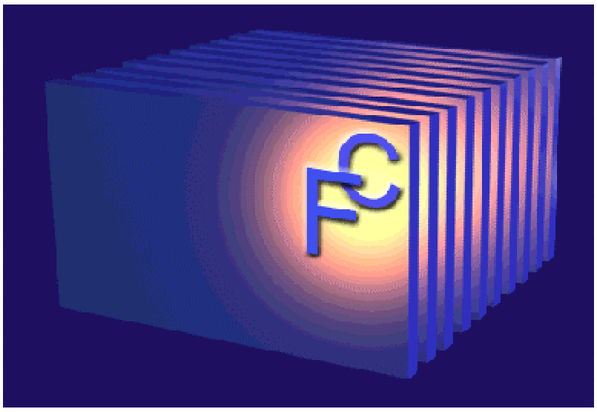


IEA Advanced Fuel Cells

Implementing Agreement

Annual Report 2002

Version 1

April 2003

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:

Mrs Heather Haydock
Secretary, IEA Advanced Fuel Cells Executive Committee
AEA Technology Environment
E6 Culham
Abingdon
Oxfordshire OX14 3ED
United Kingdom

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 ten countries have signed the Implementing Agreement and two countries (Spain and Denmark) have left the Agreement. The current participants are Australia, Belgium, Canada, Finland, France, Germany, Italy, Japan, Korea, the 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.

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 thirteen IEA-member countries participated in this Implementing Agreement during 2002. 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
Canada	Delegation to the OECD	November 1991
France	L'Agence de l'Environnement et de La Maîtrise de l'Energie (ADEME)	August 1996
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 and Ms C Handley (both AEA Technology, UK). The IEA/OECD representative is currently Mr Tom Howes from the Office of Energy Efficiency, Technology and R&D (who recently replaced Mr Yoshiyuki Tsuji).

The following table lists all the Executive Committee Members at the end of 2002, their Alternates and the Operating Agents of the different Annexes. Addresses and contact numbers are given in Appendix 1 to this report.

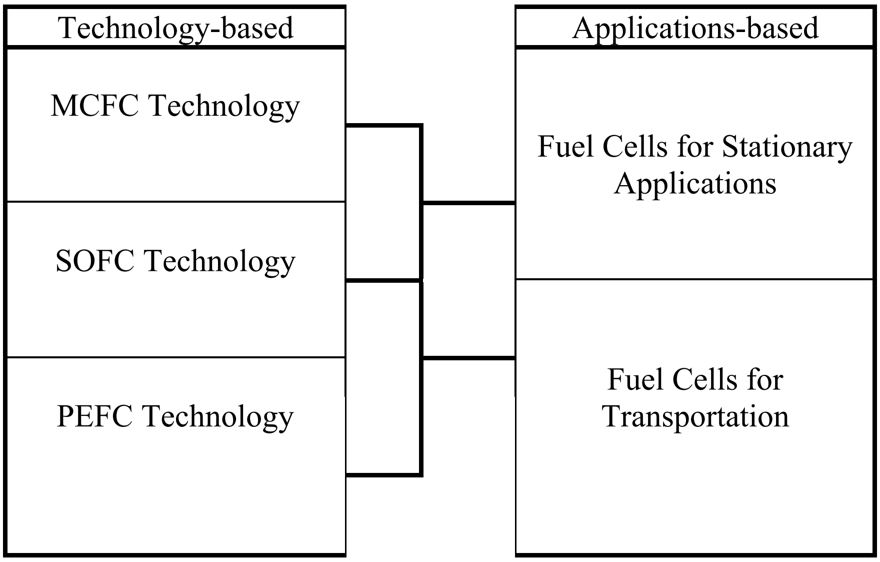
Country	Ex Co Member	Alternate Member	Operating Agent	Annex No.
Australia	B Godfrey	K Foger		
Belgium	G van Bogaert			
Canada	V Scepanovic	E Andrukaitis		
Finland	J Wide	R Rosenberg		
France	G Chaumain	N Thybaud		
Germany	D Stolten	H Nabielek		
Italy	R Vellone	A Moreno		
Japan	T Ninomiya	H Ochi	T Ninomiya	XIV
Korea	H-C Lim	T-H Lim		
Netherlands	S van der Molen			
Norway	P-Ø Hjerpaasen	R Hildrum		
Sweden	L Sjunnesson	B Gustafsson	B Ridell	XII
Switzerland	A Hintermann			
UK	R Eaton	J Marsh		
USA	J Milliken	M Williams	D Myers	XI
			S Subhash	XIII
			R Ahluwalia	XV

1.3 CURRENT AND FUTURE ANNEXES

Five Annexes were ongoing during 2002:

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

Finland and Belgium both joined the Implementing Agreement in 2002.

There were changes in the Executive Committee membership for Canada, Norway, France, Switzerland, Sweden, Italy and Germany. Dr Vesna Scepanovic (Natural Resources Canada) replaced Dr Martin Hammerli (also Natural Resources Canada) as ExCo Member for Canada. Mr Per Øyvind Hjerpaasen (Statkraft) replaced Dr Trygve Riis (Research Council of Norway) as Member for Norway and Ms Ragne Hildrum (Statkraft) replaced Mr Hjerpaasen as Alternate member. Dr Gerard Chaumain (ADEME) became ExCo Member for France and Nathalie Thybaud replaced him as Alternate member. Alfonse Hintermann (Swiss Federal Office of Energy) replaced Dr Martin Rüegsegger (Swiss Federal Office of Energy) as Member for Switzerland. Bernt Gustafsson (STEM) replaced Magnus Gustafsson as (STEM) Alternate member for Sweden. Angelo Moreno (ENEA) replaced Francesco di Mario (ENEA) as Alternate member for Italy. Dr Heinz Nabielek was appointed as Alternate member for Germany.

There were two changes of Operating Agent, with Dr Subhash Singhal (Pacific Northwest National Laboratory, USA) replacing Mr Hiroshi Fujii (NEDO, Japan) for Annex XIII and Dr Deborah Myers (Argonne National Laboratory, USA) replacing Dr Romesh Kumar (Argonne National Laboratory, USA) for Annex XI.

2.2 ACTIVITIES AND DECISIONS

2.2.1 Activities

Two Executive Committee meetings were held. The 24th Executive Committee meeting was held in Paris, France in May and the 25th meeting was held in California, USA in November.

The programme launched a new web site for ExCo members in April 2002, providing details of forthcoming meetings and downloadable papers and reports. This was 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 2001 Annual Report was prepared and distributed.

A special edition of the IEA OPEN Bulletin was prepared on fuel cells and the activities of this Implementing Agreement. This bulletin was released to coincide with the US Fuel Cell Seminar in November 2002.

Dr Nabielek gave a presentation on the topic of carbon dioxide capture and removal using fuel cells at a planning workshop of the IEA Task Force on Zero Emissions Technologies Strategies in Washington DC on 19-20 March 2002.

