International Energy Agency (IEA) Advanced Fuel Cells
Implementing Agreement

ANNUAL REPORT 2012

June 2013

iea Energy Technology Network

This Annual Report has been prepared by the Annex 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

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).

In the AFC IA we work to advance the state of understanding of all our members in the field of fuel cells, both in terms of the technology development and the application specific issues that need to be solved.

The world of fuel cells is rapidly developing, both in terms of improving the technology to give longer and better fuel cell lifetimes and reliability, and in terms of increasing market penetration.

Fuel cells are once again receiving high levels of attention as numerous companies release fuel cells that are tailored for customer requirements. Fuel cell cars are on the brink of commercialisation, with one major car company having already begun production in 2013, and two further manufacturers planning to begin in the next two years.

The key highlight from 2012 is that fuel cells are providing reliable, efficient power in a multitude of locations and to a wide range of customers already.

- In 2012 stationary fuel cells dramatically expanded:

> Over 42,000 deployed in Japan for domestic level energy generation and for hot water, fuelled by the gas grid. Demand is expected to remain very strong into 2013.

> Many deployments achieved for telecoms as back-up power and excellent performance reported during Storm Sandy in the USA.

> Numerous large companies utilising fuel cells to help fulfil their energy base load requirements, including ebay, Walmart, BMW and Coca-Cola.

- Fuel cells penetrated into other markets, with forklift truck deployments in the USA taking off. These initially benefitted from the ARRA, but purchases have continued after the end of this, with three times the levels of additional purchases with no subsidy, made by repeat and new customers giving over 3000 fuel cell powered fork lift trucks in operation now in North America. There are several companies pursuing fuel cell forklift trucks in Europe currently [1].

Such developments, often still assisted by government support, demonstrate that fuel cell products are entering markets and providing convenient, suitable energy. Companies are finding that fuel cells deliver on their promises.

Attention is turning to more efficient use of the power generated by renewables, especially wind in Europe. Fuel cells and electrolysers have a key role to play here. We expect this area to develop rapidly over the next few years.

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 to Executive Committee meetings on a sponsorship basis, providing direct access to the most current international technical discussions on fuel cells and the opportunity of building up an international network.

For further information please see our website **www.ieafuelcell.com** or contact us directly.

Detlef Stolten
Chairman of the Advanced Fuel Cells Implementing Agreement

[1] Fuel Cells Today, 31st May 2013, First Hydrogen Station for Fuel Cell Forklift Trucks in France.

2. Introduction

The aim of the Advanced Fuel Cells Implementing Agreement (AFC IA) is to contribute to the research & development (R&D) of fuel cell technologies (FC), 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 enabling focus 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, 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 the technology of the fuel cells, working together to improve and advance this technology.

Key Messages from the Advanced Fuel Cells Implementing Agreement

- In the longer term, hydrogen and fuel cell technologies can be part of the solution to convert and store energy, and thereby contribute to the integration of fluctuating renewable energy in energy systems.
- Fuel cell systems have proven remarkable long term stability enabling commercial usage of this technology. The acceptance of fuel cells is increasing rapidly through demonstration programmes which take place under real conditions.

2.1 NATIONAL OVERVIEWS

Here we provide a brief summary of each member country's position with regard to fuel cells, which is often related to their national priorities within the energy arena.

2.1.1 Austria

The major energy policy goals of Austria are to stabilize energy consumption at 1,100 PJ by 2020, and to reduce greenhouse gas emissions by 16% (base year: 2005) by 2020. Renewable energy in Austria contributes 26%, and by 2020 this figure should be 34%. The R&D programs strategically cover fuel cell topics in order to support the development of innovative companies in this field.
2 to 4 million EUR 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 118 million EUR have been supported over the last few years. The new programme, "Mobility of the Future (2012- 2020)", provides an annual budget of 14-19 million EUR 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 program, including 30 microCHP fuel cell systems, will occur. It is currently under negotiation between the Austrian utility companies, manufacturers and ministries.

Fuel cell	Infrastructure
H filling stations operational	1 public station in Vienna, two non-public stations in Graz and Sattledt.

2.1.2 Denmark

Denmark has ambitious plans for renewable energy by 2020:

- 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.

Fuel cells		Details
MW installed and operational	1 MW and 62 kW	Danish companies have installed an additional 1,944 MW abroad
Number of domestic stationary units	50 units	Danish companies have installed an additional 38 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	19 vehicles	Additional 18 vehicles abroad
H filling stations operational	4 stations in Denmark and 3 stations abroad, built by Danish companies.	

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 reach the level of 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.

Two hydrogen filling stations are in operation, both operated by Oy Woikoski Ab.

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.

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 order to guarantee the further development of these technologies in 2006 government, industry and science began a strategic alliance called the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) in Germany, to speed up the process of market preparation of products. The total budget of NIP invested over a period of ten years until 2016 amounts to 1.4 billion EUR.

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 as well as R&D projects. Specific programme areas within NIP are:

- Transport and Hydrogen Infrastructure.
- Hydrogen Provision.
- Stationary Energy Supply.
- Special Markets.

Fuel cells		Details
MW installed and operational	~ 8MW (not all operational)	Most systems, especially the newly built ones, are 1 kW systems.
Number of domestic stationary units	300 units	Callux project
New in 2012	~ 100 units	Callux project
Number of other stationary units (large scale)	~ 35	Information as of 2007
Number of operational fuel cell vehicles	110 cars and 8 buses	Clean Energy Partnership (CEP)
Portable units	24,000	Number of units sold by SFC, German company (Press Release from 05/2012)
H filling stations operational	27 stations in Clean Energy Partnership (CEP)	

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 of Israel launched a national program 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 at least seven universities, and several highly advanced industrial fuel cell enterprises conducting R&D and demonstration programs. The programmes span a broad range of applications including stationary and automotive, based on SOFC and Alkaline FC technologies and using methanol, hydrogen, etc. as the fuel.

R&D programmes support the development of fuel cells and their applications, including the TEPS group (Transportation Electric Power Solutions), 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 10 million USD.

2.1.7 Italy

In 2013 the National Energy Strategy to 2020 for Italy was published; its focus is to reduce the cost and dependence on energy imports for Italy, while maintaining the environmental targets.[2] These objectives should be achieved through increasing energy efficiency[3] and the use of renewables,[4] 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 & Fuel Cells roadmap. Currently 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.

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

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

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

[4] 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.

Fuel cells		Details
Number of domestic stationary units	150	Either installed or due to be installed in 2013-14, ene. field programme.
Number of other stationary units (large scale)	~ 200	Remote systems for telecom repeater stations.
H 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, particularly with the successful commercialisation of residential fuel cell systems through the "Ene-Farm" products microCHP, the first of which were launched at the beginning in 2009. The total number of installed systems is over 42,000 by the end of March 2013. Toyota announced its intention to develop a new high performance fuel cell stack in September 2012, and will release a new Ene-Farm model. A further subsidy round was announced in December 2012, of 25 billion JPY, available for 53,000 units (approx. 250 million USD, 190 million EUR). This will provide a subsidy of 0.45 million JPY for each unit (4,400 USD 3,500 EUR) and the units should be installed by March 2014.

The government subsidy for Ene-Farm products will be completed in 2015, with the assumption that the price for a domestic fuel cell system will drop to around 700,000 – 800,000 JPY in 2016. The target sales price by 2020-2030 is 500,000 – 600,000 JPY in the NEDO (New Energy and Industrial Technology Development Organisation) scenario. To date the price has dropped in line with expectations.

Japan is also a leading country for fuel cell cars, with the Toyota new-generation FC vehicle concept (FCV-R) unveiled in 2011 at the Tokyo Motor Show, and Nissan unveiling their new fuel cell SUV concept (TeRRA) at the Paris Motor Show in 2012. Ten energy companies and three automakers made a joint statement in 2011 committing to 100 hydrogen refuelling stations in 2015 around major cities, to coincide with the market introduction of FCEV from the automakers Toyota, Honda and Nissan. The key issue with the development of FC vehicle technologies to enable full commercialisation in 2025-2030 remains cost reduction of the fuel cell system itself.

A new research focus of triple combined power, using 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 target technology development for SOFC for commercialisation with a budget of 1.24 billion JPY in 2013 and will run to 2017, and target technology development for hydrogen utilisation, with a budget in 2013 of 2 billion JPY to run to 2017.

Fuel cells		Details
MW installed and operational	~ 29 MW[5] 0.6 MW	Ene-Farm PAFC technology
Number of domestic stationary units	~ 42,000 units	Ene-Farm
New in 2012	14,477 units	
Number of other stationary units (large scale)	6	PAFC technology, 200-10 kW those shipped in 2011 only
Number of operational fuel cell vehicles	50 cars and buses	
H filling stations operational	16 stations	

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

2.1.9 Korea

The national program of fuel cells in Korea is mainly driven 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 is 46 billion KRW, approximately 43 million USD, government funding only).

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 the power sources, with the Korean government subsidising 80% of the installation costs of fuel cells in 2012. The subsidy available will be gradually reduced to 30% by 2020.

Fuel cell vehicle commercialisation is underway with the second phase of the demonstration program running from 2010 to 2013. One hundred fuel cell vehicles are in operation providing data on durability, operational cost and the effect on the environments. 13 hydrogen stations are currently in operation and the government target is to increase this number to 48 by 2015 and 500 by 2030.

Fuel cells		Details
MW installed and operational	MCFC : 51.2MW PAFC : 4.8MW PEFC : 345kW	MCFC : 100kW/300kW/1.2 MW/2.4MW/5.6 MW POSCO Energy Products PAFC : 400kW UTC Products PEFC : 1kW FCP, GS Fuel Cell etc. Products
Number of domestic stationary units	345 units	
New in 2012	120	1kW units
Number of other stationary units (large scale)	35	MCFC : 23 units PAFC : 12 units
New in 2012	MCFC : 11.2MW PAFC : 4.8MW	
Number of operational FC vehicles	100 SUV’s, 6 buses	SUV equipped with 100kW stack, 700 Bar Tank (6 kg H_2) Bus equipped with 200kW stack, 700 Bar (30 kg H_2)
H filling stations operational	13 hydrogen stations are in operation and 1 is under construction in 2012.	

2.1.10 Mexico

Mexico sees itself as an ideal manufacturing location for advanced emerging technologies and is keen to work with and use fuel cells. Installations of fuel cells in Mexico include at least 114 units of Ballard’s ElectraGenTM-ME, and a number of Microm units.

Within the National Science and Technology Council, hydrogen research is a feature of the Science & Technology programmes, with a number of projects supported including those for new application projects.

Hydrogen technologies are included in the clean and efficient energy technologies portfolio, and are often included in the renewable energy section.

Fuel cells		Details
MW installed and operational	0.28MW [6]	
Portable units		Several low power (0.5 – 2kW) FC's (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 technology companies and academic research. 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 program (about 600,000 EUR per year) and on-going surveillance and participation in IEA and EU activities (about 250,000 EUR per year).

Fuel cells		Details
MW installed and operational	Less than one MW	Several back up power units are installed
Number of domestic stationary units	Less than 10	Several hydrogen PEFC units running, with about 5 new ones in 2012
Number of operational fuel cell vehicles	2 will be delivered in April 2013	The city of Malmö
Portable units	A growing number	myFC a Swedish company has recently commercialised the Powertrekk unit
H filling stations operational	One movable one in Arjeplog mainly for winter test cars	

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.

Fuel cells		Details
MW installed and operational	0.26	1 MCFC plant with 240kW, a few domestic SOFC systems (1 to 3kW), a few 1 to 2kW systems for UPS (Telecom)
Number of domestic stationary units	~15	Some are not in the field, but with the developers (Hexis)
Number of other stationary units	~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, plus other pilot and demonstration vehicles (municipal vehicle Hy.muve, a few passenger cars)
H filling stations operational	Two, with a further one planned: • First one opened in Spring 2012, utilising alkaline electrolysis with 130kg H_2/d, 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.	

During 2012 two Jupiter fuel cell systems were installed in Davos and Luzern, providing power for telecoms systems. Both systems have been developed and installed by FutureE Fuel Cell Solutions GmbH from Nürtingen, Swisscom's cooperation partner within the EU's "fit-up" project.

[6] Considering that Ballard units come in 2.5 and 5 kW, 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.

2.1.13 USA

"Advancing hydrogen and fuel cell technology is an important part of the Energy Department's efforts to support the President's all-of-the-above energy strategy, helping to diversify America's energy sector and reduce our dependence on foreign oil."

- Energy Secretary Steven Chu

The USA's Fuel Cells Technologies Program aims to enable the widespread commercialization 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. This had funding of 44 million USD in 2012, and focuses on fundamental research as well as demonstration projects and market realization. The key targets that many other countries also reference are:

Fuel cells

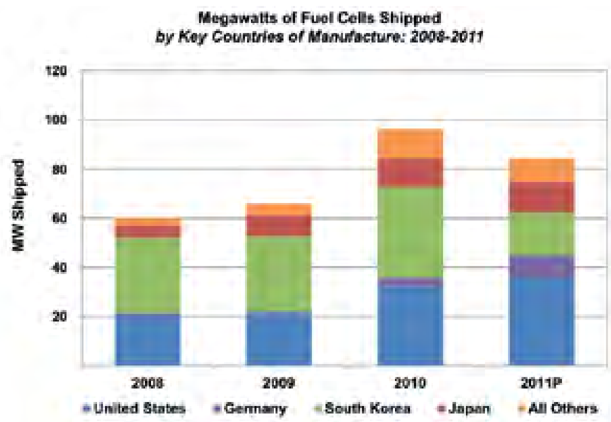
- By 2015, develop a fuel cell system for portable power (<250W) with an energy density of 900Wh/L
- By 2017, develop a direct-hydrogen fuel cell power system for transportation with a peak efficiency of 60% and 5000-hour durability, that costs of 30USD/kW at high volume
- By 2020, develop distributed 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 1500USD/kW
- By 2020, develop medium-scale CHP fuel cell systems (100kW–3MW) that with electrical efficiency of 50%, CHP efficiency of 90% ,and are durable for 80,000 hours at a cost of 1,500USD/kW for operation on natural gas and 2,100USD/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/L at a cost of 1000USD/kW

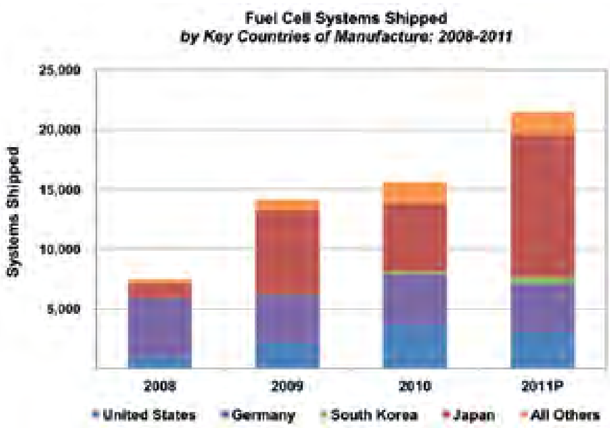
Hydrogen storage

- 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/L (0.040kg hydrogen/L).
- Ultimate full-fleet target of 2.5kWh/kg system (7.5 wt.% hydrogen) and 2.3kWh/L (0.070 kg hydrogen /L).

