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The European Union approach to fuel cell development [1]

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Abstract

The European Union (EU) approach to fuel cell development should be viewed within the wider context of energy and environment policy. The energy policy is built on four main pillars — ensuring security of supply including the long term substitution of fossil fuels, improving competitiveness, achieving greater sustainability, and developing clean, efficient energy technologies. The prospect of fuel cells, as well as other technologies, to contribute positively to all these aspects of energy policy is widely recognised. Fuel cells can exploit diversified primary energy sources including renewable, and offer intrinsically clean, highly efficient energy conversion. Over successive Framework Programmes for Research, the European Commission has increased its financial support to fuel cell RTD & D. The recently launched Fifth Framework Programme introduces a problem-solving approach in which fuel cells will have to compete for funding support by demonstrating their ability to achieve ambitious cost and performance targets. © 2000 Elsevier Science S.A. All rights reserved.

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1. Background

Under the Kyoto protocol established by the UN Framework Convention on Climate Change, the EU has set a target for an 8% reduction in greenhouse gas emissions compared to 1990 levels, to be achieved by 2008–2012. Among measures to achieve this, the EU White Paper ''Energy for the Future'' calls for a doubling of the share of renewable energy sources, from around 6% to 12% by 2010. As the trend in external dependency is forecast to increase substantially over the next 20 years, long-term security of energy supply will be one of the main energy policy priorities for 1999, and the Commission will present a Communication outlining new policy initiatives.

Following a Council Resolution, the European Commission (EC) intends to introduce an Action Plan for Energy Efficiency in 1999, covering the period to 2002, corresponding to the SAVE II Programme — part of the Energy Framework Programme. SAVE II will be the principal coordinating arm of the Action Plan. The Commission's strategy on energy efficiency embodies a number of different approaches. These include, inter alia, introducing energy efficiency as part of other Community and Member State policies (e.g., regional, urban, taxation, research), and Community Initiatives for coordinated policies (e.g., energy labelling). The promotion of CHP, and developing less environmentally damaging energy alternatives for transport can be anticipated. Both are important applications areas for fuel cell technologies.

Fuel cells clearly address many of these political issues. However, they are still at a relatively early stage of development and it remains to be established the real contribution they can make, particularly in terms of their cost-effectiveness. Research and demonstration evidently has an important role to play in this context.

2. The European Union RTD & D strategy

The prospect of fuel cells has been recognised virtually since the inception of The European Union Framework Programme for Research. Some basic materials research of a generic nature was supported early in the Framework Programme. However, in the Second Framework Programme (1988–1992) (FP2), some 8 Meuro was allocated to fuel cell projects. Funding for fuel cell RTD quadrupled to 32 Meuro in the Third Framework Programme (1992–

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1995) and grew by a further 70% to 54 Meuro in the Fourth Framework Programme (1994–1998). It should be appreciated that these figures do not correspond to a specific a priori budget allocation to fuel cells. Budget allocation is the subject of political decision at a more aggregated Specific Programme level. Indeed, the research policy of the Framework Programme is to stimulate a ''bottom-up'' approach, rather than mandate specific technologies, enabling greater opportunities for innovation.

This approach is further reinforced in the Fifth Framework Programme, adopted at the end of 1998, which emphasises the need for research to respond to important economic, social and environmental challenges. This ''problem solving'' approach, where possible and appropriate, establishes quantified cost and performance targets, not necessarily related to specific technologies, which reflect the aims of EU policies. This provides freedom for research consortia to come forward with proposals for developing innovative technologies that have credibility to achieve these goals.

The importance of fuel cells to contribute to clean and efficient energy production was central to DG XII (formerly the Directorate General for Science, Research and Development and now the Research Directorate General) and DG XVII (Directorate General for Energy) jointly initiating a dialogue with concerned stakeholders to develop a strategy for fuel cell technology acquisition in 1995. The strategy document was revised in 1998, following a broad-based consultation of stakeholders, including representatives from industry, universities, R&D centres, national energy agencies and relevant European Federations. It was intended to ensure coherence between the R&D and Demonstration activities managed by the European Commission and national programmes and to help in the definition of technical priorities for calls for proposals.