Dr Nabielek also gave a presentation on the work of this Implementing Agreement at a workshop organised by the IEA and Chinese Ministry of Science and Technology in Beijing on 17 May 2002.

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 25th ExCo meeting, the ExCo unanimously invited Mexico to participate in the Implementing Agreement. This invitation was conditional upon the written approval of at least one Operating Agent, following consultation with his annex experts.

ExCo Members agreed to develop a proposal for a new strategy and workplan for the period 2004-2008. The Chairman and Vice Chairman were charged with preparing a proposal for discussion at the Spring 2003 ExCo meeting..

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 2003 Executive Committee meetings will be held in Helsinki, Finland on 8/9 May 2003 and in Germany on 23/24 October 2003 (provisional dates).

A proposal for a continuation programme between 2004 and 2008 will be developed and submitted to the IEA. The End-of-Term report for the current programme will also be prepared during 2003.

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 in Annex XI, Phase II, which are detailed in Section 4.1. Examples include: a new method for making membrane-electrode-gasket assemblies (MEGAs) that can be individually tested and repeatedly assembled and disassembled; a new method for making high surface area catalysts in a low-temperature, short processing timestep; a new process for making high-performance cells by solution-casting the membrane electrolyte on the electrode; long-term testing of 2 kW-class stacks; new screening processes and apparatus for electrocatalysts using millimetre-scale glassy carbon and gold microelectrodes; integration and testing of 5 kW-class combined heat and power systems for residential applications; development of activated carbon odorant removal materials; and development and demonstration of 2.5 kW and micro DMFCs.

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..

3.3 ACHIEVEMENTS OF ANNEX XIII SOFC

Annex XIII held a very successful third Annex workshop in November 2002. The workshop was attended by nine participating countries who exchanged information on their research activities and gave technical presentations on issues relating to SOFC Systems.

3.4 ACHIEVEMENTS OF ANNEX XIV MCFC

The latest R&D data on stack performance was presented and discussed at the Annex XIV annual workshop. Discussions centred on reducing stack degradation rates through better design and improved materials. Information was also exchanged on test procedures for MCFC components and stacks, as part of an ongoing process of understanding national differences in test procedures and standardisation of practices.

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, which are summarised in Section 4.1. These include:

Supporting studies: Studies are coming to agreement on economics of hydrogen production through multiple pathways. Well-to-wheel studies have quantified the fuel economy and greenhouse gas emission benefits of fuel cell vehicles (FCV) relative to current and advanced gasoline and diesel internal combustion engines (ICE) and ICE hybrids. A major study has released its findings on methanol fuel specifications, fire safety assessment, health assessment, methanol FCV emissions, environmental assessment, methanol FCV commercial assessment, and methanol refuelling needs.

Research, development and demonstration activities: Experiments are being conducted to compare the flammability and explosion behaviour of hydrogen with that of traditional fuels. Development of Generation 2 SOFC auxiliary power unit (APU) that is 75% smaller in weight and volume than its predecessor was reported. A composite metal membrane (CMM) module for H_2 separation in on-board steam reforming of methanol has been developed that gives a 99.9995%-pure H_2 permeate stream containing <1 ppm CO_2 and <1 ppm CO after more than 400 thermal cycles and 750 pressure cycles. A project is underway to develop, build, bench demonstrate, and deliver a 5-kg H_2 capacity hydrogen storage system based on $NaAlH_4$ derived compounds. A screw-type compressor was outfitted with a water injection system to combine the functions of air compression and air humidification and installed in Volkswagen Bora. Hybrid H_2 FC buses, IRISBUS and Citaro FC-Bus, are being introduced into commercial service. A Generation II methanol-fuelled hybrid bus with two 50-kW PEMFC systems and a 30-kWh Pd-acid battery back has yielded 38% tank to DC/DC converter efficiency.

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 participated in this Annex during the year 2002:

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.

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

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, membrane electrode assemblies (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 at Philadelphia, U. S. A, on May 17–18, 2002, for the spring meeting and at Palm Springs, U. S. A., on November 22–23, 2002 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

- Appropriate phase separation in the polymer electrolyte can be achieved by placing the ionic groups in the graft chains rather than having them randomly dispersed along the main polymer backbone. Thus, with controlled polymer morphology, proton transport can be facile even with low water content (Canada).
- A new method has been developed to manufacture membrane-electrode-gasket assemblies (MEGAs) that facilitate stack build-up, pre-assembly cell testing, and easy stack disassembly and reassembly (Italy).
- A new method has been developed to prepare high surface area, Pt/C and Pt-Ru/C catalysts for hydrogen, methanol, and reformate applications. The low temperature, short time process yields increased crystallinity and stability than the equivalent commercial catalysts (Italy).
- A technique using a gold wire embedded between two Nafion 112 sheets has been developed for the measurement of anode and cathode overpotentials separately (Korea).

- A new process has been developed for making cells by solution-casting the membrane on an electrode (MOE). The MOE cells have intimate contact between electrodes and electrolyte, yielding a 10% increase in current density at 0.6 V compared to a conventional cell (Korea).
- A 200 cm^2 active area, 40-cell, 2-kW-class stack has been built and operated for over 1800 h. After 1800 h, the stack performance showed a rapid decay of over 4 mV/h, most likely due to degradation of the catalyst and contamination of the polymer electrolyte (Korea).
- Palladium-rich alloys have been tested for CO tolerance in PEFCs. The best performance is provided by $PtPd_4$ (Netherlands).
- Small amounts of methanol, 8%, in the fuel gas were found to poison cell performance at 100–200˚C. Good performance could be recovered by removing the methanol from the fuel gas (Norway).
- Using ultra-high vacuum electrochemical transfer studies, it has been determined that the overpotential for the electrochemical oxidation of CO can be reduced from nearly 0.8 V of Pt(111) to 0.4 V on Pt(111)-(2x2)Sn; the tin is leached out at low potentials, however (U. K.).
- Combinatorial screening processes and apparatus have been developed for the evaluation of thin-film electrocatalysts and high surface supported catalysts, using millimetre-scale 8 x 8 glassy carbon and 10 x 10 gold micro-electrodes (U. K.).

