INTERNATIONAL ENERGY AGENCY

ADVANCED FUEL CELLS PROGRAM

STRATEGY FOR THE PERIOD 1999 TO 2003

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ABSTRACT

The IEA-Implementing Agreement had been in place since 1990 and provides the legal structure for the international co-operation of fuel cell research and development. Fourteen countries are currently involved (April 1998). This strategy paper provides an updated strategy for the program from 1999 to 2003.

Fuel cell systems offer clean and high-efficient conversion of gaseous energy carriers. World-wide, fuel cells are being intensively developed and demonstrated, to prepare for implementation and to prove the benefits to society.

The main objective of the Implementing Agreement is to promote the development and implementation of fuel cell systems through international co-operation.

This strategy paper evaluates the potential benefits and market opportunities for fuel cell based systems; both in stationary and transportation applications. An introduction is given which summarises activities and accomplishments through the co-operation, as described in the Annexes to the Implementing Agreement. It appears that the Agreement provides an effective basis for targeted activities of experimental and informational kind.

Given the state of the art of the technology and market expectations, the following main strategic choices have been set to promote the objectives of the Implementing Agreement for the next five years (1999 to 2003):

1- Continue and expand the informational network
2- Perform market assessment and monitoring
3- Identify and lower barriers to implementation
4- Stimulate co-operative R&D activities which:
  * promote the development of technical and economically viable stacks and systems,
  *stimulate tools for, and knowledge of balance of plant (BOP) design options,
  * increase the value of demonstration programs,
 and
  *contribute to feasibility studies of the deployment of fuel cell based technology.

These choices provide the framework for the joint activities to be defined in new Annexes to the Agreement.

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1 OBJECTIVES

The major objective of the implementing agreement is strengthening of the co-operation on the development and implementation of fuel cell systems.
This will be accomplished through the international network by activities like co-operative research, the exchange of experience and data, and by market and systems studies.

2 INTRODUCTION [1]

Fuel cell based energy conversion systems offer potential energy, environmental and economic benefits. This is the reason that intensive development efforts are being made throughout the world in order to determine the viability of the technology. In order to accelerate developments and make best use of resources, intensive co-operation has been initiated on National and International levels.

The International Energy Agency (IEA), has been shown to provide a useful legal framework for intensive international co-operation for member countries. The objective of the IEA- Implementing Agreement on Advanced Fuel Cells is to continue, strengthen and expand International co-operation on the development and implementation of fuel cells and their systems.
The current aim is to optimise the strong international network through activities like co-operative research, system studies and the exchange of experience and data. The agreed activities and work plans are formalised in Annexes to the Implementing Agreement.

The 'Implementing Agreement for a program of research, development and demonstration on advanced fuel cells' formally came into force when seven countries (see Table 1) signed up to the Agreement on April 2nd, 1990. Since that time, the number of Signatory countries has increased to fifteen (June 1998).

[1] Explanations of some technical terms and abbreviations for types of fuel cells are given at the Glossary, Appendix 1.

Table 1 Signatory countries to the IEA Implementing Agreement (by June 1998).

Country	**Signatory Party**	**Signature**
Australia	Ceramic Fuel Cells Limited	November 1995
Canada	Natural Resources Canada (Delegation to the OECD)	November 1991
Denmark	Danish Energy Agency	September 1990
France	L'Agence de l'Environnement et de la Maitrise de l'Energie (ADEME)	August 1996
Germany	Forschungszentrum Jülich (KFA Jülich)	December 1992
Italy	Ente per le Nuove Tecnologie l'Energia e l'Ambiente (ENEA)	April 1990
Japan	New Energy and Industrial Techno-logy Development Organisation (NEDO)	April 1990
Korea	Korean Institute for Science and Technology (KIST)	April 1998
Netherlands	Netherlands Agency for Energy and the Environment, NOVEM	April 1990
New Zealand	University of Waikato	February 1996
Norway	Research Council for Norway (Norwegian Council for Scientific and Industrial Research)	April 1990
Sweden	Swedish Board for Industrial and Technological Development (NUTEK)	April 1990
Switzerland	Office Féderale de l'Energie (OFEN)	April 1990
United Kingdom	Department of Trade and Industry (Department of Energy)	September 1990
United States	Department of Energy (US-DOE)	May 1995

The first term of the Agreement originally ran from 1990 until December 1995, and it was then extended until the end of 1998. During the first term, the number of Annexes increased from two to five. These have all been finalised by now (list of Annexes given in table 2). Five new Annexes have been developed and initiated to be active during the three year period from 1996-1998.

