Development of Hydrogen and Fuel Cells within German, European and International Networks

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ABSTRACT:

The hydrogen and fuel cell technology is of vital importance to the future energy supply in Germany and worldwide. But high costs and inadequate performance and durability currently prevent the general market entry of the technology. To overcome the barriers German companies and institutes are very active in the field of research and development as well as demonstration and early markets where fuel cell applications can already today compete with conventional technology. The strong commitment of the private sector is accompanied by the prominent German programmes for hydrogen and fuel cells which translates into considerable budgets at federal and regional level. The Federal Government recently announced additional funding of 500 million € for the following ten years, i.e. a doubling of the present efforts. In addition, the German Strategy Council Hydrogen and Fuel Cells was established in 2005. But to reach the goal of the hydrogen economy efficiently and without duplication of work a common European and international approach is needed to complement the national activities. Therefore, German stakeholders actively participate in the European Hydrogen and Fuel Cell Technology Platform (HFP), the International Partnership for the Hydrogen Economy (IPHE), and the activities of the International Energy Agency (IEA). The National Coordination Office Juelich (NKJ) supports the national activities and connects them with European and international initiatives.

KEYWORDS: Germany, fuel cell and hydrogen R&D and demonstration, early markets, European and international cooperation

1. Opportunities and Perspectives of Hydrogen and Fuel Cells

According to energy experts from all over the world, the fuel cell and hydrogen energy technology plays a central role in Germany's and the world's future energy supply. This is particularly true for a deployment in the transport sector which is marked by an extreme dependency on oil (98 % in Germany). However, hydrogen and fuel cells are also promising alternatives in the areas of stationary (decentralised) energy supply and portable applications.

Energy policy aims at the preservation of a cost-effective, secure, environment- and climate friendly as well as socially acceptable energy supply. Economic policy strives at the integration of the comprehensive know-how into new technology fields to guarantee a positive economic development.

The key arguments for the hydrogen and fuel cell technology are:

- Hydrogen can be produced from various primary and secondary energy carriers and can thus contribute to the diversification of energy carriers (motivation: ease dependence on oil).
- Fuel cells are highly efficient in all areas of performance, operation and application (conservation of resources, decrease in costs).
- Zero-emissions at point of hydrogen usage (bundling and thus less complicated handling of emissions at the hydrogen production site in case of fossil energy sources).
- A cost-effective deployment of hydrogen and fuel cell technologies is foreseeable (portable applications by 2010, stationary applications by 2010-15, mobile applications by 2020) and already implemented in early markets.
The ongoing activities in the area of hydrogen and fuel cell technologies are marked by two key priorities. On the one hand, the technology with its current development and cost status is to be introduced in early market segments. Industry organisations involved would thus be enabled to benefit from the revenues and to fund future developments. Furthermore the deployment and testing of the present state of development would reveal insights into the suitability for daily use and potential deficiencies in the development. On the other hand, new well-coordinated government funded research programmes responding to the experiences gained in the markets need to be drawn up. With the hydrogen and fuel cell technologies having reached a high technical and scientific state of development already innovative leaps forward could thus be made to satisfy the requirements of the mass markets, such as the automotive or the energy industry in the medium-term. Apart from lower costs key objectives in this context are enhanced durability and reliability and the optimisation of hydrogen storage in automotive applications in order to come to higher ranges.

2. Germany’s Activities in This Area

German activities in the area of hydrogen and fuel cells reach far back to the beginnings of energy research programmes in the Federal Republic of Germany. Since 1974, specific R&D programmes have been financially supported in Germany. When examining the historical development of government funding for hydrogen on the one hand and fuel cells on the other hand it becomes clear that until 1995 the focus was on hydrogen technologies. The 1995 evaluation of the results of the R&D programmes showed that although the hydrogen technology was available and largely operative it was not economically feasible. The hydrogen economy was still expected to be in the far future. Since, public funding has mainly been concentrating on fuel cell technologies. That does not mean, however, that no research in hydrogen technologies is done in Germany. Apart from direct project support government allocates quite considerable financial means to the national research centres (in particular Research Centres Juelich and Karlsruhe as well as the German Aerospace Centre) that are joined together in the Helmholtz Association (HGF). These research institutes carry out works on fuel cells as well as hydrogen.