Establishing the level of fuel cell penetration of a market is not simple. The following graphs, generated by Pike Research highlight two different approaches; the MW of power shipped (top), and the number of fuel cell systems shipped (bottom). Pike research estimates that if all government policies relevant to stationary fuel cells are carried out, the potential global market would surpass three gigawatts (GW) in 2013, and increase to more than 50 GW by 2020.

Figure 1: MW and number of fuel cells shipped





2.2 THE INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) is an autonomous agency 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 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 currently 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 visit www.iea.org/aboutus/standinggroupsandcommittees/

2.3 THE ADVANCED FUEL CELLS IMPLEMENTING AGREEMENT

The scope of the Advanced Fuel Cells Implementing Agreement (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 developments 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 cell (PEFC) systems, as well as focusing on applications of fuel cells, specifically stationary power generation, portable power applications and transport applications. Information exchange occurs 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 Advanced Fuel Cells Implementing Agreement is February 2009 to February 2014.

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 2012.

The scope of the Advanced Fuel Cells Implementing Agreement Programme for 2009-2014 is shown in the table below.

Table 1: 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

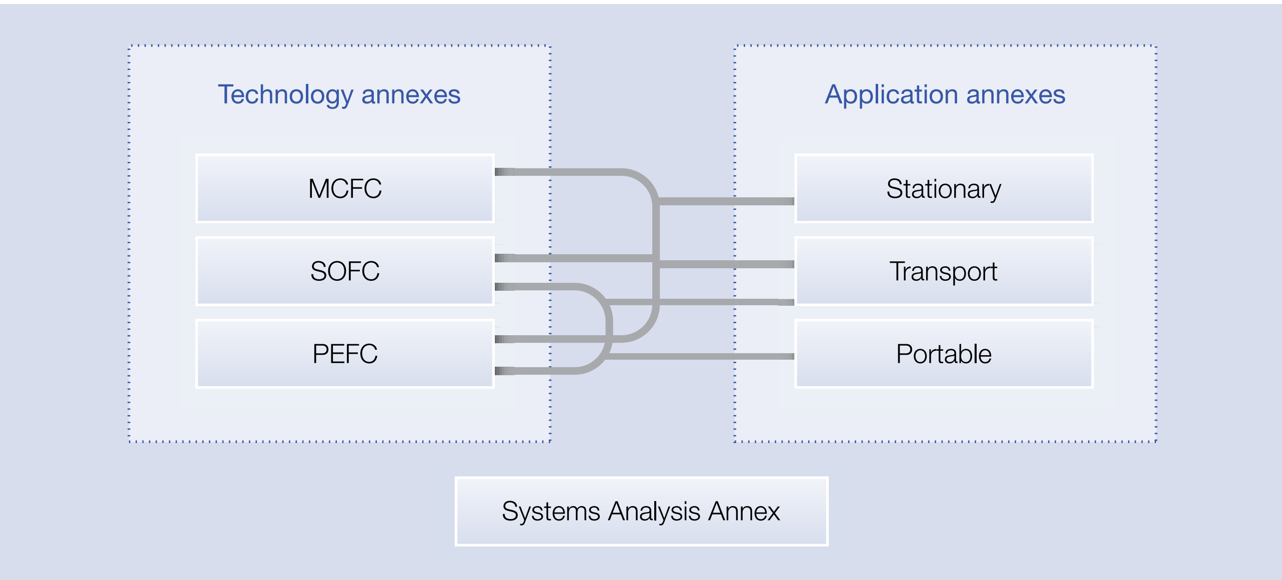
2.4 CURRENT ANNEXES

Seven Annexes were active in 2012. Together these seven annexes form an integrated programme of work for February 2009 to February 2014, comprising three technology-based annexes (MCFC, SOFC and PEFC) three application-based annexes (stationary, transportation and portable applications), with the Systems Analysis Annex encompassing all these areas as shown in Figure 3 below.

Figure 2: Active Annexes in 2012.

Annex	Title
Annex 22	Polymer Electrolyte Fuel Cells
Annex 23	Molten Carbonate Fuel Cells
Annex 24	Solid Oxide Fuel Cells
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

Figure 3: Active Annexes within the AFC IA Programme.



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.

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 systems is being carried out.

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

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

3. Executive Committee Report

3.1 ACTIVITIES

Two Executive Committee (ExCo) meetings were held in 2012, the first in Toronto, Canada, and the second in Mainz, Germany. A joint session with the Hydrogen Implementing Agreement was held as part of the Executive Meeting in Toronto, where the focus was on how the two Implementing Agreements could ensure best coverage of areas that potentially overlap.

Table 2: Executive Committee Meetings 2012

Meeting	Date and place meeting held
ExCo44	7th – 8th June 2012, Toronto, Canada
ExCo45	4th – 5th December 2012, Mainz, Germany

The web site of the Implementing Agreement (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.

3.2 MEMBERSHIP

In 2012 the Advanced Fuel Cells Implementing Agreement welcomed Israel as a new full member to the Implementing Agreement, with effective membership beginning in 2013.

Interest in joining was expressed by Russia and China. Sponsorship was offered to TVEL of Russia, to become an industrial sponsor.

During 2012 several countries left the Implementing Agreement, in response to the shifting priorities of their governments. Belgium and the Netherlands ceased to be members in 2012, and Canada announced its intention to withdraw, effective from November 2012.

In 2012 the Executive Committee membership for Sweden changed as Mr. Bernt Gustafsson retired from the Swedish Energy Agency and Mr. Bengt Ridell became the interim full member for Sweden. In Korea Dr. Tae-Hoon Lim became the full member replacing Dr. Hee Chun Lim, with Dr. Jonghee Han becoming the Alternate Member. For Japan, Mr. Masatoshi Iio was replaced by Mr. Horiuchi and Mr. Kanesaka as the Members in April.

Prof. Detlef Stolten (Germany) continued his work as Chairman, with Dr. Angelo Moreno (Italy) and Dr. Nancy Garland (USA) continuing as Vice-Chairs. François Cuenot remained as the IEA Desk Officer.

The following fifteen IEA member countries participated in this Implementing Agreement during 2012.

Table 3: Advanced Fuel Cells Implementing Agreement Member Countries

Country	Signatory Party	Date of Signature
Australia	Ceramic Fuel Cells Limited (CFCL)	November 1995
Austria	Austrian Energy Agency (EVA)	September 2004
Canada	Delegation to the Organisation for Economic Co-operation and Development (OECD)	November 1991
Denmark	Riso National Laboratory	September 2004
Finland	Finnish National Technology Agency (TEKES)	May 2002
France	Commissariat à l'Energie Atomique (CEA)	May 2005
Germany	Forschungszentrum Jülich	December 1992
Israel	Ministry of Energy and Water Resources	December 2012
Italy	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA)	April 1990
Japan	New Energy and Industrial Technology Development Organisation (NEDO)	April 1990
Korea	The Korea Electric Power Corporation (KEPCO)	April 1998
Mexico	Electrical Research Institute	June 2006
Sweden	The Swedish Energy Agency (from December 1998, previously NUTEK)	April 1990
Switzerland	Office Féderale de l'Energie (OFEN)	April 1990
USA	Department of Energy	May 1995

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.

There were no changes to the procedural guidelines for the programme during this year.

3.4 KEY DECISIONS IN 2012

1. The members achieved consensus on an updated Mission Statement and Objectives. Special consideration was given to how this IA can better fulfil the requirements of the EUWP, CERT and the IEA, whilst continuing the knowledge and policy sharing work that members find so valuable.
2. Each Annex committed to producing an Annual set of Key Messages, as well as investigating the production of one published article or paper a year.
3. ExCo members will share national noteworthy developments including projects, policies, targets and technology breakthroughs with the Secretary, so these can be shared on the AFC IA website to achieve improved publically available information on the AFC IA website.
4. The AFC IA has decided to explore the interest in initiating two new subtasks to investigate the state of play of electrolysers within PEFC and SOFC. Currently no IA addresses this area.
5. It was decided to offer sponsorship status to TVEL of Russia.
6. The AFC IA ExCo will, with the HIA, provide a joint update to the relevant Chapters of the Energy Technology Perspectives that potentially cover hydrogen and fuel cells, so the IEA have a resource to draw upon for the next update.
7. Alongside one of the ExCo meetings each year, it was proposed to work to hold a complementary workshop/ technical day involving our members, Annex experts, companies and interested parties. The aim is to develop a specific topic, gaining technical insights, economic insights and share our knowledge with host country participants and generate a summary output at the end. Suggested initial topics are biomass and fuel cells; energy efficiency and fuel cells; fuel cell powered fork lift trucks.

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 2013. The 46th meeting will be held in Salzburg, Austria on May 22-23rd, 2013. The 47th meeting will be held in Israel in November 2013.

Continued implementation of the approved work programme for the seven current Annexes is planned, and there will be development of the contents of the book to be published from Annex 28 Systems Analysis.

ANNEX 22

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

Key Messages – Polymer Electrolyte Fuel Cells

- The fuel cell system improvements and the successful development of hydrogen pressure tanks have allowed a range of 560km for fuel cell electric vehicle FCEV to be demonstrated.
- The cold weather performance of FCEV is now equivalent to that of gasoline-powered vehicles.
- Looking to the near future a number of automobile manufacturing companies are planning to launch fuel cell vehicles targeting widespread commercialisation by 2015. Hence the demand for fuel cells (typically PEFCs) is expected to increase in the automobile sector.
- The demand for portable fuel cells (mainly DMFCs) is also expected to increase, especially in the consumer and industrial electronics sectors.
- New cathode catalysts based on platinum-yittrium bimetallic alloys achieved four times higher catalytic activity than the common Pt catalyst used in PEFC.
- The operation of an integrated 5kW high temperature PEFC stack targeting APU applications has successfully been demonstrated with synthetic kerosene reformate. It reached the project goal: electric power of 5kW at 0.5A/cm^2 and 160°C.

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 (PEFCs), 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 sectors. The activities Annex 22 cover all aspects of these two types of fuel cells, from individual component materials to whole 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. Xiaoping Wang at Argonne National Laboratory, United States Department of Energy.

Country Participant	Associated Institution
Austria	Graz University of Technology
Canada	Ballard Power Systems Simon Fraser University and NRC Canada
Denmark	IRD Fuel Cell Technology Research Centre A/S
Finland	VTT Technical Research Centre of Finland Spinverse Oy
France	Atomic Energy Commission (CEA)
Germany	Research Centre Jülich and ICT Fraunhofer
Italy	Italian National agency for new technologies, Energy and sustainable economic development (ENEA)
Japan	Toyota Motor Company
Korea	Korea Institute of Energy Research (KIER) and Korea Institute of Science and Technology (KIST)
Mexico	Instituto de Electricas (IEE)
Sweden	KTH - Royal Institute of Technology
USA	Argonne National Laboratory (ANL)

The long-term performance and stability of PEFC are critical to the successful commercialisation of the technology. Annex 22 saw a greater emphasis of R&D focused on Membrane Electrode Assembly (MEA) component degradation, including catalyst, catalyst support and the proton exchange membrane, with the use of more advanced characterisation tools to reveal the mechanisms occurring. Significant knowledge and insights into the degradation mechanisms were gained, which will help to minimise the degradations and improve the lifetime of the PEFC performance. It is expected that this topic will continue to be one of the research focuses going forward.

4.1.1 Activities

The seventh workshop of the Annex 22 Working Group was held on June 21-22, 2012 at the Korea Institute of Energy Research (KIER), Korea. Ten representatives from five countries attended the workshop, addressing advanced catalysts and membrane materials development, degradation mechanistic investigation of PEFC components, and (Fuel Cell Hybrid Vehicle) FCHV development. The workshop also included tours to the fuel cell laboratories at KIER and to the Hydrogen and the Fuel Cell Center for Industry, Academy, and Laboratories in the Buan area. The Buan center works to evaluate systems up to 200kW, and the intention is that it becomes a world-class research, development, and demonstration hub for different hydrogen and fuel cells systems and for education, training and commercialisation.

The eighth Workshop of the Annex 22 Working Group was held on November 29-30, 2012 in Espoo, Finland. The workshop considered catalyst and membrane material development and characterisation, MEA degradation, PEFC component characterisation and PEFC system development and demonstration. The workshop also included tours of the various fuel cell laboratories and facilities at VTT, Technical Research Centre of Finland in Espoo. Twelve representatives from nine countries attended the workshop.

Annex 22, at Argonne National Laboratory, co-ordinated two meetings for the Durability Working Group that was established in 2010 among technical experts of eight DOE sponsored Durability projects and DOE personnel (US Department of Energy). The group provides a forum for the exchange of information, the discussion of issues and protocols related to degradation mechanisms of polymer electrolyte fuel cells and stacks.

4.1.2 Technical Developments

Annex 22 has three active subtasks, and the work and results are reported for each subtask.

Subtask 1 - New Stack Materials

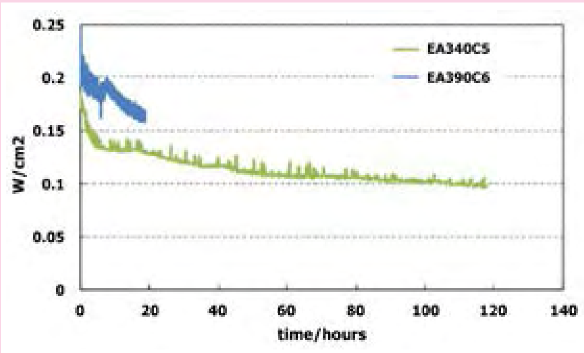
Information exchange in this subtask focuses on research aiming to develop improved, lower-cost membranes, electrode catalysts and structures, MEAs, bipolar plates, and other stack materials and designs.

High temperature PEFC (HT-PEFCs) can offer both improved PEFC performance and system efficiency for the 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 key.

- New platinum-transition metal catalysts for high temperature PE fuel cells are investigated at Graz University of Technology, where it has been identified that a ratio of platinum and cobalt of 1:5 exhibits the most promising results as highly active oxygen reduction reaction catalysts. In has also been found that the catalyst stability can be increased by depositing an additional platinum layer on top of the previously fabricated Pt-Co catalyst.