Table 2. List of Annexes

Annex	Status	Name
from 1990-1995		
I	completed	MCFC; Balance of Plant Analysis
II	completed	SOFC; Modelling and Evaluation
III	completed	MCFC; Materials and Electrochemistry
IV	completed	PEFC
V	completed	Fuel Cells: System Analysis
from 1996-1998		
VI	active	MCFC under real Operating Conditions
VII	active	SOFC under real Operating Conditions
VIII	active	Collaborative Research on PEFC
IX	active	Fuel Cell Systems for Stationary Applications
X	active	Fuel Cell Systems for Transportation

Since 1990 extensive progress has been made in the development and demonstration of fuel cells and their systems. For instance, the IEA collaboration succeeded into developing common testing procedures for the evaluation of the performance of cells. This allowed most of the participating countries to produce reliable cells.
Furthermore, views on the best market potentials and approach have become increasingly clear and realistic, which affects the objectives of the development programmes.

Also non-technical factors have changed, e.g. the attainment of commercial activities and alliances. As a consequence the relative proportion of commercially sensitive information has increased. Therefore, while some truly collaborative development takes place between commercial players, these factors mitigate against a comprehensive government led international development program like that pursued under the IEA Implementing Agreement so far.

Furthermore changing socio-political of National and International objectives are involved, which leads to continuously changing targets and means.

Against this background, the strategy of this Implementing Agreement has been reviewed, to provide an updated framework for co-operation and to ensure the effectiveness of that co-operation.

3 FUEL CELLS: BENEFITS AND OPPORTUNITIES

3.1 General properties

As previously stated, the interest in fuel cell technology is based on the expected energy, environmental and economic benefits. These benefits are projected from the principles of the electrochemical conversion process, which promises high efficiency and very low emissions; consistent with the objectives of the Kyoto conference on Global Warming and greenhouse gas reduction (1997).

Also other interesting features can be derived from those principles such as:

Systems

- Fuel flexibility. Fuel cells ultimately use hydrogen and oxygen to convert these into water. Since all chemical energy carriers may be converted into hydrogen-rich gases, this means that various fuels can be used; both from fossil and renewable sources. Consequently, while developed and introduced for fossil fuels, fuel cell systems offer very good opportunities in renewable energy structures (bio-fuels, H2-economy etc.).
- Modularity. Cell stacks can be produced as building blocks for systems of different sizes. System design and maintenance can benefit greatly from this feature. Modular systems can be technically and economically beneficial.
- Low level of vibration and noise. The fuel cell produces no noise. Low level noise is given from the associated blowers and compressors.

Stacks

- Good performance at small unit sizes. Unlike reciprocating and rotating combustion engines, the properties of fuel cells are well-developed at small unit size.
- Good part-load performance. The electrical efficiency may even rise at part-load conditions. The reason for this is that the internal power loss reduces at lower current density.

3.2 Application fields of fuel cells

3.2.1 Stationary generation, current options

Fuel cell systems will have to compete with combustion based technologies; e.g. the rotating and reciprocal engines. Manufacturing industries and supply chains have been well- developed for both stationary and traction purposes. Market confidence has been gained, as these established technologies have matured through an intensive optimisation process through many years of experience. Even recently, major improvements have been made toward lower NOx levels in the off-gas and increasingly higher efficiencies. It is expected that large steam and gas turbine combinations (>100 MWe STAG) will soon reach 60% LHV. However smaller systems have substantial lower efficiencies, while obeying usual scale factors. Extensive profitable markets support incremental developments.

The technical developments however, seem to approach theoretical efficiency limits for the combustion based systems. The reason for this is that traditional combustion engines are limited by the principles of thermal engines as described by the Carnot efficiency. As a consequence, this requires higher temperatures to increase the efficiency. The current temperatures approach the limits of materials stability and thermal NOx formation.

3.2.2 Traction, current options and outlook

Recent developments of diesel and otto combustion engines have reduced harmful emissions significantly. Nevertheless, they still emit harmful emissions, including greenhouse gasses. Fuel cell electric vehicles are expected to become more effective and clean. By contrast to fossil fuel driven vehicles, a fuel cell electric vehicle operating on hydrogen produced from water by a renewable energy source, is a zero emission vehicle.