Germany is a federal republic and thus large parts of the R&D and demonstration projects are supported by the Federal States. In this respect, the active networks in the Federal States of North Rhine-Westphalia, Baden-Wuerttemberg and Bavaria are particularly worth mentioning. They integrate partners from industry and science and initiate research, development, demonstration and market implementation projects in the area of hydrogen and fuel cell technologies. Hamburg, Lower Saxony and Hesse as well as most of the other states have founded similar initiatives and have initiated hydrogen and fuel cell activities partly funded by the respective states.

The rationale for the Federal States’ activities can primarily be found in economic and industrial reasons: The objective is to sensitise the companies based in the respective Federal States for the hydrogen and fuel cell market and thus to enable them to benefit from the future creation of value. Moreover, the Federal States aim to improve their conditions for industry and to safeguard employment.

Thanks to the positive R&D results in the past years market implementation is increasingly being discussed and even tackled practically. This is happening at a regional and national level and is interlinked with European and international approaches. The following examples are to illustrate the regional and national efforts:

- In 2001, the Federal Ministry of Economics and Labour launched the Investing - into - the - Future Programme (ZIP) in order to promote the preparation of the market implementation of hydrogen and fuel cell technologies. The ZIP programme results endorse that in spite of successful demonstration projects major efforts are still necessary to manufacture and run the systems in a competitive, i.e. cost-efficient, reliable and customer friendly way. German manufacturers and future operators of fuel cell systems usually assume 50 % of their projects’ total costs. Research institutes and universities are involved into the ZIP projects. Education, training and standardisation are elements playing an important role for market implementation. They are considered in the ZIP programme, too. The total budget of 55 million € was allocated as follows:
The project “Clean Energy Partnership” is a demonstration project in Berlin with two public filling stations for liquid and gaseous hydrogen. The second filling station was opened recently, in March 2006. About 20 vehicles, cars and busses, running on fuel cells and combustion engines, are being operated for five years (since November 2004). Total budget of the project is 33 million €, 5 million € are funded by the three Federal Ministries of Transportation, Economics and Environment. The remaining funds are assumed by the companies involved, i.e. Aral, BMW Group, Berliner Verkehrsbetriebe (BVG), Daimler Chrysler, Ford, GM/Opel, Hydro, Linde, TOTAL and Vattenfall Europe [1].

North Rhine-Westphalia: One of the key objectives of North Rhine-Westphalia’s activities related to hydrogen and fuel cell technologies is the launch of the fuel cell in early market segments to serve as a bridge to mass markets. Against this background various applications have been or are being developed in North Rhine-Westphalia that can already be implemented in the market today thanks to technical advantages, such as a longer operating time and shorter refuelling (or charging) times. Some examples of this development are a fuel cell midibus, a cargo bike, forklifts, mobile fuelling solutions, UPS (uninterruptable power supply) applications, for example for telecommunication, APU (auxiliary power supply) applications etc. Moreover, preparations for the necessary hydrogen infrastructure (filling technique and cartouches with 700-bar technique) are underway. The first two above-mentioned vehicles as well as the hydrogen infrastructure are also deployed within the EU project HYCHAIN-MINITRANS that will make use of around 180 small vehicles running on hydrogen in four European regions (apart from Germany, France, Spain and Italy are involved). Parts of the applications mentioned will also be demonstrated around North Rhine-Westphalia’s football stadiums in the context of the FIFA World Cup 2006 [2].
Public funding in Germany

Total public funding for fuel cell and hydrogen technologies in Germany amounts to 65 to 75 million € per year. Out of this budget, 30 to 35 million € per year are borne by the Federal Ministries with the Federal Ministry of Economics and Technology assuming the lion’s share at the moment. The Federal States support fuel cells and hydrogen with about 18 to 22 million € per year with North Rhine-Westphalia, Baden-Wuerttemberg and Bavaria being the most important funding sources at Federal State level. Other public support institutions allocate 2 to 3 million € per year. Together, the Federal Government (90 %) and the Federal States (10 %) bear the above-mentioned institutional funding for the national research centres that amounts to 15 million € per year.

