International Energy Agency (IEA) Technology Collaboration Programme on Advanced Fuel Cells

ANNUAL REPORT 2014

Energy Technology Network

The AFC TCP, the Technology Collaboration Programme on Advanced Fuel Cells is a Programme of Research, Development and Demonstration on Advanced Fuel Cells, and functions within a framework created by the International Energy Agency (IEA). Views, findings and publications of the AFC TCP do not necessarily represent the views or policies of the IEA Secretariat or of all its individual member countries.

This Annual Report has been prepared by the National Members, 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:

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1. Chairman's Welcome

Welcome to the Annual Report of the Technology Collaboration Programme on Advanced Fuel Cells (AFC-TCP), a technology platform of the International Energy Agency (IEA).

Having agreed to an even stricter climate target of 1.5 °C for a global warming at the COP21 in Paris there is a need for clean energy technology to be introduced into the market in the mid- and long-term.

Reducing CO_2 emissions by 80% by 2050 is a disruptive goal entailing a disruptive technology switch. This is even more true since the time-line is stricter than often perceived. Having new technologies in full operation in 2050 requires their market introduction by 2040 at the latest for a market penetration period of 10 years. If another 10 years of development are needed by industry to make products affordable and reliable, the research period for first generation products ends around 2030, less than 15 years from now. Hence, all things considered, a disruptive technology switch is on our doorsteps.

This means first generation technologies have to have a notable level of technology readiness already today. Such technologies are wind power, solar power and as a long-established one hydro power. Additionally, heat pumps, geothermal energy etc. are penetrating the market. More recently, yet very determinedly, industry enters the market with fuel cells for stationary applications, fork lifts and the like and transportation. Multiple companies world-wide offer electrolysis units in the MW range already. Hence, fuel cells and hydrogen technology is ready in time for the transformation of the energy system. As systems analyses make clear, volatile power input could only be matched by storing chemical energy for its high energy density – compared to mechanical and electrical storage – hydrogen is expected to play a major role in providing mass and long-term storage of green energy.

The Annex "Electrolysis" of this Technology Collaboration Programme is determined to contribute to providing an international pre-competitive platform for collaboration on materials, electrochemistry and design of water electrolysers for hydrogen generation, meeting the requirements of being cost-effective, long-term stable and safe.

The fuel cell annexes of this Technology Collaboration Programme are dedicated to foster the research and development of fuel cells for stationary and portable applications as well as for transportation.

This Technology Collaboration Programme provides the broadest technical platform for collaboration and information exchange on this subject. Fuel cells offer a high electrical efficiency of up to 60% already in small units. That makes them attractive for use in future energy systems. Their ability to use hydrogen as a fuel simplifies the system designs and facilitates the dynamic response of such systems. Many more aspects of fuel cells and their status can be discovered in this report, which compiles the status of fuel cells and electrolysers in the participating countries of the Technology Collaboration Programme on Advanced Fuel Cells.

I hope you enjoy reading this report and I wish it may inspire readers from non-member countries to join this Technology Collaboration Programme.

Prof Dr Detlef Stolten
Chairman of the Technology Collaboration Programme on Advanced Fuel Cells

Professor Stolten is Director of the Institute for Energy and Climate Research – Electrochemical Process Engineering at Research Centre Julich, Germany. His research focus is on electrochemistry, chemical engineering and systems analysis for DMFC, HT-PEFC and SOFC technology.

2. Introduction

The aim of the Technology Collaboration Programme on Advanced Fuel Cells is to contribute to the research, development and demonstration (RD&D) of fuel cell technologies. It also disseminates information on fuel cell technologies to all its member countries and organisations.

The international collaboration that we create in the AFC TCP aids RD&D efforts by directly sharing information and new developments, focusing on the key areas important to member countries, companies and research institutions. The collaboration between countries facilitates the creation of demonstration programmes, and identifies the barriers for market introduction of fuel cell applications and works to lower them.

The AFC TCP is in a unique position to provide an overview of the status of fuel cell technology and deployment in its member countries, and the opportunities and barriers they face. Our focus is to work together to improve and advance fuel cell technology.

Key messages – facts

Technology Collaboration Programme on Advanced Fuel Cells

- Solid state storage for low pressure hydrogen systems is available on the market.
- The latest data from the US show that the fuel efficiency of fuel cell buses can be twice that of diesel or compressed natural gas (CNG) buses.
- Electrochemical production of hydrogen by water electrolysis is a well-established technological process worldwide. If water electrolysis technology is to be widely and sustainably used on the mass market for the storage of renewable energy, further steps must be taken to solve outstanding technical issues (such as low power densities and inadequate stability), and the high manufacturing and operating costs associated with the technologies in use.
- Catalysts – platinum alloys have higher performance and durability than straight platinum, producing very high performing materials.
- Catalysts – core shell catalysts are a rapidly developing area and the first such example has been licensed to a Japanese company.
- The technology for fuel cell electric vehicles is ready for market introduction. Hydrogen infrastructure remains an obstacle, but developments are addressing this. Two car manufactures already have semi-automated production of fuel cell vehicles.
- Materials-based hydrogen storage has proved to be very challenging to achieve.

Key Messages – observations

Technology Collaboration Programme on Advanced Fuel Cells

- The technical challenges for near-term development are improved stack performance, scale-up to megawatt size, grid integration and high-pressure operation. Stack performance needs include improved membranes and catalysts. Megawatt scale-up needs include reducing capital costs by 50% on a per kilowatt basis. Improving the durability of cell materials, including a better understanding of degradation mechanisms, is important.
- Future solutions for transportation will very likely encompass a notable share of fuel cell vehicles because of their high efficiency, high cruising range, and the option to easily and rapidly refuel.
- New cell design and alternative fuel/oxidant technologies play an important role in portable and light traction systems. Also, liquid and solid media for hydrogen and oxygen storage may have a role in the stealth capability of military applications.

- Portable fuel cells will have an impact on military applications because they are suitable for portable handheld power devices, auxiliary power units (APU) and aerial/underwater unmanned vehicles (AUV/UUV). The market for portable fuel cell devices could also benefit from improvements coming from military applications.
- Fuel cells have achieved significant ramp-up of unit production and deployment over the last few years. What is needed now is the market, visibility and policy support. Policy support can be technology neutral, but it is needed.

2.1 THE INTERNATIONAL ENERGY AGENCY

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

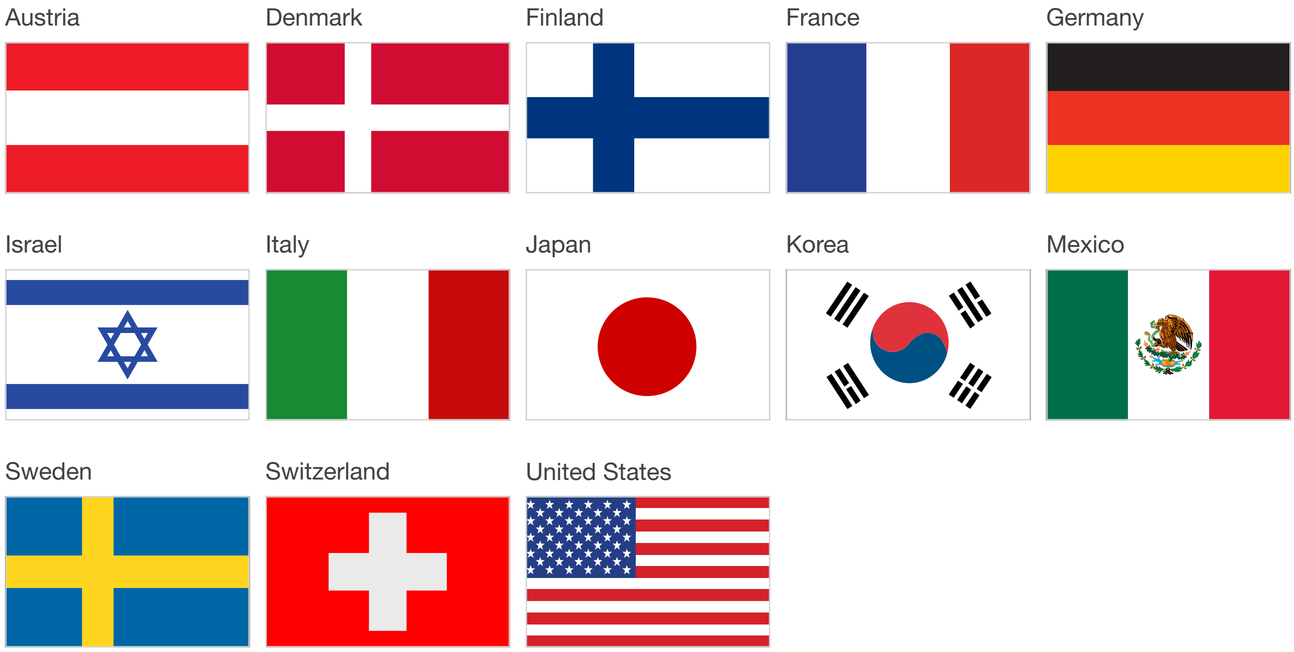
- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global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

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

The multilateral technology initiatives (Technology Collaboration Programmes) supported by the IEA are a flexible and effective framework for IEA member and non-member countries, businesses, industries, international organisations and non-governmental 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 39 Technology Collaboration Programmes (TCP) working in the areas of:

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



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

2.2 THE TECHNOLOGY COLLABORATION PROGRAMME ON ADVANCED FUEL CELLS

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

The current period of the AFC TCP is February 2014 to February 2019. The AFC TCP was awarded a new period by CERT, via the IEA Working Party on End-Use Technologies (EUWP), which commenced in 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 2014.

The scope of the AFC TCP Programme for 2014 to 2019 is shown in Table 1.1.

Table 2.1: Scope of the AFC TCP from 2014 to 2019

Information management	Implementation and application issues	Technology development Applications: Stationary, mobile, portable
Using internal and external networks	**Working to reduce barriers**	**Technologies: Electrolysis, SOFC, PEFC**
Co-ordination within the Technology Collaboration Programme Co-ordination with other Technology Collaboration Programmes 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 • Database Fuel processing Power conditioning Safety analysis

2.3 NATIONAL OVERVIEWS

In this section, we provide a summary of each member country's position with regard to fuel cells in 2014, which is often related to their national priorities within the energy arena. At the end of each country profile, there is a table summarising the developments and state of play of fuel cell technologies within the country.

2.3.1 Austria

The major energy policy goals of Austria are to stabilise energy consumption at 1,050 PJ by 2020 and to reduce greenhouse gas (GHG) emissions by 16% (base year: 2005) by 2020. Renewable energy in Austria contributes 32.5% to the energy mix and by 2020 this figure should be 34%. The R&D programmes strategically cover fuel cell topics to support the development of innovative companies in this field. In 2014, EUR 8 million was spent on national fuel cell and hydrogen projects.

Fuel cell projects in the mobility sector are focused on competitiveness, and solutions to modernise and 'green' the transport system. In total, about 500 projects with public funding of EUR 118 million have been supported over the last few years. The new programme, 'Mobility of the Future (2012–2020)', provides an annual budget of approximately EUR 15 million for R&D in the whole transport sector.

During 2014/15, a major demonstration programme including between 20 and 30 micro combined heat and power (micro-CHP) fuel cell systems in Austria is taking place. It is under negotiation between the Austrian utility companies, manufacturers and ministries. In total, 10 units have been installed.

Table 2.2: Summary of Austrian fuel cell information

Description	Number of units	Details, comments and companies involved
Domestic stationary units[2]:	10	Up to 30 systems (micro-CHP) are planned in Austria as part of the ene.field demonstration project. There are 10 units. Vaillant, Viessmann and Bosch are involved
Operational fuel cell vehicles in 2014	3	Hydrogen passenger cars, type: Hyundai ix35
Operational refuelling stations	3	The three operational hydrogen refuelling (HRS) stations are in Vienna, Innsbruck and Graz

2.3.2 Denmark

The Danish Government's long-term goal for the country's energy policy is to be independent of fossil fuels by the year 2050.

The green transition of the energy system has accelerated over the past years and the share of renewable energy in the Danish energy system has been increased significantly. In 2014, wind power contributed 39.1% to the total electricity consumption in Denmark. The wind power output fluctuates with the wind conditions and as wind's share of electricity generation increases further, the demand for solutions to convert and store energy to balance the power system increases.

It is envisaged that hydrogen and fuel cell technologies will be a part of the future green energy system with a high proportion of renewable energy. Danish energy technology programmes support the development of new hydrogen and fuel cell technologies for a variety of applications.

In 2014, the Danish programmes granted public support for 16 RD&D projects in the field of hydrogen and fuel cells. The projects cover many different applications including transport, hydrogen refuelling stations, electrolysis, back-up power and continuous power generation. Research for new and better materials was also supported. The total budget for the supported projects amounted to EUR 32.8 million of which EUR 20 million is public support.

Table 2.3: Summary of Danish fuel cell information

Description	Number of units	Details, comments andcompanies involved
Capacity of installed and operational units	1 MW	Danish companies have installed an additional 2.4 MW of capacity abroad
Domestic stationary units	302	Danish companies have installed an additional 811 units abroad
New for 2014	30 units	Danish companies have installed an additional 104 units abroad
Operational fuel cell vehicles	42	An additional 12 Danish vehicles are abroad Additionally, Hyundai is operating ix 35 hydrogen fuell cell cars in Denmark
Operational refuelling stations	Seven hydrogen and one methanol refuelling stations	Danish companies have installed an additional eight HRS abroad

[2] Status August 2015

2.3.3 Finland

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

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

- The first commercial applications of fuel cell back-up power for telecommunications base stations and portable back-up power.
- Finland's first commercial HRS.
- Significant advances in CHP based on solid oxide fuel cells (SOFC). The first 20 kWe unit was demonstrated for more than 9,000 hours in Vaasa using landfill gas.
- Finnish SOFC research is now recognised as state of the art worldwide.

Companies from industries such as energy, metals, electronics, chemicals, mechanical engineering and many others have worked together in thematic workshops and helped to form value proposition analyses for fuel cells.

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

In January 2013, Wärtsilä's fuel cell development activities were taken over by Convion Ltd. Convion is committed to commercialising fuel cell systems with power outputs of over 50 kW. By using Convion products, customers can improve their energy efficiency, power security and energy independence. Since 2000, Convion has developed and operated several generations of 20 kWe and 50 kWe SOFC systems. The first highly efficient product in Finland will be operated from February 2015, and first customer deliveries of the new C50 product will be made in 2016.

Figure 1: 50 kWe system from Convion Ltd.

Elcogen Oy opened the first pilot production line for its E1000 (1 kWe) and E3000 (3 kWe) stacks in Finland in 2014. Elcogen E1000 is optimised for micro-CHP applications with easy connection interfaces and Elcogen E3000 (see Figure 2) is optimised for larger CHP applications with high-level integration possibilities. Elcogen stacks have superior performance already at 600°C. Elcogen has been providing both stack types to fuel cell system integrators for evaluation purposes.

Figure 2: Elcogen E3000 stack

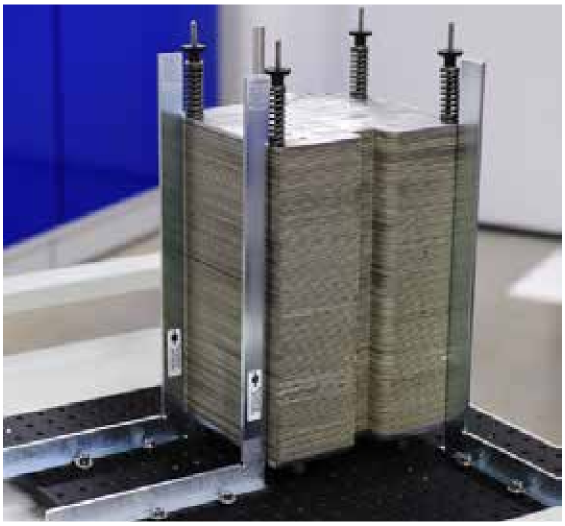


Table 2.4: Summary of Finnish fuel cell information

Description	Number of units	Details, comments and companies involved
Capacity of installed and operational units	20 kWe	Convion Ltd
Domestic stationary units	1	
New for 2014	1	
Operational fuel cell vehicles	1 car	Hyundai
Operational refuelling stations	3 hydrogen	Woikoski Ltd

2.3.4 France

France started to implement the Energy Transition Law with the following main objectives:

- Reduce GHG emissions by 40% between 1990 and 2030.
- Reduce final energy consumption by 50% by 2050 compared with 2012 base year.
- Reduce fossil fuel consumption by 30% by 2030 compared with 2012 base year.
- Increase the level of renewable energy in the overall energy mix to 23% by 2020 and to 32% by 2030.
- Reduce the nuclear part of electricity production from 75% to 50% by 2025.
- Strengthen energy efficiency standards for buildings.

Hydrogen is considered an alternative fuel and is seen to be a solution for storing renewable energy (in particular through power to gas). The Energy Transition Bill has been adopted by the French Parliament in October 2014 and passed to the Senate for approval. The final vote is expected by mid 2015.

Investment Programme (PIA)

In 2009, France launched a EUR 35 billion investment programme to fund projects that were concerned with preparing for the future. Many of these were energy-related. Owing to the success of the initial investment, a new phase worth EUR 12 billion was agreed in 2013 for investment between 2014 and 2024.

New French Industry (NFI)

34 plans have been developed to renew French industry, of which seven concern mobility, along with a ministerial initiative on energy storage. The proposed roadmaps were validated on July 9, 2014 in presence of the French President. Hydrogen and fuel cells are part of the Energy Storage Plan. The Renault HyKangoo has since been presented to the President at the Palais de l'Elysée. Sustainable transport and mobility was also the subject of one of three round tables at an environmental conference at the Palais de l'Elysée in November 2014.

Energy Storage Plan

Initially dedicated to energy storage in batteries, it has now been agreed that the Energy Storage Plan should include hydrogen technology. The Plan is coordinated by Mrs Florence Lambert, CEO of CEA Liten and is supported by many French companies (Air Liquide, AREVA SE, Bolloré, Forsee Power, McPHY Energy, Michelin, Prollion, SAFT, SOLVAY RHODIA, Zodiac AEROSPACE, Arkema, Alstom, BIC, DCNS, EADS, EDF, E4V, GDF-Suez, Pellenc, Renault, Symbio FCell, Total, Venturi, GRT-Gaz, Dassault Aviation, Atawey) and academic and public actors (RS2E, CNRS, CEA, MERPN, MEDDE, CGI). The proposed actions concerning hydrogen include:

- Developing a competitive stack production.
- Developing high pressure storage.
- Defining a business model for infrastructure deployment.
- Developing a power-to-gas demonstration.

Parliamentary reports

Two parliamentary reports considering hydrogen as part of energy transition and sustainable mobility were published in 2014.

- Hydrogen: the engine of energy transition?
- The new serene and sustainable mobilities: design and use ecological vehicles.

H2 Mobilité France

A coalition of public and private organisations formed with the intention of developing a National Implementation Plan for a rollout of hydrogen mobility in France. The Plan was released in mid 2014. The use of hydrogen in transport can deliver significant economic and societal benefits to France, including increased domestic energy production, reduced carbon dioxide (CO_2) emissions and improved local air quality. The H2 Mobilité France coalition aims to build on existing regional activities in France to develop a flexible and phased hydrogen mobility deployment strategy, which will ensure manageable risks and sizes of investment at each stage in the rollout. By beginning in regional clusters based on pilot regions with a transition to national coverage, the approach allows a rollout that is synchronised with the rate of technology development. H2 Mobilité France is part of the Hydrogen Infrastructure for Transport project that seeks to link hydrogen launch markets across Europe.

The first stage of H2 Mobilité France is based on optimising hydrogen vehicle and refuelling station technology to reduce investment costs, while deploying vehicles in sufficient numbers to allow high throughput refuelling stations. More specifically:

- Using range-extended battery vehicles that have over 50% lower capital cost than full fuel cell vehicles in the early years, before affordable mass-market fuel cell drivetrains are produced in their 10,000s by global car makers.
- Targeting sales of fleets of hydrogen vehicles into captive fleets in specific locations – which ensures infrastructure is well loaded by predictable back-to-base users.
- Using lower pressure tanks (35 MPa) – which reduces the cost of the vehicle drivetrain, and the hydrogen fuelling and logistics systems compared with the 70 MPa systems being promoted by global car makers.

Cost analysis of hydrogen production techniques suggests a mixture of water electrolysers, existing industrial by-product and steam methane reforming can provide a cost-effective and low CO_2 production mix in the early years. Water electrolysers are expected to have an increasing share of hydrogen production (75% by

2030), due to very low well-to-wheel emissions, and their wider benefits such as providing services to the electricity grid, supporting renewables, etc.

Table 2.5: Summary of French fuel cell information

Description	Number of units	Details
Domestic stationary units	8	Baxi, Panasonic, Viessmann
Other stationary units (large scale)	1 (100 kW): hydrogen and fuel cell system coupled with a photovoltaic plant for peak shaving on electric grid	Myrte Project (Corsica) led by AREVA SE
Operational fuel cell vehicles	MobiPost (five units): 1 kW fuel cell system	La Poste
	HyKangoo (10 units): 5 kW range extender system	SymbioFCell, Renault, La Poste
	GreenGT H2 (one unit): 300 kW fuel cell racing	GreenGT, SymbioFCell
	Fork-lift fleet testing (nine units) on Air Liquide plants and on IKEA plant	Hypulsion (GV Axane/Plugpower)
	Hyundai ix35 (two units)	Air Liquide
	Sail boat 'Zero CO_2': 35 kW polymer electrolyte fuel cell (PEFC) system	CEA
	Passenger boat MOST'H: 12 kW PEFC system	Saint Nazaire
	Alterbike	Cycleurope, Pragma Industries, Ventec
Portable units	Fuel Cell PACRETE 1 W and 3 W, Planar Fuel Cell 3 W and 10 W, Fuel cell powered speleology helmet	Paxitech
Operational hydrogen refuelling stations	Six (Albi, Audincourt, Grenoble, Paris, Sassenage and Tavaux)	Air Liquide, AJC, EDF, Haskel

2.3.5 Germany

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

The focus is large-scale demonstration projects and R&D projects. Specific programme areas within NIP are:

- Transport including hydrogen infrastructure.
- Hydrogen production.
- Household energy supply.
- Industrial applications.
- Special markets for fuel cells.
- Cross-cutting themes.

As of December 2014, the funding for demonstration projects (Federal Ministry of Transport and Digital Infrastructure (BMVI)) amounted to EUR 409 million (EUR 850 million budget in total) and for R&D projects (Federal Ministry for Economic Affairs and Energy (BMWi)) EUR 132 million (EUR 247 million budget in total)[2].

[2] NOW Annual Report 2014.

The VDMA Fuel Cell Business Survey reported that a ‘still-moderate’ EUR 70 million in revenue was generated by German fuel cell industry in 2014 from commercially available fuel-cell heaters and power supply facilities. A growth of 80% is predicted for 2015[3].

Table 2.6: Summary of German fuel cell Information[4]

Description	Number of units	Details
Capacity of installed and operational units	2.35 MW[5]	
Domestic stationary units	1,000[6]	500 units in Callux project[5]
Operational fuel cell vehicles	111 cars and 10 buses	Clean Energy Partnership (CEP) fleet[7]: Cars: 80 Daimler, 3 Ford, 2 Honda, 13 Hyundai, 5 Toyota, 8 Volkswagen and Audi. 30 additional GM/Opel cars until the end of 2014 Buses: 8 Mercedes Benz, 2 Solaris
Portable units	Special markets: 5,400 systems produced in 2013[5]	
Operational hydrogen refuelling stations	18 public refuelling stations under CEP[8]	

The VDMA Fuel Cell Business Survey reported that a ‘still-moderate’ EUR 70 million in revenue was generated by German fuel cell industry in 2014 from commercially available fuel-cell heaters and power supply facilities. A growth of 80% is predicted for 2015[3].

2.3.6 Israel

The development of fuel cells and hydrogen technologies in Israel is driven by private companies, academic research and the Government – individually and in collaboration. Since 2010, the Government has been conducting a national programme to establish Israel as a centre of knowledge and industry in the field of fuel alternatives for transportation, with fuel cells promoted as a viable option.

There are fuel cell research groups in seven universities, and several highly advanced industrial fuel cell enterprises conducting RD&D programmes. The programmes span a broad range of applications, including stationary and automotive, that are based on SOFC and alkaline fuel cell (AFC) technologies, and use methanol, hydrogen and other alternatives as the fuel.

RD&D programmes support the development of fuel cells and their applications, including the Transportation Electric Power Solutions (TEPS) group that started in 2011 as a unique collaboration between industry, academia and Government, and aimed to promote advanced fuel cell technologies and solutions. The Government supports innovative research in this area, invests in and encourages private companies, supports national infrastructure, and supports international cooperation and collaboration. In

[3] VDMA Fuel Cells Working Group Business Survey 2015.
[4] This information was correct as of April 2015.
[5] Information from VDMA Fuel Cells Association, Konjunkturspiegel für die Brennstoffzellen-Industrie 2013.
[6] Press release from Callux, http://www.callux.net/pm_2015-04-07.html
[7] Presentation from T. Brachmann, Clean Energy Partnership Arbeitsgruppe Mobilität, NIP Vollversammlung und Statusseminar Brennstoffzelle 2015; and http://cleanenergypartnership.de/h2-mobilitaet/cep-fahrzeugflotte/ Accessed on 21.09.2015.
[8] Information from Clean Energy Partnership, http://cleanenergypartnership.de/en/faq/hydrogen-infrastructure/?scroll=true as of July 2015.

