IEA Advanced Fuel Cells

Implementing Agreement

Annual Report 2003

April 2004

INTERNATIONAL ENERGY AGENCY

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

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

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Distribution List

- Executive Committee (1 copy each)
- IEA Secretariat (100 copies)
- All Operating Agents and Proposed Operating Agents
- Other Participants (on request)

1. INTRODUCTION

1.1 GENERAL

The Implementing Agreement for a programme of research, development and demonstration on advanced fuel cells was signed by seven countries in Paris on April 2nd, 1990. Since that time, a further eleven countries have signed the Implementing Agreement and three countries (Spain, New Zealand and Denmark) have left the Agreement. The current participants are Australia, Belgium, Canada, Finland, France, Germany, Italy, Japan, Korea, Netherlands, Norway, Sweden, Switzerland, UK and USA.

The aim of the IEA Advanced Fuel Cells programme is to advance the state of understanding of all Contracting Parties in the field of advanced fuel cells. It achieves this through a co-ordinated programme of research, technology development and system analysis on Molten Carbonate (MCFC), Solid Oxide (SOFC) and Polymer Electrolyte Fuel Cell (PEFC) systems. There is a strong emphasis on information exchange through Task 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 Task.

The current five-year programme (1999-2003) covers fuel cell technology and its potential applications in stationary power generation and transport. The IEA's Committee on Energy Research and Technology (CERT) approved a five-year extension to this Implementing Agreement in November 2003.

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 Tasks.

1.2 PARTICIPANTS

The following fifteen IEA-member countries participated in this Implementing Agreement during 2003. Spain, Denmark and New Zealand were previously Participants but left the Implementing Agreement before 1999.

Country	Signatory Party	Date of Signature
Australia	Ceramic Fuel Cells Limited (CFCL)	November 1995
Belgium	Vlaamse Instelling voor Technologisch Onderzoek (VITO)	November 2002
Canada	Delegation to the OECD	November 1991
France	L'Agence de l'Environnement et de La Maîtrise de l'Energie (ADEME)	August 1996
Finland	Finnish National Technology Agency (TEKES)	May 2002
Germany	Forschungszentrum Jülich	December 1992

Italy	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA)	April 1990
Japan	New Energy and Industrial Technology Development Organisation (NEDO)	April 1990
Korea	The Korea Electric Power Corporation (KEPCO)	April 1998
Netherlands	Netherlands Energy Research Foundation (ECN) (from October 1999, previously Netherlands Agency for Energy and the Environment (NOVEM)	April 1990
Norway	Research Council for Norway (from October 1994, previously the Norwegian Council for Scientific and Industrial Research)	April 1990
Sweden	The Swedish National Energy Administration (STEM) (from December 1998, previously NUTEK)	April 1990
Switzerland	Office Féderale de l'Energie (OFEN)	April 1990
United Kingdom	Department of Trade and Industry (from April 1992, previously the Department of Energy)	September 1990
United States	Department of Energy	May 1995

The Executive Committee meets twice a year under the Chairmanship of Prof Lars Sjunnesson (Sydkraft, Sweden). The Vice-Chairman is Prof Detlef Stolten and the Secretariat consists of Mrs H Haydock, Miss C Handley and Mrs G Gordon (all AEA Technology, UK). The IEA/OECD representative during 2003 was Mr Tom Howes from the Office of Energy Efficiency, Technology and R&D.

The following table lists all the Executive Committee Members at the end of 2003, their Alternates and the Operating Agents of the different Annexes. Addresses and contact numbers are given in Appendix 1 to this report.

Country	Ex Co Member	Alternate Member	Operating Agent	Annex No.
Australia		K Foger		
Belgium	G van Bogaert			
Canada	V Scepanovic	E Andrukaitis		
Finland	J Laine	R Rosenberg		
France	G Chaumain	N Thybaud		
Germany	D Stolten	H Nabielek	LGJ de Haart	XIII
Italy	R Vellone	A Moreno		
Japan	F Shouji	H Ochi	F Shouji	XIV
Korea	H-C Lim	T-H Lim		
Netherlands	S van der Molen			
Norway	R Hildrum	R Aaberg		

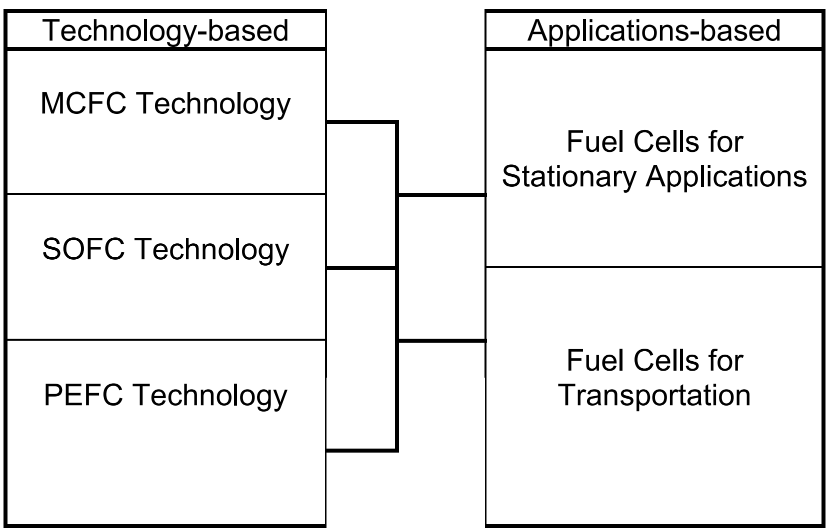
Sweden XII	L Sjunnesson	B Gustafsson		B Ridell
Switzerland	A Hintermann			
UK	R Eaton	M Heffernan		
USA	J Milliken	M Williams	D Myers	XI
			R Ahluwalia	XV

1.3 CURRENT AND FUTURE ANNEXES

Five Annexes were ongoing during 2003:

Annex XI	Polymer Electrolyte Fuel Cells.
Annex XII	Fuel Cells for Stationary Applications.
Annex XIII	Solid Oxide Fuel Cells.
Annex XIV	Molten Carbonate Fuel Cells
Annex XV	Fuel Cells for Transportation.

Together these five annexes form an integrated programme of work for 1999 to 2003, comprising three technology-based annexes (MCFC, SOFC and PEFC) and two application-based annexes (stationary and transportation applications), as shown below.



The programme places a greater emphasis on application- and market-orientated issues than previously, whilst continuing to address technology development and information management. The scope and timing of the programme are shown below.

Scope of the programme for 1999-2003

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

Timescales

	1996	1997	1998	1999	2000	2001	2002	2003
MCFC	Annex VI				Annex XIV			
SOFC	Annex VII			Annex XIII				
PEFC	Annex VIII			Annex XI				
Stationary Systems	Annex IX			Annex XII				
Transportation		Annex X				Annex XV		

2. EXECUTIVE COMMITTEE REPORT

2.1 MEMBERSHIP AND PARTICIPATION

There were changes in the Executive Committee membership in 2003 for Australia, Finland, Japan, Norway and the UK. Mr Jerri Laine (TEKES) replaced Mr J Wide (also TEKES) as member for Finland. Mr Fujio Shouji (NEDO) and Mr Tomohiko Ikeya (NEDO) replaced Mr Toru Ninomiya (NEDO) and Mr Hiroshi Ochi (NEDO) as Member and Alternate for Japan. Ms Ragne Hildrum (Statkraft) replaced Mr Per Øyvind Hjerpaasen (Statkraft) as Member for Norway and Rolf Aaberg replaced Ms Ragne Hildrum (Statkraft) as alternate Member for Norway. Mr Martin Heffernan (DTI) replaced Mr James Marsh (DTI) as alternate Member for the UK.

There were two changes of Operating Agent, with Dr LGJ (Bert) de Hart (Forschungzentrum Juelich Germany) replacing Dr Subhash Singhal (Pacific Northwest National Laboratory, USA) for Annex XIII and Mr Fujio Shouji (NEDO, Japan) replacing Mr Toru Ninomiya (NEDO, Japan) for Annex XIV.

2.2 ACTIVITIES AND DECISIONS

2.2.1 Activities

Two Executive Committee meetings were held. The 26th Executive Committee meeting was held in Espoo, Finland in May and the 27th meeting was held in Dusseldorf, Germany in October.

The web site for ExCo members was updated during 2003, providing details of forthcoming meetings and downloadable papers and reports. This is in addition to the public web site (www.ieafuelcell.com), which provides information on the programme, downloadable publications, contact details and links to other fuel cell organisations.

The 2002 Annual Report was prepared and distributed.

An End-of-Term Report was prepared and presented with a proposal for a five-year extension to the IEA End-Use Working Party at its meeting in Washington DC on 9 October 2003 and the Committee on Energy Research and Technology (CERT) on 6 November 2003. These committees unanimously approved the End-of-Term Report and extension request.

On behalf of the ExCo, the Secretary prepared a contribution on the Advanced Fuel Cells Implementing Agreement for the EUWP Autumn Status Report on Transport related Implementing Agreements. The Secretary also prepared a chapter on fuel cells for a forthcoming IEA report on energy technologies.

The Executive Committee continued to co-ordinate its activities with other relevant IEA Implementing Agreements. This has included cross-representation on the Executive Committees of the Hydrogen Implementing Agreement and IEA Coal Research, and the participation of Hydrogen IA and Hybrid & Electric Vehicles IA representatives at Annex XV meetings.

2.2.2 Decisions

Following a presentation at the 27th ExCo meeting, the ExCo unanimously invited Austria to participate in the Implementing Agreement. This invitation was conditional upon the written approval of at least one Operating Agent, following consultation with his or her annex experts.

All of the existing Participants agreed to participate in a new five-year programme commencing 1st January 2004.

2.2.3 Financing and Procedures

All activities under the Annexes of the Implementing Agreement are task shared. The only cost shared activity is the Common Fund, which provides funding for the Executive Committee Secretariat.

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

2.2.4 Future Plans

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

The two Executive Committee meetings will be held in 2004. The first, in Vienna, Austria on 1-2 April, will include a joint meeting with the IEA Hydrogen Executive Committee at this meeting. The second meeting will be held in Korea the week of the 11-15 October (provisional dates).

Proposals will be brought forward for six new Annexes and an accompanying programme of cross-cutting workshops and other activities. The six Annexes will comprise three technology-specific annexes on PEFC, SOFC and MCFC, and three application-specific annexes on stationary, transportation and portable applications.

3. KEY ACHIEVEMENTS

This section of the Annual Report summarises the key achievements of the programme during the year.

3.1 ACHIEVEMENTS OF ANNEX XI PHASE II PEFC

There have been a number of important technical achievements for Annex XI Phase II, as detailed in section 4.1.

3.2 ACHIEVEMENTS OF ANNEX XII FUEL CELLS FOR STATIONARY APPLICATIONS

Annex XII has been investigating the market conditions and performance requirements for fuel cell systems in different countries and in different applications, from small-scale applications in single houses through to large-scale power generation applications. Its initial results suggest that market conditions vary widely between different IEA countries, due to climatic variations (which affects CHP operation) and differences in fuel and electricity prices. Potentially attractive niche markets have been identified for uninterruptible power supply (UPS) and small stand-alone systems, while single house applications have limited prospects except in remote locations.

Among the major findings from Annex XII Stationary Fuel Cells can be mentioned;

- The market for fuel cells in residential applications is a very difficult market to reach both for technical and for economic reasons. Fuel cell installations for bigger buildings serving several households can be more favourable as the demand changes will levelled out and the running hours longer.
- The medium sized fuel cells from 50 kWe up to about 1 MWe operating in large buildings and in industries have a large potential market, as soon they are commercial at competitive price levels.
- The market opportunity for larger fuel cells in the 200 kW to 500 kW scale is larger than the corresponding opportunity for residential systems or very large multi – MW systems. The technology to develop large fuel cells has been more difficult than previously expected and the competition is harder from other technologies as the size of the plant increase. Ideally, larger 5 MW to 20 MW hybrid-fuel cell systems, commanding very high efficiency would be ideal for serving urban load centres.
- To increase the market opportunity for larger the fuel cell systems it is essential for a break-through in performance and cost of fuel cell system.

3.3 ACHIEVEMENTS OF ANNEX XIII SOFC

Annex XIII held a very successful fourth Annex workshop in September 2003. The workshop was attended by seven participating countries who exchanged information on their research activities and gave technical presentations on issues relating to SOFC cell and stack modelling.

3.4 ACHIEVEMENTS OF ANNEX XIV MCFC

The latest R&D Data on stack technology was discussed at the Annex XIV annual workshop. The latest test procedures and test conditions for out and in cell/stack were introduced. The results of this subtask will be reviewed for the standard of MCFC test procedures in the new Annex XVII.

