International Energy Agency (IEA) Advanced Fuel Cells
Implementing Agreement

ANNUAL REPORT 2011

June 2011

iea Energy Technology Network

This Annual Report has been prepared by the 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. Chair's Report

Welcome to the 2011 Annual Report of the Advanced Fuel Cells Implementing Agreement, a technology platform of the International Energy Agency, IEA.

Fuel cells are distinguished by their high efficiency and low emissions. 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 have moved from being a research and development based area into a reliable market product.

Fuel cells had for some time fallen out of the public's attention, though research and industry maintained their efforts, as batteries became the focus. However, attention is once again being focused onto the area of fuel cells as numerous companies release newly developed fuel cell systems for transportation and stationary applications that are tailored for customer requirements. Fuel cell cars are on the brink of commercialization, with series production planned to start in the next two years.

The reason for attention once again focusing on fuel cells is that they offer the clear advantages of longer operating time or cruising range over batteries, and offer lower emissions and better energy efficiency over internal combustion engines or turbines. Whenever sustained operation over long periods is required fuel cells provide the advantage of being able to deliver uninterrupted operation when connected to the gas grid, or if off grid, being limited only by the size of the attached gas tank and frequency of refilling. Fuel cells offer the further advantage of being closer to conventional safety concepts than batteries by having the energy carrier stored in a tank, well shielded from the oxidant. Existing battery concepts store the energy carrier and the oxidant inside the battery separating both just by a few micro-meters, which has proved to be a safety issue in the past.

The hybridisation of fuel cells systems together with batteries offers advantages in many cases, in particular, producing cost effective solutions for transportation. In terms of introducing electrical components into drivetrains, battery and fuel-cell technologies are an excellent combination.

A major concern for fuel-cell-based transportation is the hydrogen infrastructure. Hence, we have been working together with the hydrogen implementing agreement and we are going to strengthen the relationship in the years to come.

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

INTRODUCTION TO THE REPORT

The aim of our Implementing Agreement is to contribute to the research & development (R&D) of fuel cell technologies, deployment of fuel cell technologies and dissemination thereof for all our member countries and organisations. We foster and assess R&D and deployment of fuel cells on an international basis and convey key messages to the community, the IEA, policy makers and the public. We liaise and work with other IAs where we can add value. We have an on-going programme of cooperation particularly with the HIA, where technology advancements, demonstration programmes and policy development work are shared both within our collective meetings and between members on an on-going basis to our mutual benefit.

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. The key highlights from this year are:

- In 2011 fuel cells achieved longevity, with 3000 hours of operation for PEM FC and 50,000 hours of SOFC systems being achieved.
- Market conditions have strongly improved.
- Fuel Cells and the hydrogen economy are beginning to deliver on their promises, particularly within the transport sector and the stationary sector.

However challenges remain; although fuel cells have been developed to the point of market penetration the associated hydrogen infrastructure has not been developed to keep pace with fuel cell development.

The AFC IA places a great emphasis on application - and market-orientated issues, whilst continuing to address technology development and information management. We have a particular focus on:

- international research and development
- applications
- markets and penetration of fuel cells
- lifetimes
- costs
- benefits of fuel cell systems.

Our member countries and organisations strongly value the insights that are provided and the sharing of technical progress, national policies and approaches to developing this technology area. This added value of our work enables member countries to gain important insights into developments in this field and better understand where their own efforts can be focused.

Fuel cells are distinguished by their high efficiency and low emissions. They are competitive products which can replace conventional energy conversion technologies and over the past few years have moved from being a research and development based area into a reliable market product.

Fuel cells bring the benefits of decreasing dependence on fossil fuels and increased security of supply, both key, and growing, challenges. At the large scale (MW), fuel cell technology can be used for energy generation on its own or within a system integrated with renewable energy generation technologies, such as wind and landfill gas, to provide energy to electricity grid systems when demand is high, rather than when generation is high, enabling a better integration of supply and demand from renewables.

At the small scale, fuel cell technology offers reliable heat and electricity generation away from national grids in stationary applications, as well as offering considerably higher vehicle ranges and longer operating times over batteries in transportation applications. The recharging time necessary for batteries is a problem that can be avoided by using fuel cells. Both of these advantages offer huge potential to industries ranging from personal electronics devices that could run for weeks on a single charge, through the leisure industry for vehicles and boats with zero emissions when stationary, to considerable military applications.

2011 saw a significant shift away from nuclear energy generation following the Great East Japan Earthquake and the Fukushima Daiichi nuclear disaster. Germany announced in May 2011 that it would be phasing out nuclear power, with all such power plants expected to be offline by 2021. In Japan there was a strong move of public opinion against nuclear power by the close of 2011.

Throughout the world public opinion and policy makers are embracing efficiency and environmentally friendly power production while moving away from combustion-based processes and nuclear power, and fuel cell technology offers an exciting way to facilitate both of these aims. 2011 was the first year that over 100 MW of generating capacity was shipped.[1]

Our work in 2011

Six Annexes were active in 2011. There are three key technologies for fuel cells: PEMFC, MCFC and SOFC, and we have an active Annex operating for each of these technologies. These Annexes focus on the cutting edge development of the technology and its integration with energy systems, such as wind power, CHP and grids.

There are three application annexes covering the range of potential applications: stationary which looks at domestic energy and power installations as well as large scale energy generation; transport which considers all related applications including cars, motorbikes, vans, APUs for trucks, ships and forklift trucks; and the portable area which encompasses devices ranging from those for mobile homes and boats, military applications and electronic mobile devices. Each of these Annexes continued their work of focusing on the installation and use of fuel cells to enable activities and products. They focus on the technology development status, market penetration, opportunities and barriers as well as companies that are active in these areas, and then disseminating these results back to the Implementing Agreement member countries.

2011 was a year of considerable expansion for stationary fuel cells with an outstanding expansion of the ENE-FARM stationary fuel cell program in Japan. By January 2011 close to 14,000 fuel cell systems had been installed in buildings in Japan, with 9,250 units sold in 2011. The increase in demand for domestic CHP stationary fuel cells in Japan must also be acknowledged as being affected by the national power shortages that resulted from the Great East Japan Earthquake in 2011. Work within Annex 25 shows that demand is expected to be maintained into 2012, both in Japan and in northern Europe with programmes such as the Callux Programme in Germany getting underway.

Annex 26 highlighted fuel cell powered material handling equipment as a real success story from 2011. Nearly 700 such vehicles deployed with the assistance of funding from the American Recovery and Reinvestment Act in the USA, and building on their successful deployment, several thousand are now in use across the US, having been procured with no subsidy.[2] There is evidence that the deployment of fuel cell powered material handling equipment will be successful rolled out into Europe in the near future, beginning to replace ICE and battery powered equivalents.

[1] The Fuel Cell Today Industry Review, 2012, www.fuelcelltoday.com/analysis/industry-review/2012/the-industry-review-2012
[2] Source : www1.eere.energy.gov/hydrogenandfuelcells/pdfs/iea_hia_fctp_overview_oct12.pdf

Work in Annex 27 has shown that new models and tools are being developed that closely mirror real world behaviour, demonstrating a better understanding of fuel cell stacks which will enable more rapid improvements to be made going forward.

In 2011 we instigated work on a new Task area, the Systems Analysis Annex, which will provide a reliable interpretation of the current status for fuel cells, and the future potential of the technology. This new Annex will provide a competent and factual information base for technical and economic studies.

Moving forward the intention of the Implementing Agreement in 2012 is to further engage with fuel cell development in countries and organisations with more recently developed programmes and practices, as well as continuing to understand national priorities in these areas and share these. The work to be conducted in the new Annex 28 will allow us to better understand the whole system of fuel cells, and the results from our work in this area will allow us to better inform the IEA and the world at large of the benefits that fuel cells can bring.

In 2012 we expect to place a greater emphasis in utilising our expertise and our unique position of understanding of the worldwide status of fuel cell technology development and deployment to engage to a greater extent with the IEA EUWP and with policy leaders internationally.

2. Introduction

2.1 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 consult www.iea.org/techagr

2.2 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 research, technology development and system analysis on Molten Carbonate (MCFC), Solid Oxide (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. There is a strong emphasis on information exchange through Annex meetings, workshops and reports.

The work is undertaken on a task-sharing basis with each participating country providing an agreed level of effort over the period of the Annex.

The current period of the 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 2011.

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 for 2009-2014

Information Management Internal and external network	**Implementation and Application Issues** Reduction of barriers	**Technology Development** Stationary, Mobile, Portable MCFC, SOFC, PEFC
Co-ordination within the Implementing Agreement Co-ordination with other Implementing Agreements Public awareness and education	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 • minimise size of stack Balance of Plant • tools • availability • data base Fuel processing Power conditioning Safety analysis

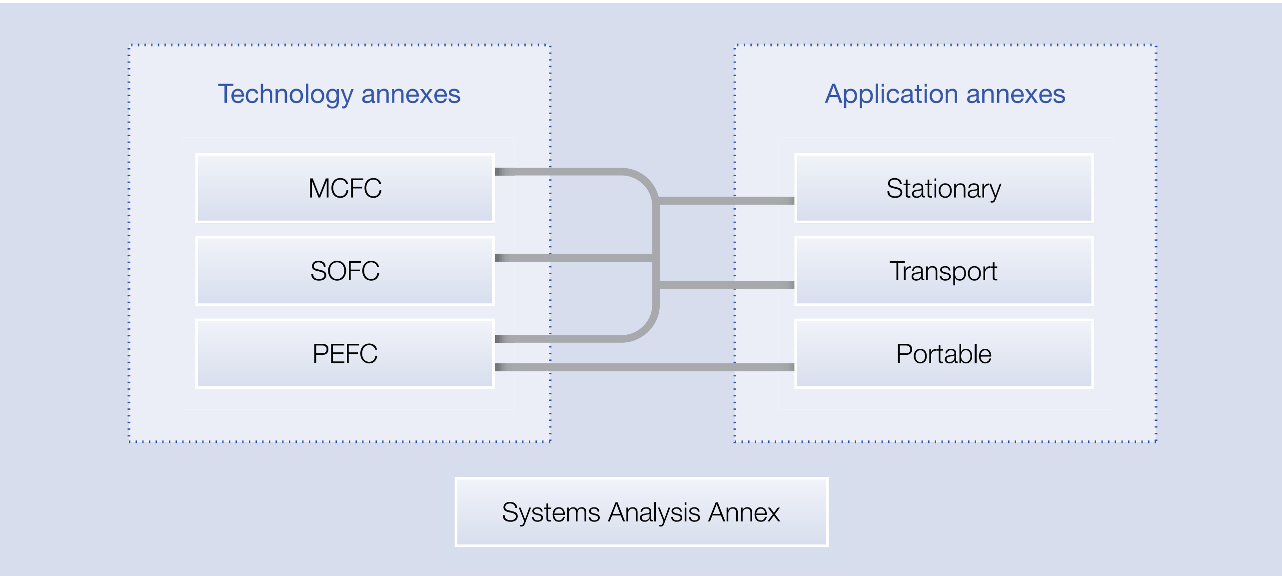
2.3 CURRENT ANNEXES

Seven Annexes were active in 2011:

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

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) and three application-based annexes (stationary, transportation and portable applications), with the Systems Analysis Annex encompassing all these areas as shown in Figure 1 below.

Figure 1 Diagram illustrating the relationship between the three technology-based annexes and the three application-based annexes



3. Executive Committee Report

3.1 ACTIVITIES

Two Executive Committee (ExCo) meetings were held in 2011, the first hosted by Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA) in Italy, and the second by the Instituto de Investigaciones Eléctricas (IIE) in Mexico.

Table 2 Executive Committee Meetings 2011

Meeting	Date and place meeting held	Hosted by	Country Presentation
ExCo42	19th and 20th May 2011 in Rome, Italy	Dr Angelo Moreno from ENEA	Italy, Japan and Canada
ExCo43	27th and 28th October 2011 in Cuernavaca, Mexico	Dr Ulises Cano Castillo from IIE	Mexico, Korea, Sweden and United States

The web site of the IA (www.ieafuelcell.com) was actively maintained and updated, providing a resource for the IA and a repository of on-going activity.

3.2 MEMBERSHIP

The IEA Advanced Fuel Cells Implementing Agreement has 18 member countries, as detailed in Table 3 below.

Although no new member countries joined the Implementing Agreement, interest in joining was expressed by the EC Joint Research Centre (JRC) (Petten) and a unanimous vote of approval was given to the JRC joining.

There were changes in the Executive Committee membership for Japan and Denmark in 2011.
Mr. Lennart Andersen became the Member for Denmark, with Mrs. Inger Pihl Byriel and Ms. Anne Nielsen remaining as Alternate Members. In Japan Mr. Masatoshi Iio replaced Mr. Atsuo Okawara as the Member.

In 2011 Prof. Detlef Stolten (Germany) was elected as the new Chairman, with Dr. Angelo Moreno (Italy) and Dr. Nancy Garland (USA) elected as the new Vice-Chairs.

François Cuenot remained as the IEA Desk Officer.

The following eighteen IEA member countries participated in this Implementing Agreement during 2011. Norway and Turkey left the Agreement during 2011.