Subtask 2: Balance-of-Plant Issues

- A 20-kW fuel cell test laboratory is being set up in a dedicated hydrogen building. The facility includes test benches for 400 W, 2 kW, and 6-kW fuel cells, controller, and a thermal management system (Belgium).
- The design, construction, and results of testing a 100-cell, 5-kW stack operating on H_2/air showed good overall performance, but did identify one or more poorly performing cells. Except for two bad cells, all of the cells achieved an open circuit voltage in excess of 0.95 V. Under heavy loads, many of the cells showed erratic behaviour. An efficiency of 38% was achieved, compared to the 18–22% efficiency for a 5-kW diesel electric generator (Italy).
- Under strong government support, fuel cell demonstrations are being planned for industrial and consumer applications, including passenger cars. Technology development efforts include segmented electrodes for improved membrane humidification, low-cost austinitic separators with metallic precipitates as current paths, and the development of codes and standards (Japan).
- A 5-kW class PEFC system has been developed for residential application and operated for over 1000 h. Contributing developments include high-performance MEAs; CFD design and optimisation of flow fields in the separator plates; 2.5-kW, 40-cell, 300 cm^2 area stacks with a performance of 0.54 V at 110 A; and a natural gas reformer with <5 ppm CO (but 9.5% methane slip). The net system efficiency ranged from 24% at peak power to 30% at maximum efficiency (Korea).
- Activated carbons impregnated with transition metals have been developed to remove sulphur-containing odorants from natural gas upstream of the fuel processor (Netherlands).
- Various Cu-Zn-Cr-Zr catalysts have been tested for the steam reforming and combined steam and oxidation reforming of methanol. The catalytic activity was found to be correlated with the surface area of copper, with Cu_6Zn_9 as the most active catalyst for both steam and combined reforming (Sweden).

- Simulation of a steam-reformed methane-fuelled 40-kW combined heat and power system showed an electrical efficiency of over 41%, a high grade heat availability of over 15% and a low grade heat availability of over 31%, for a combined heat and power efficiency of 87% for the system (U. K.).
- Direct sodium borohydride fuel cells are being investigated in a U. K./U. S. joint fuel cell program. Due to a higher open circuit voltage of 1.64 V and fuel energy density (9285 Wh/kg for $NaBH_4$ vs. 6200 Wh/kg for CH_3OH), such a fuel offers a 20-fold increase in power over that of their best DMFCs (U. K.).
- Modelling and analysis of a high temperature (150˚C) gasoline-fuelled PEFC system has shown that efficiency increases moderately with decreasing autothermal reforming temperature (between 1100 and 1300 K), increasing pressure (from 1.5 to 2.75 atm), and increasing stack temperature (from 150 to 200˚C). Compared to the equivalent low temperature (80˚C) system, the high temperature system offers an increase in efficiency from 37.7% to 39.3% (U. S. A.).

Subtask 3: Direct Methanol Fuel Cells

- Electrochemical impedance spectroscopy (EIS) has shown that the cathode accounts for a significant portion of the total impedance in a DMFC, contrary to the conventional wisdom that the anode kinetics are the overwhelming source of the overall polarisation in DMFCs (Canada).
- Five 0.5-kW modules, each with twenty-seven 384 cm^2 cells, have been combined into a 2.5-kW stack. A combined preheater/humidifier/exhaust gas clean up module has been developed to improve system performance and oxidise any methanol that may be present in the stack exhaust (Germany).
- The fuel cell research centre at KIST is developing micro DMFCs for portable power applications. A six cell monopolar stack has achieved 40 mW/cm^2 at 4 M methanol under passive conditions. Various micro DMFC power packs have been successfully applied to toys, cellular telephones, and electronic displays (Korea).
- Titanium mesh-based new anode supports for DMFC use are being investigated to obtain improved catalytic performance over carbon-supported catalysts (U. K.).
- Empirical and deterministic models of DMFCs are being developed. The proposed empirical equation fits well measured data from a single cell DMFC over methanol concentrations of 0.125–0.75 M and cell temperatures of 30–90˚C (U. K.).
- A 30-cell, 0.45 V/cell, 45 cm^2 active area, 80-W DMFC stack has been built as replacement for the BA-5590 primary Li/SO2 battery used in military telecommunication systems. Tests showed 90% fuel utilisation, ~320 W L^{-1} power density, and 36% efficiency (U. S. A.).

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

Canada:	Membrane characterisation, fuel processing, modelling, and direct methanol fuel cells
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
Netherlands:	CO tolerance, sulphur removal from fuel gas, and end-use aspects
Norway:	Fuel gas contaminant effects
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, high-temperature polymer electrolytes, 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, I'Energia e I'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 is achieve a better understanding of how stationary fuel cells, in some applications, may be deployed into the energy systems of some countries. The main emphasis of the work will be:

- to describe the technical solution for implementing at least two different fuel cell technologies in at least two different participating countries,
- to identify the parameters of specific importance when introducing the technologies,
- 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 be:

- 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 comprises four subtasks.

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

The work in the sub-task shall be to identify where, to what extent, in what way and which fuel cells could (and should) be used in residential areas.

The subtask shall mainly concentrate on technical and economical matters for fuel cell stationary systems in individual houses and small buildings. The work shall focus on different installations using information from the participating countries.

- Individual houses and building in cold climate
- Individual houses and buildings in warm climate
- Stand-alone systems including air condition
- CHP including electricity, heating, cooling and hot water

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

The work in the sub-task shall be to identify where, to what extent, in what way and which fuel cells could (and should) 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 shall mainly concentrate on technical and economical matters for fuel cell stationary systems in buildings etc. the work shall focus on different installations using information from the participating countries.

Subtask 3 Fuel cell systems for power generation (1000 kW - 10 MW)

The subtask shall focus on applications for utilities. Examples of different applications chosen from the participating countries to be investigated will be:

- 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

The high temperature fuel cell technology may be utilised alone or in combination with a gas turbine. Examples of alternative systems to be investigated include:

- Atmospheric SOFC & MCFC;
- Atmospheric SOFC combined with gas turbine
- Pressurised SOFC & MCFC combined with gas turbine.

A number of possible combinations of power systems with both high temperature fuel cells and gas turbines exist. It is an important issue for the subtask to evaluate and discuss such possible systems. The possibility of using industrial hydrogen will be investigated.

Subtask 4 Implementation / deployment of fuel cell technologies

The work in the task is 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 evaluation may include technical, economic and environmental issues as well as socio-economic issues. The work shall identify and analyse obstacles and how they can be overcome. In general terms the quality acceptance of the technology shall be analysed.

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 subtask shall highlight the interplay between the evaluation of the technology, the market and the role of the authorities, all of them are essential for the introduction of any new technology.

The report from the subtask shall address issues like:

- Identification, evaluation and analysis of key factors that will influence the introduction of fuel cell technology for stationary systems in the participating countries.
- Identification of 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 studies from different countries both existing and planned systems.
- Environmental aspects such as emissions, decommissioning, LCA.
- Identification of initial markets.

4.2.6 Task Results

The different conditions for the introduction of fuel cells have been investigated by using a questionnaire. These results will be used in the coming subtask reports.

All subtasks have a first draft of the final subtask report and presented background material. Some results already achieved are:

- 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

- It will be difficult to introduce fuel cells in a large scale in single-family houses. It is not possible to make these installations competitive with the forecasted investment costs within the energy market today. The market driver for these applications will most probably be for homes in remote locations or in areas with a weak power grid.