3.5 ACHIEVEMENTS OF ANNEX XV FUEL CELL SYSTEMS FOR TRANSPORTATION

A number of significant technical achievements were reported by the experts participating in Annex XV and are summarized in Section 4.1. A hydrogen fueling station is being built in Stockholm for the European CUTE project. A study has projected the fuel economy of hydrogen fuel cell vehicles to be 2.5-3.0 times the fuel economy of conventional gasoline ICE vehicles. The Scania hybrid FC bus project has obtained data on fuel consumption on duty cycles, auxiliary sub systems, fuel cell subsystem, noise, performance and reliability. A modeling study has estimated the premium that the early adopters of fuel cell vehicles will be willing to pay. A project is obtaining data on on-board storage of hydrogen using catalyzed $NaAlH_4$ derived compounds. An economic analysis shows that a gas station based on autothermal cyclic reforming will meet the DOE cost target for hydrogen of $2.50/kg at large sizes, 500-1500 kg H_2/day, and when mass produced, 100-500 units/year A hydrogen dispenser and cylinder filling algorithm has been developed that addresses the issues of temperature rise, potential cylinder underfilling and metering accuracy. Tests on Santa Fe fuel-cell hybrid vehicle show that compared to its conventional ICE counterpart, the fuel economy is 156% higher on the New European Drive Cycle, 185% higher on the Japanese driving schedule, 181% higher on U.S urban drive cycle, and 83% higher on U.S highway cycle. The Turin fuel cell bus has been run for 5000 km over ten months on drive cycles simulating six different routes with 35 km/h as the top speed. The bus has passed all tests related to hydrogen safety (leakage, detection and reliability), performance, functionality, energy management requirements, fuel cell start-ups and shut-downs, and fuel economy. A compact, sulfur-tolerant fuel processor that uses a noble metal alloy CPOX/ATR and a single-stage Pd membrane based high-temperature WGS reactor can achieve <1 min start-up for 50% of full power and 31% overall PEFC system efficiency. An experimental project (FASTER) is studying the feasibility of fast-starting a fuel processor for gasoline fueled automotive fuel cell systems to meet the targets of 60 s in 2005 and 30 s in 2010. A compact 9-kWt gasoline reformer for auxiliary power units (2.5 kW) has been developed and started from cold in 1200 s. A fuel processor system was fabricated that utilizes rapid-cycle pressure-swing adsorption (PSA) to purify H_2 from a gas mixture generated by auto-thermal reforming of a hydrocarbon fuel. The PSA H_2 product contains less than 50 ppm CO, at least 95% H_2, and 70% of the H_2 in the feed is recovered in the product stream.

4. TASK REPORTS

4.1 REPORT TASK XI PHASE II POLYMER ELECTROLYTE FUEL CELLS

4.1.1. Duration

This Annex, Task XI Phase II, entered into force on January 1, 2002, and is scheduled to remain in force until December 31, 2003.

4.1.2 Operating Agent

Argonne National Laboratory, Contractor, for the United States Department of Energy

4.1.3 Participants

Agencies from eleven countries were involved in this Annex during the year 2003:

Belgium:	Flemish Institute for Technological Research, Vito
Canada:	The Government of Canada
Germany:	Forschungszentrum-Jülich GmbH
Italy:	Ente per le Nuove Technologie, l'Energia e l'Ambient, ENEA
Japan:	New Energy and Industrial Technology Development Organisation, NEDO
Korea:	Korea Institute of Science and Technology
Netherlands:	Netherlands Energy Research Foundation (ECN)
Norway:	Norwegian Technical University, NTNU
Sweden:	Swedish National Energy Administration (STEM)
United Kingdom:	Secretary of State for Industry
United States:	The Department of Energy of the U. S. Government.

4.1.4 Objective

The objective of this Task is to contribute to the identification and development of techniques to reduce the cost and improve the performance of polymer electrolyte fuel cells (PEFCs) as well as PEFC systems.

4.1.5 Task Description

This Task consists of three subtasks:

Subtask 1. New Materials
Research in this subtask aims to develop improved, lower-cost membranes, electrode catalysts and structures, MEAs, bipolar plates and other stack materials and designs. The specific effort includes composite and high-temperature membranes, reduced precious metal loadings in electrodes with

enhanced tolerance to carbon monoxide, higher activity cathodes, and lower cost bipolar plates and other stack materials.

Subtask 2. Balance-of-Plant Issues
This subtask addresses the balance-of-plant in PEFC systems. The work is divided into fuel processor development, end-use aspects, and component and systems modelling. The fuel processor work is developing new catalysts and supports, dynamic models, and compact reformers. The end-use aspects are examining contaminants, operating environments, and duty cycles. The modelling activity has the objective of developing system designs that offer the efficiency and dynamic response needed by the end-use application, while maintaining costs, weights, and volumes within target values.

Subtask 3. Direct Methanol Fuel Cells
The objective of this subtask is to improve the performance and lifetime of direct methanol fuel cells. This involves the identification and development of new anode and cathode catalysts, new electrode/electrolyte structures, high-temperature membranes, as well as new concepts in stack materials and designs.

4.1.6. **Progress Summary**

4.1.6.1 Background

This Annex continues the work previously conducted under Annex XI, Annex VIII, and Annex IV. Belgium and Norway are two countries that did not participate in Annex XI but are participating in this Phase II of Annex XI.

4.1.6.2 Activities

The Annex XI Phase II working group met on the coastal steamer Hurtigruten travelling from Trondheim to Bergen, Norway on May 6-7, 2003 for the spring meeting, and at Miami Beach, Florida, U. S. A., on November 7-8, 2003 for the fall meeting. Discussions at these workshops indicate that progress is being made in all subtasks of the Annex, as highlighted in the next section.

4.1.6.3 Technical Accomplishments

Subtask 1: New Materials

- Self-organizing sulfonated styrene-fluoropolymer di-block co-polymers resulted in membranes with higher proton conductivity than that of Nafon at 80ºC under low humidity conditions. (Canada)
- Determined that the ion exchange capacity of the bulk membrane affects the cathode electrode performance by effecting the degree of flooding of micropores responsible for the gas phase diffusion of oxygen to the catalyst sites. (Canada)
- Polymer-graphite composites were developed to decrease the thickness, increase the strength, and decrease the manufacturing costs of bipolar plates. (Canada)
- A novel method for preparing carbon-supported platinum-ruthenium alloy catalysts for PEFC's was developed and patented. These catalysts have performance similar to commercial E-Tek samples but with increased stability and decreased cost. (Italy)

- Under strong government support, fuel cell demonstrations are being planned for industrial and consumer applications, including passenger cars. Technology development efforts include low-cost austinitic separators with metallic precipitates as current paths, improved direct methanol fuel cell components, and the development of codes and standards. (Japan).
- Bilayer anode electrodes with improved CO-tolerance have been developed with fast CO and slow hydrogen oxidation kinetics on the outer catalyst layer and fast hydrogen oxidation and slow CO oxidation on the inner catalyst layer. (The Netherlands)Improvements in the fabrication of the electrode layers for polybenzimidazole-phosphoric acid high temperature fuel cells resulted in cells with a maximum power density of 800 mW/cm² at 175ºC (hydrogen/air). It was concluded that the load-following response of these cells is fast and sufficient for automotive applications. (Norway)
- Composite proton-conducting membranes of perfluorosulfonyl fluoride copolymer resin and mordenite powder resulted in a stable cell performance for twenty hours at 120ºC whereas a cell with a pure polymer membrane underwent a significant performance loss in two hours. (Korea)
- Using ultra-high vacuum techniques, it was determined that Sn promotes the oxidation of CO on Pt(111) by forming adsorbed –OH at low potentials. (United Kingdom)
- Using a newly-developed high throughput electrocatalyst screening technique, it was found that larger particles of platinum are more active than smaller particles for methanol oxidation and oxygen reduction. (United Kingdom)
- A high throughput vapour deposition apparatus was developed to form arrays of catalysts containing varying ratios of three materials. Screening of arrays of gold, platinum, and palladium catalysts showed that catalysts high in palladium and low in gold have the highest CO oxidation and oxygen reduction activity. (United Kingdom)
- Proton-conducting dendrimers have been attached to polymer backbones to form membranes for operation at >120ºC and low relative humidity. Initial measurements showed one such membrane to have a conductivity of 0.1 S/cm at 76ºC and 6% relative humidity. (United States)

Subtask 2: Balance-of-Plant

- Test benches for alkaline and polymer electrolyte fuel cell stacks up to 20 kW_e have been constructed, requiring specialized gas humidifying equipment. Nexa and Ballard stacks have been tested. (Belgium)
- A 15 kW_e natural gas-fueled PEM system has been built using a partial oxidation reformer, three Nuvera fuel cell stacks, and a CNR preferential oxidizer. (Italy)
- Analysis of a 5 kW combined heat and power PEM system has shown that using a variable-flow compressor, rather than constant flow, and matching electric energy production with energy demand provides the highest energy savings. (Italy)
- A micro methanol fuel processor and fuel vaporizer have been designed and fabricated. The processor produces 15 kW_e hydrogen containing <2% CO. (Korea)

- A self-sustainable 5 kW_e methanol autothermal reformer for fuel cell-powered vehicles has been constructed using in-house developed catalysts. The reformer achieved full power in 300 seconds. (Sweden)
- Direct borohydride fuel cells are being developed in a joint U.K.-U.S. venture The best performance to date,70 mW/cm² at 80ºC, was obtained with a planar design, using a hydroxyl-conducting membrane, and potassium borohydride in a potassium hydroxide solution. (United Kingdom)
- A hybrid system with a diesel fuel processor and battery pack has been modelled for use as an auxiliary power source for a ship hotel load. The analysis resulted in a steady-state fuel processor efficiency of 87% and an electrical efficiency of approximately 30% (based on the lhv of the fuel). (United Kingdom)
- A natural gas PEFC system has been modelled for building cooling, heating, and power (BHCP). Absorption cooling was introduced to utilize the excess heat in the summer for cooling needs and a heat pump to compensate for a deficiency of waste heat in the winter. The projected system efficiencies are 70-85% during summer and 115% during winter. (United States)
- An automotive gasoline fuel processor is being designed and fabricated to start in less than 60 seconds. Simulation has shown that the current design, based on autothermal reforming, should be able to supply 75% of the rated hydrogen within 30 seconds, 90% within 60 seconds, and achieve a steady-state efficiency of >80%. (United States)

Subtask 3: Direct Methanol Fuel Cells

- Twenty, eighty, and five hundred watt direct methanol fuel cell systems have been developed for military (20 and 80 W) and auxiliary power unit (500 W) applications. Considerable progress has been made in improving the power density of these systems. A specific power density of 290 W/kg has been achieved. (United States)

4.1.7 Work Plan For Next Year

The general consensus of the Working Group is that, due to the rapid advances being made in the development of polymer electrolyte fuel cells, it is difficult, and perhaps inappropriate, to develop a detailed work plan for any significant length of time. Instead, each participant is working from a generic program plan that identifies the tasks and areas of effort. These are summarised below, by participating country.

Belgium:	Fuel cell, stack, and component testing, system integration and testing, determination of technical feasibility of using ammonia as a distributed fuel for fuel cells
Canada:	Membrane, electrode, and bipolar plate development, characterisation, and modelling
Germany:	Direct methanol fuel cells, materials, and systems

Italy:	MEAs, catalysts, fuel cell stack and system testing and analysis
Japan:	Stack materials and component designs, MEAs, bipolar plates, effects of ambient air contaminants, codes and standards, and demonstrations of fuel cell electric vehicles, fuelling stations, and stationary systems
Korea:	Stack development and testing, MEA fabrication development and performance characterisation, system integration and testing, and micro direct methanol fuel cells for consumer applications
The Netherlands:	CO tolerance, low humidity membranes, and system and cell modeling
Norway:	High temperature polymer electrolyte fuel cell development and the integration of a methanol reformer and a high temperature fuel cell
Sweden:	Fuel processing, fuel cell materials and designs
United Kingdom:	CO tolerance, electrocatalyst development, systems analysis, direct sodium borohydride fuel cells, and direct methanol fuel cells
United States:	Modelling and systems analysis, automotive reformer development, high-temperature polymer electrolytes, non-platinum electrocatalysts, and direct methanol fuel cells

4.2 REPORT TASK XII FUEL CELL SYSTEMS FOR STATIONARY APPLICATIONS

4.2.1 Duration

The Annex entered into force during 1999 and shall remain in force until December 31, 2003.

4.2.2 Operating Agent

The Swedish National Energy Administration acting through Sydkraft AB, Sweden.

4.2.3 Participants

The Contracting Parties, which are the Participants in the Task are:

Forschungszentrum Jülich GmbH (Germany)
Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, ENEA (Italy)
The New Energy and Industrial Technology Development Organisation, NEDO (Japan)
The Research Council of Norway
The Swedish National Energy Administration
L'Agence de l'Environment et de la Maitrise de l'Energie, ADEME (France)
Ceramic Fuel Cells Ltd (Australia)
Energieonderzoek Centrum Nederland ECN (The Netherlands)
United States of America Department of Energy (USA)
Swiss Federal Office of Energy (Switzerland)
Technical Research Centre of Finland, VTT (Finland)

A full list of participating experts is provided in appendix 7 to this report.