2014, total Governmental support to these programmes was about USD 10 million.

2.3.7 Italy

2014 marked the beginning of the Italian initiative to create a National Platform for hydrogen and fuel cell technologies, with the example of the European FCH JU in mind. This Platform is intended to represent and voice the interests of the considerable – though fragmented over many small players – share of resources specialised in and dedicated to the development and deployment of hydrogen and fuel cell technologies in Italy.

After the first edition of the Italian General State of Play held in December 2013, a task force took shape that set up a large questionnaire that was sent to all 190 players – large, small, academic and industrial – in the italian field of hydrogen and fuel cell technologies. The input was gathered throughout 2014 and is being elaborated for presentation at the National Day in 2015. From the responses to the questionnaire, an inventory of activities, competences, running projects and active personnel in the area was created. With this information, the Platform aims to make an impact at the political level and to harness and support a structural policy in terms of hydrogen and fuel cell deployment in the country.

With the third largest number of funded beneficiaries in the European FCH JU programme, Italy remains at the forefront of RD&D of fuel cell technology. A vast network of universities and research institutes covers the full spectrum of applications.

In terms of industry, the main players continue to be SOFCpower (now SOLIDpower, producing stationary micro-CHP systems based on proprietary SOFC technology) and ElectroPower Systems (off-grid power solutions based on proprietary PEFC technology). Other original equipment manufacturers (OEMs) include Dolomitech (group transport applications based on automotive PEFC) and Genport (portable fuel cell powered devices). Companies pursuing development activities are Saremar (on-board power for naval applications), ICI Caldaie (large residential-scale CHP with PEFC technology).

Table 2.7: Summary of Italian fuel cell information

Description	Number of units	Details, comments and companies involved
Capacity of installed and operational units	More than 1 MW, over 500 systems	Installation of first large-scale systems (400 kW) under negotiation
Domestic stationary units	75	A further 85 are being installed
New for 2014	20 units	
Other stationary units (large scale)	350	Remote systems for telecom repeater stations, EPS
Operational fuel cell vehicles	30	Milano and Bolzano (25 Hyundai ix35 purchased for leasing)
Portable units	20	
Operational hydrogen refuelling stations	11	The active stations are in Bolzano and Milan: a station in Rome is planned.

2.3.8 Japan

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

Commercialisation of the ENE FARM micro-CHP residential fuel cell products has been particularly successful. The first of these products was launched in early 2009, and the total number of installed systems was over 113,000 by the end of 2014. A further subsidy round for ENE FARM was announced in December 2014 with JPY 20 billion (USD 170 million, EUR 150 million) made available for 36,243 units. This funding will provide a subsidy of JPY 0.38 million for each polymer electrolyte fuel cell (PEFC) unit (USD 3,200, EUR 2,800) and JPY 0.43 million for each SOFC unit (USD 3,600, EUR 3,200), respectively. A new system has been added to the ENE-FARM range of products that continues to generate and supply power for households even if there is a general blackout. Almost all ENE-FARM types have this function, which has a very good reputation among consumers.

The Strategic Road Map for Hydrogen and Fuel Cells published in 2014 by the Japanese Ministry of Economy, Trade and Industry says 'The key for prevailing the system is to shorten the time to payback for end users: we aim to cut the period down to 7-8 years by 2020 and even 5 years by 2030'. Therefore, not only cutting costs but also reducing time to payback is important.'

The Road Map also stated that fuel cells for commercial and industrial use would be released onto the market in 2017 as one of the processes of expanding the use of fuel cell technology – and conveying to the world the information on the potential of hydrogen by taking advantage of the 2020 Summer Olympic Games in Tokyo.

A number of Japanese car manufacturers are developing fuel cell systems for transport. Toyota Motor Corporation launched the 'Mirai' hydrogen fuel cell electric vehicle (FCEV) in Japan on 15 December 2014. Honda Motor Corporation will launch an FCEV in 2016 and Nissan Motor Corporation in 2017.

It is important for the number of hydrogen refuelling stations to increase. In 2011, 10 Japanese energy suppliers and three vehicle manufacturers made a joint statement committing to having 100 hydrogen refuelling stations available in 2015, which will be situated in four main urban areas, to coincide with the market introduction of the FCEVs from Toyota, Honda and Nissan. The key issue for FCEVs, to enable full commercialisation between 2025 and 2030, remains cost reduction of the fuel cell system itself. By the end of 2014, there were 62 FCEVs, 5 fuel cell buses and 17 hydrogen refuelling stations.

Table 2.8: Summary of Japanese fuel cell information

Description	Number of units	Details, comments and companies involved
Capacity of installed and operational units	Approximately 80 MW[9] 1.6 MW 1.8 MW	ENE FARM at the end of 2014 Phosphoric acid fuel cell (PAFC) technology (estimation) SOFC technology
Domestic stationary units	113,684	ENE FARM as end of 2014
New for 2014	36,943 units	ENE FARM as only 2014
Other stationary units (large scale)	Approximately 20 4	PAFC technology, 100 kW those shipped in 2014 only SOFC technology
Operational fuel cell vehicles	62 cars and 5 buses	
Operational hydrogen refuelling stations	17	

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

2.3.9 Korea

The national programme of fuel cells in Korea is driven mainly by the Ministry of Trade, Industry & Energy (MOTIE), which works for the commercial adoption of fuel cells as a strategic technology for future hydrogen infrastructure, and promotes innovative technology that will reduce the price and enhance performance and durability of fuel cells. The national RD&D programmes focus mainly on the development of technologies for power generation (molten carbonate fuel cell (MCFC) and SOFC), fuel cell vehicles (PEFC) and bulidings (PEFC) applications.

Since 2012 when the Renewable Portfolio Standard (RPS) was introduced, the number of large-scale (over 300 kW) stationary fuel cells has increased rapidly – stationary fuel cells (mostly MCFC and PAFC) with an installed capacity of 160 MW are operating at 29 sites in Korea.

POSCO Energy which is a strategic partner of FuelCell Energy in the USA, announced that it was starting to manufacture MCFC components, stacks and systems in Korea. The manufacturing facility is under construction in Pohang and will begin producing MCFC cell components in late 2015.

Doosan Fuel Cell merged with Fuel Cell Power, which is a manufacturer of PEFC for residential and building application. Also, it announced it was buying US-based ClearEdge Power, a fuel cell manufacturer for buildings. Doosan Fuel Cell will produce PAFC as well as PEFC for stationary use.

By the end of the second phase of the fuel cell vehicle demonstration programme, over 100 fuel cell vehicles had been operating and provided data on durability, operational cost and effect on the environment. Hyundai Motors has installed a production facility at Ulsan, Korea capable of producing 1,000 ix35 fuel cell vehicles a year.

There are 18 hydrogen fuelling stations installed in Korea. The Government plans to increase this number and willl announce the new installation target in late 2015.

Table 2.9: Summary of Korean fuel cell information

Description	Number of units	Details, comments and companies involved
Capacity of installed and operational units	MCFC: 149.2 MW PAFC: 15 MW PEFC: 1.064 MW	MCFC: 100 kW, 300 kW, 1.2 MW, 2.4 MW POSCO Energy Products PAFC: 400 kW Doosan (ClearEdge) Products PEFC: 1 kW, 5 kW Doosan (Fuel Cell Power), S-Fuel Cell Products
Domestic stationary units	948	2006–2014 – 1 kW and 5 kW residential and building use
New for 2014	132 1 kW and 5 kW units	
Other stationary units (large scale)	MCFC: 23 sites PAFC: 6 sites	
New for 2014	46.2 MW	MCFC and PAFC
Operational fuel cell vehicles	125 passenger cars 5 passenger cars commercially sold in 2014	Sport utility vehicle (SUV) equipped with 100 kW stack, 70 MPa (700 bar) Tank (6 kg hydrogen)
Portable units		
Operational hydrogen refuelling stations	18 stations (7 in operation, 1 under construction)	

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

2.3.10 Mexico

In the last 2-3 years, there has been an increased interest from the Government and private sector on electrically powered transportation in Mexico. Such interest has explored, at least in technical studies and feasibility analysis, the possibilities for hydrogen fuel cell technology as a component in electrical traction systems, including public and utility transportation. Fuel cells have been considered through some studies as either the source of electrical power or in combination with electrical energy storage (battery) technologies to reduce costs and improve performance. Also, an autonomous transport system has been considered to bring potential benefits of fuel cell technology as a range extender for a battery-based system. Recently, the National Mexican Science and Technology Council (Conacyt) approved projects on this subject including installing infrastructure to test and develop power plants for such applications and a soon-to-be-revealed utility vehicle based on the Instituto de Investigaciones Eléctricas (IIE) PEFC technology. These projects also include the development of bespoke power electronics for the fuel cell power plant and battery bank, and a specifically designed and built vehicle platform.

There has also been interest from private companies and research institutions on fuel cells to increase the endurance performance in applications such as unmanned aerial vehicles (UAVs). Some projects have been submitted to CONACyT seeking funding as the markets for these (such as security, surveillance and mapping) are very attractive and numerous.

Particular concerns exist that relate to fuel infrastructure challenges that transportation applications will face if fuel cells are integrated in the technology portfolio of that sector. Costs of hydrogen refuelling stations and on-board storage options are at the centre of discussions and are recognised as highly relevant issues that may limit implementing real-world projects. Despite this, two companies are interested in hydrogen refuelling stations, particularly dispatch electronic control and hydrogen generation, due to their experience in related sectors.

On the other hand, RD&D activities continue to focus on alternative membranes and catalysts, which are central to many academic institutions, while fewer engineering projects have been realised.

The Electricity Federal Commission (formerly the only utility company in Mexico) has been considering developing recharging stations in urban areas for battery-electric private cars, which are seen as contenders to fuel cell vehicles.

Table 2.10: Summary of Mexican fuel cell information

Description	Number of units	Details, comments and companies involved
Domestic stationary units	Capacity of installed and operational units 0.2 MW[10]	Ballard, IdaTech (originally) and Horizon
New for 2014	10 kW	It is estimated that an additional 10 kW of capacity was acquired through R&D projects
Operational fuel cell vehicles		One utility vehicle prototype developed by R&D consortium[11] One small demonstration car with a PEFC as a battery charger[12] At least two academic institutions have converted small cart-type vehicles to operate with PEFC

[10] Considering that Ballard units come in 2.5 kW and 5 kW, installed capacity might be greater, as it has been reported that 114 units of Ballard's ElectraGenTM-ME have been installed in Mexico. Other units originally from IdaTech and commercialised by Microm may change this number. It is unknown if the user Telecomm company is still relying on PEMFC systems after some years in operation.

[11] Technical Consortium includes IIE, CIMA-ITESM, IPICYT, CENIDET and UASLP.

[12] Integrated by CINVESTAV, an academic institution.

Description	Number of units	Details, comments and companies involved
Portable units	Approximately 50 kW	Several low power (0.5 kW to 2 kW) (PEFC) are on test in different R&D organisations
Operational hydrogen refuelling stations		One for a small fleet in the tourist sector has been proposed and expects funding.

2.3.11 Sweden

Sweden has set ambitious energy goals to combat climate change, improve energy security and strengthen competitiveness. By 2020, Sweden shall have:

- A share of at least 50% renewable energy in gross final consumption and 10% renewable energy in the transport sector.
- A 20% reduction in energy intensity (2008 base year).
- A 40% reduction in GHG emissions (2008 base year).

Looking further ahead, Sweden has set a target for a fossil fuel-independent vehicle fleet by 2030 as a step of the way towards zero net GHG emissions by 2050. To reach these goals, research and development in clean energy technologies must be prioritised. Fuel cells have the possibility to contribute to these goals.

The hydrogen and fuel cell activities in Sweden are driven from the bottom-up – by industry, academic research and experts. The aim of the Swedish Government is to observe the market and to support industry and universities with national activities. In 2009, the Swedish Government initiated a vehicle research programme called Fordonstrategisk Forskning och Innovation (FFI) – Strategic Vehicle Research and Innovation. FFI is a major partnership between the Government and the automotive industry, which includes joint funding of research, innovation and development concentrating on climate, environment and safety in the automotive industry. The fuel cell research activities in FFI have focused on PEFC and SOFC (about EUR 600,000 per year). The Swedish Energy Agency (SEA) also finances participation in fuel cells and hydrogen-related International Energy Agency (IEA) and EU activities (about EUR 80,000 per year). At the start of 2014, the SEA also launched a project to cover the international business development for fuel cell transport applications (about 100,000 per year). Overall, the Government spends around EUR 2 million yearly on fuel cell and hydrogen projects in Sweden.

National stakeholders have been developing a plan for hydrogen infrastructure development in Sweden between 2014 and 2020 as part of the EU-financed project HIT-Hydrogen Infrastructure for Transport, National Implementation Plan Sweden (NIP-SE).

Table 2.11: Summary of Swedish fuel cell information

Description	Number of units	Details, comments and companies involved
Capacity of installed and operational units	Less than 1 MW	Some back-up power units are installed most for test or demonstrations
Domestic stationary units	Fewer than 10	A few PEFC units running but not really as residential fuel cells
New for 2014	One single test unit	
Other stationary units (large scale)	There are not yet any large fuel cells installed in Sweden	

Description	Number of units	Details, comments and companies involved
Operational fuel cell vehicles	Four Hyundai fuel cell cars are based in Malmö	Two of the Hyundai cars are part of the EU Next Move project. The Skåne region is sharing the project with the City of Copenhagen. Another car is operated by the city of Malmö and the fourth is owned and operated by Hyundai in Sweden
Portable units	myFC Powertrekk, with PEFC technology. A portable charger for mobile phones, GPS or similar USB connected units. A new portable charger, JAQ was announced for introduction in the autumn of 2015. It will be smaller and easier to operate.	myFC a Swedish company has commercialised the Powertrekk unit. It is now fully commercialised and sold at major home electronics stores and at several major online shops.
Operational hydrogen refuelling stations	In 2014, Sweden had two operational hydrogen refuelling stations in the city of Malmö and one new 70 MPa (700 bar) moveable station that is placed there temporarily as part of the NextMove project. The hydrogen refuelling station from 2003 has been tested and found to be serviceable. It can deliver hydrogen at up to 35 MPa (350 bar) One movable hydrogen refuelling station is in the Arjeplog vehicle test centre in the far north of Sweden. This station is used for wirnter testing of FCVs Two more Hydrogen refuelling stations are decided and the will be inaugurated during the autumn of 2015. One of the them will be placed at the the Stockholm – Arlanda Internatinal airport. The other one I Gohenburg in connection to that PowerCell HQ.	

2.3.12 Switzerland

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

Table 2.12: Summary of Swiss fuel cell information

Description	Number of units	Details, comments and companies involved
Capacity of installed and operational units	0.26 MW	1 240 kW MCFC plant, a few domestic SOFC systems (1 kW to 3 kW) and a few 1 kW to 2 kW systems for uninterruptable power supplies (UPS) (telecommunications)
Domestic stationary units	Approximately 15	Some are not in the field, but with the developers (Hexis)
Other stationary units (large scale)	Approximately 10	One large MCFC plant, the others are small units for UPS
Operational fuel cell vehicles	Five buses and five other vehicles	Five buses from Daimler on regular services, and a few other pilot and demonstration vehicles (municipal vehicle Hy.muve, and a few passenger cars)
Portable units	13	Swiss railway minibars powered by PEFC-system
Operational hydrogen refuelling stations	3 (plus 2 at the planning stage)	Non-public, 30 MPa (300 bar) (one larger for five buses, two smaller on industrial sites)

2.3.13 United States

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

The mission of the Fuel Cell Technologies Office is to enable the widespread commercialisation of a portfolio of hydrogen and fuel cell technologies through applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges. The appropriation for FY13 was USD 97,984,000 and for FY14 was USD 92,928,000. Following are the key targets that many other countries also reference.

Fuel cells:

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

Hydrogen storage:

- By 2017, develop and verify on-board hydrogen storage systems with specific energy of 1.8 kWh/kg (5.5 wt% hydrogen) and energy density of 1.3 kWh/litre (0.040 kg hydrogen/litre) at a cost of USD 10/kWh (USD 333/kg hydrogen stored).
- Enable an ultimate full-fleet target of 2.5 kWh/kg system (7.5 wt% hydrogen) and 2.3 kWh/litre (0.070 kg hydrogen/litre) at a cost of USD 8/kWh (USD 266/kg hydrogen stored) for on-board automotive hydrogen storage.

A number of key accomplishments were identified in 2014.

Vehicles/buses

- Hyundai started to accept leasing applications for its 2015 Tucson FCEV (known as the Hyundai ix35 outside of the US) at three select Southern California Hyundai dealers. Hyundai recorded the first US lease of the Tucson FCEV in June, to a family in Tustin, California.
- Argonne National Laboratory and Lawrence Berkeley National Laboratory reported the development of a new catalyst structure called a nanoframe that offers the potential for an improvement in catalyst activity of more than 30 times. DOE estimates that catalyst costs represent nearly half of stack costs at high volume. In financial year ending 30 September 2014, DOE invested nearly USD 13 million in R&D related to fuel cell catalysts.

Materials handling

- Hyster-Yale Materials Handling Inc. acquired Nuvera for an undisclosed price. Hyster-Yale expects to spend between USD 40 million and USD 50 million to bring Nuvera fuel cell and hydrogen generation products to market.
- Total fuel cell power generation capacity in the United States was near 200 MW by the end of 2014.

Hydrogen stations

- In California, more than 50 hydrogen refuelling stations were open or in progress at the end of the year, after the California Energy Commission awarded USD 46.6 million in May 2014 for 28 hydrogen refuelling stations and a mobile refueller. A start-up company, FirstElement Fuel, won financing for 19 hydrogen refuelling stations, with support from Toyota (at least USD 7.2 million) and Honda (USD 13.8 million).
- In November 2014, Toyota and Air Liquide announced plans to build 12 hydrogen refuelling stations in North-eastern states that have adopted California's Zero Emission Vehicle program.

Stationary systems

- FuelCell Energy completed installation of a 14.9 MW fuel cell power park on only 1.5 acres of land in downtown Bridgeport, Connecticut. Dominion, the electric and gas utility, owns and operates the fuel cells.
- Bloom Energy reports it had about 130 MW of capacity installed in the US in 2014, the majority in California.
- The DOE estimates that 4,000 fuel cell telecommunication back-up power systems were in use in the US in 2014.

Policy

- The US federal tax credit for fuel cell power systems is scheduled to expire in 2016. The federal tax credit for FCEVs expired at the end of 2014.
- In May 2014, California joined many of its Zero Emission Vehicle (ZEV) program partners (including Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont) in a Multi-State ZEV Action Plan to achieve 3.3 million ZEVs on the road by 2025.
- US Government dataset shows the capacity of fuel cell systems installed in the US in 2014 from domestic production was 63 MW. In addition, the capacity of complete systems exported for installation abroad was 3 MW.

Table 2.13: Summary of US fuel cell information

Description	Number of units	Details, comments and companies involved
Capacity of installed and operational units	312 MW	Fuel cell systems with a capacity of 63 MW were installed in the US in 2014 from domestic production. In addition, the capacity of complete systems exported for installation abroad was 3 MW. This new capacity is in addition to the 249 MW installed previously plus 27 MW exported
Domestic stationary units	1	Small scale (less than 100 kW) only
New for 2014	27	There are eight hydrogen refuelling stations for which the deployment year is uncertain. This is the total of large and small-scale stationary units
Other stationary units (large scale)	26	Large scale (over 100 kW) only
Operational fuel cell vehicles	179 cars and 19 buses	179 FCEVs are registered with the California Department of Motor Vehicles (DMV), a growth of 43% from the previous year's estimate[13].[14]
Operational hydrogen refuelling stations	1	1 non-retail station in 2014[15] (an additional seven non-retail stations were operational in 2013 or before)

[13] http://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2015.pdf
[14] http://www.afdc.energy.gov/uploads/publication/fc_buses_2014_status.pdf
[15] http://cafcp.org/stationmap

2.4 CURRENT ANNEXES

The following Annexes were active in 2014:

Annex	Title
Annex 30	Electrolysis.
Annex 31	Polymer Electrolyte Fuel Cells (PEFC).
Annex 32	Solid Oxide Fuel Cells (SOFC).
Annex 33	Fuel Cells for Stationary Applications (including MCFC).
Annex 34	Fuel Cells for Transportation.
Annex 35	Fuel Cells for Portable Applications.
Annex 36	Systems Analysis.
Annex 37	Modelling

Together, these annexes form an integrated programme of work from February 2014 to February 2019, comprising three technology-based annexes (Electrolysis, SOFC and PEFC) and three application-based annexes (stationary, transportation and portable applications), with the systems analysis and modelling Annexes encompassing all these areas.

2.5 HOW TO JOIN THE AFC TCP

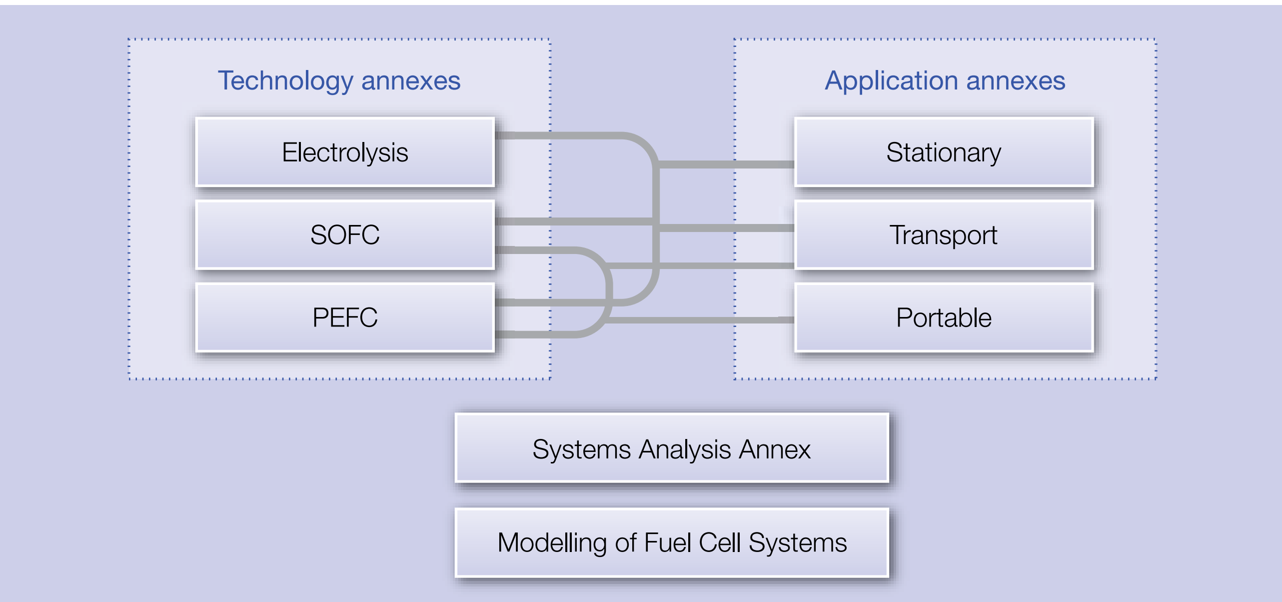
The AFC TCP welcomes new participants from IEA and non-IEA countries. It is a task-sharing activity, so we encourage countries with a significant programme of fuel cell research, development and commercialisation of this technology to become member countries.

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

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

If you are interested in joining the AFC TCP, please contact the Secretary, Dr Fiona Porter (Secretariat-AFCIA@ricardo-aea.com).

Figure 3: Summary of Current Annexes



3. Executive Committee Report

3.1 ACTIVITIES

Two Executive Committee (ExCo) meetings were held in 2014, the first in Seoul, South Korea and the second in Grenoble, France.

Table 3.1: Executive Committee Meetings 2014

Meeting	Date and place that meetings were held
ExCo48	13 and 14 June 2014, Seoul, South Korea
ExCo49	4 and 5 December 2014, Grenoble, France

The TCP's website (www.ieafuelcell.com) was actively maintained and updated, providing a resource for TCP members, a repository of on-going activity and a source of fuel cell information with the reports. In particular, publication of two newsletters a year was linked to the website (with the articles available through the website) and the creation of an interactive map demonstrating the geographical location of all the AFC TCP's stakeholders, including Executive Committee Members and Alternate Members, Operating Agents, Annex Members and Member Companies.

The AFC TCP continues to produce two newsletters a year, sharing the work of the group with a wide audience. They are available through the website and are sent by email directly to the people on our distribution list.

Annex activity

It was decided in 2014 that MCFC technology had essentially moved to the point where the technology was available as a relatively standardised offering internationally. Therefore, it was thought that it would be more appropriate to consider the technology going forward within Annex 33: Fuel Cells for Stationary Applications (which now includes MCFC), and to focus on its demonstration and use, as technological development was now only carried out by a few commercial companies. Hence the MCFC activities now form part of Annex 33.

The MCFC Annex ultimately produced the report 'MCFC Status Booklet' as a summary of MCFC technology status and its final output. This was published in early 2015 and is available through the AFC TCP website.

The production of a book from the activities of Annex 36: Systems Analysis continues, with the intention to produce a completed and published work in 2015. Additionally, in 2014, it was agreed that a further publication would be produced by the group, focusing on the roadmaps and plans underway in each member country to bring clarity and summary to this topic. The intention is to publish this work in 2015 as well.

In 2013, the AFC TCP voted to take forward the suggestions for two new Annexes, Modelling and Electrolysis. The preliminary work programmes for these new Annexes were further developed in 2014. At the December 2014 ExCo meeting, Operating Agents were appointed and the work programmes adopted.