- The initial niche markets for fuel cells like UPS, small stand-alone systems etc. could already have big commercial market today, if commercial products were available on the market and the technology reliable. The demand for these markets is growing rapidly, and is dependent on the general technical development.

- The codes and standards which are under development are essential for the introduction of stationary fuel cells

4.2.7 Work Plan for Year 2003

The Annex report and all subtask reports will be finalised during 2003.

A suggestion of a new Annex in the coming Implementing Agreement will be worked out during the autumn of 2003.

The first meeting of 2003 will be held in Kobe, Japan, May 14 – 16, 2003 and the final meeting of the Annex in autumn 2003.

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 2002: Dr. S.C. Singhal (Pacific Northwest National Laboratory, USA). For 2003, Dr. L. G. J. de Haart (Forschungzentrum Juelich, Germany) will take over the responsibility of the role of Interim Operating Agent until December 2003.

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. The Operating Agent will select the topic for the next meeting in agreement with the participants and will also select the next interim Operating Agent.

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 (Finland)

4.3.4. Objective

To organize a series of annual workshops on specific topics, each to be organized 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, NL
Task B: Low temperature operation	May/June 2001	Tokyo, Japan
Task C: Systems	November 2002	Palm Springs, California, USA
Task D: Modelling of Cell and Stack Operation and Electrode Processes	September 2003	Germany

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

In this reporting period, preparations were made for the workshop on "Low temperature operation", which was held from 31st May- 1st June in Tokyo, Japan at The New Energy and Industrial Technology Organization, NEDO. Also, preparations were made for the topical meeting organized by EPFL & ESF with endorsement of the Swiss Federal Office of Energy, Switzerland on "SOFC Materials and Mechanisms", which was held from 16th-19th January. A Workshop on SOFC Systems was held in Palm Springs, California, USA on November 18, 2002.

4.3.7 Progress in Period

4.3.7.1 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, and the Palm Springs workshop was held in 2002. Topical meetings under the umbrella of Annex XIII were also held (Sweden in 2000, Switzerland in 2001 and 2002).

4.3.7.2 Administration

The Operating Agent prepared a concept work plan for Annex XIII, which was presented to and accepted by the ExCo meeting in April in Sweden. Nine countries are formally participating in Annex XIII: Canada, Germany, Switzerland, United Kingdom, The Netherlands, Japan, USA, Australia and Sweden. The status of France in the Annex still needs to be clarified. Finland joined the Annex in 2002.

During the Tokyo workshop in May/June 2001, the representative of PNL, USA (Dr. S.C. Singhal) made the official announcement that he will act as interim Operating Agent for Annex XIII for the period of January 2002 - December 2002.

4.3.7.3 Activities

The NEDO workshop was very successful and highly appreciated by participants. Nineteen participants from nine participants' countries to Annex XIII (excluding Sweden) attended this workshop. With this workshop, the objective of Annex XIII was fully achieved for 2001 and thereafter, i.e. to have annual workshops in different participating countries over two days (dealing with general progress on the first day and focusing on a special topic on the second day) with open discussions and having a link between the workshop and another large SOFC conference. The topical meeting in Switzerland was also successful, it focussed on the topic of SOFC Materials and Mechanisms. The Workshop in Palm Springs, California in 2002 was also very successful; it was attended by participants from nine member countries, including Finland for the first time. The workshop consisted of status of SOFC Research, Development and Demonstration in member countries and selected presentations on SOFC Systems.

4.3.7.4 Technical Accomplishments

At the Palm Springs Workshop on November 18, 2002, representatives from nine countries (Australia, Canada, Finland, France, Germany, Japan, Netherlands, UK and USA) discussed status of SOFC research, development and demonstration in their countries. In addition, four papers dealing with SOFC Systems were presented.

4.3.7.5 Future Plans

The next workshop will be held on September 22-23, 2003 in Germany (near Juelich) in conjunction with the Grove Symposium in UK. The topic of the next workshop will be "Modelling of Cell and Stack Operation and Electrode Processes".

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, Operation 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 first 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 first 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

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. At the next meeting, test procedures on each test (single-cell, short-stack, stack) will be discussed and standardization of the notation for test data will be 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 exchange 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)

4.4.6 Work Plan for Next Year

The fourth meeting will be held on October in 2003 at KIST in Korea, where the activities will be 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

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	Autumn: 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 is scheduled to remain in force for a period of three years starting from January 1, 2001, i.e., until 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:

<u>Subtask 1. Advanced Fuel Cell Systems</u>
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.

<u>Subtask 2. Fuel Infrastructure</u>
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 refuelling 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.

4.5.6.2 Activities

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 fuelled fuel-cell vehicles, and results from demonstration programs.

4.5.6.3.Technical Accomplishments

Hydrogen Infrastructure and Hydrogen Stations

- A study on economics of various routes for commercialization of hydrogen filling stations shows that from the standpoints of economics, dispensing reliability, floor space requirement, flexibility and ease of transition, the LH2 delivery from a central SMR is the best solution for all scenarios investigated. The projected cost of H_2 is 5.5 euros/kg at a low liquid fuel substitution rate (0.1%) and 2.40 euros/kg at a high substitution rate (50%) (Germany).
- The existing hydrogen infrastructure in United States has been compared to what would be needed if 50% of vehicles were powered by hydrogen fuel cells. Centralized production of H_2 with periodic delivery to fueling stations is the least costly option. On-site production of H_2 may become cost-competitive if the ongoing developments are successful (United States).
- A study on hydrogen opportunity and challenges estimates the lowest delivered cost of H_2, without taxes, as \$5.50-\$8./kg at 0.1 TPD with LH2 delivery, CGH2 delivery or on-site electrolysis, \$2-\$3.50/kg at 1 TPD with on-site SMR, and \$1-\$2/kg at 10 TPD also with SMR (Netherlands).
- A number of demonstration projects on hydrogen infrastructure and utilization are underway in Italy. The Milan project involves production of hydrogen from natural gas, utilization of reformate in a MCFC plant, powering of a PEFC plant with hydrogen purified from a reformate stream, liquid and compressed hydrogen filling

station, a hydrogen bus minifleet, and a cogeneration plant. The Turin project will produce hydrogen for the Irisbus using an electrolyzer with electricity produced with hydropower from Alps. The Florence project will supply hydrogen with an electrolyzer for the FC bus for urban transport (Italy).