4.2.4 Objective

The main objective of the work in Annex XII has been to receive a better understanding how stationary fuel cells in some applications may be deployed into the energy systems in some countries. The main emphasis of the work has been

- to describe the technical solution for implementing of residential fuel cells for CHP applications under Northern European conditions.
- to investigate the different conditions for the introduction of stationary fuel cells in the participating countries
- to investigate the early markets for commercialisation of stationary fuel cells

- to follow up and analyse the development of the different fuel cell technologies and their road to commercialisation
- to analyse the most important parameters from a technical, economic, environmental and socio-economic point of view.

4.2.5 Task Description

The technologies to be analysed shall mainly be focused on,

- Polymer Electrolyte Fuel Cell in on-site application (up to 500 kW)
- Solid Oxide Fuel Cell and Molten Carbonate Fuel Cells, alone or in combination with a gas turbine in a stand alone or an industrial application or in a district heating network (500 – 2000 kW or more)

The Task has been fulfilled by work undertaken in four different sub-tasks. The sub-tasks are described more in detail below. It has been important for the success of the Task that all participants have been active in (all) the different sub-tasks.

General background for Sub-tasks 1-3

Sub-tasks 1-3 deal with the consideration of introducing fuel cells at different applications in the participating countries. The sub-tasks have covered the following items.

- Which fuel cell(s) to be applied in different applications in the participating countries.
- Comparison with competing technologies.
- System configurations for different applications.
- Key factors for introduction.
- Identification of leading actors.
- Environmental considerations.

The different conditions for fuel cells in the participating countries have investigated by a questionnaire. The questionnaire has included both the basic conditions for an introduction of fuel cells as well as the market conditions and identification of possible niche markets in the participating countries. The results from the questionnaire have been analysed and submitted by NEDO, Japan within the work of Subtask 2.

Subtask 1 **Fuel cells for residential customers (up to 10 kW)**

The work in the subtask was to identify where, to what extent, in what way and which fuel cells that should (could) be used in the residential area.

The subtask should mainly concentrate on technical and economical matters for fuel cell stationary systems in individual houses and small buildings. The work has focused on a residential CHP installation in Northern European climate. An important issue has been to analyse the basic conditions and market possibilities for residential fuel cell systems in single- family houses.

Of importance has been to clarify the market and the variation of demand.

Subtask 2 **Fuel cells for large buildings etc. (30 kW – 1000 kW)**

The work in the subtask was to identify where, to what extent, in what way and which fuel cells that should (could) be used for consumers such as commercial buildings, large buildings, small industry and hospitals.

- Local CHP installations
- Other installations, UPS, emergency power etc.

The subtask has mainly concentrated on technical and economical matters for fuel cell stationary systems in buildings etc. The work has focused on different installations using information from the participating countries.

To be able to collect all the necessary information from the different participating countries has a questionnaire been worked out and analysed within the subtask. The results from the questionnaire have been used also in the other subtasks.

Subtask 3 **Fuel cells systems for power generation (1000 kW – 10 MW)**

The subtask has focused on applications for utilities. Examples of different applications chosen from the participating countries to be investigated has been

- a grid connected power station with the highest possible electric efficiency
- a CHP (combined heat and power) plant in a district heating system with a high electric efficiency in combination with a high fuel utilisation.

Special focus has been given to the high temperature fuel cell technology utilised alone or in combination with a gas turbine.

The main part of the activities in the subtask has been to describe and analyse the current situation and trends for the developers of large fuel cells systems.

Subtask 4 **Implementation/deployment of fuel cell technologies**

The work in the task in Annex XII has been to identify all relevant aspects of importance for the fuel cell technology to be implemented into the different energy systems in the participating countries. The evaluations have included technical economic and environmental issues as well as socio-economic issues. The work has identified and analysed obstacles and how they shall be overcome.

There are huge differences in the energy systems of the participating countries, which will influence the introduction of fuel cells in the energy system, e.g. differences in political questions, energy prices, fuel prices, competition, including the deregulation of the energy market, imported or domestic fuels etc.

The subtasks have highlighted the interplay between the evaluation of the technology, the market and the role of the authorities, all essential for the introduction of any new technology.

The work in the subtasks addresses issues like:

- Identification, evaluation and analysis of key factors that will influence the introduction of the fuel cell technology for stationary systems in the participating countries.
- Identify existing and required standards that could apply to fuel cells
- User requirements
- Evaluation of demonstrations, public feed-back, licensing etc..
- Public acceptance of fuel cell technology and hydrogen systems.
- Non-technical barriers (e.g. regulations, standards etc.)
- Case stories from different countries both existing and planned systems
- Environmental aspects such as emissions, decommissioning, toxicity of materials
- Identify initial markets

4.2.6 Task Results

The different conditions for the introduction of fuel cells have been investigated by using a questionnaire. The conditions for fuel cells are very different in the participating countries that will influence the commercial introduction of fuel cells. The main differences are in prices for fuel and electricity and the market for CHP applications mainly depending on the local climate

Among the major findings from Annex XII Stationary Fuel Cells can be mentioned;

- The market for fuel cells in residential applications is a very difficult market to reach both for technical and for economic reasons. Fuel cell installations for bigger buildings serving several households can be more favourable as the demand changes will levelled out and the running hours longer.
- The medium sized fuel cells from 50 kWe up to about 1 MWe operating in large buildings and in industries have a large potential market, as soon they are commercial at competitive price levels.
- The market opportunity for larger fuel cells in the 200 kW to 500 kW scale is larger than the corresponding opportunity for residential systems or very large multi – MW systems. The technology to develop large fuel cells has been more difficult than previously expected and the competition is harder from other technologies as the size of the plant increase. Ideally, larger 5 MW to 20 MW hybrid-fuel cell systems, commanding very high efficiency would be ideal for serving urban load centres.
- To increase the market opportunity for larger the fuel cell systems it is essential for a break-through in performance and cost of fuel cell system.

4.2.7 Work Plan for Year 2004

The final executive summary report and all the subtask reports will be approved printed and published in accordance with the IEA guidelines.

The new annex regarding stationary fuel cells Annex XIX will start during the spring 2004 after approval from the ExCo.

4.3 REPORT TASK XIII SOLID OXIDE FUEL CELLS

4.3.1 Duration

January 1999 – December 2003.

4.3.2 Operating Agent

Interim Operating Agent until December 2000: Dr. Joep P.P. Huijsmans (Netherlands Energy Research Foundation ECN).
Interim Operating Agent until December 2001: Dr. M. Suzuki / Mr. H. Fujii (NEDO, Japan).
Interim Operating Agent until December 2002: Dr. S.C. Singhal (Pacific Northwest National Laboratory, USA).
Interim Operating Agent until December 2003, Dr. L.G.J. (Bert) de Haart (Forschungzentrum Juelich, Germany).

Each interim Operating Agent is responsible for the preparation, execution and documentation of the annual workshop, including the production and dissemination of the proceedings. The Operating Agent will also be responsible for reporting to the Executive Committee.

4.3.3. Participants

Ceramic Fuel Cells Ltd (Australia)
Natural Resources Canada (Canada)
ADEME (France)
Forschungszentrum Jülich (Germany)
The New Energy and Industrial Technology Development Organisation, NEDO (Japan)
ECN (Netherlands)
Swedish National Energy Administration (Sweden)
Swiss Federal Office of Energy (Switzerland)
DTI (UK)
US DOE (USA).
VTT Processes (Finland) (from 2002)

4.3.4. Objective

To organise a series of annual workshops on specific topics, each to be organised by and in a different country. Each workshop will be organized over two days, with the first day discussing general progress and the second focusing on a chosen topic. Where possible, these workshops will be linked into relevant conferences, in order to minimise travelling costs. The workshops should lead to open discussions relating to common problems and have realisable and achievable aims.

4.3.5 Task Description

Representatives from 10 countries (see above participants list) participated in an Annex XIII planning meeting on September 17th September 1999 in London (Imperial College; organized by Stuart Woodings of DTI). The experts attending the meeting agreed on the objectives of the Annex described above and agreed on an Operating Agent "system" as described above. It was decided that the Annex XIII would comprise a series of workshops on specific topics, each to be organized by and in a different country. The provisional list of workshops is as follows:

Planning workshop	September 1999	London, UK
Task A: Low cost manufacture and design	July 2000	Petten the Netherlands
Task B: Low temperature operation	May/June 2001	Tokyo Japan
Task C: SOFC Systems	November 2002	Palm Springs California, USA
Task D: Modelling of Cell and Stack Operation and Electrode Processes	September 2003	Jülich Germany (tbc)

Topical meetings are organized as satellite meetings around the above tasks. In September 2000 a topical meeting was organised in Sweden on "SOFC/GT modelling". In January 2001 a topical meeting was organized in Switzerland on "SOFC Materials and Mechanisms".

4.3.6 Progress Summary

4.3.6.1 Overview

After the London planning meeting in September 1999 for IEA Annex XIII "SOFC" the organization of the system of interim operating agents and workshops around specific themes was set in operation. As a result the Petten workshop was held in 2000, the Tokyo workshop was held in 2001, the Palm Springs workshop was held in 2002 and the Jülich workshop was held in 2003. Topical meetings under the umbrella of Annex XIII were also held (Sweden in 2000, Switzerland in 2001).

4.3.6.2 Administration in 2003

The interim Operating Agent for 2003 prepared status reports on Annex XIII for the ExCo meetings held in May 2003 in Finland and in October 2003 in Germany.

The interim Operating Agent prepared a concept work plan for a new Annex on SOFC for the next period from 2004 to 2008 presented at the ExCo meeting held in May 2003 in Finland.

The work plan, with comments from the ExCo, was discussed with the attending representatives of Annex XIII at the September 2003 Workshop in Jülich, Germany. The revised work plan was then presented at the ExCo meeting in October 2003 in Germany.

4.3.6.3 Activities in 2003

Preparations were made for the 2003 Workshop which was held on September 22-23 in Jülich, Germany. The workshop was attended by eighteen representatives of seven of the participating countries; Canada, Finland, Germany, Japan, the Netherlands, Switzerland and the USA. They all presented the status of SOFC R,D&D in their respective country. Not able to attend the workshop were representatives from Australia, France, Sweden and the United Kingdom.

On the first day of the Workshop the participants made a visit to the Institute for Energy Process Engineering at the Forschungszentrum Jülich: Members of the institute conducted a technical tour not only through the SOFC laboratories, but also the activities on fuel processing and low temperature fuel cell DMFC were presented.

During the second part of the workshop eight presentations were made by experts from participating countries dealing with the selected topic of the workshop 'Modelling of cell and stack operation and electrode processes'. The presentations showed that in the recent years a real progress has been made not only in the modelling capacities extending to larger stacks, but also in the direction of transient and dynamic behaviour.

4.3.6.4 Technical Accomplishments in 2003

The selected topic for the 2003 Workshop was 'Modelling of cell and stack operation and electrode processes'. During the workshop eight presentations were made by experts from participating countries dealing with this selected topic. The presentations showed that in the recent years a real progress has been made not only in the modelling capacities extending to larger stacks, but also in the direction of transient and dynamic behaviour.

4.3.6.5 Future Plans

The representatives in the Annex XIII expressed their wish to continue with an Annex on SOFC in the next period 2004-2008 of the Implementing Agreement on Advanced Fuel Cells. A work plan was presented to the ExCo at the meeting in October 2003 in Germany.

4.3.6.6 Conclusion

The system of interim Operating Agents and the organisation by these Operating Agents of workshops linked to other large, international SOFC conferences has so far turned out to be a successful concept. The openness of discussions, the open exchange of technical know-how and the intimate atmosphere of such workshops, was highly appreciated by the participants of the all workshops. The consolidation of this concept is assured by the enthusiastic and positive reactions of new interim Operating Agents in this Annex.

The Executive Committee is invited to note the satisfactory progress achieved and to endorse the future plans presented.

4.4 REPORT TASK XIV MOLTEN CARBONATE FUEL CELLS TOWARDS DEMONSTRATION

4.4.1 Duration

Original period: January 1, 2000 to December 31, 2003.

4.4.2 Operating Agent

New Energy and Industrial Technology Development Organization (NEDO) of Japan.

4.4.3 Participants

Original Participants:

Germany	Forschungszentrum Jülich GmbH (KFA) through Motoren und Turbinen Union Friedrichshafen GmbH (MTU)
Italy	Ente Nazionale per le Nuove Tecnologie l'Energia e l'Ambiente (ENEA)
Japan	New Energy and Industrial Technology Development Organization (NEDO)
The Netherlands	Netherlands Energy Research Foundation (ECN)
Korea	Korea Institute of Science and Technology (KIST) through Korea Electric Power Research Institute(KEPRI)
United States	US Department of Energy (DOE) through Fuel Cell Energy (FCE)

4.4.4 Objective

The objective shall be to provide for further international collaboration in the research and development of certain aspects of MCFC technology, in order to realize commercialisation of the MCFC system. These aspects shall include:

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

4.4.5 Task Description

(a) Subtask A: Stack and New-material Technology for Longer Life, Higher Performance and Lower Cost.
Subtask-leader: ENEA(Italy).