3.2 MEMBERSHIP

In 2014, AFC TCP welcomed Dr Jimi Lee from the Korea Institute of Energy Technology Evaluation and Planning (KETEP) as the full member for Korea.

Interest in joining our work was again expressed by China, with Dr Zhan from Xiamen University attending the spring ExCo meeting to share fuel cell activities at Xiamen University and the wider Chinese context.

Sadly, Finland withdrew as a member country, but VTT Technical Research Centre Ltd (VTT) of Finland applied to join as a sponsoring organisation. VTT was formally invited to join at the autumn ExCo meeting in 2014.

To facilitate the membership of sponsoring organisations a set of Terms of Reference for Sponsoring Organisations Joining the AFC TCP was developed. This included establishing the Common Fund contributions, and the legal text of the AFC TCP was also updated to better enable sponsors to fully participate.

A new Operating Agent, Dr Fabio Matera of ITAE in Italy, was appointed as the Operating Agent for Annex 34: Portable Fuel Cells.

The following 13 IEA member countries participated in this TCP during 2014.

Table 2.2: Technology Collaboration Programme on Advanced Fuel Cells member countries

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

3.3 FINANCING AND PROCEDURES

All activities under the Annexes of the Technology Collaboration Programme are task shared. The only cost-shared activity is the Common Fund, which provides funding for the ExCo Secretariat. The new funding arrangements were introduced in 2011, whereby there are three tiers of Common Fund contributions; the level of payment is led by a country's level of GDP. This funding arrangement was maintained in 2014.

3.4 KEY DECISIONS IN 2014

- The Electrolysis Annex and the Modelling Annexes were set up and their activities commenced. The Electrolysis Annex has the potential to work closely with the Hydrogen Technology Collaboration Programme.
- It was unanimously voted to close the MCFC Annex and to move the activities to the Stationary Annex as a subtask, given that most activity is now concerned with the installation of products.
- Within Annex 33: Stationary Fuel Cells, a new set of subtasks has been identified for the new term. A new direction is Subtask 6: Fuel Cells In Future Energy Systems, which encompasses different power-to-fuel systems, smart grids and energy storage.
- The 'Terms of Reference for Sponsoring Organisations Joining the AFC TCP' document was updated and adopted to better facilitate sponsoring organisations joining the activities of the AFC TCP. In addition, the AFC TCP's legal text was updated, again to better enable sponsoring organisations to participate in this TCP.
- Unanimous approval was given for Belgium to join the TCP as a full Contracting Party (WaterstofNet as the representative) and for VTT to join as a Sponsoring Organisation.
- Dr Fabio Matera (ITAE, Italy) was accepted as the new Operating Agent for Annex 35: Portable Fuel Cells.

3.5 FUTURE PLANS

Information exchange with other IAs continues to be encouraged, building on links already in place with the Technology Collaboration Programmes on Hydrogen and on Hybrid Electric Vehicle.

Two ExCo meetings will be held in 2015. The 50th meeting will be held in Zurich, Switzerland on the 23 and 24 April 2015, and the 51st meeting will be held in Phoenix, Arizona, USA on the 15 and 16 October 2015.

Continued implementation of the approved work programme for the eight current Annexes is planned, with the intention of completing the activities of the Systems Analysis Annex and publishing its final output.

The objective of this annex is to provide international information sharing and learning between experts with knowledge and experience on electrolyser technologies. It seeks to understand how these can be deployed to accelerate the development of PEM, Alkaline and Solid oxide electrolysis towards commercialisation.

4. Annex reports

4.1 ANNEX 30 REPORT

ELECTROLYSIS

Key Messages – Facts

Electrolysis

- Electrochemical production of hydrogen by water electrolysis is a well-established technological process worldwide.
- If water electrolysis technology is to be widely and sustainably used on the mass market for the storage of renewable energy, further steps must be taken to solve outstanding technical issues, such as:

> Low power densities and inadequate stability.

> The high manufacturing and operating costs associated with the technologies currently in use.

- The dominant technologies in commercial installations are alkaline electrolysis with a liquid alkaline electrolyte and acidic electrolysis with a proton-conducting polymeric solid electrolyte (PEM).
- Alkaline membrane electrolysis and solid oxide electrolysis cells (SOEC) are in pre-commercial development in laboratories.
- SOEC development has profited from solid oxide fuel cell (SOFC) know-how, but further work is still required, especially with respect to the optimisation of electrode materials and improvement of long-term stability

Key Messages – Opinion

Electrolysis

- The technical challenges for near-term development of PEM electrolysis are improved stack performance, scale-up to megawatt size, grid integration and high-pressure operation.
- Stack performance needs include improved membranes and catalysts.
- Megawatt scale-up needs include reducing capital costs by 50% on a per kilowatt basis.
- Improving the durability of cell materials, including a better understanding of degradation mechanisms is important.

The objective of the Electrolysis Annex is to provide international information sharing and learning between experts with knowledge and experience on electrolyser technologies. It seeks to understand how these can best be deployed in energy systems to accelerate the development of the following technologies towards commercialisation:

- PEM electrolysis (electrodes, catalyst coated membranes (CCMs), stacks, lifetime enhancement, test protocols, balance of plant, etc).
- Alkaline electrolysis including alkaline membrane electrolysis.
- Solid oxide electrolysis.

The overall focus of the technical Annexes within the AFC TCP are those fuel cell technologies that are most likely to lead to commercialisation in the relatively near future. This approach has been applied to the selection of the electrolysis technologies selected to be focused on here. These make up the subtasks within Annex 30.

This Annex is new in 2014, having been set up in response to an increasing interest in utilising renewable energy across Europe. Particular issues are stranded energy[16] and energy generated when grid output exceeds demand. The Annex will run until 2019, culminating in a summary report on the status of electrolysis. The Operating Agent is Jürgen Mergel of Forschungszentrum Jülich GmbH. Participating organisations are listed in Table 4.1.

[16] For example, for a fuel cell vehicle, when there is crash or fire and an inability to remove energy from the damaged system.

Table 4.1: List of participating organisations in Annex 30

Country Participant	Associated Institution
Denmark	Technical University of Denmark
Denmark	IRD Fuel Cells
Germany	Forschungszentrum Jülich GmbH
Germany	Siemens
Germany	DLR Stuttgart
Germany	Fraunhofer ISE
Germany	HYDROGENICS Europe
Germany	ThyssenKrupp Electrolysis
Germany	Smart Testsolutions
Germany	Projektträger Jülich
Japan	NEDO
Japan	Technova Inc
South Korea	KIST, Korea Institute of Science and Technology
Switzerland	Paul Scherrer Institut (PSI)

Electrolysis offers one of the best methods of ensuring full use of renewable energy. Electrochemical production of hydrogen by water electrolysis is a well-established technological process worldwide. However, if water electrolysis technology is to be widely and sustainably used on the mass market for the storage of renewable energy, then further steps must be taken to solve outstanding technical issues. These include low power densities, inadequate stability, and the high manufacturing and operating costs associated with the technologies currently in use.

The dominant technologies in commercial installations are alkaline and PEM electrolysis.

Figure 4: Comparison of alkaline and PEM electrolysis technologies (Source: Forschungszentrum Jülich GmbH

Alkaline water electrolysis

Advantages:

- Well-established technology
- No noble metal catalysts
- High long-term stability
- Units up to 750 Nm^3/h (3.5 MW)
- Relatively low investment costs

Challenges:

- Increasing the current densities
- Expanding the part-load capacity
- System size and complexity
- Reduction of gas purification requirements

V

PEM water electrolysis

Advantages:

- Higher power densities
- Higher efficiency
- Good partial load toleration
- Simpler system structure
- Compact stack design allows high pressure operation

Challenges:

- Cost reduction by increasing current density and reduction or substitution of noble metals and cost-intensive components
- Increasing the long-term stability
- Scale-up stack and peripherals

In comparison to alkaline electrolysis, PEM electrolysis permits a much larger partial load range. This is particularly beneficial for operation with renewable energy sources, but the production rates of commercial products (less than 65 normal cubic metres per hour ($Nm^3 h^{-1}$)) are low. The main challenge for PEM electrolysis is the cost, which is dominated by the stack components, so there is a need to investigate the reduction of noble metal content. However, by increasing current density or decreasing catalyst loading, it is possible to decrease the costs relative to alkaline electrolysis. The durability of PEM electrolysers is an issue (especially with increases in temperature) and lifetimes are approximately one third shorter than alkaline counterparts. PEM electrolysers are typically on the kW scale. However, most commercial electrolysers use alkaline electrolysis and are at the MW scale (such as those available from Hydrogenics and McPhy).

As such, new catalysts and membranes for PEM electrolysis will be a key focus of this Annex. Some of the technical challenges for near-term development that the Annex will investigate are improved stack performance, scale-up to megawatt size, grid integration and high-pressure operation. Stack performance in this sense includes improved membranes and catalysts. On the other hand, achieving megawatt scale-up will require a target 50% reduction on capital costs on a per kilowatt basis. Finally, when considering the improvement of durability of cell materials, it will be important to include a better understanding of degradation mechanisms.

Alkaline membrane electrolysis and SOEC are in pre-commercial development in laboratories. SOEC development has profited from SOFC know-how, but further work is still required, especially with respect to the optimisation of electrode materials and improvement of long-term stability.

4.1.1 Activities

The key activity undertaken in 2014 was the commencement of the Electrolysis Annex. This involved establishing the participants and the most relevant areas to address.

Jürgen Mergel of Forschungszentrum Jülich GmbH was then appointed and approved as Operating Agent at the June 2014 ExCo. The first Annex meeting was held at Forschungszentrum Jülich GmbH on the 11 and 12 December 2014. In total, 25 participants from five member countries took part. The aims of the first workshop were information exchange and discussion of future ANNEX 30 activities. An information-exchange session was held regarding news and recent developments in water electrolysis. Future topics were then discussed.

4.1.2 Technical developments

Although the Annex is sufficiently new as to not present technical developments itself, it is noteworthy that the first SOEC electrolyser was installed in Germany in 2014.

4.1.3 Work plan for next year

The intention going forward is that Annex 30 will hold two annual workshops where representatives from the participating countries will present the status of electrolysis research, development and demonstration (RD&D) in their respective countries. This will include identifying the relevant technical challenges and degradation mechanisms across the electrolysis technologies, discussion of their status and the creation of test procedures. By the end of the first year of operation, the Annex aims to have completed a review of the following:

- Standardisation of test procedures/protocols:
  - > Components (for example catalysts, membrane, CCM, separator plate)

> Single cells and stack (characteristic U(i) curves, dynamic test protocol….).

- Long-term measurements:

> Impurity influence on durability and lifetime.

> Durability and lifetime issues (operating parameters, rated power, dynamic operation).

- Accelerated stress tests:

> For components (ex-situ) and cells (in-situ).

> Durability and lifetime issues (@rated power and @ dynamic operation).

- Standardisation of definitions:

> System boundaries: what belongs to a system?

> Standby/cold-start/black-start.

- Standards/definition of key performance indicators:

> Technical parameters (including performance, efficiency, beginning of life (BoL), end of life (EoL) analysis.

> Energy consumption (including alternating current (AC)-level, including/excluding purification/drying).

- Standard single cell (common test fixtures).
- Market overview and development.

In the second year of the Annex, the intention is to produce a document describing standard test protocols for components and single cells, and an electrolysis glossary for common standard definitions.

Additionally, contact is sought between this Annex and the International Electrotechnical Commission (IEC) Technical Committee 105, which has created a new group dedicated to test procedures for electrolysis testing.

The objective of this annex is to contribute to the identification and development of techniques and materials that can reduce the cost and improve the performance and durability of polymer electrolyte fuel cells (PEFC) and direct fuel PEFC and corresponding fuel cell systems.

4.2 ANNEX 31 REPORT

POLYMER ELECTROLYTE FUEL CELLS (PEFC)

Key Messages – Facts
Polymer electrolyte fuel cells

- Commercialisation of fuel cell vehicles (FCV) for mass-transportation becomes closer to reality with the planned launch of a passenger FCV saloon by Toyota and Honda in 2015, and an innovative leasing programme by Hyundai in 2014.
- Worldwide governmental and industrial commitments in fuel cell research and commercialisation remain strong.
- Developments in new fuel cell materials have made significant advancements recently (such as platinum-based, core-shell catalyst; non-precious metal catalyst; and high-temperature membranes).
- Studies in components and systems have made significant progress (such as graphite-coated bipolar plate; online fuel cell performance monitoring; and system modelling and simulation.
- Cost, performance and durability are stated as the major barrier to larger scale production.

Key Messages – Opinions
Polymer electrolyte fuel cells

- With the anticipated launch of a commercial FCV, an acceleration in the development of fuel cell materials, stack component and systems is expected.
- Reducing cost and improving durability still remain the top priorities in fuel cell material and systems R&D.
- Major technology breakthroughs (such as high temperature membranes and low-cost catalysts) will accelerate the implementation of fuel cells in transportation and other sectors.
- New ideas and 'out-of-box' thinking are essential for fuel cell technology breakthroughs. Therefore, these should be incentivised and encouraged.

The objective of Annex 31: Polymer Electrolyte Fuel Cells is to contribute to the identification and development of techniques and materials that can reduce the cost and improve the performance and durability of PEFC, direct fuel polymer electrolyte fuel cells (DF-PEFC) and corresponding fuel cell systems.

The R&D activities in Annex 31 cover all aspects of PEFC and DF-PEFC, from individual component materials to whole stacks and systems. These activities are divided into three major subtasks:

1. **New stack materials**

   Research into new stack materials aims to develop improved, durable, lower-cost polymer electrolyte membranes, electrode catalysts and structures, catalyst supports, membrane-electrode assemblies, bipolar plates, and other stack materials and designs for PEFC.

2. **System, component and balance-of-plant issues in PEFC systems**

   This subtask includes systems analysis, stack/system hardware designs and prototypes, and modelling and engineering. It also engages in testing, characterisation and standardisation of test procedures related to end-user aspects, such as the effects of contaminants on durability, water and heat management, operating environments and duty cycles, and freeze-thaw cycles. The development of fuel processors for PEFC for combined heat and power (CHP) and auxiliary power unit (APU) applications is also addressed in this subtask.

3. **DF-PEFC technology**

The third subtask focuses on the research and development of DF-PEFC technology, including systems using direct methanol fuel cells, direct ethanol fuel cell and direct borohydride fuel cells. It involves development of the cell materials, investigation of relationship between cell performance and operating conditions, stack and system design and analysis, and investigation of fuel-specific issues for these DF-PEFC systems.

This Annex has been in operation since February 2014. It will run until February 2019, following the granting of a new period of 5 years for the AFC TCP by the IEA in 2013. Dr Di-Jia Liu of Argonne National Laboratory assumed the role of Operating Agent for this Annex in December 2013.

Table 4.2: List of participating organisations in Annex 31

Country Participant	Associated Institution
Austria	Graz University of Technology
Denmark	IRD Fuel Cell A/S
Denmark	Danish Power Systems
Finland	VTT (x2)
France	Commissariat à l'Energie Atomique (CEA)
Germany	Forschungszentrum Jülich
Germany	ICT Fraunhofer
Israel	Ariel University
Italy	CNR-ITAE
Japan	Daido University
South Korea	Korea Institute of Energy Research
South Korea	Korea Advanced Institute of Science and Technology (KAIST)
Mexico	Instituto de Investigaciones Eléctricas (IIE)
Sweden	KTH – Royal Institute of Technology (x3)
USA	Argonne National Laboratory

PEFCs generally operate with a low temperature and have a rapid response. Their significant benefit is a high output power density. PEFCs are particularly versatile and are used in many applications – the most common uses include the automotive, portable power, APU, stationary power (residential, commercial) and CHP sectors. As such, there is much interest in studying PEFCs and accelerating their development for further commercialisation, hence the objectives of Annex 31.

The low cost and long-term stability of PEFCs are critical to the successful commercialisation of the technology. Often, precious metals are used for the catalyst in PEFCs which brings negative cost implications. Additionally, stability is affected by performance degradation, membrane degradation and possible catalyst posioning issues. The research shared within Annex 31 identifies balanced approaches in materials, components, systems and alternative fuel research in the member countries to reduce these limiting characteristics of current PEFCs. The Annex is addressing the catalyst metals through improvements in platinum (Pt) catalysts and researching Pt-free alternatives. Stability issues are confronted through activities such as investigations of alternative membrane materials, monitoring and diagnostic developments, and new modelling approaches.

4.2.1 Activities

Annex 31 continues the AFC TCP's focus on PEFCs, building on the work achieved previously in Annex 22 (2009 – 2014).

The first meeting of Annex 31 (what would have been the 11th meeting of Annex 22) took place at KIST, Seoul, Korea on the 13 and 14 June 2014. In total, 12 participants from eight member countries attended (Austria, Denmark, Germany, Japan, Korea, Mexico, Sweden and the USA) to give technical presentations, followed by a business discussion on future meeting venues and thoughts on IEA publications.

The second meeting of Annex 31 was held at Krystal Palace in Cancun, Mexico, on 2 and 3 October 2014. It was attended by 11 representatives from nine countries (Canada, Denmark, France, Germany, Italy, Japan, Korea, Mexico and the USA) and observers from ITC and Brazil. This followed a similar structure to the previous meeting.

4.2.2 Technical Developments

Subtask 1: Stack Materials

Forschungszentrum Jülich

Forschungszentrum Jülich GmbH investigated bipolar plate (BPP) materials for their susceptibility to electrochemical corrosion and the formation of a boron-doped diamond (BDD) protective coating using hot-filament chemical vapour deposition (CVD) method. Metallic BPPs can increase volumetric and gravimetric power densities due to their low thickness and offer the potential for innovative designs. However, they must be coated to prevent perforation or power drops caused by corrosion.

Forschungszentrum Jülich representatives revealed to the Annex members that they had found BDD coatings exhibited an 'outstanding improvement' in corrosion resistance with high stability under fuel cell polarisation conditions. Impact to the interfacial contact resistance[17] was minimal before and after its exposure to acid corrosion for four days. Imaging comparisons with the metal and other 'well-known' coatings demonstrated that only BDD coating has no crack and depletion after acid exposure tests.

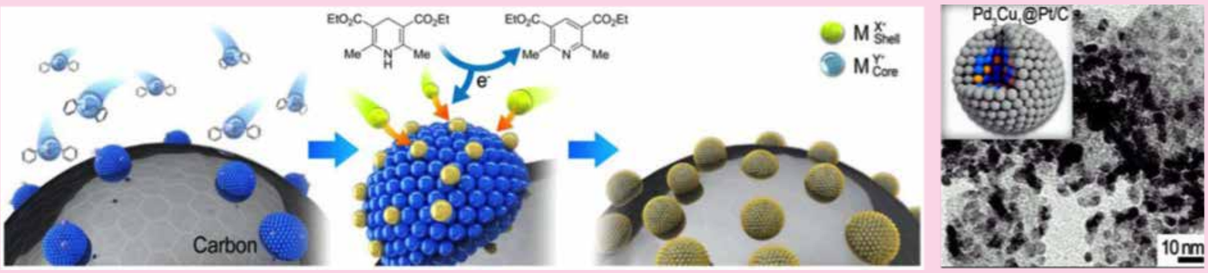
Figure 5: Corrosion resistant bipolar plate with boron-doped diamond coating developed by Forschungszentrum Jülich

The Korea Institute of Energy Research (KIER)

With alkaline membrane fuel cells (AMFCs), it is possible to have catalysts that do not contain precious metals. However, they have several issues including inferior performance compared with that of PEFCs. To address the difference in AMFC and PEFC performance, KIER investigated hydrogen oxidation and oxygen reduction reactions at the Pt-ionomer interface. KIER used two alkaline polymer electrolytes – phenylpentamethyl guanidinium tethered perfluorinated polymer (Nafion-FA-TMG) and benzyl-trimethyl ammonium

[17] The contact resistance refers to the contribution to the resistance of a system arising from the contacting interfaces of connections, as opposed to the intrinsic resistance.

Figure 6: The synthetic scheme and microscopic structure of the new catalyst, Pd3Cu@Pt/C, developed by KIST [18]



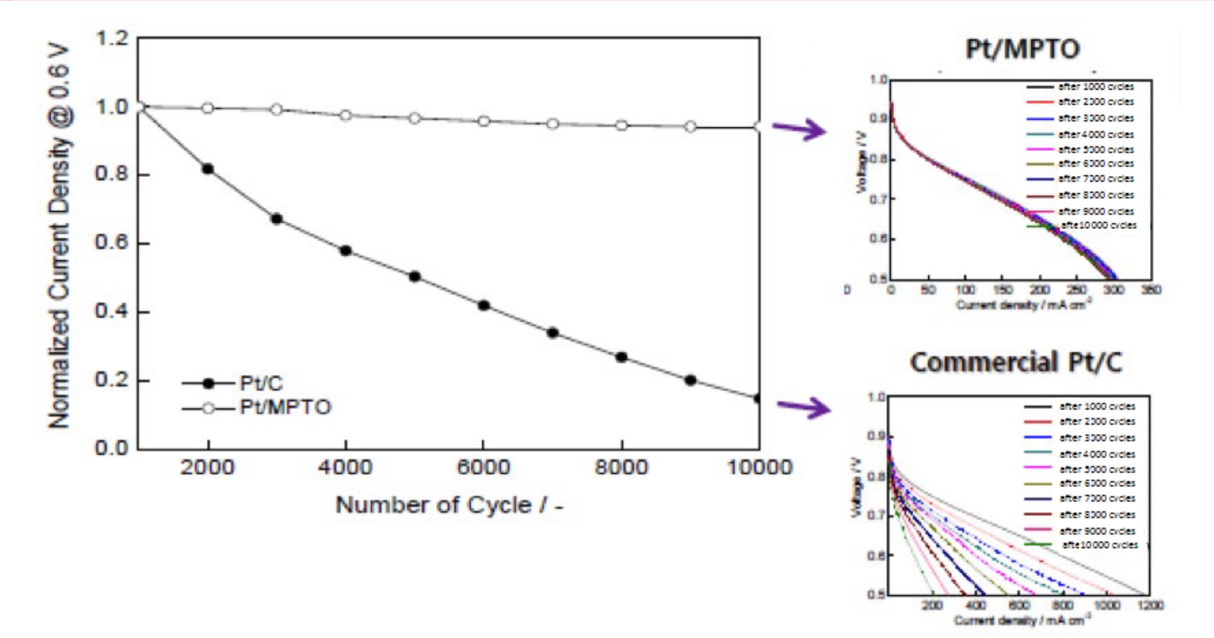
tethered polyphenylene (ATM-PP). After discovering that organic cation adsorption in alkaline electrolytes inhibits the hydrogen oxidation reaction (HOR) activity of polycrystalline Pt, it was found that TMG cations had a lower desorption potential than that of benzyl-trimethyl ammonium (BTMA) cations. It was also found that the flexible chain mobility of the Nafion-FA-TMG ionomer helps desorption of the cationic group, and that the rigid polyphenylene polymer backbone of ATM-PP limits desorption of BTMA cations.

KIER also investigated alternative catalyst supports for PEFCs to increase their durability. Conventional PEFCs use carbon-based materials to support the catalyst, but these suffer from carbon corrosion. Work has been carried out to assess the durability of PEFCs and their key degradation pathways.

A range of options was considered for more durable catalyst support materials. Magnéli-phase titanium oxides (MPTOs) have sufficient electrochemical durability, electrical conductivity and potential stability to be used as alternative catalyst support materials. However, they have insufficient surface area in their conventional state to replace carbon supports. KIER developed a bead milling method that successfully increased the surface area of MPTOs. The MPTO with a high surface area was then subject to several accelerated stress and potential cycling tests. The Pt/MPTO electrode displayed superior corrosion tolerance compared to the Pt/carbon in a single cell. A single cell underwent potential cycling between 0.9 V and 1.3 V with a 100 mVs^{-1} scan rate for 10,000 cycles. The Pt/MPTO electrode displayed no significant change in the cell current density while the commercial Pt/carbon electrode lost most of its current density.

[18] From: S. J. Hwang, S. J. Yoo, J. Shin, Y.-H. Cho, J. H. Jang, E.A. Cho, Y.-E. Sung, S. W. Nam, T.-H. Lim, S.-C. Lee, S.-K. Kim, "Supported Core@Shell Electrocatalysts for Fuel Cells: Close Encounter with Reality", Scientific Reports, 3, 1309 :1-1309 :7 (2013).

Figure 7: Comparison of durability between Pt/MPTO and Pt/C through a multiple potential cycling test [19]



Instituto de Investigaciones Eléctricas (IIE)

IIE, in collaboration with Brazilian researchers via the Mexican (CONACYT) and Brazilian (CNPq) research councils, is developing nano-based materials [20] to improve the performance and lifetime of fuel cell using the following approaches:

- New nano-sized electro-catalysts for reducing the load of platinum.
- Carbon nanotubes to avoid carbon corrosion.
- Nano-metal composite ion exchange membranes as a substitute for Nafion®.
- To integrate nano-based components into membrane electrode assemblies (MEAs) to test internal fuel cell hardware.

IIE's methodology for synthesising multi-wall carbon nanotubes, uses CVD from a metal organic precursor which was cheaper, enabled lower temperatures and is more easily scaled up.