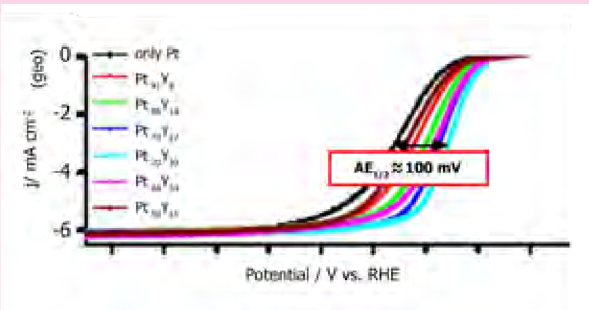
- KIER has developed anion-conducting pore-filling membranes (PFM) for solid alkaline fuel cells, because these allow the use of less expensive, non-precious metal catalysts lowering the fuel cell cost. One PFM reached 120h operation with cell performance loss of 50%, one of the longest tests reported for alkaline electrolyte membranes.

Figure 4: Power density as a function of operating time at 0.6V for a single solid alkaline fuel cell using an anion-conducting pore-filling membrane developed at KIER.



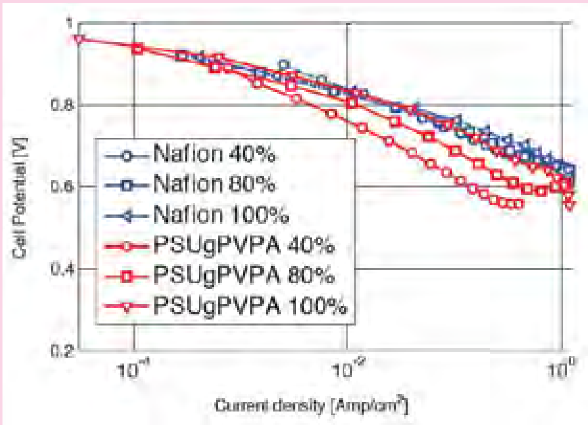
- KIST is developing highly-active oxygen reduction reaction catalysts for PEFC and has identified that adding yttrium to a platinum catalyst can increase the Oxygen Reduction Reaction (ORR) activity by four times with no degradation after 300 cycles.

Figure 5: Alloying of Pt with Y enhances ORR activity of Pt, with the $Pt_{70}Y_{30}$ composition being the most active (light blue curve).



- KTH in Sweden has synthesised and investigated a new binder to replace Nafion ionomer in the cathode layer in order to enhance the cathode performance and stability. The new binder can offer a higher proton concentration, as well as better chemical and thermal stability and this material achieves comparable performance to Nafion ionomer at 80°C and high relative humidity percentage as shown in Figure 6.

Figure 6: Polarisation curve of MEAs with Nafion or PSUgPVPA ionomer in cathode layer at different relative humidity levels.

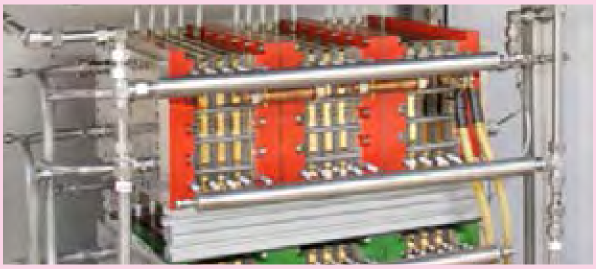


Subtask 2 - Systems, Component, and Balance-of-Plant

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

- Forschungszentrum Jülich, Germany, is developing a 5kWe high temperature PEFC stack for APUs. One of the three modules comprising the 5kW stack has run 2,300h with only a 10% power loss and is still running. The fuel used is synthetic kerosene-based reformate, containing 33% H_2, 21.4% H_2O, 15.6% CO_2, and 1% CO. It has 75 to 85% H_2 utilisation and an average cell voltage of 450-500mV. It reached the project goal of delivering electric power of 5kW at 0.5A/cm² and 160°C.

Figure 7: 5kWe HT-PEFC stacks consisting of 70 cells made into two sub-stacks with each having three modules, integrated and demonstrated at Jülich.



- Toyota Motor Corporation in Japan is researching membrane electrode gas diffusion assembly and vehicle application of PEFC. The fuel cell vehicle cruising range has been significantly improved to 560km under real use conditions by increasing the hydrogen tank pressure and system efficiency. An in-situ technique was developed for visualisation of water generated inside the fuel cell during power generation below freezing point, which helped the development of proper water management during PEFC cold start-up. As a result, cold-weather performance has been improved to the point that Toyota FCEV has the equivalent cold start and driving performance to that of a gasoline-powered vehicle.

- KIER has investigated the effect of carbon corrosion on MEA performance through analysing microstructural changes in the cathode catalyst layers and polarisation losses of the PEFC. The findings here showed that carbon corrosion led to microstructural changes of the cathode catalyst layer, the growth and detachment of the platinium nanoparticles, and the increased hydrophilicity of the cathode layer due to formation of carbon oxide species. All of these contributed to the decay of the MEA's performance.

- Argonne National Laboratory in the USA has systematically investigated various causes for electrocatalyst degradation and how these affect the long-term PEFC performance. It was identified that catalyst particle size is the primary governing factor in the electrochemically-active surface area and ORR mass activity loss leads to cell performance degradation. Also the upper potential limit and potential increase rate were identified as significantly affecting the degradation rate of the cell performance. It was therefore concluded that the DOE target of 5000h operation lifetime can be achieved with a catalyst particle size of larger than 5nm.

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.

- Graz University of Technology is investigating the possibility of using new catalysts for the ethanol oxidation in alkaline media which are not doped with platinum. It was found that nickel and gold are both active towards ethanol oxidation reaction and catalysts with thermally pre-treated and oxidized support materials exhibit best performance.

4.1.3 Work Plan for Next Year

During 2012, the research and development (R&D) reported within the Annex addressed all the critical technical barriers/issues that hinder PEFC and direct fuel PEFC technologies from achieving widespread commercialisation. For both technologies, R&D is focused on cell and stack materials, components and systems, with improved MEAs, reduced catalyst and system costs, improved catalyst and support durability, and enhanced system design and analyses. Although significant progress has been made in many areas, 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 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

Key Messages – MCFC

- A 11.2MW (four 2.8 MW 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 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.
- 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 for further international collaboration in the research and development of certain aspects of MCFC technology, in order to realise commercialisation of the MCFC system. The aspects include:

a. Improvement of performance, endurance, and cost effectiveness, for stacks and balance of plant (BoP).

b. Development and standardisation of effective test-procedures for materials, cells and stacks.

c. 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).

Participants

Country Participant	Associated Institution
Germany	Forschungszentrum Jülich GmbH (KFA) 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)

Molten Carbonate Fuel Cells 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 life time extension and cost reduction to achieve market comparability with competing technologies. Many institutions and research activities focus on these technical huddles, particularly focusing on corrosion prevention and electrolyte management.

4.2.1 Activities

The fourth meeting of Annex 23 was held in Fukuoko, Japan on the 29-30th October 2012, and was held in conjunction with Annex 25, Stationary Fuel Cells. At this meeting three countries (Japan, Italy, Korea) and six experts participated from Annex 23. The co-working of Annex 25 and 23 was successful in 2012, as there is considerable overlap when MCFC installations are considered. This meeting focused on the technical improvements in life time and cost reduction for MCFC. Also new applications of MCFC systems were discussed, such as CO_2 separation, biogas utilisation and hydrogen production.

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 licencing agreement. Fuel Cell Energy has now delivered 180MWe of MCFC and has a backlog of another 120MWe. A further 100MW+ contract has been 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 new Federal Ministry of Education and Research government complex in Berlin.

Market Perspectives

In Korea the feed in tariff programme, in operation since 2007, was replaced by the RPS (Renewable Portfolio Standard) in 2012, with fuel cells counted 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 54 billion USD through to 2022. The competence of fuel cells against other renewables will decide the size of the fuel cell market.

Figure 8: Artists impression of the completed Hwasung 58MW site, currently under construction.

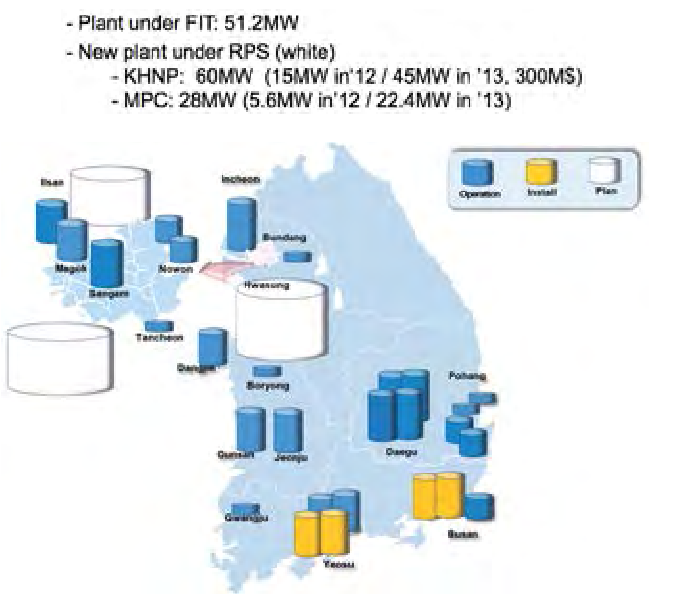
POSCO had 51.2MW of installed capacity of MCFC over a total of 16 sites in Korea at the end of 2012, and has commercialised products available at 300kW, 1.4MW and 2.8MW, demonstrating the market readiness of this product area. Also, a light-weighted & down-scaled 100kW class MCFC system has been developed with FCE and operated at two sites in Seoul city. In order to cope with pollutant regulation and 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 occurring in 2012–13. The intention is to achieve high efficiency (greater than 48%) and long-term operation (higher than 40,000h). Doosan Heavy Industry is looking for new applications for MCFC, such as CO_2 capture, desalination, and higher efficiency system combined with turbines, etc.

In the USA there are 33 states and the District of Columbia that have instituted RPS mandates; five states that have adopted non-binding renewable

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



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 wide spread, such as CHP, biomass and landfill gas[7]. 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.

The cost to manufacture an MCFC plant in the USA is today approximately 2000 USD/kWe with the aim to further decrease the costs to 1500 USD/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.

World-wide there are large MCFC plants in operation at 64 sites with a total production of about 1.2TWh, and 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.

Publications from this Annex

The preparation of the MCFC booklet is in the final stage, with contributioans from ENEA (Italy), KIST (Korea) and FCE (USA). It is intended that the booklet will include a global overview of the status of Molten Carbonate Fuel Cells, as well as highlighting the special features of MCFC such as MCFC for CO_2 separation, MCFC in the gas grid and for production of hydrogen, and MCFC in the waste-to-energy chain.

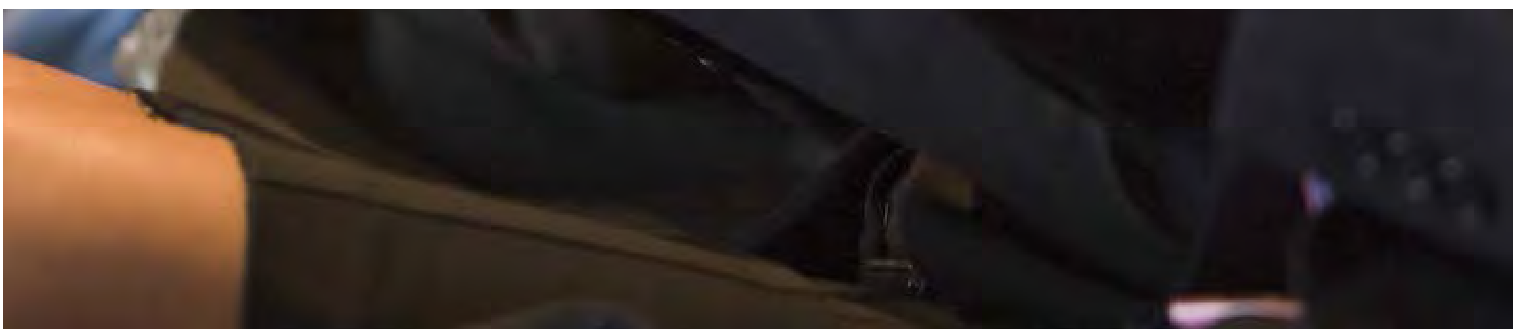
[7] Source 2009: www.epa.gov/chp/state-policy/renewable_fs.html

4.2.3 Work Plan for Next Year

The next MCFC Annex meeting will take place in October 2013, in Columbus, Ohio, USA and will be held in conjunction with the Fuel Cell Seminar 2013. Considerable experience from system operations demonstrates that life time enhancement and cost reduction are still needed to make MCFC systems compatible with the market.

It is the intention that the set of Key Messages will be updated and released for this Annex, together with the MCFC booklet.

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

Key Messages – SOFC

- The Callux Programme in Germany and the Ene-Farm products in Japan, both for domestic scale CHP provision from fuel cells, have begun to use SOFC systems.
- Large scale installations provided by Bloom Energy in the USA have achieved significtant adoption in a number of States by large companies, and Bloom Energy has expanded production to the east coast of the USA, as well as maintaining the California headquarters and manufacturing site.

The aim of Annex 24 is the continuation and intensification of the open information exchange to accelerate the development of Solid Oxide Fuel Cells (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, and institutions 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 the VTT Technical Research Centre in Finland.

Participants

Country Participant	Associated Institution
Australia	Ceramic Fuel Cells Ltd
Canada	Natural Resources Canada
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
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)
Netherlands	The Energy research Centre of the Netherlands (ECN)
Sweden	Swedish National Energy Administration
Switzerland	Swiss Federal Office of Energy
USA	US 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 40-60%, depending on the power plant configuration. SOFC's efficiency is unique in being practically independent by the system's scale, and one kilowatt power output systems have been demonstrated to have 60% net efficiency.

SOFCs 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 (<1kWe).
- Auxiliary Power Units (APU) and back-up power (1-250kWe).
- Stationary small-scale combined heat and power (m-CHP) (1-5kWe).
- Stationary medium-large scale (0.1-10MWe).

4.3.1 Activities

The Annex meeting 2012 in Luzern, Switzerland had to be cancelled. The next annual meeting was decided to be held in Okinawa on Saturday 5th of October 2013. The meeting will be held in conjunction with the SOFC XIII conference.

Annex 24 contributed to the arrangement of one international workshop in 2012, the Fuel Cell Systems Workshop, May 30th – 31st 2012, in Bruges, Belgium.