The strategy covers both high and low temperature fuel cell technologies, and identifies research and demonstration priorities, as well as cost and performance targets. The strategy foresees that initially, fuel cell applications are likely to be in a range from 10 kW to 5 MW and will have to compete with present technology, including gas and steam turbines in simple or combined cycle operation, stationary diesel engines, as well as gasoline and diesel engines for ship, road and rail propulsion. To a large extent, the cost and performance targets reflect future anticipated developments for competing technologies, so that for mobile fuel cells, for example, the challenge is to be competitive with the internal combustion engine, and, specifically, future diesel hybrid propulsion.

The main issues for fuel cells are cost reduction and, for some fuel cell types, performance improvement. These two issues are closely linked. Stack lifetime and power density influence stack replacement costs and maintenance requirements, while electrical efficiency and plant availability influence the likely payback time for a given capital cost. A fuel cell developer may not wish to optimise the electrical efficiency of the system if this drives up other costs. If fuel cells are to become commercial, big efforts also have to be made on simplification, optimisation and integration of the Balance of Plant (BOP).

Market and institutional barriers, such as reluctance to invest in new technologies and lack of awareness of the technology, will become increasingly important once the feasibility of fuel cells has been demonstrated and they move to the commercialisation phase. Prospective customers must be convinced of the benefits to their businesses before a market for fuel cell systems will emerge. This is a difficult phase in the commercialisation of any new technology, for economies of volume production cannot be achieved until demand is sufficiently high, and demand in turn depends on cost reductions achievable through volume production.

Temporary measures such as fiscal incentives are helpful to kick-start the process, though these will normally depend on a complex interplay of EU, national and local level policies. For example, a significant driver for implementing fuel cell vehicles might be the achievement of the European voluntary target for fleet average CO_2 emissions of 120 g/km by 2010, while at the same time meeting the EURO IV (2005) thresholds for pollutant emissions, or more stringent pollutant emissions thresholds that could subsequently emerge. While at aggregate EU level, air quality targets may be achievable through a combination of fleet replacement and further development of conventional technologies and cleaner fuels, local pollution hotspots may require special local measures, including new technologies such as battery, hybrid or fuel cells.

The need to achieve performance improvements and cost reductions, and to demonstrate operational feasibility, durability and maintainability and to assess future economic viability, requires a coherent and consistent RTD and Demonstration effort. The EU fuel cell strategy addresses the technical priorities and indicative level of funding that would be required for RTD and Demonstration phases until 2005, to make a significant impact on fuel cell commercialisation. The main elements of the EU fuel cell strategy developed in 1995 are: (a) to focus on R&D and Demonstration of low temperature fuel cells (Solid Polymer Fuel Cells — SPFC, and Direct Methanol fuel Cells — DMFC) which have the capability for low cost per kW. SPFCs are expected to find applications in co-generation in buildings, and both SPFCs and DMFCs in transport in the medium term — though the latter finally depends to a large extent on the fuel of choice for transport; (b) to assess the feasibility of fuel cell networks consisting of a centralised hydrogen reformer supplying hydrogen for both vehicle fuelling stations and decentralised fuel cell systems at domestic or industrial level; (c) to maintain R&D efforts on presently expensive high temperature fuel cells which offer opportunities for industrial co-generation and large scale electricity production in the longer term; and (d) to limit the size of fuel cell stacks and stand-alone systems to around 200–300 kW with reasonable costs for a 40.000 h operation. At this scale, conventional gas turbines have low efficiencies and are very expensive, while diesel engines cause pollutant emissions 3-4 orders of magnitude higher than those of fuel cells.

Following the stakeholders' meeting in May 1997, the main recommendations to up-date the strategy are the following:

- a targeted dissemination programme is needed to promote awareness of the benefits of fuel cell technologies;
- a greater focus should be given to R&D and Demonstration programmes with applications-driven technology, cost and performances targets;
- focus should be given to stand-alone systems not networks;
- there are opportunities for SPFC bus fleet demonstration;
- the fuel processing options for transport should be comprehensively evaluated;
- support should be envisaged for combined high temperature fuel cell and gas turbine technology.

These recommendations were taken into consideration in the preparation of the work programmes for the Fifth Framework Programme. Its emphasis on problem solving against specified targets, provides appropriate enabling opportunities to implement the fuel cell strategy.