Another focus has been PEFC-MEA fabrication. The IIE MEA fabrication protocol comprises layering a Pt/carbon catalyst, Nafion, ethanol and water ink mixture onto a supportive gas diffusion layer, drying, and finally heating and cooling. The IIE undertook two phases of optimisation for the creation of its MEAs. The first phase consisted of controlling ink rheology and catalyst layer disposition. The second phase involved Pt loading reduction, Nafion load adjustment and automatic spray deposition control. It was found that such optimisation significantly improved the fuel cell performance.

[19] Didem C. Dogan, Sun-Mi Hwang, Eun-Hwa Jang, Sung-Dae Yim, Young-Jun Sohn, Sung-Hyun Kim, Tae-Hyun Yang, and Gu-Gon Park, Highly Platinum-Loaded Magnéli Phase Titanium Oxides as a High Voltage Tolerant Electrocatalyst for Polymer Electrolyte Fuel Cells, J. Nanosci. Nanotechnol. 2015, Vol. 15, No. xx

[20] Nanomaterials describe materials for which a unit is usually sized (in at least one dimension) between 1 and 100 nanometers (10–9 metres)

The IIE has filed for four MEA fabrication patents and plans to develop hybrid power systems for electric utility vehicles and trains, and to integrate further nanomaterials into MEAs to enhance their performance.

Argonne National Laboratory (Argonne)

The US Department of Energy's (DOE) targets include reducing fuel cell cost to USD 30/kW and increasing durability from 2,500 hours to 5,000 hours for widespread commercialisation – advancements in PEFC materials and components have the potential to benefit a wide range of applications.

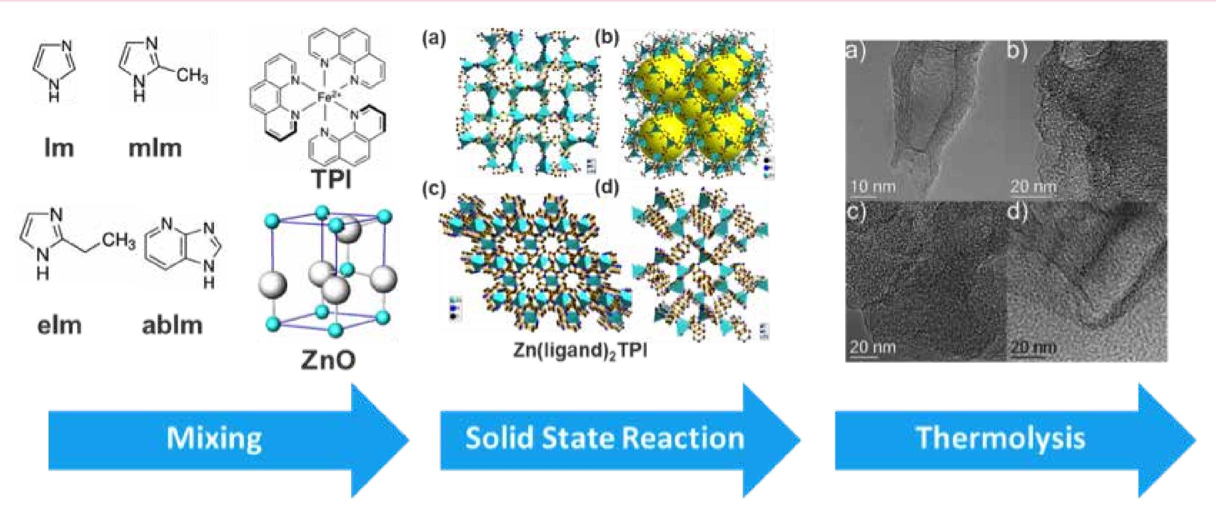
Argonne is conducting research into the main challenges for catalysts:

- Identifying suitable Pt alloys.
- Finding novel support structures.
- Lowering or removing the Pt group metal (PGM) content.

For example, Argonne has also produced a catalyst with a polyhedral platinum-nickel nanoframe structure. In a fuel cell test, the electrode with nanoframe catalyst demonstrated three time higher mass activity than the DOE target. It also showed good durability in a rotated disk electrode (RDE) cycling, with no degradation after 10,000 cycles.

In another area, Argonne has pioneered a new way of preparing highly efficient, non-platinum group metal (non-PGM) catalysts using metal-organic frameworks as precursors. More recently, Argonne developed a low-cost, 'one-pot' synthesis method which is versatile and capable of producing multiple zeolitic imidazolate framework (ZIF) based non-PGM catalysts. The new catalysts showed high surface area and active site density, leading to high catalytic activity toward oxygen reduction reaction. The approach provided a useful platform for studying the impact by metal and ligand on catalytic activity.

Figure 8: Preparing multiple ZIF-based non-PGM catalysts using 'one-pot' synthesis developed at Argonne National Laboratory



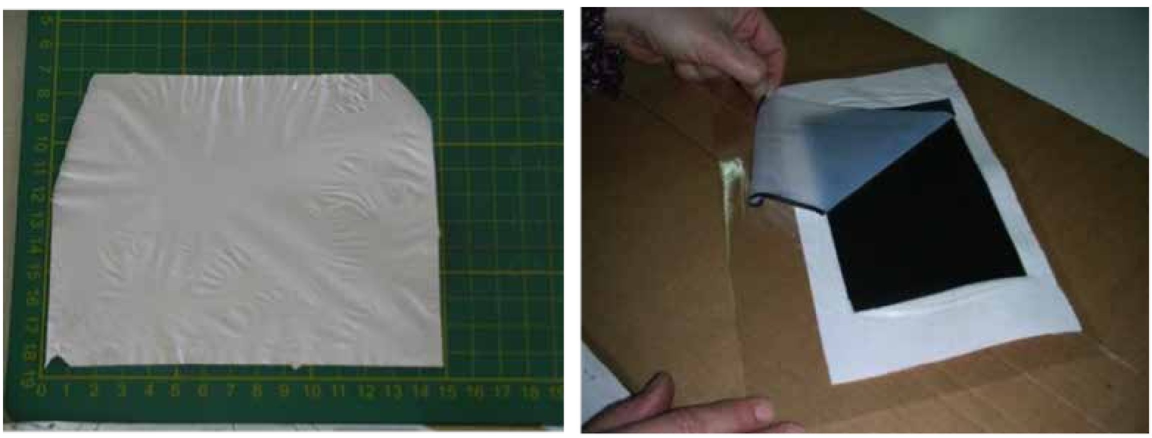
CNR-ITAE

CNR-ITAE's R&D focus areas and core capabilities in PEFC include:

- Developing new polymer electrolytes with increased conductivity, increased mechanical and chemical durability, and reduced material costs.
- Integrating membranes and electrodes to optimise mechanical and chemical interactions of the catalyst, support, ionomer and membrane, and to minimise interfacial resistances.
- Assessing catalysts and supports with reduced precious metal loading, increased activity and durability, and lower costs.
- Expanding the operating range of MEAs and improving durability through cycling.
- Scaling fabrication processes for production of membranes, electrodes, MEAs and bipolar plates.
- Bipolar plate research for lower weight and volume, and with negligible corrosion.

PEFC membranes operated under heightened working temperatures can increase carbon monoxide tolerance and improve heat recovery. However, a drawback of this is the in-plane tension resulting from membrane shrinkage when drying. To overcome the membrane fatigue from the stress induced by repeated humidity cycling, CNR-ITAE is developing composite and reinforced approaches for membranes based on Nafion and sulfonated polyether ether ketone (SPEEK). For Nafion composite membranes, inorganic oxides were added (such as silicon dioxide (SiO_2), titanium dioxide (TiO_2) and zirconium dioxide (ZrO_2)) to improve hygroscopicity and mechanical properties, and immobilise heteropolyacids (phosphotungstic acid) on inorganic oxides to improve the proton conduction through the acid functionality. Similarly, H-BETA, yttria-stabilised zirconia (YSZ), SiO_2-NH_2 and tetrapyridylporphyrin (TPyP) as additives for SPEEK-based systems were evaluated. The new membranes were subsequently incorporated into the electrode and tested in fuel cells under different humidity and temperatures.

Figure 9: Oxide added composite proton conductive membrane developed by CNR-ITAE



Subtask 2: System, Component and Balance of Plant

Graz University of Technology (TU Graz)

TU Graz has developed advanced fuel cell diagnostics, particularly three-dimensional analysis and condition diagnostics of fuel cells and pinhole localisation in PEFC. TU Graz seeks to improve three-dimensional fuel cell stack diagnosis in real-time to optimise fuel cell efficiency and extend lifetimes.

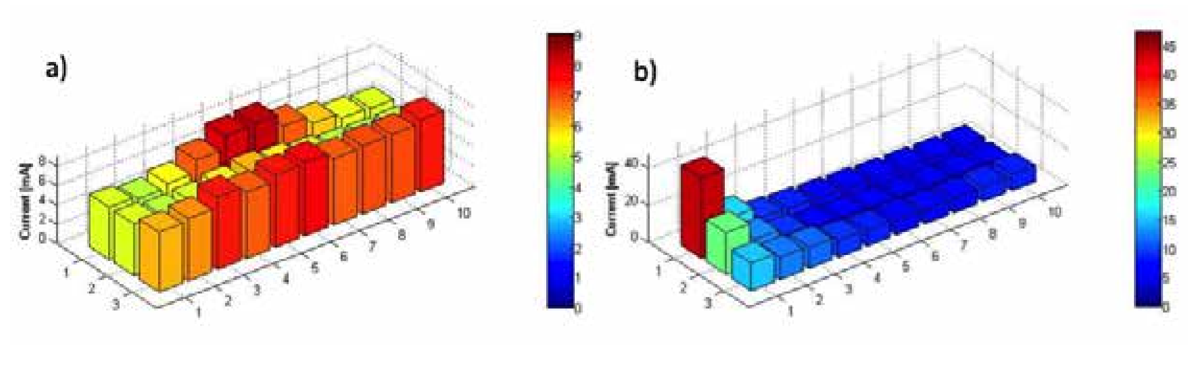
Large signal equivalent circuits have been developed to simulate polarisation curves, electrochemical impedance spectra and total harmonic distortions of a stack or its sub-components. By positioning newly developed shunt sensor plates around the cell of interest, harmonic distortions have been measured at four frequencies in multiple cells, and current and temperature profiles of the cells recorded. Multipole equivalent circuits enable three-dimensional analysis with the same number of shunt sensor plates.

TU Graz also investigated pinhole localisation in PEFCs, which act to increase the local temperature, decrease fuel efficiency and could have safety implications. However, fuel cell performance and membrane resistance were not found to be suitable indicators for pinhole detection.

Daido University

Various claims on performance of new fuel cell materials have prompted the New Energy and Industrial Technology Development Organization (NEDO) of Japan to establish a standard cell evaluation method so that the performance of MEA materials can be compared to that of a reference cell. Under the PEFC Evaluation Project, NEDO has formed a team of people with the aim of evaluating MEA materials that have been newly developed under NEDO projects or others through the unified in-situ evaluation method. Daido University is the lead organisation of this project and the team has evaluated over 50 newly developed materials, such as core-shell, de-alloyed and carbon alloy catalysts, and membranes.

Figure 10: Clear increase of current cross over in the perforated area (pinhole) was detected by electrochemical method



The Fuel Cell Commercialisation Conference of Japan (FCCJ) has worked with three Japanese automobile manufacturers and defined the target performance, durability, and cost of fuel cells for transportation application. Based on the FCCJ's protocol, Daido University and other team members of the PEFC Evaluation Project published an intelligible 'Cell Evaluation and Analysis Protocol Guideline', which standardises the fuel cell test in Japan.

KTH Royal Institute of Technology in Sweden (KTH)

KTH has carried out various aspect of fuel cell research. In 2014, it reported mainly its work on how ammonia contamination affects the performance of PEFCs. KTH observed that high concentration of ammonia has a detrimental effect on the overall fuel cell performance, although the membrane resistance accounted for only 3% of the total decay. It was found that fuel cell operation at high current densities may mitigate the decreased membrane conductivity caused by ammonia. Mechanistically, ammonium ion diffuses and/or migrates from the anode to the cathode, affecting the cathode ionomer resistance. Conversely, catalyst deactivation by ammonia is the major contributor to the degradation of fuel cell performance. KTH proposed that the decrease of the electrocatalytic surface area may be related to the change of interaction between ionomer and catalyst.

Figure 11: Professor Göran Lindbergh, an Annex 31 representative, introduced his fuel cell research to US President Barack Obama during his visit to KTH

Danish Power Systems (DPS) and other Danish activities

IRD Fuel Cells A/S carried out a field demonstration of a hydrogen village. During the demonstration, which finished in 2014, 32 hydrogen-fuelled micro-CHP units were installed in single family homes using central, on-site, hydrogen production from renewable sources and a dedicated smart grid. The target houses were outside district heating and natural gas grids, so fuel cells were a practical solution when the old boilers needed replacing.

DPS specialises in high temperature PEM MEAs based on polybenzimidazole (PBI) and focuses on the following aspects of commercialisation:

- Durability and methods of testing – particularly to address degradation modes during closed circuit (CC) and start/stop use.
- Cost – the cost of the MEAs (Pt loading), BPP and gaskets.
- Performance – including improved catalysts and platinum utilisation.

DPS has been carrying out activities on the Fuel Cell and Hydrogen Joint Undertaking (FCH-JU)[21] CISTEM[22] project, which aims to develop a new CHP technology based on fuel cells that is suitable for fitting into large-scale, peak-shaving systems for wind turbine, natural gas and smart grid applications (outputs of up to 100 kW). Optimising operating conditions has been carried out by controlling oxygen-enriched cathode air and backpressures. DPS has developed a testing protocol to assess the start-stop cycling performance of the fuel and shared this with the Annex. Sharing newly developed testing protocols in the way that DPS did is useful for progressing harmonisation of testing internationally, which will bring the various benefits of a standardised approach.

Subtask 3: Direct Fuel Polymer Electrolyte Fuel Cells

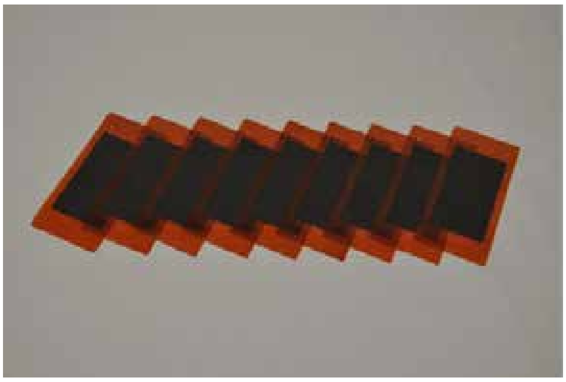
Frauhofer ICT

Frauhofer ICT has focused on three primary topics relevant to direct alcohol fuel cell and automotive PEFC applications. They are:

- Alkaline anion exchange membrane direct alcohol fuel cells.
- Anode catalysts for high temperature PEFCs.
- Mass spectrometric investigation of carbon support corrosion in automotive PEFC MEAs.

In a 2011 study[23], it was shown that palladium has a higher activity than platinum for alcohol oxidisation in alkaline environments, but a CO_2 current efficiency (CCE) of almost zero (for pure palladium). Fraunhofer ICT synthesised other binary palladium catalysts such as palladium-nickel and palladium-silver for electrochemical testing. The properties of the catalysts for methanol oxidation and then ethylene glycol oxidisation were studied, revealing a Pd_3Ag/C catalyst had the highest performance for both alcohols. For PGM-free cathode catalysts, Ag_2O and MnO_2 materials were tested in an alkaline environment. The silver-based catalyst showed lesser stability and alcohol tolerance. However, the manganese-based catalyst exhibited a 'high tolerance for alcohol and no signs of a quick degradation'.

Figure 12: BPI based high temperature polymer electrolyte fuel cell membrane developed at DPS



[21] The FCH JU is the result of long-standing cooperation between representatives of industry, the scientific community, public authorities, technology users and civil society in the context of the European Hydrogen and Fuel Cell Technology Platform.

[22] Construction of Improved HT-PEM MEAs and Stacks for Long Term Stable Modular CHP Units.

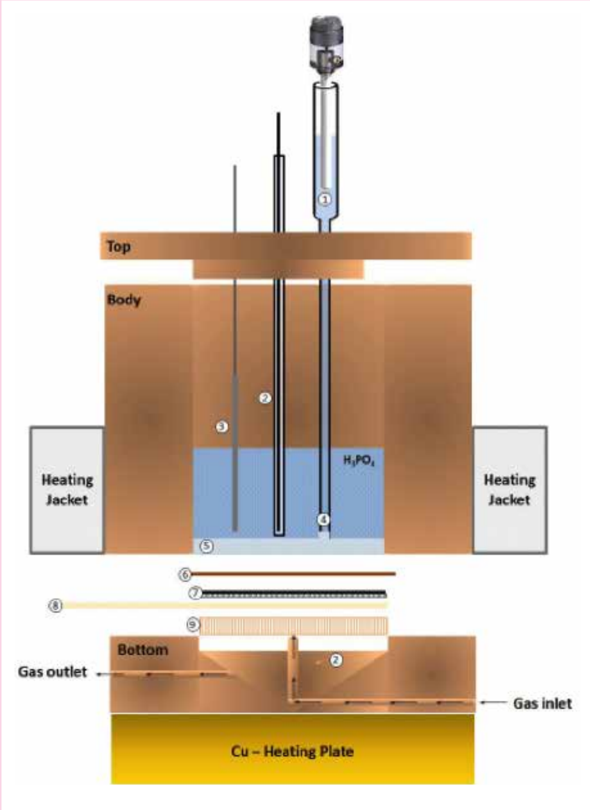
[23] D. Bayer, C. Cremers, H. Baltruschat, J. Tübke, ECS Trans. 41(1), 2011, 1669-1680.

Under the second topic, Fraunhofer's anode catalyst work addressed the obstacle of incomplete ethanol conversion in DEFCs. Previously, differential electrochemical mass spectrometry has been restricted to investigation in liquid electrolyte when investigating ethanol oxidisation. Fraunhofer ICT scientists piloted a new set-up which allows for inline mass spectrometric measurement under almost differential conditions at a gas diffusion electrode. The experimental set up for this method was shared with the Annex members.

In the carbon support corrosion study, Fraunhofer ICT's results showed that carbon corrodes at constant potentials of 1.2V versus RHE (reversible hydrogen electrode) and above and does not seem to be catalysed by platinum, which is quickly passivated with the formation of an oxide layer.

Similarly to the testing protocol shared by DPS, the distribution of such evaluation methods will assist in creating international standard practices so that MEAs, in this case, can be characterised and reliably compared.

Figure 13: Differential electrochemical mass spectrometry set up at Frauhofer ICT allowing inline mass spectrometric measurement under almost differential conditions at a gas diffusion electrode[24]



4.2.3 Work plan for next year

The areas of active R&D within Annex 31 address all the critical technical barriers that prevent PEFC technologies from achieving large scale commercialisation. The active R&D includes improved membrane-electrode assemblies, materials, and stack components; reduced catalyst cost, improved catalyst and support durability, system design and control without compromising performance; and component materials, MEAs, stacks, and systems for improved direct fuel cells. In recent years there has also been increased activity on catalyst activity improvement, reducing or replacing precious metals, new and low cost component development and new stack control and monitoring techniques. Alkaline membrane fuel cells and direct hydrocarbon fuel cells have also been included more recently. The diversification of the Annex' activities is harmonious with the one of the Annex' key activities: attracting new members. This will be a major focus for

[24] TC. Niether, M.S. Rau, C. Cremers, D.J. Jones, K.Pinkwart, J. Tübke
Development of a novel experimental DEMS set-up for electrocatalysts characterization under working conditions of high temperature polymer electrolyte fuel cells
Journal of Electroanalytical Chemistry Vol 747, 2015, pp 97-103

next year, where the Annex plans to continue to seek new members and participation by identifying and generating value for new and existing Annex members.

Additional focus areas for the future include:

- Creating a closer tie to industry to ascertain a better perspective of the status of and requirements for fuel cell commercialisation.
- Initiating a public outreach from the Annex.
- Encouraging theme-based publications which will be sponsored by the Annex.

The objective of this annex is to assist, through international co-operation, the development of Solid Oxide Fuel Cells towards commercialisation, seeking to reduce the cost, improve the lifetime and increase the availability of SOFC technology.

4.3 ANNEX 32 REPORT

SOLID OXIDE FUEL CELLS

Key messages – facts
Solid oxide fuel cells

- SOFC is good for distributed combined heat and power production.
- +50% electrical efficiency at system level have been reached at 1.5 kWe and 20 kWe class.
- +40 000 hours runtime for SOFC stack proved.
- Key barriers are stack's limited lifetime and/or too high manufacturing costs.

Key messages – opinions
Solid oxide fuel cells

- SOFC has the potential for high electrical efficiency, 55-60%, and total efficiency up to 90% for CHP.
- With additional stack related development steps a commercially feasible system having an investment cost (excl. stacks) of less than EUR 2,000/kW can be achieved in large scale.
- For stationary applications, voltage degradation rates below 0.25%/kh (per 1000 hours) can ensure lifetime long enough for the products.
- 1% degradation acceptable if stack cost is low enough.

The objective of Annex 32: Solid Oxide Fuel Cells is to assist, through international co-operation, the development of SOFC technologies. It facilitates the continuation and intensification of the open information exchange to focus and accelerate the development of SOFC towards commercialisation, primarily seeking to reduce the cost, improve the lifetime and increase the availability of SOFC technology.

The Operating Agent for this Annex is Dr Jari Kiviaho of the VTT Technical Research Centre of Finland.

Table 4.3: List of participating organisations in Annex 32

Country Participant	Associated Institution
Denmark	Risø DTU National Laboratory for Sustainable Energy
Finland	VTT
France	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)
Germany	Forschungszentrum Jülich GmbH
Germany	Fraunhofer IKTS
Germany	eZelleron GmbH
Italy	ENEA Centro Ricerche Casaccia
Japan	Japan Institute of Advanced Industrial Science and Technology (AIST)
Japan	Technova
Korea	Korea Institute of Energy Research (KIER)
Sweden	Department of Energy Sciences
Switzerland	SOLIDpower SpA (HTceramix)
USA	Pacific Northwest National Laboratory
USA	National Energy Technology Laboratory (US DOE)
USA	Delft University of Technology

Solid oxide fuel cells (SOFCs) are considered an advantageous technology in energy production having many advantages over conventional power trains, such as combustion engines, including:

- High efficiency, especially at small scale.
- Fuel flexibility.
- Insignificant NO_x, SO_x and particulate emissions, reduced CO_2 emissions.
- Silent and vibration-free operation.

SOFCs are particularly well suited for combined heat and power production (CHP) or for hybrid systems (where the SOFC stacks are coupled to a gas turbine) due to their high operating temperatures. Fuel processor design is simpler than low temperature fuel cell types thanks to the possibility of direct oxidation of carbon monoxide and the use of hydrocarbon fuels via internal reforming reactions. SOFCs can be utilised for various applications with different power scales (e.g. auxiliary power units for cars and trucks, residential CHP, distributed CHP or stationary power production). In particular, the most promising areas where pioneering companies and product development are looking at are:

- Mobile, military and strategic (less than 1 kW).
- Auxiliary power units (APU) and back-up power (1 kW – 250 kW).
- Residential combined heat and power (1 kW – 5 kW).
- Stationary medium to large scale (20 kW – 10 MW).

Whereas record fuel efficiency is proven, long lifetime of fuel cell systems under real-life operation is a challenge for the durability of fuel cell stacks and system components. Significant improvements in this respect have been achieved in the last 7 years: robust designs and more stable materials have been developed in laboratories worldwide, but these need to be engineered and assembled into end-use products with sometimes aggressive utilisation profiles. This poses a challenge to the fuel cell stacks and the other components of SOFC systems. An operating lifetime of at least 40,000 hours in the case of small-scale systems and even more for large-scale systems is required, which calls for better overall designs, given by real operational feedback. At the same time, investment costs related to the deployment of SOFC systems has to be decreased as much as possible to enable breakthrough on the commercial energy markets and thereby generate this operational experience.

When compared to established technologies for energy production (e.g. engines or gas turbines) widespread commercialisation of the SOFC technology is hindered by a relatively high cost of the SOFC-specific system components and limited availability of products, again due to the absence of developed markets and production.

Therefore, reduction of cost, long lifetime and availability are the high-level objectives for the SOFC technology in general, and for the AFC IEA TCP – Annex 32 in particular. These are prerequisites for a SOFC system for stationary and micro CHP applications and the targets that the Annex wishes to clarify, bring closer and help the community to strike.

The inherent voltage degradation phenomena of SOFC stacks is the most important factor that affects the durability and lifetime of a SOFC system. For stationary applications, voltage degradation rates below 0.25%/kh have to be achieved to ensure lifetimes long enough for the products. In addition to the SOFC stack, also the other components of the system, and the system as a whole, must endure years of continuous operation without unreasonable performance degradation or component failures. With the advent of large scale, standardised production of dedicated components and peripherals for SOFC systems, the lifetime and performance of system components can be better established, predicted and improved.

The means Annex 32 intends to employ the following to reach these overall objectives:

- The continuation and intensification of the open information exchange to focus and accelerate the development of SOFC towards commercialisation.
- The organisation of a series of annual workshops where representatives from the participating countries present the status of SOFC research, development and demonstration in their respective countries, in addition to discussing a selected topic.
- Where possible, these workshops will be linked to other relevant conferences, to maximise scientific impact and minimise travelling costs. The workshops lead to open discussions relating to common problems and will be organised to have realisable and achievable aims.

Active partners of Annex 32 are Denmark, Finland, France, Germany, Italy, Japan, Korea, Sweden, Switzerland, the USA and the Netherlands.