4.3.2 Technical Accomplishments

Technology Perspective

Mobile, military and strategic: One of today's major concerns in the energy field is to fulfil the requirements for mobile applications (<1kWe), especially in the field of military defence and strategic reconnaissance. Above all, reduced weight and volume with high power densities, as well as robustness, are the required characteristics. The portable electronics market represents a niche market for solid oxide fuel cell micro-systems. State of the art Li-ion and Ni-ion rechargeable batteries and PEFCs have significantly lower energy densities than SOFC systems, so SOFC have much to offer. More powerful hand-held electronic devices such as mobile phones or laptops could be used uninterrupted for weeks fuelling the micro-unit with a small fuel cartridge. Fuel consumption in military defence applications represents an enormous economic cost to Defence departments, and thus to the taxpayers. Currently, power generator sets (gensets) are the largest consumers of fuel on the battlefield, making the transport of fuel the army's Achilles' heel. SOFC systems not only offer up to 85% fuel savings when compared to traditional diesel electricity generators, they can also run on a variety of fuels. The silent operation of fuel cell technology is an inherent advantage for strategic operations, and the generation of water as a by-product makes the unit even more appreciated, as it could be a source of clean water for soldiers. In the civilian field there is a vast number of telecommunication systems located in isolated regions, far away from the natural gas grid or electricity network, which are powered by traditional inefficient stand-alone gensets. SOFC technology fits like a glove for supplying clean, reliable and efficient energy to the telecommunications' network. Another industry that could certainly take advantage of these characteristics is the oil & gas industry. Apart from providing more efficient power off-shore, SOFC systems can be used for cathodic protection of gas pipelines to prevent corrosion, substituting the devices used today which have an extremely low efficiency.

Auxiliary Power Units: Auxiliary Power Units: SOFC can be employed in auxiliary power units (APU) for on-board generation of electricity on vehicles of any kind. The main scope for application is that of electricity supply while a vehicle is at a standstill, ranging from caravans stationed overnight to aircraft parked at an airport gate. An SOFC based APU also improves electricity generation efficiency during the vehicles' journeys and can supply back-up power during emergencies. Many large vehicles run on diesel today, and SOFC offers the advantage of being able to operate on diesel reformate without the necessity of further gas processing steps that would be required to purify the reformate to hydrogen. It is the ideal APU unit from a size of 500We up to several tens of kWe for road vehicles or even several hundreds of kWe as required by aircraft and marine vessels. The efficiency of electricity generation on board vehicles using a conventional generator coupled to the engine is today in the range of 10 to 15%. The system net efficiency of an SOFC APU could reach above 30%, which would more than double the power yield from the same amount of fuel. Additionally, on-site emission of diesel fumes, noise, and other pollutants would be reduced to near zero. Utilisation of the heat produced by the SOFC for heating or cooling (via absorption coolers, for instance) on the vehicle would further increase the overall efficiency.

Small scale stationary: Stationary small scale power plants (1-5kWe) are usually referred to as micro-CHP, i.e. residential scale combined heat and power. The great potential of this application lays in the fact that both power and heat for a household can be generated on the premises, from a single primary energy carrier, such as natural gas (NG) or liquefied petroleum gas (LPG). This obviates transportation losses and greatly enhances the utilisation of these fuels, reducing waste. Each end-user thus becomes a producer as well, creating the opportunity to sell electricity when supply exceeds the household's demand. Considerable amounts of primary energy input can be saved by producing power on the spot and utilising the excess heat for heating purposes, rather than relying on centralised production of power and separate heat generation. Two main modalities of micro-CHP systems can be distinguished: those that obtain the fuel from the grid (e.g. NG) and those that work isolated from the grid (off-grid or stand-alone) thus having to store the fuel. Thanks to the widespread availability of natural gas through the distribution grid, the grid connected application has the potential to become very widespread, and the potential market – aiming in particular at the replacement of old household boilers – could be of several hundreds of thousands of systems per year in Europe alone.

Medium-Large scale: Electricity can be transported over long distances with little power loss, but heat cannot be piped efficiently far from the point of generation. In order to make use of the generated heat, power plants should therefore be located nearby the end-users. Such decentralisation of power generation facilities improves overall efficiency, since the by-product heat can also be used. However, conventional power plants cannot be scaled-down without efficiency loss, and the negative impact of a combustion based plant is generally not desirable in the vicinity of the end-user basin. Medium and large

SOFC based generation systems avoid these drawbacks and can efficiently combine heat and power delivery at "neighbourhood scale". Cogeneration plants in the range of hundreds and thousands of kilowatts need not be limited to satisfy households and industry demand: hotels, hospitals, university campuses, airports and many other large centres can benefit from having their own, independent power and heat supply. Medium-scale SOFC generation can also fit the needs of the automotive industry for clean and efficient powering, either by integrating the unit inside the vehicle or by externally recharging battery electric vehicles (BEV).

The transportation sector represents the fastest growing sector in terms of energy consumption, with a vast majority of greenhouse gas emissions being produced by road-based transport. Battery-recharging stations installed strategically in areas isolated from the electricity grid could contribute to improving the infrastructure and promoting the use of electric vehicles, thereby reducing local CO_2 emissions and overall fuel consumption. Though smaller systems limit the liability of SOFC products in the early stages of market introduction, and are therefore favoured by industry today, large-scale SOFC plants certainly represent the next step in providing clean affordable energy to society at large. At multi-megawatt scale, traditional powering technologies can be integrated into fuel cell-based power plants to achieve even higher electrical efficiencies, for example by incorporating a bottoming cycle with gas and/or steam turbines working either under atmospheric or pressurised conditions. Integrated gasification fuel cell power plants (IGFC) become economically feasible with large-sizes, as the efficiency of turbines increases with their size.

For each of these fields of applications, there are already pioneering industrial developers attempting to enter the market and gaining valuable experience and expertise in terms of practical know-how and end-user requirements. This front-line activity is essential in order to accelerate the progress of SOFC's robustness, cost reductions and consumer familiarity compared to the conventional technologies commonly utilised.

4.3.3 Work Plan for Next Year

The next SOFC Annex meeting will take place in conjunction with SOFC XIII meeting, in October 2013, Okinawa, Japan.

The IEA Annex 24 SOFC pamphlet "International Status of SOFC technology 2012-2013" will be published during the first quarter of 2013. The authors are Stephen J. McPhail, Luigi Leto and Carlos Boigues-Munoz from ENEA, Italy.

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 – Stationary Fuel Cells

- Installations of stationary fuel cells and their successful application have accelerated dramatically in 2012, with over 40,000 domestic micro-CHP installations in Japan, and nearly 1,500 back up installations operating; some of them were providing excellent service during Storm Sandy.
- In the USA, industry has planned the further purchase of more than 1,300 fuel cell powered emergency backup installations, each of these without any DOE subsidy towards the purchase.
- Callux in Germany, with up to 800 micro-CHP fuel cells, continues to develop and the ene.farm program in Europe with 1000 micro CHP fuel cells is taking off.
- The strongly increasing volume of stationary fuel cells is enabling improved automatic industrial production and that increases the quality and reliability of the systems. It also improves the likelihood of achieving the target prices that will be competitive on the market.
- Subsidies are still important for the growing deployment of stationary fuel cells on the markets.
- Stationary fuel cells systems exist that have been in operation for over ten years with the same fuel cell stack.

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 The Swedish Energy Agency acting through E.ON Sverige AB, Sweden.

Participants

Country Participant	Associated Institution
Australia	Ceramic Fuel Cells Limited
Austria	Austrian Energy Agency
Canada	National Research Council
Denmark	Haldor Topsoe, Dantherm Power
Finland	Technical Research Centre of Finland, VTT, Wärtsilä
France	Commissariat à l'énergie atomique et aux énergies alternatives (CEA), GDF-Suez
Germany	Forschungszentrum Jülich
Italy	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, (ENEA)
Japan	The New Energy and Industrial Technology Development Organisation (NEDO), Panasonic, Aisin Seiki, Toshiba
Korea	Institute of Science and Technology (KIST)
Mexico	Instituto de Investigaciones Electricas (IEE)
Netherlands	Energieonderzoek Centrum Nederland (ECN)
Sweden	Grontmij
Switzerland	Beratung Renz Consulting, Swiss Federal Office of Energy
USA	Department of Energy (DOE), EPRI, PNNL

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

A key element of the work of this Annex is recognising and highlighting 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.

There is considerable expansion of stationary fuel cells occurring currently, with both the growth in domestic level systems for CHP (Combined heat and power) and commercial systems that provide power and backup 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 key steps for market introduction and expansion.

4.4.1 Activities

Two Annex 25 meetings were held in 2012. The first on the 19th and 20th April, in Paris Saint Denis, France, was hosted by GDF Suez. 17 participants from 10 countries, as well as a guest from Spain, attended.

The second meeting was held on the 29th and 30th October in Fukuoka, Japan, where 13 participants from 7 countries attended.

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

Decisions taken by Annex 25 in 2012:

- 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 for fuels for fuel cells, with a focus on biofuels, will be compiled by ENEA, Italy, and an outline presented in Spring 2013.
- More answers on the questionnaire in Subtask 5 are required from participants.

4.4.2 Technical Developments

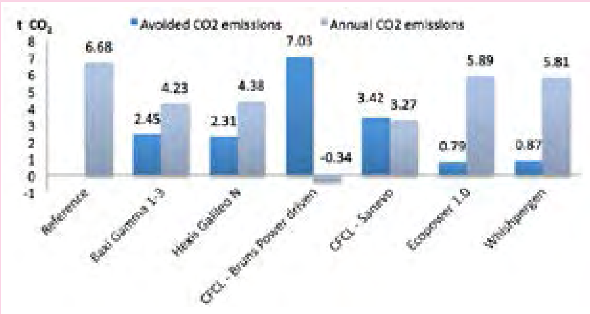
Subtask 1 - Small Stationary Fuel Cells

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. But in general the market activities for small stationary fuel cells for residential use have increased significantly in the past few years.

Conditions for microCHP

In 2012 Subtask 1, Annex 25, published an interim report which focuses on the conditions for microCHP in Germany (essentially domestic scale), and makes a comparison of different technologies including internal combustion engines (ICE), Stirling engines, PEFC and different SOFC technologies used to provide microCHP. A conclusion was that the high efficiency SOFC units can operate for longer periods of the year as they are less dependent on the heating demand as the other technologies.

Figure 10: CO_2 emissions and avoided emissions of domestic fuel cell systems based on a standard domestic consumption of a German house.



MicroCHP Fuel Cells in Germany

MicroCHP technology has a renewed focus in Germany, with new subsidies for domestic systems. A major reason for this is the coming shift in technologies for power production after the decision to close all nuclear power plants. Dachs microCHP engines (gas or LPG powered) have sold 20,000 units in Germany and the total amount of microCHP units is about 40,000.

The third phase of the Callux Programme is underway in Germany, with field tests begun in 2012 and the intention to install and operate 800 fuel cell microCHP appliances, with market introduction in 2016[8]. Fuel cell systems are provided by Baxi Innotech (PEFC), Hexis (SOFC) and Vaillant (SOFC). By the end of 2012, the 260 fuel cells systems deployed so far had reached one million hours of operation.

The project FuelCell@Home, arranged by the North German energy service provider EWE Energie AG, is planning to install and operate 200 SOFC systems. Tests carried out by GDFSuez on CFCL units have recently involved the charging of an electric car which verified the high electrical efficiency of 60%.

The difference between the price of natural gas and electricity is relatively high in Germany compared to several other European countries, which favours the introduction of fuel cells and an obvious large market is the replacement of old heating systems. The heat demand for new houses has decreased significantly from about 300kWh per m^2 a in 1980 to below 50kWh per m^2 a today. But the average specific heat demand for the building stock in Germany is still in the range of 200kWh per m^2 a. The electricity demand is increasing and this may open up the market for highly efficient fuel cells used as microCHP.

European ene.field Project: microCHP Fuel Cells

In September 2012 the European ene.field project was announced. The project allows a group of Europe's leading microCHP developers to embark on a large field validation of the technology under a common analysis framework. ene.field will deploy and monitor around 1,000 new installations of residential fuel cell CHP systems across twelve key member states, with fuel cells delivered from nine different suppliers using various technologies[9]. It represents a step change in the volume of fuel cell deployment for this sector in each country. By learning the practical implications of installing, operating and supporting a fleet of fuel cells with real world customers, ene.field will demonstrate the environmental and economic potential of fuel cell microCHP, and lay the foundations for market exploitation. About 173 installations are expected in Germany and 172 in Italy.

Japan's Ene-Farm Prodcts: microCHP Fuel Cells

In Japan the impressive set of Ene-Farm products, originally released in 2009, continue to increase their market penetration. The scheme has resulted in the

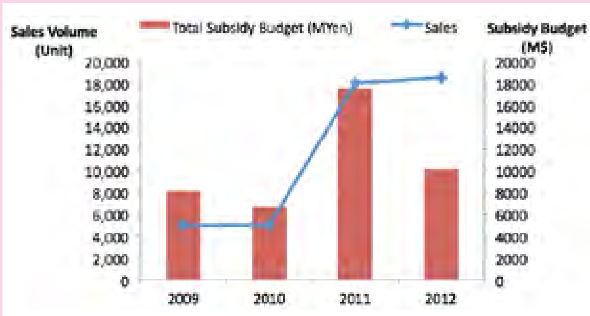
[8] For up to date information on the Callux Programme and new installations see the website www.callux.net
[9] For more information in the ene.field programme please see enefield.eu/.

largest number of fuel cell deployments for a single purpose in the world, with delivered prices decreasing according to plan, higher durability of the units being achieved and less maintenance required.

Figure 11: Ene-Farm product from Toshiba, Chofu Seisakusho Co Ltd and Osaka Gas Co.

At the end of 2011, 28,010 fuel cell systems had been installed in Japan, with the total subsidy budget for 2011 having been increased twice as the interest for fuel cells was higher than expected, due in part to the Fukushima disaster. The subsidy budget for FY2012 was 10,090 million JPY or nearly 14,500 systems, which would bring the total number of installed systems to 42,487.

Figure 12: Annual subsidy budget towards, and annual sales volumes of, Ene-Farm products in Japan



PEFC is the dominating technology in the Japanese Ene-Farm products. Panasonic is one of the major suppliers and have recently released a new model that is taller, but requires less space at 2m^2 and has a significantly lower price. The durability is estimated to be 50,000 hours with about 4,000 start and stop cycles included.

Toshiba, Chofu Seisakusho Co Ltd and Osaka Gas Co. have delivered 748 of their PEFC Ene-Farm products, and have released a new PEFC model with significant improvements to the previous model. The electric efficiency LHV is 38.5% and the total efficiency including the use of produced heat is 94%. The design life is set to 80,000 hours and the maintenance interval is once every 3.5 years. The new system is designed for cold-starts down to -20°C.