3. Overview of RTD&D in the EU Fourth Framework Programme (1994–1998)

Although the definition of the work programme for the Fourth Framework Programme predated the EU Fuel Cell Strategy, the scope of projects funded is in line with the strategy. Fuel cell RTD and demonstration is largely supported under the Non-nuclear Energy Programme — otherwise known as JOULE-THERMIE. Some basic materials and process related research is also supported under the BRITE-EURAM Programme. The overall EU support to fuel cell and related RTD&D in the Fourth Framework Programme is some 54 Meuro, with approximately 41.3 Meuro allocated to 23 JOULE contracts, and 10.4 Meuro allocated to 12 THERMIE demonstration projects, including three accompanying measures. Table 1 gives an overview of the funding distribution to the various fuel cell technologies.

The support in the Fourth Framework Programme for RTD&D covers the range of fuel cell technologies, both at individual component and system level. EU support is on a shared-cost basis — normally 50% of full costs for RTD projects and 35% for demonstration. Projects require participation from at least two EU member or associated states.

It can be seen from Table 1 that the larger part of the funds in the Fourth Framework Programme — some 30.3 Meuro over four years (around 55%) — was allocated to SPFC and related fuel processing technologies and DMFC development. This covers research effort on materials, stack components, fuel processors, system integration, through to prototype technology demonstrators.

Component level RTD projects supported by JOULE III include a Siemens led project, which focuses on reducing PEM stack costs by cheaper materials/production process. A second, led by CLC is developing SPFCs with higher temperature materials. Together, these benefit from EU support of some 4.0 Meuro. Three further projects concerning DMFC development, coordinated by Siemens, Ciemat and SRTI System respectively, receive EU funding of 7.2 Meuro. Effort on fuel processing presently concentrates on methanol reforming, with support of 4.4 Meuro. One project led by Wellman CJB is developing an inte-

Table 1
Fourth Framework Programme 1994–1998: total costs and EU funding allocations by fuel cell type (M€)

Fuel cell type	NNE-JOULE (RTD)		NNE-THERMIE (Demonstration)		Grand totals	
	Total costs	EU support	Total costs	EU support	Total costs	EU support
SPFC (Stationary)	7.668	4.056	11.941	3.339	19.609	7.395
SPFC (transport, includes fuel processing)	25.812	13.588	8.750	3.500	34.562	17.088
Totals SPFC	33.480	17.644	20.691	6.839	54.171	24.483
DMFC	13.490	7.221	–	–	13.490	7.221
SOFC	17.616	8.958	–	–	17.616	8.958
FC Network	1.385	0.756	–	–	1.385	0.756
MCFC	15.881	6.300	6.350	2.266	22.231	8.566
PAFC	–	–	8.820	0.976	8.820	0.976
Accompanying Measures	0.155	0.112	0.388	0.279	0.543	0.391
Concerted Actions (High temp. FCs)	0.305	0.300	–	–	0.305	0.300
Totals	82.312	41.291	36.249	10.360	118.561	51.651

grated reformer and gas clean-up system. A second, co-ordinated by Haldar Topsoe is concerned with the design and development of a compact 25 kW methanol reformer. Thirdly, work on cost-competitive processes for membrane separation (for gas clean-up) is being led by ECN. The THERMIE programme also supports three SPFC stationary demonstration projects, including a 250 kWe/237 kWth PEM CHP based system in Berlin, and a PEM generator fuelled by waste H_2 at an industrial site of Air Liquide (total funding 3.3 Meuro).

Three JOULE III projects concern fuel cell vehicles development. PSA leads the HYDRO-GEN project — the development of a small monospace vehicle with a De Nora fuel cell, fuelled by compressed hydrogen, aiming at 300 km range. The project also includes some stack/membrane development effort. Volkswagen coordinates the CAPRI project — a fuel-cell/battery hybrid based on a Golf chassis. CAPRI incorporates a Ballard stack and is fuelled by reformed methanol. The autothermal reformer and gas clean-up are developed by Johnson–Matthey, with ECN mainly responsible for the systems integration and Volvo the air compressor. The project FCBUS, now led by Air Liquide, should deliver a compressed hydrogen fuelled De Nora fuel cell/battery hybrid bus based on a Scania platform with ZF transmission. The THERMIE demonstration programme supports two fuel cell vehicle demonstration projects — one an LH_2 fuelled M.A.N. 12 m bus to be demonstrated in Berlin, Copenhagen and Lisbon, the other, the development of a multi-purpose fuel cell driven vehicle platform, led by CNIM of France. In total, the EU support to these vehicle projects amounts to 11.4 Meuro — against estimated project total costs of 24.4 Meuro.