The overall operating Agent of Annex 32 is Dr. Jari Kiviaho from VTT Technical Research Centre of Finland (e-mail: jari.kiviaho@vtt.fi, gsm: +358 505116778).

4.3.1 Activities

The new period for this Annex started in 2014, and a brief update was provided on Annex 32 at the December 2014 meeting in Grenoble, France, however otherwise this Annex has not met formally in 2014 due to Finland re-considering their involvement with and resourcing of fuel cell research in general. Therefore it was not possible for the Operating Agent to organise and run a workshop. Activities will recommence in 2015.

4.3.2 Work plan for next year

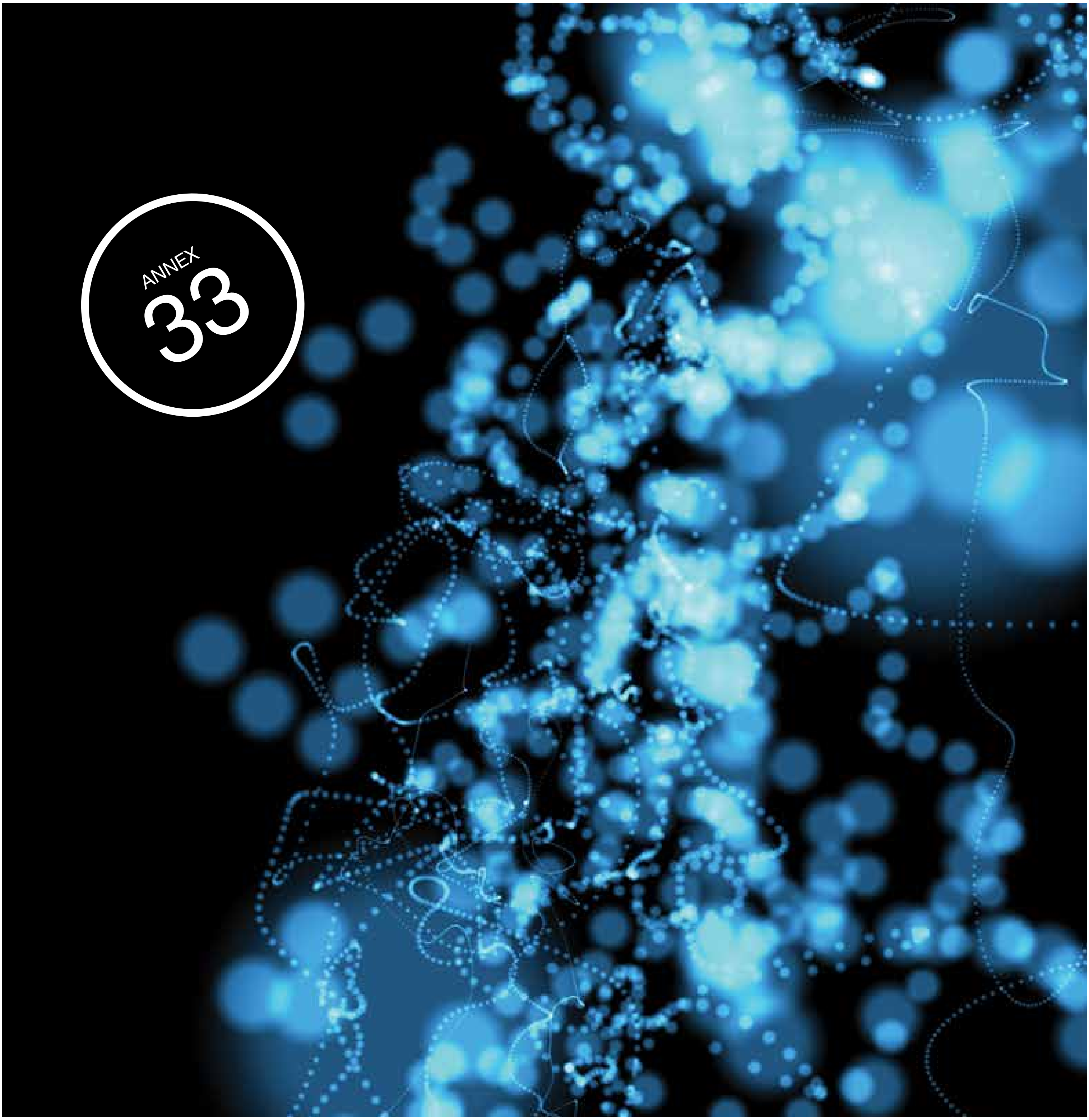
The overall objective is the continuation and intensification of the open information exchanges to accelerate the development of SOFC towards commercialisation.

Coming back from the break discussion will be held on where specifically the annex plans to develop and why, but in general the main focus areas are the following:

- Costs structures of SOFC stacks and the whole SOFC systems.
- Degradation mechanisms and accelerated life-time testing.
- Durability and lifetime issues.
- Identification of possible opportunities for collaboration.

The next meeting will be held in conjunction with SOFC XIV in Glasgow on the 31 July and 1 August 2015. This will be followed by a meeting to be held in conjunction with European Fuel Cell Forum in Luzern on July 2016.

Work will be carried out to update the 2013 SOFC Yellow Pages document in 2015/2016. This publication was extremely well received, with a number of producers wishing to contribute to an updated version.



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

4.4 ANNEX 33 REPORT

STATIONARY FUEL CELLS

Key messages – facts
Stationary fuel cells

- The installation and sales of stationary fuel cells has increased significantly in the last year. In September 2014 100,000 fuel cells were sold in Japan.
- A higher efficiency is important for the economy and the environment. The number of SOFC in sizes up to 5 kWe has increased extensively.
- Large fuel cells from 100 kWe up to MW-class is a success in several regions, but they depend heavily on subsidies.
- Fuel cells as back-up or power in remote areas is an increasing market worldwide in telecommunication and data centres.

Key messages – opinions
Stationary fuel cells

- Stationary fuel cells.
- The developers of fuel cells from Japan has a great advantage with huge amounts of installations and experience from operation and production. These experiences are essential for a commercial breakthrough globally.
- Larger fuel cells using biogas as a fuel have several advantages over other technologies and will be important for the reduction of GHGs.
- New building and energy directives can be of great advantage for fuel cells.

The objective of the Stationary Fuel Cells Annex is to better understand how stationary fuel cell systems may be deployed in energy systems. The Annex follows on from Annex 25, which ended in February 2014. Annex 33 has been in operation since February 2014 and will run until February 2019. The Operating Agent for this Annex is Bengt Ridell, from SWECO/Grontmij AB, financed by the Swedish Energy Agency.

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

The work focuses on the requirements from the market for stationary applications – opportunities and obstacles. The market development is followed closely with a special focus on fuels, environment and competiveness. In addition to fuel cells requirements for all kinds of stationary applications, Annex 33 also investigates grid connections and in some cases standalone applications.

The research activities in Annex 33 cover all fuel cell technologies and sizes under development via six subtasks. These provide a new direction for the Annex as it includes fuel cells in future energy systems, encompassing different power to fuel systems, smart grids and energy storage. The six subtasks are:

1. **Fuel cells for residential buildings: Germany, Japan, Denmark**

   This investigates the market potential for residential stationary fuel cells.

2. **Fuels for Fuel Cells: ENEA Italy**

   This identifies where fuel cells can have a significant advantage over competing technologies via their fuels with focus on renewable fuels but also natural gas will be dealt with.

3. **The Implementation of the new Buildings and Energy Directives: opportunities or threats for fuel cell systems: Austria**

   This is a new subtask and investigates the consequences and opportunities for fuel cells caused by the new European Building Directive (EPBD) along with other directives, such as the Energy Efficiency Directive (EED) and the Ecodesign and Labelling Directive.

4. **Large fuel cells plants and development of the MCFC technology: Switzerland, Korea**

   This subtask will include follow up of demonstrations and use of larger fuel cells plants. The previous MCFC annex will be incorporated in this subtask.

5. **Fuel cells in the future energy systems and modelling of fuel cell systems: Switzerland, USA**

   The purpose of the subtask is to find different role for fuel cells in future energy systems, smart-grids, power to fuel etc. The modelling part will be as to review cases developed by Gaia ERI, USA.

6. **Market status and role out strategies: Sweden**

   This subtask presents the latest market developments and other news.

The membership of this Annex continues to grow as the area becomes more focused on market applications. There is still considerable research activity relating to stationary fuel cells, but products are beginning to enter the mainstream markets. New members have joined the Annex from Italy and from Sweden, but representatives from Israel have not joined in 2014.

Table 4.4: List of participating organisations in Annex 33

Country Participant	Associated Institution
Austria	Austrian Energy Agency (x2)
Belgium	Waterstofnet
Denmark	Dantherm Power
Denmark	IRD
Finland	VTT
France	GDF Suez
Germany	E.ON
Germany	FCES
Germany	FZJ Jülich
Italy	ENEA
Italy	SOLIDPOWER
Japan	Technova Inc (NEDO)
Japan	Toshiba
Japan	Panasonic
Japan	AISIN Seiki
Korea	Korea Institute of Science and Technology (KIST)
Sweden	Grontmij
Sweden	PowerCell AB
Switzerland	Beratung Renz Consulting
USA	Energy Systems (Doosan)
USA	Gaia ERI
USA	US Department of Energy

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

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

The motto for Annex 33 is 'to prepare stationary fuel cells for the market and the market for stationary fuel cells'. It is important to advise authorities and developers of the key steps necessary for market introduction and expansion.

4.4.1 Activities

Annex 33 held two meetings in 2014. The first was hosted by hosted by ENEA, and held in Trento, Italy in April. Annex 33 members in attendance included Austria, Denmark, France, Germany, Japan, Sweden and the USA.

The second meeting took place in Hobro, Denmark in October 2014. The participants include Germany, Japan, the USA, Sweden, Italy, France, Finland, Switzerland, Denmark, Austria, Belgium, Israel, Mexico and South Korea.

A report from Subtask 1, a position paper for small fuel cells in buildings is based on the conditions in Germany including market viability and requirements have been published.

The major ongoing programs from Japan, Germany and Denmark for small stationary fuel cells for buildings have been followed closely and the last meetings have had special focus on Japan, Germany the European ENE. FIELD project

4.4.2 Technical Developments

Subtask 1: Small Stationary Fuel Cells for Residential Buildings

Germany, Japan and Denmark.

This subtask investigates market possibilities and viability for the small residential stationary fuel cell market

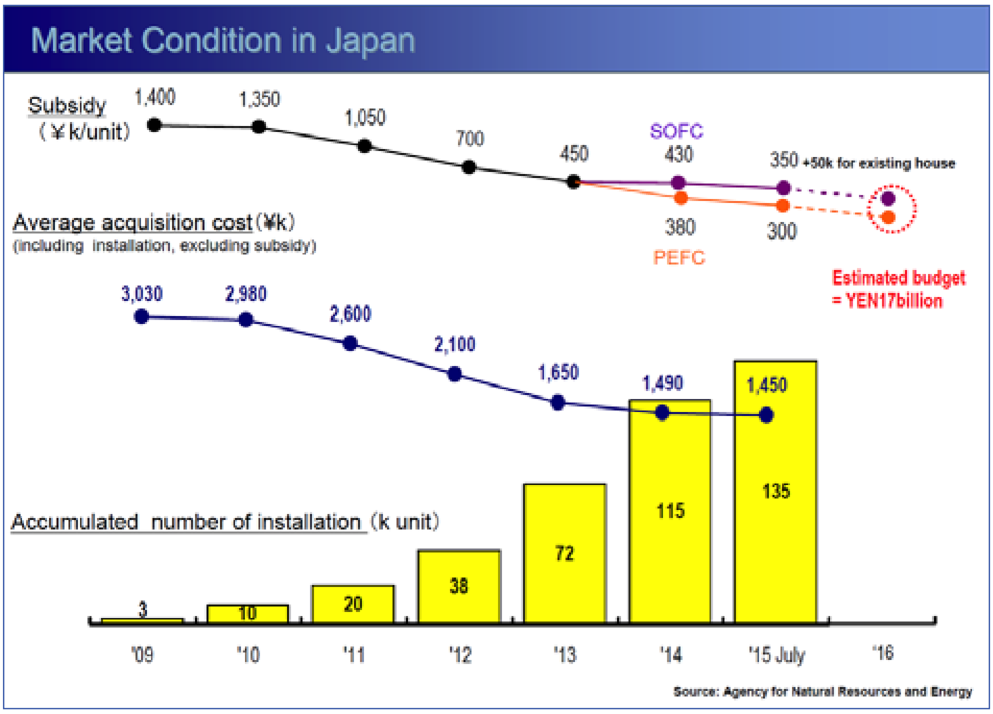
The market activities have increased significantly, especially larger demonstration projects for small stationary fuel cells for residential use. The market conditions can vary significantly between different regions for energy demand, energy prices and the regulatory framework. The EU-project FC-Eurogrid is investigating this issue in detail.

High electric efficiency for CHP is becoming more and more important as the heat demand for new buildings is decreasing and electricity demand is increasing.

SOFC for residential fuel cells is an increasing market in Japan and Northern Europe today: Aisin CFCL, Staxera, Hexis and TOFC have started with prototypes in Denmark and Japanese companies are entering the European market.

In Japan, PEFC is dominating – 100,000 units have been installed, but the rate of sales of SOFC is increasing. During the introductory period, annual sales are limited by the subsidy rendered by the government. PEMFC have sold more due to price competitiveness and earlier penetration in the market.

Figure 14. Annual sales and subsidies



In Europe, the ENE.FIELD project brings together eight mature European micro fuel cell combined heat and power (FC-CHP) manufacturers into a common analysis framework to deliver trials across all of the available fuel cell CHP technologies. ene.field will deploy up to 1,000 residential fuel cell Combined Heat and Power (micro-CHP) installations, across 11 key European countries. It represents a step change in the volume of fuel cell micro-CHP (micro FC-CHP) deployment in Europe and a meaningful step towards commercialisation of the technology. GDF-Suez are participants in ene.field and in Annex 33 and explained that they will install 27 fuel cells in France – including 5 BAXI Premio (PEM) and 5 HEXIS Galileo (SOFC). The French gas distributor GRDF plans to install 10 Vaillant systems.

A report has been published under this subtask. This can be downloaded from the AFC website. A new version is planned.

An important message from the work to date has been that for fuel cells in buildings a high electric efficiency is a great advantage.

Subtask 2 – Fuel for Fuel Cells

This subtask identifies where fuel cells can have a significant advantage over competing technologies via their fuels. For example it considers the following:

- Renewable biofuels and hydrogen from intermittent power sources such as solar and wind.
- Fuels that do not compete with food production.
- Waste fuels, including hydrogen.

- Anaerobic digester plants, sewage gas.
- Waste from agriculture or from the food industry.
- Issues for natural gas, such as gas quality and impurities.

Contributions have been made by ENEA, considering Biogas for fuel cells, by GDF Suez on natural gas quality, by Dantherm Power on fuels for residential fuel cells, and by GDF Suez on natural gas quality.

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

Technical developments in 2014 included work by Nicola di Giulio's of the University of Genova on 'High temperature fuel cells, innovative applications and contamination issues'. Further to this, the influences of different impurities such as H_2S, SO_2 and NOx on MOFC and SOFC have been investigated by experiments and simulations.

Natural Gas Quality

Figure 15 illustrates examples of outcomes from the study of natural gas quality in France. The natural gas quality varies significantly and can disturb the operation of the fuel cells. This is an important problem to solve, particularly with regards to the export market for CHP units.

Figure 15: Wobbe at border delivery points (MJ/m^3 at 15/15)

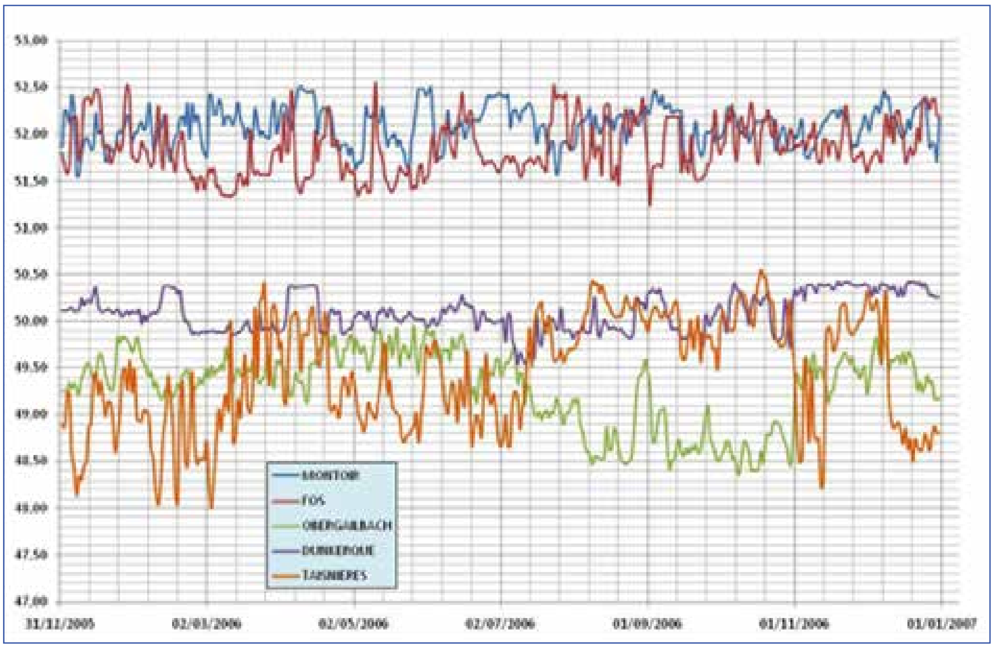


Table 4.5: Natural gas nitrogen content

	LNG	Domestically produced natural gas			Overseas natural gas	
		Chiba Region	Japan Sea Region	Hokkaido Region	The Netherlands	Germany
Methane	89.60	99.54	88.01	86.65	81.30	86.46
Ethane	5.62	0.00	5.18	7.74	2.90	1.06
Propane	3.43	0.00	1.82	2.80	0.40	0.11
Butane	1.35	0.00	1.00	1.12	0.10	0.03
C5+	0.00	0.00	0.64	0.26	0.10	0.02
Nitrogen	0.00	0.06	2.49	1.43	14.30	10.24
Carbon dioxide	0.00	0.40	0.86	0.00	0.90	2.08

Dantherm

Dantherm Power presented at both 2014 Annex meetings on their Danish demonstrations project on fuel cell based Micro-CHP and fuelling options for fuel cells. Figure 16, extracted from the presentation, describes a micro-CHP system fuelled by hydrogen and natural gas based on LT-PEM. Figure 17 shows a schematic for a hydrogen-fuelled LT-PEM system. Both figures are courtesy of the Danish µCHP Program.

Figure 16: Schematic showing the fuel cell micro-CHP fuelled by hydrogen and natural gas

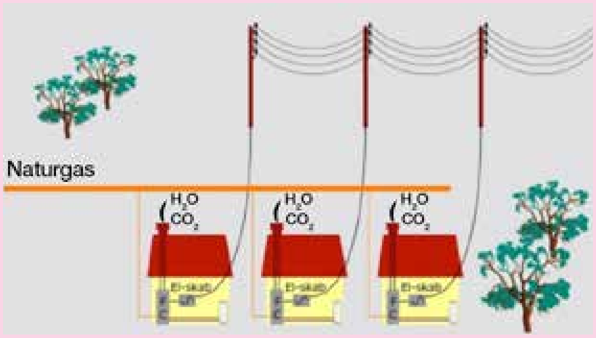
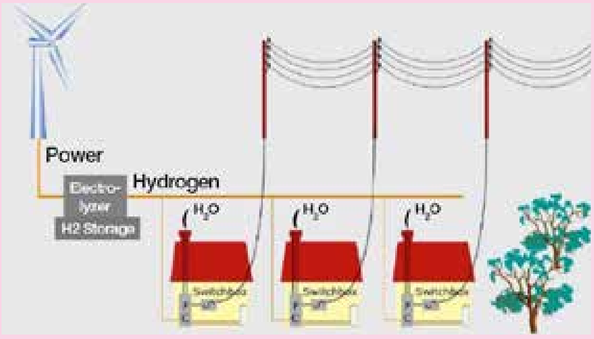


Figure 17: Schematic showing the fuel cell micro-CHP fuelled by hydrogen



Subtask 3: The implementation of the new buildings and energy directives: opportunities or threats for fuel cell systems

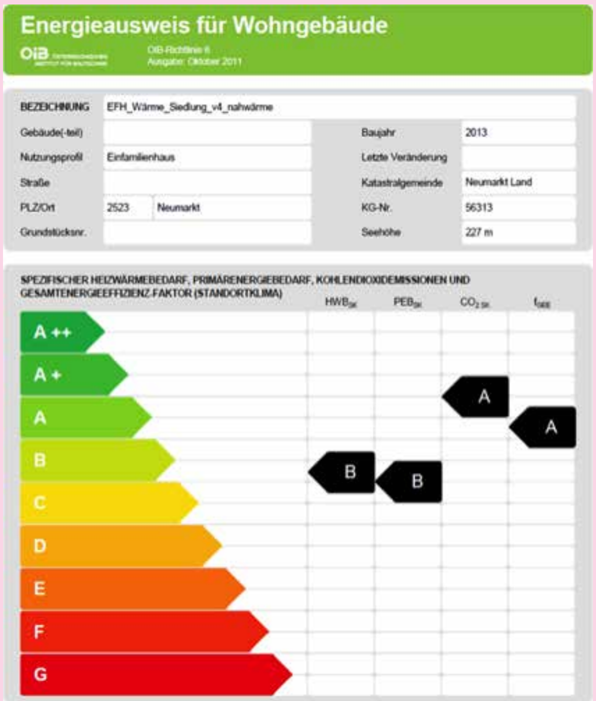
This subtask is new for 2014 and is led by the Austrian Energy Agency. It is reviewing the impacts of the following Directives, whose relevance is described below:

- Energy Efficiency (EE) Directive:
  > Acceptance of fuel cells as energy efficiency measure.
  > Development of methodologies to show the energy efficient performance of fuel cells compared to conventional technologies (linked to CEN methodologies).
- Ecodesign and Labelling Directive:
  > Suggestions for ecodesign standards for stationary fuel cells.
  > Higher class labels for fuel cell systems.
- Building Directive (EPBD):
  > Cost optimality, lower energy demand and power demand, EPCs – an opportunity or threat for fuel cell systems in EU member states?
- RES Directive:
  > Diversification of subsidy schemes for biogas/ biomass fuel cell systems an RES hydrogen fuel cell systems.

Overall, the Directives introduce feed-in tariffs, tax reductions and investment subsidies for CHP and renewable fuel use.

The EPBD in Austria recently expanded the list of labelled considerations for its buildings from heating demand to include primary energy demand, CO_2 emissions and total energy efficiency (including efficiencies for the heating system, domestic hot water, electricity demand for pumps, lighting and ventilation, air conditioning, etc). An example of the relevant label is shown in Figure 18.

Figure 18: An Austrian example of a label required by the EPBD



The new subtask has planned preparatory work through to spring of 2015, including analysis of these Directives and the relevant Regulations with regards to role of fuel cells, and to output a first draft of a questionnaire exercise for participating countries.

Austrian Energy Agency

Manuel Mitterndorfer from Austrian Energy Agency (AEA) presented in Trento on the implementation of European Directive and regulations. The presentation particularly focused on identifying if there are opportunities or threats from the Buildings Directive (EPBD) for fuel cell systems in EU member states. This subtask is also looking at the impacts on cost optimality, lower energy demand and power demand and EPCs under EPBD. Based on the requirements of EPBD in Austria a reference building was developed for an economic and ecological evaluation of fuel cell systems. The performance of the fuel cell was measured:

Large fuel cell plants and development of the MCFC technology

The continuation of the activities in the previous MCFC Annex will be performed under this subtask. KIST from Korea, Fuel Cell Energy USA and ENEA Italy will provide detailed information about the development MCFC technology and market. The forms and actions are still under discussion. To start will issues regarding the status of the technology and market be dealt with. Specific technical issues will be handled as soon as they are demanded by the participants.

The development of the market for other large-scale fuel cells will be reported in this subtask (for example, SOFC, PAFC and large-scale PEFC). The conditions for the implementation of large scale fuel cells and the performance etc will be discussed.

The activities in Korea and the expansion of POSCO Energy fuel cells were presented by KIST. POSCO Energy is now manufacturing complete MCFC systems from cell to energy plant. The manufacturing capacity in Korea is today 100 MWe per year. The basic module is a 2.5 MWe plant with 47% electrical efficiency LHV. Korea has today installed in total 150 MWe of MCFC plants at 23 different sites. The largest plant is in Hwasung 59 MWe owned by Gyeonggi Green Energy.

Different fuels are used. In Busan is one 1.2 MWe unit installed at the wastewater treatment plant using biogas as fuel. POSCO Energy is planning to build a larger plant of 20 MWe at World Cup Park in Seoul using landfill gas as fuel.

POSCO Energy is exporting MCFC to other countries in Asia. The first export plant is a 300 kWe plant in Jakarta, Indonesia.

POSCO is also developing a SOFC technology – a 10 kWe unit is ready.

Fuel Cell Energy USA presented their concept with poly-generation from an MCFC plant including generation of hydrogen as vehicle fuel. Fuel cell Energy has developed a Solid State Hydrogen Separation unit EHS each unit with a capacity of 25 kg Hydrogen per day. The EHS unit is modular and can easily be scaled up to MW size.

Two different site using hydrogen production from MCFC were presented Orange county WWT plant and one in Vancouver Canada that can handle production cold weather. Both sites are using biogas as fuel from ADG or Landfill gas.

