International Energy Agency (IEA) Advanced Fuel Cells
Implementing Agreement

EXECUTIVE SUMMARY FOR THE ANNUAL REPORT 2013

September 2014

iea Energy Technology Network

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

This Executive Summary for the 2013 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:

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

Contents

Chairman's Foreword

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

Fuel cells are distinguished by:

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

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

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

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

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

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

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

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

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

1. Executive Summary

The Advanced Fuel Cells Implementing Agreement (AFC IA) contributes to the research and development (R&D) of fuel cell technologies, deployment of fuel cell technologies and contributes to the research, development and deployment (RD&D) of the fuel cell technologies. It also disseminates information on fuel cell RD&D to all our member countries and organisations.

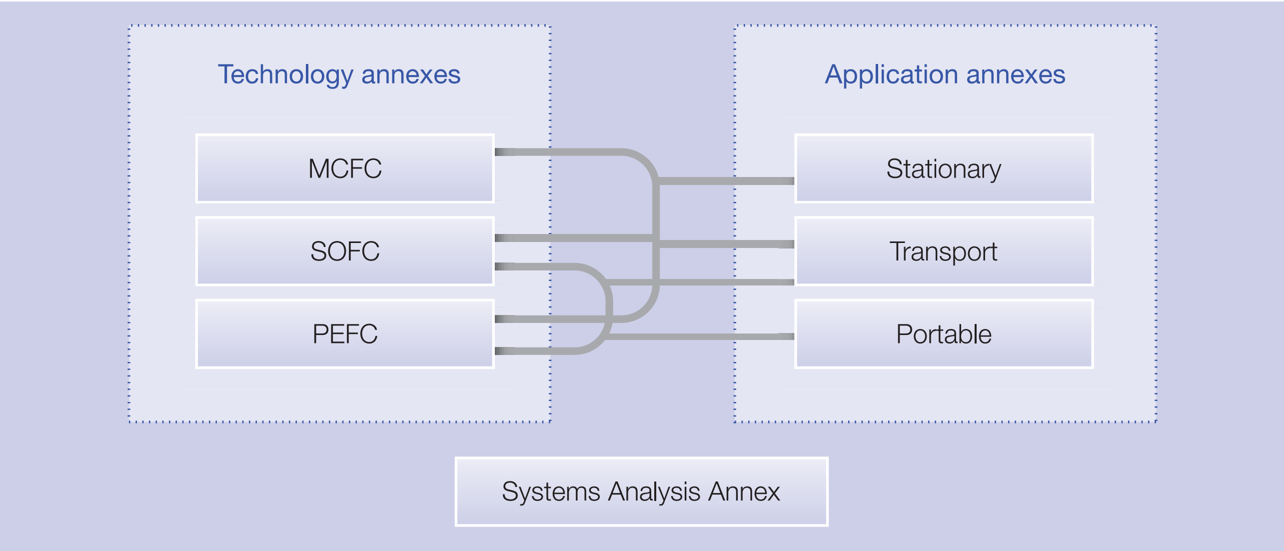
The activities of the AFC IA are led by the Executive Committee (ExCo). The ExCo comprises Members and Alternate Members who are national policy leads and leading fuel cell experts and come from each of the 13 member countries. The expertise availible in the ExCo ensures that the group is well placed to provide a comprehensive overview of the status of fuel cell technology, deployment status, and the opportunities and barriers faced by fuel cell technologies internationally.

The ExCo meets twice a year to review technical progress in the Annexes (see below) and developments at a national level. It also releases statements aimed at policy makers to provide the latest informaiton and guidance on the status of fuel cell technology.

In the AFC IA, seven Annexes were active in 2013. It is in these Annexes that the focused technical discussions are held and approaches and results shared:

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

Figure 1: Active Annexes within the AFC IA Programme



1.3 HOW TO JOIN THE AFC IA

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

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

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

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

2. Key Messages from the Executive Committee

The ExCo comprises two experts from each member country or sponsoring organisation. It serves to guide and oversee the work of the Implementing Agreement as a whole.

The Operating Agents of each Annex, the Annex lead, work closely with the ExCo to share technical developments and insights.

Each year, the ExCo prepares a set of key messages. These are aimed at fellow experts and policy makers working in the area of fuel cells, and share the insights and significant developments that have occurred. The intention is that these messages will inform, guide and be a helpful resource for decision makers.

Key Messages – Facts

Advanced Fuel Cells Implementing Agreement

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

Key Messages – Opinion

Advanced Fuel Cells Implementing Agreement

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

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

3. Key Messages from the Current Annexes

Every year, each Annex prepares a set of key messages that are aimed at fellow experts and policy makers working in the area of fuel cells. These share the insights and significant developments that have occurred. The key messages are tailored specifically to the areas that each Annex focuses on. The hope is that these will inform, guide and be a helpful resource for decision makers.

3.1 ANNEX 22

POLYMER ELECTROLYTE FUEL CELLS (PEFC)

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

Key Messages – Facts
Polymer Electrolyte Fuel Cells

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

Key Messages – Opinion
Polymer Electrolyte Fuel Cells

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

3.2 ANNEX 23

MOLTEN CARBONATE FUEL CELLS (MCFC)

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

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

Key Messages – Facts
Molten Carbonate Fuel Cells

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

Key Messages – Opinion
Molten Carbonate Fuel Cells

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

3.3 ANNEX 24

SOLID OXIDE FUEL CELLS (SOFC)

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

Key Messages – Facts
Solid Oxide Fuel Cells

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

Key Messages – Opinion
Solid Oxide Fuel Cells

- SOFC for CHP and power only, for stationary industrial, commercial, residential and small applications are relatively mature and are at the threshold of the commercialisation process.
- With the advent of certain additional stack related development steps, a commercially feasible system for large scale projects with an investment cost

(excluding stacks) of less than EUR 2,000/kW can be achieved.
- SOFC using metallic support is one promising emerging technology for Auxiliary Power Unit (APU) applications with lower material costs, higher robustness during fabrication and operation.

3.4 ANNEX 25

STATIONARY FUEL CELLS

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

Key Messages – Facts
Stationary Fuel Cells

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

Key Messages – Opinions
Stationary Fuel Cells

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

3.5 ANNEX 26

FUEL CELLS FOR TRANSPORTATION

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

Key Messages – Facts
Fuel Cells for Transportation

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

Key Messages – Opinions
Fuel Cells for Transportation

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

3.5 ANNEX 26

FUEL CELLS FOR TRANSPORTATION

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

Key Messages – Facts
Fuel Cells for Transportation

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

Key Messages – Opinions
Fuel Cells for Transportation

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

3.6 ANNEX 27

FUEL CELLS FOR PORTABLE APPLICATIONS

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

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

Key Messages – Facts
Fuel Cells for Portable Applications

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

Key Messages – Opinions
Fuel Cells for Portable Applications

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