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
Belgium	Vlaamse Instelling voor Technologisch Onderzoek (VITO)	November 2002
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
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
Netherlands	Netherlands Energy Research Foundation (ECN) (from October 1999, previously Netherlands Agency for Energy and the Environment)	April 1990
Norway	Research Council for Norway (from October 1994, previously the Norwegian Council for Scientific and Industrial Research)	April 1990 (left the Agreement in early 2011)
Sweden	The Swedish Energy Agency (from December 1998, previously NUTEK)	April 1990
Switzerland	Office Féderale de l'Energie (OFEN)	April 1990
Turkey	Tübitak Marmara Research Center Energy Institute	June 2007
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.

There were no changes to the procedural guidelines for the programme during this year, but a significant change to the funding arrangements was approved for 2012 onwards, see Decision 3 below.

3.4 KEY DECISIONS IN 2011

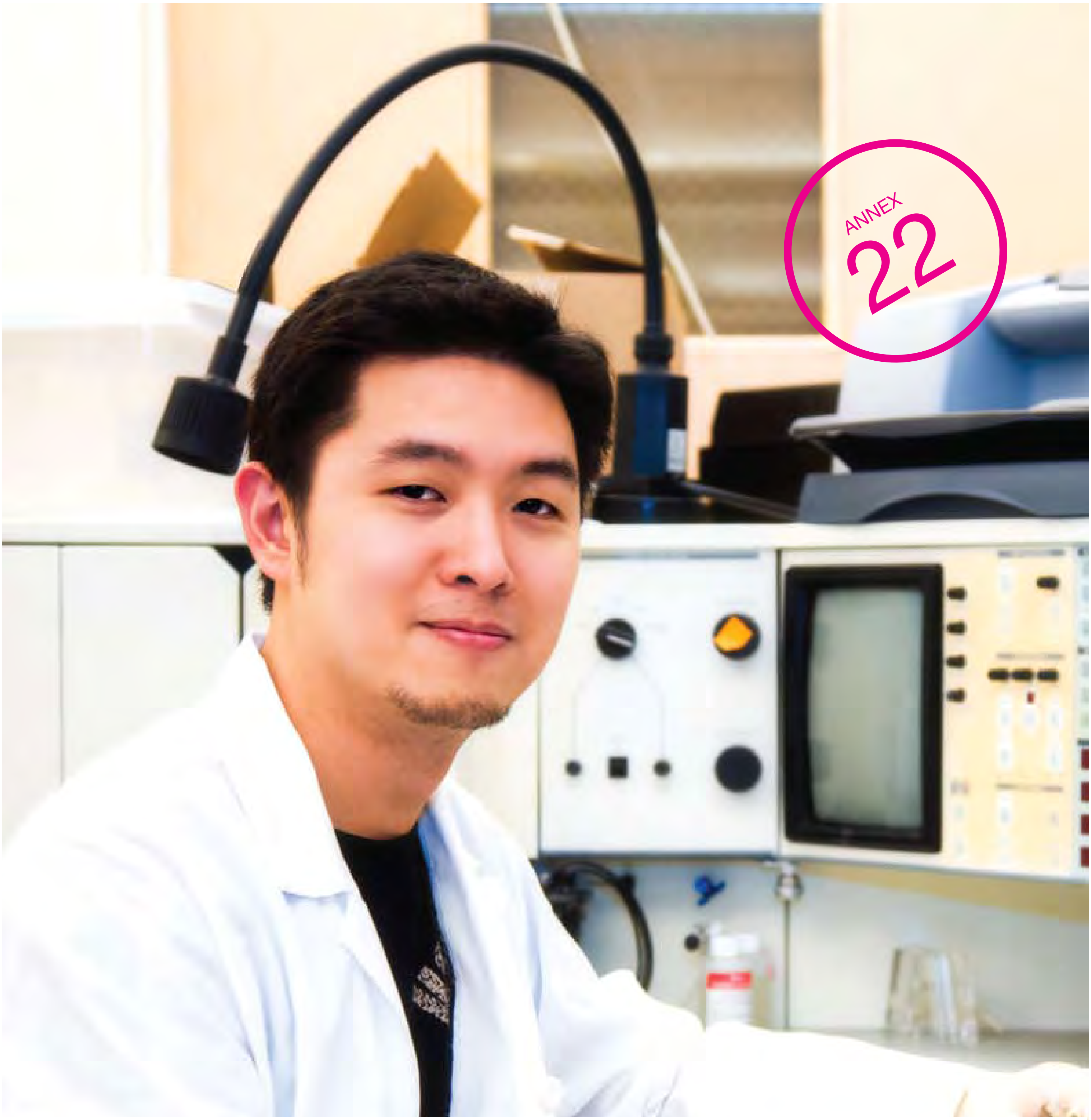
1. A unanimous vote was taken that Operating Agents for Annexes must attend at least one ExCo meeting a year and give a full presentation of the activities of the Annex they are responsible for at this meeting.
2. Companies are welcome to join the Executive Committee of this implementing agreement as sponsors.
3. The funding arrangements for the Executive Committee were changed to introduce a three tier systems of fees for members, based on the GDP of the member country. This arrangement is to be set for 2 years and then reviewed. The reason for this was to drive an increase in funds for greater Secretariat activity, and to recognise the scale of benefits derived by different countries.

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 2012. The 44th meeting will be held in Toronto, Canada on June 7-8, 2012 in conjunction with WHEC 2012. The 45th meeting will be held in Israel in December 2012.

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

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, and stationary power (residential, commercial), and combined heat and power sectors.

The R&D activities in Annex 22 cover all aspects of these two types of fuel cells, from individual component materials to whole stacks' systems. Annex 22 has three active subtasks, and the work and results are reported for each subtask:

1. New stack materials
2. System, component, and balance-of-plant
3. DF-PEFCs, such as the direct methanol fuel cell (DMFC) and the direct ethanol fuel cell (DEFC).

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.

Participants

Country Participant	Associated Institution
Austria	Graz University of Technology
Belgium	Flemish Institute for Technological Research (VITO)
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
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	Kyushu University Technova
Korea	Korea Institute of Energy Research (KIER)
Mexico	Instituto de Electricas
Netherlands	The Energy research Centre of the Netherlands (ECN)
Sweden	KTH Royal Institute of Technology
Turkey	Tübitak Marmara Research Centre Energy Institute
USA	Argonne National Laboratory (ANL)

4.1.1 Activities

The Fifth workshop of the Annex 22 Working Group was held on July 4-5, 2011 in Graz, Austria. The workshop consisted of a technical presentation and discussion session, a tour of the fuel cell laboratories at Graz University of Technology, and a tour of the fuel cell and hydrogen facilities at the headquarters of the AVL Fuel Cell Engineering and Testing Company at Graz. Nine representatives from six countries attended the workshop, particularly focusing on Subtasks 2 and 3.

The Sixth Workshop of the Annex 22 Working Group was held on December 12-13, 2011, at the Jülich Research Centre, Germany. The workshop consisted of a technical presentation and discussion session and a tour of the fuel cell laboratories including DMFC, HT-PEFC, fuel processing, and SOFC manufacturing and testing facilities at the Institute of Energy and Climate Research (IEK-3), Jülich. Thirteen representatives from seven countries attended the workshop.

4.1.2 Technical Accomplishments

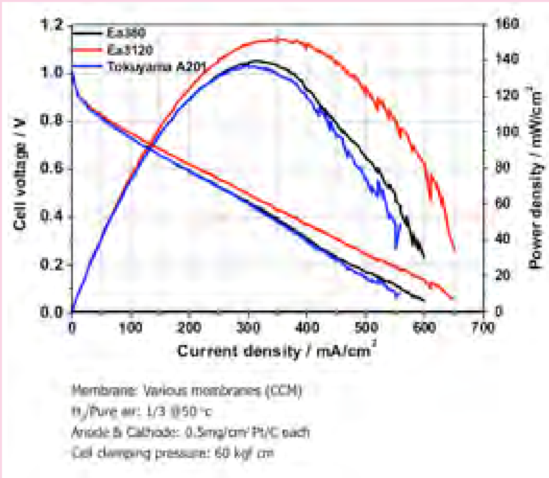
Subtask 1 - New Stack Materials

Research in this subtask aims to develop improved, lower-cost membranes, electrode catalysts and structures, membrane-electrode assemblies (MEAs), bipolar plates, and other stack materials and designs.

Alkaline fuel cells are being investigated as promising alternatives to the more conventional acidic fuel cells because less expensive, non-noble metals can be used as effective catalysts to reduce the cost of the fuel cell system to <$30/kW.

- KIER in Korea has identified a novel anion-conducting pore-filling membrane for a solid alkaline fuel cell, which is thermally and mechanically stable to 150°C and has shown better ion conductivity than a commercial membrane. A single cell on hydrogen and air with the KIER membrane produced a peak power density of 150 mW/cm^2 at 350 mA/cm^2. Essentially this new membrane has a higher ionic conductivity, better mechanical and chemical stability, and greater cell performance than the commercial product (see Fig 2.).

Figure 2 Polarization curves for MEAs using the developed pore-filling membranes and a commercial membrane[1]



- Kyushu University of Japan has developed a catalyst consisting of platinum (Pt) nanoparticles supported on ordered mesoporous carbon (OMC). The catalyst exhibited a much higher catalytic activity for oxygen reduction than the traditional Pt nanoparticles supported on carbon black. The enhancement of ORR

[1] Seok-Hee Park, Young-Woo Choi, and Chang-Soo Kim

(oxygen reduction reaction) activity was attributed to the unique microstructure of the catalyst (<1 nm Pt particles inside the mesopores in contact with Nafion).

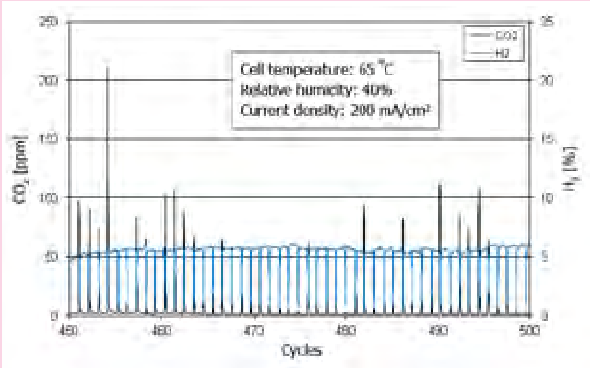
Subtask 2 - Systems, Component, and Balance-of-Plant

This subtask addresses system-level and balance-of plant issues in PEFC systems. This subtask involves development, engineering, modelling, testing, and standardization of test procedures. Several highlights from the range of work conducted and reported in this Annex are shared below.

Greatly increased research emphasis has been placed on the durability investigation of PEFCs under varied stressed operating conditions, which has helped to gain insights into the fuel cell degradation mechanisms.

- Fuel starvation was explored at the Graz University of Technology, Austria, to explore the associated stress factor in low temperature fuel cells. This identified that cell performance degrades with fuel starvation cycles (see Figure 3 below) due to oxidation of the carbon support to CO_2 where the extent of degradation was found to depend on cell operating parameters.
- Graz University of Technology also explored the alternative fuel cell type, zinc-air fuel cell (also considered to be a battery) by investigating the lifetime of the bi-functional air electrodes. It was identified that the cathode performance degradation was due to disintegration of the carbon support.

Figure 3 Carbon dioxide release coincides with drop of fuel content[2]



- Degradation investigation at Argonne National Laboratory, USA indicated that smaller catalyst nanoparticles (<3.5 nm) degrades much more that larger particles sizes and faster anodic ramp during potential cycling leads to greater performance loss.
- The Simon Fraser University and NRC investigated the interrelationship between the microstructure and ionomer content of the cathode layers (CLs) and the performance of the cathode, specifically the effects of carbon support microstructure and ionomer content on water vapour sorption and retention in catalyst layers (CLs). It was identified that the water sorption enhances electrochemically-active surface area and proton conductivity of CL, therefore tailoring the microstructure of the CLs to suit different operating conditions yields higher performance.

[2] Astrid Stadlhofer and Viktor Hacker

Fuel cell systems, combined with batteries, super-capacitors, and fuel processors respectively, are being developed for a broad range of applications, such as automobiles, forklift trucks, auxiliary power units (APUs) heavy-duty trucks, and residential combined heat-and-power units (CHP).

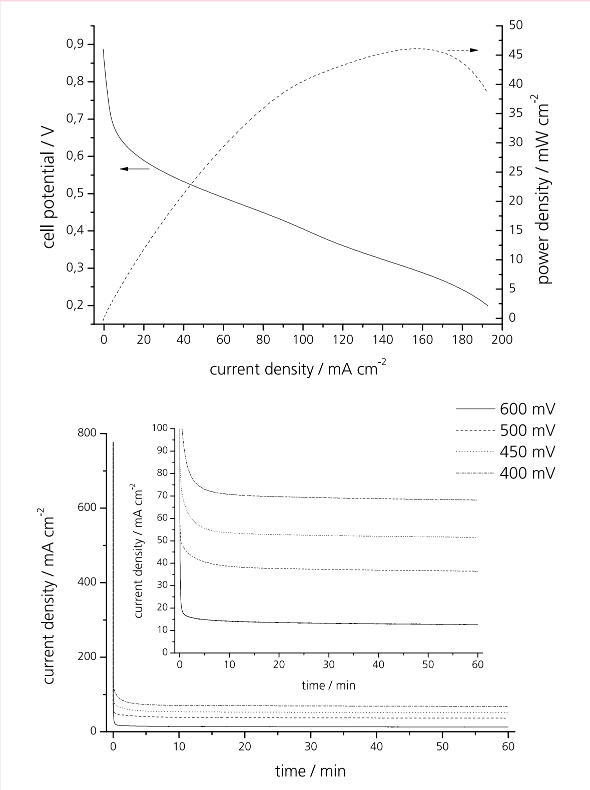
- A hybrid forklift power source with peak power of 50 kWe has been developed at VTT, Finland. It consists of two 8 kW PEFC systems, lead-acid battery packs, and ultra-capacitor modules. The anode side balance of plant and control strategy were optimised to improve PEFC system performance, durability, and cost, by investigating the effect of fuel quality, membrane permeability, volume of purged anode gas, purged anode gas composition, and cell voltage dependence on H_2 mole fraction, on the system level.
- The effect of organic impurities on the PEFC anode activity was investigated at the KTH, Royal Institute of Technology in Sweden for an Auxiliary Power Unit (APU) based on PEFC operating on diesel reformate. This identified that a reduced form of CO_2 poisons the Pt anode, but to a lower extent than compared to CO itself, while a low concentration of toluene in the fuel shows little poisoning effect.
- KIER in Korea built a 1 kW residential combined heat and power unit, based on PEFC using their own fuel cell and reforming technologies. Modelling tools (e.g., simulators) are being developed to optimise component efficiency, control, and operation.