3.3 Market assessment

World wide programs have been initiated to uncover the capabilities of fuel cells and their systems and to translate the potential into practical viable technologies. The increased understanding of the technical abilities of systems and the recent successes in the development of fuel cell stacks give rise to high expectations for their applicabilities.

3.3.1 Stationary fuel cell systems

The current status of knowledge on fuel cells and the market needs indicate good competitive arguments for example in:

- Relatively small scale fuel cell systems in combined heat and power use. Small scale could range from micro-CHP (per house) to larger unit sizes; suitable for house blocks or offices, thus avoiding transmission losses and cost. Indicative values range from 1 kWe to 10 MWe. The application could also involve the need for cooling. This can be generated via absorption chillers while using the generated heat.
- Medium seized, simple cycle units (about 10 - 50 MWe) can be optimised for (mainly) power generation for on-site application. - Next generation technology will be the integrated fuel cell-gas turbine systems, which promise to have unprecedented ultra-high efficiencies of over 70 % LHV, even at rather small system sizes (from 6 MWe). Therefore these systems will strongly compete with current technologies in on-site power generation, up to about 50 MWe.
- In the long run, larger integrated systems; exceeding 100 MWe, are likely to be deployed. Extensive experience has to be obtained first to gain the required confidence and make the technology available for mass-production.

It is expected that economic efficiency of ultra-high efficient systems will become attractive, because the higher-efficiency reduces the fuel cost of the generated electricity. At the same time, fuel is being conserved. This has advantages concerning the rational use of the fossil fuels and, consequently, a reduction of CO2 production is obtained.
Furthermore, the high efficiency argument and fuel flexibility will become of major importance when high added value fuels, from renewable sources are introduced. Inversely, it will stimulate the use of renewable fuels.

3.3.2 Transportation applications

The market opportunities for fuel cell systems in transportation are based on the strong arguments concerning their high efficiency and environmental benefits. Governments also see other arguments; e.g. long term energy security.

It is generally accepted that the PEFC has good potential for traction applications. The low-temperature SOFC is also believed to have potential, possibly to be proved in a longer time-frame. Seemingly the PAFC and AFC became less favoured than previously expected.

Major break-throughs have recently been made with PEFC-based systems. Car manufacturers and stack producers in Europe, Japan and USA have started to promote their activities and form strategic alliances to be first in the business of fuel-cell driven busses and cars. Evidently, international competition promotes progression.

The opportunities in transportation are related to:
- Positive results of intensive technical- and economical feasibility studies obtained by potential market parties.
- The enormous volume of the automotive market. Even partial replacement of combustion based traction would generate major business opportunities for fuel cells.
- Relatively short term implementation. The learning curve appears to be steep. Current first demonstrations are promising. Present scenarios of car manufacturers aim at mass implementation as of the year 2003, starting via fleet-owners of busses and cars.

The competitiveness of fuel cells based, hybrid systems is higher rated than the combustion engine based version, because fuel cells offer higher efficiencies and better part-load performance, and are inherently cleaner than the combustion based systems.

3.4 Conclusions

Given the fundamental differences in combustion engines and fuel cells and the recent experimental results, it becomes clear that the technical performance of fuel cell systems can become superior to combustion engines. This is based on the efficiency, part-load performance and very low emissions.

For the development and demonstration of stationary transportation and applications, modularity is a major advantage ; the benefits of fuel cells can be demonstrated at small dimensions. This will generate a lot of experience at relative low financial risk.

The well-established, large-scale STAG units hold a strong technical and economic position. Large fuel cell based systems will become technically competitive. Once the integration with gas turbines is realised, the scale of these systems will gradually increase as experience is gained with system operation.

High-efficiency and fuel flexibility of fuel cell systems is expected to promote the introduction of renewable energy carriers.

The availability of cost-effective and durable stacks is seen as the major break-through to be made. Only then, can the technical expectations be translated into the expected energy and economic benefits.

4 MAJOR ACHIEVEMENTS

The Agreement has contributed to technology development through the provision of expert networks. This provided for instance conditions to:

- share R,D&D results,
- define measurement and monitoring techniques,
- exchange information on cell, stack and system performance,
- collaborate on the development of new procedures and models, and to
- share information on application requirements.

Through the task-sharing mechanism and by sharing resources, participants maximised the cost effectiveness. In this way the Agreement has contributed to national fuel cell programmes and, indirectly, to the further collaboration through bilateral projects and EC-sponsored research.