In this subtask, a basic analysis is made of stack performance improvements needed for commercial systems. Discussion focuses on the following topics.

(1) Survey of long lifetime stack
(2) Survey of high performance stack
(3) Survey of low cost stack.

(b) Subtask B: MCFC Test Procedures and Standardization
Subtask-leader: MTU(Germany)

.
This subtask focuses on a review of test procedures presently used by MCFC developers to characterise their raw materials and finished components in order to qualify them for use in the fuel cells. On the basis of information collected from the participants "Master Test Procedures" shall be drafted. These may subsequently be used as the basis of standard procedures, following agreement by the participants.

(1) Discussion and Adoption of "Master Test Procedures" for Cathodes and Metallic Hardware
(2) Discussion and Adoption of "Master Test Procedures" for Anodes Electrolyte and Matrices
(3) Final discussion of all procedures and their implementation as standards

(c) Subtask C: Plant Development and Test Experience
Subtask-leader: NEDO (Japan).

In this subtask, technical reviews will be made, aimed at the realisation of effective MCFC systems. Discussion will be carried out on performance, reliability, cost, operability, etc. Activities will be carried out on the following items. Items (1) through (3) will be discussed at every meeting to share up-to-date information of the participants' experiences.

(1) Survey of Stacks
(specifications, performance, operating conditions, start-up procedures, etc.)
(2) Survey of System configuration and BOP components
(total efficiencies, control, site space, improvement of components, etc.)
(3) Operation test experiences of stacks and systems
(operating data, problems and their countermeasures, etc.)
(4) Possibility of more effective systems in the future
(higher efficiencies, utilisation of coal gas, CO_2 recovery, etc.)
(5) Barriers to commercialisation
(cost, market, operability, etc.).

4.4.6 Progress Summary

4.4.6.1 Background

The attractions of the Molten Carbonate Fuel Cell (MCFC) as a power source have been understood for quite some time. However, it has also been realized that a number of problems, mainly related to endurance and cost, have to be overcome or overridden before commercialization of MCFC technology can come within sight. By the end of 1991, initiatives were taken for collaborative work in this respect, within the IEA Programme on Advanced Fuel Cells. After canvassing interest during a workshop in June 1992 at ECN in The Netherlands, Annex III "MCFC Materials and Electrochemistry" was started in May 1993 with the participation of Germany, Italy, Japan, the Netherlands and Sweden. The Annex remained active to the end of 1995, dealing with the endurance problems connected to corrosion of the bi-polar plate, dissolution of the cathode, and the electrolyte inventory of MCFC stacks. Apart from an extensive date-exchange and fruitful expert discussions, the main result of the Annex was a consensus on the relative importance of the endurance limitations mentioned. In addition, life-time estimations were made relating to the eventual mal-functioning of cells and stacks caused by the phenomena studied.

At the finalisation of Annex III it was recognised that, for further progress in endurance improvement and cost reduction, better quantitative studies would be necessary. Such studies should, in addition to estimates for endurance limitations by mal-functioning, analyse the rate of gradual degradations of stack performance and assess its contributions. Subsequently, ways to reduce the various degradation contributions should be identified.

From another Annex under the Advanced Fuel Cell Program, Annex I “MCFC BOP Analysis” it became clear that further work would be necessary to reveal possibilities for Balance-of-Plant (BOP) technology with improved reliability and reduced cost. Also, the study of BOP provides for interfacing between system-user requirements and stack operational windows, and the resulting consequences for performance and endurance.

In the course of the work performed in Annex III, frequently data was encountered without proper description of the used methods or procedures, or obtained with methods not allowing for easy comparison. The demand was felt for the development and standardisation of effective test-procedures for MCFC materials, cells and stacks.

In the second phase of the IEA Programme on Advanced Fuel Cells, the various Annexes were divided in fuel-cell-type oriented Annexes, concerning materials, cell, stack and Balance-of-Plant aspect, and Annexes regarding system aspects, applications, and user requirements. In this manner, Annex VI “MCFC under Real Operating Conditions” concentrated on the manufacturer’s capabilities to improve MCFC technology, frequently communicating with Annex IX “Fuel Cell Systems for Stationary Applications” about the conditions set by applications and users.

The final meeting of Annex VI was held on April 15-16,1999 in Petten, and the Annex concluded at the end of 1999. The purpose of Annex VI activities had been accomplished and the final report was submitted and approved at the 19th

ExCo Meeting. Annex VI activity was succeeded by Annex XIV which is active between 2000 and 2003.

4.4.6.2 Activities

The first meeting was held on October 26-27, 2000 in Danbury, USA hosted by Fuel Cell Energy. All participants attended the meeting. The activities for each Subtask were discussed at the meeting and agreed by the participants.

The objectives of the first meeting were as follows:
Subtask-A: Survey of long lifetime stack
Subtask-B: Master test procedures for cathode and metallic hardware
Subtask-C: 1. Survey of stack, balance of plant (BOP) and system.
2. Operational test experience

The second meeting was held on September 17-19, 2001in Rome, Italy hosted by ENEA. All participants attended the meeting. The activities for each Subtask were discussed at the meeting and agreed by the participants.

The objectives of the second meeting were as follows:
Subtask-A: Survey of high performance stack
Subtask-B: Master test procedures for anodes, electrolyte, matrix and cells & stacks
Subtask-C: 1. Survey of stack, BOP, system
2. Operation test experience
3. Possibility of more effective system in the future

The third meeting was held on October 7-9, 2002 in Munich, Germany hosted by MTU. All participants except The Netherlands attended the meeting. The activities for each Subtask were discussed at the meeting and agreed by the participants.

The objectives of the third meeting were as follows:
Subtask-A: Survey of stack cost reduction
Subtask-B: Confirmation of data by sample test
Subtask-C: 1. Survey of stack, BOP, system
2. Operation test experience
3. Solution towards commercialisation

The fourth meeting was held on October 15-17 2003 in Korea hosted by KIST. All of the participants except The Netherlands attended the meeting. The activities for each Subtask were discussed at the meeting and agreed by the participants.

The Objectives of the fourth meeting were as follows:

Subtask-A Summary of stack technology
Subtask-B Implementation of the procedures as standards
Subtask-C 1. Survey of stack, BOP, system
2. Operation test experience
3. Summary of system configuration.

4.4.6.3 Technical Accomplishments

First meeting

Subtask A: Survey of long lifetime stack

In this subtask, participants made presentations on long lifetime stacks. The latest R&D data from each country's developers were provided and discussed. Presentations were as follows:

A-1 Cathode Polarization as a function of Electrolyte Filling Level and Gas Composition by Manfred Bischoff (MTU)
A-2 Highlights of the next 5 years programme (2000-2004) Strategy and expected results by Angelo Moreno (ENEA)
A-3 Long-term Performance of Li/Na cell & stack by Izaki (CRIEPI)
A-4 Korea's Activities on Improving Lifetime of MCFC by Tae Hoon Lim (KIST)
A-5 Development of a low cost durable stack design by S.B.van der Molen (ECN)
A-6 Status of Carbonate Fuel Cell Material by C.Y.Yoh (FCE).

Subtask B: Master test procedures for cathode and metallic hardware.

In this subtask, participants made presentations on master test procedures for cathode and metallic hardware. Test Procedures and standards from each country's developers were provided and discussed. Presentations were as follows:

B-1 Evaluation test condition & post test procedure by Izaki (CRIEPI)
B-2 Standard test procedures for characterisation of stacks by S.B.van der Molen (ECN)
B-3 Test Procedures for MCFC Materials and Components by Manfred Bischoff (MTU).

Subtask C: 1. Survey of stack, BOP, systems
2. Operational test experience.

In this subtask, participants made presentations on stacks, BOP, systems and operational test experience. Presentations were as follows:

C-1 Danbury 250kW Power Plant Demonstration Experience by Mohammad Farooque (FCE)
C-2 Operating Experience with a 270kW MCFC System by Manfred Bischoff (MTU)
C-3 The Italian experience 100kW MCFC Cogeneration Plant New rectangular full area stack (STD3) by Angelo Moreno (ENEA)
C-4 Results of 1000kW MCFC plant and 200kW & Outline of the new project by Tooi (MCFC-RA)

1. Demonstration of the first 1000kW MCFC Power Plant in Japan
2. Verification test of 200kW class AIR-MCFC stack
3. MCFC Research and Development in Japan

C-5 Operating and Experience of a 25kW MCFC System by Hee Chun Lim (KEPRI).

Second meeting

Subtask A: Survey of high performance stack

In this subtask, participants made presentations on high performance stack. Presentations were as follows:

A-1 "Molten Carbonate Fuel Cells Towards Demonstration" by Angelo Moreno (ENEA)
A-2 "Investigation of Fused Salts" by Manfred Bischoff (MTU)
A-3 "R&D Activities for Durable MCFC in Korea" by Tae Hoon Lim (KIST)
A-4 "Survey of Technology for longer cell & stack life in Japan" by Izaki (CRIEPI)
A-5 "Ansaldo Research Actions to Improve Lifetimes" by Passalacqua (Ansaldo)

Subtask B: Master test procedures for anodes, electrolyte, matrix and cells & stacks

In this subtask, participants made presentations on master test procedures for anodes, electrolyte, matrix and cells & stacks. Presentations were as follow:

B-1 "Test Procedures for MCFC Materials and Components" by Bischoff (MTU)
B-2 "Single Cell test for MCFC in KIST" by Tae Hoon Lim (KIST)
B-3 "Evaluation test condition & post test items" by Izaki (CRIEPI)
B-4 "ECN contribution to IEA meeting MCFC" by Bert Rietveld (ECN)

Subtask C: 1. Survey of stack, BOP, system
2. Operation test experience
3. Possibility of more effective system in the future

In this subtask, participants made presentations on survey of stack, BOP, system, operation test experience and the possibility of more effective system in the future. Presentations were as follow:

C-1 "Current Status of MCFC R&D at The Kawagoe MCFC Test Station"by Andoh (MCFC-RA)
C-2 "100kW MCFC System Development in Korea" by Choong-Gon Lee (KEPRI)
C-3 "Gas Clean-up and Pre-reforming" by Bischoff (MTU)
C-4 "Status of MCFC technology at ECN/BCN" by Bert Rietveld (ECN)
C-4 "Electrochemical Energy Conversion Section Molten Carbonate Fuel Cell Laboratory" by Leonardo Giorgi (ENEA)

Third meeting

Subtask-A: Survey of stack cost reduction

In this subtask , there were seven presentations about activities of longer life for MCFC with cell and stack tests. Participants discussed items for protecting corrosion and avoiding Ni-shorting. All participants agreed issues for long life and would continually discussed progress of each issue in the next meeting. Presentations were as follows:

A-1 "Stack and new material technology for longer life and cost reduction" by Dr. Moreno (ENEA)
A-2 "Key points of the R&D activities in ENEA and AFCo" by Mr. Passalacqua (AFCo)
A-3 "Development of Stabilized Cathode in KIST" by Dr. Tae Hoon Lim (KIST)
A-4 "Evaluation of a 10kW class short-stack for 10,000 hours" by Dr. Izaki (CRIEPI)
A-5 "Short Stack High-Pressure Test by Mr. Tooi (IHI)
A-6 "Advances, Aging Mechanism and Lifetime in MCFC"by Manfred Bischoff (MTU)
A-7 "Status of Carbonate Fuel Cell Materials" by Dr. Farooque(FCE)

Subtask-B: Confirmation of data by sample test

In this subtask , there were four presentations about test procedure for cells and small stacks. Participants discussed procedure of comparing data each other's. It was proposed to decide a standard test condition and a standard equation for comparison. In the next meeting, participants would discuss this mater and conclude this task. Presentations were as follows:

B-1 "Evaluation tests with small-single cells" by Dr. Izaki (CRIEPI)
B-2 "Single Cell Test in KIST" by Dr. Hann (KIST)
B-3 "Experience of test procedures and standardization at Ansaldo Fuel Cells"by Mr. Passalacqua (AFCo)
B-4 "Single Cell Tests" by Dr. Bischoff (MTU)

Subtask-C: 1. Survey of stack, BOP, system
2. Operation test experience
3. Solution towards commercialisation

In this subtask, there were four presentations about project activity in each country. Participants had latest information on MCFC R&D in other countries. All participants agree to continue these information exchanges in this subtask. Presentations were as follows:

C-1 "Development of 300kW-class MCFC compact system" by Mr. Shimizu (MCFC-RA)
C-2 "The MTU Fuel Cell Hot Module Cogeneration Unit 230 kW "by Mr. Huppmann (MTU)

C-3 "Progress Status of a 100kW MCFC system development" by Ms. Seo (KEPRI, KEPCO))
C-4 "Highlights on MCFC plant development and validation tests at Ansaldo Fuel Cells" by Mr Passalacqua (AFCo)

Fourth meeting

Subtask A: Stack and new-material technology for longer life, higher performance and lower cost.