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.

- Alkaline anion exchange membrane direct alcohol fuel cells are being developed at the Fraunhofer ICT in Germany. The electro-oxidation behaviour of methanol, ethanol, and ethylene glycol (EG) on Pt was investigated, with ethylene glycol being identified as a promising fuel. Following on from this, alternative electrode materials for fuel oxidation were investigated.

Figure 4 AEM-DEGFC single cell characteristics under potentiodynamic conditions (upper) and potentiostatic conditions (lower)[3]



[3] Carsten Cremers at Fraunhoger ICT.

The oxidation behaviour of ethanol on Pd, Au, and Ni showed that Pd can be used as the alternative. Single cell performance was optimized by studying the effects of fuel type (ethanol, EG), temperature, fuel flow rate, membrane type, and cathode composition. It was found that ethylene glycol is the better fuel, and that the instability in cell performance was due to instability of the membrane.

- Jülich Research Center in Germany has developed kW DMFC systems for forklift applications. Optimisation of all aspects including electrode layers, MEA, the stack, system, and degradation/durability, 8500 hours operation have been achieved with an average voltage decay of ~13 μV/h, demonstrating significant improvements in performance and durability.

DMFC systems for applications such as a 24 W portable system for soldier power, and a 2.2 kW DMFC/battery hybrid system for electric cars, small carts, and scooters are being developed at KIER, Korea. The research activities include DMFC component materials (for catalysts and MEAs) and development focuses on system design and evaluation, and heat and water management studies.

In the near future a number of automobile 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. Additionally, the demand for portable fuel cells (mainly DMFCs) is expected to increase, especially in the consumer and industrial electronics sectors. These sectors could grow to dominate the fuel cell market in the future.[4]

[4] World Fuel Cells to 2015, Copyright 2011 The Freedonia Group, Inc., from ASDReports website

Recommended Publications

- Wilhelm, J; Janßen, H; Mergel, J; Stolten, D. 2011, Energy storage characterization for a direct methanol fuel cell hybrid system, Journal of Power Sources 196(12), 5299-5308.
- Soboleva, T; Malek, K; Xie, Z; Navessin, T; Holdcroft, S. 2011, PEMFC Catalyst Layers: The Role of Micropores and Mesopores on Water Sorption and Fuel Cell Activity, ACS Applied Materials & Interfaces 3 (6) 1827-1837.
- Takasaki, F; Matsuie, S; Takabatake, Y; Noda, Z; Hayashi, A; Shiratori, Y; Ito, K; Sasaki, K. 2011, Carbon-Free Pt Electrocatalysts Supported on SnO(2) for Polymer Electrolyte Fuel Cells: Electrocatalytic Activity and Durability, Journal Of The Electrochemical Society 158 (10) B1270-B1275.
- Park, SH; Choi, YW; Park, JS. 2011, Characterization of sulfonated poly(styrene-co-pyrrolidone) pore-filling membranes for fuel cell applications, Journal of Applied Electrochemistry 41 (7) 849-857.
- Keränen, T.M.; Karimäki, H.; Viitakangas, J.; Vallet, J.; Ihonen, J.; Hyötylä, P.; Uusalo, H.; Tingelöf, T.; Development of integrated fuel cell hybrid power source for electric forklift, (2011) Journal of Power Sources, 196 (21), pp. 9058-9068.
- Ramschak, E.; Fouquet, N.; Brandstätter, H.; Hacker, V.: Online Fuel Cell Monitoring and Operating Conditions Identification Including Life Time Measurement. - in: Journal of automotive safety and energy 2 (2011) 1, S. 45 – 52
- Cremers, C.; Niedergesäß, A.; Jung, F.; Müller, D.; Tübke, J.: Development of an Alkaline Anion Exchnage Membrane Direct Ethylene Glycol Fuel Cell Stack, ECS Transactions 2011 41(1), 1987 – 1996

- Bayer, D,: Cremers, C.; Baltruschat, H.; Tübke, J.; The Electro-Oxidation of Ethanol in Alkaline Medium at Different Catalyst Metals, ECS Transactions 2011 41(1), 1669 - 1680.

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.

4.1.3 Work Plan for Next Year

During 2011, the active research and development (R&D) 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, the R&D focused on cell and stack materials and components and system, with improved MEAs, reduced catalyst and system costs, improved catalyst and support durability, and enhanced system design and analysis. 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.

This year we continue to see increased activity in fuel processor development for small-scale PEFC power plants, in residential PEFC system development and demonstrations, and for APU applications. Participants in this Annex are expected to contribute significantly to these developments.

It is the intention of this Annex that a set of Key Messages will be released for this Annex, together with a technical publication.

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

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)
Sweden	KTH Royal Institute of Technology
Turkey	Tübitak Marmara Research Centre
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.

4.2.1 Activities

The third meeting of Annex 23 was held in Rome, Italy on the 12th December 2011, hosted by ENEA. There were six participants, with Italy, Germany and Korea all sharing national updates.

4.2.2 Technical Accomplishments

- Germany has three operating MCFC systems

> The T-Systems Data Centre in Munich, which is a cogeneration application using biomethane as the fuel source. It has been operating for 31,570 hours.

> The municipal Sewage Plant in Moosburg, a cogeneration application that uses sewage gas from municipal waste water that has been operational for nearly 20,000 hours.

> A hospital in Bad Berka, which has a trigenerational approach that uses natural gas as the fuel and has been operating for nearly 50,000 hours continuously.

Figure 5 The Hospital at Bad Berka, with the Molten Carbonate Fuel Cell has been operational for 49,025 hours.

- In Italy the focus at ENEA remains on MCFC for CO_2 separation and the study of the effects of impurities such as SO_x and NO_x on the electrodes.

- Korea has 45.7MW of installed capacity of MCFC, with 5.6MW of further capacity under construction, over a total of 16 sites. These range from relatively small systems installed in parks, to the world's largest installation at 11.2 MW. There is a wealth of data now available on the reliability and output of these systems.

- Korea has two manufacturers of MCFC systems

> POSCO have commercialised products available at 300kW, 1.4kW and 2.8MW, demonstrating the market readiness of this product area. Further products are at the product development stage including products designed to give outputs of 100kW and 12MW.

> Doosan Heavy Industry has a 300kW system installed and operating in Boryung. This internal reforming system has been built up using Doosan' own components for the stack and the system.

Figure 6 The 300kW MCFC system at Boryung. Here a value engineered product design has been accomplished to achieve system commonality.

Items	Specifications
Stack Power	300 kw
Energy Efficiency	>87%
Electrical Efficiency	>48%
Decay rate	0.20%/1.000hr
Mission Life	+40,000hr

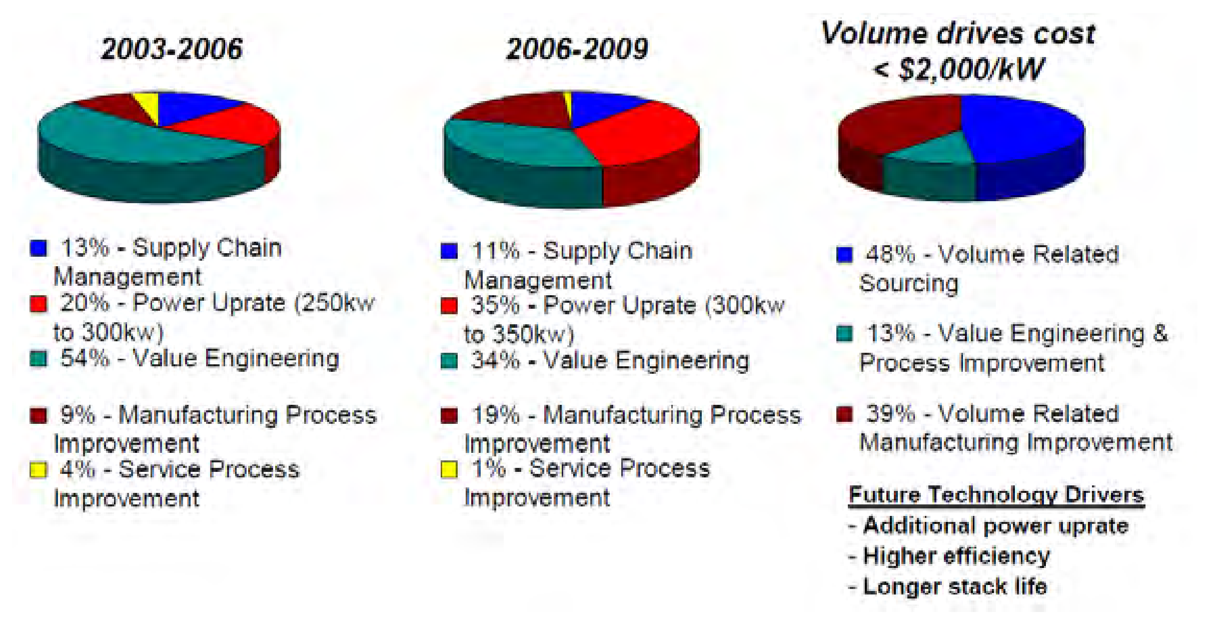
> Doosan Heavy Industry has several further areas under development currently including using MCFC for energy recovery generation within a natural gas pressure regulation station utilising a turbo expander system for extra power generation while heat from the MCFC is supplied to the pressure regulation station itself and the use of MCFC within a desalination plant where the heat is used to drive the desalination process, and the use of MCFC for CO_2 capture.

- Fuel Cell Energy (FCE) in the USA continue their activities on MCFC systems, and at the end of 2011 had 180MW of installed fuel cells.

> FCE currently produces commercial MCFC systems from 300 kilowatts (kW) to 2.8 megawatts (MW), scalable up to 50 MW and their power plants have generated over 650 million kW hours of electricity and are generating power at more than 50 installations worldwide.

> FCE continues to focus on technology development to achieve extended life time and to reduce the cost of their systems, which are both key issues.

Figure 7. The development and relative importance of cost-cutting measures in FCE's approach



Market Perspectives

In Korea the feed in tariff programme, in operation since 2007, will be replaced by the RPS (renewable portfolio standard) from 2012. The feed in tariff operated successfully and resulted in the installation of 50MW of distributed fuel cell CHP. Fuel cells are included within the eligible renewable energy technologies that form the RPS. The RPS will mandate 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 350 MW/year of additional renewable energy is required from 2012 through 2016 and 700 MW/year through to 2022. The total market size will be around USD 54 billion through to 2022. The competence of fuel cells against other renewables will decide the size of the fuel cell market.

In the USA there are currently 33 states and the District of Columbia that have instituted RPS mandates, and 5 states that have adopted non-binding renewable energy goals. 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.[5] In total these markets represent the potential for an estimated 76,750 MW 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.

2011 was a year of significant change in the field of MCFC. Although FCE in the USA and POSCO in Korea have installed increased numbers of MCFC systems all over the world, European companies in this field have experienced difficulties in 2011. Ansaldo Fuel Cell Co (AFCO) in Italy and Tognam (part of MTU) in Germany announced they were to cease their MCFC activities in 2011. From MTU a new joint venture company emerged, Fuel Cell Energy Solutions, founded by FCE and the Fraunhofer IKTS. Fuel Cell Energy Solutions will take over the technologies developed for MCFC by MTU.

Publications from this Annex

The preparation of the MCFC booklet is in the final stage, with contributions 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. It will also focus on the changes that have occurred within the European arena.

Achievements of the Annex

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.

In order to penetrate the market, companies are trying to develop new applications for niche markets. Such MCFC systems, including MCFC systems for CO_2 separation, H_2 producers and biogas utilising systems, are under consideration.

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

4.2.3 Work Plan for Next Year

2011 was a year of change for this Annex. A number of new MCFC systems were installed and existing ones maintained successful operation. Over the same time period some companies left the research and development area while new companies were created and entered this area.

The next MCFC Annex meeting will take place on 29-30th October 2012 and will be held in conjunction with Annex 25, Stationary Fuel Cells, at Fukuoko, Japan. Considerable experience from system operations demonstrates that life time enhancement and cost reduction are still needed to make MCFC systems compatible with the market. Therefore, the Annex meeting in 2012 will focus on technical improvement in life time and cost reduction. Also, discussion of new applications of MCFC systems, such as CO_2 separation, biogas utilisation and H_2 production will be addressed.