In 2011 a 700 We SOFC Ene-Farm product was launched by Osaka Gas, Aisin Seiki, Kyocera and Toyota, and 800 SOFC units had been installed by the end 2012. This has an electrical efficiency of 46.5% (LHV) and total efficiency including heat is 90%. The units are controlled primarily by the electricity demand with a power range of 100 We up to 700 We. The scheduled maintenance is once every 3.5 years and the SOFC units are smaller than the PEFC units. Honda announced in 2012 it was developing SOFC products for residential cogeneration, in conjunction with NGK Spark Plug Co. Ltd.

The large sales volumes of Ene-Farm products have driven improvements and products are becoming smaller, cheaper and more efficient. The government subsidies in 2012 were 18.5% to 30% of the price, depending on the model. The maximum subsidy available in the most recent round of funding available, decided in December 2012 is 0.45 millions JPY per unit (3,500 EUR, 4,500 USD). The intention is to bring the subsidies to an end in 2015 when the price has reached a commercial level of about 700,000 JPY or 7000 EUR per unit. The final price is expected to be around 500,000 JPY in the years 2020-2030 with a sales volume of 50,000 units per year.

Panasonic are exploring the export of PEFC units to the European market, joining the Callux Programme in Germany in cooperation with Viessmann. Also within the Callux Programme Bosch Logopower is marketing a new SOFC microCHP with fuel cell systems from Aisin Seiki and stacks from Kyocera, Japan.

MicroCHP Fuel Cells in Italy

Crisalide is an Italian collaboration to stimulate micro-cogeneration, and between 2011 and 2012 SOFC microCHP were installed at seven sites fuelled by natural gas, and ranging in size from 500We to 1kWe.

Small stationary Fuel Cells in Denmark

The majority of Dantherm Power's systems are fuelled by hydrogen, but the company, in conjunction with Topsoe Fuel Cells, has delivered twenty PEFC microCHP systems in Denmark which use natural gas or bio methane as the fuel. The stacks in these units are water cooled and the units are supplied with a gas burner that can be used for heating. These units have steam methane reforming and the water from the reforming can be reused in the system. The demonstration project has achieved more than 53,000 operation hours with a practical electrical and thermal efficiency of 32% and 62% respectively. Seventeen installations are in private homes and three are in public buildings near Varde in west Denmark.

Dantherm also has a significant deployment of more than 100 units in Denmark, and over 500 across Europe of small stationary fuel cells for the telecoms industry used as backup power. There are also substantial installations of telecoms back up power provided by Dantherm's fuel cells in India and Canada. Utilising fuel cells as telecom back up power is becoming well established in the USA, with over 650 publically disclosed installations throughout the country.

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 the use of fuel cells, mainly considering waste biofuels and used biofuels. Examples of appropriate fuels include 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.

One project that has been followed in detail by Annex 25 is the 1MWe PEFC fuel cell installed at Solway in Lillo-Antwerpen that uses surplus hydrogen from a chemical plant.

A new 50kWe PEFC project has begun which aims to use excess hydrogen from the Chlorine-Alkali industry as fuel. The unit is placed in the harbour area of Helsinki, and is mainly financed by TEKES the government agency and VTT, but one part is also financed by private industry.

Utilising Biogas

ENEA in Italy has investigated using biogas as the fuel for direct fuel cells (DFC) in Europe. Biogas from anaerobic digestion of organic wastes such as wastewater treatment plants, landfills, waste from food industries, breweries etc. is a promising alternative in the transition from fossil to sustainable fuels and hydrogen. A CHP system based on DFC technology can achieve an efficiency of 90% if the heat generated by the fuel cell is managed in order to accelerate the anaerobic digestion and therefore increase the total efficiency of the system. This technology has been previously deployed in the USA, in fact, in California more than half of Fuel Cell Energy's MCFC installations operate on renewable biogas.

All biogas plants produce impurities that must be removed before the biogas is used in fuel cells and also often in internal combustion engines. The variation within the fuel stream can in some cases be considerable. Hydrogen solfide (H_2S) in particular is a critical compound which cannot be eliminated completely even after gas clean-up. ENEA has carried out tests and analysis to develop tailored solutions to improve state-of-art industrial components in order to minimise the effects of H_2S poisoning.

The incentives to use ADP biogas as fuel for fuel cells in the USA are favourable and the number of installations has increased, especially in California and the northeast of the USA. Biogas is classed as a renewable fuel eligible for incentive funding in 27 states of the USA, and in many other countries throughout the world.

Utilising excess wind power

Denmark shared the concept and advantages of using a reversible SOFC or an SO electrolyser, to utilise excess wind power that can occur. This scenario is likely to occur more often in the future in northern Europe as electricity generated from wind power will expand significantly. The process, called power to gas, produces methane from hydrogen and CO_2 through a methanator, with the excess heat from the methanator used in the electrolyser.

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

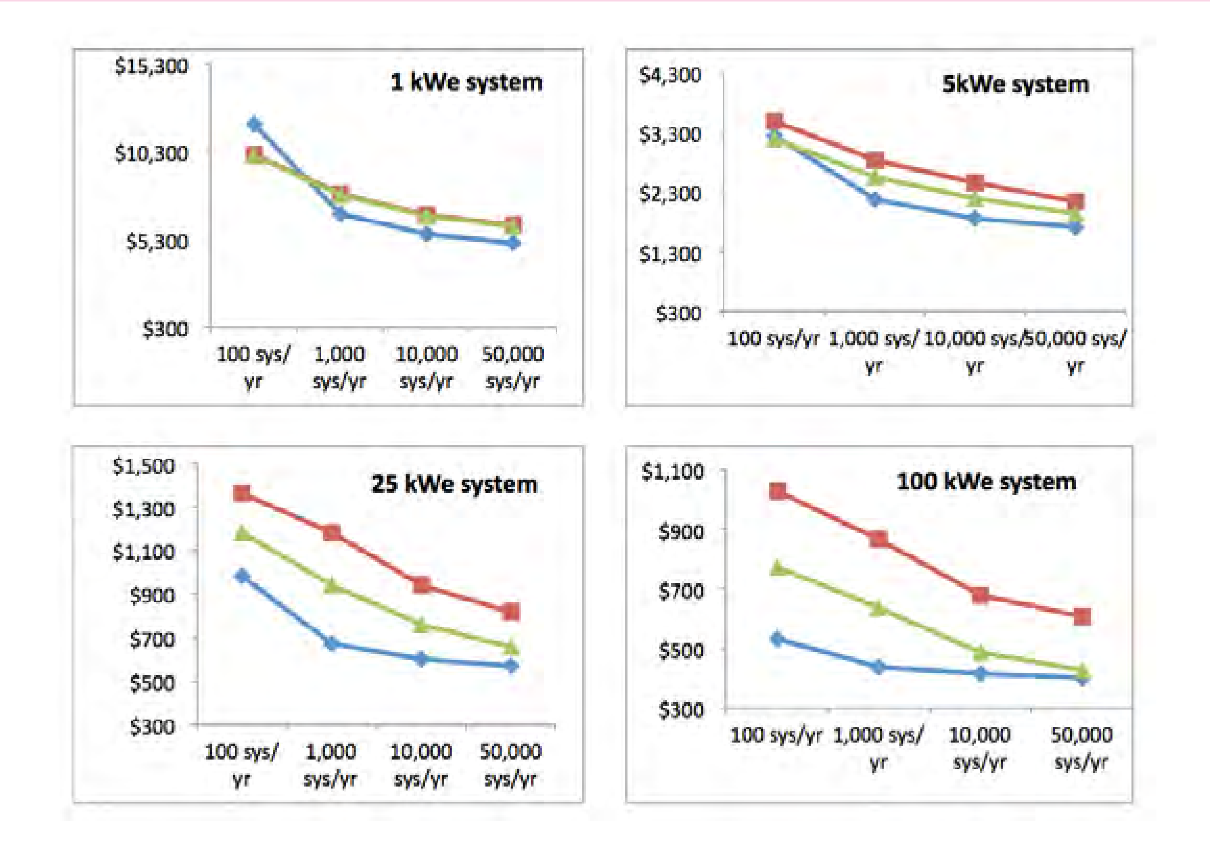
Subtask 4 aims to identify optimal design, operating and control strategies for fuel cells systems for CHP and tri-generation and hydrogen production.

A new study evaluated the costs for fuel cells and fuel cell components considering different production rates.[10] The analysis was carried out for low temperature PEM, high temperature PEM and SOFC operating on natural gas, and considered rates from 100 systems per year to 50,000 systems per year. For a 1–5kWe SOFC it was identified that the fuel processing subsystem is the greatest contributor to total system costs supposing a production level of 1,000sys/year and above. In particular, the natural gas compressor is the major contributor followed by gas alarms and sensors. For larger systems (i.e. 100kWe and more) the greatest contributor to cost is the fuel

[10] Manufacturing Cost Analysis of Stationary Fuel Cell Systems, Strategic Analysis Inc, www.ieafuelcell.com/documents/SA_DFMA_Cost_Analysis_of_Stationary_Fuel_Cells_Sept_2012_Final_Deliverable_5-2-8_rev_4-5-2013.pdf

cell subsystem, accounting for more than 50% of the total cost in all the scenarios. The water pump and condenser are also significant costs.

Figure 13: The cost in USD per kWe shown for SOFC (blue), HT PEM (red) and LT PEM (green), over four manufacturing rates per year. Four size system are considered: 1kWe (top left), 5kWe (top right), 25kWe (bottom left) and 100kWe system (bottom right)



Subtask 5: Status of large fuel cells - market and demonstrations

Large fuel cell units over 100kWe are located in just a few countries, most in the USA and Germany. A recent report from Fuel Cells 2000, "State of the States fuel cell report" provides an excellent overview of the USA.[11] Within subtask 5 questionnaires have been generated to gather information on technology status, efficiency of systems and governmental support programs, to form the basis of the Subtask Report.

The major supplier of large SOFC plants is Bloom Energy in the USA, delivering large plants from 100KWe up to several MWe and achieving 50% electric efficiency. The power density is low at 100kWe, and each system weighs 11tons. Customers

[11] A link is provided at the Advanced Fuel Cells website, www.ieafuelcell.com/fuelcells.php

include eBay, Apple, Google, Coca-Cola, Wal-Mart and several power utilities. There is also the option to buy on a power purchase agreement (PPA) arrangement, so the energy produced is bought, rather than the fuel cell systems themselves.

UTC Power, which recently became ClearEdge Power, signed an exclusive agreement with Newmark Energy Solutions to sell UTC Power fuel cells to power buildings. UTC use a 400kWe PAFC, designed for both distributed electricity generation and CHP applications. Customers and installations include two Connecticut supermarkets (Whole Foods Market, Stop & Shop), Cox Communications (CA), a high school (CT), a residential apartment building (NY), and twelve units will be installed in the new World Trade Centre building in New York City, totalling 4.8MW. Today there are 40 "PureCell Model400" units in operation. UCT's largest plant is operating in South Korea, installed by Samsung in 2008 and owned by GS Power in the city of Anyang, it is a 4.8MWe plant. The units are sold today with a ten year stack life guarantee and the SMR catalyst is also designed to function for more than ten years. The new units are certified as Ultra-low emissions (CARB 2007).

Fuji Electric produce a PAFC, 100kW system that they have begun to market specifically at hospitals, with several installations already in Japan, and market activities now beginning in Europe. In 2012 Daimler ordered a 100kW unit to be installed in Hamburg.

Fuel Cell Energy in the USA has recently started a new company with the Fraunhofer institute in Dresden, restarting the production of MCFC in Europe under the name Fuel Cell Energy Solutions. The plans are to have more flexible sizes that can be suitable for the European market, and new contracts for deliveries to Germany have already been signed. Previously Germany was the main driver in Europe for large fuel cell development and deployment, but new activities have also started in Denmark.

Subtask 6: Market Status

This subtask highlights the latest developments in stationary fuel cells. Bloom Energy quadrupled its Californian manufacturing facility in 2011 and is now looking to further expand with the construction of a new manufacturing facility in Newark on the US East Coast in 2013.

UTC Fuel Cells has sold in total about 300PAFC in 19 countries. About 80 were reported as being the PureCell 400, while the rest are the older 200kWe ONSI units. A system at the plant at Mohegan Sun in Connecticut has been in operation for over 90,000hours with the original stack, running for over ten years. A PureCell for European conditions, i.e. a 50Hz unit, is under development and the marketing in Europe has started. The heat can be extracted at different temperature levels to be utilised for the production of steam, to heat tap water or to be used for absorption chillers.

In the USA utilising large installations of fuel cells to provide backup power has proved very successful, with numerous success stories emerging after storms Sandy and Irene, including ReliOn Inc PE fuel cells and Altergy's FCs powering telecoms towers, and Bloom Energy and UTC providing back up power to data centres and other sensitive users through periods when the main electricity supply was down. It was reported that while various diesel, propane and battery cell phone towers were affected by storm Sandy, all of the cell towers powered by fuel cells successfully continued operating without issue.[12]

Dantherm power reported that it has delivered more than 500 back-up power PEFC systems world-wide, totalling more than 1MWe. Most systems are back-up power for telecom stations. The majority of the systems are fuelled with hydrogen.

Achievements during 2012

Within this Annex the achievements have been to work and to publicise the success of domestic fuel cell installations, demonstrating the parallels and challenges of the various schemes. How the market volumes can further expand in different regions with different conditions and how stationary fuel cells will approach commercialisation are discussed in the Annex.

Publications from this Annex

Annex 25 produced an Interim Report on the current position of fuel cells globally, specifically relating to progress made within the area of stationary fuel cells. Currently this document is intended for ExCo members only.

In 2013 the new report on fuel for fuel cells will be published by ENEA, Italy. From Subtask 1 a new report is planned to be compiled during the year and also a report from Subtask 5 large fuel cells.