In this subtask, participants made presentations on the corrosion protection for steal of separator plate or current corrector. Presentations were as follows:

A-1 "Post-test Analysis of MCFC Short Stack" (IHI)
A-2 "Lifetime evaluation of Al-Fe coating" (KIST)
A-3 "Corrosion of stainless steel in the MCFC environment" (MTU)
A-4 "Manufacturing process for Carbonate Fuel cell Active Components (FCE)
A-5 "Main Actions on R&D at Ansaldo Fuel Cells (ANSALDO)

Subtask B: MCFC Test Procedures and Standardisation

In this subtask, the latest procedures and test conditions for out and in cell/stack were introduced. Presentations were made as follows:

B-1 "Operating tests and conditions for MCFC in CRIEPI (CRIEPI)
B-2 "Procedure for evaluating MCFC components (KIST)
B-3 "Component tests in single cells and lab-size-stacks" (MTU)
B-4 "Experience of test procedures and standardisation at Ansaldo Fuel Cells" (ANSALDO)

Subtask C: Plant development and Test Experience

In this subtask, the progress of MCFC R&D and the commercialisation program in each country was introduced. All participants agreed to exchange information continuously.

C-1 "Research of Compact System at Kawagoe MCFC test station" (MCFC-RA)
C-2 "Preparation of 100 kW pilot plant for demonstration" (KIST)
C-3 "DFC Update" (FCE)
C-4 "DFC Stack Multi-Fuel Operation Experience" (FCE)
C-5 "Experience with Hot Module field test units after three years of testing" (MTU)
C-6 "B-5 The demo phase program and manufacturing facilities of Ansaldo Fuel Cell (ENEA)

4.4.6 Work Plan for Task XVII

Korea will be the Operating Agent for the new MCFC annex. The work plan for the new annex was discussed at the fourth meeting in Korea. Three sub-tasks were agreed.

Subtask-A: Studies of stack/cell

Subtask-B: Operating experience/Fuels for MCFC

Subtask-C: BOP updating and Optimisation

The first meeting of Task XVII will be held in October 2004 in Japan.

Activity Schedule for Annex XIV

Year	2000	2001	2002	2003
Subtask A	Survey of long lifetime stack	Survey of high performance stack	Survey of stack cost reduction	Summary of stack technology
Subtask B	Master test procedures for cathodes and metallic hardware	Master test procedures for anodes, electrolyte, matrix and cells & stacks	Confirmation of data by sample test	Implementation of the procedures as standards
Subtask C	1. Survey of stack, BOP, system 2. Operation test experience	1. Survey of stack, BOP, system 2. Operation test experience 3. Possibility of more effective system in the future	1. Survey of stack, BOP, system 2. Operation test experience 3. Solution towards commercialisation	1. Survey of stack, BOP, system 2. Operation test experience 3. Summary of system configuration
Meeting Time & Place	26-27th October U.S.A	17-19th September Italy	7-9 th October Germany	15-17 October Korea

4.5 REPORT TASK XV FUEL CELL SYSTEMS FOR TRANSPORTATION

4.5.1 Duration

This Annex entered into force on May 1, 2001 and ended on December 31, 2003.

4.5.2 Operating Agent

Argonne National Laboratory, Contractor, for the United States Department of Energy.

4.5.3 Participants

Agencies from seven countries participated in this Annex during the year 2001:

Canada:	The Government of Canada
Germany:	Forschungszentrum-Jülich GmbH
Italy:	Ente per le Nuove Technologie, l'Energia e l'Ambient, ENEA
Korea:	Korea Institute of Science and Technology
Netherlands:	Netherlands Energy Research Foundation (ECN)
Sweden:	Swedish National Energy Administration (STEM)
United States:	The Department of Energy of the U. S. Government.

A full list of participating experts is provided in Appendix 7 to this report.

4.5.4 Objective

The overall objective of this Task is to promote the commercialization of fuel cells for transportation. More specifically, the objective is to discuss and coordinate activities related to technology, energy efficiency, performance, emissions and economics of production and distribution of alternative fuels for fuel cells and of the fuel cell systems.

4.5.5 Task Description

This Task consists of three subtasks:

Subtask 1. Advanced Fuel Cell Systems
This subtask analyzes the polymer electrolyte fuel cells (PEFC), solid oxide fuel cells (SOFC) and phosphoric acid fuel cells (PAFC) for generating traction power and auxiliary power. The traction fuel cell systems may be stand-alone or battery hybrids, powered with conventional or alternative fuels. The systems are analyzed in terms of technology readiness, energy efficiency, performance, emissions and economics.

Subtask 2. Fuel Infrastructure
This subtask addresses issues pertaining to production and distribution of alternative fuels (hydrogen, methane, propane, methanol, ethanol, and Fischer-

Tropsch-Synthesis liquids) for fuel cells. The specific efforts include technology of manufacturing and distributing alternative fuels, material balances, byproducts and recycling, energy consumption and emissions from stationary sources during fuel production, fuels infrastructure, life-cycle analysis (well to wheel) of different fuel choices, and refueling safety practices for fuel cell vehicles.

Subtask 3. On-board Fuel Storage and Processing
This subtask assesses the impact of fuel choice for on-board fuel storage and fuel processing technology. Some of the topics included in this subtask are on-board hydrogen storage technology, impact of fuel composition on on-board fuel processing technology, activity of catalysts for different fuels and fuel components, and development of fuel blends and specifications.

4.5.6 Progress Summary

4.5.6.1 Background

This Annex is the successor to Annex X that ran from 1997 through 1999. Switzerland, a participant in Annex X, elected not to join in this Annex. Canada, Italy and Korea are three countries that did not participate in Annex X but are active in Annex XV.

4.5.6.2Activities

The Annex XV working group met in Düsseldorf, Germany, on June 28, 2002, for the spring meeting and in Palm Springs, U.S.A., on November 17–18, 2002 for the fall meeting. Consistent with the work plan, discussions at these workshops were focused on hydrogen infrastructure and hydrogen stations, hydrogen fuel cell vehicles, liquid fueled fuel-cell vehicles, and results from demonstration programs.

4.5.6.3Technical Accomplishments

Hydrogen Infrastructure and Hydrogen Stations

- The role of fuel cells in a sustainable society has been evaluated by conceptualizing a futuristic infrastructure of a medium-size city of 250,000 inhabitants. Three eco-refineries can produce sufficient hydrogen (3 X 50 MW LHV) to power fuel cell buses, fuel cell cars and fuel cell light rails. Possible hydrogen production technologies include catalytic reforming of energy crops, gasification of biomass, fermentation, electrolysis with power produced from renewables (solar, wind, etc) and artificial photosynthesis. For the Swedish town Uppsala, the hydrogen infrastructure can be built in three steps. The first eco-refinery can be built by 2015 to supply hydrogen for city buses and fleet vehicles that may also generate electric power when not in use. The second eco-refinery can be built in 2020 to produce hydrogen for fuel cell vehicles. By 2025, the third eco-refinery can be added to supply hydrogen for all fuel-cell cars, buses and light rails and produce electric power and heat when not in service. (Sweden).

- A hydrogen fuelling station will be built in Stockholm to produce, store and dispense hydrogen for the fuel cell bus procured under the CUTE program. The station will use an electrolyser to produce hydrogen at 60 Nm^3/h (120 kg/day) at 10 bars. The target efficiency is 60-70%. The station will be capable of filling the bus, 40 kg storage capacity at 350 bars, in <15 min (Sweden).
- Initial hydrogen infrastructure options in Germany have been evaluated. An economic study suggests a three-stage introduction of hydrogen into the market place. In stage 1, liquid hydrogen is transported to the local filling stations. Stage 2 involves transition to on-site production of hydrogen by reforming of natural gas. Stage 3 consists of centralized production of hydrogen from renewables and transport to local stations through dedicated hydrogen pipelines (Germany).
- A hydrogen refueling system based on auto-thermal cyclic reforming (ACR) of natural gas is being assembled. Prototypes have been built for all sub-systems: autothermal cyclic reformer, shift reactors, pressure swing adsorber (PSA), hydrogen compressor, hydrogen storage tanks, and hydrogen dispenser. A study has shown that from the standpoints of efficiency, capital cost and reliability, a high-pressure reformer (7 bars) is better than a low-pressure reformer with syngas compressors between the reformer and the PSA. A low-pressure 150 kWt prototype reformer has been operated stably using cascade control. The reformer will be upgraded to operate at high pressure by March 2004. The PSA unit uses three vessels each with three layers of alumina (moisture adsorption), carbon (CO, CO_2 & CH_4 adsorption) and zeolite (N_2) beds. The two-stage hydrogen compressor is hydraulically driven to raise pressure to 6500 psig. Compressed hydrogen is stored in three banks. The cascade dispensing option allows direct series of transfers from the three banks and simultaneous filling of one bank while another is being emptied. An economic analysis shows that the ACR will meet the DOE cost target for hydrogen of $2.50/kg at large sizes, 500-1500 kg H_2/day, and when mass produced, 100-500 units/year (United States).
- GTI is using its compact SMR technology to develop and demonstrate a high-efficiency natural gas-to-hydrogen fueling station at 50 kg H_2/day capacity. The fuel processing system is fully integrated with the steam generator, heat recovery, catalytic combustion, steam reformer, and CO shift and methanation (optional), and can achieve an efficiency of 83% on LHV basis. The reformate gas leaving the fuel processor contains 79-80% H_2 on dry basis and ~700 ppm CO that can be reduced to <6 ppm with the methanation catalyst. The gas purification system uses reduced-pressure pressure swing adsorption that can capture up to five different non-hydrogen components: H_2O, CO_2, CO, CH_4 and N_2. Primary and secondary compressors capable of delivering hydrogen at 80 psig and 7000 psig are being developed. Compressed hydrogen is stored in a three-bank cascade at 7000 psig. A hydrogen dispenser and cylinder filling algorithm has been developed that addresses the issues of temperature rise, potential cylinder underfilling and metering accuracy (United States).
- A project is underway evaluate energy stations that would provide hydrogen to fuel cell vehicles, as well as power, heat and cooling to buildings to optimize energy use and minimize cost. A filter has been applied to reduce the matrix of possible configurations to four promising technologies:

conventional system (SMR, reformate fuel cell, PSA), lower cost fuel cell system (SMR, PSA, direct hydrogen fuel cell), small scale purification system (SMR, reformate fuel cell, fluorine metal hydrides), and simple cogeneration system (air compressor, ATR, PSA, direct hydrogen fuel cell). Several operating strategies (base load, peak shaving, back-up power) are being evaluated to trade-off electricity generation with production of hydrogen for vehicle fuelling (United States).

Fuel Cell Systems and Vehicles

- Technical behaviour and performance of pressurized, direct-hydrogen FC systems for hybrid vehicles have been evaluated. A H_2 FC vehicle can give 2.5-2.7 times the fuel economy of today's gasoline ICE vehicle. The fuel economy multiplier can be increased to 3 by hybridizing the H_2 fuel cell system with an energy storage device. For optimum performance, it is important to properly integrate the compressor-expander (CEM) module into the FC system (United States).
- The Scania hybrid fuel cell bus project has gathered data on the complete vehicle duty cycles, energy consumption by auxiliary sub systems, fuel cell system, noise and performance and reliability. The hybrid bus with an electric drivetrain gave 42-48% lower fuel consumption than a conventional diesel bus. About 22-28% of the fuel saving was due to regenerative brakes. Even without an AC system, the bus auxiliary sub systems consumed about 10-25% of the electric power. The FC system had a peak efficiency of 44% and average efficiency of 41%. The bus produced 7 dB (A) lower (about four times lower) noise than a conventional diesel bus (Sweden).
- Consumer behaviour has been modelled to project the premium that the early adopters of fuel cell vehicles will be willing to pay. It is argued that the fuel cell technology will confront two niche markets (A and B) before the mass market (C). The premium of adoption is highest at point of entry (A) and decreases to zero in mass market (C). In the secondary niche market B the product adoption is based on utility to customers who are willing to pay for the increased utility. A regression analysis predicts that in year 2010 the European consumers in the secondary niche market B will be willing to pay up to €2000 for subcompact and €3000 for compact vehicles for increased fuel economy and acceleration (Germany).
- Hyundai Motor Company has equipped Santa Fe SUV with a battery - hydrogen fuel cell hybrid (FCHEV). The ambient pressure PEFC system is rated at 75 kW. The Ni-MH battery system has a maximum power of 30 kW and operates at 216-384 V. A buck/boost type of bidirectional DC/DC converter interfaces the battery with the electric drive train which consists of a 65 kW AC induction motor capable of delivering 172 Nm torque at a gear ratio of 10. Hydrogen is stored in a 3 layer-composite 72-L tank equipped with an in-tank regulating system. Tests show that compared to the conventional ICE Santa Fe, the fuel economy of the FCHEV is 156% higher on the NEDC, 185% higher on J10-15 schedule, 181% higher on FUDS, and 83% higher on FHDS. Compared to the FC version of Santa Fe, the improvement in fuel economy with hybridization is 6% on NEDC, 17% on J10-15 schedule, 18% on FUDS and 1% on FHDS (Korea).