It is the intention that a set of Key Messages will be 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

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, in addition to discussing a selected topic. The areas of particular focus and learning are the durability and costs of SOFC stacks and systems.

All participants are influential players in this field, commanding budgets that total millions of Euros for SOFC research and development.

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.

Since SOFC systems can be built to any scale from several watts to several hundreds of kilowatts, they 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 (<1 kW_e)
- Auxiliary Power Units (APU) and back-up power (1-250 kW_e)
- Stationary small-scale combined heat and power (m-CHP) (1-5 kW_e)
- Stationary medium-large scale (0.1-10 MW_e)

Theoretically the power produced by an SOFC can reach up to 70% of the inlet fuel energy; in practice, within an end-user-ready system, efficiencies are between 40-60%, depending on the power plant configuration. Combustion-based technologies can only reach 55% electrical efficiency in very large-scale power plants (of hundreds or thousands of Megawatts). The SOFC efficiency is unique in being practically independent of scale (several watts to several hundreds of kilowatts) and systems have been demonstrated with 60% net efficiency even at one kilowatt of delivered power. Due to the high operating temperatures of 600-900°C SOFC systems offer the advantage of being able to use a wide range of fuels without the need for an external reformer.

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)

4.3.1 Activities

The 2011 Annex meeting was held on the 1st May, in Montreal. 18 participants from 12 countries came together to discuss their national status and policies for this area, as well as durability and degradation of SOFC, accelerated testing, progress of the SECA programme and the new EU initiative on Fuel Cells and Hydrogen.

Annex 24 contributed to two international workshops in 2011:

- International Workshop on Degradation Issues in Fuel Cells - 21st-23rd September 2011, Thessaloniki.
- SOFC for Next Generation Power Plants Symposium - 23rd June 2011, Netherlands.

4.3.2 Technical Accomplishments

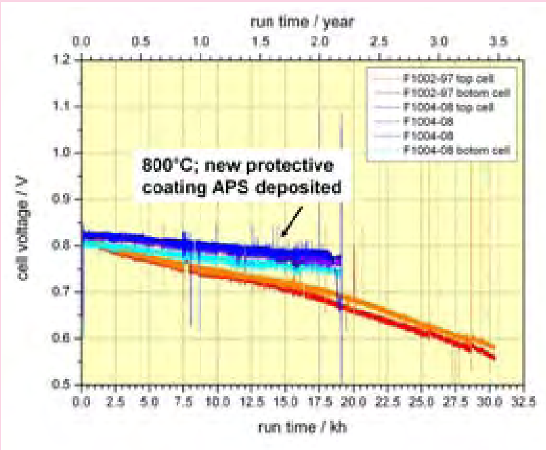
There is evidence that the market for SOFCs has grown at 40-50% each year over the past three years, although the market is still small at 18,000 units in 2011. Activities within the area of SOFC are intensifying due to its ability to provide higher electrical efficiencies and its ability to excel at producing a continuous electricity supply. There are pre-commercial products entering onto the market with 150,000 hours run time (17 years).

Highlights of work discussed and progressed within this Annex include:

- SOFC stack operation at Forschungszentrum Jülich has achieved 30,000 hrs run time (red and orange lines below). This demonstrates excellent lifetime improvements. Such stacks, while still operational, are already out of date in terms of the technology used to build them, and the newer SOFC stacks show significantly improved cell voltage, over an already considerable lifetime of 2 years (18,000 hrs, blue and light blue lines below). This demonstrates that large scale stacks are viable for large scale power production.

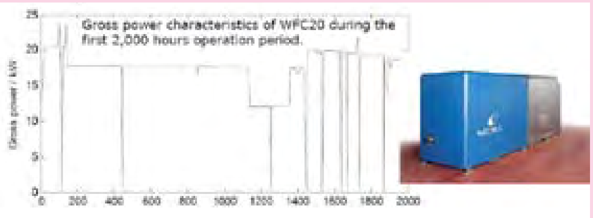
  The current target for new SOFC stacks is 80,000 hours or 9 years.

Figure 8. SOFC stack voltage output at Forschungszentrum Jülich over 30,000 hours, 3.5 years.



- In Denmark, SOFC stacks operated by the Finnish company Wärtsilä run on landfill gas. 20kW systems are used, demonstrating only a 0.7 - 0.9% degradation per 1000 hours of operation. It has also been shown that the system can cope with methane levels fluctuating, and with impurities in the fuel which were cleaned via a commercially available cleaning system. There was step-degradation due to loading discontinuations, which included four shutdowns, none of which were due to the fuel cell, but were due to interruptions in the biogas feed, component malfunctions or grid instabilities. These systems have achieved long run times, which demonstrates that large SOFCs can be run efficiency and smoothly.

Figure 9. In operation gross power output over the early operation stage of an SOFC system running on landfill gas in Denmark.



- A 10kW planar SOFC system designed and constructed by VTT (Finland) has been operating for over 5000 hours (over 6 months). The system is fully automated (24/7), fuelled by natural gas with anode gas recycling, grid connected and has a VPS 10 kW_e planawr stack.

  The results show that stack efficiency is 60%, with net efficiency at 50%. Degradation in the whole system is maintained at less than 1% to date, i.e. the reformer, afterburner, anode exhaust gas recycling system, power conditioning, blowers, heat exchangers, sulphur removal unit and other necessary components have not had any additional effect on the degradation of the stack. Hence the main and practically only source of degradation is the stack itself.

Figure 10. 10 kW SOFC system at VTT, Finland.

Technology Perspective

Mobile, military and strategic: One of today's major concerns in the energy field is to fulfil the requirements for mobile applications (<1 kW_e), 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 PEMFC 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 uninterruptedly 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 the 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: 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 the 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 500 W_e up to several tens of kW_e for road vehicles or even several hundreds of kW_e 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 (1-5 kW_e) 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 pressurized 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.

4.4.3 Work Plan for Next Year

The Next SOFC Annex meeting will take place in conjunction with SOFC XIII meeting, in October 2012, Okinawa, Japan (http://www.sofc-xiii.com/).

In addition “The Second Symposium on Solid Oxide Fuel Cells for Next Generation Power Plants’ (focusing on biomass gasifier-SOFC systems) will be held at Imperial College London in 2013. The meeting organizer will be Dr PV Aravind from the Technical University Delft.

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

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

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 on fuel cells for stationary applications; both opportunities and obstacles that must be overcome are investigated and discussed. The market development is followed closely with a special focus on fuels, system optimisation, environment and competiveness together with follow up on the real status of stationary fuel cell technology.

Annex 25 has six subtasks:

- Subtask 1: Small Stationary Fuel cells
- Subtask 2: Fuel for Fuel Cells
- Subtask 3: Fuel Cell Plant Components
- Subtask 4: Analysing design, operating and control strategies for stationary fuel cells systems
- Subtask 5: Status of large fuel cells market and demonstrations
- Subtask 6: Market Status

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
Belgium	WatersofNet
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)
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)
Korea	Institute of Science and Technology (KIST)
Mexico	Instituto de Investigaciones Electricas (IEE)
Netherlands	Energieonderzoek Centrum Nederland (ECN)
Sweden	Grontmij
Switzerland	Swiss Federal Office of Energy
USA	Sandia National Laboratories

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

A key element of the work of this Annex is that the conditions for the introduction of stationary fuel cells are different in each country, even if they are neighbours. Varying electricity production systems have been adopted by 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.

4.4.1 Activities

Two Annex 25 meetings were held in 2011. The first on the 10th and 11th May, in Antweroen-Lillo, Belgium, was hosted by Solway and Waterstofnet. 13 participants from 9 countries came together to discuss all subtasks and recent developments.

The second Annex 25 meeting was held on the 31st October in the USA, arranged in connection with the Fuel Cell Seminar 2011 in Orlando, Florida, USA. 13 participants from 8 countries attended, together with guests from the USA.

A number of decisions were taken at this meeting, including:

- to develop a questionnaire for Subtask 2
- to finalise a subtask report for Subtask 1 investigating the possibilities of introducing residential fuel cells in different regions
- Annex 25 members will update the ETSAP Technology Brief for fuel cells.

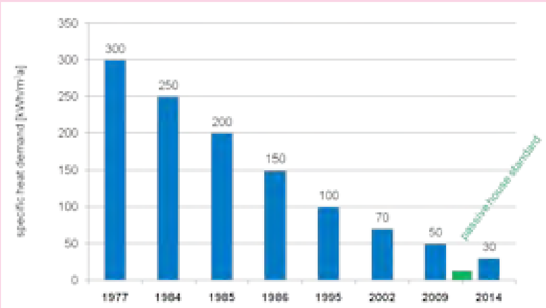
4.4.2 Technical Accomplishments

Subtask 1 - Small Stationary Fuel Cells

The market activities for small stationary fuel cells for residential use have increased significantly. The market conditions vary significantly between different regions both for energy demand and also with respect to energy prices, as investigated by the EC project FC-Eurogrid.[6] As seen in the Figure below the average heat demand for a house has significantly dropped from 1977 to today, and it is anticipated that it will continue to fall in the future. Meanwhile the electricity demand from houses is increasing, hence high electric efficiency is of increasing importance.

A number of countries in Europe commonly have household heating systems based on wall-mounted gas boilers. There is the possibility of replacing these with fuel cell systems in the future and microCHP fuel cell systems offer a further alternative. Examples from Germany include the various systems installed under the Callux programme[8] by a number of utility companies.

Figure 11. The historical heat demand of domestic residences, and forecast to 2014.[7]



[6] Evaluating the Performance of Fuel cells in European Energy Supply Grids, http://www.fch-ju.eu/project/evaluating-performance-fuel-cells-european-energy-supply-grids

[7] Source: Energy Conservation Regulation.

[8] www.callux.net

Today about 200 residential fuel cell systems, both PEFC and SOFC, have been installed in Germany under this programme. The installation of a further 800 fuel cells is planned under the Callux programme.

A key activity of this Annex's work is understanding the different available heating systems and microCHP systems such as ICE from Dachs and from Senertec and the fuel cells that are installed in the Callux program that are tested and demonstrated by utility companies such as E.ON, EWE or by manufacturers like Baxi, Bruns and Vaillant.

Also in Germany, the recent CFCL's high efficiency SOFC fuel cell systems are being trialled and 72 units have been installed, operating at up to 1kWe with a target of 60% electrical efficiency. The intended retail price of the SOFC units is €15,000. Staxera, Hexis and TOFC have started installing SOFC prototypes in Denmark.

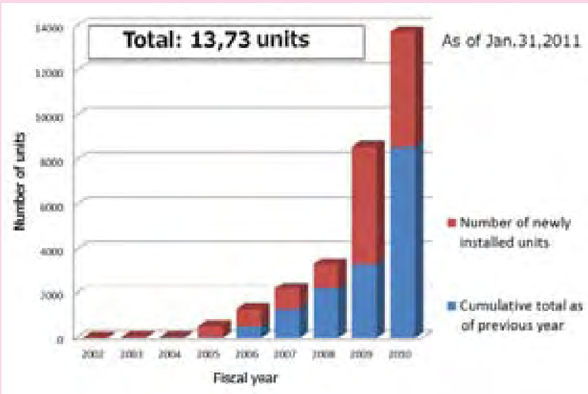
SOFC for residential fuel cells is a developing and increasing market in Northern Europe today.

Dantherm Power in Denmark produces a back-up power unit based on a hydrogen/air mix and PEFC technology. The output range is from 0.7 kWe to 2.0 kWe and the major market today is the telecom industry. In total over 500 Dantherm systems have been delivered, totalling more than 1 MWe installed. Denmark also has a microCHP program with the intention of installing 100 microCHP fuel cells in homes, using different fuels such as natural gas, biogas and hydrogen, and using different technologies and suppliers of fuel cells including PEFC and SOFC technology.

Topsö Fuel Cells and Dantherm Power have developed an SOFC 1.3 kWe unit with an efficiency of 37.9 % to the grid. This is the first unit and significant improvements are expected to be made in future versions.

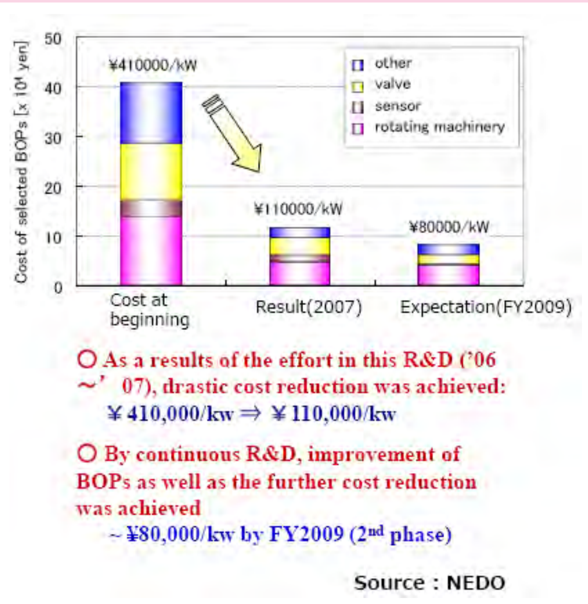
In Japan, the ENE-Farm programme has accelerated with the number of installed units in households standing at nearly 14,000 units in early 2011, and a further 5000 expected to be installed during the course of 2011. Most of the stationary fuel cells in Japan use PEFC technology, with the expected life-time of units at 6 years. The subsidy for each unit today is up to 1.05 MYen which includes 50% of the total installed costs. The expected target price in 2020 is 0.4 MYen. PEFC is the dominating technology in Japan, but the SOFC program has increased recently with more than 230 units in operation, from 6 different suppliers. The efficiencies of such units range from 36.4% to 42%.

