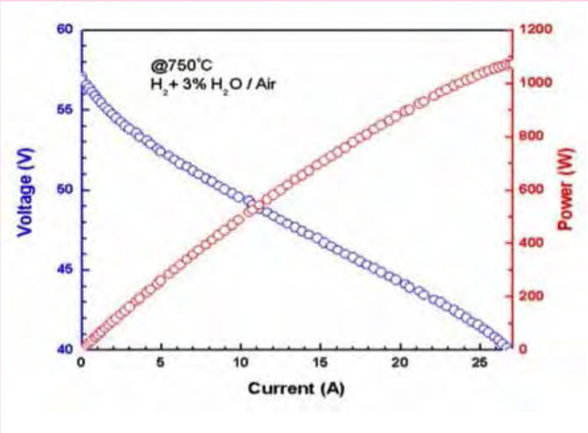
Development of SOFC is also strongly supported in Germany with the Callux project which has incentivised the production and deployment of SOFC fuel cell technology. Callux is scheduled to run until 2015 and to date has been responsible for about 250 systems being installed for in field testing. The size of the SOFC industry has seen a large increase and about 300 people are now working for SOFC companies, with around 100 scientists working on SOFC development in research centres. Proof of Callux's success can also be taken from the increasing number of companies manufacturing and selling SOFC systems in Germany and Austria. It was recently highlighted that:

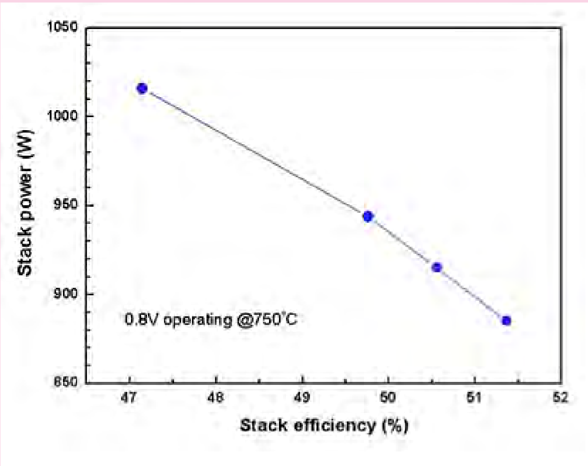
- Three companies are manufacturing and selling SOFC systems.
- Two companies are manufacturing and selling SOFC stacks.
- One company is selling standard interconnects.
- One company is developing glass seals for SOFC stacks.
- One company is developing and selling SOFC system components.
- Two companies are developing SOFC systems for APU applications.
- Two companies are developing SOFC systems for portable applications and back-up power.
- Four companies are developing SOFC systems for household applications.
- Three research institutions are developing SOFC cells, stacks and systems.

Korea has supported an increasing number of research, development and deployment projects for small scale stationary SOFC systems. Some of the existing projects are highlighted below:

- During the past six years, POSCO Energy Research Institute of Industrial Science & Technology (RIST) in Korea has been carrying out a project to develop a 10kW highly reliable SOFC fuel cell with multiple unit stacks. This system has achieved successful operation with grid connection.
- SK Innovation in Korea has developed 1kW and 3kW SOFC systems. Various tests of the first prototype in 2012 achieved stable continuous operations for weeks with an electrical efficiency of 41%. This efficiency was improved to 45% in 2013 thanks to a system upgrade that introduced full automation. Field tests of more than 10 units are planned for 2014, with the intention to achieve 48% electrical efficiency for the commercialisation stage.
- KoMiCo in Korea has been developing a single SOFC cell and stack for residential micro-CHP applications, to be used in the Green-Home Programme. The project has developed a reliable cell fabrication process with quality control for planar and tubular cells and more than 6,000 cells have been produced since 2008. Electrical efficiency of between 47% and 51% has been achieved in a 1,020W to 870W stack in hydrogen (Figure 14).

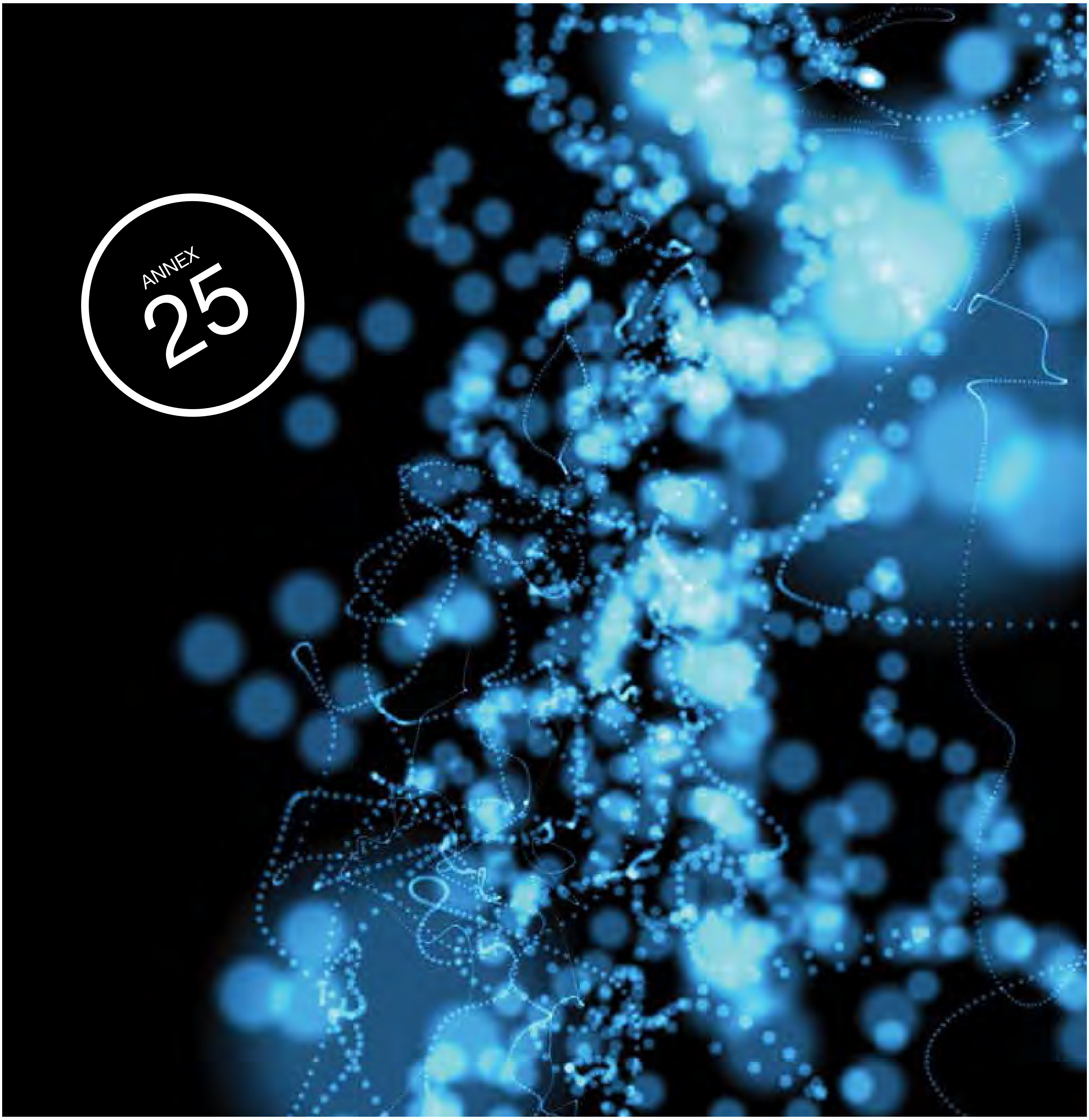
Figure 14: KoMiCo SOFC fuel cell. The bottom graph shows Voltage versus Current, and Power versus current at 750⁰C, while the top right graph shows that an electrical efficiency of between 47% and 51% has been achieved in a 1,020W to 870W stack in hydrogen.





4.3.3 Work Plan for Next Year

The next SOFC Annex meeting will take place in conjunction with a scientific conference or symposium in 2015, but the exact location and place are yet to be decided.



The objective of this annex is to understand better how stationary fuel cell systems may be deployed in energy systems.

4.4 ANNEX 25 REPORT

STATIONARY FUEL CELLS

Key Messages – Facts
Stationary Fuel Cells

- The use of biogas as fuel for fuel cells has increased in the USA, especially California and the Northeast USA, supported by the available incentives.
- MCFC are becoming more commercialised, reliable and competitive. The installations are growing in size and numbers, and are now manufactured in several places around the world.
- Japanese fuel cell companies have begun to consider export to Europe in collaboration with European fuel cell developers for domestic scale installations.
- SOFC for residential fuel cells in Japan and Europe is gaining market share.
- One third of all MCFC systems in operation in the world are running on biogas.

Key Messages – Opinions
Stationary Fuel Cells

- To date, fuel cells have been a competitive alternative to battery systems used in material handling equipment, telecom stations, back-up systems and APUs.
- A high electric efficiency is essential for micro-CHP fuel cells as it enables more operating hours per year. In this case, micro-CHP is not dependent on the heat demand for the efficient operation of the plant. This will improve the economy and the environmental impact for the system.
- Fuel cells for CHP applications can have an important role in the energy system as they have high efficiency and can use local fuel, such as biogas, with high efficiency.
- The possibilities of producing hydrogen, electricity and heat from biogas by MCFC technology is an interesting alternative for the coming hydrogen infrastructure.

The objective of Annex 25 is to better understand how stationary fuel cell systems may be deployed in energy systems. The work focuses on the requirements from the market for stationary applications; both opportunities and obstacles. Market development is followed closely with a special focus on fuels, system optimisation, environment and competiveness together with following up on the real status of stationary fuel cell systems.

The Annex has been in operation since February 2009 and will run until February 2014. The Operating Agent for this Annex is Bengt Ridell, from Grontmij AB, financed by The Swedish Energy Agency.

Table 19: List of Participating Organisations in Annex 25

Country Participant	Associated Institution
Australia	Ceramic Fuel Cells Limited
Austria	Austrian Energy Agency
Denmark	Haldor Topsoe Dantherm Power
Finland	Technical Research Centre of Finland VTT Wärtsilä
France	GDF-Suez
Germany	Forschungszentrum Jülich E.ON New Buildings and Technology Fuel Cell Energy Solutions
Italy	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
Japan	The New Energy and Industrial Technology Development Organisation (NEDO) Panasonic Aisin Seiki Toshiba
Sweden	Grontmij
Switzerland	Beratung Renz Consulting Swiss Federal Office of Energy
USA	Department of Energy EPRI UTC Power SA Inc

Stationary fuel cells are defined as fuel cells that provide electricity and potentially heat, and are designed not to be moved. Such systems can utilise the widest range of fuel cell technologies, with MCFC, PEFC, PAFC and SOFC systems all in operation around the world.

A key element of the work of this Annex is that the conditions for the introduction of stationary fuel cells are different in each country, even if they are neighbours. Electricity production systems vary between different countries, influenced by historic domestic sources of primary power or the introduction of nuclear power. The varying environmental, policy and economic environments that exist amplify these differences.

This Annex is extremely active as there is considerable expansion of stationary fuel cells occurring currently, with both the growth in domestic level systems for CHP and commercial systems that provide power and back-up power such as for the telecoms industry or for data centres.

The motto for Annex 25 is ‘to prepare stationary fuel cells for the market and the market for stationary fuel cells’. It is important to advise authorities and developers of the key steps necessary for market introduction and expansion.

4.4.1 Activities

Two Annex 25 meetings were held in 2013. The first on 11 and 12 April in Berlin, Germany was hosted by NOW. Sweden, Italy, Australia, Denmark, USA and France attended the meeting.

The second meeting was held on 21 October in Columbus, Ohio, USA in conjunction with the fuel cell seminar 2013 hosted by USA and Sweden. Participants from USA, Denmark, Sweden, Germany, Japan and Finland attended the meeting.

The Interim Report from Subtask 1, micro-CHP Appliances in Residential Buildings is available on the AFC IA website. It investigates the possibilities of introducing residential CHP fuel cells in different regions.

Decisions taken in 2013:

- The draft report from Subtask 1 will be the basis for a report regarding small stationary fuel cells in buildings. All participants are asked to contribute to the international section of the paper.
- A new paper of fuels for fuel cells, with a focus on biofuels, will be compiled by ENEA, Italy.