Figure 4 illustrates the breakdown of the public funding according to thematic areas of the ongoing projects. It becomes clear that:

- Fuel cell technologies clearly receive more financial support than hydrogen technologies.
- Among the different fuel cell types the largest share of the funds is allocated to PEMFCs.
- Among the different applications the stationary use of fuel cells receives a larger share than mobile applications. However, industrial R&D for mobile applications is considerably higher than public funding.
- The lowest share is allocated to portable applications. However, a new programme for micro fuel cells launched in early 2006 by the Ministry of Education and Research that will provide funds of 20 million € over the next four years has not been incorporated in figure 4.

Figure 4: Breakdown of the public funding according to thematic areas of the ongoing projects
In addition to the existing public funding the German Federal Government recently announced to allocate a further 500 million € for the field of hydrogen and fuel cells over the following decade. This so-called “Innovation Programme Hydrogen and Fuel Cell Technologies” is part of the “High-Tech Strategy Germany” and is to contribute to the maintenance and expansion of Germany’s good starting position for the development and the market implementation of the hydrogen and fuel cell technology. The concrete schedule for the allocation and the thematic breakdown of these funds is currently being discussed among the units in charge. Over and above that, the Strategy Council Hydrogen and Fuel Cells has been instructed to set up a roadmap by the end of 2006 pointing out thematic priorities and the respective funding needs. One focus of the funding allocation is expected to be on demonstration projects. Over the total 10-year period these additional funds announced nearly add up to a doubling of the Federal Government’s current financial support.

Like in previous programmes the additional public funding for projects is expected to be at least redoubled by private companies’ investments so that hydrogen and fuel cell technologies will benefit from an additional 1 billion € over the next ten years.

In general, private companies provide considerable funds exceeding the public allocations by far to contribute to the developments that are prerequisites for a hydrogen economy and for the application of fuel cells. Famous companies acting at the regional up to the international level are BMW, DaimlerChrysler, Opel/GM, Linde, Air Liquide, MTU CFC Solutions, RWE, EON, Umicore, 3M, Vaillant and Viessmann amongst others.

5th Energy Research Programme

At present, government R&D project support is based on the 5th Energy Research Programme that was adopted in mid-2005 under the motto “Innovations and New Energy Technologies” [3]. Fuel cells and hydrogen form an important part of this programme. In order to reach market implementation the above-mentioned cost reductions and optimisations regarding performance and durability are needed. They can be achieved through R&D efforts and the production of a larger number of units. In general, the following cost targets apply:

- portable fuel cell 1,500 to 2,500 €/kW,
- stationary fuel cell 1,000 to 1,500 €/kW,
- mobile fuel cell 50-150 €/kW.

The Federal Government has concentrated its R&D support for fuel cells on those technological fields and areas of application in which a quick market implementation seems most likely from today’s perspective:

- the molten carbonate fuel cell (MCFC) and the solid oxide fuel cell (SOFC) in the high temperature area and
- the polymer electrolyte membrane fuel cell (PEMFC) and – as a variant of the PEMFC - the direct methanol fuel cell (DMFC) in the low temperature area.

Over and above that, there are cross-cutting R&D issues concerning fuel processing (desulphurisation, purification, reforming etc.), the preparation of the development of a fuel infrastructure, particularly for mobile and portable applications, modelling, inverter technologies, recycling concepts and the evaluation of demonstration measures, developments for the drawing-up of codes and standards as well as preparatory measures for education and training. The involvement of SMEs is generally regarded as a very important issue, too.

At present, hydrogen is produced through the reforming of natural gas, large-scale electrolysis or as a by-product in chemical industry. At the long term the production from renewable energy carriers is the favoured option. On the way there, hydrogen could be generated from natural gas and coal with carbon capture and storage being applied at the same time. The 5th Energy Research Programme supports related research efforts in the section of power plant technology.

At the long term hydrogen will only manage to assert itself as a secondary energy carrier that is really taken seriously if the costs for renewables can be substantially reduced. Germany’s related R&D measures are considerable, but will not be described here in detail. Technologies for electrolytic hydrogen production are
available and can be improved through detail advancements in case of new findings in materials and basic research.

Apart from the question of CO$_2$ free production of hydrogen there is still no satisfying solution to the problem of hydrogen storage, particularly concerning transport applications. The following technologies are being applied or discussed amongst others:

- Pressurised tanks and metal hydrides for the storage of gaseous hydrogen are state of the art, but they are still being further developed (e.g. doubling the pressure from 350 to 700 bar).
- Storage systems for liquid hydrogen have already been developed and are being deployed. For this reason, only detail advancements can be expected.
- The high expectations concerning the economically interesting storage capacity in carbon structures have not been confirmed so far.