Figure 12 Number of installed small stationary fuel cells in Japan.[9]



[9] Source: 2010 SOFC Demonstrator Project.

Figure 13 Cost reductions achieved from 2006 to 2007, and those anticipated to 2009 from the SOFC Demonstrator Programme in Japan.[9]



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

The WaterstofNet project is connected to the largest hydrogen distribution network in the world that spans parts of France, Belgium, and the Netherlands. The hydrogen network is about 1000 km long, is owned by Air Liquid and has an operating pressure of 80 bars. This network is currently only considered for industrial use. One significant activity within the WaterstofNet project is the building of a large scale 1 MWe PEMFC power plant, with a capital investment of €5 million. This PEMFC will have a peak power of 1.7 MWe, generated by 12 modules of Nedstack PEM fuel cells. Only European technology will be used in the plant including the PEM membrane, catalysts, and all other components.

Figure 14 1 MWe – PEM Power Plant at Solvay, Antwerp

Natural gas qualities

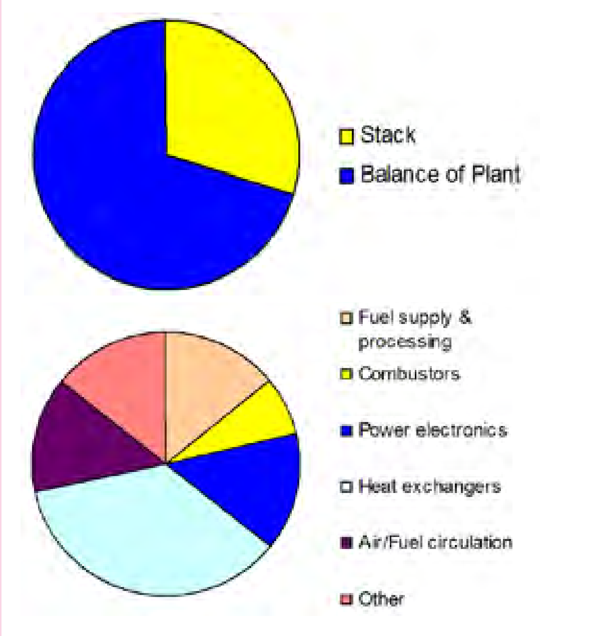
The qualities and specifications of different sources of natural gas can vary significantly. This has been identified as having an influence on the performance of fuel cells systems, and this has occurred recently in Denmark in connection with the microCHP demonstration program. Initially the natural gas used was supplied from Danish wells in the North Sea, but was then switched to the natural gas imported from Germany. This had different nitrogen content to the original gas supply, and affected the performance of the fuel cells negatively. If performance is sufficiently badly affected then the fuel reforming element of the fuel cell would need to be improved to address the change.

Subtask 3: Fuel Cell Plant Components

This work seeks to identify projects in which BoP (balance of plant) components are developed and consider their approaches and targets. There is a significant difference between the hot BoP that is developed by the fuel cell system developers and the cold BoP that is more conventional technology. The intention is that SOFC, MCFC and HT-PEFC systems will be considered where possible.

Currently the cells and the stack are the single most expensive elements of a fuel cell system. As products mature and given that the cells and stack are essentially modular the proportion of the total system is expected to fall to less than 50%. Below, an example of an SOFC CHP system is given and it can clearly be seen that currently the stack cost is less that 50% of the total costs, the remaining costs are made up of a number of components. To bring the total cost of a fuel cell system down to market ready levels each of these components will require optimisation.

Figure 15 LHS Breakdown of costs for generic SOFC CHP system, and RHS breakdown of costs of principal components and sub-systems.



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

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

PNNL have undertaken modelling work that sought to identify the optimal parameters for tri-generation, including hydrogen production from high temperature fuel cell systems and cooling with an absorption chiller. A network of fuel cells for supply of energy to a large campus has been modelled. The model contains combined cooling, heating and power or tri-generative fuel cell systems that can convey electricity, recoverable heat, and chilled water to multiple buildings via networks and includes hydrogen production.

This work has identified that:

- Thermal storage is occasionally economical
- Cooling storage is rarely economical
- Electrical storage is not economical.

The assumption was that the hydrogen produced would be used as fuel for vehicles. A 1 MWe SOFC could produce sufficient hydrogen to refuel 2600 cars.

Subtask 5: Status of large fuel cells market and demonstrations

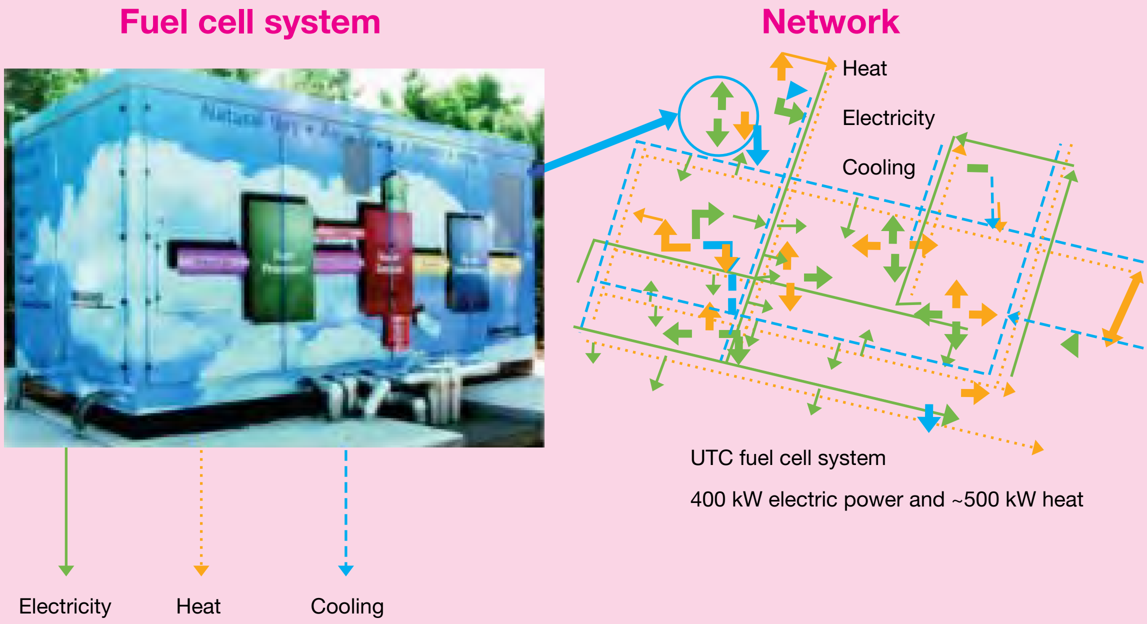
There are a number of new large demonstration projects near to installation.

MCFC systems tend to be large, and there is about 100 MW installed capacity across 52 systems across the USA, Europe, Japan and Korea. Continuous cost reductions have been achieved, but subsidies (such as FIT and RPS) are still useful and necessary to promote the introduction of this technology into the marketplace. Specific applications such as the coupling with biogas from Anaerobic Digestion (almost 11.5 MW already installed at several different customer sites), hybrid configuration with gas turbines and integration with natural gas pipelines are promising.

Recent developments in the market include:

- The number of suppliers of large fuel cells is decreasing - MTU and Ansaldo have ceased their activities, although others might take over the business elements.
- It has been identified that it is more difficult than previously anticipated to scale up SOFC.
- PEFC is losing market share for residential fuel cells in Europe
- MCFC is becoming more and more reliable as an economic product.

Figure 16 A modelled system that is a tri-generative fuel cell system that conveys electricity, recoverable heat, and chilled water to multiple buildings via networks, and includes hydrogen production.



Subtask 6: Market Status

The aim of this subtask is to highlight the latest developments in the area of stationary fuel cells for example new technology break-throughs, major programmes and market development. Recent highlights include the following three topics below.

Hydrogen and Wind Power

A presentation was made, followed by a discussion, regarding the possibility of producing hydrogen in offshore wind-farms and using the hydrogen as transport fuel and as an energy carrier for stationary use.

HyRamp

The HyRamp organisation represents different regions in Europe, currently covering 31 regions. These regions will have a total budget in 2015 of 82 M€ of local funding available for hydrogen and fuel cell projects. The HyRamp HQ is situated in Brussels and HyRamp is closely connected with the FCH JU.

IEA ETP and Hydrogen

The IEA in Paris has started to consider hydrogen and fuel cells in their scenarios for the Energy Technology Perspectives (ETP). In two of five scenarios hydrogen is considered as a fuel: the Blue Map and the Blue-map-shift. Hydrogen will then be taken into account both in the transport sector and as a fuel for CHP in the building sector. In both of these scenarios fuel cells are the technology assumed to be used to convert this fuel into usable energy.

Achievements during 2011

Installations of stationary fuel cells have continued to accelerate in 2011. Significant numbers of new household fuel cells have been installed, including:

- The outstanding expansion of the ENE-FARM stationary fuel cell program in Japan with close to 14000 fuel cells installed in buildings in Japan by January 2011. It is expected that the number of installed fuel cells in Japan will rise significantly following the earthquake and the Fukushima disaster in early 2011 with the implications that these events had for stable electricity supply.
- Major on-going programs in Germany and Denmark for small stationary fuel cells for buildings.
- The development of both PEFC and SOFC microCHP fuel cell systems by Dantherm Power, and consideration of their market viability.

Within the area of large fuel cell systems, several significant new systems have come to fruition:

- The 1 MWe PEFC project from Nedstack and the future use of the fuel cell at Solvay-Solvic in Lillo using surplus hydrogen from chemical production especially chlor-alkali plants.
- The demonstration of large fuel cell systems with special focus on MCFC and UTC Power PAFC.

Overall this sector had a significant increase in sales compared to 2010, almost doubling the generation capacity. This sector accounted for 81MW of generation capacity by the end of 2011.[10]

Publications from this Annex

Annex 25 produced a summary document 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.

[10] The Fuel Cell Today Industry Review, 2012.

4.4.3 Work Plan for Next Year

The next stationary fuel cells Annex meeting will take place in conjunction with the MCFC Annex meeting, on the 29-30th October 2012, in Fukuoko, Japan.

It is the intention of this Annex that a set of Key Messages will be released for this Annex, together with the updated technical summary publication highlighted above. Several publications are planned to be submitted, including: small scale stationary fuel cells; fuels for fuel cells; status of large fuel cells systems.

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

The overall objective of Annex 26 is to develop the understanding of fuel cells for transportation with their particular properties, applications, and fuel requirements. The specific objectives are to:

- Improve the common understanding of state of the art fuel cell systems, on board fuel storage systems, technology development directions, cost reduction approaches.
- Improve the concepts for alternative fuels by discussing manufacturing technologies, required infrastructure for storage and distribution, efficiencies and emissions during fuel production
- Leverage the emissions work being carried out in Participants' organisations
- Jointly review the on-going work on practices and procedures relevant to alternative fuels and fuel cell vehicles, and help identify their niche applications
- Accelerate the market entry of advanced fuel cell systems for transportation by identifying open development issues of common interest and making recommendations on private and government strategies.

Annex 26 has four subtasks. These are:

Subtask A Advanced Fuel Cell Systems for Transportation: This subtask focuses on the fuel cell system and hydrogen storage technology. It proposes to prepare an inventory of markets and a summary of gaps and barriers.

Subtask B Fuel Infrastructure: This subtask focuses on distributed and central hydrogen production technologies and WTW studies.

Subtask C Technology Validation: This subtask evaluates hydrogen production methods, considers production efficiency and hydrogen purity features. It also examines the status of hydrogen network activities.

Subtask D Economics: This subtask exchanges and compares cost models and assesses the economic gap of fuel cells in transport.

The 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 Argonne National Laboratory, United States Department of Energy.

Participants

Country Participant	Associated Institution
Austria	A3PS
Canada	Ballard Power Systems
Denmark	H_2 Logic
Finland	Helsinki University of Technology
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
USA	Argonne National Laboratory (ANL)

4.5.1 Activities

The work of this reorganised Annex began in 2011, with the first meeting in conjunction with the Fuel Cells Durability Workshop on 20th September 2011 in Thessaloniki, Greece. At this meeting specific focus was given to durability issues within fuel cells systems for transportation.

4.5.2 Technical Accomplishments

For fuel cells used in transportation applications, issues of durability and component degradation are crucial 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, temperatures, and humidities. These issues have a high prominence in this Annex, therefore, and the fuel cell operation and design optimisation focus on the parameters of specific interest for transport applications.

An example of this is the work carried out by Ballard on the trade-offs in system and stack design and cost. For instance, humidification level impacts component degradation in a complex manner, with corresponding effects on life-cycle costs, as illustrated qualitatively in Fig. 17. Other operating conditions influence the system design and component materials selection, such as conditions during shut-down and start-up, ambient and operating temperature, and cell voltage and voltage cycling. Good mechanistic understanding and validated predictive models are needed to enable reliable design decisions and to minimise costs.