4.4.2 Technical Developments

Subtask 1 – Small Stationary Fuel Cells

This subtask investigates market possibilities and viability for the small residential stationary fuel cell market. The market conditions can vary significantly between different regions for energy demand, energy prices and the regulatory framework. On the other hand, increasing electricity demand and decreasing heat demand for buildings is now a common trend, therefore electric efficiency for CHP is becoming more important. For this reason, SOFC for residential fuel cells is increasing in market popularity due to the high performances being achieved. In Northern Europe, CFCL, Staxera, Hexis and TOFC have started to deploy prototypes in Germany and Denmark. Meanwhile Japanese companies are now entering the European market introducing products developed under the Ene-Farm incentives. SOFCPower from Italy will join the large Ene.field project being carried out in several European countries. PEFC is the dominating technology in the Japanese Ene-Farm programme, while in Europe, SOFC systems are attracting more attention. Table 20 shows the advantages and disadvantages of an SOFC system compared to other generation technologies.

Table 20: Key advantages of SOFC technology (Source: Fraunhofer IKTS)

Market segments	Key advantages of SOFC
Micro-CHP (1kW to 3kW)	• High electrical efficiency • Low noise and vibration • Seamless integration into existing building infrastructure • Redundant heating and electricity
Off-grid (1kW to 20kW)	• Electricity without grid • Self-starting, silent, near zero emissions • High efficiency reduces logistics and fuel transportation cost • Methanol and LPG is readily available • Bioethanol – CO_2 neutral and easy to handle
Small-CHP (20kW to 100kW)	• Electricity generation cost on grid parity • Better efficiency than centralised generation • Easy siting as there is no limiting heat sinks • Multi-fuel – CO_2-neutral if biomass is used

Micro-CHP Fuel Cells in Germany

BMWi has estimated that, in 2011, almost a third of the total energy consumed in Germany was used by private households, and half of this was consumed for household heating. Conventional domestic heating systems are low temperature or condensing gas/oil boilers, wood pellet systems, heat pumps or solar thermal systems. Recently, thanks to incentives such as the Callux project and FuelCells@Home, new innovative systems such as micro-CHP with gas engine, fuel cells and Stirling engines have entered the market.

For these reasons, CHP devices have been installed around the country (Figure 15) It has been calculated that between July 2012 and November 2012 [18] a total CHP capacity of 116MWe has been installed in Germany as described in Table 21.

The Callux project is extremely active in Germany, with up to 560 fuel cell heating appliances installed as part of the Callux field test at the end of 2013. These are planned to be operated, in some cases, until 2015. A map with a geographical distribution of the projects is shown in Figure 15. Three system manufacturers are involved in the project: BAXI INNOTECH, Hexis and Vaillant. Since the beginning of the project, three generations of fuel cell heating appliances have been developed, and, over the course of the project, a production cost reduction of 60% and a servicing and replacement parts cost reduction of 90% have been achieved.

Figure 15: Geographical distribution of Callux projects in Germany. The size of a house on the map indicates how many projects are being implemented at a location

(Source: Callux standard presentation, 14.03.2014)

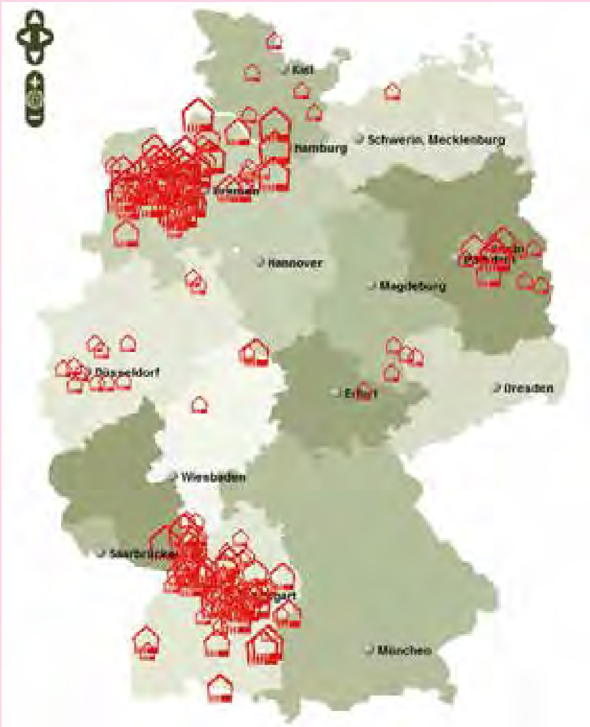


Table 21: New installed CHP devices between July 2012 and November 2012

(Source: http://dip21.bundestag.de/dip21/btd/17/117/1711775.pdf)

CHP device power rate	Systems installed	Cumulative capacity
Micro-CHP (1kW to 3kW)	935	11MWe
Between 50kWe and 250kWe	75	11MWe
Between 250kWe and 2MWe	50	40MWe
More than 2MWe	6	54MWe
TOTALS	1,066	116MWe

[18] http://dip21.bundestag.de/dip21/btd/17/117/1711775.pdf

Over the course of the Callux programme, in addition to cost reductions, CHP devices have also seen improvements in both their electric and total efficiency performances (Figure 16). Other technical advances are a significant reduction in dimension and weight (up to 50%), reduction of pollutant and noise emissions, increasing annual operating times, increasing power to heat ratio and decreasing stack degradation rates.

Figure 16: Efficiency coefficient (CE test standard) for CHP FC generation 1, 2 and 3 under the Callux project

European ene.field Project: micro-CHP Fuel Cells

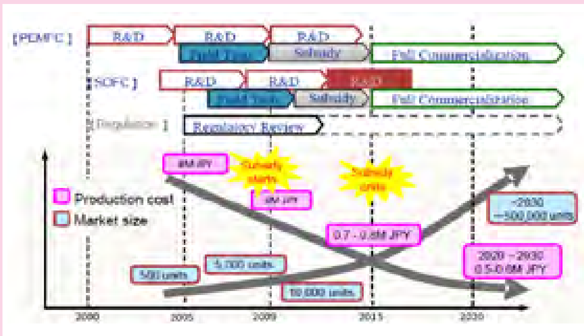
ene.field is the largest European demonstration project on fuel cell micro-CHP for private domestic applications. The project was announced in September 2012 and will run for a five year period. During this time, systems will be demonstrated for two to three years. Throughout the demonstration phase, the project aims to collect detailed performance data, lifecycle cost and environmental assessments, market analysis and commercialisation strategies. The consortium brings together 26 partners including the leading European FC micro-CHP developers, European utilities and research institutes.

ene.field will deploy up to 1,000 residential fuel cell micro-CHP installations, across 12 key Member States. The first two micro-CHP fuel cells systems, installed under the ene.field project, were completed in Germany in September 2013.

Japan's Ene-Farm Products: micro-CHP Fuel Cells

In Japan the impressive set of Ene-Farm products, originally released in 2009, continue to increase their market penetration. The market size is foreseen to constantly increase over the coming years, with 500,000 units expected to be installed by 2030. One of the main achievements of this scheme has been the reduction in production costs, which is expected to be ten times lower than the 2005 costs by 2015 (Figure 17).

Figure 17: Japan Ene-Farm achievements and timeline
(Source: NEDO)



More than 40,000 units received subsidies between 2009 and 2012. A subsidy budget of JPY 25,000 million for installations between December 2012 and Mach 2014 was approved in October 2012. This subsidy is expected to increase the market size by an additional 50,000 units, bring the total number of installed systems to more than 90,300. A further subsidy budget of JPY 22,400 million for 2014 was requested in September 2013.

Figure 18: Annual subsidy budget towards and annual sales volumes of Ene-Farm products in Japan (2013 and 2014 values are estimates)

PEFC is the dominating technology in the Japanese Ene-Farm programme with around 40,000 units installed, compared to 800 installed SOFC units.

Last year Panasonic and Tokyo Gas launched the latest fuel cell model which has been tailored for condominiums and features a number of modifications to ensure that the units meet the more stringent installation standards placed on those buildings. This fuel cell model opens a new market and Tokyo Gas is aiming for sales of 500 units in 2014. Interest has already been expressed from a couple of real estate companies that are keen to adopt the new fuel cell in two properties, comprising a total of 456 units [19].

Subtask 2 – Fuel for Fuel Cells

Fuels for fuels cells can offer a significant advantage to the system over competing technologies. This subtask looks at the use of waste to energy through fuel cells, mainly considering waste biofuels and used biofuels. Examples of appropriate fuels considered are:

- Renewable fuels.
- Fuels that do not compete with food production.
- Waste fuels including hydrogen.
- Anaerobic digester plant outputs.
- Waste from the agriculture or food industry.

Some of the benefits that can be achieved by exploiting alternative fuels for fuel cells are:

- Reduced dependence on primary energy carrier imports.
- Decentralised heat and power generation.
- Increase of local productivity.
- Maximum efficiency in the use of fuel.
- Clean on-site heat and power.

Utilising Biogas

ENEA in Italy has investigated using biogas as the fuel for direct fuel cells (DFC) in Europe. Main biogas producers are agricultural biogas plants, wastewater treatment plants, anaerobic bio waste treatment facilities, sewage sludge and landfills. Potential sources include manure, energy crops, organic waste from agriculture and food industry, municipal bio waste, sewage and landfill disposal.

It has been estimated that biogas production in Europe is around 10.1Mtoe and 35.9TWh of electricity has been generated using this gas. Germany accounts for 50% of the European gas production while Italy accounts for 11%. The main sources of biogas in Europe are landfill (31%), sewage sludge (12%) and other with anaerobic digestion (57%). The produced biogas is mainly used to generate electricity (59%) or in cogeneration and other activities (41%).

[19] www.gizmag.com/panasonic-ene-farm-home-fuel-cell-condominium/29487/

In Italy, in 2011, a total of 2.8GW and 10.8TWh were produced from biomass. Table 22 gives a list of biogas sources and generation from these in Italy in 2011, while Table 23 gives the overall biogas potential in Italy by different sources.

RSE (Ricerca Sistema Energetico) in collaboration with Serenergy and Enesyslab is monitoring the performance of a HT-PEM fuel cell system fed with biogas. The experimental activity aims to assess the long term operation of an HT-PEM power generation system fed with biogas. Parts of the tests were carried out in laboratory, but the major research effort was focused on on-site long-term tests. The system operates on a mobile unit, fed with biogas produced by an industrial size anaerobic digester. It was installed near Padua, in North East Italy. The system has been continuously operating for more than five months. Although fuel cell performances with pure hydrogen is slightly higher, biogas gives comparable results and it is a promising alternative fuel (Figure 19).

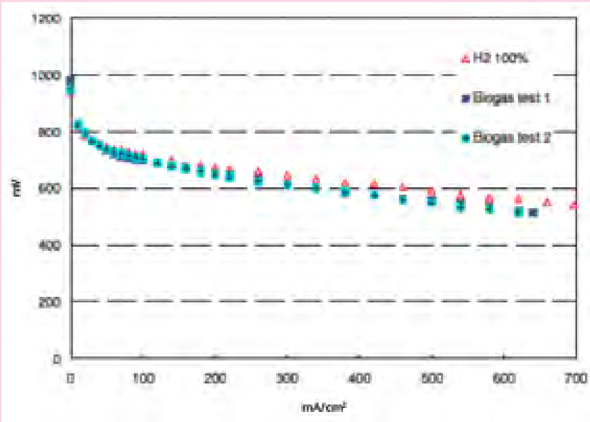
Table 22: Biogas plants in Italy in 2011

Type	Number of plants	MW	GWh
Landfill	260	356.4	1,528.1
Wastewater Treatment Plant	60	29.7	62.5
Manure	165	89.5	361.6
Residues from agricultural and forestry	334	297.9	1,452.5
TOTALS	819	773.4	3,404.7
Organic waste	71	827.5	2,217.7
TOTALS	890	1,061	5,622.4

Table 23: Biogas potential in Italy from different biogas sources

Overall biogas potential	ICE [20] Jenbacher	MCFC FCE
Power capacity (MW)	1,071	1,183
Electrical energy (GWh)	8,212	9,543
Thermal Energy (GWhth)	8,437	8,121
Avoided CO_2 (Mton)	3.4	3.9
Toe [21]	1.5	1.8
% on EE from RES	10%	12%

Figure 19: I-V curve for HT-PEM fed by pure Hydrogen and Biogas from ETRA biogas plant

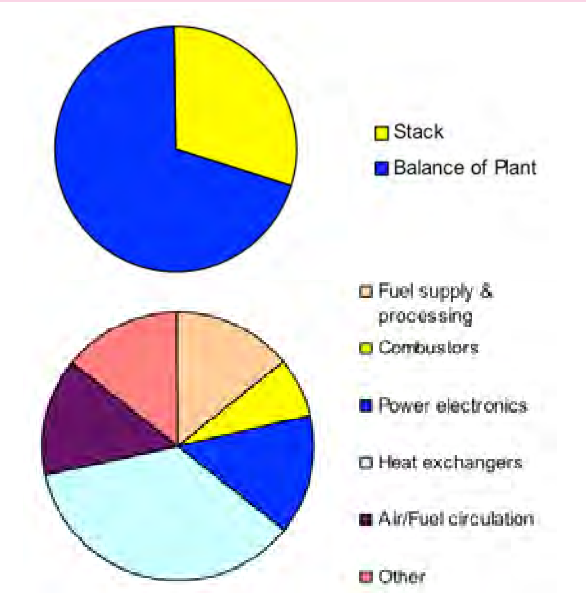


[20] ICE: Internal Combustion Engine
[21] Toe: Tonne of oil equivalent

Subtask 3 – Fuel cell plant components

To date, fuel cells and stacks are the most expensive element of a fuel cell system. However, as products mature the proportion of the total system is expected to fall to less than 50%. Excluding cell and stack, heat exchangers are the third most expensive component (Figure 20).