At present, there do not seem to be new technological approaches for cost-efficient hydrogen storage. Nevertheless, provisions making quick reactions to promising basic and materials research findings possible are made within the programme. In 2004, a panel of experts analysed the R&D needs for hydrogen technologies and gave an account of the findings [4].

**Strategy Council Hydrogen and Fuel Cells**

The Strategy Council Hydrogen and Fuel Cells is a body of government, industry and academia representatives. It was founded in 2005 when the previously independent bodies for hydrogen and fuel cells joined together in the face of their large intersections. The Strategy Council assumes the following tasks in the field of hydrogen and fuel cells [5]:

- integration of individual strategies in order to come to a National Hydrogen and Fuel Cell Roadmap (until end of 2006)
- balancing of interests and consensus building
- trustful exchange of information among the government, industry and research community
- solving specific tasks by the set-up of temporary working groups
- dissemination of the results in national, European and international bodies as well as in the general public

The Strategy Council is led by a **Coordination Group** (around 15 members) who is in charge of the preparation of the Strategy Council events and the work to be accomplished in between the meetings of the Plenary Assembly. It is composed of (Federal) Government, industry and academia representatives. The Federal States or their initiatives and the industry alliances are represented by the Fuel Cell Alliance Germany (Brennstoffzellen-Bündnis Deutschland BZB) [6] in the Coordination Group. The speakers of the Coordination Group are Prof W. Tillmetz (Centre for Solar Energy and Hydrogen Research ZSW), Prof J. Garche (Weiterbildungszentrum Ulm WBZU) and Dr Klaus Bonhoff (Daimler Chrysler). The Federal Government is represented by the three Ministries of Economics, Transportation and Research. The Coordination Group roughly meets every other month.

Furthermore, the Strategy Council has a **Plenary Assembly** composed of around 100 experts from all areas of hydrogen and fuel cell technologies. Representatives from the Federal States or Initiatives and of the alliances are also members of the Plenary Assembly. The Plenary Assembly sits once a year and is open to new members.

Over and above that, specific and temporary **Working Groups** are built within the Strategy Council. Their members are recruited from the experts in the Plenary Assembly and they report on the state of their work. The following Working Groups are currently in place:

- Education and Training of the public,
- Reformation,
- PEFC,
- Membranes.
The Strategy Council's secretariat functions are assumed by the National Coordination Office Juelich for Hydrogen and Fuel Cells (NKJ) [7].

The NKJ that is a part of Project Management Juelich (PJU) was launched in September 2004. It is currently being funded by the Federal Ministry of Economics and Technology (BMWi) and the Ministry of Economic Affairs and Energy of the State of North Rhine-Westphalia (MWME NRW).

In addition to the support of the Strategy Council the NKJ assumes further information and coordination tasks. The main aims are the linkage of national activities with the regional networks and over and above that the optimisation of the national integration into European and international activities. The NKJ offers the following services:

- focussed information on national, European and international initiatives promoting fuel cells and hydrogen,
- up-to-date overview of all hydrogen and fuel cell projects with German collaboration,
- up-to-date links to the hydrogen and fuel cell initiatives in Germany’s Federal States,
- newsletter on ongoing national, European and international R&D collaboration,
- qualified contact persons for questions concerning government research funding in the field of hydrogen and fuel cells based on the Federal Government’s 5th Energy Research Programme.

3. Activities at European Level

Hydrogen and fuel cell R&D has been supported through the European R&D Framework Programmes for years and it has substantially strengthened inner-European cooperation. In Framework Programme 6 (2002-2006) the European Commission (EC) spends about 275 Mio € on hydrogen and fuel cells, i.e. around 65 Mio € per year. German industry and research institutions are coordinating and participating in many of the EC-funded projects. Within Framework Programme 7 (2007-2013) that is being prepared at the moment energy will be one of the nine thematic areas in the field of “collaborative research” and hydrogen and fuel cells will be one of the eight priorities in the thematic area “energy”.