The hydrogen is extracted from the exhaust gas of the MCFC. This gas is otherwise preheating the inlet air. The about 24% of the hydrogen produced in the

MCFC plant can be used as hydrogen vehicle fuel. For instance in the large 14.9 MWe MCFC park in Bridgeport CT is the potential for hydrogen production 6 tons per day.

Subtask 5: Fuel Cells in Future Energy Systems

Subtask 5 is new for 2014 and is led by Stephan Renz of Switzerland.

Particular areas of focus are:

- Different power to gas/fuel systems.
- Smart grids.
- Energy storage.

The main topic is to study the role of fuel cells in different future energy systems like smart grids or renewable systems including intermittent production etc. special applications can be fuel cells in combination with heat pumps and the power-to-fuel concept. USA will contribute to the subtask by presenting their work on modelling and validation of different fuel cells systems. Several reports have been presented and discussed in the previous Annex 25. The plans are to continue with these reviews also in Annex 33. Some reports will be available on the Annex 33 website after they have been published.

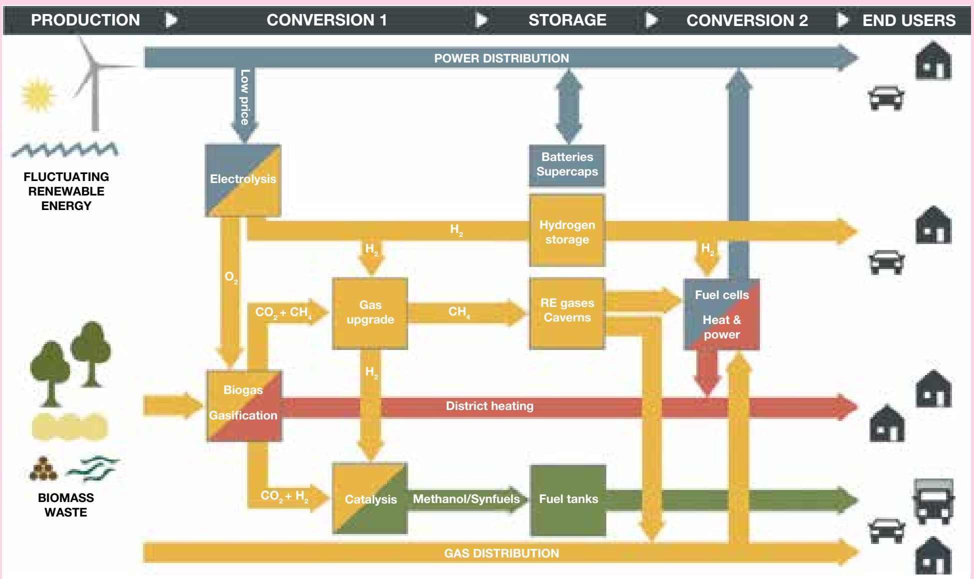
The Danish Partnership for Hydrogen & Fuel Cells

The Danish Partnership for Hydrogen & Fuel Cells presented in Denmark, October 2014 on the Danish ambition of independency of fossil fuels, which is a strong driver for Hydrogen and Fuel Cells. The targets for developing hydrogen and fuel cells technologies in Denmark are in place to:

- Balance the future renewable based energy system.
- Fuel the transport sector with renewable energy.
- Obtain a strong position for trading of electricity.
- Have an early market entry.

The presentation proposed a schematic (Figure 19) for integration of renewable energy.

Figure 19: Integration of renewable energy sources



In terms of green transport Denmark is planning to have a country wide Hydrogen Refuelling Stations (HRS) network by 2015 covering top 6 cities. Between 2013- and 2014 a staged approach that coordinates HRS network & FCEV roll-out and ensures public support is being used. There is currently extensive national market FCEV/HRS planning and modelling ongoing on continuous basis.

Denmark also has a large budget to potentially use for hydrogen and fuel cells compared to many other countries. Hydrogen and fuel cells will play a key role in the future of Denmark:

1. Danish energy policy is a strong driver for technological development within hydrogen and fuel cells.
2. Hydrogen and fuel cells will play a key role for the future energy system.
3. The transition is affordable and technically feasible.
4. Hydrogen and fuel cell products have the potential of economic growths.

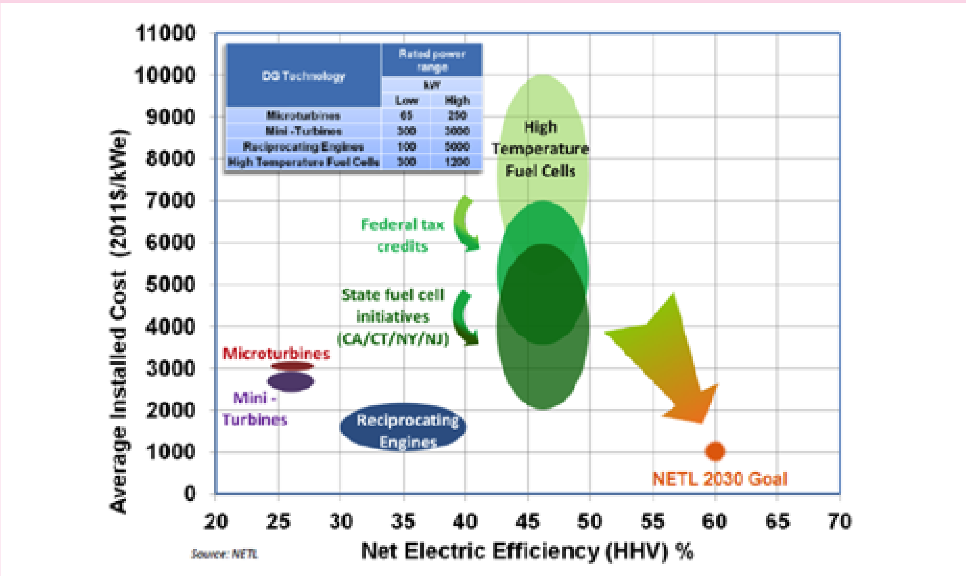
Subtask 6: Market Status

Subtask 6 highlights the latest developments in stationary fuel cells. Examples of sources of information include:

- Solid State Energy Conversion Alliance (SECA) program information from US DOE.
- CFCL and E.ON: micro CHP systems for sustainable buildings.
- Dantherm Power's experience from micro CHP demonstrations.
- SOFCPOWER 5 kWe SOFC for buildings.

Figure 20 gives a perspective on current costs and performance of fuel cells compared to alternative technologies – and the NETL 2030 goal.

Figure 20: Distributed generation – current performance and cost perspective



2014 was the first year for Annex 33 several new subtasks has started compared to the previous Stationary. The plans are to compile and publish at least the following reports

- Subtask 1: Fuel Cells in Buildings. This report will be compiled in cooperation between Ulf Birnbaum and the Operating Agent.
- Subtask 2: Renewable Fuels for Fuel Cells. ENEA will provide this report a draft of the final report will be presented and reviewed in the spring meeting 2016.
- Subtask 3: EU Directives. The Austrian Energy Agency will provide a draft final report from this study in Subtask towards the end of 2016.
- Subtask 5: Fuel Cells in Future Energy Systems. Stephan Renz will write this report.

4.4.3 Work Plan for Next Year

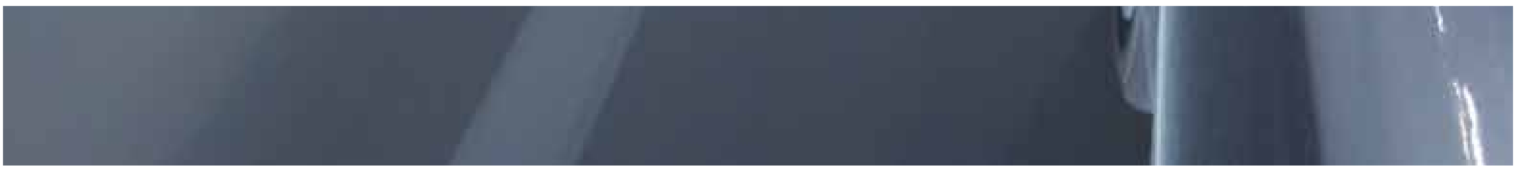
It was decided to merge the MCFC Annex into the work of the stationary annex going forward, as MCFC activities are now carried out by only a few producers – essentially, harmonisation or production has now occurred and the systems are now used in stationary applications, especially the grid level applications in South Korea.

Subtask 3 has planned preparatory work through to spring of 2015, including analysis of the Energy Efficiency (EE) Directive, the Ecodesign and Labelling Directive, the Building Directive (EPBD) and the RES Directive and the relevant Regulations with regards to role of fuel cells. This will lead to the output of a first draft of a questionnaire exercise for participating countries. Subtask 3 has also planned meetings to analyse the results of the questionnaires, assess the outlook for fuel cells in participating countries and to give an overview of the regulations in other non-EU countries. In 2016, the subtask will present their draft and final report.

Next year, the Annex intends to conduct activities to attract new members. It will continue to have two meetings in 2015, and as pre-commercialisation has started there is to be a larger focus on market issues and a new topic: the different frameworks, Directives and available subsidies.

The next meeting, in April 2015, will be hosted by the Austrian Energy Agency; the autumn 2015 meeting will be held in Los Angeles in connection with the Fuel Cell Seminar.

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



4.5 ANNEX 34 REPORT

FUEL CELLS FOR TRANSPORTATION

Key messages – facts
Fuel cells for transportation

- Cost of fuel cell electric buses (FCEBs) has consistently decreased over time, but remains a barrier to the uptake of the technology.
- FCEB fuel economy consistently higher (2X) than diesel and CNG baseline.
- FC powerplant lifetime is 16,000 hours (max) versus 25,000 hour target.
- FCEB lifetime is currently 5 years or100,000 miles (161,000 km), target is 12 years or 500,000 miles (805,000 km).
- Between 55% and 72% bus availability, target is between 85% and 90%.

The objective of Annex 34 is to develop an understanding of fuel cells for transportation with their particular properties, applications, and fuel requirements. Vehicles addressed include fork-lift trucks, passenger cars, auxiliary power units (APU), buses, light duty vehicles and aviation power. This follows on from Annex 26.

This Annex has been in operation since February 2009 and will run until February 2019. The Operating Agent for this Annex is Dr Rajesh Ahluwalia from the United States Department of Energy's Argonne National Laboratory (ANL), in Illinois.

Table 4.6: List of participating organisations in Annex 34

Country	Associated Institution	Name
Austria	A3PS	M. Nikowitz M-M. Weltzl
Denmark	H_2 Logic	M. Sloth
Finland	Aalto University VVT	A. Lajunen T. Keranen
France	Institut FC Lab CEA Liten	F. Petit L. Antoni
Germany	Forschungszentrum-Jülich GmbH RWTH – Aachen	T. Grube B. Gnörich
Italy	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)	M. Conte
Korea	KIST Hyundai Motor Corporation	EunAe Cho Sungho Lee
Sweden	Volvo Technology Corporation PowerCell	A. Selimovic P. Ekdunge
USA	Argonne National Laboratory (ANL)	R. Ahluwalia

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

4.5.1 Activities

The seventh workshop of Annex 34 was held on December 3, 2014 in Grenoble, France. The workshop consisted of technical presentations and discussions with particular emphasis on hydrogen infrastructure and technology validation. Fourteen representatives from five countries participated in the workshop.

4.5.2 Technical developments

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

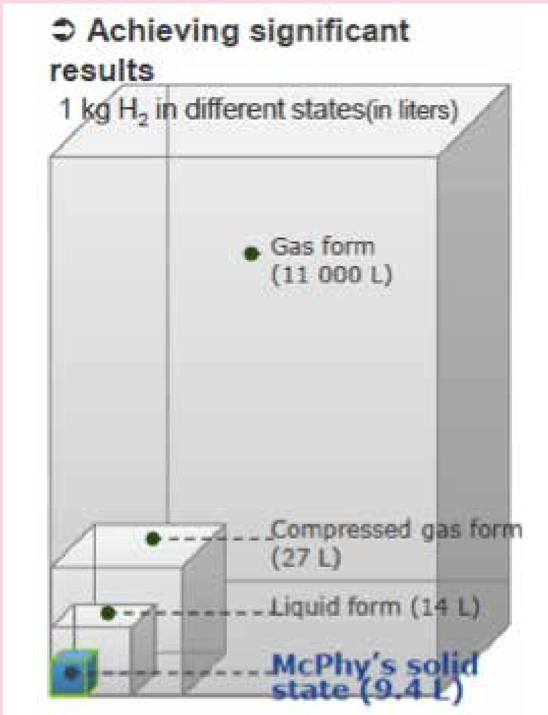
Subtask A Advanced Fuel Cell Systems for Transportation

This subtask focuses on the fuel cell system and hydrogen storage technology technology.

FC Heavy is an ongoing project for the School of Engineering at Aalto University. The project aims to create a model of a heavy machine powered by a fuel cell. Its current objective is to evaluate the energy effiency and dynamic performance of hybrid fuel cell machines. A model developed previously is being integrated into the Autonomie vehicle simulation software, which is being developed in collaboration with ANL. The technological viability and lifecycle costs of hybrid fuel cell powertrains are also being investigated.

McPhy Energy has made progress in the use of metal hydrides (MgH_2) to store hydrogen in a solid state, which enables a significantly greater density of hydrogen storage. McPhy has developed additives and nano-structured MgH_2 to speed up the processes of hydrogenation and dehydrogenation during hydrogen absorption and desorption cycles. Systems are available for 100-300 kg solid hydrogen storage at hydrogen production sites.

Figure 21: The storage space required for solid state H_2, as developed by McPhy



The Austrian FCH-Cluster, with A3PS, have been working on some vehicle concepts, including simulation. These include modular systems for innovative propulsion systems, such as ICE and xEV systems. They are working on the development of production processes, including synergies between and parallel propulsion of conventional, hybrid and fuel cell propulsion systems. This area of research also includes the optimisation of hydrogen storage in the vehicle, including the maximisation of capacity and the minimisation of costs. Finally, there has been work on the testing and validation of components, systems and vehicles, including work towards the geometrical and functional integration of new technologies into the vehicle.

The Argonne National Laboratory has investigated cell performance and performance degradation using different cathode catalysts. More specifically, they have found higher kinetic performance in cells with smaller particles and those alloyed with cobalt. They also observe that kinetic benefits are offset by mass transport effects at higher current densities. These are trends in initial cell performance. Some general trends were also found for cycling durability. It was seen that there is a higher stability in systems with larger cathode catalyst particle sizes; catalysts with particles that are in excess of around 5 nanometres meet US Deparment of Energy targets for performance loss associated with degradation.

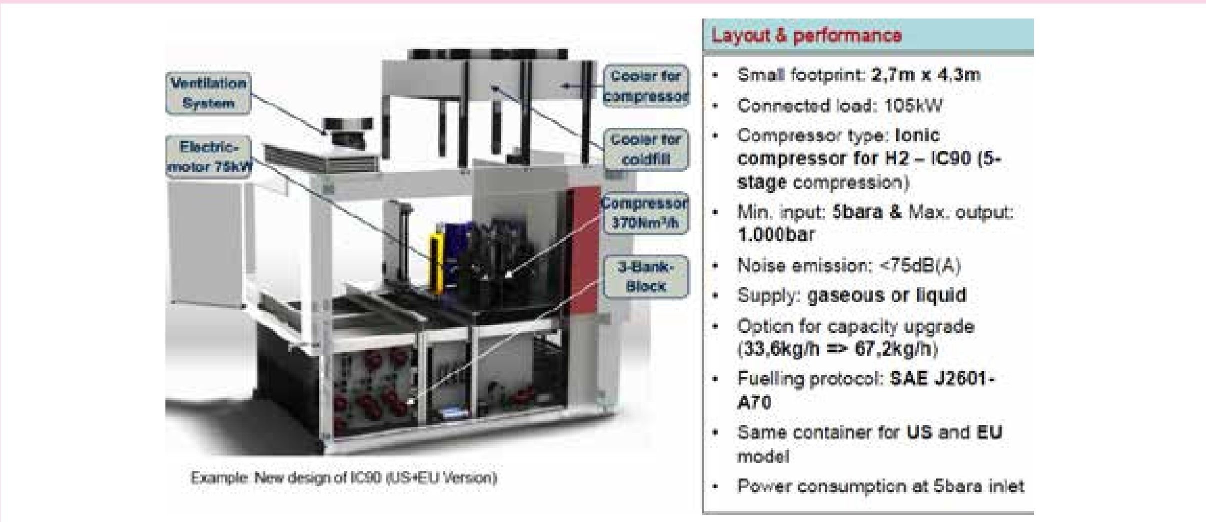
Ballard has investigated the relationship between performance degradation and air quality impact. They have found that generated SO_2 concentrations rise as performance degrades, as measured by the fuel cell voltage. The test was carried out on three PEFC-powered buses in Hamburg. They also observe that the membrane lifetime is positively correlated with the amount of time spent at higher voltages, but negatively correlated with the number of air/air starts.

Subtask B: Fuel Infrastructure

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

A3PS have supported the Linde Group in continued development of their hydrogen refuelling stations. The Group are moving from prototypes to small-series serial production, which has led to the construction of the world's first production facility in for hydrogen-fueling stations based in Vienna. As a result of this first station, an agreement has been put in place with the Iwatani Corporation of Japan for the delivery of 28 of the units. The Linde Group is demonstrating technology leadership through its innovative IC90 ionic compressor, Figure 22.

Figure 22: Hydrogen fuelling station for serial production: the Linde Group IC90 Ionic Compressor



Subtask C: Technology Validation

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

The US Department of Energy presented a series of American accomplishments in the field of transport. These are the results from a study looking at fuel cell-powered buses. The buses in the test have fuel economies that are up twice as good as the expected baseline economy, as based on 2016 and ultimate targets. The Department of Energy has introduced funding for light-duty fuel cell vehicle data collection projects. They have set aside USD 5.5 million for the project, which has six industrial partners and has collected data from up to 90 vehicles including fuel cell powered vehicles by Honda, Toyota and Nissan. The study will be evaluating fuel cell stack durability and efficiency, range, driving behaviour, fuel economy, maintenance, on-board hydrogen storage performance, hydrogen refuelling performance and vehicle safety. The first composite data products are scheduled for release in October 2014.

A demonstration and validation test is underway for a high-pressure liquid hydrogen pump, located in Ontario, California. The project is demonstrating the viability of cryogenic pressurised hydrogen storage and delivery. Phase 1 will involve the manufacture of a new generation pressure vessel. Phase 2 and 3 will look at long-term LH2 pump and vessel testing. The study is being carried out with support from the US Government, Linde North America, BMW and Spencer Composites. The project will receive USD 1.6 million in funding.

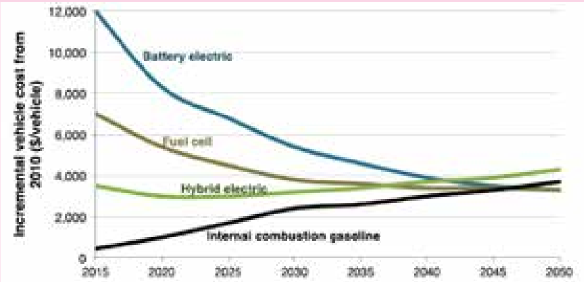
Finally, Air Products and Chemicals Inc. has partnered with Structural Composite Industries to develop advanced tube trailers for hydrogen delivery. The objective of the project is to develop a system based on high-pressure composite over-wrapped pressure vessel (COPV), which is a type of composite storage technology, and test it for six months in real-world conditions. This technology can provide up to three times the capacity and eliminates the need for a compressor at the station site, thus decreasing station space needs and capital costs. It is expected that hydrogen fuelling costs can be lowered by between 30% and 60% as the trailer would be capable of transporting up to 920 kg of hydrogen on a single trailer.

Subtask D: Economics

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

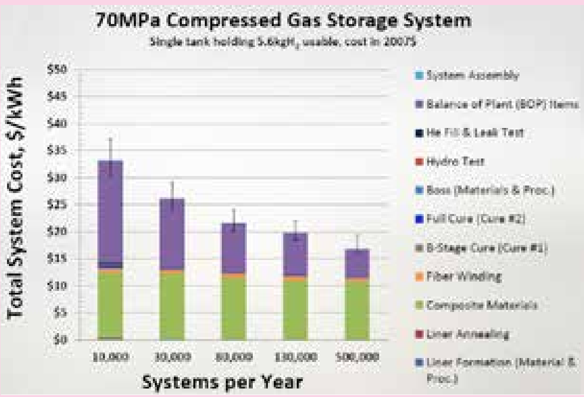
The ICCT are conducting an assessment into electric vehicle technologies and costs. The study will look into the details and costs of long-term advanced internal combustion engines, hybrid technologies and electric vehicle technologies, Figure 23. The current output shows that fuel cell vehicles have a better economic performance than current battery electric vehicle.

Figure 23[25]: Output from the ICCT EV Technology-Cost Assessment



The focus during 2014 has also been around the cost of compressed gas storage systems. A study has estimated the system costs for a single 700 bar tank that shows that the tank material costs are mainly driven by the carbon fibre cost and balance of plant at all annual production rates modelled (Figure 24).

Figure 24: System cost results



Publications from this Annex

A key publication from the Annex in this period is:
T. Q. Hua, R. K. Ahluwalia, L. Eudy, G. Singer, B. Jermer, N. Asselin-Miller S. Wessel, T. Patterson, and J. Marcinkoski, 'Status of Hydrogen Fuel Cell Electric Buses Worldwide', Journal of Power Sources, Vol. 269, pp. 975-993, 2014.

4.5.3 Work plan for 2015

The 8th Annex meetings will be held in Forschungszentrum Jülich, Germany, on 24 June 2015 and the 9th meeting took take place on 11 November 2015, hosted by A3PS in Vienna, Austria.

Some of the key areas that the Annex are focusing on for future work include investigating the niche applications that are attractive for market entry of fuel cell vehicles, investigating the main cost and durability barriers to mass adoption of fuel cells for light duty vehicles and looking into the future competitors to help address the questions of reduction of GHG emissions and fossil fuel consumption. These research areas have been mapped out as follows over the next 5 years:

- 1-2 years: fuel cell speciality transport applications.
- 1-2 years: fuel cell vehicles: fossil fuel consumption, WTT efficiencies and emissions.
- 1-3 years: fuel cell systems for Light Duty Vehicles.
- 3-5 years: cost projections for fuel cell systems and hydrogen storage.
- 3-5 years: degradation mechanisms and mitigation strategies.

[25] Published in Transitions to Alternative Vehicles and Fuels (2013), The National Academies Press.

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 35 REPORT

FUEL CELLS FOR PORTABLE APPLICATIONS

Key message – facts
Fuel cells for portable applications

- The market for portable fuel cells is one of the most interesting of the early markets.
- Durability of up to 20,000 hours in a DMFC system is proven. This is one step towards reducing the systems CAPEX and to become cost competitive to other technologies.
- There is a lot of research in the field of alkaline membranes for catalysts, as current portable fuel cells use cheap catalyst materials (such as nickel) that have low power density and durability.
- Portable SOFC systems fuelled by LPG are available in the sub-100 W class.
- The field of portable fuel cells for military applications is very active and is considered a challenging field.
- Active research is being conducted in a number of areas: development of new and alternative materials for membranes and catalysts, alternative fuel cell designs and fuels, and new diagnostic models and techniques for fuel cells.
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- Active research is being conducted in a number of areas: development of new and alternative materials for membranes and catalysts, alternative fuel cell designs and fuels, and new diagnostic models and techniques for fuel cells.

Key messages – opinions
Fuel cells for portable applications

- Future research topics will concentrate on increasing durability and reducing cost.
- New cell designs and alternative fuel/oxidant technologies will play an important role in portable and light traction systems.
- Portable fuel cells could be used for military applications, such as portable handheld power devices, APU and Aerial/Underwater Unmanned Vehicles (AUV/UUV).
- Liquid and solid media for hydrogen and oxygen could influence the stealth capabilities of fuel cells used in transport applications for military purposes.
- However, the major trend for portable fuel cells is to move away from conventional hydrogen fed PEM to systems operated with liquid fuels and alternative electrolytes.
- The market for portable fuel cell devices could benefit from the technological improvements arising from the use of fuel cells in military applications.

Annex 35 is concerned with fuel cells and fuel cell systems for portable applications and light traction. A 'portable system' ranges from a micro system at 250 W for small mobile applications up to a several kW system that can be moved by four people (the EC definition of 'portable') which is suitable for light traction and grid-independent stationary applications. This follows from Annex 27.

This annex focuses on the specific research demands and technical conditions needed to deliver viable fuel cells for portable applications. Promising technologies for these applications are polymer electrolyte fuel cells (PEFC) operated with methanol or hydrogen fuel. However, ethanol and propane are also potential fuels that can be used in these systems.

The Annex has been in operation since April 2004 and will run until February 2019. The Operating Agent for this Annex is Dr Fabio Matera from Istituto di Tecnologie Avanzate per l'Energia (ITAE) of the National Research Council of Italy (CNR), in Italy, who takes over from Dr Martin Müller.