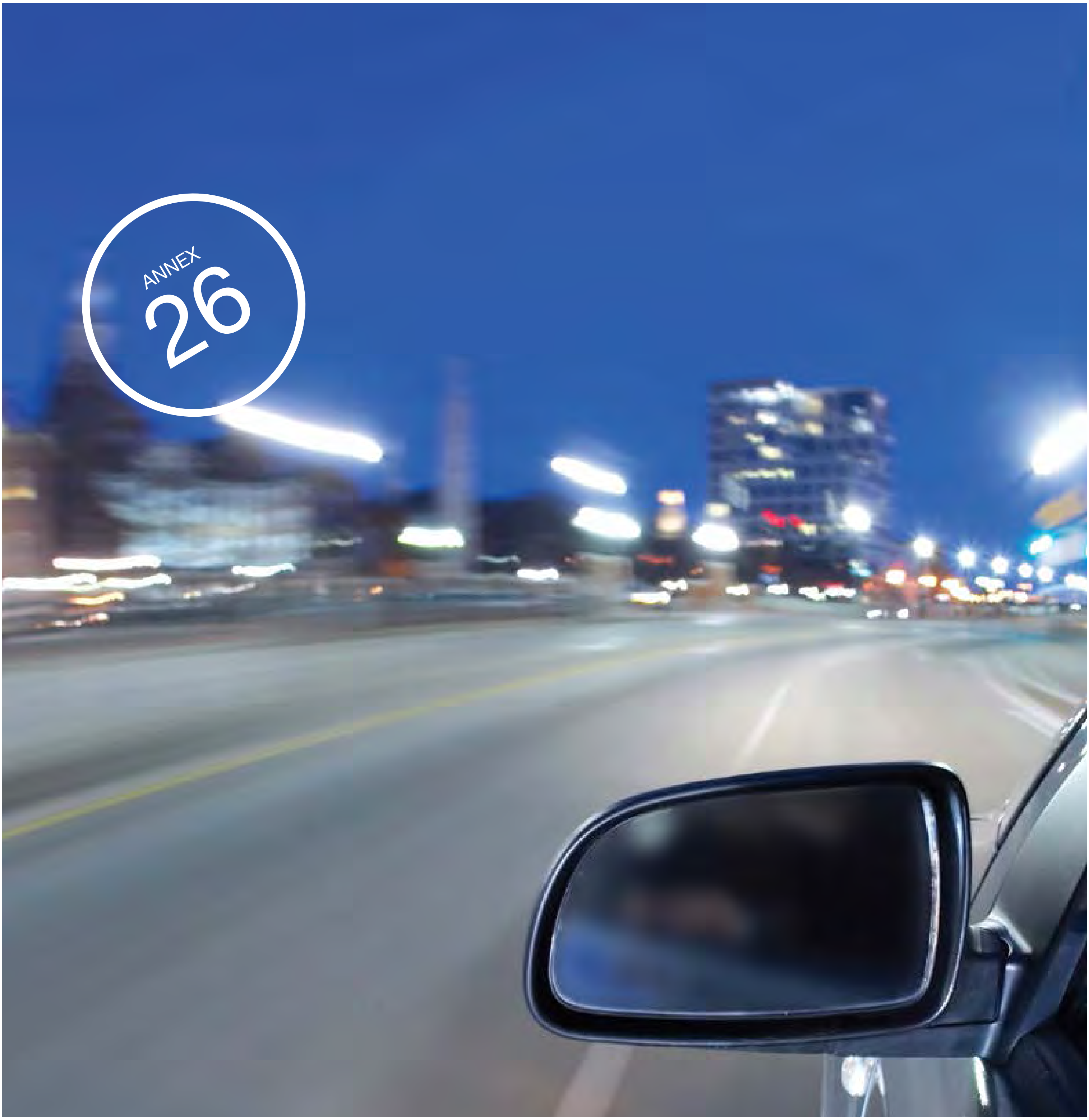
4.4.3 Work Plan for Next Year

The next stationary fuel cells Annex meeting will take place at NOW, in Berlin Germany, on the 11-12 April 2013.

The autumn meeting will take place October 21, 2013 in connection to the Fuel Cell seminar in the USA Columbus, Ohio.

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

[12] Calling all fuel cells, http://energy.gov/articles/calling-all-fuel-cells



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 – Fuel Cells for Transportation

- Fuel cell electric vehicles achieved more than twice the efficiency of today's gasoline vehicles with refuelling times of five minutes average for four kilograms of hydrogen. (DOE Controlled Hydrogen Fleet and Infrastructure Validation and Demonstration Project)
- The 2nd generation buses in the US fuel cell electric bus program 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 1st generation buses, and the top fuel cell power plant has surpassed 12,000h demonstrated lifetime.
- Ballard's 150kW HD6 stack for fuel cell buses has demonstrated a 12,000h lifetime that has been validated via accelerated testing in the laboratory. The next-generation HD7 stack is projected to have a greater than 25,000h lifetime.
- The capital cost of fuel cell buses has shown a three-to-four fold reduction from 3 million EUR to 0.75-1.25 million EUR over the time period 2003 to 2013, with a further decrease to 0.35-0.55 million EUR anticipated by the year 2018-2022, 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 in 2015-2020, and with diesel buses in 2025.
- Diesel-based PEFC APUs are showing 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 2nd 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 2012, with several thousand being deployed in the USA, and deployment beginning to occur in Europe.

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 forklift trucks, passenger cars, APUs (auxiliary power units), 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.

Participants

Country Participant	Associated Institution
Austria	A3PS
Canada	Ballard Power Systems
Denmark	H_2 Logic
Finland	Aalto University and VVT
France	Institut FC Lab
Germany	Forschungszentrum-Jülich GmbH
Italy	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, (ENEA)
Korea	Hyundai Motor Corporation
Sweden	Volvo Technology Corporation and 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. There is a consensus that automotive manufacturers are aiming at 2015 as the year to begin wide scale introduction of fuel cell electric vehicles after several years of successful demonstration projects and programmes.

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 Fuel Cell Electric Vehicles (FCEV) by 2015. Following this 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 H&FC) to work to promote the production of FCEV.

In 2011 in Japan, the car manufacturers Toyota, Honda and Nissan, signed a MoU with 10 Japanese oil and energy companies covering a reduction in the costs of the vehicles, as well as the establishment of 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 undertook to provide FCEV demonstration vehicles and the countries would further develop their refuelling infrastructures. The subsequent H2Moves project is demonstrating 19 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 20 million EUR of grant funds to increase the number of hydrogen filling stations in Germany to 50 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 this gives the essential variable output. Fuel cell electric vehicles provide the advantages of large range, quick refuelling, and a system that is very similar to the conventional systems used today for petrol and diesel, together with the main advantage of zero tailpipe emissions.

Figure 14: ix35 Hyundai fuel cell car

4.5.1 Activities

The fourth workshop of Annex 26 was held on May 22nd-23rd, 2012 in Gothenburg, Sweden. The workshop consisted of technical presentations and discussions, a tour of the fuel cell and battery test facilities at Volvo Technology Research Centre, and a tour of the fuel cell and fuel processor facilities at PowerCell Sweden AB. Thirteen representatives from six countries participated in the workshop.

4.5.2 Technical Developments

Durability and component degradation are crucial issues in fuel cells for transportation 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 humilities.

Subtask A Advanced Fuel Cell Systems for Transportation

This subtask focuses on the system and hydrogen storage technology.

Aalto University and VTT in Finland have evaluated the effects that acceleration, deceleration and lifting have on a fuel cell when installed on a hybrid forklift, to learn about PEFC hybridisation and system integration. It was found that, on average, balance of plant (BoP) components account for 6% of losses during operation, and that in triple hybrids (fuel cell, battery and ultra-capacitor) the required voltage window may limit the utilisation of ultra-capacitors.

PowerCell in Sweden has developed a 3kW PEFC APU, the “Power Pack”, that operates on conventional fuels (diesel, gasoline, biogas, methanol as well as hydrogen) but with zero emissions of NO_x, CO and SO_x, low noise and vibration levels and achieves high fuel efficiency. The 2nd generation Power Pack shows significant improvements in reversible degradation over the 1st Generation unit. It is aimed at truck, marine and RV (recreational vehicle) applications. Road diesel is expected to be the fuel of choice however, for which it has an internal reformer to produce a hydrogen-rich gas.

PowerCell Sweden AB and EMB Elektromotoren und Gerätebau Barleben GmbH have created a new fuel cell centre in Barleben, Saxony Anhalt, Germany. This is a joint-venture for fuel cell development, manufacturing and distribution to the market.

Moby Post is a consortium project of nine partners across France, Germany, Italy and Switzerland that aims to develop a sustainable mobility concept. It plans to deploy ten light duty FC vehicles fuelled by hydrogen for two postal sites in Franche-Comté for La Poste. The hydrogen fuel is locally produced using solar power and water electrolysis. By the end of 2012 this project was ready to begin construction of the vehicles and the infrastructure site. The intended power train has been running since the summer of 2012, using the prototype vehicle developed by Ducati Energia.

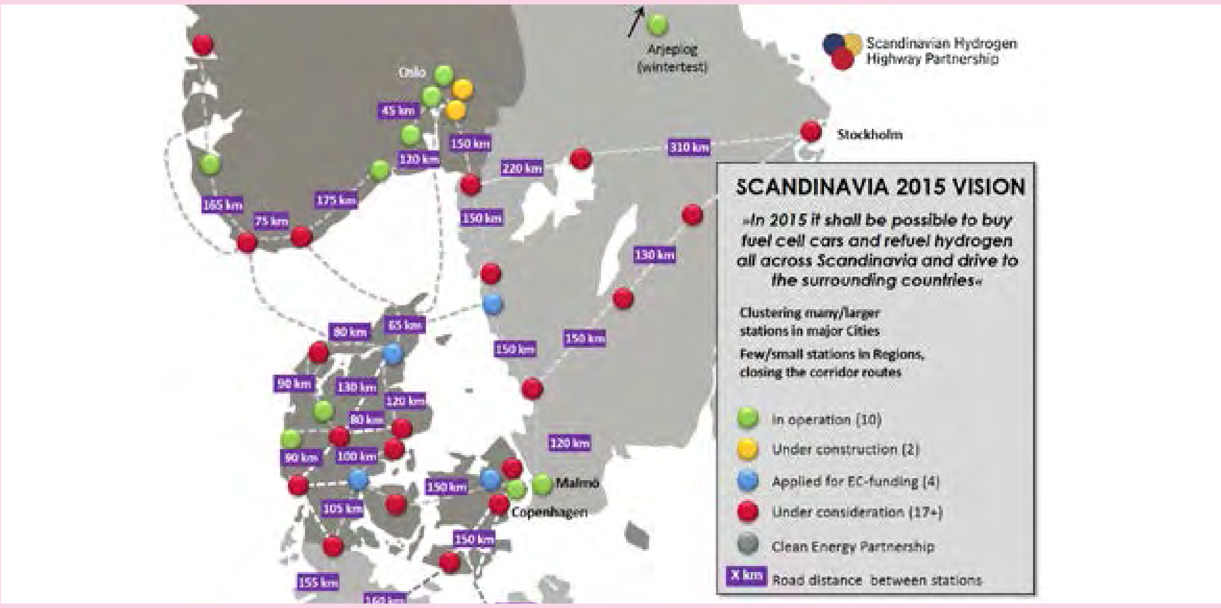
During the Paris motor show in October 2012 SymbioFCell and Renault presented Renault Kangoo ZE, a 5kW PEFC vehicle, with a 1kg tank of hydrogen stored at 350bar. The small van has achieved a driving range of 300km.

Subtask B Fuel Infrastructure

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

The Scandinavian vision is that it is possible to use a fuel cell car across all of Scandinavia and drive into the surrounding countries. As of 2012, 49 hydrogen vehicles were registered across Scandinavia and ten refuelling stations were in operation with a further two stations under construction. An additional 21 stations are planned and they will be operational in 2015 (Figure 15).

Figure 15: Scandinavia 2015 vision - hydrogen fuelling station cell in operation (green), under construction (yellow) and planned (blue and red), as of 2012



Three MultiEnergy Stations have been installed in Italy to promote the use of hydrogen fuelled vehicles. Two experimental stations for prototypes fuelled with pure hydrogen and HCNG blends (4-9% hydrogen mixed with natural gas) have been installed at ILT Technology and ENEA sites. A total of seven new hydrogen stations are planned within CHIC and HighVLOCITY EU projects.

According to the TÜV-SÜD operated website H2Stations.org there were 202 hydrogen stations in operation world-wide at the end of 2012, although some are not available for public use. A further 105 stations are reported as planned, although this number does not include all those committed by Japan.[13] There is substantial activity in advance of 2015 and the anticipated significant deployment of FCEV.

Argonne National Laboratory in the USA has carried out a life-cycle analysis (LCA) using GREET to evaluate the fuel cycle and the vehicle cycle emissions. It was found that on a life-cycle basis emissions from plant construction are negligible compared to fuel and vehicle-cycle emissions. The main contributor to emissions is the well-to-pump cycle (WTP) which, in the case of FCEV, accounts for about 280g CO_2e/mi out of a total emission of 350g CO_2e/mi.

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.

Many fuel cell bus demonstration projects have been carried out around the world, including in Brazil, Canada, China, Europe, Korea and the United

[13] Hydrogen stations: www.netinform.net/h2/H2Stations/Default.aspx

States. One of the largest fuel cell vehicle validation programmes is being run by BCTransit in Canada. It was inaugurated as the world's largest fleet of hybrid FC buses for the 2010 Winter Olympic Games in Whistler, and is a five year trial for 20 hybrid fuel cell buses, to end in 2014. The buses are supplied by New Flyer which adapted a twelve meter bus platform to install a Ballard FC velocity-HD6 150kW fuel cell system and hydrogen storage unit able to carry up to 60kg of hydrogen at 350bar. To successfully deploy this new technology the world's largest hydrogen refuelling station was completed. At this station 1,000kg of hydrogen can be dispensed per day and 18 buses can be consecutively refuelled in about ten minutes per bus. This validation project has helped Ballard to improve the fuel cell stack lifetime, the Ballard FC velocity-HD6 has been validated for 12,000hrs and the new FC velocity HD7, which will be ready in 2014, has an expected operating lifetime of over 25,000hrs. This fuel cell bus fleet has achieved over 1.5million miles of revenue service.[15]

In Europe, the CHIC project (Clean Hydrogen in European Cities) a total of 38 FC buses have been deployed in the major European cities including ten buses in Hamburg, five in Bolzano and Aargau, three in Milan and two in Cologne. Another project is High V.LO City which will implement a fleet of 15 H2 hybrid FC public buses in three regions across Europe with significantly enhanced fuel economy and high levels of availability. These two projects aim to prove the high reliability of FC buses, demonstrating the performance of hybrid fuel cell buses has improved to reach a fuel economy of 7-12kg/100 km, equivalent to a 40% improvement over an equivalent diesel route at parity of calorific content.

As of August 2012, 25 fuel cell buses were in demonstrations at ten locations in the USA. Additional demonstration projects are under consideration and will field seven more fuel cell buses in 2013. An additional 13.5 million USD in funding was approved in 2012. Access to hydrogen fuel continues to be one of the biggest hurdles to adoption of any fuel cell vehicle. Several demonstration projects have been delayed because of issues with access to fuel.[15]

In 2012 the US Department of Energy released its final report from its Controlled Hydrogen Fleet and Infrastructure Validation and Demonstration Project. This long running project (2005 – 2011) encompassed over 180 fuel cell electric vehicles, more than 500,000 trips, more than 3.6 million miles travelled, and the completion of more than 33,000 fill-ups at hydrogen refuelling stations across the USA, including 25 project fuelling stations. This work has identified that the fuel cell electric vehicles under test achieved more than twice the efficiency of today's gasoline vehicles with refuelling times of five minutes average for four kilograms of hydrogen.