Examples from the current phase of the programme include the compilation of an inventory of MCFC stack and systems testing procedures (Annex V), the exchange of new information on in-situ monitoring of SOFC performance (Annex VII) and the collaborative development of an improved reformer model for the steam reforming of methanol (Annex VIII). Though it is difficult to compare the importance the achievements yet, Annex X’s extensive network of experts from academia, research institutes and the car industry is seen as a particularly important achievement.

The information exchange in expert groups is expected to lead to the achievement of significant technical objectives during the course of this year (1998). These include the development of standard test procedures for MCFC materials, cells and stacks, the identification of degradation mechanisms for SOFC and PEFC stacks under real operating conditions and the initial assessment of fuel cell systems against user requirements for stationary and transport applications. Furthermore detailed information has been and will be given in the Annual reports.
The IEA Advanced Fuel Cells Programme is regarded highly recognised by the international fuel cells research community and is increasingly recognised by potential users, as evidenced by the participation of car manufacturers in Annex X. There are no comparable international collaboration organisations in the field.

5 STRATEGY AND TARGETS

5.1 General

Participation in the IEA Advanced Fuel Cells Programme has been restricted to those countries with an active National Program of importance. This will remain a basic condition to participate; as the arguments of cost effectiveness and time are felt important to the current Participants.

Strengthening of the co-operation will be accomplished through activities which:

- Continue and expand the informational network,
- Perform market assessment and monitoring,
- Identify and lower barriers to implementation,
- Stimulate co-operative R&D activities which:
  * promote the development of technical and economically viable stacks and systems,
  * stimulate tools for, and knowledge of balance of plant(BOP) design options,
  * increase the value of demonstration programs by evaluating test data, and
  * contribute to feasibility studies of the deployment of fuel cell based and

technology.

5.2 Continue and expand the informational network

Internal management. Network formation was a major target and accomplishment of the Implementing Agreement so far. It lowered the barriers to co-operation and information exchange in fuel cell technology.

It is expected that an increasing part of the information will be of commercial importance. Thus, legal terms and practical guidelines have to be developed to deal with such information at the outset of new Tasks.

IEA-interactions. The interaction with related other IEA-Implementing Agreements; e.g., ‘Alternative Motor Fuels’, ‘Electric Vehicles’ and ‘Hydrogen, will be stimulated by establishing a regular mode of interaction.
External communication. It is felt important to increase the dissemination of information outside the IEA co-operation. The ways and means will be reviewed. A practical approach will be considered.

It is felt that fuel cell technology will become of increasing importance to developing countries. Therefore a more active dissemination program will be aimed at that target group. Information could for instance be condensed in a newsletter to be broadly distributed. Other options can be: open workshops, educational seminars, exchange of personnel etc. Furthermore, the use of the Internet will be considered.

5.3 Perform market assessment and monitoring

Energy structures and user requirements were important subjects in the previous terms of the Implementing Agreement. Demand side issues for fuel cells in stationary applications were studied in Annex V, and later IX. It appeared important to investigate differences between countries in terms of energy carriers, energy distribution, cost of electricity and user requirements. Conclusions could be drawn for the room of investment of fuel cell systems.

These are major considerations for any fuel cell system manufacturer.

The market can be assessed and monitored by combining:

- the survey of the technical and economical needs in a changing energy structure
- the evaluation of energy and fuel issues and their environmental impact,
- the estimates of the total market demand in terms of new and renewed power capacity, as a function of time;
- the assessment of status and progress of competitive technologies.

And, concerning fuel cell systems:

- the determination of the product/market combinations of fuel cell based systems; which will become competitive in both performance and price.

The strategy will therefore be to stimulate market assessment studies and active monitoring programs. This will include feasibility studies of the deployment of fuel cell based technology.

This kind of actions become of higher importance because of the increase in the number of Signatory Countries and the rapidly changing demand structures (e.g., caused by deregulation).

5.4 Identify and lower barriers to implementation

Specifically non-technical barriers and uncertainties may form barriers toward implementation. These have to be identified and actively approached; e.g., legal barriers. This includes regulations, norms and life cycle aspects. The public awareness about the new technology has to grow. The current positive developments and the approaching procurement of practical fuel cell systems emphasises the necessity of such actions.

5.5 Stimulate co-operative R&D activities

5.5.1. Development of technical and economically viable stacks

The heart of the technology is the availability of cost-effective, durable stacks.