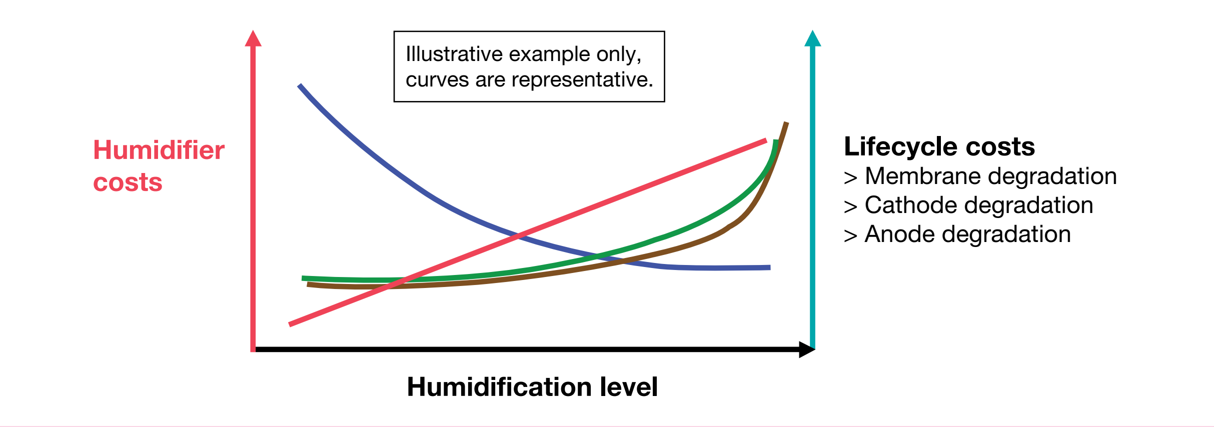
There are a several projects underway in this area of research internationally and Annex 26 seeks to bring together the issues and outputs, generating the overview perspective.

Subtask A Advanced Fuel Cell Systems for Transportation

Within the US there are five relevant projects receiving government support to investigate durability in PEM Fuel Cells, as well as the more general durability aspects of accelerated stress testing, system and air contaminants and work towards the development of Durable Catalysts. These are:

1. 'Polymer Electrolyte Fuel Cell Lifetime Limitations: The Role of Electrocatalyst Degradation', with JMFC, UTRC, MIT, UT-Austin and UW-Madison.
2. 'Durability Improvements Through Degradation Mechanism Studies' led by LANL and with ANL, LBNL, ORNL, Ballard, Ion Power and UNM as partners.
3. 'Durability of Low-Pt Fuel Cells Operating at High Power Density', led by Nuvera with ANL and LANL as partners.

Figure 17 Humidification level impacts component degradation in a complex manner[11]



[11] Source: S. Knights, MITACS Workshop, Toronto, 2011.

4. 'Development of Micro-Structural Mitigation Strategies for PEM Fuel Cells: Morphological Simulations and Experimental Approaches' led by Ballard, and with partners at Georgia Tech, LANL, MTU, Queen's Univ and UNM.
5. 'Analysis of Durability of MEAs in Automotive PEMFC Applications' led by DuPont and has Nissan, IIT and 3M as partners.

Within the EU a significant project is the DECODE Project, 'Understanding of Degradation Mechanisms to Improve Components and Design of PEFC'.[12] This project has 11 partners across Europe, including Vovlo and Opel. The aim of this project is to identify degradation mechanisms with particular emphasis on liquid water and to subsequently modify components to achieve significantly improved PEFC durability. This project produced a description of the feedback between performance and aging, i.e. a durability indicator, which was the first example of such a predictor in the literature and hence provides an important tool going forward to contribute predicting durability of PEFC systems.

FC-GEN, a project involving a number of European partners[13], has the objective of developing and demonstrating a proof-of-concept complete fuel cell auxiliary unit in a real application, on-board a truck. The project began in 2011, and will run to 2014. The targets that this project has set itself for the auxiliary Power Unit are:

Table 4 Targets for the FC-GEN Project for the APU

Issues	FC System Stack and BoP
Durability (hours)	20,000
Cost (Euro/kW)	≤ 400
Efficiency	See text
Weight (kg) Volume (L)	50 150
Noise (dB)	< 60

In terms of fuel efficiency the target is to reduce fuel consumption through an 80% reduction compared to conventional idling (>4 litres/hour) and a 40% reduction compared to diesel based APU.

A second project in this same area is DESTA, Demonstration of the 1st European Solid Oxide Fuel Cell Truck Auxiliary Power Unit.'[14] The SOFC technology offers significant advantages compared to other fuel cell technologies because of its compatibility with conventional road fuels. The aims of this project are to successfully demonstrate and operate the SOFC APU on board a Volvo truck during parking and driving, achieving a 35% system electrical efficiency at a product cost of €1,000/kW. Ultimately the aim by completion of the project in 2014 is to demonstrate reduction of CO_2 emission and pollutants compared to conventional engine idling of heavy duty trucks.

These fuel cell APU projects offer the potential for a significant deployment of these technologies in the commercial truck market in the near future, with

[12] Partners: Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Chalmers University of Technology, Friedrich-Alexander-Universität Erlangen-Nürnberg, Commissariat à l'Energie Atomique (CEA), DANA SEALING PRODUCTS - VICTOR REINZ, REINZ-Dichtungs-GMBH, Adam Opel GmbH, European Commission, DG Joint Research Centre, Institute for Energy (JRC-IE), SGL Technologies GmbH, SOLVAY SOLEXIS S.p.A., VolvoTechnology AB, Zentrum für Sonnenenergie-und Wasserstoff-Forschung Baden-Württemberg (ZSW)

[13] Participants: Volvo Technology AB, Powercell Sweden AB, Forschungszentrum Juelich GMBH, Institut Jozef Stefan, Centro Ricerche Fiat SCPA, Institut fuer Mikrotechnik Mainz GMBH, Johnson Matthey PLC and Modelon.

[14] Participants: AVL List GmbH, J. Eberspächer GmbH & Co, Topsoe Fuel Cells A/S, Volvo Technology AB and Forschungszentrum Juelich GmbH.

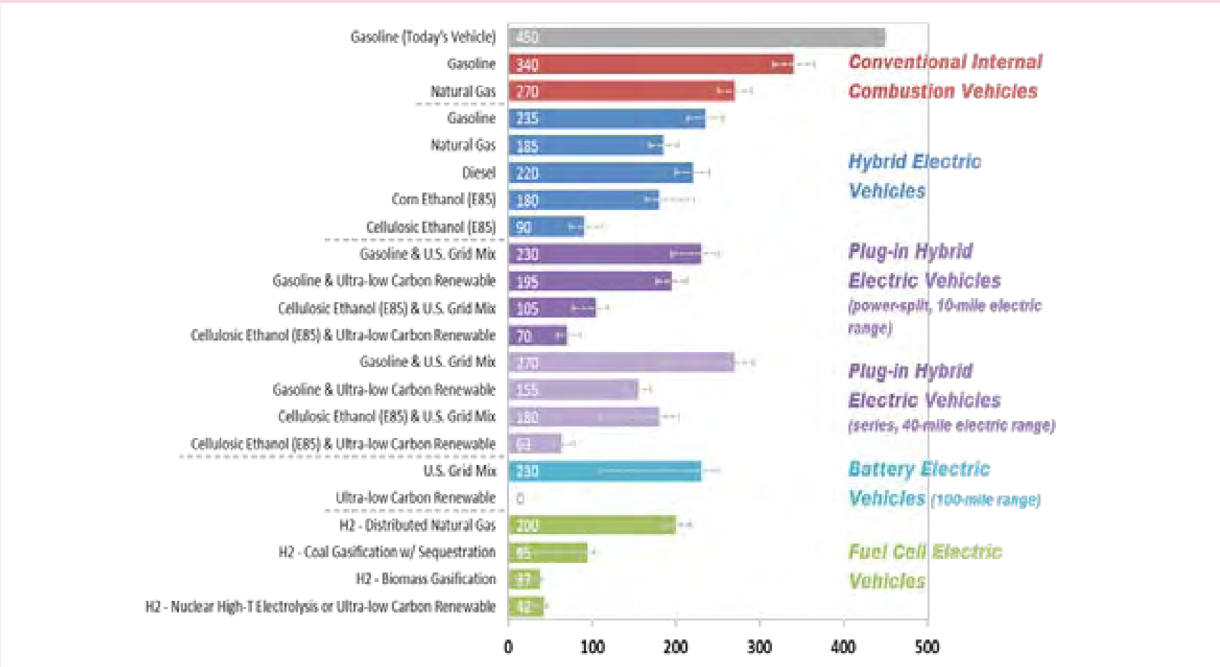
corresponding benefits of reduced fuel consumption and lower greenhouse gas (GHG) emissions, compared to the current practice of using the truck's main engine for the auxiliary loads, even when the truck is parked. Because of the multiple partners in each of the projects, Annex 26 offers an excellent forum to report; share the progress of the projects and design and validation data as they are obtained. Annex 26 enables the results to reach a wide international audience on a regular basis.

Subtask B On-board Hydrogen Storage Systems

A major aspect of the issues related to the fuel infrastructure required to provide the hydrogen (or other fuels) for use by the fuel cells in transport applications is the use of various primary energy sources and the emissions of GHG and other regulated pollutants in the process.

A comprehensive well-to-wheels analysis has been carried out by Argonne National Laboratory, in the USA. This work considers a wide range of energy options for transport, as illustrated by the graph below (Figure 18 Well-to-wheels Greenhouse Gas Emissions). It is readily seen from these results that fuel cell electric vehicles offer significant reduction in GHG emissions over the entire fuel cycle. If natural gas is used to produce the hydrogen for the automotive fuel cells, there is a >50% saving of GHG emissions compared to petrol; with hydrogen from biomass, nuclear, or renewable energy, potential savings in GHG emissions may be as high as 90%. Further, in the USA, using natural gas to produce the hydrogen for FCEVs would not greatly strain the natural gas production or supply network; even one million FCEVs on the road would increase the annual natural gas consumption by less than 0.2%.[15]

Figure 18 Well-to-Wheels Greenhouse Gas Emissions by various fuel pathways



[15] *Fuelling 1 million FCEVs with hydrogen from natural gas would require ~1billion cubic meters/year of NG; current NG consumption in the US is about 600 billion cubic meters/year.

Subtask C Hydrogen infrastructure

The successful deployment of fuel cell vehicles also requires the implementation of a corresponding hydrogen production and distribution infrastructure. To achieve this, demonstrations are essential for validating fuel and fuel cell technologies in integrated systems. As of mid-August 2011, in the USA there were:

- 155 fuel cell vehicles being operated on public roads
- 24 hydrogen fuelling stations for these vehicles
- Over 131,000 vehicle hours of operation, corresponding to vver 3 million miles travelled by FC vehicles
- 2,500 hours driven by a single fuel cell unit (nearly 75,000 miles) demonstrating good durability
- On-the-road fuel cell vehicle efficiency of 53-59%
- Driving range of 196 and 254 miles between refuelling (430 miles on separate FCEV).

For other types of fuel cell applications, H_2 fuel cell buses have demonstrated a 42% to 139% better fuel economy compared to diesel & CNG buses. Demonstration fuel cell-powered fork-lift trucks have had over 45,000 refuellings at Defense Logistics Agency sites in the US; fuel cell-powered fork-lift trucks now represent a near-commercial technology that is being deployed in increasing numbers without government subsidies. Combined heat, hydrogen, and power (CHHP) fuel cell systems have demonstrated an efficiency of 54% (hydrogen + power) when operating in hydrogen co-production mode, and at a capacity of 100 kg-H_2/day of renewable hydrogen supply.

The European Fuel Cell Demonstration Project for Road Vehicles has three phases under the 7th Framework Program. Phase I ends in 2011, where the intention is to deploy up to 25 cars per OEM and 100 vehicles in total in more than one EU region, along with 10–20 buses from each OEM and 100 buses in total over 3 EU regions.[16] Phase II will build on the efforts of Phase I, with a 2020 "Snapshot" target of 0.4 to 1.8 million fuel cell vehicles on the roads in EU.

Subtask D Economics

Investigation of the potential mass manufacture costs of fuel cells is an important area, to allow better understanding of the benefits that this technology could offer in the future. As production of fuel cells is still often for demonstration purposes, citing the actual cost of production is often not accurate for production volume scale up.

Fuel cell system manufacturing cost analyses in the US over several years, with annual updates to take into account developments in the fuel cell technologies, have shown that the projected high-volume manufacturing cost of 80-kWe automotive fuel cell systems has been reduced from $108/kW in 2006 to $51/kW in 2010, as shown in Fig 19.[17] This represents more than a 30% reduction in costs from 2008, and more than an 80% reduction in costs since 2002. Figure 4 shows these projected manufacturing costs as a function of the annual production rate, with the greatest reductions occurring as manufacturing volumes approach and exceed 25,000 systems/year.

[16] Source JTI FCH Transportation Committee

[17] Based on projection to high-volume manufacturing (500,000units/year).

Figure 19 Projected Transportation Fuel Cells System Costs, assuming 500,000 units a year.