Table 4.7: List of participating organisations in Annex 35

Country	Associated Institution	Name
Austria	Graz University of Technology	Theo Friedrich, Christoph Grimmer, Stephan Weinberger, Viktor Hacker
Germany	Fraunhofer Institut Chemische Technologien	Carsten Cremers, Tilman Jurzinsky
	NEXT-ENERGY	Alexander Dyck
Italy	Institute of Advanced Technologies for Energy (ITAE), National Research Council (CNR)	Irene Gatto Fabio Matera
Korea	Korea Institute for Energy Research (KIER)	Sang-Kyung Kim
Sweden	Intertek Semko	Maria Wesselmark

Fuel cells used to power portable and small mobile applications offer higher power density, longer operating times and shorter refuelling times compared to battery powered operation. Fuel cells can also avoid the need to spend time recharging batteries. Potential applications for portable fuel cells include Auxiliary Power Units (APU)/ Uninterruptible Power Supply (UPS) for mobile homes and boats, personal (handheld) power, military applications for soldiers in the field and for aerial, ground and underwater unmanned vehicles.

4.6.1 Activities

The last meeting was held at the Instituto di Tecnologie Avanzate per l'Energia Nicola Giordano, in Messina, Italy on 11 and 12 September 2014. It was attended by six members from five institutions: NEXT-ENERGY, Fraunhofer Institut Chemische Technologien, Graz University of Technology and CNR-ITAE.

4.6.2 Technical developments

This Annex focuses mainly on fuel cells for portable and light traction applications. Within this, the Annex works on four aspects:

- **Subtask 1: System Analysis and Hybridisation.**
- **Subtask 2: System, Stack and Cell Development.**
- **Subtask 3: Codes and Standards, Safety, Fuels and Fuels Packaging, Transportation.**
- **Subtask 4: Performance and Lifetime Enhancement.**

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

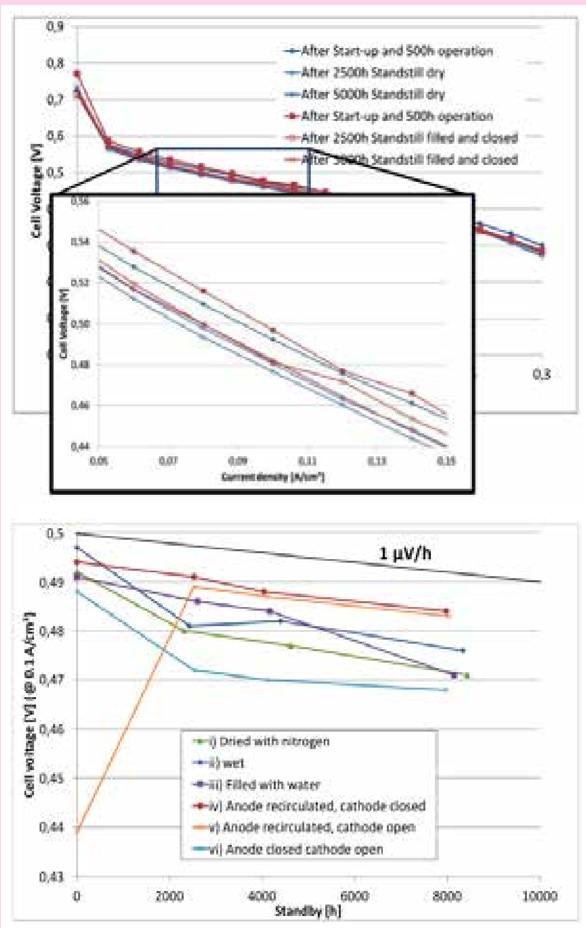
Portable fuel cells are usually used in conjunction with batteries: one option is to provide recharging of batteries, enabling remote and silent recharging; another is in hybrid systems, where the battery is used for start-up and peak shaving.

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

Subtask 1: System Analysis and Hybridisation

DMFC research activities have continued at Forschungszentrum Jülich during 2014. Their most recent work has been on the use of DMFC for uninterruptible power systems (UPS) in telecommunications and in light traction applications. In these applications, it is found that the degradation

Figure 25: Degradation during stand-still in a single cell and performance when anode fed continuously with methanol during stand-still



of membrane electrode assemblies (MEAs) is too high for systems in standby; between 2 µV and 5 µV per hour for a single cell (Figure 25). Forschungszentrum Jülich have been looking at alternative standby strategies, finding that the best results are obtained when the anode is continuously fed with methanol; degradation is close to 1 microvolts per hour. There are plans to test different reactivation procedures over the next few months.

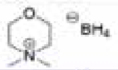
Subtask 2: System, Stack and Cell Development

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

One possible way to reduce costs is to replace the PEFC membrane, with an alkaline anion exchange membrane (AEM) as it avoids the need for platinum in the catalyst. These can use non-fluorinated membranes which introduces the possibility of using more readily available fuels such as ethanol or ethylene glycol, rather than methanol. This area is under investigation at the Korea Institute of Science and Technology (Korea), the Jagiellonian University (Poland), NEXT-ENERGY (Germany) and at CNR-ITAE (Italy).

At Graz University of Technology they have been researching the relative advantages of Ionic Liquid Borohydride (IL-BH_4), as compared to systems based on sodium borohydride ($NaBH_4$) (Figure 26). A foam-based catalyst form of IL-BH_4 is stable at ambient temperatures and pressures and is composed of non-noble metals. The University has utilised the catalyst in a batch hydrogen release process, using a self-regulating two-chamber batch cell. It has been found that the Ionic Liquid form has a number of advantages, including higher storage density, improved hydride stability and increased solubility. It is has also been observed that this process does not create precipitation. These properties depend largely on the organic cation. However, one downside is that the Ionic Liquid cation has a high molar mass.

Figure 26: Structures and hydrogen capacity of borohydride catalysts

Name	Structure	H2 capacity (theor.)
TMPA - BH_4		6.9 wt%
TOMA - BH_4		2.1 wt%
BMPyr - BH_4		5.1 wt%
DMMor - BH_4		6.1 wt%
TEMA - BH_4		5.5 wt%
$NaBH_4$		10.8 wt%

Current activities at Graz involve the development of support and catalyst materials, increasing the size of the IL-BH_4 fuel cell and implementing recycling by eletrochemical reduction. It is thought that this technology could be used in small to medium sized systems. Very small applications could include an ‘UPP’ mobile phone charger, using a metal hydride storage system. However, it is noted that this may be too difficult to adapt with present technology. Pragma Industries has built a motorcycle powered by a small sodium borohydride fuel cell, which is another example of an application for a small system. Medium-scale applications could range from 100 W to 1 kW and power devices such as forklifts and mopeds There could aslo be automotive applications for these systems.

Challenges identified include meeting the DOE targets, the gravimetric and volumetric system density of IL-BH_4, hydrogen and gas purification, and gas-liquid separation. A particular challenge would be the construction of a demonstration system.

In response to the EU-KORANET Joint Call on Green Technologies, the ACME project has been looking into new materials for use in fuel cells. The stated objective of the project is to develop stable, highly-conductive anionic membranes for application in fuel cells, solar cells (DSSC) and electrochemical CO_2 pumps. This project has been a collaboration between the Korea Institute of Science and Technology (KIST) and the Jagiellonian University of Krakow. These institutions have focused respectively on polymer synthesis and computational chemistry. As part of this project, NEXT-ENERGY has been looking into the electrochemical characterisation of these membrances, as well as carrying out application tests. Work has been done on developing platinum-free Membrane-Electrode-Assemblies (MEA). The project has also looked at alkaline polymer membrane fuel cells for platinum-free operation and the associated system design advantages for various applications. The outcomes of this project will include three scientific publications.

CNR-ITAE has also contributed to this area, using low-cost polymers as hydrophobic fillers to produce a composite membrane that has a high water retention rate at low temperature and high proton conductivity when highly sulphonated. This membrane will be used in a prototype, which will be of a borohydride or air-breathing type. This research is being carried out under the framework of the National Programme for Military Technology Research.

Some of the focuses of the NEXT-ENERGY Fuel Cell Division has been on using fuel cells as micro-CHP, as well as system analysis and characterisation. Reseach into characterisation has been focused on degradation in high-temperature fuel cells, the description of chemical and physical behaviours in fuel cells and approaches on using HT-PEM systems as micro-CHP. Micro-CHP has become a major topic and is a unique feature of the German research landscape. Other focus areas include system optimisation and industry research in the context of system analysis.

Research has also been done into the reduction of platinum content in direct methanol fuel cell (DMFC) cathodes at Forschungszentrum Jülich GmbH. Platinum presents a significant costs for such cells. With a partner organisation, they observe that platinum is used more efficiently at low loadings, in terms of power output per gram of platinum. They have also found that platinum-nickel catalysts can be more efficient than catalysts of pure platinum. They have also created a new tool for the detection of the current distribution in fuel cells and electrolysers. Hierarchically structured support leads to higher activity. Future research should focus on repeating these developments for anodes.

Subtask 3: Codes and Standards, Safety, Fuels and Fuels Packaging, Transportation

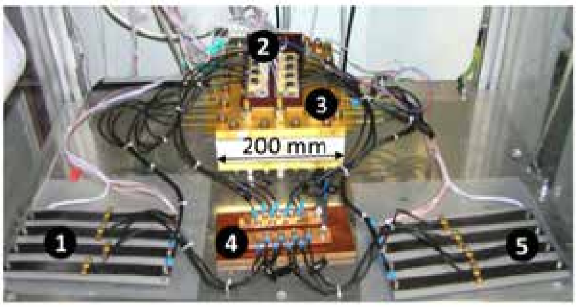
Work has continued on the EU project 'Development of PEM Fuel Cell Stack Reference Test Procedures for Industry' that is scheduled to run until August 2015. The project has 11 partners and aims to propose and validate harmonised and industrially relevant test procedures for PEMFC stacks. This includes generic test modules and application-specific test programmes for automotive, stationary and portable aplications. The developed test programmes are designed to assess functionality/performance as a function of relative humidity, temperature and pressure, as well as endurance during stop/start cycles and load cycling. Safety and environmental factors are also considered.

The IEC TC105 Working Group have been working on developing these standards for fuel cells and are these being mirrored by the German DKE K 384 Group.

Subtask 4: Lifetime Enhancement

Forschungszentrum Jülich GmbH has made progress in the development of a new tool for detecting the current distribution within fuel cells and electrolysers. The new detection technique uses equalising currents in the bipolar plate of the tool for detecting current distribution. The theoretical model for this process had already been developed: following validation tests it has been found that the local resolution is limited to around 25% of the active cell area with a three-slit configuration. The sensor (Figure 27) is easily integrated into a stack, as it is thin and all sensors are located outside of the stack. The setup also has a positive influence on stack performance, as the additional metal layer improved lateral conductivity by up to two orders of magnitude.

Figure 27: Experimental set up for the validation of the current distribution detector



Picture of the setup that is used for the investigation. From left to right: adjustable resistors (1); inductive current sensors (2); experimental setup (3); contact board (4); adjustable resistors (5).

Publications from this Annex

A selection of the key publications in 2014 are:

- A. Dyck, Fuel Cells Bulletin, 2014 (2014) 12-16.
- D. Henkensmeier, H. Cho, M. Brela, A. Michalak, A. Dyck, W. Germer, N.M.H. Duong, J.H. Jang, H.-J. Kim, N.-S. Woo, T.-H. Lim, International Journal of Hydrogen Energy, 39 (2014) 2842-2853.
- A. Saccà, R. Pedicini, A. Carbone, I. Gatto, P. Fracas, E. Passalacqua, Chemical Physics Letters, 591 (2014) 149-155.
- R. Pedicini, B. Schiavo, A. Saccà, A. Carbone, I. Gatto, E. Passalacqua, Energy 64 (2014) 607-614.
- A. Alvarez, C. Guzmán, S. Rivas, J. Ledesma–García, L. G. Arriaga, A. Saccà, A. Carbone, E. Passalacqua, Int. J. of Hydrogen Energy, published 2014.
- A. Stassi, I. Gatto, V. Baglio, A. S.Aricò, International Journal of Hydrogen Energy, (2014) 1–7.
- M. Müller, J. Hirschfeld, R. Lambertz, A. Schulze Lohoff, H. Lustfeld, H. Pfeifer, M. Reißel, Journal of Power Sources, Volume 272 (2014) 225-232.
- Henkensmeier et al., International Journal of Hydrogen Energy (2014).
- F. V. Matera, I. Gatto, G. Giacoppo, O. Barbera, E. Passalacqua, International Journal of Hydrogen Energy, submitted.

4.3 Work Plan for Next Year

The next meeting is planned for 16 and 17 September 2015 at NEXT ENERGY, in Germany.

A set of Key Messages from this Annex will be published along with a technical publication in 2015. The group also decided to foster collaboration for a joint proposal within Horizon 2020 framework.

The objective of Annex 36 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 36 REPORT

SYSTEMS ANALYSIS

Annex 36 (previously Annex 28) is concerned with assisting 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. This will be achieved through the production of a book titled 'Data, Facts and Figures on Fuel Cells'.

The Annex began in October 2011 and is expected to run until December 2015. The leaders for this Annex, acting as the Operating Agent, were Professor Dr Detlef Stolten of Forschungszentrum Jülich and Dr Nancy Garland of United States Department of Energy (DOE).

4.7.1 Activities

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

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

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

4.7.2 Technical Developments

Achievements during 2014

Work is ongoing on the technical book 'Data, Facts and Figures on Fuel Cells'. The individual chapters have been written by subject experts in the field and the chapters have been carefully reviewed by the editorial team of D. Stolten, N. Garland and R. C. Samsun to ensure a consistent approach throughout the book.

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

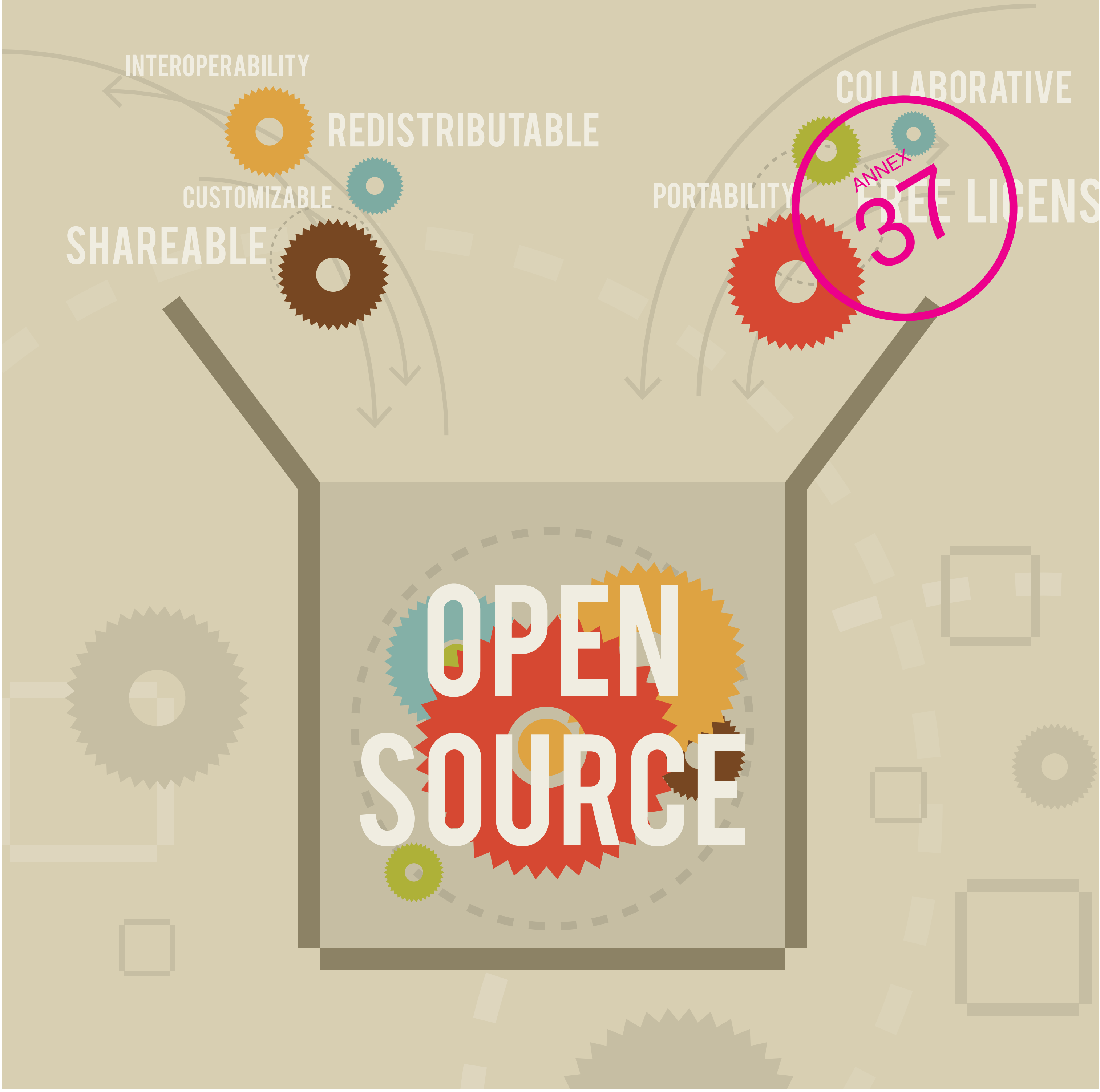
- Transportation.
- Stationary.
- Materials Handling.
- Fuel Provision.
- Codes and Standards.

At present, the USA, Germany, Korea, Japan, Italy, Austria, Canada, Denmark, the UK, China and Australia are represented in the book. As of the end of 2014 there have been 40 confirmed contributions. There are 33 chapters of which 15 chapters have been accepted, 4 chapters are being revised and 14 chapters are under review. A further 9 chapters are still expected.

4.7.3 Work plan for 2015

It is expected that the final nine chapters will be delivered in 2015. The editorial process is ongoing and can only be concluded after all chapters are delivered. It is the intention of the editorial team that the book will be published in late 2015 or early 2016.

Next steps for the Annex are to discuss whether it is of interest to build a new structure to carry out systems analysis work under the IEA Technology Collaboration Programme with the guidance of a new Operating Agent or whether to close out the Annex upon publication of the book.



The objective of this Annex 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.

4.8 ANNEX 37 REPORT

MODELLING OF FUEL CELLS

Annex 37 started in 2014 and is concerned with further developing the open source modelling approaches and the knowledge base to facilitate the development of fuel cell technology. This will be done through the development and application of open-source computational fluid dynamic (CFD) models of fuel cells and electrolysers.

Key Message – facts

Modelling of fuel cells

- Virtual prototyping of fuel cells is here to stay.
- Open source software allows the scientist/engineer complete control over the developed model.
- By sharing the interface among groups (public access), code development can be accelerated, without compromising the application (which is private).
- The IEA AFCIA is an excellent way to bring together and coordinate international groups active in open source modelling.

Key Messages – opinions

Modelling of fuel cells

- Best people to develop fuel cells models are fuel cells scientists, assisted by numerical specialists.
- By invoking object oriented principles, it is possible to build bigger and better models, without reinventing the wheel – re-use existing objects and procedures.
- The open source paradigm is best suited to the continuously changing software landscape.
- The scientist/engineer must have control of software to optimally parallelise for high performance computing.

4.8.1 Activities

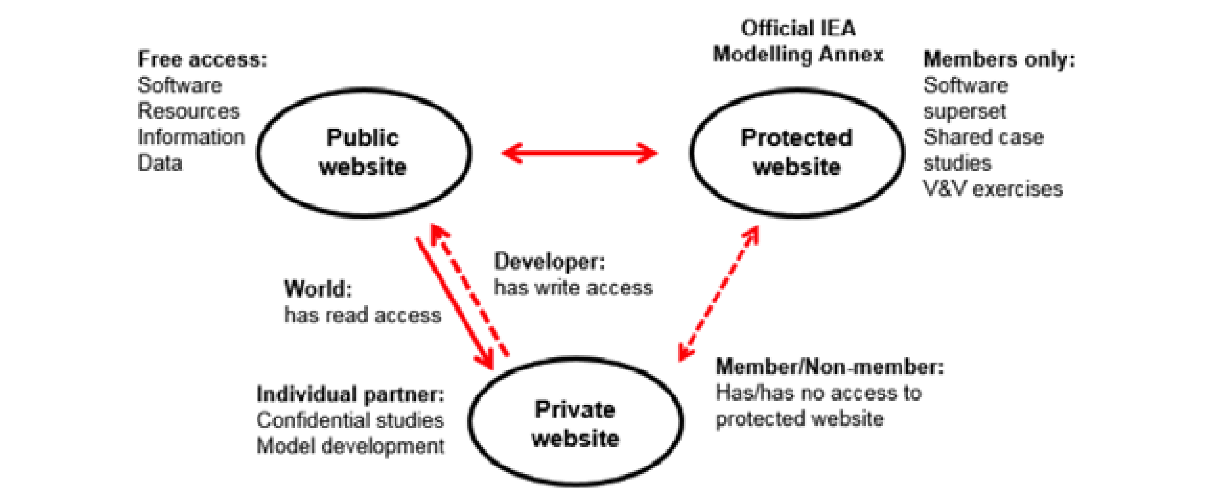
The Annex formally started in the summer of 2014 at the Executive Committee meeting in Seoul, South Korea. Since then, the Operating Agent has contacted experts and others relevant to the field from Member Countries to obtain interest in participation.

The Operating Agent, Prof. Steven Beale, attended the Executive Committee meeting in December 2014 in Grenoble, France to discuss the direction of the Annex. Since then four Annex meetings have been scheduled.

4.8.2 Technical Developments

The Annex intends to focus on building next generation codes in a coordinated and targeted manner and to apply them to real-world designs. An important component of this activity will be the bringing together of expert open-source modellers from member countries and elsewhere. This will help to avoid the duplication of research efforts and bring a focus to distributed activities in modelling. The Annex will play a major role in coordinating this activity.

Figure 28: Open access organisation for Annex 37



Open-source software has many advantages and few drawbacks. The Annex is working on the development of multi-scale and multi-physics models with OpenFOAM and other open source code libraries. The code is checked into a repository for use by multiple experts, simultaneously. The goal is to use computer models to make the difference in effective design. By being able to prototype with the best possible modelling tools, the construction of better fuel cells is facilitated. So far modellers have been able to run models with up to 1,000 cores with near linear performance, a thirty-fold increase on previous efforts.

Outreach efforts have been positive, with a number of responses from a range of institutions in member and other countries. However there is still a need to establish contacts in Asia, namely from China, Japan, Korea and other groups. Formal invitations have been dispatched and are effecting results.

Table 4.8: Positive responses to outreach efforts

Country	Associated institution	Name
Sweden	Lund University	Martin Andersson
Italy	Politecnico di Milano	Andrea Casalegno
Croatia	University of Zagreb	Ankica Đukic
France	CEA	Mathias Gerard
Denmark	Technical University of Denmark	Henrik Lund Frandsen
Germany	Deutsches Zentrum für Luft und Raumfahrt	Thomas Jahnke
Croatia/UK	Zagreb U/Wiki	Hrvoje Jasak
Italy	ENEA	Stephen McPhail
Canada	Queen's University	Jon Pharoah
Sweden	Lund University	Bengt Sundén
EU/ Belgium	Joint Research Centre	Georgios Tsotridis
USA	Lawrence Berkeley National Laboratory	Adam Weber

4.8.3 Work Plan for Next Year

The Annex kick-off meeting is scheduled for the 20 January 2015, at the Forschungszentrum Jülich, Germany.

The goals of the kick-off meeting are to establish common projects or groups of projects and strategic priorities, to define tasks/subtasks for annex, to engage in strategic and tactical planning, to build a network of developers/ users, to develop a framework for code validation and verification and to identify available databases of experimental data and gaps.

Annex 37 has three stated targets, which are:

- Build optimised cell models of fuel cells and electrolysers;
- Use codes to do practical stack design for solid oxide (SO) and polymer electrolyte membrane (PEM) fuel cells; and
- Parallelise and run models on super-computers with more than 1,000 cores.

Further meetings include:

Grenoble France, 31 March 2015

Fira Greece, 28 Sept. 2015, in conjunction with 3rd Degis workshop

Naples Italy, 18 Dec. 2015, in conjunction with EFC-15 conference, and a workshop on open source modelling on 15 December

APPENDICES

Appendix 1

MEMBERSHIP INFORMATION

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

For more information regarding specific Annex details, please contact the Operating Agents or key members of their teams from the information below. These details are correct at the time of publication.