- For a hydrogen refueling system based on auto-thermal cyclic reformer (ACR), a high-pressure reformer (7 bars) gives better efficiency, lower capital cost and higher reliability than a low-pressure reformer with syngas compressors between the reformer and the PSA. For a 1500-car station, the estimated cost of delivered hydrogen is $2.50/kg if the stations are mass produced at 100 units/year and $3.25/kg at 10 units/year. For an 80-car station the estimated cost is $6/kg at 100 units/year and $8/kg at 10 units/year (United States).
- GTI is using its compact SMR technology to develop and demonstrate a high-efficiency natural gas-to-hydrogen fueling station. For fast-fill dispensing, an algorithm has been developed on the basis of a first-principle thermodynamic model and empirical data from extensive data. Preliminary system economics indicates that depending on production volume, learning curve, utility rates and tax incentives, the expected cost of hydrogen is $2.55-$4.16/kg (United States).
- EIHP2, the European Integrated Hydrogen Project – Phase II, is a three-year project with objectives to initiate and assist the development of regulations and standards needed to allow the safe and financially viable introduction of mass-produced hydrogen road vehicles and refueling infrastructure (Sweden).
- Experiments with hydrogen release at 21 bars through a 1-cm hole showed a 9-m long buoyant flammable cloud while LPG released at 5.1 bars through a 1-cm hole produced a cloud that touches the ground and extends horizontally up to 45 m. Experiments at small scale unconfined explosions show that hydrogen explosions are actually milder (smaller overpressure) than with acetylene (Netherlands).

Hydrogen Fuel Cell Vehicles

- Technical analyses indicate that an advanced hydrogen fuel cell (FC) system on a Ford Explorer SUV platform can achieve a tank-to-wheel (TTW) efficiency of 46.6% and a TTW fuel economy of 57 mpgge (miles per gallon gasoline equivalent) on the SAE cycle. With off-board hydrogen produced in a large central station from North American natural gas (NG), the well-to-wheel (WTW) efficiency is 27.2%, the WTW energy consumption is 3.2 MJ/mile, and it emits 220 g/mile of the greenhouse gas (GHG) CO_2 (United States).
- For optimal performance, it is important to properly integrate the compressor-expander (CEM) module into the FC system. Whereas, the radiator cooling load as a fraction of the fuel heating value increases in an ICE as the vehicle speed is reduced, it decreases in a H_2 FC system. The condenser cooling load as a fraction of the fuel heating value is highest at about 60 mph. In a stand-alone FC system, it is not always possible to be self-sufficient in water at idling conditions (United States).
- A screw-type compressor was outfitted with a water injection system to combine the functions of air compression and air humidification without requiring an additional heat exchanger. Volkswagen Bora was reconfigured with a 40-kW H_2 fuel cell system (750-cell stack) that uses the screw compressor and a 210-Wh supercapacitor energy storage system. In simulated HIL tests, the vehicle obtained a peak efficiency of 50% at 30% rated power and 35% at rated power (Germany).
- A high-temperature polymer electrolyte membrane, that does not require high humidity to maintain its proton conductivity, eases the requirements of air

compression, water management and heat rejection. To be useful in transportation applications, it must preserve the cold start capabilities and immobilized functional groups, have conductivity comparable to Nafion at the operating temperature, and be stable and cheaper (Netherlands).

- In cooperation with other organizations, ENEA is starting a project on R&D of novel Mg-based metal hydrides that can store and release >5% H_2 below 200^oC. The plan is to design and engineer a working prototype of a conventional AB5 type metal hydride and test it on bench top and in a vehicle (Italy).
- A project is underway to develop, build, bench demonstrate, and deliver a 5-kg H_2 capacity hydrogen storage system based on $NaAlH_4$ derived compounds. System and cost studies have led to an initial design and identification of major contributors to cost and weight. A 50-g H_2 apparatus has been used for establishing a database for thermodynamic and physical/transport properties. A 1-kg H_2 prototype system has been designed and is being fabricated (United States).
- Performance of a H_2 FC system for hybrid vehicles was evaluated using a 100-cell stack rated at 4.1 kW at 0.7 V cell voltage and 43.5% oxidant utilization. The operating pressures are 1.5-1.8 bar for H_2 and 1.2-1.3 bar for air. The operating temperatures are 80^oC stack, 40^oC coolant inlet and 65^oC air outlet. The stack is internally humidified with water that flows through the coolant passages. The hydrogen passages inside the stack are dead-ended with a periodic purge of H_2 every 15 minutes (Italy).
- An 8-m FC hybrid bus with 50-km/h top speed, 16% maximum grade, 150-km range, and a capacity of 30 passengers is being designed and built for operation in the city of Florence. The selected H_2 fuel-cell system has a nominal rating of 16.8 kW net power and 42% efficiency on LHV basis. Five tanks, weighing 180 kg, will store 5 kg of H_2 at 200 bars. The battery pack consists of 30 modules of lead-acid batteries, weighs 450 kg, and has 42-Ah capacity (Italy).
- IRISBUS, a series hybrid FC bus outfitted with a new FC stack, a new stack coolant loop, and a new DC/DC converter, has logged on more than 1500 km in simulated urban routes. In year 2003, it will be tested on roads in Torino under real operating conditions. Also, the construction of the refueling station to recharge the compressed H_2 cylinders will be completed (Italy).
- DaimlerChrysler is building 30 FC buses for the EU projects CUTE (Clean Urban Transport for Europe) and ECTOS (Ecological City Transport System). Citaro FC-Bus, introduced in 2001, has a 250-kW stack powered with hydrogen stored as compressed gas in cylinders at 350 bars, and has a diving range >200 km. DaimlerChrysler is planning to introduce 60 concept cars in international cooperative ventures. These will be based on the F-Cell, A-class passenger car which uses a 72-kW stack powered by compressed hydrogen stored at 350 bars and has a top speed of 140 km/h and a driving range of 150 km (Germany).

Liquid Fueled Fuel-Cell Vehicle Systems

- Experimental data on copper based catalysts with Zn, Cr and Zr as promoters, indicates that Cu_6Zn_9 is the most active catalyst for both steam and auto-thermal reforming of methanol, and there is a direct correlation between catalytic activity and the copper surface area and the reducibility of the metal oxides (Sweden).
- A composite metal membrane (CMM) module for H_2 separation has been developed that gives a 99.9995%-pure H_2 permeate stream containing <1 ppm CO_2 and <1 ppm CO after more than 400 thermal cycles (RT to 350^oC at 130 psi) and 750 pressure

cycles (ambient pressure to 130 psi at 350°C). With 30 to 100 psi pressure differential, the measured hydrogen flux varies between 15 and 35 cc/min/cm^2 for a unit cell and 10-25 cc/min/cm^2 for a module (Korea).