Figure 20: The top diagram shows a breakdown of costs for generic SOFC CHP System. Stack component (represented in yellow) accounts for about 20% of all the system's cost. The bottom diagram shows a breakdown of costs of principal components and sub-systems.



VTT is developing and manufacturing components and prototypes, such as catalytic burners, fuel pre-reformers, vaporisers and heat exchangers, to improve design and reduce costs. Components are often custom made with project partners or by sub-contractor collaboration.

Subtask 4 – Analysing design, operating and control strategies for stationary fuel cells systems

Subtask 4 aims to identify optimal design, operating and control strategies for fuel cells systems for CHP and tri-generation and hydrogen production. The activities of subtask 4 have contributed to three works produced by Whitney Colella at SA Inc:

- 'Analysing design, operating and control strategies for stationary fuel cells systems' has been finalised and discussed and feedback has been given during the compilation of the report.
- 'Design, Manufacturing, and Life Cycle Performance for Low Temperature Proton Exchange Membrane (PEM), High Temperature PEM, and Solid Oxide (SOFC) Fuel Cell Systems (FCS)'. The report details efforts to conceptually design and estimate the capital cost of different types of stationary fuel cell systems. Each system is configured for operation in CHP mode to allow utilisation of the system exhaust heat for building heating. The costs for stack and balance of plant components were analysed for each system both low and high temperature fuel cells in different sizes from 1kWe up to above 100kWe and for different production volumes. The cost results of all three FCS designs are compared to assess capital cost differences. One of the findings was that for a given cumulative global installed quantity, it is more cost-effective to produce fewer very large systems as compared to a large number of lower power systems.
- 'Assessing Electrical Sub-system Configurations and Installation Costs for Stationary Fuel Cell Systems' was presented and discussed. Fuel

Cell systems in four sizes from 1kWe up to large systems of 100kWe have been analysed. Five different applications have been studied:

- > Net-metering.
- > No net- metering.
- > Off grid systems.
- > Critical loads during grid outages.
- > Start during black-out.

Different hardware configurations were studied and the necessity for extra load banks, batteries to fulfil the requirements. Also different fuel cells technologies SOFC, LTPEM and HTPEM are included in the investigations. Especially the small systems are sensitive to special requirement because of the higher costs. It was found that the manufacturing volume has little impact on electrical subsystem equipment costs: the percent change in cost on the electrical sub-system equipment between low and high manufacturing rates is small today. This result is not surprising considering that electrical subsystem components are already mass-produced in high volumes, in a competitive, commodity market. Market penetration by even up to 50,000 stationary FCS/year does not significantly increase the global demand for these components (such as electrical meters and load banks).

Subtask 5 – Status of large fuel cells – market and demonstrations

The large fuel cell units of over 100kWe are located in just a few countries; most of them are in the USA, Korea and Germany. The market expansion of fuel cells, especially large MCFC in Korea is impressive. LG from Korea has also recently bought SOFC technology from Rolls-Royce and POSCO has started to produce MCFC with technology from Fuel Cell Energy. Government support for deployment of large fuel cells remains essential for market expansion, and approaches include tax credits and support for the use of renewable energy sources. Furthermore Fuji Electric has started to export larger units from Japan again.

The major supplier of large SOFC plants is Bloom Energy in the USA, who provides large plants from 100KWe up to several MWe. The customers are mostly large companies like eBay, Apple, Google, Coca-Cola and Walmart and several power utilities. The Bloom Energy SOFC reuses the produced heat; the systems are not designed for CHP. The power density is low; a 200kWe system weighs 19 tons.

Subtask 6 – Market Status

This subtask highlights the latest developments in stationary fuel cells.

Power to gas and smart grids is important coming technologies as the installations of intermittent wind and solar power is rapidly increasing. Fuel cells can have an important role in this kind of system, and there is the possibility to use the huge natural gas grid for energy storage including biogas, as proposed by Fraunhofer IKTS.

Fraunhofer IKTS have formed FCES, Fuel Cells Energy Solutions, in conjunction with Fuel Cell Energy in the USA. IKTS will provide about 150 specialists, who will focus on improving the MCFC technology.

FCES will produce MCFC plants for Europe. They have R&D activities for small portable PEFC and SOFC systems of different sizes including participation in EU-projects. They have already received several contracts for delivery of MCFC plants in Europe. The option to use an MCFC system as a hybrid plant that includes hydrogen production could potentially be important for the European market.

Fraunhofer IKTS has together with Plansee developed a Hotbox CFY stack 820We called Mk31. Fraunhofer will test these stacks in field test units in sizes from 0.5kWe up to 1.2kWe in off grid mode fuelled with LPG.

E.ON in Germany is focusing on business models for fuel cells and is especially interested in power to gas where fuel cell technology can contribute both electricity production and also electrolysis. E.ON is active in the Callux project and has installed 34 micro-CHP fuel cell units so far. A new project within the E.ON Group is SOFC-PACT, field trials of 50 SOFC CHP from CFCL in the UK, Germany and the Netherlands.

Dantherm Power has delivered about 800 PEFC units to customers; most of them back-up power for telecom systems worldwide which use air cooled stacks. The biggest customers are in Denmark, Canada and India. New markets in China with China Mobile as a large customer for telecom back-up power stations, Japan and South Africa are developing. The delivered systems are in sizes from 0.5kWe up to 100kWe and they have sold in total, worldwide, more than 1MWe.

Dantherm Power has also installed 20 micro-CHP plants in Denmark. These use natural gas or bio-methane as fuel, are water cooled and the units are supplied with gas burner that can be used for extra heating. These units have SMR and the water from the reforming can be reused in the system. These systems have been in operation for a total of 125,000 hours, with some single systems in operation for up to 7,000 hours.

FCE operate the MCFC hydrogen production plant in Orange County, California, which uses biogas from a waste water treatment plant as the fuel with the hydrogens extracted from the exhaust stream. The fuel utilisation in the MCFC is 75% so there is still a significant amount of hydrogen in the stream, although extraction will reduce the production of electricity and heat. Extraction is achieved using a Proton Exchange Membrane under high pressure 88MPa (880 bar, 12,800psi). It can then directly be used as transport fuel in a FCV using 70MPa (700 bar, 10,153psi).

The SOFC SECA programme in the USA has three industry teams – LG, partly owned by Rolls-Royce; Fuel Cell Energy – Versa Power, which now is 100% owned by Fuel Cell Energy; and Delphi, now alone because UTCPower (now ClearEdge Power) has left the SECA industry team. The budget has decreased significantly from about USD 50 million to USD 25 million per year, although to date the DOE has invested USD 500 million and there have been about 200 projects. The next major milestone is POC (proof of concept) with 125kWe stacks, then to develop a 250kWe SOFC unit for distributed generation. The long-term goal for 2025 is to use large SOFC units in IGFC coal based power plants.

Fuel Cell Energy (Versa Power) has installed a 60kWe SOFC module that is grid connected. LG has tested a 18.8kWe system for 3,500 hours with a degradation rate of 1.1% per 1,000 hours. Delphi has developed a large cell 403cm^2 that has been tested for more than 5,000 hours and will be used in the coming larger systems.

The European ENE.Field project, which started in September 2012, and has total costs estimated as EUR 52 million, intends to install 1,000 micro-CHP units in 12 different countries, from eight different suppliers of fuel cells systems. The first installations have now been made, most of the installations are planned to be performed during 2013 and 2014. The project is planned to end in 2017.

Achievements during 2013

Within this Annex, the main achievements have been to work and to publicise the success of domestic fuel cell installations, demonstrating the parallels and challenges of the various schemes.

One important achievement that has been discussed frequently is that to enter the export market it is essential, and a great advantage, to cooperate with local suppliers of Balance of Plant and to adapt the units to local conditions.

The questions of how market volumes can further expand in different regions under different conditions and how stationary fuel cells will approach commercialisation will be discussed in the Annex in the future.

4.4.3 Work Plan for Next Year

The next stationary fuel cells Annex meeting will take place at ENEA, in Trento, Italy on the 23 and 24 April 2014.

The autumn meeting will take place in October 2014 in Denmark hosted by Dantherm Power.

The Reports described above will be generated and shared with the IA members, the IEA and the public through our website.

The overall objective of this annex is to develop understanding of fuel cells with their particular properties, applications, and fuel requirements.

4.5 ANNEX 26 REPORT

FUEL CELLS FOR TRANSPORTATION

Key Messages – Facts
Fuel Cells for Transportation

- Fuel cell electric vehicles used in the DOE's Controlled Hydrogen Fleet and Infrastructure Validation and Demonstration Project achieved more than twice the efficiency of today's gasoline vehicles with average refuelling times of five minutes for four kilograms of hydrogen. The second generation vehicles met the 2009 target of 250 miles driving range.
- The fuel cell stacks in the Demonstration Project accumulated actual on-road operating times that exceeded 2,200 hours maximum and 1,100 hours average.
- The second generation buses in the US fuel cell electric bus programme are achieving double the fuel economy of conventional buses and meeting the target of 8 miles per diesel gallon equivalent. The average availability is 53% and improving, the miles between road calls have shown 38% improvement over the first generation buses, and the top fuel cell power plant has surpassed 12,000 hours demonstrated lifetime.
- The capital cost of fuel cell buses has shown a three-to-four fold reduction from EUR 3 million to between EUR 0.75 and EUR 1.25 million over the years 2003 to 2013.
- Diesel-based PEFC APUs show stable performance of the internal reformer and the fuel cell stack. The auto thermal reformer is able to maintain CO levels within the allowable limits during power transients. The second generation stack has significantly reduced reversible and irreversible voltage degradation of the cells.
- Use and deployment of fuel cell powered forklift trucks is a real success story in 2013, with several thousand being deployed in USA without government funding. Deployment is beginning to occur in Europe.

Key Messages – Opinions
Fuel Cells for Transportation

- The projected cost of automotive fuel cells at high volume manufacturing is USD 55/kW based on 2013 stack and balance-of-plant component technologies and USD 1,500/troy ounce (31.1 grams) platinum price.
- Automotive fuel cell stacks have achieved 2,500 hours projected lifetime when allowing for 10% voltage degradation, based on the field data collected in the DOE Controlled Hydrogen Fleet and Infrastructure Validation and Demonstration Project.
- Ballard's 150kW HD6 stack for fuel cell buses has demonstrated a 12,000-hour lifetime that has been validated via accelerated testing in the laboratory. The next-generation HD7 stack is projected to have a greater than 25,000-hour lifetime.
- The capital cost of fuel cell buses is anticipated to decrease to EUR 0.35 to EUR 0.55 million by the year 2018/22, driven mainly by manufacturing breakthroughs and high-volume manufacturing. The total cost of ownership is anticipated to be competitive with trolley buses for new routes by 2015/20 and with diesel buses by 2025.

The objective of Annex 26 is to develop the understanding of fuel cells for transportation with their particular properties, applications, and fuel requirements. Vehicles addressed include fork-lift trucks, passenger cars, auxiliary power units (APU), buses, light duty vehicles and aviation power.