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Annex 32 Solid Oxide Fuel Cells

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Annex 34 Fuel Cells for Transportation

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Annex 35 Fuel Cells for Portable Applications

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Appendix 2

ANNEX EXPERTS

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

ANNEX 30: ELECTROLYSIS

<table>
<tr><th>Expert</th><th>Associated Institution</th><th>Institutional Community</th><th>Country</th></tr>
<tr><td colspan="4">OPERATING AGENT: DR JÜRGEN MERGEL, FORSCHUNGSZENTRUM JÜLICH GMBH,GERMANY</td></tr>
<tr><td>Eric Christensen</td><td>Technical University of Denmark</td><td>A</td><td rowspan="3">Denmark</td></tr>
<tr><td>Laila Grahl Madsen</td><td rowspan="2">IRD Fuel Cells</td><td rowspan="2">I</td></tr>
<tr><td>Theiss Stenstroem</td></tr>
<tr><td>Detlef Stolten</td><td rowspan="9">Forschungszentrum Jülich GmbH</td><td rowspan="9">R</td><td rowspan="17">Germany</td></tr>
<tr><td>Jürgen Mergel</td></tr>
<tr><td>Martin Müller</td></tr>
<tr><td>Wiebke Maier</td></tr>
<tr><td>L Blum</td></tr>
<tr><td>Marcelo Carmo</td></tr>
<tr><td>David Fritz</td></tr>
<tr><td>Norbert Lutterbach</td></tr>
<tr><td>Alexander Hahn</td></tr>
<tr><td>Manfred Waidhas</td><td>Siemens</td><td>I</td></tr>
<tr><td>Fabian Burggraf</td><td>DLR</td><td>R</td></tr>
<tr><td>Tom Smolinka</td><td rowspan="2">Fraunhofer ISE</td><td rowspan="2">R</td></tr>
<tr><td>Thomas Lickert</td></tr>
<tr><td>Bernd Pitschak</td><td>Hydrogenics</td><td>I</td></tr>
<tr><td>Lukas Lüke</td><td>ThyssenKrupp</td><td>I</td></tr>
</table>

Klemens Höbing	Smart Testsolutions	I	Germany
Francesco Massari	McPhy	I	Italy
Kazuja Kubo	NEDO	R	Japan
Akiteru Maruta	Technova Inc.	I	
Hans-Joachim Neef	Energie-Agentur NRW	G	
Dirk Henkensmeier	KIST, Korea Institute of Science and Technology	R	South Korea
Hyoung-Juhn Kim			
Hyun Jong Jang			
Lorenz Gubler	Paul Scherrer Institut (PSI)	R	Switzerland

ANNEX 31: POLYMER ELECTROLYTE FUEL CELLS

Expert	Associated Institution	Institutional Community	Country
OPERATING AGENT: XIAOPING WANG/DI-JIA LIU, ARGONNE NATIONAL LABORATORY, USA (R)			
Viktor Hacker	Graz University of Technology	A	Austria
Steen Yde-Andersen	IRD Fuel Cell Technology Research Centre A/S	R	Denmark
Jari Ihonen	VTT Processes, Technical Research Centre of Finland	R	Finland
Henri Karimäki			
Thierry Priem	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)	R	France
Werner Lehnert	Forschungszentrum Juelich GmbH	R	Germany
Carston Cremers	ICT Fraunhofer	R	
Alex Schechter	Ariel University	A	Israel
Alessandra Carbone	CNR-ITAE	R	Italy
Antonella Giannini	Italian National Agency for New Technologies, Energy and Environment (ENEA)	R	
Akimasa Daimaru	Daido University	A	Japan

Gu-Gon Park	Korean Institute for Energy and Research (KIER)	R	Korea
EunAe Cho	Korea Advanced Institute of Science and Technology (KAIST)	R	
Ulises Cano	The Electric Research Institute (IIE)	R	Mexico
Lars Pettersson	Royal Institute of Technology (KTH)	A	Sweden
Göran Lindbergh			
Rakel Wreland Lindstrom			
Di-Jia Liu	Argonne National Laboratory	R	USA

ANNEX 32: SOLID OXIDE FUEL CELLS

Expert	Associated Institution	Institutional Community	Country
OPERATING AGENT: JARI KIVALHO, VTT, FINLAND (R)			
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Florence Lefebvre-Joud	Commissariat à l'Energie atomique et aux énergies alternatives (CEA)	R	France
Julie Mougin			
Ludger Blum	Forschungszentrum Jülich	R	Germany
Josef Mertens		R	
Corinna Jaehnig	Fraunhofer IKTS	R	
Mihails Kusnezoff		R	
Thomas Pessara	Ezelleron	I	
Angelo Moreno	Italian National Agency for New Technologies, Energy and Environment (ENEA)	R	Italy
Stephen McPhail			
Harumi Yokokawa	National Institute of Advanced Industrial Science and Technology (AIST)	R	Japan

Akiteru Maruta	Technova	I	Japan
Rak-Hyun Song	Korea Institute for Science and Technology (KIER)	R	Korea
Bengt Sunden	Lund Institute of Technology	A	Sweden
Martin Andersson			
Olivier Bucheli	HTceramix	I	Switzerland
Subhash Singhal	Pacific Northwest National Laboratory	R	USA

ANNEX 33: FUEL CELL SYSTEMS FOR STATIONARY APPLICATIONS

Expert	Associated Institution	Institutional Community	Country
OPERATING AGENT: BENGT RIDELL. GRONTMIJ AB, SWEDEN (I)			
Günter Simader	Austrian Energy Agency (E.V.A)	G	Austria
Manuel Mittendorfer			
Viktor Hacker	TU Graz	R	
John Hansen	Haldor Topsoe	I	Denmark
Per Balslev	Dantherm Power	I	
Kim Rune Larsen	IRD	I	
Jari Kiviaho	VTT, Technical Research Centre of Finland	R	Finland
Stephane Hody	GDF Suez	I	France
David Dupuis			
Thierry Priem	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)	G	
Ulf Birnbaum	Forschungszentrum Julich	R	Germany
Christian Wunderlich	IKTS Fruenhofer, Dresden	R	
Christian Lorenz	E.ON	I	

Gennadi Finkelshtain	GenCell	I	Israel
Angelo Moreno	Italian National Agency for New Technologies, Energy And Environment (ENEA)	R	Italy
Stephen McPhail			
Viviana Cigolotti			
Stefano Modena	SOFC Power	I	
Akiteru Maruta	Technova Inc	I	Japan
Yasuhi Ogami	Toshiba	I	
Nishimora Osamu	AISIN Seiki	I	
Noboru Hashimoto	Panasonic	I	
Tae-Hoon Lim	Korea Institute of Science and technology (KIST)		Korea
Jonghee Han			
Bengt Ridell	Grontmij AB	I	Sweden
Per Ekdunge	PowerCell AB	I	
Stephan Renz	Renz Beratung	I	Switzerland
Whitney Colella	The Pacific Northwest National Laboratory (PNNL)	R	USA
Dan Rastler	EPRI	I	
Shailesh Vora	National Energy Technology Lab	R	
Mark Williams	Department of Energy (DOE)	G	

ANNEX 34: FUEL CELLS FOR TRANSPORTATION

Expert	Associated Institution	Institutional Community	Country
OPERATING AGENT: RAJESH AHLUWALIA, ARGONNE NATIONAL LABORATORY, USA (R)			
Michael Nikowitz	A3PS	I	Austria
Mikael Sloth	H_2 Logic	I	Denmark
Antti Lajunen	Finland-Aalto University	A	Finland
Laurent Antoni	Commissariat à l'Energie Atomique (CEA)	R	France
Bernard Frois			
Laure Guetaz	CEA	R	
Christophe Avril	MaHyTec	I	
Eric Claude	Air Liquide	I	
Dr-Ing Bruno Gnörich	RWTH Aachen University	A	Germany
T Grube	Forschungszentrum Jülich	R	
John German	ICCT	R	
S McPhail	Italian National Agency for New Technologies, Energy And Environment (ENEA)	R	Italy
Rajesh Ahluwalia	Argonne National Laboratory	R	USA
Amgad Elgowainy			
Thanh Hua			
D-J Liu			
Deborah Myers			
Jason Marcinkoski	Department of Energy	G	
Brian James	Strategic Analysis (SA)	I	
Whitney Colella			

ANNEX 35: FUEL CELLS FOR PORTABLE APPLICATIONS

Expert	Associated Institution	Institutional Community	Country
OPERATING AGENT: DR FABIO MATERA, ISTITUTO DI TECHNOLOGIE AVANZATE PER L'ENERGIA (ITAE),ITALY(ITAE),ITALY			
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Christoph Grimmer			
Stephan Weinberger			
Viktor Hacker			
Carsten Cremers	Fraunhofer Institut Chemische Technologien	R	Germany
Tilman Jurzinsky			
Alexander Dyck	NEXT-ENERGY		
Irene Gatto	Institute of Advanced Technologies for Energy (ITAE), National Research Council (CNR)	R	Italy
Fabio Matera			
Sang-Kyung Kim	Korea Institute for Energy Research (KIER)	R	Korea
Maria Wesselmark	Intertek Semko	I	Sweden

ANNEX 36: SYSTEMS ANALYSIS

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

ANNEX 37: MODELLING OF FUEL CELLS SYSTEMS

Expert	Associated Institution	Institutional Community	Country
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Didier Jamet	Commissariat à l'énergie atomique et aux énergies alternatives	G	France
Mathias Gerard			
Andrea Casalegno	Politecnico di Milano	A	Italy
Domenico Ferrero	Politecnico di Torino	A	
Massimo Santarelli			
Stephen McPhail	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile	R	
Andrei Kulikovsky	Forschungszentrum Jülich	R	Germany
David Fritz			
Dieter Froning			
Ludger Blum			
Steven Beale			
Uwe Reimer			
Werner Lehnert			
Thomas Jahnke	Deutsches Zentrum für Luft- und Raumfahrt	R	
Wolfgang Bessler	Hochschule Offenburg	R	
Bengt Sunden	Lund University	A	Sweden
Martin Andersson			
Adam Weber	Lawrence Berkeley National Laboratory		United States

Appendix 3

FUEL CELL COMPANIES

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
AUSTRIA					
AVL	Cell/stack/system	Simulation software, monitoring technique, system tests and development	kW	Automotive powertrains; All applications for SOFC; Mobile applications for PEMFC	www.avl.com
Fronius	Stack/system	System development	kW	Electrolysis, Forklift, Home energy system	www. fronius.com
Magna Steyr	Storage	Liquid, 70 MPa (700 bar)	kW	Automotive	www. magnasteyr.com
OMV	Fuelling	70 MPa (700 bar)		Hydrogen Filling stations, operator	www.omv.com
Plansee	Cell/stack	SOFC	W, kW	Component manufacturer	www. Plansee.at
RAG	Storage	-	-	Storage, power to gas	www.rag-energy-storage.at
Schunk Bahn- und Industrietechnik GmbH	Stacks, system	PEFC		Portable	www.schunk-group.com
DENMARK					
Danish Power Systems	Stack components	MEAs for HT PEMFC	10 cm^2 – 300 cm^2	All applications for HT PEMFC	www. dapoesy.com
Dantherm Power	System	SOFC, PEFC	1 kW	Dantherm Power	System
Green Hydrogen. dk	System			Alkaline electrolysis	N/A, new website coming soon
Haldor Topsoe A/S	Components and stack	SOFC	1.5 kW - 6 kW	Micro-CHP, APU CHP 10 kW to 50 kW	www. topsoefuelcell. com

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
H2 Logic A/S	H2Drive® Fuel cell systems	PEFC	10 kW	Material handling vehicles	www. h2logic.com
	H2Station®: hydrogen refuelling stations	Gaseous hydrogen	35MPa – 70MPa	35 MPa for fork-lifts & busses 70 MPa for cars	
IRD A/S	Stack and System	PEFC	1.5 kW	Micro-CHP units	www.ird.dk
		DMFC	500 W	UPS – communications, IT back up power, remote power	
		PEFC	800 W	Refuelling	
SerEnergy	Components Stack System Solutions	PEFC	300 W - 50 kW	Backup power APU Aux vehicles Automotive Refuelling – through partners	www.serenergy. com
FINLAND					
Convion Oy	System	SOFC	20 – 100 kW	Stationary	www.convion.fi
Elcogen Oy	Single cells and stacks	SOFC	1-10 kW	Stationary	www. elcogen.com
Fitelnet Oy	Integrated modules	PEFC, methanol	1kW – 5kW	Back-up power, military, UPS	www.fitelnet.fi
Oy Woikoski Ab	Hydrogen production and filling stations	Hydrogen, refuelling stations	35 MPa – 70 MPa (350 bar – 700 bar)	Filling stations	www. woikoski.fi
T Control Oy	Integrated modules	PEFC, hydrogen and methanol	1kW – 5kW	Back-up power, telecom base stations, UPS	www.tcontrol.fi

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
FRANCE					
Ad-venta	Components			Storage, FC systems	www.innovative-gas-engineering.com/en/
AJC	HRS	Hydrogen Refuelling Stations		Transportation	www.rhone-alpes.developpement-durable.gouv.fr/IMG/pdf/Dossier_de_presse_AJC_SAS_cle2978ae.pdf
Areva H2 Gen	Production	PEM Electrolyser		Storage, transportation, backup	www.arevah2gen.com/
Areva SE	Systems	PEFC + electrolyser: Greenergy Box™	Hundreds kW	Grid stabilisation, emergency back-up systems	www.areva.com/EN/operations-407/helion-fuel-cell-and-hydrogen-energy-specialist.html
Ataway	System		0.5 kW to 50 kW	Clean and autonomous power supply for off-grid sites and transportation	http://ataway.com/
Axane (Air liquide subsidiary)	Systems	PEFC	0.5 kW to 10 kW	Clean and autonomous power supply for off-grid sites	www.airliquide-hydrogen-energy.com/en/who-we-are/axane.html
CEA	Component, stack, system	SOFC, PEFC	10 W to 50 kW	R&D	www-liten.cea.fr/index_uk.htm
CNRS	Component, stack, system			R&D	www.cnrs.fr/
HyPulsion[26]	System	PEFC	1.5 kW to 14 kW	Integrated Fuel cells systems for fork-lift trucks	www.plugpower.com/
Mayhtec	Storgage	Compressed, Hydride, Hybrid		Transportation, stationary	www.mahytec.com/fr/accueil.html

Company Name	Area (stack/system)	Type of technology	Scale / Range	Application	Website
McPhy Energy	Production,storage	Electrolyser		Stationary storage	www.mcphy.com/fr/
PaxiTech	MEA, GDE, stack, systems, educational kit, test equipment	PEFC	4 W to 10 W	Portable power	www.paxitech.com
Pragma Industries	Stack, test equipment, electronic loads, hydrogen storage	Roll to roll PEFC	10 W to 100 W	Portable tools	www.pragma-industries.com
Raigi	Storage	PEFC		Portable	www.raigi.com/
Stelia Composites	Storage	High pressure gas	350 bar to 700 bar	Transportation	www.composites-aquitaine.com/site/FO/scripts/siteFO_accueil.php?lang=FR
SymbioFCell	System	PEFC	5 kW, 20 kW to 300 kW	Integrated fuel cells systems for range extenders (5 kW) and full-power heavy-duty vehicles (20 kW to 300 kW)	www.symbiofcell.com
WH2	System	Methanol, Hydrogen	25 W to 4 kW	Clean and autonomous power supply from green H_2	www.wh2.fr

Company Name	Area (stack/system)	Type of technology	Scale / Range	Application	Website
GERMANY					
3M Deutschland GmbH	Stack	MEA catalysts			www.mmm.com
Ätztechnik Herz GmbH & Co. KG	Stack	BPP			www.aetztechnik-herz.de/
balticFuelCells GmbH	Stack,system	PEFC		Stationary/ transportation/ portable	www.balticfuelcells.de
BAXI INNOTECH GmbH	System	PEFC		Stationary	www.baxi-innotech.de
Ceramic Fuel Cells GmbH	Stack,system	SOFC		Stationary	www.ceramicfuelcells.de
Clariant Produkte (Deutschland GmbH)	System	Reformer catalysts			www.clariant.com/
Daimler AG	Stack,system (FCV)	PEFC		Transportation	www.daimler.com
DBI Gas- und Umwelttechnik GmbH	System			Stationary	www.dbi-gut.de
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), ITT	Stack,system	PEFC, SOFC		Stationary, transportation	www.dlr.de/tt
EBZ GmbH Fuel Cells & Process Technology	System	SOFC		Stationary, transportation	www.ebz-dresden.de
Eisenhuth GmbH & Co. KG	Stack (BPP)				www.eisenhuth.de
Elcore GmbH	System	PEFC		Stationary	www.elcore.com
EnBW Energie Baden-Württemberg AG	System (utility)			Stationary	www.enbw.com/ brennstoffzelle

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
ElringKlinger AG	Interconnectors, metal bipolar plates, stack	PEFC, SOFC		Wide rang of applications	www.elringklinger.de/en/products-technologies/fuel-cells
E.ON Ruhrgas AG	System (utility)			Stationary	www.eon.com/en.html
EWE AG	System (utility)			Stationary	www.ewe.de
eZelleron GmbH	System			Transportation, portable	www.ezelleron.de
FCPower Fuel Cell Power Systems GmbH	System	PEFC		Stationary	www.fcpower.de
Forschungszentrum Jülich GmbH	Stack,system	PEFC, SOFC		Stationary,transportation,portable	www.fz-juelich.de www.fuelcells.de
Fraunhofer-Institut für Keramische Technologien und Systeme IKTS	Stack,system	SOFC, MCFC		Stationary, portable	www.ikts.fraunhofer.de
Fraunhofer-Institut für Solare Energiesysteme ISE	Stack,system	PEFC		Transportation, portable	www.h2-ise.de
Fraunhofer-Institut für Chemische Technologie ICT	Stack,system	AFC, PEFC		Transportation, portable	www.ict.fraunhofer.de
Freudenberg FCCT KG	Stack (components)				www.freudenbergfcct.com
FuMA-Tech GmbH	Stack (membranes)				www.fumatech.com
FuelCell Energy Solutions GmbH	Stack,system	MCFC		Stationary	www.fces.de
FuelCon AG	System	PEFC, SOFC			www.fuelcon.com

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Gräbener Machinentechnik GmbH	Stack				www.graebener-maschinentechnik.de/
HAW Hamburg	System			Stationary, transportation	www.haw-hamburg.de/m/
Heliocentris Academia GmbH	System			Stationary	www.heliocentris.com
HIAT gGmbH, Hydrogen and Informatics Institute of Applied Technologies	Stack (components)	PEFC			www.hiat.de
Hüttenberger Produktionstechnik Martin GmbH	Stack (components)	PEFC		Portable	www.huettenberger-produktionstechnik.de
Karlsruher Institut für Technologie (KIT)	Systems, stack components			Stationary, transportation	www.iwe.uni-karlsruhe.de
Linde Material Handling GmbH	System			Transportation	www.linde-mh.de/
N2telligence GmbH	System		Greater than 10 kW	Stationary	www.n2telligence.com/
New enerday GmbH	System	SOFC		Stationary, transportation, portable	www.new-enerday.com
NEXT ENERGY EWE-Forschungszentrum für Energietechnologie e.V.	Stack, system	PEFC		Stationary, transportation	www.next-energy.de
Polyprocess GmbH	Stack components				www.polyprocess.de/
Proton Motor Fuel Cell GmbH	Stack, system	PEFC		Stationary, transportation	www.proton-motor.de

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Riesaer Brennstoffzellentechnik GmbH	Stack,system	PEFC		Stationary	www.rbz-fc.de
Robert Bosch GmbH	System			Stationary	www.bosch.de/
Schunk Bahn - und Industrietechnik GmbH	Stack				Schunk Bahn- und Industrietechnik GmbH
SFC Energy AG	Stack, system	PEFC		Portable	www.sfc.com
SolviCore GmbH	Stacks, MEAs, cells				www.solvicore.com
Sunfire GmbH	Stack, system	SOFC		Stationary	www.sunfire.de
TU Bergakademie Freiber	System			Stationary, transportation, portable	www.gwa.tu-freiberg.de/
Ulmer Brennstoffzellen Manufaktur GmbH	Stack, system	PEFC		Stationary, transportation	www.ubzm.de
Umicore AG	Stack (Catalysts)				www.umicore.com/
Vaillant Deutschland GmbH & Co. KG	System	SOFC		Stationary	www.vaillant.de
Viessmann Werke GmbH & Co. KG	System	PEFC		Stationary	www.viessmann.com
VNG-Verbundnetz Gas AG	System			Stationary	www.vng.de
WS Reformer GmbH	System (fuel processor)				www.wsreformer.de

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)	Stack, system	PEFC		Stationary, transportation, portable	www.zsw-bw.de
ZBT GmbH	Stack, system	PEFC		Stationary, transportation, portable	www.zbt-duisburg.de
ITALY					
Dolomiteck	System	PEFC	10s of kW	Transport application – hydrogen and fuel cell mini buses	www.dolomitech.com
Electropower system	Stack and system	PEFC	2 kW to 10 kW	Back-up power, remote areas application, standalone systems	www.electropowersystems.com
GENPORT	System	PEFC	300 W to 1,000 W	Portable	www.genbee.it
SOLIDpower	Stack and system	SOFC	1 kW to 10 kW	Micro-CHP units for small households	www.solidpower.com/
JAPAN					
Aisin Seiki	System	SOFC	1 kW class	Stationary	www.aisin.com/
Aquafairy	System	PEFC	A few W to 200W	Portable	http://www.aquafairy.co.jp/ www.rohm.com/web/global/
Bloom Energy Japan	System	SOFC	200 kW	Stationary	www.bloomenergy.jp/
Daihatsu Motor	System	AFC	10 kW class	Transportation	www.daihatsu.com/company/index.html

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Fuji Electronic	System	PAFC	100 kW	Stationary	www.fujielectric.com/
Fujikura	System	DMFC		Portable, APU	www.fujikura.co.jp/eng/
Honda Motor	System	PEFC, SOFC	100 kW class 10 kW class	Transportation Stationary	http://world.honda.com/
IHI Aerospace	System	PEFC		APU	www.ihi.co.jp/ia/en/index.html
Iwatani	System	SOFC	200 W	Portable	www.iwatani.co.jp/eng/index.php
JX Nippon Oil	System	SOFC	1 kW class	Stationary	www.noe.jx-group.co.jp/english/
Kyocera	Stack	SOFC	1 kW class	Stationary	http://global.kyocera.com/
Mitsubishi Gas Chemical	System	DMFC	300 W	Portable	www.mgc.co.jp/eng/index.html
Mitsubishi Heavy Industries	System	SOFC	250 kW to 100 MW	Stationary	www.mhi.co.jp/en/index.html
Miura	System	SOFC	5 kW class	Stationary	www.miuraz.co.jp/en/
Murata Manufacturing	Stack	SOFC	1 kW class	Stationary	www.murata.com/index.html
NGK Insulators	Stack	SOFC	1 kW class	Stationary	www.ngk.co.jp/english/index.html
NGK Spark Plug	Stack	SOFC	1 kW class	Stationary	www.ngkntk.co.jp/english/index.html
Nissan Motor	System	PEFC	100 kW class	Transportation	www.nissan.co.jp/EN/index.html

Company Name	Area (stack/ system)	Type of technology	Scale / Range	Application	Website
Panasonic	System	PEFC	1 kW class	Stationary	http://panasonic.net/
Sumitomo Precision Products	Stack	SOFC	5 kW-class	Stationary	www.spp.co.jp/English/index2-e.html
Suzuki Motor	System	PEFC	a few kW to 100 kW	Transportation	www.globalsuzuki.com/corporate/index.html
Toshiba Fuel Cell Power Systems	System	PEFC	1 kW class	Stationary	www.toshiba.co.jp/product/fc/ (in Japanese)
TOTO	Stack	SOFC	1 kW class	Stationary	www.toto.co.jp/en/index.htm
Toyota Motor	System	PEFC	100 kW class	Transportation	www.toyota-global.com/
KOREA					
Doosan Fuel Cell	Stack and system	PAFC/PEFC	300 kW	Distributed power	www.doosanheavy.com
Hyundai Motors	Stack and system	PEFC	80 kW to 300 kW	FCV and bus	www.hyundai.com
POSCO Energy	Stack and system	MCFC	300 kW to 2.4 MW 100 MW per year production	Distributed power/APU for ship	www.poscoenergy.com
MEXICO					
Ballard[27]	Back-up systems	PEFC, methanol reformer	2.5 kW to 5 kW	Back-up for telecommunications and other uses	www.ballard.com

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

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SWEDEN					
Catator	Systems	Reforming catalysts and reforming technologies		Small independent fuel cells system, for instance unmanned aircraft, back-up-power/ telecommunications	www.catator.se/
Cellkraft	Stack	Robust PEFC	1 kWe to 2 kWe	Offgrid	http://cellkraft.se
Höganäs AB	Material	SOFC		Manufacturer of metal powders and developer of interconnect materials	www.hoganas.com
Impact coatings	Material			PVD coatings for fuel cell bipolar plates	www.impactcoatings.com/
myFC	Stack, system	Portable	10 We to 75 We	Charger	www.myfuelcell.se
Powercell	Stack and system	PEFC and diesel reformers	1 kWe to 10 kWe	Back-up power, powerpacks and APU for trucks	www.powercell.se
Sandvik MT AB	Material	components		Developer and manufacturer of metallic bipolar plates and interconnectors	http://smt.sandvik.com/en/
SWITZERLAND					
CEKAtec	PEFC stack, system			Portable	www.ceka.ch/en/
Celeroton	PEFC BoS			Mobility	www.celeroton.com/
Hexis	SOFC			Stationary (CHP)	www.hexis.com/
HTceramix	SOFC			Stationary (CHP)	-

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Michelin Conception	PEFC stack,system			Mobility	https://documents.epfl.ch/users/b/be/bernhard/www/CREM/Presentations/2015/Seminaire_H2/4_%20MICHELIN_PIERRE%20VARENNE.pdf
Swiss Hydrogen SA	PEFC stack, system			Mobility,stationary (UPS), hydrogen fuelling stations	http://swisshydrogen.ch
TIMCAL Graphite & Carbon	PEFC material			-	www.imerys-graphite-and-carbon.com/
USA					
Bloom Energy	System	SOFC		Stationary power	www.bloomenergy.com
Doosan Fuel Cell America, Inc.	System	PEFC		Stationary power generation	www.doosanfuelcellamerica.com/
FuelCell Energy	Systems	MCFC	Up to 90 MW	Large stationary power	www.fuelcellenergy.com
GM		PEFC		FC vehicles	www.gm.com
Nuvera	Hydrogen stations, stacks			Materials handling	www.nuvera.com/
Plug Power	System	PEFC		Materials handling	www.plugpower.com
ReliOn Inc		PEFC		Back-up power	www.relion-inc.com
UltraCell	System	AFC		Portable power	www.ultracell-llc.com/index.php