- The Methanol Fuel Cell Alliance has released its findings on methanol fuel specifications, fire safety assessment, health assessment, methanol FCV emissions, environmental assessment, methanol FCV commercial assessment, and methanol refueling needs. The methanol station at CAFCP which uses a 2000 gallon above ground storage tank and an integrated MFCA refueling nozzle was constructed at a cost of $35K (Canada).
- A gasoline fuel processor is being developed for a 25-kW PEMFC system to be deployed in a hybrid vehicle. The electrically-heated, Pd catalyst for POX has been washcoated on a metallic monolith for partial oxidation, and can be brought to temperature in <1.5 mins. The fuel processor uses a single, heat exchanger type reactor for medium temperature shift. The three-stage intercooled PROX can be started in 3 mins (Korea).
- Delphi is developing Generation 2 SOFC APU (with 2 x 30-cell stacks) that is 75% smaller in weight and volume than its predecessor. The stack has a specific volume of 1 L/kW and a specific weight of <4 kg/kW. In laboratory tests with a 3-cell stack, 7 x 7 cm cells, and 50% H_2 in anode stream, a power density of 0.375 W/cm^2 was achieved at 0.7 A/cm^2 current density (United States).
- Tubular and planar Generation 2 reformer concepts are being evaluated for SOFC APU to address issues of reformer efficiency, durability, start-up time, and weight and volume. Under POx condition, 1000°C and O to C ratio of 0.95, typical for system start-up, a single planar laboratory reformer on city "Swedish" diesel fuel generates a reformate with ~20% H_2 molar concentration, ~18% CO concentration and ~1.5% CH_4 concentration. Under endothermic condition typical of high efficiency operation, the reformer produces a gas with 42% H_2 and 38% CO at a moderate C to O ratio of 1.4 (United States).
- A Generation II methanol-fueled hybrid bus with two 50-kW PEMFC systems and a 30-kWh Pd-acid battery back has yielded 38% tank to DC/DC converter efficiency. Methanol production from coal in an 80,000 gallon/day plant is cost competitive with other options (United States).

Life Cycle Analysis

- A study on comparing different well-to-wheel analyses of future power trains on a common light-duty-vehicle platform projects 39% TTW and 25% WTW energy conversion efficiency for a cH_2 FCV (1164 kg curb weight), and 30% TTW and 19% WTW efficiency for a methanol FCV (1257 kg curb weight) (Germany).
- As a follow-up to its North American study, General Motors has completed well-to-wheel analysis of energy use and greenhouse gas emissions of advanced fuel/vehicle systems for the European market. The study confirms the earlier conclusion that hybridization reduces fuel consumption but the benefits are larger for ICE (10-30%) than for FC (~10%) vehicles. H_2 FC vehicles running on H_2 from reformed NG offer 45% reduction in GHG emissions relative to gasoline and 35% reduction relative to diesel ICE vehicles (United States).
- The causes of variability of tank-to-wheel fuel economy gain estimates made in recent landmark studies have been examined with particular emphasis placed on the MIT study, GM study for North America, the DTI study, and the ADL study (United States).

- An SMR based H_2 station is superior to other methods of generating hydrogen and a high-pressure reformer is preferred over a system that uses a reformate compressor. Under the future scenarios, the direct hydrogen FCV gives more than 2.5 times better fuel economy than the conventional gasoline ICE vehicle, and the large battery cases give better fuel economy than the small battery cases due to greater regenerative braking. (United States).

4.5.7 Work Plan for Next Year

The general consensus of the Working Group is to organize the Annex XV activities into three study groups. The activities within each study group and the contributors are listed below.

Fuels Study (Well to Tank)

- Alternative fuels infrastructure technology: APCI, GE, GTI, Methanex, Shell
- Hydrogen stations: APCI, Methanex, NREL, ChevronTexaco, Shell
- Life cycle analysis: ANL, GM, Methanex, Shell
- Economics: ADL, Methanex, TU-Berlin

Fuel Cell Vehicle Study (Tank to Wheel)

- Integrated PEFC systems for vehicles: DaimlerChrysler, Ford, GM, Hyundai, Siemens, Volvo
- PEFC system technology: ANL, ECN, ENEA, FEV, SWRI
- APU technology: FEV, LANL, Delphi, FZJ, Volvo
- Fuel processing: ANL, Delphi, ECN, ENEA, LANL, Hyundai, Shell
- On-board hydrogen storage: ChevronTexaco, ENEA, NREL, UTRC
- Platinum group metal requirement: ADL, FZJ
- Comparison with ICE's: ENEA, FEV, VKA/RWTH
- Emissions: ADL, ECN, ENEA
- Economics: ADL, TU-Berlin

System Integration Study (Source to Wheels)

- Safety
- Government role: TU-Berlin
- Technology demonstrations: CAFCP, ENEA (IrisBus), GU, Siemens (MAN-city)
- Comparative analysis: ANL, FEV, GM

APPENDICES

Appendix 1 Membership of the Executive Committee

1.1 Members and Alternate Members

Australia	Dr B Godfrey Ceramic Fuel Cells Ltd 170 Browns Road Noble Park Victoria 3174	Tel: (+) 61-3-9554-2312 Fax: (+) 61-3-9790-5600
	Dr K Foger Ceramic Fuel Cells Ltd 170 Browns Road Noble Park Victoria 3174	Tel: (+) 61-3-9554-2311 Fax: (+) 61-3-9790-5600
Belgium	Mr G van Bogaert VITO Boeretang 200 B-2400 Mol	Tel: (+) 32-14-335911 Fax: (+) 32-14-321185
Canada	Dr V Scepanovic NRCan 580 Booth St. Ottawa ONTARIO K1A 0E4	Tel: (+) 1-613-996-5965 Fax: (+) 1-613-996-9416
	Dr E Andrukaitis Department of National Defence, Canada National Defence Headquarters Constitution Building 305 Rideau Street, 8th Floor Ottawa Ontario KIA 0K2	Tel: (+)1-613-990-0638 Fax: (+)1-613-993-4095
Finland	Mr J Laine National Technology Agency (TEKES) PO Box 69 FIN-00101 Helsinki	Tel: (+)358-10-521-5874

	Dr Rolf Rosenberg VTT PO Box 1404 FIN-02044 VTT	Tel: (+)358-9-456-6342 Fax: (+)358-9-456-6390
France	Dr G Chaumain ADEME 2 square Lafayette BP406 49004 ANGERS Cedex 01	Tel: (+)33-1-41-91-4017 Fax: (+)33-1-41-91-4002
	Ms N Thybaud ADEME 2 square Lafayette BP406 49004 ANGERS Cedex 01	Tel: (+)33-2-41-91-4023 Fax: (+)33-1-41-91-4002
Germany	Prof D Stolten Forschungszentrum Jülich IWV-3: Energy Process Engineering D-52425 Jülich	Tel: (+)49-2461-613076 Fax: (+)49-2461-613385
	Dr H Nabielek Forschungszentrum Jülich PBZ: Project Fuel Cells D-52425 Jülich	Tel: (+)49-2461-613271 Fax: (+)49-2461-618162
Italy	Dr R Vellone CRE-Casaccia Via Anguillarese 301 00060 S. Maria di Galeria ROME	Tel: (+)39-06-3048-3126 Fax: (+)39-06-3048-3795
	Dr A Moreno CRE-Casaccia Via Anguillarese 301 00060 S. Maria di Galeria ROME	Fax: (+)39-06-3048-6306
Japan	Mr T Ninomiya NEDO 1-1, 3 Chome Higashi-Ikebukuro Toshima-Ku TOKYO 170-6028	Tel: (+)81-3-3987-9432 Fax: (+)81-3-5992-5233