- A project is underway to develop, build, demonstrate, and deliver a 5-kg capacity hydrogen storage system using catalyzed $NaAlH_4$ derived compounds. Kinetic tests for absorption and desorption of hydrogen have been performed on a 50-g prototype with 6-mol% $TiCl_3$ as catalyst. These show that during charging the hydride has a temperature-dependent incubation time for absorption which is 30 min at 75°C, 12 min at 90°C and <1 min at 130°C. The measured activation energy for desorption is 91 kJ/mol for $NaAlH_4$ and 41.5 kJ/mol for Na_3AlH_6. Desorption capacity of NaAlH4 has been measured to decrease by 10% after 20 cycles; the capacity loss apparently stopped after 15 cycles. The loss has been tentatively attributed to impurities in 99.95% H_2 (typical contaminants: N_2, O_2, H_2O, CO, CO_2 and CH_4). Depending on the consolidation method, the hydride packing density in Al foam is 38% of the theoretical value and the volumetric density of stored hydrogen is 50% of the DOE goal of 36 kg H_2/m^3 (United States).
- To date, forty three (43) fuel-cell light duty vehicles and three (3) fuel cell buses have been operated within the California Fuel Cell Partnership. Seven (7) first-generation fuel cell buses have been ordered with the delivery scheduled to begin in 2004; these will be operated in real-world conditions at three transit partner sites. Hydrogen infrastructure is being demonstrated at twelve (12) sites in California. Plans for years 2004 through 2007 call for placing up to 300 fuel-cell fleet vehicles in service and having them operated by real-world users, expanded fueling infrastructure to support fleet demonstrations, preparing communities with emergency response training and permit assistance and continued public outreach (United States).
- Endurance tests have been conducted on the Turin fuel cell bus. The bus has been run for 5000 km over ten months on drive cycles simulating six different routes with 35 km/h as the top speed. The bus has passed all tests related to hydrogen safety (leakage, detection and reliability), performance, functionality, energy management requirements, fuel cell start-ups and shut-downs, and fuel economy (Italy).

On-Board Fuel Processing

- An on-board fuel processor based on partial oxidation of methane (MEPOX) is being tested for technical feasibility and performance at 5 Nm^3/h of H_2 rated capacity. The reactor train includes a POX catalyst operating at 800°C (O/C=1) and 2.5 bar, a Fe_3O_4/Cr_3O_4 high temperature shift catalyst at 400°C, a $CuZn/Al_2O_3$ low temperature shift (HTS) catalyst at 215°C and 0.3% Pt/Al_2O_3 selective oxidation catalyst (SOX) at 90°C. A heat exchanger downstream of the POX reactor raises steam for the HTS step. Heat exchangers are also located downstream of the HTS and LTS reactors to raise steam that is added to the reformate entering the LTS reactor. Air used in the partial-oxidation step is pre-heated regeneratively by the reformate leaving the POX reactor. The fuel processor will be tested for performance under steady-state and dynamic conditions, CO concentration in the product stream, and response to rapid changes in H_2 demand (Italy).
- A compact, sulfur-tolerant fuel processor is being developed for automotive fuel cell systems. It uses a noble metal alloy CPOX/ATR and a single-stage Pd membrane based high-temperature WGS reactor. The stainless-steel supported membrane reactor is of shell and tube construction, and operates

at up to 7 bars and 400^oC. It obtains ~96% hydrogen separation into a steam permeate stream. The reactor configuration and design have been optimized with a model that predicts <1 min start-up for 50% of FPS full power and 31% overall PEFC system efficiency. With advances in deposition of Pd on porous stainless-steel tubes, hydrogen permeance of 40-50 $m^3/m^2.h.atm^{0.6}$ at H_2/N_2 selectivity of 100-200 has been obtained. Nano-technology is being used to develop high effectiveness factor WGS catalysts (United States).

- An ethanol fuel processor is being developed for automotive fuel cell systems. The experimental FP operates at 4 bar and water/ethanol molar ratio of 3 in the reformer. The feed stream contains water/ethanol in molar ratio of 1. The auto-thermal reformer operates at 600-750^oC and produces a reformate stream containing 10% CO on dry basis. The CO concentration is lowered to 1% in the HTS reactor at 350-400^oC, to 0.2% in the LTS reactor at 300^oC and to ~100 ppm in the PrOx reactor operating at 100-200^oC. Waste heat from an after-gas burner raises steam for the ATR, pre-heats oxidation air and evaporates ethanol. Liquid water is used to quench the gas stream leaving the ATR to the HTS inlet temperature and the stream leaving the HTS to the LTS inlet temperature (Netherlands).
- An experimental project (FASTER) is studying the feasibility of fast-starting a fuel processor for gasoline fueled automotive fuel cell systems to meet the DOE targets of 60 s in 2005 and 30 s in 2010. A 30-kWt ATR-WGS-PrOx type fuel processor has been designed and a control scheme has been developed to maintain the temperature profile at all times. The start-up strategy hinges on ATR readiness, ATR start-up with liquid gasoline and liquid water and heating of critical catalyst zones. A model shows that the FASTER design can meet the 2005 DOE target for start-up time but not the proposed target of 2-MJ start-up energy consumption for a fuel processor for a 50-kWe FC system. Alternative fuel processor configurations have been modeled that meet the start-up energy target by compromising the steady-state efficiency (United States).
- A compact 9-kWt gasoline reformer for auxiliary power units (2.5 kW) has been developed. The space velocities are 55,000/h in ATR, 20,000/h in HTS, 15,000/h in LTS, 10,000/h in SOX and 65,000/h in catalyst burner (CB). The nominal operating conditions for the ATR are stoichiometry of 0.3, S/C of 2.4, 1.4 bar pressure, 500-750^oC temperature. Liquid fuel is fed to the ATR using a commercial swirl atomizer and vaporized into air and steam in a mixing section. A control system dynamically monitors temperatures at the outlets of ATR, HTS, LTS, SOX and CB and the CO concentration at FP exit, and regulates fuel water and air flow rates within the allowable limits of O/C and S/C to meet the power demand. Five heat exchangers are used to raise steam and control temperatures in the catalytic reactors. The fuel processor is started in three steps: pre-heating of ATR above the fuel boiling point by electrically heating air, operation of the reformer in the catalytic partial oxidation mode at 50% load until the heat exchangers are heated above 200^oC, and gradual introduction of water (S/C increased from 1.2 to 2.5) into the ATR until the SOX is heated to the design temperature and the outlet CO concentration is reduced to <100 ppm. The measured start-up time of the fuel processor is 1200 s while the target is 300 s (Germany).
- Reactor designs for on-board steam and auto-thermal reforming of hydrocarbon fuels are being investigated. Advantages of using Pd-Ag dense

membranes were evaluated for separating hydrogen produced in steam reforming of methanol over Cu/ZnO catalyst at 200-300°C and 1-40 bars. The membrane reactor produced a H_2 stream of sufficient purity to power a PEM cell and performed best at high pressure and high temperature. The maximum thermodynamic and kinetic advantages were not realized because the reformer performance was membrane limited and the membrane had physical defects. A different project is evaluating the benefits of using oxygen-enriched air for auto-thermal reforming of gasoline in a 1-kW annular reactor. A third project is looking at steam reforming of diesel for SOFC APUs and remote hydrogen refuelling (Canada).

- A fuel processor system was developed that utilizes rapid-cycle pressure-swing adsorption (PSA) to purify H_2 from a gas mixture generated by auto-thermal reforming of a hydrocarbon fuel. The PSA cycle selectively adsorbs CO, CO_2, N_2, H_2O, and light hydrocarbons at pressures below 5 bars and temperatures between 20 and 100°C. The PSA purifies a reformate stream which consists of less than 50% H_2. The PSA H_2 product contains less than 50 ppm CO, at least 95% H_2, and 70% of the H_2 in the feed is recovered in the product stream (United States).

Fuels for Fuel Cells

- Industrial perspective on future fuels for fuel cells was evaluated. In the near term the transport sector will continue to use reformulated gasoline (RFG) and diesel with emphasis on sulphur-free fuels and limit on MTBE in gasoline. In mid term use of gaseous fuels (CNG, LPG) will increase and clean hydrocarbon fuels such as GTL diesel, bio-ethanol and bio-diesel are likely to be introduced. In the long term hydrogen can be competitive with gasoline. The delivered cost of hydrogen and the cheapest option for producing it depend on the throughput rate. At 10-200 kg/day, electrolysis or hydrogen transport as liquid or gaseous trucks are the cheapest options ($15-$5/kg H2). Onsite partial oxidation and steam reforming become competitive at 200-20,000 kg/day and can produce hydrogen at $5-$1/kg. Centralized production of hydrogen with pipeline delivery becomes economic at throughput rate exceeding 20,000 kg/day (Netherlands).

Life Cycle Analysis

- A study is comparing well-to-wheel balances presented in U.S. and European studies. Taking gasoline ICE as the reference, the fuel economy multipliers for different powertrain concepts are 1.06 for gasoline-ICE hybrid, 1.13 for gasoline-FC, 1.18 for diesel-ICE, 1.24 for diesel-FC, 1.28 for diesel-ICE hybrid, 1.34 for MeOH-FC and 1.85 for H2-FC. On WTW basis the primary energy use (MJ/km) of competing fuel/vehicle systems is aligned as follows: NG-FTD FC (3.5), gasoline ICE (2.6), CNG ICE hybrid (2.6), NG-MeOH FC (2.5), gasoline ICE hybrid (2.4), diesel ICE (2.1), diesel ICE hybrid (1.9), and NG cH2 FC (1.8). In terms of GHG emissions (g/km) the order is slightly different: NG-FTD FC (207), gasoline ICE (185), gasoline ICE hybrid (175), CNG ICE hybrid (157), diesel ICE (153), NG-MeOH FC (147), diesel ICE hybrid (141), and NG- cH2 FC (106) (Germany).

- A study has evaluated energy consumption, GHG emissions and operating costs for different feedstocks, fuels and powertrain concepts. The study arranges the WTW efficiencies in the following order: gasoline-ICE (13%), CNG-ICE (14%), diesel ICE (17%), MeOH-FC (22%), and hydrogen FC (30%). In terms of GHG emissions (g/km) the order is: gasoline-ICE (203), diesel-ICE (155), CNG-ICE (139), and H2-FC (111). The operating costs (€/1000-km) are: gasoline-ICE (80), diesel-ICE (46), CNG-ICE (27), MeOH-FC (25), and H2-FC (18-36) (Italy).
- A study has evaluated WTW efficiencies for fuels from natural gas and biomass. For natural gas feedstock the efficiencies are ordered as CNG-FC > LNG-FC > DME-diesel >gH2-FC > MeOH-diesel. For biomass feedstock the order is DME-diesel > gH2-FC > MeOH diesel > LH2-FC. For liquid biofuels in FC hybrids the efficiencies are arranged as MeOH > LH2 > EtOH > FTD (Sweden).
- As part of the EU initiative on hydrogen energy and fuel cells, potential reductions in greenhouse gas emission by use of hydrogen fuel cell vehicles in Europe were estimated as 15 MT CO_2 in year 2020 (5% of new cars and 2% of fleet fueled by H_2 vehicles), 112 MT in year 2030 (25% of new cars and 15% of fleet fueled by H_2 vehicles) and 240 MMT in year 2040 (35% of new cars and 32% of fleet fueled by H_2 vehicles). Greenhouse gas emissions and untaxed fuel costs have been estimated for different pathways and powertrain options. On g CO_2/MJ basis, the median of estimated emissions are 100 for methanol/NG and cH2/NG, 80 for gasoline/diesel, 60 for cNG, 40 for ethanol, and 15-20 for cH2/wood, cH2/wind electricity and cH2/solar electricity. On €/MJ basis, the median untaxed fuel supply cost is 0.01 for cNG and gasoline/diesel, 0.012 for methanol/NG, 0.02 for cH2/NG and ethanol, 0.03 for cH2/wood, 0.045 for cH2/wind electricity, and 0.065 for cH2/solar electricity (Germany).
- Well-to-wheel (WTW) energy use, greenhouse gas emissions and criteria pollutant emissions (NO_x and PM_{10}) presented in the 2000 GM/ANL landmark study have been updated. The revised well-to-pump (WTP) energy efficiency for North America are 85-80% for cNG, crude/naphtha, LS/diesel and LS/gasoline, 62-56% for NG/methanol, NG/naphtha, central NG/cH2 and station NG/cH2, and 42-35% for central NG/LH2, cellulosic ethanol and station NG/LH2. The revised vehicle fuel economy ratios are 1 for cNGV, LPGV, E85 FFV, 1.4-1.6 for gasoline hybrid, gasoline FCV, diesel hybrid and methanol FCV, 2.4 for cH2 FCV and 3.5 for BP EV (United States).
- United States Department of Energy is sponsoring research, development and validation efforts on fuel cells and hydrogen production, delivery and storage technologies for transportation and stationary applications. Some of the major FY03 R&D highlights include development of high-performance matched PEM components and pilot manufacturing for high-volume MEA production, scaled up production of bipolar plates meeting DOE targets, and demonstration of a pilot plant for low-platinum electrodes. A neutron imaging technique has been developed to improve water management and effects of trace SO_2 and NO_2 in cathode air on cell performance have been determined. Improved anode and cathode formulations have been prepared and a surface modification technique has been developed for metallic bipolar plates to produce low contact resistance. High temperature membranes that can operate at 120^{o}C and 25-50% RH are being prepared.