This Annex has been in operation since February 2009 and will run until February 2014. The Operating Agent for this Annex is Dr Rajesh Ahluwalia from the United States Department of Energy's Argonne National Laboratory, in Illinois.

Table 24: List of Participating Organisations in Annex 26

Country Participant	Associated Institution
Austria	A3PS
Denmark	H_2 Logic
Finland	Aalto University VVT
France	Institut FC Lab
Germany	Forschungszentrum-Jülich GmbH
Italy	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
Korea	Hyundai Motor Corporation
Sweden	Volvo Technology Corporation PowerCell
USA	Argonne National Laboratory (ANL)

Research and development in the area of fuel cells for transportation is extremely active, with many demonstration projects underway and some initial market penetration. Fuel cell electric vehicles (FCEV) are on the road today around the world. Some are in private fleet programs while others are in the hands of consumers. Germany, Japan, Korea and Denmark have FCEV programs with plans to build stations to support commercial vehicle introduction in 2015.

Fuel cell electric vehicles require a hydrogen infrastructure to exist and commitments to providing this are accelerating. In 2009, seven of the large car makers, Daimler, Ford, General Motors, Honda, Hyundai-Kia, Renault-Nissan and Toyota, released a joint letter of understanding stating their intention to commercialise FCEV by 2015. Following this, also in 2009, in Germany a memorandum of understanding (MoU) was signed between Daimler, Shell, Total, Linde, Vattenfall EnBW, OMV and NOW GmBH (Germany's national organisation for hydrogen and fuel cells) to work to promote the production of FCEVs.

In 2011, in Japan, the car manufacturers Toyota, Honda and Nissan, signed a MoU with ten Japanese oil and energy companies covering a reduction in the costs of vehicles, as well as establishing a hydrogen infrastructure of 100 refuelling stations concentrated around Tokyo, Nagoya, Osaka and Fukuoka. Honda recently reiterated its plan to have next-generation fuel cell electric vehicles on the market from 2015. In Scandinavia, Hyundai signed a MoU in 2011 with representatives from Denmark, Finland, Norway and Sweden whereby Hyundai committed to providing FCEV demonstration vehicles and the countries would further develop their refuelling infrastructures. The subsequent H2Moves project is demonstrating nineteen FCEVs in Scandinavia.

In 2012, in Germany, a letter of intent was signed between the Federal Transport minister and Daimler, Linde, Air Products, Air Liquide and Total to secure EUR 20 million of grant funds to increase the number of hydrogen filling stations in Germany to fifty by 2015. In Denmark, in 2012, the Energy Plan announced the establishment of a countrywide hydrogen refuelling infrastructure by 2015. Honda recently reiterated its plan to have next-generation fuel cell electric vehicles on the market from 2015.

In January 2013, Daimler AG, Ford Motor Company and Nissan Motor Co. Ltd announced an agreement to develop a common fuel cell electric vehicle system together.

The fuel cells used in vehicles for transport (rather than as APU power) are usually low temperature PEFC, as these are capable of providing variable output. Fuel cell electric vehicles provide the advantages of large range, quick refuelling, and a system that is very similar to conventional systems used today for petrol and diesel, together with the main advantage of zero tailpipe emissions.

Figure 21: ix35 Hyundai fuel cell car

4.5.1 Activities

The fifth workshop of Annex 26 was held on 14 May 2013 in Arlington, USA. The workshop consisted of technical presentations and discussions with particular emphasis on hydrogen infrastructure and technology validation. Twenty representatives from six countries participated in the workshop.

4.5.2 Technical Developments

Cost and durability are regarded as crucial issues in fuel cells for transportation. The cost issues are related to the use of noble metals in electrocatalysts and their current low production volumes. The durability issues arise because of the added stresses placed on the cells due to load (cell potential) cycling and rapidly varying operating conditions of fuel and air flow rates, pressures, temperatures, and relative humidity.

Subtask A Advanced Fuel Cell Systems for Transportation

This subtask focuses on the system and hydrogen storage technology.

SymbioFCell and Renault continue to develop the Renault HyKangoo ZE, an electric van with a 10kW PEFC hydrogen range extender with 38 litres of hydrogen storage. The first customer deployments are underway with Solvay Group in Tavaux in France, and in December 2013 trials with Le Poste in Franche-Comté began with postal delivery vans that have an anticipated range of 200km.

Figure 22: The HyKangoo from SymbioFCell and Renault, an electric van with a hydrogen fuel cell range extender

Moby Post is a consortium project of eight partners across France, Germany, Italy and Switzerland that aims to develop a sustainable mobility concept. It plans to deploy ten light duty FCEV fuelled by hydrogen for two postal sites for La Poste. The design is a narrow and nimble vehicle, with a single seat, no doors and with storage in the cockpit. It is expected to have a range of 50km, a maximum speed of 45km/h and be able to carry up to 80kg of mail. The hydrogen fuel will be produced locally using solar power and water electrolysis (15kW, producing 1.5kg H_2/day).

Figure 23: MobyPost concept car

Subtask B: Fuel Infrastructure

This subtask focuses on distributed and central hydrogen production technologies and Well-to-Wheels (WTW) studies.

HySUT, the Research Association of Hydrogen Supply/Utilisation Technology in Japan, has produced the Japanese roadmap for commercialisation of fuel cell vehicles. Their main aims are to get:

1. Manufacturers to launch FCEV in the Japanese market by 2015, focusing on the four major metropolitan areas.
2. Hydrogen fuel suppliers to construct approximately 100 hydrogen refuelling stations by 2015.

Phase two HySUT projects will run from 2011 to 2015 and focus on hydrogen infrastructure delivery.

Subtask C Technology Validation

The work of this subtask discusses and evaluates field data from large demonstration programs on light-duty fuel cell vehicles, hydrogen infrastructure, and fuel cell electric buses.

DOE's Controlled Hydrogen Fleet and Infrastructure Validation and Demonstration Project concluded in 2012. Several publications have been prepared that report the results on fuel cell stack durability (2,500 hours), vehicle driving range (250 miles), system efficiency (60% at 25% power), and infrastructure cost and performance (USD 7.70/kg to USD 10.30/kg for on-site natural gas reformation and USD 10.00/kg to USD 12.90/kg for on-site electrolysis). In 2013, the technology validation activity entered a new phase for evaluation of fuel cell electric vehicles and next generation hydrogen infrastructure.

Subtask D Economics

This subtask works to exchange and compare cost models and assess the economic gaps in fuel cells and hydrogen production for transportation.

Forschungszentrum Jülich have developed a scenario that enables the exploration of how a 55% reduction in CO_2 emissions could be achieved.

Figure 24: HySUT Hydrogen Stations used in 2013 for demonstration projects (Source NEDO)

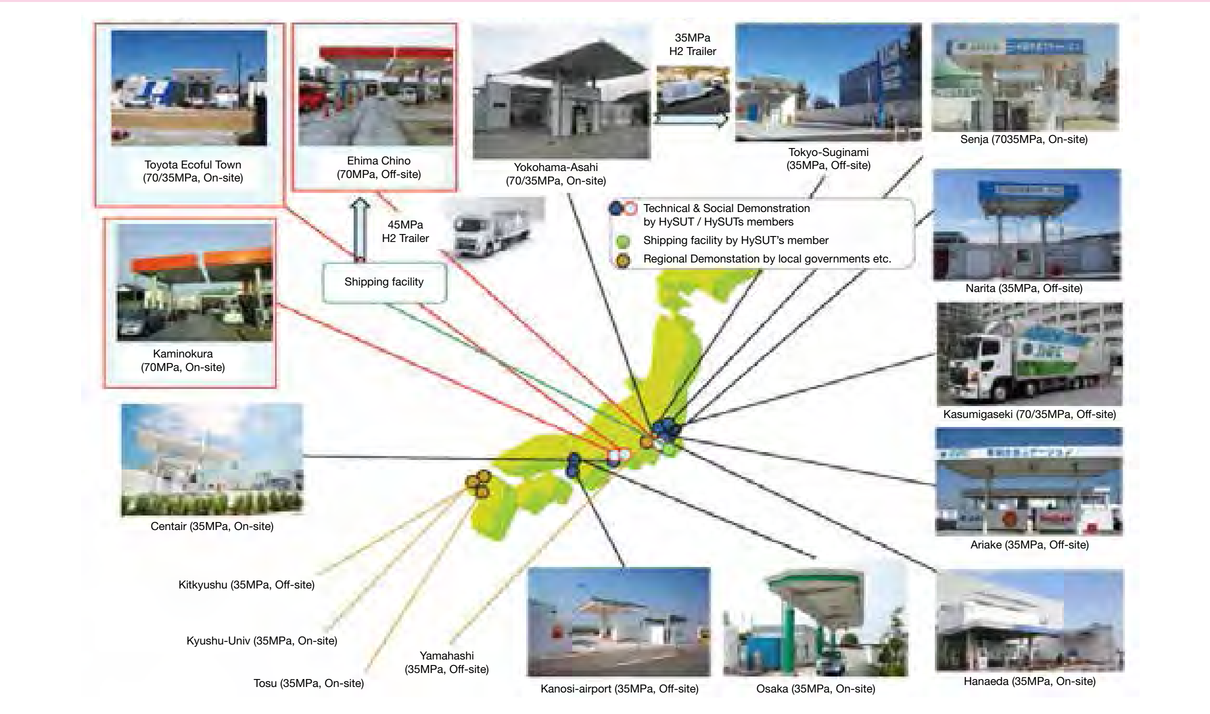
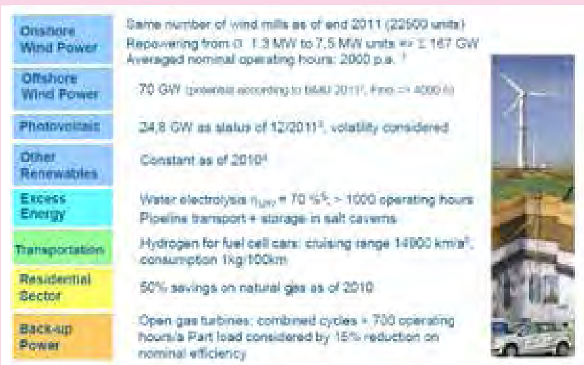


Figure 25: Scenario of the energy system for Germany in view of a 55% CO_2 reduction, developed by the Institute of Electrochemical Process Engineering (IEK-3) (Source: Forschungszentrum Jülich)



The focus is to make use of excess wind power, both onshore and offshore, to electrolyse water to generate hydrogen. This can then be stored through geological storage approaches and be made available for use in fuel cell vehicles.

Publications from this Annex

T. Hua, R. Ahluwalia, L. Eudy, G. Singer, B. Jermer, N. Miller, and T. Patterson, 'Status of Hydrogen Fuel Cell Electric Buses Worldwide,' Submitted to Journal of Power Sources, 2013.

4.5.3 Work Plan for Next Year

The next Annex 26 meeting will be held in Washington DC, USA, on June 17, 2014, in conjunction with the 2014 DOE Hydrogen and Fuel Cells Program's Annual Merit Review.

This annex is concerned with fuel cells and fuel cell systems for portable applications and light traction. Promising techniques for these applications are polymer electrolyte fuel cells operated with methanol or hydrogen.

4.6 ANNEX 27 REPORT

FUEL CELLS FOR PORTABLE APPLICATIONS

Key Message – Facts
Fuel Cells for Portable Applications

- Durability of 20,000 hours for a DMFC system has been achieved. This is one step needed to reduce the OPEX of these systems and to become cost competitive with other technologies.
- Research is being carried out on alkaline membranes. These fuel cells use cheap catalyst materials like nickel, but power density and durability are still low at present.
- Portable SOFC systems fuelled with LPG in the sub 100W class are available.

Key Messages – Opinions
Fuel Cells for Portable Applications

- Increasing the durability and simultaneously decreasing the overall costs will be the focus of research topics for the next few years.
- There is a trend away from conventional hydrogen fed fuel cells to systems operated with liquid fuels and alternative electrolytes.
- Applications of fuel cells within the military sector continue to grow, making use of the silent operation and low emissions of fuel cells.

Annex 27 is concerned with fuel cells and fuel cell systems for portable applications and light traction. A 'portable system' ranges from micro systems at 250W for small mobile applications up to several kW systems that can be moved by four people (the EC definition of 'portable') that are suitable for light traction.

Promising technologies for these applications are polymer electrolyte fuel cells (PEFC) operated with methanol or hydrogen fuel. However, ethanol and propane are also potential fuels that can be used in these systems.