Fuel Cells for forklift trucks

Using forklift trucks in materials handling warehouses is an area of application that advanced considerably in 2012. In the USA the area benefited significantly from the American Recovery and Reinvestment Act of 2009 with 41.6 million USD available in grant funding (together with fuel cells for backup power). The funds have been used in part to deploy fuel cell powered fork lift trucks, or material handling equipment (MHE) as replacements for battery and propane powered fleets. By the end of 2012 the initial grant aided purchases had led to a further three fold increase of the purchase

[14] Ballard, Hydrogen Fuel Cells Bus Case Studies, www.ballard.com/files/PDF/Bus/Bus_Case_Studies_one_pager.pdf
[15] NREL, Fuel Cell Buses in U.S. Transit Fleets: Current Status 2012

and deployment of forklift trucks across the USA, with many repeat orders without subsidy. Below are a few examples, a tiny snap shot of utilisation.[16],[17] The Fuel Cells 2000 report State of the States: Fuel Cells in America 2012, gives a total deployment of around 3,500 fuel cell powered forklift trucks, with 19 sites running an entirely fuel cell fleet, [18] Plug Power themselves report sales of over 3,900 to date, [19] and the Air Liquide HyPulsion project states levels of deployment at over 4,200 by the end of 2012.[20]

- **BMW Manufacturing Plant in Spartanburg, South Carolina**
  BMW bought a further 230 forklift trucks from Plug Power, bringing the total deployed at this site to 400, with the entire fleet now operating from fuel cells. Their operation requires 500 kilograms of hydrogen daily, provided through fourteen refuelling dispensers, with refuelling taking between 60 to 180 seconds.
- **Coca-Cola Bottling Facility in San Leandro, California**
  Coca-Cola bought 37 Plug Power GenDrive™ PEFC forklifts and 19 fuel cell pallet jacks, with power ranges of 1.8-3.2kW, to better utilise space as Coca-Cola could then eliminate their battery room and open up more than 2,000sq. ft. of floor space for storing and moving products. The company had already bought 40 fuel cell forklift trucks for their Charlotte, North Carolina site. The company says that fuel cells (including three large stationary power installations) increase productivity by 15% on average, and lower operational costs by up to 30%.
- **Sysco Warehouses, deployed nationwide**
  Sysco has bought and deployed 524 new fuel cell forklifts in 2012 at its facilities across Boston, Massachusetts; Front Royal, Virginia; Long Island, New York; San Antonio, Texas; Houston, Texas which is 100% fuel cell fleet; Philadelphia, Philadelphia; and 92 for deployment at Riverside, California in 2013. The company was already operating 98 fuel cell forklifts at the Houston site.
- **Wal-Mart Food Distribution Centres – U.S. and Canada**
  In 2012, Wal-Mart has added over 400 fuel cell forklifts to three of their warehouses – Cornwall, Ontario; Balzac, Alberta; Washington Court House, Ohio. This gives a total forklift fuel cell deployment of 601.[22] The utilisation of these trucks will help Wal-Mart warehouses reclaim floor space and cut down on refuelling time. Wal-Mart's Balzac warehouse reports expected operational savings of 269,000 USD /year, and total energy cost savings could reach 4.8 million USD by 2015 as a result of these hydrogen-fuelled forklifts.

Outside of the USA this is an area that is developing fast in Europe as well, with the HyLIFT project involving Germany, Denmark and Italy, intending to demonstrate more than 30 hydrogen powered fuel cell forklift trucks, with commercialisation into the market aimed to be achieved in 2013. The announcement in 2012 of HyPulsion, a joint venture between Plug Power and the Air Liquide subsidiary Axane SA in France, to develop a fuel cell powered forklift truck that is suitable for the European market, further strengthened this area. [21]

[16] Plug Power www.plugpower.com/Customers/WhosUsingGenDrive.aspx
[17] Fuel Cells 2000 www.fuelcells.org/wp-content/uploads/2012/12/FC-Business-Case-2012.pdf
[18] Fuel Cells 2000 www1.eere.energy.gov/hydrogenandfuelcells/pdfs/state_of_the_states_2012.pdf p72
[19] Plug Power, www.plugpower.com/News/CompanyNews/12-09-21/FUEL_CELL_MARKET_GROWS_WITH_AN_ASSIST_FROM_CHEAP_NATURAL_GAS.aspx
[20] Hypulsion www.airliquideadvancedbusiness.com/en/who-we-are/hypulsion-1.html
[21] Air Liquide press release, www.airliquideadvancedbusiness.com/en/who-we-are/hypulsion-1.html

It is estimated that the potential market in Europe is 10,000 units by 2015.[14]

Subtask D Economics

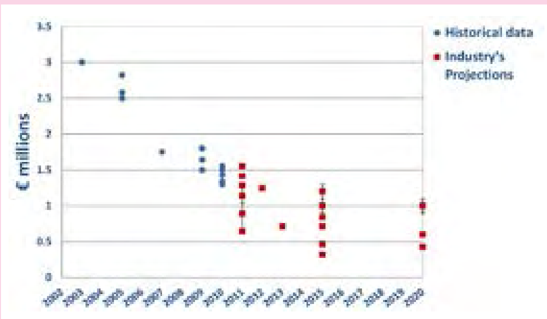
This subtask works to exchange and compare cost models and assess the economic gaps in fuel cells and hydrogen production for transportation.

The performance of hybrid fuel cell buses has greatly improved over time while capital costs have decreased. The third generation stacks, developed in 2011, have 12,000hours of run time, while the 2014 generation, i.e. the fourth generation, is anticipated to have 25,000hours of run time.

Commercialisation targets have been established for fuel cell buses by the Department of Transport in the USA. Bus lifetimes are expected to step up from the current status of five years and 100,000 miles to twelve years and 500,000 miles. Bus capital costs have already seen a substantial decrease over time and this cost is expected to decrease from 3 million EUR in 2003 to 600,000 EUR per unit by 2020 (Figure 16).

Cost reduction is driven by manufacturing breakthroughs and production rate, and figures for a 12 meter, low floor hybrid fuel cell bus powered by a 150kW fuel cell system are expected to fall by 40-50% between 2010 and 2018, with further cost reductions between 2018 and 2022. The fuel cell system is expected to be the most expensive component up to 2015, then will decrease and become comparable to the chassis and body costs in 2018, which will then become the most expensive bus components. Cost projections show that hybrid fuel cell buses will become cheaper than trolley buses between 2018 and 2022, and by 2030, they will have a cost comparable to diesel buses and diesel-hybrid buses.[22]

Figure 16: Bus Capital Costs: historical data and stakeholder perspective (€, millions)



In recent years increased emphasis on testing and characterisation of the fuel cell systems and components has occurred. There are parallel robust programmes on validating the laboratory data with field test data using bus fleets in Canada, Europe and the USA. These field tests are yielding valuable data on fuel economy, fuel cell and vehicle availability, lifetime, and operating costs. Although significant progress has been made in all of these areas, there is still the need for further advancement. Thus, it is expected that these topic areas will continue to be active for R&D in the future.

Publications from this Annex

R. Ahluwalia, X. Wang, and R. Kumar, “Fuel Cell Transit Buses,” January 31, 2012, IEA Website.

[22] NextHyLights EU Project, www.nexthylights.eu/

4.5.3 Work Plan for Next Year

The next Annex 26 meeting will be held in Arlington, VA, USA, on May 14, 2013, in conjunction with the 2013 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 – Fuel Cells for Portable Applications

- Applications of fuel cells within the military continue to grow, taking advantage 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 techniques for these applications are polymer electrolyte fuel cells (PEFC) operated with methanol or hydrogen, but 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.

Participants

Country Participant	Associated Institution
Austria	Graz University of Technology
Canada	National Resources Canada (NRC)
Germany	Fraunhofer Institut Chemische Technologien
	Forschungszentrum Jülich GmbH
	Next Energy
Italy	Italian National Council of Research (CNR) Institute of Advanced Technologies for Energy (ITAE)
Japan	The National Institute of Advanced Industrial Science and Technology (AIST)
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 electronic mobile 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 350bars. Yet 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 issues in developing MEAs (membrane electrode assemblies) are improving the durability and performance. The 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 the Fraunhofer-Institut für Chemische Technologie ICT, in Pfinztal, Germany on 27th – 28th August 2012. It was attended by six members, from four countries (Austria, Germany, Italy, and Sweden).

4.6.2 Technical Developments

This Annex considers four aspects:

- 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 forklift trucks, wheel chairs, 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 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-50W power to be utilised 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.

Ultra Electronics AMI has shipped fifteen 300W solid oxide fuel cells to the US Army's Communications-Electronics Research, Development and Engineering Centre (CERDEC) for field testing, as well as secured a 870,000 USD contract to provide 30 SOFCs to the U.S. Army's Rapid Equipping Force. Soldiers in the field will use the Ultra Electronics, AMI 300W fuel cells to recharge batteries and provide primary power to communications and information systems.

In collaboration with Lockheed Martin, Ultra Electronics AMI has announced a new version of the Stalker Unmanned Air System (UAS), called the Stalker eXtreme Endurance (XE) UAS. The new system, powered by Ultra Electronics' fuel cell, quadruples the Stalker's flight time to over eight hours without impacting the mobility or capabilities of the unmanned system. The systems have a power output of 245W-300W and are fuelled by propane.

SFC Energy AG, in Germany, has developed successful DMFC-systems targeted at the military, specifically the company has received large orders from the German Bundeswehr, for the JENNY-System which has a power output of 25W and is designed to provide the power for a soldier's radio equipment. SFC has also received large orders from the German Federal Office for Goods Transport (BAG).

Unmanned vehicles will have an increasing role, with stealth essential for the success of their missions. Thus, silent electric propulsion systems are generally employed and fuel cells have recently been considered to increase the endurance of these systems to the required levels. A project is underway with FutureE developing a hydrogen fuelled fuel cell for the UGV Mustang MK1, a small vehicle equipped with four hub motors of 0.55kW, a 3D laser scanner, a camera and several other sensors. The 2kW diesel engine has been replaced by a 2kW fuel cell system that will enhance the operation range by recharging the internal lead acid batteries.

The European Defence Agency has initiated a large scale program on unmanned maritime systems which are intended to play a significant role in future European sea defence scenarios. As part of this program the German MOD, supported by the Fraunhofer ICT and the Norwegian MOD, have started a project to demonstrate a fuel cell range extender for enhanced endurance of autonomous underwater vehicles, or AUVs. The target platform is a Maridan M600 AUV, by Atlas Maridan, and is currently powered by lithium ion batteries, achieving 11 hours of operation time. The aim is to extend the duration of operation to 24 hours using a fuel cell system fuelled by pure oxygen and hydrogen. The main challenges will be the high humidity created by the gasses and the space constraints in particular for hydrogen and oxygen storage

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 40–200W based on methanol
- Large systems 100–250W based on propane.

Aimed specifically at the public consumer is myFC, a small portable fuel cell system generating $5W_{el}$ from a PEFC, fuelled by hydrogen, generated from a fuel puck instantly when water is added. The foils and adhesives structure is essentially a FuelCellStickers™, forming a flexible assembly less than 275mm thick. [23] The price is set at 199 EUR (229 USD), with a three pack of fuel pucks at 10 EUR/12 USD, and each puck providing 4Wh. The intention is to begin with sales in Europe, the USA and Japan in 2013. PowerTrekk™

[23] www.myfuelcell.se

utilises a sodium silicide (NaSi), SiGNa hydrogen-storage technology.

Figure 17: myFC portable charger for electronic gadgets, and the power puck cartridges.

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 range is 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 3,000h and costing 5,500 EUR (7,200 USD).

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

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 intended low degradation rates and 5,000 hours of lifetime. The high operating temperature of the SOFC means that impurities in the fuel do 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.

Figure 18: SOFC 100W system from Eneramic, showing the whole system, a view into the system and the stack and fuel processing components.

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 the 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, can use non-fluorinated membranes and 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 research at Fraunhofer ICT is application orientated, with a special focus on military applications for AEMs. The work includes investigation of the reaction mechanism, the development of the catalyst and membrane electrode assemblies (MEAs) as well as demonstration systems. Single cell tests show that for high cell voltage, ethanol is characterised by higher performance than ethylene glycol: at high current densities ethylene glycol shows a higher power density.

To demonstrate the technical feasibility of such systems, a demonstration unit featuring alkaline direct ethylene glycol fuel cell was developed and presented at the FC Expo 2012 in Tokyo. Anion exchange membranes for direct alcohol fuel cells are promising in terms of power output, but the durability is still low as within seven days the performance loss is around 20%.

At the CNR-ITAE (Messina, Italy) the focus is on hydrogen fuelled fuel cells. Membranes and MEAs for PEFCs are developed for operating temperatures up to 120°C. A high precision process to manufacture membranes and CCMs (catalyst coated membranes) has been developed, producing MEAs up to 200cm^2, good coupling between electrodes and membranes and high precision cutting of manifold areas is achieved, which results in reduced manufacturing tolerances. Stack prototypes have been developed and manufactured, in the range of 500W to 3kW. Performance improvements due to the deployment of these membranes and flow structures have been achieved. To achieve higher power levels a 40 cell stack was developed with a 1500W output.

Forschungszentrum Jülich is developing DMFCs as 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. Tests under laboratory conditions[24] show the specific power output was about 120mW/cm^2. Water management is essential to achieve high performances and a low cathodic air surplus is important for the water transport inside the cell. The developed stack concept produces a very low cathodic air surplus and the system can be operated at an ambient temperature up to 40°C.

At the NRC in Canada the development of alternative membranes is also underway, to improve the performance of DMFCs. One example is sPAEEN, which has a much lower water uptake than the conventionally used Nafion membrane and provides

[24] Test condition: T= 70 C; spec. flow rate cathode = 35 ml/(cm^{2}min); spec. flow rate anode = 0,2 ml/(cm^{2}min) and the methanol concentration is less than 1 mol per litre.

better proton conductivity because of the low thickness of the membrane.

Next Energy Oldenburg, Germany is also studying the degradation mechanisms in fuel cells. An EU project called DEMMEA ("Understanding the degradation mechanisms of MEA for high temperature PEMFCs and optimisation of the individual components") has recently started. This project is related to the high temperature polymer electrolyte fuel cell and will consider platinum free alkaline fuel cells.