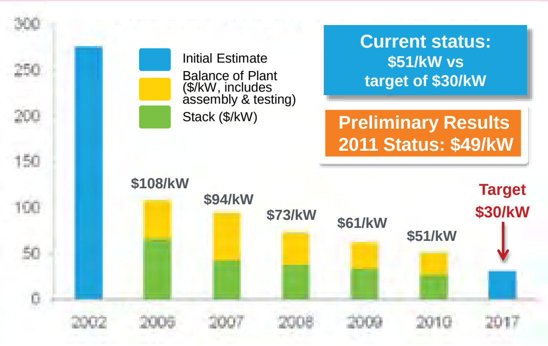
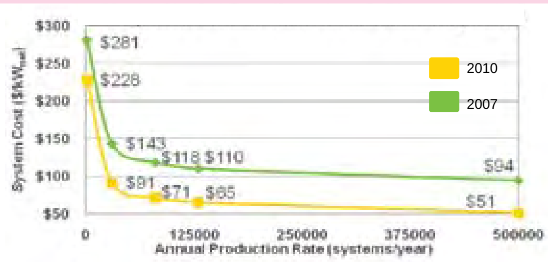


Figure 20 Projected Costs at different manufacturing rates.



Achievements during 2011

Fuel cells for transportation continue to progress rapidly in 2011. Highlights for 2011 are that over 3 million miles have been travelled in fuel cell vehicles during the course of 2011. There are now 155 new fuel cell vehicles and 24 publically available hydrogen refuelling stations in the USA (80 in total), 85 fuelling stations operational in the EU, 47 in Asia and three in the rest of the world.[18]

This Annex has successfully recommenced work, and has a growing network of experts contributing to its activities. The areas of active R&D within this Annex are addressing all the critical technical barriers to large scale commercialisation of fuel cells for transportation. The active areas include development of fuel cell systems and components, improvement of durability and reliability, and reduction of capital and operating costs.

In recent years we have seen increased emphasis on testing and characterisation of the fuel cell systems and components. There are parallel robust programs on validating the laboratory data in field tests using light-duty vehicles and bus fleets in Canada, Europe and the USA. These field tests are yielding valuable data on fuel economy, power plant and vehicle availability, component and system durability, and operating costs.

Although significant progress has been made in all of these areas, there is still need for further advancement. Thus, it is expected that these topic areas will continue to be active for R&D in the future.

[18] Source: hydrogen fuelling stations in Europe, h2stations.org, TÜV SÜD, http://www.netinform.net/H2/H2Stations/H2Stations.aspx?Continent=EU&StationID=-1#liste

4.5.3 Work Plan for Next Year

The next meeting of Annex 26 will be hosted by Volvo Technology Corporation, at Gothenburg, Sweden, in May 2012. Proposed topics for this meeting are:

- Technology validation (Subtask C): data from light duty vehicle and bus demonstration programs (Canada, Germany, Japan, Korea, U.S., EU, etc.).
- Economics (Subtask D): cost projections.

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

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 250 W for small mobile applications up to several kW systems that can be moved by 4 people (the EC definition of 'portable') that are suitable for light traction. Hence this Annex covers a considerable breadth of applications.

Promising techniques for these applications are polymer electrolyte fuel cells operated with methanol or hydrogen.

This Annex considers four aspects in this area:

- System analysis and hybridisation
- System, stack and cell development
- Codes and standards, safety, fuels and fuels packaging
- Lifetime enhancement.

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

Compared to batteries, fuel cells offer advantages in powering portable and small mobile applications. The main advantage is the high power density of the fuel and the longer operating time of the device. The time that is necessary for recharging batteries may be a problem that can be avoided by using fuel cells. Potential applications for these 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 350 bars. Yet the DMFC itself provides a much lower power density than the polymer fuel cell (PEMFC) operated with hydrogen. In most applications it is necessary to couple the fuel cell with a hybridisation battery to cope with load peaks or energy recovery.

Key issues in developing MEAs (membrane electrode assembly) are improving 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.

4.3.1 Activities

The last meeting was held in Montreal, Canada on 6th May 2011 in conjunction with the ECS-meeting. Topics that were particularly focused on were:

- System, stack and cell development
- Lifetime tests
- Catalyst preparation and corrosion.

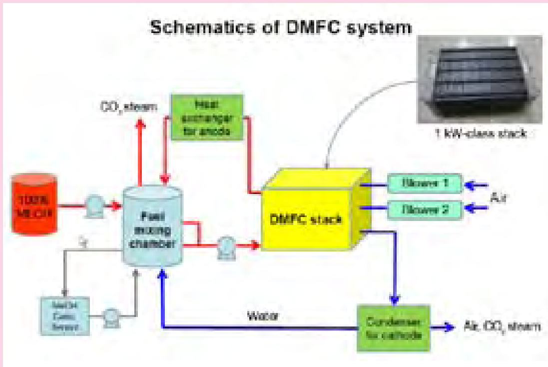
4.6.2 Technical Accomplishments

Systems for new applications that are under development in this area include systems for forklift trucks, wheel chairs, bikes and for PDAs.

Highlights of system developments within this Annex for 2011 include several pieces of work from KIER in Korea:

KIER have demonstrated a fuel cell hybrid system for a small cart. This is a constant current-mode operation with two heat exchangers as shown in the schematic below. The system is fed at the cathode by two blowers and water is recovered from the exhaust gas and pumped back to the fuel mixing chamber. For the water recovery a condenser is used. Additionally a heat exchanger is integrated into the anodic loop for cooling the system. The system is operated with pure methanol. The stack is operated with a mixture of water and methanol, this mixture is prepared within the system by using water that is recovered from the exhaust gas. For a better understanding of mass and energy flows inside the system a simulation model was developed. It demonstrated excellent correlation with the 'real world' behaviour observed by the fuel cell hybrid system.

Figure 21 Diagram showing a schematic arrangement for a hybrid fuel cell system for a small cart.



A power pack for military use has been developed by a consortium at KIER, Chungnam Nat'l University and KAIST in Korea. The power pack weighs 1.2 kg and provides 24 W of portable power, 30 W at peak power, and operates between 32-65 °C for 500 hours. This has been developed as a concept product to directly replace batteries so that the challenge of recharging time is removed as well as offering low temperature operation, a quiet product and a high efficiency system.

Within MEA development there have been some new results with radiation-grafted polymer electrolytes.Work at KIER has focused on developing a radiation grafted polymer electrolyte for low methanol crossover. This was based on ETFE (ethylene tetrafluoroethylene) membranes and radiation-grafting produced a ETFE-SS-DVB (styrol / divinylbenzol) type of membrane. The function of this membrane was demonstrated in a 6 cell stack with an electrode area of 50 cm², as shown in Figure 22 below.

The results demonstrate it is possible to operate a fuel cell stack with the modified membrane at a methanol concentration of 3 M with the same performance that is achieved with 1 M. This indicates that methanol crossover is reduced, so doesn't affect the fuel cell performance negatively. The negligible influence of the methanol concentration also means that the accuracy of the methanol dosing system need not be as high and it can be simplified and optimised going forward.

The long term stability tests of DMFC MEAs with radiation grafted PEM, conducted at KIER, demonstrate the effect of methanol concentration. The MEA that is operated with a 3 M methanol solution shows a voltage decay rate that is twice that of the cell operated with 1 M methanol water solution. This shows that initial performance is not significantly affected by the methanol concentration, but in the longer term the higher methanol concentration leads to higher degradation rates.

Figure 22 Current voltage plot of a six cell stack with grafted ETFE membranes. The stack was operated with 1 M methanol and with 3 M methanol and demonstrates that the methanol concentration does not affect the cell performance.

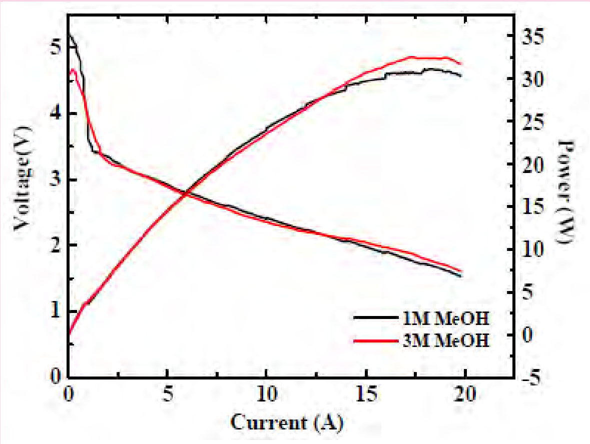


Figure 23 Operating over 1000hrs, and utilising concentrations of methanol at 1M and 3M, the above figures demonstrate the increased aging of the cell that is operated with the higher methanol concentration

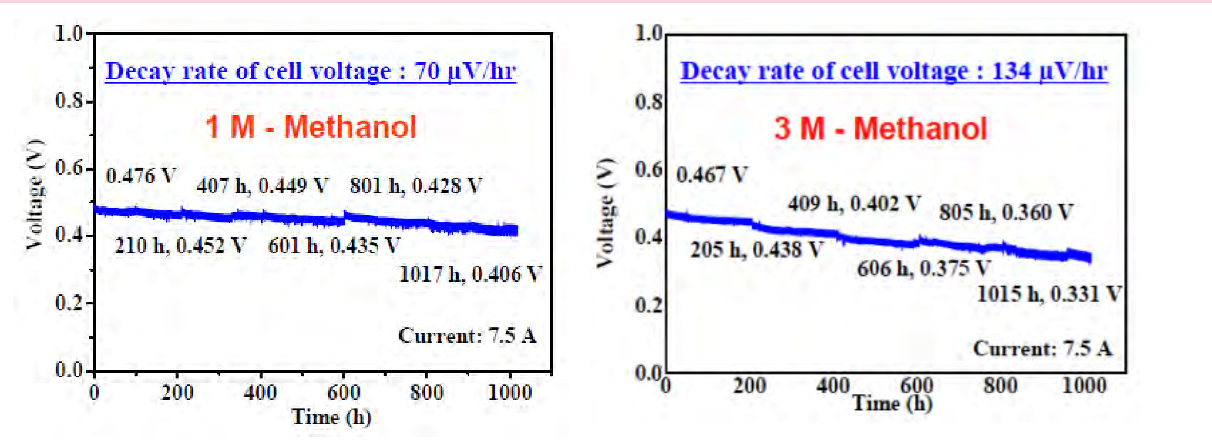
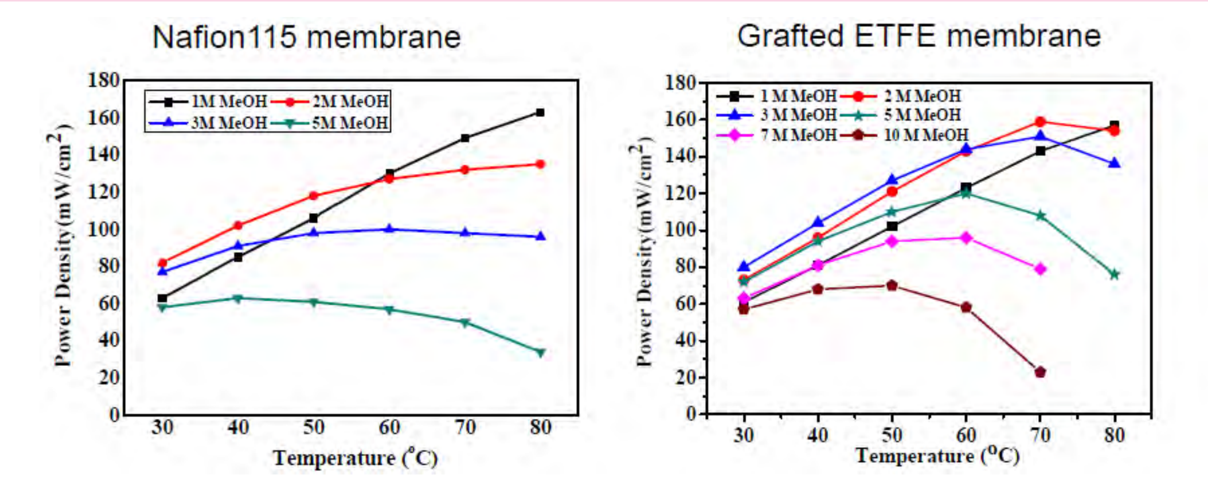


Figure 24 The temperature linked output of two fuel cells, one utilising a Nafion115 membrane and the other the grafted ETFE membrane.

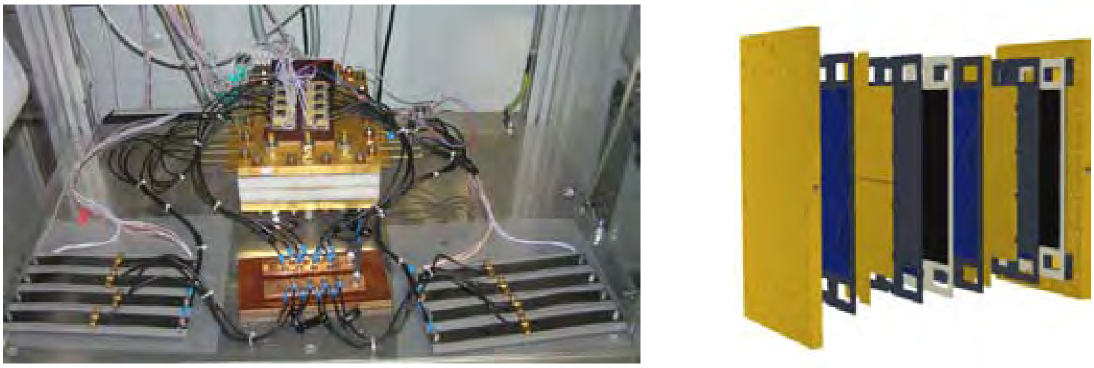


Comparing the Nafion 115 membrane, the standard membrane for DMFC application at high methanol concentration, to the grafted ETFE membrane shows that a much better performance can be achieved when using the grafted membrane material. With a grafted ETFE membrane the maximum power density that can be obtained at a methanol concentration somewhere between 2 and 3 M per litre is around three times higher than that achievable with Nafion. A further advantage is that cells that are able to achieve stable operation with high methanol concentrations, as is the case here, are well suited for operation at ambient temperatures below zero.