	Mr H Ochi NEDO 1-1, 3 Chome Higashi-Ikebukuro Toshima-Ku TOKYO 170-6028	Tel: (+)81-3-3987-9432 Fax: (+)81-3-5992-5233
Korea	Mr H-C Lim KEPRI 103-16 Munji-dong Yusong-ku Taejon 305-380	Tel: (+)82 42 865 5390 Fax: (+)82 42 865 5304/5374
	Dr T-H Lim KIST 39-1 Hawolkog-dong Sungbuk-ku Seoul 136-791	Tel: (+)82 2 958 5273 Fax: (+)82 2 958 5199
Netherlands	Dr S van der Molen ECN P O Box 1 1755 ZG PETTEN	Tel: (+)31-224-56-4380 Fax: (+)31-224-56-3489
Norway	Mr P-Ø Hjerpaasen Statkraft SF PO Box 494 N-1323 Høvik	Tel: (+)47-67-57-7364 Fax: (+)47-67-57-7098
	Ms R Hildrum Statkraft SF PO Box 494 N-1323 Høvik	Fax: (+)47-67-57-7098
Sweden	Prof L Sjunnesson Sydkraft AB SE-20509 MALMO	Tel: (+)46-40-255600 Fax: (+)46-40-6115184
	Dr B Gustafsson STEM Box 310 SE-63104 Eskilstuna	Tel: (+)46-16-544-2085 Fax: (+)46-16-544-2099
Switzerland	Dr A Hintermann OFEN CH-3003 BERNE	Tel: (+)41-31-3225654 Fax: (+)41-31-3232500

United Kingdom	Mr R Eaton DTI 1-19 Victoria Street LONDON SW1H OET	Tel: (+)44-20-7215-2650 Fax: (+)44-20-7215-2674
	Mr J Marsh DTI 1-19 Victoria Street LONDON SW1H OET	Tel: (+)44-20-7215-2652 Fax: (+)44-20-7215-2674
USA	Dr J Milliken USDOE 1000 Independence Ave EE 32, 5G-023 Washington DC 20585-0121	Tel: (+)1-202-586-2480 Fax: (+)1-202-586-9811
	Dr M Williams USDOE NETL PO Box 880 Morgontown WV 26505	Tel: (+)1-304-285-4747 Fax: (+)1-304-285-4292

1.2 Operating Agents

Annex XI	Dr R Kumar Argonne National Lab. 9700 South Cass Ave. Argonne IL 60439 USA	Tel: (+)1-630-252-4342 Fax: (+)1-630-252-4176
Annex XII	Mr B Ridell Sycon Energikonsult AB SE-20509 MALMO Sweden	Tel: (+)46-40-255996 Fax: (+)46-40-302194
Annex XIII	Dr S Subhash Pacific Northwest National Laboratory 902 Battelle Boulevard PO Box 999 Richland WA 99352 USA	Tel: (+)1-509-375-6738 Fax: (+)1-509-375-6605

Annex XIV	Mr T Ninomiya NEDO 1-1, 3 Chome Higashi-Ikebukuro Toshima-Ku TOKYO 170-6028 Japan	Tel: (+)81-3-3987-9432 Fax: (+)81-3-5992-5233
Annex XV	Dr R Ahluwalia Argonne National Laboratory 9700 S Cass Ave Argonne IL 60439	Tel: (+)1-630-252-5979 Fax: (+)1-630-252-1774

1.3 Secretariat

IEA Secretariat	Mr T Howes IEA/OECD Office of Energy Efficiency Technology and R&D 9 rue de la Fédération 75739 Paris Cedex 15 France	Tel: (+)33-1-4057-6789 Fax: (+)33-1-4057-6749
ExCo Secretariat	Mrs H Haydock AEA Technology E6 Culham Abingdon Oxfordshire OX14 3ED United Kingdom	Tel: (+)44-1235-463689 Fax: (+)44-1235-463574
ExCo Secretariat	Ms C Handley AEA Technology 156 Harwell Didcot Oxfordshire OX11 OQJ United Kingdom	Tel: (+)44-1235-433771 Fax: (+)44-1235-432390

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

Appendix 3 Task Proposals Under Consideration

There are no new annexes presently under consideration. However, the Executive Committee has been considering new activities on training fuel cell technicians and raising the profile of the Implementing Agreement through events and publications.

Appendix 4 Executive Committee Reports and Publications

The following reports have been issued:
- Minutes of 25 Executive Committee Meetings since initiation (1990).
- Annual Reports 1990-2001.
- 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 and September 1998.
- "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 to the IEA Working Party on End Use Technologies, the Committee on Energy Research and Technology and the IEA Hydrogen Executive Committee.

Appendix 5 Workshops and Task Meetings

This section lists meetings and workshops held to date and planned for 2001, for those tasks which were active during the year.

5.1 Task XI: Polymer Electrolyte Fuel Cells

5.1.1 Workshops and Meetings Held to Date

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.

5.1.2 Workshops and Meetings Planned for Next Year

Annex XI Phase II Working Group, May 6–7, 2003, Trondheim, Norway
Annex XI Phase II Working Group, October/November 2003, 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

5.2.2 Workshops and Meetings Planned for Next Year

Kobe, Japan, May 14 - 16, 2003
A final meeting will be held during the autumn of 2003.

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 Jun 2001 on "Low temperature operation".
Topical meeting on "SOFC Materials and Mechanisms", 16th – 19th January 2001, Les Diablerets, Sweden.

5.3.2 Workshops and Meetings Planned for Next Year

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

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.

5.4.2 Workshops and Meetings Planned for Next Year

Fourth meeting will be held on October , 2003 in Soul , Korea hosted by KIST.

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, 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, Palm Springs, CA, U.S.A., hosted by U.S. Department of Energy.

5.5.2 Workshops and Meetings Planned for Next Year

April 24-25 (tentative), 2003, Stockholm, Sweden, hosted by Volvo AB.
October 2003, Dates and venue to be finalized.

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.

6.3.2 Reports Planned for Next Year

- Meeting, Status, and Annual Reports for Task XI Phase II, 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.

The draft subtask reports have been prepared.

6.2.2 Reports Planned for Next Year, Annex XII

It is anticipated that five reports will be published from the Task, 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 18, 2002, by S. C. Singhal (Editor), November 2002.

6.3.2 Reports Planned for Next Year

- Proceedings of the workshop in Germany, September 2003: "Modelling of Cell and Stack Operation and Electrode Processes".

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 Task XIV.

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.