The Annex has been in operation since February 2009 and will run until February 2014. The Operating Agent for this Annex is Dr Martin Müller from Forschungszentrum Jülich GmbH, Germany.

Table 25: List of Participating Organisations in Annex 27

Country Participant	Associated Institution
Austria	Graz University of Technology
Germany	Fraunhofer Institut Chemische Technologien Forschungszentrum Jülich GmbH eZelleron GmbH Next Energy
Italy	Italian National Council of Research (CNR) Institute of Advanced Technologies for Energy (ITAE)
Korea	Korea Institute for Energy Research, (KIER)
Sweden	Intertek Semko

Fuel cells used to power portable and small mobile applications offer higher power density, longer operating times and shorter refuelling times compared to battery powered operation. The time that is necessary for recharging batteries may also be a problem that can be avoided by using fuel cells. Potential applications for portable fuel cells include mobile homes and boats, military applications for soldiers in the field, electronics rechargers and mobile electronic devices.

The direct methanol fuel cell (DMFC) that is often used in portable and small mobile devices offers the advantage of using a fuel with a volumetric energy density that is four times higher than the energy density of hydrogen at 35MPa (350 bar). However, the DMFC itself provides a much lower power density than the polymer fuel cell

(PEFC) operated with hydrogen. In most applications it is necessary to couple the fuel cell with a hybridisation battery to enable start up or to cope with load peaks and energy recovery.

Key developments of MEAs (membrane electrode assemblies) issues are improving the durability and performance of these technologies. Operation at low air stoichiometry is necessary to achieve the high operating temperatures necessary, to close the water loop and to operate the system with pure methanol or ethanol as the fuel.

4.6.1 Activities

The last meeting was held at Semko, Intertek, in Stockholm, Sweden on 12 September 2013. It was attended by six members from four countries (Austria, Germany, Italy, and Sweden).

4.6.2 Technical Developments

This Annex focuses on four aspects in this area:

- Subtask 1: System analysis and hybridisation.
- Subtask 2: System, stack and cell development.
- Subtask 3: Codes and standards, safety, fuels and fuels packaging.
- Subtask 4: Lifetime enhancement.

This Annex has identified that small portable fuel cells are being developed to power a diverse range of applications, from fork-lift trucks, wheel chairs and smart phones through to military applications for soldiers on the ground.

Portable fuel cells are usually used in conjunction with batteries; one option is to provide recharging of batteries, enabling remote and silent recharging; the other option is the operation of hybrid systems, where the battery is used for start-up and peak shaving.

Ultimately, the size of the market will depend on costs of the system, especially where the consumers do not have specific requirements such as silent running or quick refuelling. The increasing power demand of electronic devices may encourage and drive the switch to powering such devices by small fuel cell systems.

Military Applications

Recently it has become apparent that portable fuel cells have made significant inroads into military related applications. It is interesting to observe the developments as such products are driven by function to a greater extent and less by cost. Such developments will likely spill over into civilian applications. It has been identified that military applications can be broken down into the following categories:

- Soldier-worn systems that provide 20W to 50W of power to be used by the systems carried on an individual soldier. These systems are often integrated with a portable energy management system.
- Battery chargers providing power in the range of 90W to 500W and are in most cases used by entire squads.
- Tactical generators that provide power in the range of 1kW to 5kW to forward operating dismounted troops.

Applications for Individuals

Portable systems have been developed for industrial and for private use and can be summarised in the following categories:

- Small systems with up to 10W to recharge electronic devices like cell phones.
- Medium size systems (40W to 200W) based on methanol.
- Large systems (100W to 250W) based on propane.

A product aimed specifically at the public consumer is myFC, a small portable fuel cell system generating 5We from a PEFC. These systems are fuelled by hydrogen generated from a fuel puck when water is added. The price is set at EUR 199 (USD 229), with a three pack of fuel pucks at EUR 10 (USD 12). Each puck is capable of providing 4Wh of electricity. Sales begun in early 2013 and now the system is available from several sales companies in Sweden, USA, United Kingdom, Switzerland and Germany.

Figure 26: myFC portable charger for electronic gadgets, and the power puck cartridges (Source myFC)

Within medium size systems, suitable for hybridisation with batteries, SFC Energy AG has sold more than 20,000 DMFC systems and is the market leader. Their EFOY systems are designed for both industry and recreational applications, with EFOY Comfort intended to provide on board battery recharging: electrical power output of 105W; runtime of more than 3,000 hours and costing EUR 5,500 (USD 7,200). The company now earns more money in the industrial market than before, demonstrated in the 2013 fiscal report with growth in this segment of 42%. However, the number of sales of EFOY (DMFC) systems decreased from 974 to 779 systems, mainly due to the reduction in orders from Government authorities.

TRUMA has developed a system that runs on propane (liquid petroleum gas (LPG)). The system called Truma VeGA, consists of a desulfonation module, a reformer and a high temperature polymer electrolyte fuel cell stack. The system provides 250W of electricity, and can be bought either as a stand-alone unit or already installed in a new motor caravan at a cost of EUR 7,300 (USD 9,740).

Eneramic, from Fraunhofer Institute for Ceramic Technologies and Systems IKTS in Dresden, Germany, have developed a portable SOFC system that delivers 100W. The fuel cell is fuelled by LPG or bioethanol and is completely grid independent. This system has completed field trials, achieving the projected low degradation rates and 5,000 hours lifetime. The high operating temperature of SOFC means that organic impurities in the fuel does not affect the function of the stack. The system includes a start-up burner, a process air pre-heater, a fuel processor, and an after-burner.

Part of the development results of eZelleron will be brought to market in 2015. These systems have a continuous power output of 2W.

Figure 27: eZelleron 2W SOFC system operated with LPG (Source eZelleron)

Example Technical specification	
Output:	2W of continuous output
Peak power output:	5W peak power
Weight:	200 g (fueled)
Volume:	0,2 l
Output voltage:	5V
Connector:	USB 2.0
Charge:	Refillable tank
Working time when using continuous power:	56Wh
Working temperature:	-15°C to 55°C

Intertek Semko, where the last Annex meeting was held, is a global provider of quality and safety solutions, including testing and expert advisory services in the field of batteries and fuel cells. Intertek assesses more than 20,000 batteries each year, covering all chemistries and sizes. They have a deep understanding of special operating condition across a wide range of end-use applications.

Examples of modelling and simulation are:

- PEFC (cells and systems).
- DMFC (cells and systems).
- SOFC (cells and systems).
- Potential and current distribution modelling.
- Thermal analysis of cells and systems.
- Evaluation and design of thermal management systems.

For a fuel cell manufacturer, modelling makes it possible to improve the design of electrochemical cells and systems and understand possible limitations of existing designs. Through mathematical modelling, an application expert can simulate performance characteristics during different operating conditions and thereby accelerate the pace of understanding of the new electrochemical system in relation to specific application requirements.

Research activities focusing on portable fuel cells

Mid-range fuel cell systems are required for most portable applications. For many applications a liquid fed system, such as DMFC provides advantages, but the major barrier to a wide deployment of 250W and larger DMFC systems is their high price.

One possible way to reduce costs is to replace the proton exchange membrane, with an alkaline anion exchange membrane (AEM) as it avoids the need for platinum in the catalyst. These can use non-fluorinated membranes which introduces the possibility of using more readily available fuels such as ethanol or ethylene glycol, rather than methanol. This technology is not as mature as PEM based DMFC, but is under investigation at TU-Graz (Austria), Next Energy (Germany), and Fraunhofer (Germany).

The focus of Fraunhofer ICT is the testing of different catalyst materials for the Alkaline Direct Alcohol Fuel Cells (ADAFC). It has been demonstrated that PdAg/C and PdNi/C catalysts show higher activity than Pd/C. In addition, the electro-oxidation of ethanol and ethylene glycol has shown a better performance than methanol. Another research area is the analysis of more stable polymers, such as Polysulfones, for alkaline direct alcohol fuel cell applications.

Military applications for AEM are also an important research area at Fraunhofer ICT. This work includes investigation of the reaction mechanism, the development of the catalyst and membrane electrode assemblies (MEA) as well as demonstration systems. The regional eco mobility 2030 project aims to integrate a 5kW electrical power output HT-PEM with a reformer and methanol as fuel. Another project involves the development of an APU using a 3kW HT-PEFC fuelled with petrol and diesel, while Multicar M27 is a project looking to integrate a 5kW LT-PEM operated with hydrogen into a communal vehicle.

TU-Graz in particular has been developing special approaches to testing fuel cells, building on standard characterisation techniques and on real time monitoring techniques. The aim is to enable fuel cell systems to operate with highly dynamic loads, to avoid flooding or drying, reduce corrosion and increase membrane lifetime. Obtaining real time analysis enables very efficient operation of the fuel cells and this in turn allows critical operating states to be avoided, which in turn increases the lifetime of the fuel cell stack. Different online measurement techniques are available: cell voltage monitoring and impedance spectroscopy are widely known. Also current mapping systems are available for single cell measurements. Another tool that can be used to detect the cells health is the Total Harmonic Distortion Analysis (THDA). The new approach from TU-Graz and AVL is to extend the THDA and the impedance spectroscopy approach from 0D to 2D and subsequently to 3D, which will require special data acquisition hardware to be developed. Figure 28 shows a sensor board that has been developed for use in the measurements.

Figure 28: Picture of the developed sensor board, TU Graz (Source S++).

Cost reduction, as well as efficiency improvement, and increase of reliability are the most important tasks to prepare PEFC for industrial use in large quantities. The described work demonstrates that an advanced online analysis leads to better understanding and enables continuous state of health monitoring. Also a better and more reliable comparison to simulation results is now possible and will enhance the validity of the tool. The proposed solution is the integration of 3D-CFD degradation models, the experimental acquisition of critical status across the cell space, real-time data acquisition and signal analysis (based on AVL THDA technology) and correlation of results from simulation and experimentation.

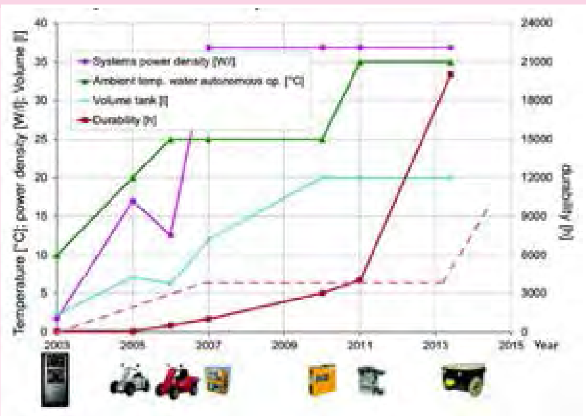
At CNR-ITAE (Messina, Italy) the focus is on hydrogen fuelled fuel cells. The centre in Messina has a particular focus on hydrogen for terrestrial, naval and space applications up to 7kW. Membranes and MEA for PEFC are developed for operating temperatures up to 120°C. A high precision process to manufacture membranes and CCM (catalyst coated membranes) has been developed, producing MEA up to 200cm^2. Furthermore, good coupling between electrodes and membranes and high precision cutting of manifold areas has been achieved, which result in improved manufacturing tolerances. A new project specifically addressing the use of a 1kW PEFC stack in lunar applications is underway, considering stationary power generation and rover activity. For this application, the system will require a closed-loop fuel cell system, running on a pure hydrogen/oxygen configuration. The experimental activity is now focused on identifying the most suitable commercial MEA to operate a stack under pure hydrogen/oxygen configuration, defining the best operating conditions for the selected MEA and completing the development of the stack design for the given conditions. An initial result obtained is that under closed-loop conditions with inappropriate humidification, the power output decreases by 30%.

Forschungszentrum Jülich is developing Direct Methanol Fuel Cells (DMFC) for battery power supply replacement. Whole systems are developed and tested, as well as new stack concepts developed for DMFC based on metallic bipolar plates that are well suited to building stacks with high power densities. The focus at Jülich ranges from MEA development, through stack and system development, with both a MEA production centre in operation and a stack production centre also in operation. The final application focus is on use with fork-lift trucks in warehouses, with UPS systems and service robots also beginning to be considered. Recent durability tests have demonstrated autonomous water operation up to 35°C ambient temperature, and an overall efficiency of 29%. The DMFC system has been shown to be durable up to 20,000 hours in highly dynamic 24/7 operation. Now the focus is on identifying other promising applications for DMFC. One suitable operational area is back-up power. In this case, the operation profile is totally different from fork-lift trucks. It is important that the system will not uncontrollably degrade during standby operation. To avoid degradation rates of more than 1μV/h at 0.1A/cm^2, different standby modes are under investigation. Another idea is the integration of DMFC into a service robot to increase its operation range. Available space in these types of application is usually very limited. Therefore, it is necessary to increase the DMFC power density. Options to enable this include switching from a graphite based design to metallic bipolar plates and to reduce the cell pitch from more than 3mm to less than 2mm.