4.6.3 Work Plan for Next Year

The next meeting is planned for September 12-13th, 2013, at Intertek, Stockholm, Sweden. It is the intention that an updated set of Key Messages for this Annex will be released, together with a technical publication.

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.

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

4.7.1 Activities

A proposal to initiate a new Annex focusing on systems analysis was made in 2010. At the 42nd ExCo meeting, in May 2011, a paper giving greater detail was shared with all Contracting Parties.

The first task of this Annex is to collect available technical, referenced 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. Experts are asked to contribute a chapter as authors, with authors then be coming participants in the Systems Analysis Annex. (This plan of action was approved by the Executive Committee at the 43rd ExCo meeting, 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 2012

During 2012 the key topics for the contents of the work were extended and refined. The content of the work was defined precisely and exchanged with Wiley-VCH in terms of a book proposal. The title of the book was defined as “Data, Facts and Figures on Fuel Cells. The book is designed 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 to provide economic data as far as publicly available for cost considerations and a full overview on demonstration data.

It addresses developers on 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 system 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 – which are delivered by many existing books – and will just focus on data, facts and figures. It will cover all fuel cell issues from the material level to the system level including the key infrastructure technologies. Creating a solid energy data basis is expected to be unique selling point for this handbook.

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 Handbook.

The main chapters of the book are:

- Executive summary of the status
- Transportation
- Stationary
- Materials Handling
- Fuel provision
- Strategies
- Codes and standards.

To give the potential authors a better impression about the nature of the book, a sample chapter was prepared and presented at the 45th ExCo Meeting in December 2012. The sample chapter will be sent to the potential authors together with a template file to prepare the manuscripts within the invitation.

4.7.3 Work Plan for Next Year

The book proposal has been accepted by Wiley-VCH. In 2013 the authors will be invited to prepare manuscripts for their chapters. The manuscripts are due
1st August 2013.

APPENDICES

Appendix 1: Membership Information
Appendix 2: Annex Experts
Appendix 3: Fuel Cell Companies

Appendix 1

MEMBERSHIP INFORMATION

Further details on our past 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

Australia

Dr Karl Föger
Ceramic Fuel Cells Ltd
170 Browns Road
Noble Park
Victoria 3174
Email: karlf@cfcl.com.au
Tel: (+) 61 3 9554 2311

Austria

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

Dr Viktor Hacker
Steyrergasse 21
A-8010
Graz
Email: victor.hacker@tugraz.at
Tel: (+) 43 316 873 8780

Belgium

Dr Yolanda Alvarez-Gallego
VITO
Boeretang 200
B-2400 Mol
Email: yolanda.alvarezgallego@vito.be
Tel: (+) 32 14 335612

Canada

Dr Vesna Scepanovic
Natural Resources Canada
580 Booth Street
Ottawa
Ontario
K1A 0E4
Email: vscepan@nrcan.gc.ca
Tel: (+) 1 613 996 6228

Dr Ed Andrukaitis
Natural Resources Canada
580 Booth Street
Ottawa
Ontario
K1A 0E4
Email: ed.andrukaitis@nrc.ca
Tel: (+) 1 613 990 0638

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

Mrs Anne Nielsen
Ministry of Climate and Energy
Danish Energy Agency
Amaliegade 44
DK-1256 Copenhagen
Email: ann@ENS.DK
Tel: (+) 45 3395 4394

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

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
IWV-3: Energy Process Engineering
D-52425 Jülich
Email: d.stolten@fz-juelich.de
Tel: (+) 49 2461 613076

Dr R Can Samsun
Forschungszentrum Jülich
PBZ: Project Fuel Cells
D-52425 Jülich
Email: r.c.samsun@fz-juelich.de
Tel: (+) 49 2461 61 4616

Italy

Dr 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

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 5201

Dr Jonghee Han
KIST
39-1 Hawolkog-dong
Sungbuk-ku
Seoul 136-791
Email: jhan@kist.re.kr

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 3183811

Netherlands

Mr Bert Rietveld
ECN
P O Box 1
1755 ZG PETTEN
Email: b.rietveld@ecn.nl
Tel: (+) 31 224 56 4452

Sweden

Dr Bernt Gustafsson
Swedish Energy Agency
Box 310
SE-63104 Eskilstuna
Email: bernt.gustafsson@
energimyndigheten.se
Tel: (+) 46 16 544 2085

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
Argonne National Laboratory
9700 South Cass Avenue
Argonne
IL 60439
USA
Email: xiaoping.wang@anl.gov
Tel: (+) 1 630 252 1182

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 40 255996

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

DESK OFFICER AND SECRETARIAT

IEA Desk Officer	Francois Cuenot Energy Technology Policy Division International Energy Agency 9, rue de la Fédération 75739 Paris Cedex 15 France Email: francois.cuenot@iea.org Tel: (+) 33 1 4057 6677
ExCo Secretariat	Dr Louise Evans Ricardo-AEA Gemini Building Fermi Avenue Harwell International Business Centre Oxfordshire, OX11 0QR United Kingdom Email: louise.evans@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 (A).

ANNEX 22: POLYMER ELECTROLYTE FUEL CELLS

Expert	Organisation	Categorisation	Country
OPERATING AGENT: XIAOPING WANG, ARGONNE NATIONAL LABORATORY, USA			
Viktor Hacker	Graz University of Technology	A	Austria
Yolanda Alvarez Gallego	Vito - Energy Technology	R	Belgium
Steven Holdcroft	Simon Fraser University	A	Canada
Shanna Knights	Ballard Power Systems	I	
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
Deborah Myers			

ANNEX 23: MOLTEN CARBONATE FUEL CELLS

Expert	Organisation	Categorisation	Country
OPERATING AGENT: TAE-HOON LIM, KIST, KOREA			
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	Organisation	Categorisation	Country
OPERATING AGENT: JARI KIVALHO, VTT, FINLAND			
Karl Föger	Ceramic Fuel Cells Ltd (CFCL)	I	Australia
Brian Borglum	Versa Power Systems	I	Canada
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
Bert Rietveld	Energieonderzoeks Centrum Nederland (ECN)	R	Netherlands
PV Aravind	TUDelft		
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	Organisation	Categorisation	Country
OPERATING AGENT: BENGT RIDELL. GRONTMIJ AB, SWEDEN			
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	
Adwin Martens	WatersofNet	I	Belgium
Vesna Scepanovic	Natural Resources Canada	G	Canada
Ed Andrukaitis			
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	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	Organisation	Categorisation	Country
OPERATING AGENT: RAJESH AHLUWALIA, ARGONNE NATIONAL LABORATORY			
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	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (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

Expert	Organisation	Categorisation	Country
OPERATING AGENT: MARTIN MÜLLER, JÜLICH RESEARCH CENTRE, GERMANY			
Viktor Hacker	Technische Universität Graz	A	Austria
Ed Andrukaitis	Natural Resources Canada	G	Canada
Christina Bock			
Martin Müller	Forschungszentrum Jülich GmbH	R	Germany
Carsten Cremers	Fraunhofer Institut Chemische Technologien	R	
Gaetano Squadrito	Institute of Advanced Technologies for Energy (ITAE)	R	Italy
Irene Gatto			
Akiteru Maruta	AIST	R	Japan
Sang-Kyung Kim	Korean Institute for Energy and Research (KIER)	R	Korea
Emelie Wennstam	Intertek Semko	I	Sweden

ANNEX 28: SYSTEMS ANALYSIS

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

Appendix 3

FUEL CELL COMPANIES IN OUR COUNTRIES

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	10-300 cm^2	All applications for HT PEMFC	www.daposy.com
H2 Logic A/S	H2Drive® Fuel cell systems	PEMFC	10 kW	Material handling vehicles	www.h2logic.com
	H2Station®: hydrogen refuelling stations	Gaseous hydrogen	35-70 MPa	35 MPa for forklifts & busses 70 MPa for cars	

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
IRD A/S	Stack and System	PEMFC	1.5 kW	Micro-CHP units	www.ird.dk
	Stack and System	DMFC	500 W and 800 W	UPS – communications, IT back up power, remote power Refuelling	
	Stack and System	PEMEC			
	Stack components	DMFC, PEM MEAs, HC MEAs			
SerEnergy	Components Stack System Solutions	PEMFC	300 W - 50 kW	Backup power APU Aux vehicles Automotive Refuelling – through partners	www.serenergy.com
Dantherm Power	System	SOFC PEMFC	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	PEM, hydrogen and methanol	1-5 kW	Back-up power, telecom base stations, UPS	www.tcontrol.fi
Fitelnet Oy	Integrated modules	PEM, methanol	1-5 kW	Back-up power, military, UPS	www.fitelnet.fi
FRANCE					
Areva	Systems	PEMFC + 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	PEMFC	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	PEMFC	4-10 W	Portable power	www.paxitech.com
Pragma Industries	Stack Test equipment Electronic Loads Hydrogen Storage	Roll to roll PEMFC	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	PEMFC	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	PEMFC	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	PEM		Stationary/ transportation	www.balticfuelcells.de
BASF SE	Stack (MEA)	PEM			www.basf-fuelcell.com
BAXI INNOTECH GmbH	System	PEM		Stationary	www.baxi-innotech.de
Ceramic Fuel Cells GmbH	Stack/System	SOFC		Stationary	www.ceramicfuelcells.de/
Daimler AG	Stack/ system (FCV)	PEM		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	PEM, 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	PEM		Stationary	www.elcore.com
EnBW Energie Baden-Württemberg AG	System (utility)			Stationary	www.enbw.com/brennstoffzelle
enymotion GmbH	Stack/System	PEM		Portable	www.enymotion.de/
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
Forschungs-zentrum Jülich GmbH	Stack/System	PEM, SOFC		Stationary/ transportation/ portable	www.fz-juelich.de www.fuelcells.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	PEM		Transportation/ portable	www.h2-ise.de
Fraunhofer-Institut für Chemische Technologie ICT	Stacks/System	AFC, PEM		Transportation/ portable	www.ict.fraunhofer.de
Freudenberg FCCT KG	Stack (components)				www.freudenbergfcct.com
FuMA-Tech GmbH	Stack (membranes)				www.fumatech.com

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
FutureE Fuel Cell Solutions GmbH	System				future-e.de/
FuelCell Energy Solutions GmbH	Stack/ System	MCFC		Stationary	www.fces.de
FuelCon AG	System	PEM, SOFC			www. fuelcon.com
Heliocentris Academia GmbH	System			Stationary	www. heliocentris.com
HIAT gGmbH, Hydrogen and Informatics Institute of Applied Technologies	Stack (components)	PEM			www.hiat.de/
Hüttenberger Produktion-stechnik Martin GmbH	Stack (components)	PEM		Portable	www. huettenberger-produktion-stechnik.de
IMM - Institut für Mikrotechnik Mainz GmbH	System (fuel processor)				www. imm-mainz.de
NEXT ENERGY EWE-Forschungs-zentrum für Energie-technologie e.V.	Stack/ System	PEM		Stationary/ Transportation	www.next-energy.de
Proton Motor Fuel Cell GmbH	Stack/ System	PEM		Stationary/ Transportation	www.proton-motor.de/
Riesaer Brennstoffzellen-technik GmbH	Stack/ System	PEM		Stationary	www.rbz-fc.de
SFC Energy AG	Stacks/ Systems	PEM		Portable	www.sfc.com
Schunk Bahn- und Industrietechnik GmbH	Stack/ System	PEM		Portable	www.schunk-fuelcells.com

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Sunfire GmbH (formerly staxera GmbH	Stack/ System	SOFC		Stationary	www.sunfire.de
Truma Gerätetechnik GmbH & Co. KG	System	PEM		Portable	www. truma.com
Ulmer Brennstoffzellen Manufaktur GmbH	Stack/ System	PEM		Stationary/ Transportation	www.ubzm.de
Vaillant Deutschland GmbH & Co. KG	System	SOFC		Stationary	www. vaillant.de
Viessmann Werke GmbH & Co. KG	System	PEM		Stationary	www.viessmann. com
WS Reformer GmbH	System (fuel processor)				www.wsreformer. de
Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)	Stack/ System	PEM		Stationary/ Transportation/ Portable	www. zsw-bw.de
ZBT GmbH	Stack/ System	PEM		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
Electropower system	Stack & System	PEM	2 - 10 kW	Back-up power, remote areas application, stand-alone systems	www. electropowersystems. com

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Dolomiteck	System	PEM	10ths of kW	Transport application - H2 and FC Mini buses	www.dolomitech.com/
GENPORT	System	PEM	300-1000 W	Portable	www.genbee.it/
JAPAN					
Aquafairy/Rohm	System	PEM	a few - 200 W	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	PEM	-	APU	www.ihi.co.jp/ia/en/index.html
Suzuki Motor	System	PEM	a few -100 kW	Transport	www.globalsuzuki.com/corporate/index.html
Daihatsu Motor	System	AFC	10 kW-class	Transport	www.daihatsu.com/company/index.html
Nissan Motor	System	PEM	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	PEM SOFC	100 kW-class 10 kW-class	Transport Stationary	http://world.honda.com/
Toyota Motor	System	PEM	100 kW-class	Transport	www.toyota-global.com/
Fuji Electronic	System	PAFC	100 KW	Stationary	www.fujielectric.com/
Toshiba Fuel Cell Power Systems	System	PEM	1 kW-class	Stationary	www.toshiba.co.jp/product/fc/ (in Japanese)
Panasonic	System	PEM	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	PEMFC, methanol reformer	1 - 15 KW	Backup for telecomm and other uses	www.microm.com.mx/
Ballard [25]	Backup Systems	PEMFC, methanol reformer	2.5 and 5 kW	Backup for telecomm and other uses	www.ballard.com

[25] 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	1 -10 kWe	Back up power, powerpacks and APU fro trucks	www.powercell.se/
Cellkraft	Stack	Robust PEFC	1-2 kWe	Offgrid	http://cellkraft.se/
myFC	Stack system	Portable	10-75 We	Charger	www.myfuelcell.se
USA					
GM, in Pontiac		PEMFC		FC vehicles	www.gm.com
Ultra Electronics		SOFC	300 W	Portable power	www.ultracellpower.com
ReliOn Inc		PEMFC		Back-up power	www.relion-inc.com
ClearEdge Power		PEMFC		Stationary Power generation	www.clearedgepower.com
Bloom Energy	System	SOFC		Stationary Power	www.bloomenergy.com
UTC Power	Stack/System	PAFC, PEMFC		Large stationary, automotive, transit buses, aerospace, defence	www.utcpower.com
Plug Power	System	PEMFC		Materials handling	www.plugpower.com
FuelCell Energy		MCFC	Up to 90 MW	Large stationary power	www.fuelcellenergy.com