The JOULE programme also funds the ''European Integrated Hydrogen Project'', led by the German organisation LBST. This is pre-normative RTD, establishing the basis for a regulation for hydrogen fuelled vehicles and investigating certain safety aspects both on the vehicle and for stationary infrastructure — essential elements for the large scale implementation of fuel cell vehicles fuelled by hydrogen.

Approximately the same level of support was allocated to RTD&D for SOFC (9.0 Meuro, or 17% of the FC budget) and MCFC technologies (8.6 Meuro, or 16%). JOULE support for SOFC and MCFC is aimed at improving durability and reducing costs, with projects in this area coordinated by RISO, ECN, and Ansaldo Ricerche, respectively. System scale-up is also addressed, and JOULE supports projects with 10 kW and 100 kW MCFC with internal and external reforming respectively. Emphasis is also given to projects dealing with prototype and systems development and Balance of Plant (BoP).

The THERMIE demonstration effort is mainly directed at proving feasibility and economic potential of MCFC and SPFC (see above) with two small demonstration projects for PAFC. The MCFC projects are mainly concerned with the demonstration of MCFC co-generation plants from 90 to 300 kWe, focusing especially on the optimisation and integration of the BoP.

4. The Fifth Framework Programme

The Fifth Framework Programme was adopted in December 1998, with a total budget of 15 Beuro for the period 1998–2002. The Fifth Framework Programme has four thematic programmes. Of these, two provide funding opportunities for fuel cell and related RTD&D. The ENERGIE part of the *Energy, Environment and Sustainable Development* programme is the logical successor to the Non-nuclear Energy (JOULE-THERMIE) programme and the *Promoting Competitive and Sustainable Growth* programme in part succeeds BRITE-EURAM. The thematic programmes each comprise a number of Key Actions that identify important industrial, social, economic and environmental problems which would benefit from advancing technology. The work programmes for the Key Actions are written in quite general terms, the emphasis being to define performance specifications rather than specific priorities for specific technologies, as was the practice for the Fourth Framework Programme. The Key Actions of greatest relevance to fuel cell RTD are to be found in the Energy Environment and Sustainable Development Programme. These are Key Action 5: *Cleaner Energy Systems Including Renewable Energies* and Key Action 6: *Economic and Efficient Energy for a Competitive Europe*. As with the Fourth Framework Programme, there is no specific budget allocation to fuel cells. Proposals for fuel cell RTD&D are therefore subject to competitive evaluation with other technologies which have prospects to achieve the overall programme goals relating to improving energy efficiency and achieving greater penetration of renewable energy systems. Nevertheless, in line with the fuel cell strategy paper, the priorities which proposals will need to address include:

- Active materials development, materials processing and stack component development aiming at improved performance durability, efficiency and reduced costs;
- Fuel reforming and gas clean-up;
- Hydrogen storage systems development
- Auxiliary components optimisation, system integration, packaging and system safety;

In addition, supporting activities are required to underpin fuel cell implementation and commercialisation:

- Pre-normative research to enable harmonisation of regulation and certification;
- Research on social, institutional and legal factors affecting FC deployment;
- Benchmarking by bench and field testing, demonstration;

- Standardised evaluation procedures and impact assessment, including Life Cycle Energy and Emissions Analysis;
- Safety testing and risk assessment;
- Develop education and training infrastructure;

Information on the Fifth Framework Programme can be obtained on the website: http://www.cordis.lu/fp5/home.html

5. Conclusion

In the medium term, fuel cells look set to deliver real energy savings and emissions benefits in line with EU policy. The EU will, therefore, continue to support applications-driven RTD&D of high and low temperature fuel cell technologies in its Fifth Framework Programme, aimed at improving functionality and demonstrating cost-effective implementation. A further aim is to stimulate greater information flow through support of Thematic Networks and Concerted Actions, and, recognising the emerging global energy market, stimulate co-operation with non-EU countries. Science and technology cooperation agreements are now in place with several countries, including Canada and the USA. These links should be developed especially in the context of pre-normative issues, for example, test procedures, standardisation including for safety-critical components, to help reduce some of the barriers to commercial implementation. It will also be important to develop human capital and resource throughout the whole fuel cell supply and support chain to bring the technology demonstrators to a level of commercial viability.