Figure 29 Service robot (top) and DMFC system that is integrated into the robot at Forschungszentrum Jülich, Germany (Source: Forschungszentrum Jülich) **(bottom).**

Development of DMFC technology has had considerable success, with significant progress against targets achieved over a 10-year research programme. During the last few years development has been targeted at improving the durability and reducing the investment needed for DMFC systems.

Figure 30: DMFC systems developed at IEK-3 (Source: Forschungszentrum Jülich). **The dashed line indicates the specific power density without hybridisation.**



Next Energy, in Germany is a research institute with a strong connection to the Carl-von-Ossietzky University in Oldenburg, is studying the materials, characterisation and systems involving fuel cells. An EU project called DEMMEA ('Understanding the degradation mechanisms of MEA for high temperature PEFC and optimisation of the individual components') has recently started. This project focuses on high-temperature polymer electrolyte fuel cells (HT-PEFC) and will consider platinum free alkaline fuel cells which consist of cheaper materials compared to classical acid PEM, an advantage for application in portable systems.

Alexander Dyck, a member and speaker of the German mirror group IEC TC 105, has recently focused on certifying fuel cell systems and reported on certified fuel cell stacks from Schunk (PEFC), Proton Motor (PEFC) and STAXERA (SOFC) which all have been certified according to IEC 62282–2 (Fuel cell technologies – Part 2: Fuel cell modules). Also the systems from enyMotion (insolvent) and Truma are certified by using an adaption of IEC 62282–4 (FC systems in transport). The systems sold by the company SFC are certified by ICE 62282-5 (Fuel cell technologies – Part 5–1: Portable fuel cell power systems – Safety).

4.6.3 Work Plan for Next Year

The next meeting is planned for 11 and 12 September 2014 at CNR-ITAE, Instituto di Technologie Avanzate per l'Energia Nicola Giordano' in Messina, Italy.

It is the intention that a set of Key Messages from this Annex will be published along with a technical publication. Work on the publication has started, but it is not yet finalised. The aim is to discuss the next steps and critical topics at the next ANNEX 27 meeting.

The objective of Annex 28 is to assist the development of fuel cells through analysis work to enable a better interpretation of the current status and the future potential of the technology. This work will provide a competent and factual information base for technical and economic studies.

4.7 ANNEX 28 REPORT

SYSTEMS ANALYSIS

The aim of Annex 28 is to assist the development of fuel cells through analysis work to enable a better interpretation of the current status, and the future potential, of the technology. This work will provide a competent and factual information base for technical and economic studies, through the production of a book titled 'Data, Facts and Figures on Fuel Cells'.

The Annex began in October 2011 and will run until December 2014. The interim leaders for this Annex, acting as the Operating Agent, are Professor Dr Detlef Stolten of Forschungszentrum Jülich and Dr Nancy Garland of United States Department of Energy (DOE).

4.7.1 Activities

A proposal to initiate a new Annex focusing on systems analysis was made in 2010. At the 42nd Executive Committee meeting in May 2011, a paper giving greater detail was shared with all National Representatives. The first task of this Annex would be to collect available technical and reference data and conduct meta-studies, with the goal of making this information available to the outside world in the form of a technical reference book. The experts will be asked to contribute a chapter as authors. The authors will then be participants in the Systems Analysis Annex. This plan of action was approved by the Executive Committee at the 43rd Executive Committee meeting in October 2011.

The delivered product in the form of a high quality technical reference book will contain concrete information about fuel cells and competitive technologies. The aim is to deliver a sound information basis to highlight the potential and advantages of fuel cells clearly.

4.7.2 Technical Developments

Achievements during 2013

The key topics for the contents of the work have been extended and were accepted by Wiley-VCH for a book proposal. The title of the book has been defined as 'Data, Facts and Figures on Fuel Cells'. The book is intended to provide an up-to-date, scientifically precise, comprehensive and easily comprehendible set of data, facts and figures for engineers and researchers with respect to fuel cell properties from materials to systems. It is proposed that the book will provide economic data as far as publicly available for cost considerations and also a full overview on demonstration data.

The work to date addresses developers at all levels of the value-added-chain yielding insight on the next higher or lower level of the value-added-chain, giving data for benchmarks and providing data on the technology readiness through test and demonstration data. Moreover, it addresses systems analysts who look into fuel cells in detail and those who compare fuel cells on a more general level with batteries, internal combustion engines or turbines. The book is for advanced users though, since it will contain few explanations on terms and scientific prinicples. These explanations are already provided by many existing books. The actual book will cover all fuel cell issues from the materials level to the systems level including the key infrastructure technologies. The unique selling point for this handbook is in creating a solid fuel cell energy data basis.

The individual chapters will be written by subject experts in the field and the chapters will be carefully reviewed by the Editors to ensure a consistent approach throughout the book.

The main chapters of the book are provided under the following headings:

- Executive summary of the status.
- Transportation.
- Stationary.
- Materials Handling.
- Fuel Provision.
- Strategies.
- Codes and Standards.

To date, 15 chapters have been submitted for the book and a further eighteen chapters are currently being written. At present, the USA, Germany, Korea, Japan, Italy and Denmark are represented in the book.

4.7.3 Work Plan for Next Year

In 2014, further authors will be invited for the topics which are still open. The editorial process is ongoing and can only be concluded after all chapters are delivered. It is the intention of the editorial team (D. Stolten, N. Garland and R.C. Samsun) that the book will be published in late 2014 or early 2015.

APPENDICES

Appendix 1: Membership Information

Appendix 2: Annex Experts

Appendix 3: Fuel Cell Companies

Appendix 1

MEMBERSHIP INFORMATION

Further details on our activities can be found on our website at www.ieafuelcells.com. For further information regarding the International Energy Agency please visit www.iea.org

For more information regarding specific Annex details, please contact the Operating Agents or key members of their teams from the information below.

CHAIR AND VICE CHAIR

Chair

Prof Dr Detlef Stolten
Email: d.stolten@fz-juelich.de
Tel: (+) 49 2461 613076

Vice-Chairs

Dr Ing Angelo Moreno
Email: moreno@casaccia.enea.it
Tel: (+) 39 06 304 84298

Dr Nancy Garland
Email: nancy.garland@ee.doe.gov
Tel: (+) 1 202 586 5673

MEMBERS AND ALTERNATIVE MEMBERS

Austria

DI Dr Günter Simader
Austrian Energy Agency
Mariahilfer Strasse 136
A-1150 Vienna
Email: guenter.simader@energyagency.at
Tel: (+) 43 1 5861524 124

Prof Dr Viktor Hacker
Inffeldgasse 25C
A-8010
Graz
Email: victor.hacker@tugraz.at
Tel: (+) 43 316 873 8780

Denmark

Mr Lennart Andersen
Ministry of Climate and Energy
Danish Energy Agency
Amaliegade 44
DK-1256 Copenhagen
Email: lea@ENS.dk
Tel: (+) 45 3392 6702

Mrs Inger Pihl Byriel
Energinet.dk
Tonne Kaersvej 65
DK-7000 Fredericia
Email: ipb@energinet.dk
Tel: (+) 45 7624 4416

Finland

Mr Heikki Kotila
National Technology Agency
(TEKES)
PO Box 69
FIN-00101 Helsinki
Email: heikki.kotila@tekes.fi
Tel: (+) 358 10 521 5874

Dr Jari Kiviaho
VTT, Fuel Cells
Biologinkuja 5, Espoo
PO Box 1000
FIN-02044 VTT
Email: jari.kiviaho@vtt.fi
Tel: (+) 358 20 722 5298

France

Dr Ing Laurent Antoni
CEA
CEA/DRT/LITEN
Route de Panorama – BP 6
F – 92265 Fonteany-aux-roses
Cedex
Email: laurent.antoin@cea.fr
Tel: (+) 33 4 38 78 60 25

Mr Thierry Priem
CEA
CEA/DRT/LITEN
Route de Panorama – BP 6
F – 92265 Fonteany-aux-roses
Cedex
Email: thierry.priem@cea.fr
Tel: (+) 33 4 38 78 55 36

Germany

Prof Dr Detlef Stolten
Forschungszentrum Jülich GmbH
IEK-3: Electrochemical Process Engineering
D-52425 Jülich
Email: d.stolten@fz-juelich.de
Tel: (+) 49 2461 613076

Dr R Can Samsun
Forschungszentrum Jülich GmbH
IEK-3: Electrochemical Process Engineering
D-52425 Jülich
Email: r.c.samsun@fz-juelich.de
Tel: (+) 49 2461 61 4616

Israel

Dr Igor Derzy
Ministry of Energy and Water
216, Yaffo St.
POB 36148
Jerusalem 91360
Email: igord@mni.gov.il
Tel: (+) 972 2 53 16 003

Dr Ela Strauss
Ministry of Science and Technology
Clermont Gano Street 3
Building C
PO Box 49100
Jerusalem 91490
Email: elas@most.gov.il
Tel: (+) 972 2 54 11 136

Italy

Dr Ing Angelo Moreno
CRE-Casaccia
Via Anguillarese 301
00060 S. Maria di Galeria
Rome
Email: moreno@casaccia.enea.it
Tel: (+) 39 06 304 84298

Japan

Mr Masatoshi Iio
NEDO
1310 Ohmiya-cho
Saiwai-ku
Kawasaki-shi
Kanagawa 212-8554
Email: iiomst@nedo.go.jp
Tel: (+) 81 44 520 5261

Mr Kenji Horiuchi
NEDO
1310 Ohmiya-cho
Saiwai-ku
Kawasaki-shi
Kanagawa 212-8554
Email: horiuchiknj@nedo.go.jp
Tel: (+) 81 44 520 5261

Mr Hiroyuki Kanesaka
NEDO
1310 Ohmiya-cho
Saiwai-ku
Kawasaki-shi
Kanagawa 212-8554
Email: kanesakahry@nedo.go.jp
Tel: (+) 81 44 520 5261

Korea

Dr Tae Hoon Lim
KIST
39-1 Hawolkog-dong
Sungbuk-ku
Seoul 136-791
Email: thlim@kist.re.kr
Tel: (+) 82 2 958 5273

Dr Jonghee Han
KIST
39-1 Hawolkog-dong
Sungbuk-ku
Seoul 136-791
Email: jhan@kist.re.kr
Tel: (+) 82 2 958 5277

Mexico

Dr Jorge M Huacuz
Electrical Research Institute
Av. Reforma 113. Col Palmira
Cuernavaca Mor.
62490 Mexico
Email: jhuacuz@iie.org.mx
Tel: (+) 52 777 362 3806

Dr Ulises Cano Castillo
Electrical Research Institute
Av. Reforma 113. Col Palmira
Cuernavaca Mor.
62490 Mexico
Email: ucano@iie.org.mx
Tel: (+) 52 777 362 3811

Sweden

Dr Kristina Difs
Swedish Energy Agency
Box 310
SE-63104 Eskilstuna Sweden
Email: kristina.difs@energimyndigheten.se
Tel: (+) 46 16 544 2296

Mr Bengt Ridell
Grontmij AB
P.O, Box 2909
SE-212 09 MALMÖ Sweden
Email: Bengt.ridell@grontmij.com
Tel: (+) 46 10 480 23 04

Switzerland

Dr Stefan Oberholzer
Swiss Federal Office of Energy
CH-3003 BERNE
Email: stefan.oberholzer@bfe.admin.ch
Tel: (+) 41 31 325 89 20

USA

Dr Nancy Garland
US DOE
1000 Independence Ave
EE 32, 5G-023
Washington DC 20585-0121
Email: nancy.garland@ee.doe.gov
Tel: (+) 1 202 586 5673

Dr Shailesh Vora
National Energy Tech. Lab.
626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
Email: shailesh.vora@netl.doe.gov
Tel: (+) 1 412 386 7515