6.5.2 Reports Planned for Next Year

- Proceedings of Fourth IEA Annex XV Meeting, February, 2003.
- Status Report on Annex XV: Fuel Cell Systems for Transportation, March 2003.
- Proceedings of Fifth IEA Annex XV Meeting, June, 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.

Appendix 7 <u>Task Experts</u>

This section lists the Operating Agents and the other experts who have participated in those tasks which 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: Romesh Kumar, Argonne National Laboratory, USA (R)

Experts:

Gilbert Van Bogaert	Vito (R)	Belgium
John Amphlett	Royal Military College (A)	Canada
Steven Holdcroft	Simon Fraser University (A)	"
Ian Wheeldon	Royal Military College (A)	"
Jürgen Mergel	Forschungszentrum-Jülich (R)	Germany
Hendrik Dohle	FZ-Jülich (R)	"
Matthias Gebert	FZ-Jülich (R)	"
Thorsten Wüster	FZ-Jülich (R)	"
Agostino Iacobazzi	ENEA (R)	Italy
Marco Brocco	ENEA (R)	"
Tomohiko Ikeya	NEDO (G)	Japan
Masashi Kano	NEDO (G)	"
Yasuo Nishimura	NEDO (G)	"
In-Hwan Oh	Korea Institute of Science and Technology (R)	Korea
Chang-Soo Kim	Korea Institute of Energy Research (R)	"
Heung Yong Ha	Korea Institute of Science and Technology (R)	"
Frank de Bruijn	ECN (R)	Netherlands
D. Papageorgopoulos	ECN (R)	"
Børre Børresen	NTNU (A)	Norway
Reidar Tunold	NTNU (A)	"
Lars Pettersson	KTH (A)	Sweden
Ruth Allen	University of Newcastle (A)	U. K.
Panagiotis Argyropoulos	University of Newcastle (A)	"
Brian Hayden	University of Southampton (A)	"
Barry Lakeman	DSTL (G)	"
Keith Scott	University of Newcastle (A)	"
Rob Thring	Loughborough University (A)	"
Eileen Yu	University of Newcastle (A)	"
Mebs Virji	Loughborough University (A)	"
Nancy Garland	U. S. Department of Energy (G)	U. S. A.
Romesh Kumar	Argonne National Laboratory (R)	"
Piotr Zelenay	Los Alamos National Laboratory (R)	"

7.2 Task XII: Fuel Cell Systems for Stationary Applications

Operating Agent: Bengt Ridell. Sycon Energikonsult AB, Sweden

Experts:

Bruce Godfrey	CFCL (I)	Australia
Karl Föger	CFCL (I)	Australia
Philippe Stevens	EDF(I)	France
Ulf Birnbaum	FZJ (R)	Germany
Oliver Weinman	HEW (I)	Germany
Gerhard Huppmann	MTU (I)	Germany
Matti Valkianen	VTT(G)	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
Lars Sjunnesson	Sydkraft (I)	Sweden
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
Gerard Chaumain	ADEME (G)	France

7.3 Task XIII: Solid Oxide Fuel Cells

Operating Agent: Subhash C. Singhal [Jan.-Dec.2002]

K. Foger	Ceramic Fuel Cells Ltd. (I)	Australia
Brian Borglum	Global Thermoelectric (I)	Canada
E. Neary	Global Thermoelectric (I)	Canada
Brian Steele	Imperial College (A)	England
H.Nabielek	FZ Julich (R)	Germany
I. C. Vinke	FZ Julich (R)	Germany
P. Stevens	EDF R&D (G)	France
T. Ninomiya	NEDO (G)	Japan
H. Fujii	NEDO (G)	Japan
Y. Baba	Tokyo Gas (I)	Japan
H. Yokokawa	AIST (R)	Japan
T. Kato	AIST (R)	Japan
H. Kishizawa	Mitsubishi Heavy Industries (I)	Japan
H. Miyamoto	Mitsubishi Heavy Industries (I)	Japan
Rolf Rosenberg	VTT Processes (A)	Finland
B. Rietveld	ECN (R)	Netherlands
M. Krumpelt	Argonne National Laboratory(A)	USA
D. Carter	Argonne National Laboratory (R)	USA
D. Rastler	EPRI (I)	USA
J. Kiviaho	VTT Processes (I)	Finland
Mark Williams	DOE (R)	USA

7.4 Task XIV: Molten Carbonate Fuel Cells

Operating Agent: Toru Ninomiya, 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

Kerry-Ann Adamson	Technische Universität Berlin	Germany
Rajesh K. Ahluwalia	Argonne National Laboratory	U.S.A.
Rod Borup	Los Alamos National Laboratory	U.S.A.
Karen Campbell	Air Products and Chemicals	U.S.A.
Eric Carlson	TIAX, LLC	U.S.A.
Mario Conte	ENEA	Italy
Roger Cracknell	Shell Global Solutions	U.K.
Robert Dempsey	ChevronTexaco Technology Ventures	U.S.A.
Erich K. Erdle	DaimlerChrysler Corporate R&T	Germany
Georg Erdmann	Technische Universität Berlin	Germany
Per Ekdunge	AB Volvo	Sweden
Matthias Gebert	Forschungszentrum Jülich	Germany
James Grieve	Delphi Automotive Systems	U.S.A.
Pede Giovanni	ENEA	Italy
Blair Heffelfinger	Methanex Corporation	Canada
Shinichi Hirano	Ford Motor Company	U.S.A.
Bernd Höhlein	Forschungszentrum Jülich	Germany
Inchul Hwang	Hyundai Motor Company	Korea
Agostino Iacobazzi	ENEA	Italy
John Kopasz	Argonne National Laboratory	U.S.A.
Ken Koyama	California Fuel Cell Partnership	U.S.A.
Ravi Kumar	GE – EER	U.S.A.
Oliver Lang	FEV Motortechnik	Germany
Göran Lindbergh	Royal Institute of Technology (KTH)	Sweden
Magnus Karlström	Chalmers University of Technology	Sweden
Ronald Mallant	ECN	Netherlands
Catherine Lentz	California Fuel Cell Partnership	U.S.A.
Tae-Won Lim	Hyundai Motor Company	Korea
William Liss	Gas Technology Institute	U.S.A.
Catherine E. Padro	National Renewable Energy Laboratory	U.S.A.
Lars Pettersson	Royal Institute of Technology (KTH)	Sweden
Stefan Pischinger	VKA/RWTH Aachen	Germany
Jaco Reijerkerk	Linde Gas	Germany
Ludmilla Schlect	Technische Universität Berlin	Germany
Jan Teuben	Shell Global Solutions	Netherlands
Stefan Unnasch	TIAX, LLC	U.S.A.
Gerald Voecks	General Motors Corp. (GAPC)	U.S.A.
Manfred Waidhas	Siemens AG	Germany
Michael Wang	Argonne National Laboratory	U.S.A.
Robert Wimmer	Georgetown University	U.S.A.