4.5.7 Work Plan for Next Year

The term for Annex XV has ended. Starting next year, the activities of this Annex will be folded in to Annex XX with work in four sub-tasks.

- Subtask A: Hydrogen infrastructure
- Subtask B: Advanced fuel cell systems
- Subtask C: Technology validation
- Subtask D: Assessment and Economics

APPENDICES

Appendix 1 Membership of the Executive Committee

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Appendix 2 Executive Committee Meetings to Date

1st meeting	April 2, 1990, Paris, France.
2nd	November 25, 1990, Phoenix, Arizona, USA.
3rd	June 27-28, 1991, Petten, The Netherlands
4th	February 7, 1992, Makuhari, Japan
5th	September 24-25, 1992, Malmo, Sweden
6th	March 15, 1993, Rome, Italy
7th	September 28, 1993, London, United Kingdom
8th	March 15, 1994, Zürich, Switzerland.
9th	October 11, 1994, Jülich, Germany
10th	May 11-12, 1995, Oslo, Norway
11th	September 18th, 1995, Loughborough, United Kingdom
12th	February 1-2, 1996, Tokyo, Japan
13th	September 17-18, 1996, Roskilde, Denmark
14th	April 15-16, 1997, Vancouver, Canada
15th	September 18-19, 1997, Amsterdam, The Netherlands
16th	March 19-20, 1998, Santa Fe, USA
17th	October 1-2, 1998, Melbourne, Australia
18th	April 13-14, 1999, Jülich, Germany
19th	September 20-21, 1999, London, UK
20th	April 10-11, 2000, Malmö, Sweden
21st	November 4, 2000, Portland, Oregon, USA
22nd	May 3-4, 2001, Capri, Italy
23rd	September 5-6, 2001, Basel, Switzerland
24th	May 30-31, 2002, Paris, France
25th	November 22-23, 2002, Palm Springs, California, USA
26th	May 8 , Espoo, Helsinki, Finland
27th	October 23-24, 2003, Dusseldorf, Germany

Appendix 3 Task Proposals Under Consideration

Proposals will be brought forward at the first ExCo meeting of 2004 for six new Annexes and an accompanying programme of cross-cutting workshops and other activities. The six Annexes will comprise three technology-specific annexes on PEFC, SOFC and MCFC, and three application-specific annexes on stationary, transportation and portable applications.

Appendix 4 Executive Committee Reports and Publications

The following reports have been issued:

- Minutes of 27 Executive Committee Meetings since initiation (1990).
- Annual Reports 1990-2002.
- Strategy and Procedural Guidelines for the IEA Advanced Fuel Cells Programme, Utrecht, The Netherlands (1992).
- Revised Procedural Guidelines for the IEA Advanced Fuel Cells Programme (1998)
- Updated Implementing Agreement (1998).

- Strategy for the IEA Advanced Fuel Cells Programme 1999-2003 (1998).
- "International Co-operation of Fuel Cell R&D via the International Agency", K Joon, H Barten, paper presented at the 1994 Fuel Cell Seminar, San Diego, USA.
- "The IEA Advanced Fuel Cells Programme", K Joon, invited paper presented at the 2nd International Fuel Cell Conference, Kobe, Japan, February 1996.
- End of Term Reports to the IEA in September 1995, September 1998 and October 2003.
- "Progress in Fuel Cell Development through Co-operation in the Framework of the International Energy Agency", K Joon, L Sjunnesson, invited paper presented at the 3rd International Fuel Cell Conference, Nagoya, Japan, December 1999.
- Summary Final Report of the IEA Advanced Fuel Cells Programme 1996-1999.

In addition, verbal presentations have been given by the Chairman and Secretary to the IEA Working Party on End Use Technologies, the Committee on Energy Research and Technology, the Working Party on Fossil Fuels and the IEA Hydrogen Executive Committee.

Appendix 5 Workshops and Task Meetings

This section lists meetings and workshops held to date and planned for 2004, for those tasks that were active during the year.

5.1 Task XI: Polymer Electrolyte Fuel Cells

5.1.1 Workshops and Meetings Held to Date

Annex XI Working Group, May 17–18, 2001, Nynashamn, Sweden
Annex XI Phase II Working Group, May 17–18, 2002, Philadelphia, Pennsylvania, U. S. A.
Annex XI Phase II Working Group, November 22–23, 2002, Palm Springs, California, U. S. A.
Annex XI Phase II Working Group, May 6-7, 2003, Trondheim, Norway
Annex XI Phase II Working Group, November 7-8, 2003, Miami Beach, Florida, U. S. A.

5.1.2 Workshops and Meetings Planned for Next Year

Annex XI Phase II Working Group, May 2004, specific dates and venue yet to be determined
Annex XI Phase II Working Group, October/November 2004, specific dates and venue yet to be determined.

5.2 Task XII: Fuel Cell Systems for Stationary Applications

5.2.1 Workshops and Meetings Held to Date

"Pre-meeting", London, September 15, 1999
First meeting Rome, Italy, February 8-9, 2000
Second meeting Portland, Oregon, USA, October 30, 2000
Third meeting Paris, France, April 5-6, 2001
Forth meeting September 10, 2001 London, UK

Fifth meeting April 10 –11, 2002, Oslo, Norway
Sixth meeting October 10, 2002, Hamburg, Germany
Final meeting November 3, 2003, Miami, USA

5.2.2 Workshops and Meetings Planned for Next Year

The first meeting in Annex XIX will be held in April 2004 in Rome, Italy.

5.3 Task XIII: Solid Oxide Fuel Cells

5.3.1 Workshops and Meetings Held to Date

IEA Annex XIII Plenary meeting on 6th July 2000 at ECN, Petten, the Netherlands, with status reports of SOFC activities of participating countries except Sweden, and including France.
Workshop Annex XIII in Petten on 6th and 7th July 2000 on “Cost-effective and scaled up manufacturing technology for SOFC ceramics”.
Topical meeting on “Modelling and Simulation of hybrid SOFC/Gas Turbine Systems and Components”, 21st and 22nd September 2000, Ystad, Sweden.

IEA Annex XIII Plenary meeting on 31st May 2001 at NEDO, Tokyo, Japan, with status reports of SOFC activities of participating countries, except Sweden.
Workshop Annex XIII in NEDO on 31st May and 1st June 2001 on “Low temperature operation”.
Topical meeting on “SOFC Materials and Mechanisms”, 16th – 19th January 2001, Les Diablerets, Sweden.

IEA Annex XIII Plenary meeting and Workshop was held in Palm Springs, California, USA on November 18th, 2002. At this Workshop, status reports from member countries and selected papers on SOFC Systems were presented.

IEA Annex XIII Plenary meeting on 22nd September at Forschungszentrum Jülich, Germany, with status reports of SOFC activities of participating countries, except Australia, France, Sweden and the United Kingdom.
Workshop Annex XIII at Forschungszentrum Jülich, Germany on 22nd and 23rd September 2003, on “Modelling of Cell and Stack Operation and Electrode Processes”.

5.3.2 Workshops and Meetings Planned for Next Year

Future meetings on Solid Oxide Fuel Cells will be organised by Annex XVIII.

5.4 Task XIV: Molten Carbonate Fuel Cells

5.4.1 Workshops and Meetings Held to Date

First meeting was held on October 26-27,2000 in Danbury, USA hosted by Fuel Cell Energy.

Second meeting was held on September 17-19, 2001 in Rome ,Italy hosted by ENEA .
Third meeting was held on October 7 -9 , 2002 in Munich ,Germany hosted by MTU.
Fourth meeting was held on October 15-17, 2003 in Soul , Korea hosted by KIST.

5.4.2 Workshops and Meetings Planned for Next Year

The first meeting in Annex XVII will be held in Japan in October 2004.

5.5 Task XV: Fuel Cell Systems for Transportation

5.5.1 Workshops and Meetings Held to Date

July 1-2, 2001, Lucerne, Switzerland, hosted by Paul Scherrer Institute.

December 10-11, 2001, Sacramento, CA, U.S.A., hosted by U.S. Department of Energy

June 27-28, 2002, Düsseldorf, Germany, hosted by Ministry of Economic Affairs, Energy and Transport of the Federal State Nordrhein-Westfalen (NRW).

November 17-18, 2002, Palm Springs, CA, U.S.A., hosted by U.S. Department of Energy.

June 17-18, 2003, Stockholm, Sweden, hosted by Volvo AB.

November 7-8, 2003, Miami Beach, FL, U.S.A., hosted by U.S. Department of Energy.

5.5.2 Workshops and Meetings Planned for Next Year

Future meetings on transportation fuel cells will be organized by Annex XX.

Appendix 6 Task Reports and Publications

This section lists task reports and publications produced to date for those tasks which were active during the year. These publications are classified according to the following system.

Level	Classification	Report Type	Distribution
1a	Restricted - sub-task participants only	Working papers	Distribution limited to those experts participating in the specific sub-task.
1b	Restricted - annex participants only	Sub-task reports, detailed technical reports	Distribution limited to those experts participating in the annex.

2a	Restricted - annex participants and Ex Co members only	Summary technical reports	As above + Ex Co members from countries participating in annex for personal reference and approvals.
2b	Restricted - countries participating in annex only	Summary technical reports, summary final reports	As above + Ex Co members from countries participating in annex may distribute report to organisations in that country not participating in the annex
2c	Restricted - IA signatory countries only	Summary final reports	Distribution to any organisation in a country participating in the IA

3a	Unrestricted within IEA	Annual reports; summary final reports	Open distribution to all countries in IEA.
3b	Unrestricted	Annual reports; summary final reports	Open distribution including countries not in IEA. To publicise and inform about IEA programme.

Some of the reports are classified according to an earlier system which only used three levels:
Level 1: Experts participating in relevant Sub-task only.
Level 2: Participating Countries and all Executive Committee Members.
Level 3: Unrestricted.

6.1 Task XI: Polymer Electrolyte Fuel Cells

6.1.1 Reports, Papers and Abstracts Published to Date (level 3b)

- "State of the art of multi-fuel reformers for fuel cell vehicles: Problem identification and research needs," Pettersson, L. J. and Westerholm, R. (2001), *Int. J. Hydrogen Energy* **26**, 243-264.
- "Deactivation of copper-based catalysts for fuel cell applications," Lindstrom, B. and Pettersson, L. J. (2001), *Catal. Lett*. **74**, 27-30.
- "Hydrogen generation by steam reforming of methanol over copper-based catalysts for fuel cell applications," Lindstrom, B. and Pettersson, L. J. (2001). *Int. J. Hydrogen Energy* **26**, 923-33.
- "Catalytic hydrogen generation from methanol," Agrell, J., Lindstrom, B., Pettersson, L. J., and Jiirds, S. G. (2002). in Spivey, J.J. (Ed.), Catalysis - Specialist Periodical Reports, Royal Society of Chemistry, Cambridge, Vol. 16, pp. 67-132.
- "Steam reforming of methanol over copper-based monoliths: The effects of zirconia doping." Lindstrom, B. and Pettersson, L. J. (2002), *J. Power Sources* **106**, 264-273.
- "Combined Reforming of Methanol for Hydrogen Generation over Monolithic Catalysts," Lindstrom, B., Agrell, J., and Pettersson, L. J. (2002), *Chemical Engineering Journal*, in press.
- "Activity and characterization of Cu/Zn, Cu/Cr and Cu/Zr on (-alumina for methanol reforming for fuel cell vehicles," Lindstrom, B., Pettersson, L. J., and Menon, P.G. (2002), *Appl. Catal. A*., in press.
- "The influence of carbon dioxide on PEM fuel cell anodes," F. A. de Bruijn, D. C. Papageorgopoulos, E. F. Sitters, G. J. M. Janssen, *J. Power Sources*, **110**(2002), 117-124.
- "Examining a Potential Fuel Cell Poison, A Voltammetry Study of the Influence of Carbon Dioxide on the Hydrogen oxidation Capability of Carbon-Supported Pt and PtRu Anodes," D. C. Papageorgopoulos and F. A. de Bruijn, *J. Electrochem. Soc.*, **149**(2002), A140-Al45.
- "The inclusion of Mo, Nb and Ta in Pt and PtRu carbon supported electrocatalysts in the quest for improved CO tolerant PEMFC anodes," D. C. Papageorgopoulos, M. Keijzer and F. A. de Bruijn, *Electrochimica Acta*, 48(2002), 197-204.