OPERATING AGENTS

Annex 22

Dr Xiaoping Wang
Email: xiaoping.wang@anl.gov
Tel: (+) 1 630 252 1182

Dr Di-Jia Liu
Email: djliu@anl.gov
Tel: (+) 1 630 252 4511

Argonne National Laboratory
9700 South Cass Avenue
Argonne
IL 60439
USA

Annex 23

Dr Tae-Hoon Lim
Korea Institute of Science and Technology
39-1 Hawolkog-dong
Sungbuk-ku
Seoul 136-791
Korea
Email: thlim@kist.re.kr
Tel: (+) 82 2 958 5273

Annex 24

Dr Jari Kiviaho
VITO Technical Research
PO Box 1000
FIN-02044 VTT
Finland
Email: jari.kiviaho@vtt.fi
Tel: (+) 358 20 722 5298

Annex 25

Mr Bengt Ridell
Grontmij
SE-20509
Malmo
Sweden
Email: bengt.ridell@grontmij.se
Tel: (+) 46 10 480 23 04

Annex 26

Dr Rajesh Ahluwalia
Argonne National Laboratory
9700 South Cass Avenue
Argonne
Il 60439
USA
Email: walia@anl.gov
Tel: (+) 1 630 252 5979

Annex 27

Dr Martin Müller
Forschungszentrum Jülich
D-52425 Jülich
Germany
Email: mar.mueller@fz-juelich.de
Tel: (+) 49 2461 61 1859

Annex 28

Interim Operating Agents

Dr Nancy Garland
Email: nancy.garland@ee.doe.gov
Tel: (+) 1 202 586 5673

Dr Professor Detlef Stolten
Email: d.stolten@fz-juelich.de
Tel: (+) 49 2461 613076

DESK OFFICER AND SECRETARIAT

IEA	Alexander Körner
Desk Officer	Energy Technology Policy Division
	International Energy Agency
	9, rue de la Fédération
	75739 Paris Cedex 15
	France
	Email: alexander.koerner@iea.org
	Tel: (+) 33 1 4057 6657

ExCo	Dr Louise Evans
Secretariat	Ricardo-AEA
	Gemini Building
	Fermi Avenue
	Harwell International Business Centre
	OX11 0QR
	UK
	Email: secretariat-AFCIA@ricardo-aea.com
	Tel: (+) 44 1235 75 3673

Appendix 2

ANNEX EXPERTS

This section lists the Operating Agents and the other experts who have participated in those tasks that were active during the year. Each organisation is categorised as government or government agency (G), research institution (R), industry (I) or academic institution (A).

ANNEX 22: POLYMER ELECTROLYTE FUEL CELLS

Expert	Associated Institution	Institutional Community	Country
OPERATING AGENT: XIAOPING WANG/DI-JIA LIU, ARGONNE NATIONAL LABORATORY, USA (R)			
Viktor Hacker	Graz University of Technology	A	Austria
Steen Yde-Andersen	IRD Fuel Cell Technology Research Centre A/S	R	Denmark
Pertti Kauranen	VTT Processes, Technical Research Centre of Finland	R	Finland
Timo Keranen			
Laurent Antoni	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)	R	France
Carston Cremers	ICT Fraunhofer	R	Germany
Werner Lehnert	Forschungszentrum Juelich GmbH		
Antonella Giannini	Italian National Agency for New Technologies, Energy and Environment (ENEA)	R	Italy
Toshihiko Yoshida	Toyota Motor Company	I	Japan
Akiteru Maruta	TechNova	I	
Gu-Gon Park	Korean Institute for Energy and Research (KIER)	R	Korea
Young-Woo Choi			
Ulises Cano-Castillo	The Electric Research Institute (IIE)	R	Mexico
Lars Pettersson	Royal Institute of Technology (KTH)	A	Sweden
Göran Lindbergh			
Rakel Wreland Lindstrom			

Xiaoping Wang	Argonne National Laboratory	R	USA
Di-Jia Liu			
Deborah Myers			

ANNEX 23: MOLTEN CARBONATE FUEL CELLS

Expert	Associated Institution	Institutional Community	Country
OPERATING AGENT: TAE-HOON LIM, KIST, KOREA (R)			
Dr Steiner	MTU Aero Engines	I	Germany
Angelo Moreno	Italian National Agency for New Technologies, Energy and Environment (ENEA)	R	Italy
Stephen McPhail			
Viviana Cigolloti			
Suk-Woo Nam	Korea Institute for Science and Technology (KIST)	R	Korea
Jonghee Han			
Hee Chun Lim	Korea Electric Power Research Institute (KEPRI)	R	
Taewon Lee	Doosan Heavy Industry	I	
Jungtae Hwang	POSCO Energy	I	
Mohammad Farooque	Fuel Cell Energy (FCE)	I	USA
Yoshiyuki Izaki	Central Research Institute of Electric Power Industry (CRIEPI)	R	Japan (Observer)
M. Yoshikawa			

ANNEX 24: SOLID OXIDE FUEL CELLS

Expert	Associated Institution	Institutional Community	Country
OPERATING AGENT: JARI KIVALHO, VTT, FINLAND (R)			
Karl Föger	Ceramic Fuel Cells Ltd (CFCL)	I	Australia
Sören Linderoth	Risø National Laboratory	R	Denmark
Jari Kiviaho	VTT Processes, Technical Research Centre of Finland	R	Finland
Laurent Antoni	Commissariat à l'Energie atomique et aux énergies alternatives (CEA)	R	France
Florence Lefebvre-Joud			
Julie Mougin			
Robert Steinberger-Wilckens	Forschungszentrum Jülich	R	Germany
Angelo Moreno	Italian National Agency for New Technologies, Energy and Environment (ENEA)	R	Italy
Stephen McPhail			
Harumi Yokokawa	National Institute of Advanced Industrial Science and Technology (AIST)	R	Japan
Akiteru Maruta	Technova	I	
Rak-Hyun Song	Korea Institute for Science and Technology (KIER)	R	Korea
Mohsen Assadi	Lund Institute of Technology	A	Sweden
Olivier Bucheli	HTceramix	I	Switzerland
Subhash Singhal	Pacific Northwest National Laboratory	R	USA
Shailesh Vora	Department of Energy (DoE)	G	

ANNEX 25: FUEL CELL SYSTEMS FOR STATIONARY APPLICATIONS

Expert	Associated Institution	Institutional Community	Country
OPERATING AGENT: BENGT RIDELL. GRONTMIJ AB, SWEDEN (I)			
Karl Föger	Ceramic Fuel Cells Ltd (CFCL)	I	Australia
Günther Simader	Austrian Energy Agency (E.V.A)	G	Austria
Julia Gsellmann			
Viktor Hacker	TU Graz	R	
John Hansen	Haldor Topsoe	I	Denmark
Per Balslev	Dantherm Power	I	
Jari Kiviaho	VTT, Technical Research Centre of Finland	R	Finland
Matias Halinen			
Erkko Fontell	Wärtsilä	I	
Thierry Priem	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)	G	France
Ulf Birnbaum	Forschungszentrum Julich	R	Germany
Martin Müller			
Angelo Moreno	Italian National Agency for New Technologies, Energy And Environment (ENEA)	R	Italy
Akiteru Maruta	Technova Inc	I	Japan
Tajima Osamu	University of Yamanashi	R	
Noboru Hashimoto	Panasonic	I	
Tae-Hoon Lim	Korea Institute of Science and technology (KIST)		Korea
Ulises Cano Castillo	Instituto de Investigaciones Electricas (IEE)	R	Mexico
Jorge M. Huacuz			

Paul van den Oosterkamp	Energieonderzoek Centrum Nederland (ECN)	R	Netherlands
Bengt Ridell	Grontmij AB	I	Sweden
Stephan Renz	Renz Beratung	I	Switzerland
Whitney Colella	The Pacific Northwest National Laboratory (PNNL)	R	USA
Shanna Knights	Ballard Power Systems	I	
Dan Rastler	EPRI	I	
Shailesh Vora	National Energy Technology Lab	R	
Stephane Hody	GDF Suez	I	
Mark Williams	Department of Energy (DoE)	G	

ANNEX 26: FUEL CELLS FOR TRANSPORTATION

Expert	Associated Institution	Institutional Community	Country
OPERATING AGENT: RAJESH AHLUWALIA, ARGONNE NATIONAL LABORATORY, USA (R)			
Gabriela Telias	A3PS	I	Austria
Bernhard Egger			
Mikael Sloth	H_2 Logic	I	Denmark
Jussi Suomela	Helsinki University of Technology (TKK)	R	Finland
Laurent Antoni	Commissariat à l'Energie Atomique (CEA)	R	France
Florent Petit	Institut FC Lab , Université de technologie de Belfort-Montbéliard	R	
T Grube	Forschungszentrum Jülich	R	Germany
Ludwig Joerissen	Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)	R	
M Conte	Italian National Agency for New Technologies, Energy And Environment (ENEA)	R	Italy
Tae Won Lim	Hyundai Motor Company	I	Korea
Per Ekdunge	PowerCell	I	Sweden
Rajesh Ahluwalia	Argonne National Laboratory	R	USA
Romesh Kuma			
Azra Selimovic	Volvo AB	I	
Silvia Wessel	Ballard Power Systems	I	

ANNEX 27: FUEL CELLS FOR PORTABLE APPLICATIONS

<table>
<tr><th>Expert</th><th>Associated Institution</th><th>Institutional Community</th><th>Country</th></tr>
<tr><td colspan="4">OPERATING AGENT: MARTIN MÜLLER, JÜLICH RESEARCH CENTRE, GERMANY (R)</td></tr>
<tr><td>Viktor Hacker</td><td>Technische Universität Graz</td><td>A</td><td>Austria</td></tr>
<tr><td>Martin Müller</td><td>Forschungszentrum Jülich GmbH</td><td>R</td><td rowspan="3">Germany</td></tr>
<tr><td>Carsten Cremers</td><td>Fraunhofer Institut Chemische Technologien</td><td>R</td></tr>
<tr><td>Thomas Pessara</td><td>eZelleron GmbH</td><td>I</td></tr>
<tr><td>Fabio Matera</td><td rowspan="2">Institute of Advanced Technologies for Energy (ITAE)</td><td rowspan="2">R</td><td rowspan="2">Italy</td></tr>
<tr><td>Irene Gatto</td></tr>
<tr><td>Akiteru Maruta</td><td>AIST</td><td>R</td><td>Japan</td></tr>
<tr><td>Sang-Kyung Kim</td><td>Korean Institute for Energy and Research (KIER)</td><td>R</td><td>Korea</td></tr>
<tr><td>Emelie Wennstam</td><td>Intertek Semko</td><td>I</td><td>Sweden</td></tr>
</table>

ANNEX 28: SYSTEMS ANALYSIS

An interim team of professionals led by Professor Dr Detlef Stolten of Forschungszentrum Jülich, Germany and Dr Nancy Garland of United States Department of Energy.