Before mass production can reduce the price of the product, the design and materials will have to be well defined. Major efforts are made on different types of fuel cells to reach this goal. In the Implementing Agreement, co-operation on this topic, has been recognised as a key issue. This was reflected in the activities performed in Annex II, and later in Annexes: III, IV, VI, VII and VIII.

For the next five years, the promotion of developments to cost reduction, durability and reliability of stacks will remain main objectives. Development routes are being redefined because it has been recognised that the operating characteristics of the system determine the conditions in the stack. Once the materials and designs of stacks have been reasonably well defined, the key issue will become their manufacture in high volume.

5.5.2. Tools for, and knowledge of balance of plant (BOP) design options

5.5.2.1 Stationary applications

Annex I: "MCFC, Balance of Plant" turned out to be a good basis to initiate the co-operation. Lessons were learned and basic information was generated for BOP-designs to be applied in the demonstration programmes.

Small scale CHP and integrated fuel cell-gas turbine systems are expected to offer the best prospects for entering the energy market. Participating Countries should discuss how this could be promoted through the co-operation.

The motto in the next five years, 1999-2003 will thus be: 'Meeting the user requirements'. But, the answer to this is expected to differ strongly from country to country, since the technical and economical requirements differ strongly. Thus, it will be valuable to involve the local users of the technology at this point.

The availability of components appears to be a general problem. This could be assessed and a data base could be generated.

Since fuel flexibility is a main issue in the use of fossil and renewable fuels, fuel processing is of general importance. Developments on this subject will therefore be stimulated, in relation to requirements of the fuel cell stack.

5.5.2.2 Transportation applications

Given the commercial interests of Participants, care has to be taken to handle sensitive information. Conditions have to be acceptable for industrial participants. This aspect has been experienced extensively by the Participants in the Annex VIII: PEFC and the new Annex X: ‘Fuel cell systems for transportation’.

This is seen as a prerequisite condition to attract fuel cell industry and car-manufacturers from Japan, Europe and the USA in the co-operation. The ability to handle commercially important information will become a major issue in some future activities, as concluded in 5.1.

5.5.3 Evaluating test data of demonstration programs

Making available test data of demonstrations to be discussed and evaluated by experts will increase the shared experience for the benefit of all participants and future demonstrations. Furthermore, case-studies on failures will be very valuable towards to successful system design and handling.

The experiences with different systems could reported, for instance in fact sheets. The general information could be recorded on data sheets.

5.5.4 Feasibility studies of the deployment of fuel cell based technology.

It has to be considered if the scope of the Implementing Agreement will absorb alternative applications in fuel cell related technology e.g., oxygen generation, electrolysis, and chemical cogeneration.

5.6. Summary

Various issues of preceding paragraphs have been condensed in Table 3 to be of help in the discussions to define activities for future Annexes.

Table 3. Summary of issues derived from the strategic discussions.

IEA ADVANCED FUEL CELLS PROGRAMME
1999 - 2003

Information Management	**Implementation issues**	**Technology development**	
In- and external network	Reduction of barriers	Stationary and Mobile	
		Stacks	**Systems**
Co-ordination with IA's	Legal issues	Design	Infrastructure
Dissemination	Standards, regulations	Performance	Requirements
Public awareness	Environmental issues	Cost	Design
Education	Market assessment	Manufacture	Demo evaluation
Data sheets	Competition	Materials	BOP- Tools -availability - Data base
	Techno-econ. evaluation	Models	
	Life cycles	Standards	Fuel processing
	Spin-off issues		Power condition
			Safety analysis

6 EPILOGUE

As a matter of principle, the success of the Implementing Agreement depends on the degree of participation in the activities. It is the task of the Participating Countries to identify and promote strategic objectives which accord with their interests, and to find consensus with other interested Participants to initiate new activities.

It is furthermore important to evaluate the effectiveness of the management of the Implementing Agreement. This will include the processes, ways and means, and functions of the Executive Committee and Operating Agents.

A number of potential activities seem to need joint funding. Therefore, internal discussions are necessary to determine if the current task-sharing mechanism can be successful for all the activities of the next term.

APPENDIX 1:

GLOSSARY

BOP: balance of plant
Cell: basic unit consisting of the electrolyte and two electrodes
CHP: combined heat and power, or cogeneration
EV: electric vehicle
LHV: lower heating value
MCFC: Molten carbonate fuel cell
PEFC: Polymer electrolyte fuel cell
SOFC: Solid oxide fuel cell
Stack: combination of multiple cells and gas, electric and thermal provisions
STAG: steam and gas turbine combination