- "CO Tolerance of Pd-Rich Platinum Palladium Carbon-Supported Electrocatalysts," D. C. Papageorgopoulos, M. Keijzer, J. B. J. Veldhuis, and F. A. de Bruijn, *J. Electrochem. Soc*. **149**, A1400-1404 (2002).
- "The Development of Lightweight, Ambient Air Breathing, Tubular PEM Fuel Cell," K. J. Green, R. Slee, and J. B. Lakeman, *J. New Materials for Electrochemical Systems*, **5**, 1–7 (2002).
- "Performance of High-Temperature Polymer Electrolyte Fuel Cell Systems," 2002 Fuel Cell
- Seminar Abstracts, November 18–21, 2002, Palm Springs, California, pp. 866–869.

Reports (Level 2b)

- Summary Report on Annex XI Phase II Workshop, May 6-7, 2003 Trondheim to Bergen, Norway.
- Summary Report on Annex XI Phase II Workshop, November 22-23, 2002, Palm Springs, CA, U.S.A.
- Status Report on Annex XI Phase II: Collaborative Research on Polymer Electrolyte Fuel Cells

6.1.2 Reports Planned for Next Year

Meeting, Status, and Annual Reports for the Polymer Electrolyte Fuel Cell Task, Level 2.

6.2 Task XII: Fuel Cell Systems for Stationary Applications

6.2.1 Reports Published to Date

- Meeting, Status and Annual Reports for Annex XII.

6.2.2 Reports Planned for Next Year, Annex XII

The official final summary report from Annex XII is prepared and will be published during the spring of 2004.

Five reports will be published among the participants, one summary report from the Task and a more detailed report from each of the Subtasks.

The final report will also include a number of special reports covering technical and market issues prepared within the subtasks.

6.3 Task XIII: Solid Oxide Fuel Cells

6.3.1 Reports Published to Date

- Proceedings of the workshop at ECN, Petten, the Netherlands on 5-7th July 2000: "Cost effective and up-scaled manufacturing technology for SOFC ceramics", by J.P.P. Huijsmans (editor). September 2000, pp 342.

- Proceedings of the workshop at NEDO, Tokyo, Japan on 31st May and 1st June 2001: “Low temperature operation”, by H. Fujii (editor). September 2001.
- Proceedings of the Workshop in Palm Springs, USA on November 18th, 2002, by S. C. Singhal (Editor), November 2002.
- Proceedings of the workshop at Forschungszentrum Jülich, Germany, on September 22nd and 23rd 2003: “Modelling of Cell and Stack Operation and Electrode Processes”, by L.G.J. (Bert) de Haart (Editor), September 2003

6.3.2 Reports Planned for Next Year

Meeting, Status, and Annual Reports for the Solid Oxide Fuel Cells Annex XVIII.

6.4 Task XIV: Fuel Cell Systems for Stationary Applications

6.4.1 Reports Published to Date

- Meeting, Status and Annual Reports for Task XIV.

6.4.2 Reports Planned for Next Year

- Meeting, Status and Annual Reports for Annex XVII.

6.5 Task XV: Fuel Cell Systems for Transportation

6.5.1 Reports Published to Date

- Status Report on Annex XV: Fuel Cell Systems for Transportation, August 2, 2001.
- Proceedings of IEA Annex XV Workshop and Kick-Off Meeting, October 23, 2001.
- Proceedings of Second IEA Annex XV Meeting, March 1, 2002.
- Status Report on Annex XV: Fuel Cell Systems for Transportation, April 1, 2002.
- Status Report on Annex XV: Fuel Cell Systems for Transportation, September 1, 2002.
- Proceedings of Third IEA Annex XV Meeting, November 1, 2002.
- Proceedings of Fourth IEA Annex XV Meeting, March 2003.
- Status Report on Annex XV: Fuel Cell Systems for Transportation, April 2003.
- Proceedings of Fifth IEA Annex XV Meeting, July 2003.
- Status Report on Annex XV: Fuel Cell Systems for Transportation, July 2003.
- Proceedings of Sixth IEA Annex XV Meeting, November 2003.
- Status Report on Annex XV: Fuel Cell Systems for Transportation, December 2003.

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6.5.2 Reports Planned for Next Year

- Meeting, Status and Annual Reports for Annex XX

Appendix 7 Task Experts

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

7.1 Task XI: Polymer Electrolyte Fuel Cells

Operating Agent: Debbie Myers, Argonne National Laboratory, USA (R)

Experts:

Gilbert Van Bogaert	Vito (R)	Belgium
Steven Holdcroft	Simon Fraser University (A)	Canada
Titichai Navessin	Simon Fraser University (A)	"
Agostino Iacobazzi	ENEA (R)	Italy
Fabrizio Alessandrini	ENEA (R)	"
Tomohiko Ikeya	NEDO (G)	Japan
Chang-Soo Kim	Korea Institute of Energy Research (R)	Korea
Tae-Hyun Yang	Korea Institute of Energy Research (R)	"
Gaby Janssen	ECN (R)	Netherlands
Torsten Berning	NTNU (A)	Norway
Børre Børresen	NTNU (A)	"
Kristian Heen	NTNU (A)	"
Torstein Lange	SINTEF (R)	"
Lars Pettersson	KTH (A)	Sweden
Brian Hayden	University of Southampton (A)	U.K.
Barry Lakeman	DSTL (G)	"
Christopher Lee	University of Southampton (A)	"
Kevin Pointon	DSTL (G)	"
Mebs Virji	Loughborough University (A)	"
Rajesh Ahluwalia	Argonne National Laboratory (R)	U. S. A.
Shabbir Ahmed	Argonne National Laboratory (R)	"
Nancy Garland	U. S. Department of Energy (G)	"
Romesh Kumar	Argonne National Laboratory (R)	"
Piotr Zelenay	Los Alamos National Laboratory (R)	"

R = research institution, A = academic institution, G = government

7.2 Task XII: Fuel Cell Systems for Stationary Applications

Operating Agent: Bengt Ridell. CarlBro Energikonsult AB, Sweden

Operatin Agents:

Bengt Ridell	CarlBro(I)	Sweden 2001 - 2003
Lars Sjunnesson	Sydkraft (I)	Sweden 1999 - 2001

Experts:

Bruce Godfrey	CFCL (I)	Australia
Karl Föger	CFCL (I)	Australia
Philippe Stevens	EDF(I)	France
Ulf Birnbaum	FZJ (R)	Germany
Oliver Weinmann	HEW (I)	Germany
Gerhard Huppmann	MTU (I)	Germany
Matti Valkianen	VTT(G)	Finland
Rolf Rosenberg	VTT(G)	Finland
Erkko Fontell	Wärtsilä(I)	Finland
Hiroshi Fujii	NEDO (G)	Japan
Peter vander Laag	ECN (R)	The Netherlands
Sergio Castedo	Statkraft(I)	Norway
Ragne Hildrum	Statkraft (I)	Norway
Steffen Møller-Holst	NTNU (R)	Norway
Angelo Moreno	ENEA (G)	Italy
Bengt Ridell	CarlBro (I)	Sweden
Mark Williams	DoE (G)	USA
Dan Rastler	EPRI (I)	USA
Stephan Renz	Thoma & Renz (I)	Switzerland

Experts who have left the Annex:

Kenji Kono (G)	NEDO (G)	Japan
Rune Øyan (I)	Statkraft (I)	Norway
Minoru Suzuki	NEDO (G)	Japan
Ammi Amarnath	EPRI (I)	USA
Marco Brocco	ENEA (G)	Italy
Hiroshi Oshi	NEDO (G)	Japan
Sytze van der Molen	ECN (R)	The Netherlands
Per Øyvind Hjerpaasen	Statkraft (I)	Norway
André Marquet	EDF (I)	France
Lars Sjunnesson	Sydkraft (I)	Sweden
Gerard Chaumain	ADEME (G)	France

7.3 Task XIII: Solid Oxide Fuel Cells

Operating Agent: L.G.J. (Bert) de Haart [Jan.-Dec.2003]

Participants of the 2003 Workshop held September 22nd-23rd, 2003, Jülich, Germany

Brian Borglum	Global Thermoelectric (I)	Canada
Dennis Prediger	Global Thermoelectric (I)	Canada
Ludger Blum	Forschungszentrum Jülich (R)	Germany
Nicola Bundschuh	German Aerospace Center (R)	Germany
Andreas Gubner	Forschungszentrum Jülich (R)	Germany
Bert de Haart	Forschungszentrum Jülich (R)	Germany
Axel Müller	Universität Siegen (A)	Germany
Heinz Nabielek	Forschungszentrum Jülich (R)	Germany
Robert Steinberger-Wilckens	Forschungszentrum Jülich (R)	Germany
Detlef Stolten	Forschungszentrum Jülich (R)	Germany
Hiroshi Fujii	NEDO (G)	Japan
Yoshio Matsuzaki	Tokyo Gas (I)	Japan
Jari Kiviaho	VTT Processes (R)	Finland
Timo Kivisaari	Wärtsilä Corporation (I)	Finland
Matti Lindfors	VTT Processes (R)	Finland
Bert Rietveld	Energie Onderzoekscentrum Nederland (R)	the Netherlands
Alphons Hintermann	Swiss Federal Office of Energy (G)	Switzerland
Subhash Singhal	Pacific Northwest National Laboratory (R)	USA

7.4 Task XIV: Molten Carbonate Fuel Cells

Operating Agent: Fujio Shouji , NEDO, Japan (G)

Experts:

Manfred M.Bischoff	MTU (I)	Germany
Angelo Moreno	ENEA (G)	Italy
Biagio Passalacqua	Ansaldo(I)	"
Paolo Capobianco	"	"
Kazuhiro Satoh	NEDO (G)	Japan
Toru Shimizu	MCFC Research Association (R)	"
Hideaki Andoh	"	"
Masaaki Tooi	IHI(I)	"
Yoshiyuki Izaki	CRIEPI (R)	"
Tae Hoon Lim	KIST (R)	Korea
Jonghee Han	"	"
Hee Chun Lim	KEPRI (R)	"
Choong-Gon Lee	"	"
Hai-kyung Seo	KEPCO(R)	"
S. B. van der Molen	ECN (R)	Netherlands
Bert Rieveld	"	"
Hans Maru	FCE (I)	U. S. A.
Mohammad Farooque	"	"

7.5 Task XV: Fuel Cell Systems for Transportation

Operating Agent: Rajesh K. Ahluwalia, ANL, U.S.A.

EXPERTS

1	Kerry-Ann	Technische Universität Berlin	Germany
2	Rajesh K.	Argonne National Laboratory	U.S.A.
3	Rod Borup	Los Alamos National Laboratory	U.S.A.
4	Karen Campbell	Air Products and Chemicals	U.S.A.
5	Eric Carlson	TIAX, LLC	U.S.A.
6	Mario Conte	ENEA	Italy
7	Roger Cracknell	Shell Global Solutions	U.K.
8	Robert Dempsey	ChevronTexaco Technology	U.S.A.
9	Erich K. Erdle	DaimlerChrysler Corporate R&T	Germany
10	Georg Erdmann	Technische Universität Berlin	Germany
11	Per Ekdunge	AB Volvo	Sweden
12	Matthias Gebert	Forschungszentrum Jülich	Germany
13	James Grieve	Delphi Automotive Systems	U.S.A.
14	Pede Giovanni	ENEA	Italy
15	Blair Heffelfinger	Methanex Corporation	Canada
16	Shinichi Hirano	Ford Motor Company	U.S.A.
17	Bernd Höhlein	Forschungszentrum Jülich	Germany
18	Inchul Hwang	Hyundai Motor Company	Korea
19	Agostino Iacobazzi	ENEA	Italy
20	John Kopasz	Argonne National Laboratory	U.S.A.
21	Ken Koyama	California Fuel Cell Partnership	U.S.A.
22	Ravi Kumar	GE – EER	U.S.A.
23	Oliver Lang	FEV Motortechnik	Germany
24	Göran Lindbergh	Royal Institute of Technology (KTH)	Sweden
25	Magnus Karlström	Chalmers University of Technology	Sweden
26	Ronald Mallant	ECN	Netherlands
27	Catherine Lentz	California Fuel Cell Partnership	U.S.A.
28	Tae-Won Lim	Hyundai Motor Company	Korea
29	William Liss	Gas Technology Institute	U.S.A.
30	Catherine E.	National Renewable Energy	U.S.A.
31	Lars Pettersson	Royal Institute of Technology (KTH)	Sweden
32	Stefan Pischinger	VKA/RWTH Aachen	Germany
33	Jaco Reijerkerk	Linde Gas	Germany
34	Ludmilla Schlect	Technische Universität Berlin	Germany
35	Jan Teuben	Shell Global Solutions	Netherlands
36	Stefan Unnasch	TIAX, LLC	U.S.A.
37	Gerald Voecks	General Motors Corp. (GAPC)	U.S.A.
38	Manfred Waidhas	Siemens AG	Germany

39	Michael Wang	Argonne National Laboratory	U.S.A.
40	Robert Wimmer	Georgetown University	U.S.A.