Appendix 3

FUEL CELL COMPANIES

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
AUSTRIA					
AVL	Cell/stack/system	Simulation software, monitoring technique, system tests and development	kW	Automotive powertrains; All applications for SOFC; Mobile applications for PEMFC	www.avl.com
Fronius	Stack/system	System development	kW	Electrolysis, Forklift, Home energy system	www.fronius.com
Magna Steyr	Hydrogen tank	Liquid, 700 bar	kW	Automotive	www.magnasteyr.com
OMV	Hydrogen station	700 bar		Hydrogen Filling stations, operator	www.omv.com
Plansee	Cell/stack	SOFC	W, kW	Component manufacturer	www.Plansee.at
DENMARK					
Danish Power Systems	Stack components	MEAs for HT PEMFC	10 cm^2 – 300 cm^2	All applications for HT PEMFC	www.daposy.com
H2 Logic A/S	H2Drive® Fuel cell systems	PEFC	10 kW	Material handling vehicles	www.h2logic.com
	H2Station®: hydrogen refuelling stations	Gaseous hydrogen	35MPa – 70MPa	35 MPa for fork-lifts & busses 70 MPa for cars	

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
IRD A/S	Stack and System	PEFC	1.5 kW	Micro-CHP units	www.ird.dk
	Stack and System	DMFC	500 W	UPS – communications, IT back up power, remote power	
	Stack and System	PEFC	800 W	Refuelling	
SerEnergy	Components Stack System Solutions	PEFC	300 W - 50 kW	Backup power APU Aux vehicles Automotive Refuelling – through partners	www.serenergy.com
Dantherm Power	System	SOFC PEFC	1 kW, 1,7 kW, 5 kW 50 kW	Micro-CHP units, UPS/BackUp - cell phone network, emergency communication, Fiber broad band network	www.dantherm-power.com
Topsoe Fuel Cell	Stack	SOFC	1.5 kW 6 kW	Micro-CHP APU CHP 10-50 kW	www.topsoefuelcell.com

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
FINLAND					
Convion Oy	System	SOFC	20 – 100 kW	Stationary	
Elcogen Oy	Single cells and stacks	SOFC	1-10 kW	Stationary	www. elcogen.com
Oy Woikoski Ab	Hydrogen production and filling stations	Hydrogen, refuelling stations	350-700 bar	Filling stations	www. woikoski.fi
T Control Oy	Integrated modules	PEFC, hydrogen and methanol	1kW – 5kW	Back-up power, telecom base stations, UPS	www.tcontrol.fi
Fitelnet Oy	Integrated modules	PEFC, methanol	1kW – 5kW	Back-up power, military, UPS	www.fitelnet.fi
FRANCE					
Areva	Systems	PEFC + electrolyser: Greenergy Box™	Hundreds kW	Grid stabilization/ emergency backup systems	www.areva. com/EN/ operations-408/ hydrogen-and-fuel-cells.html
Axane (Air liquid subsidiary)	Systems	PEFC	0.5- 10 kW	Clean and autonomous power supply for off-grid sites	www.airliquide-hydrogen-energy. com/en/who-we-are/axane.html
PaxiTech	MEA, GDE, stack, systems, educational kit, test equipment	PEFC	4-10 W	Portable power	www. paxitech.com
Pragma Industries	Stack, test equipment, electronic loads, hydrogen Storage	Roll to roll PEFC	10-100 W	Portable tools	www.pragma-industries.com

Company Name	Area (stack/system)	Type of technology	Scale / Range	Application	Website
HyPulsion (GV Axane/PlugPower	System	PEFC	1.5-14 kW	Integrated Fuel cells systems for forklift trucks	www.airliquide-hydrogen-energy.com/en/who-we-are/hypulsion-1.html
SymbioFCell	System	PEFC	5 kW, 20-300 kW	Integrated Fuel cells systems for Range Extenders (5 kW) and Full Power heavy duty vehicles (20-300 kW)	www.symbiofcell.com
GERMANY					
balticFuelCells GmbH	Stack/ system	PEFC		Stationary/ transportation	www.balticfuelcells.de
BASF SE	Stack (MEA)	PEFC			www.basf-fuelcell.com
BAXI INNOTECH GmbH	System	PEFC		Stationary	www.baxi-innotech.de
balticFuelCells GmbH	Stack/System	PEFC		Stationary/ transportation/ portable	www.balticfuelcells.de
Ceramic Fuel Cells GmbH	Stack/System	SOFC		Stationary	www.ceramicfuelcells.de/
Daimler AG	Stack/ system (FCV)	PEFC		Transportation	www.daimler.com
DBI Gas- und Umwelttechnik GmbH	System			Stationary	www.dbi-gut.de
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), ITT	Stack/system	PEFC, SOFC		Stationary/ transportation	www.dlr.de/tt
EBZ GmbH Fuel Cells & Process Technology	System	SOFC		Stationary/ transportation	www.ebz-dresden.de

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Eisenhuth GmbH & Co. KG	Stack (BPP)				www.eisenhuth.de
Elcore GmbH	System	PEFC		Stationary	www.elcore.com
EnBW Energie Baden-Württemberg AG	System (utility)			Stationary	www.enbw.com/brennstoffzelle
E.ON Ruhrgas AG	System (utility)			Stationary	www.eon.com/en.html
EWE AG	System (utility)			Stationary	www.ewe.de
eZelleron GmbH	System			Transportation/ portable	www.ezelleron.de
FCPower Fuel Cell Power Systems GmbH	System	PEFC		Stationary	www.fcpower.de
Forschungs-zentrum Jülich GmbH	Stack/System	PEFC, SOFC		Stationary/ transportation/ portable	www.fz-juelich.de www.fuelcells.de
Fraunhofer ICT – IMM	System (fuel processor)				www.imm.fraunhofer.de
Fraunhofer-Institut für Keramische Technologien und Systeme IKTS	Stack/System	SOFC, MCFC		Stationary/ portable	www.ikts.fraunhofer.de
Fraunhofer-Institut für Solare Energiesysteme ISE	Stacks/System	PEFC		Transportation/ portable	www.h2-ise.de
Fraunhofer-Institut für Chemische Technologie ICT	Stacks/System	AFC, PEFC		Transportation/ portable	www.ict.fraunhofer.de
Freudenberg FCCT KG	Stack (components)				www.freudenbergfcct.com

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
FuMA-Tech GmbH	Stack (membranes)				www. fumatech.com
FutureE Fuel Cell Solutions GmbH	System				www.future-e.de/
FuelCell Energy Solutions GmbH	Stack/ System	MCFC		Stationary	www.fces.de
FuelCon AG	System	PEFC, SOFC			www. fuelcon.com
Heliocentris Academia GmbH	System			Stationary	www. heliocentris.com
HIAT gGmbH, Hydrogen and Informatics Institute of Applied Technologies	Stack (components)	PEFC			www.hiat.de/
Hüttenberger Produktion-stechnik Martin GmbH	Stack (components)	PEFC		Portable	www. huettenberger-produktion-stechnik.de
New enerday GmbH	System	SOFC		Stationary/ Transportation/ Portable	www.new-enerday.com
NEXT ENERGY EWE-Forschungs-zentrum für Energie-technologie e.V.	Stack/ System	PEFC		Stationary/ Transportation	www.next-energy.de
Proton Motor Fuel Cell GmbH	Stack/ System	PEFC		Stationary/ Transportation	www.proton-motor.de/
Riesaer Brennstoffzellen-technik GmbH	Stack/ System	PEFC		Stationary	www.rbz-fc.de
SFC Energy AG	Stacks/ Systems	PEFC		Portable	www.sfc.com

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Schunk Bahn- und Industrietechnik GmbH	Stack/ System	PEFC		Portable	www.schunk-fuelcells.com
Sunfire GmbH	Stack/ System	SOFC		Stationary	www.sunfire.de
Truma Gerätetechnik GmbH & Co. KG	System	PEFC		Portable	www.truma.com
Ulmer Brennstoffzellen Manufaktur GmbH	Stack/ System	PEFC		Stationary/ Transportation	www.ubzm.de
Vaillant Deutschland GmbH & Co. KG	System	SOFC		Stationary	www.vaillant.de
Viessmann Werke GmbH & Co. KG	System	PEFC		Stationary	www.viessmann.com
VNG-Verbundnetz Gas AG	System			Stationary	www.vng.de
WS Reformer GmbH	System (fuel processor)				www.wsreformer.de
Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)	Stack/ System	PEFC		Stationary/ Transportation/ Portable	www.zsw-bw.de
ZBT GmbH	Stack/ System	PEFC		Stationary/ Transportation/ Portable	www.zbt-duisburg.de
ITALY					
SOFC - Power	Form powder to power, stack & System	SOFC	1 - 10 kW	Micro-CHP units	www.sofcpower.com

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Electropower system	Stack & System	PEFC	2 - 10 kW	Back-up power, remote areas application, stand-alone systems	www.electropowersystems.com
Dolomiteck	System	PEFC	10s of kW	Transport application – hydrogen and fuel cell Mini buses	www.dolomitech.com/
GENPORT	System	PEFC	300-1000 W	Portable	www.genbee.it
JAPAN					
Aquafairy/Rohm	System	PEFC	a few kWs to 200W	Portable	www.aquafairy.co.jp/en/index.html www.rohm.com/web/global/
Iwatani	System	SOFC	200 W	Portable	www.iwatani.co.jp/eng/index.php
Mitsubishi Gas Chemical	System	DMFC	300 W	Portable	www.mgc.co.jp/eng/index.html
Fujikura	System	DMFC	-	Portable/APU	www.fujikura.co.jp/eng/
IHI Aerospace	System	PEFC	-	APU	www.ihi.co.jp/ia/en/index.html
Suzuki Motor	System	PEFC	a few kWs to 100kW	Transport	www.globalsuzuki.com/corporate/index.html
Daihatsu Motor	System	AFC	10 kW class	Transport	www.daihatsu.com/company/index.html
Nissan Motor	System	PEFC	100 kW class	Transport	www.nissan.co.jp/EN/index.html

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Honda Motor	System System	PEFC SOFC	100 kW-class 10 kW-class	Transport Stationary	http://world.honda.com/
Toyota Motor	System	PEFC	100 kW-class	Transport	www.toyota-global.com/
Fuji Electronic	System	PAFC	100 KW	Stationary	www.fujielectric.com/
Toshiba Fuel Cell Power Systems	System	PEFC	1 kW-class	Stationary	www.toshiba.co.jp/product/fc/ (in Japanese)
Panasonic	System	PEFC	1 KW-class	Stationary	http://panasonic.net/
Aisin Seiki	System	SOFC	1 kW-class	Stationary	www.aisin.com/
JX Nippon Oil	System	SOFC	1 kW-class	Stationary	www.noe.jx-group.co.jp/english/
Miura	System	SOFC	5 kW-class	Stationary	www.miuraz.co.jp/en/
Bloom Energy Japan	System	SOFC	200 kW	Stationary	www.bloomenergy.jp/
Mitsubishi Heavy Industries	System	SOFC	250 kW-100 MW	Stationary	www.mhi.co.jp/en/index.html
Kyocera	Stack	SOFC	1 kW-class	Stationary	http://global.kyocera.com/
TOTO	Stack	SOFC	1 kW-class	Stationary	www.toto.co.jp/en/index.htm
NGK Spark Plug	Stack	SOFC	1 kW-class	Stationary	www.ngkntk.co.jp/english/index.html

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
NGK Insulators	Stack	SOFC	1 kW-class	Stationary	www.ngk.co.jp/english/index.html
Murata Manufacturing	Stack	SOFC	1 kW-class	Stationary	www.murata.com/index.html
Sumitomo Precision Products	Stack	SOFC	5 kW-class	Stationary	www.spp.co.jp/English/index2-e.html
KOREA					
POSCO Energy	Stack & System	MCFC	300 KW ~ 2.4 MW 100 MW/yr production	Distributed Power/APU for Ship	www.poscoenergy.com
Doosan Heavy Industry	Stack & System	MCFC	300 kW	Distributed Power	www.doosanheavy.com
Fuel Cell Power	Stack & System	PEFC	1 kW	Building Power	www.fuelcellpower.co.kr
GS Fuel Cell	Stack & System	PEFC	1 ~ 200 kW	Building Power/ submarine	www.gsfuelcell.com
Hyundai Motors	Stack & System	PEFC	80 ~ 300 kW	FCV and bus	www.hyundai.com
MEXICO					
Microm	Backup Systems	PEFC, methanol reformer	1 - 15 KW	Backup for telecomm and other uses	www.microm.com.mx/
Ballard [21]	Backup Systems	PEFC, methanol reformer	2.5 - 5 kW	Backup for telecomm and other uses	www.ballard.com

[21] Ballard has a production facility in Tijuana, México where the ElectraGenTM-ME is manufactured.

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
SWEDEN					
Powercell	Stack and systems	PEFC and diesel reformers	1kWe - 10kWe	Back up power, powerpacks and APU fro trucks	www.powercell.se/
Cellkraft	Stack	Robust PEFC	1kWe - 2kWe	Offgrid	http://cellkraft.se/
myFC	Stack system	Portable	10kWe - 75kWe	Charger	www.myfuelcell.se
SWITZERLAND					
FutureE Fuel Cell Solutions GmbH	System				
USA					
GM, in Pontiac		PEFC		FC vehicles	www.gm.com
Ultra Electronics		SOFC	300 W	Portable power	www.ultracellpower.com
ReliOn Inc		PEFC		Back-up power	www.relion-inc.com
ClearEdge Power		PEFC		Stationary Power generation	www.clearedgepower.com
Bloom Energy	System	SOFC		Stationary Power	www.bloomenergy.com
UTC Power [22]	Stack/System	PAFC, PEFC		Large stationary, automotive, transit buses, aerospace, defence	www.utcpower.com
Plug Power	System	PEFC		Materials handling	www.plugpower.com
FuelCell Energy		MCFC	Up to 90 MW	Large stationary power	www.fuelcellenergy.com

[22] As of early 2013, ClearEdge Power bought UTC Power's fuel cell business, and as such UTC Power no longer have an involvement in the fuel cell sector