Work is also underway at Forschungszentrum Jülich in Germany in the area of system developments for portable fuel cells. This work has focused on validating a new current distribution diagnostics tool for fuel cell stacks. The diagnostic tool is based on highly conductive contact plates that are integrated into bipolar plates. The current passes through a bridge between neighbouring contact plates and is measured. The principle of the measurement method is that it will detect defects by measuring the equalizing current (in plane) in the cell. Ultimately it was demonstrated that this was a reliable and simple diagnostic tool that could be utilized at very low cost and was easy to integrate into fuel cell stacks. The integration of highly conductive plates also reduces the influence of bad spots on neighbouring cells and so improves the performance of stacks.

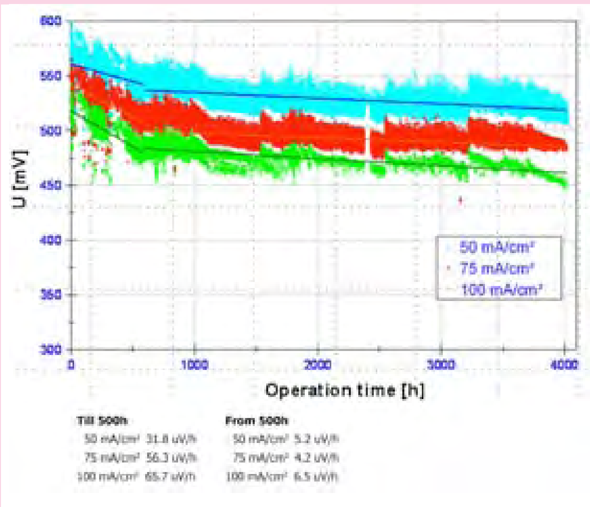
Research into the durability of MEAs has provided a number of improvements to the system including a new purification procedure for stack components, more stable commercial MEAs produced by Johnson Matthey, improved water management inside the stack and a new joining technique for the condenser element of the system that can be formed without the use of adhesives. Together these improvements allow the system to achieve considerably improved durability, a significant enhancement on the previous

Figure 25 Set up required to achieve the current distribution diagnostic tool. LHS setup in the laboratory, RHS sketch of the setup for a short stack



system. Improved durability and operating time is a key area where fuel cell stacks must demonstrate improvement to achieve cost competitiveness with other technologies such as batteries, and this work demonstrates this is being achieved.

Figure 26 Average cell voltage at different current densities depending on the operating time. The filter values of the voltage signal are recorded during operation with a realistic load profile at different current densities.



Key technology developments within portable fuel cells in 2011 include radiation grafted membranes which reduce the costs of fuel cell systems and reduce the methanol crossover, and the development of durable DMFC-hybrid-systems in the kW-power range with a degradation rate of 7 μV/h @ 0.1 A/cm² in operation with dynamic load profile. Assuming it is possible to maintain this degradation rate, operating lifetimes of more than 10,000hrs will be possible.

The German company SFC Energy (formerly SFC Smart Fuel Cell) is the leading fuel cell system provider for portable applications. In 2011 the company sold 3,371 DMFC fuel cell systems for portable applications, with the majority of these in the leisure field, e.g. power supplies for RVs, boats, etc.

Sales of portable fuel cells remained relatively flat in 2011, however significant progress was made in the application of fuel cell electronics chargers, and the review ‘Fuel Cells Today’ is anticipating significant growth in 2012, estimating a seven fold increase.[19]

[19] The Fuel Cell Today Industry Review, 2012.

4.6.3 Work Plan for Next Year

The next meeting is planned for 2012, on the 27-28th August.

It is the intention that a 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 National Representatives. The first task of this Annex would be 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. It was agreed that representatives from each of the existing Annexes be members of the new Systems Analysis Annex.

The aim is also that outputs be specific to the application they are referring to. For example the costs of PEM fuel cells for transport and for stationary applications are quite different. This Annex offers the opportunity to clearly demonstrate this and provide clear reliable evidence of the current state of technology, costs and opportunities. It is expected that the content will include the efficiency of well to wheel calculations, efficiencies of fuel cells, conversion of available data into new charts to illustrate new aspects, etc. The plan is to start by defining the work content. The experts will be asked to contribute a chapter as authors. The authors will then be participants in the Systems Analysis Annex.

This plan of action was approved by the Executive Committee at the 43rd ExCo meeting, October 2011.

The suggested breakdown of activity is:

Collect data on electro-mobility and provide data basis

The goal is to provide a data basis for various analyses in electro-mobility. Data collection will focus on fuel cells in transportation, with emphasis given to data enabling answering of the following:

- What kind of vehicles are tested as prototypes or small fleets?
- Which efficiencies are reached and which can be reached?
- What are the ranges of the fuel cell vehicles?
- How are the ranges determined?
- What kind of data is available concerning the reliability of fuel cell vehicles?
- What are the new concepts and potentials?

Benchmark data on competitive technologies which can be alternatives to fuel cells in transportation will also be given. The collected data will be openly and publicly available in the form of a technical reference book, so that the IEA Advanced Fuel Cells Implementing Agreement can act as a source of information. The collected data can be used in internal and external studies.

Collect data on stationary fuel cells and provide data basis

A separate area of focus is stationary fuel cell systems. The data collection will focus on aspects including the following:

- Electrical and total system efficiency
- Installed power for prototypes and field tests
- Available systems classified according to the power class and fuel options

- Measured emissions
- Lifetime and degradation rates.

Comparisons against alternative systems must also be considered. Additionally, key information about conventional energy conversion systems for stationary applications and other new technologies must be collected for comparison.

Competent technical and market analysis including cost analysis

The last area of focus will be to use the collected information for electro-mobility and stationary fuel cells to facilitate a competent technical and market analysis. The overall aim of the activity is to present the current status and the future potentials of fuel cells for electro-mobility and stationary applications. In addition cost estimations must be carried out to present the feasibility of introduction and wide utilisation of fuel cells in larger markets as well as niche applications.

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. The analysis efforts should end up with concrete numbers, such as addressing emissions reduction and efficiency increase. Through publication of the results, the outcome and outreach of the Implementing Agreement is enhanced.

4.7.2 Technical Accomplishments

Work on this Annex commenced in October 2011 led by the interim work stream leaders Prof. Dr. Detlef Stolten and Dr. Nancy Garland.

Achievements during 2011

During 2011 the key topics for the contents of the work were identified and refined. Considerable effort was invested in the best arrangement of such topics to allow the most successful investigation of the data, and the most useful outputs to be generated to inform those close to the world of fuel cells, and those at a greater distance who would also benefit from the higher level information such as policy makers.

4.7.3 Work Plan for Next Year

The key topics and their arrangement, essentially the Table of Contents, will be finalised, and work will begin on inviting experts as authors to contribute and join the Annex. The work will integrate advanced fuel cell research, technology and infrastructure and implementation methodology.

APPENDICES

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

Austria

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

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

Belgium

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

Canada

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

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

Denmark

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

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

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

Finland

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

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

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

Italy

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

Japan

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

Korea

Dr H-C Lim
KEPRI
103-16 Munji-dong
Yusong-ku
Taejon 305-380
Email: fclim@kepri.re.kr
Tel: (+) 82 42 865 7540

Dr T-H Lim
KIST
39-1 Hawolkog-dong
Sungbuk-ku
Seoul 136-791
Email: thlim@kist.re.kr
Tel: (+) 82 2 958 5201

Mexico

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

Sweden

Prof L Sjunnesson
E.ON (Sweden)
SE-20509 MALMO
Email: lars@sjunnesson.org
Tel: (+) 46 40 25 5600

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

Switzerland

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

Turkey

Ms. G Behmenyar
Tübitak Marmara Research Centre
Baris Mah. Doktor Zeki Acar Cad
Anibal yolu uzeri No. 1
41470 Gebze/KOCAELI
Turkey
Email: gamze.behmenyar@mam.gov.tr
Tel: (+) 90 262 677 27 20

B. Erdör Türk
Tübitak Marmara Research Centre
Baris Mah. Doktor Zeki Acar Cad
Anibal yolu uzeri No. 1
41470 Gebze/KOCAELI
Turkey
Email: betul.turk@mam.gov.tr
Tel: (+) 90 262 677 27 20

USA

Dr N 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 S D 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 X 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 T-H 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 J Kiviaho
VITO Technical Research
PO Box 1000
FIN-02044 VTT
Finland
Email: jari.kiviaho@vtt.fi
Tel: (+) 358 20 722 5298

Annex 25

Mr B Ridell
Grontmij
SE-20509
Malmo
Sweden
Email: bengt.ridell@grontmij.se
Tel: (+) 46 40 255996

Annex 26

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

Annex 27

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

Annex 28

Interim Operating Agents

Dr N 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

Prof D 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

Ms F 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: secretariat-AFCIA@aeat.co.uk
Tel: (+) 44 870 190 8226

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 (R)			
Viktor Hacker	Graz University of Technology	A	Austria
Damijan Movrin			
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			
Olivier Lemaire	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)	R	France
Sylvie Escribano			
Carston Cremers	ICT Fraunhofer	R	Germany
Werner Lehnert	Forschungszentrum Juelich GmbH		
Jürgen Mergel			
Antonella Giannini	Italian National Agency for New Technologies, Energy and Environment (ENEA)	R	Italy
Kazunari Sasaki	International Research Centre for Hydrogen Energy, Kyushu University	A	Japan
Akari Hayashi			
Akiteru Maruta	TechNova	I	

Gu-Gon Park	Korean Institute for Energy and Research (KIER)	R	Korea
Minjin Kim			
Young-Jun Sohn			
SeokHee Park			
Sang-Kyung Kim			
Ulises Cano-Castillo	The Electric Research Institute (IIE)	R	Mexico
Lars Pettersson	Royal Institute of Technology (KTH)	A	Sweden
Rakel Wreland Lindstrom			
Evren Gunen	Tübitak Marmara Research Centre Energy Institute	G	Turkey
Xiaoping Wang	Argonne National Laboratory	R	USA
Deborah Myers			
Piotr Zelenay	Los Alamos National Laboratory	R	

ANNEX 23: MOLTEN CARBONATE FUEL CELLS

Expert	Organisation	Categorisation	Country
OPERATING AGENT: TAE-HOON LIM, KIST, KOREA (R))			
Manfred M.Bischoff	MTU Aero Engines	I	Germany
B. Marcenaro	Ansaldo Energia	I	Italy
Angelo Moreno	Italian National Agency for New Technologies, Energy and Environment (ENEA)	R	Italy
Stephen McPhail	Italian National Agency for New Technologies, Energy and Environment (ENEA)	R	Italy
Viviana Cigolloti	Italian National Agency for New Technologies, Energy and Environment (ENEA)	R	Italy
Tae-Hoon Lim	Korea Institute for Science and Technology (KIST)	R	Korea
Jonghee Han	Korea Institute for Science and Technology (KIST)	R	Korea
Sung-Pil Yoon	Korea Institute for Science and Technology (KIST)	R	Korea
Hee Chun Lim	Korea Electric Power Research Institute (KEPRI)	R	Korea
Joong Hwan Jun	Research Institute of Industrial Science & Technology (RIST)	R	Korea
Hans Maru	Fuel cell Energy (FCE)	I	USA
Mohammad Farooque	Fuel cell Energy (FCE)	I	USA
Yoshiyuki Izaki	Central Research Institute of Electric Power Industry (CRIEPI)	R	Japan (Observer)
Y. Mugikura	Central Research Institute of Electric Power Industry (CRIEPI)	R	Japan (Observer)
M. Yoshikawa	Central Research Institute of Electric Power Industry (CRIEPI)	R	Japan (Observer)

ANNEX 24: SOLID OXIDE FUEL CELLS

Expert	Organisation	Categorisation	Country
OPERATING AGENT: JARI KIVALHO, VTT, FINLAND (R)			
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			
Takashi Ujiie	New Energy and Industrial Technology Development Organization (NEDO)	G	Japan
Harumi Yokokawa	National Institute of Advanced Industrial Science and Technology (AIST)	R	
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
Georg Trnka			
Julia Gsellmann			
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	
Rolf Rosenberg	VTT, Technical Research Centre of Finland	R	Finland
Matias Halinen			
Jari Kiviaho			
Timo Kivisaari	Wärtsilä	I	
Erkko Fontell			
Antoine Aslanides	EDF Group	I	France
Ludmilla Gautier			
Thierry Priem	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)	G	
Ulf Birnbaum	Forschungszentrum Julich	R	Germany
Gerhard Huppmann	MTU Aero Engines	I	

Angelo Moreno	Italian National Agency for New Technologies, Energy And Environment (ENEA)	R	Italy
Usamu Tajima	New Energy and Industrial Technology Development Organization (NEDO)	G	Japan
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: DR 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, JUELICH 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.