European Hydrogen and Fuel Cell Technology Platform (HFP)

In 2003, the EC launched the European Hydrogen and Fuel Cell Technology Platform (HFP) [8] to accelerate the development and the implementation of marketable systems and components for mobile, stationary and portable applications. Within the HFP industry, research and government representatives collaborate to develop and successively implement appropriate strategies. Germany strongly participates in the HFP panels and working groups at all levels. It is represented in the Advisory Council, the HFP’s steering committee, and in the Mirror Group, the committee for the national and partly also for the regional government representatives. Moreover, German representatives acted as leading members in the Steering Panels “Strategic Research Agenda” and “Deployment Strategy” that have set up separate strategy papers and one common summarising document (“Strategic Overview”) for Europe [9, 10, 11].

Germany is also strongly represented in the Implementation Panel serving as a succeeding committee of the Steering Panels and working out an Implementation Plan by October 2006. This Implementation Plan is to provide recommendations on concrete, realisable and verifiable activities including the mechanisms and financial instruments to be applied. It will not focus on the EU programmes alone (in particular Framework Programme 7), but will rather also give recommendations as to potential activities at Member State and regional levels.

A new instrument is being discussed for the implementation of the European hydrogen and fuel cell strategy, in particular in European Lighthouse Projects: the Joint Technology Initiative (JTI) – an industry-oriented commercial company. The JTI will be integrated in Framework Programme 7. Questions regarding the legal form of the company, the potential involvement of Member States, regions, SME and research institutes, the selection procedure of the supported projects and the funding have not been answered yet. By the end of 2006, the preparatory discussions regarding the JTI – as well as Framework Programme 7 – are expected to be concluded.
**ERA-NET HY-CO**

In addition to that, specified R&D topics shall be implemented in the medium-term through project support in the context of joint, coordinated national programmes. Regarding the thematic area hydrogen and fuel cells, this is currently being prepared by the ERA-NET “HY-CO” funded by the EC. ERA-NET projects (“European Research Area”) have been set up in different fields. In general they aim at the harmonisation of national programmes to facilitate joint activities.

At present, the ERA-NET HY-CO that is coordinated by Project Management Juelich comprises 21 partners from 18 countries and regions [12]. The network consists of institutions that are in charge of the management of the national hydrogen and fuel cell R&D programmes, i.e. of representatives from the ministries of energy, economy or research and their agencies. Since these representatives are in close contact with the industrial and scientific representatives carrying out the research projects in the individual countries a network of the regional and national groups is set up that constitutes a valuable element in the “European Research Area”. HY-CO thus also serves as an interface to integrate the Member States’ positions into the work of the Implementation Panel of the HFP.

The National Coordination Office Juelich (NKJ) is striving to be a nodal point in this network and to connect German aspects with European, and beyond that with international hydrogen and fuel cell initiatives.

4. Activities at International Level

**International Partnership for the Hydrogen Economy (IPHE)**

In addition to the set-up of the technology platform HFP at the European level, the International Partnership for the Hydrogen Economy (IPHE) was founded in 2003 on the initiative of the US [13]. The IPHE aims at an effective and efficient introduction of the hydrogen and fuel cell technology thanks to international collaboration in research, development and demonstration and based on political coordination. The IPHE is divided into a political and a technical committee and its secretariat resides in the US Department of Energy. Germany and Iceland share the chair of the technical committee (Implementation and Liaison Committee ILC). One core objective is the integration of industry and science representatives – often called stakeholders – into IPHE activities. Australia, Brazil, Canada, China, France, Germany, Iceland, India, Italy, Japan, the Republic of Korea, New Zealand, Norway, the Russian Federation, the United Kingdom, the United States, and the European Commission are IPHE member states.

At the moment the activities focus on the identification of possible collaborative actions within the IPHE. In early June a workshop is therefore being held in the context of the WHEC 2006 at Lyon to develop issues that could be dealt with in collaborative projects, (new) working groups and conferences. This will be based on the results of the former IPHE working groups that have identified the general R&D needs regarding hydrogen and fuel cells in their so-called Scoping Papers.

At the moment the following international working groups and task forces are active: Project Evaluation & Monitoring, Codes & Standards, Education, Demonstration & Infrastructure. At all IPHE meetings additional groups can be established if needed or existing groups can be dissolved after accomplishing their tasks. Ten projects have been recognised as IPHE Projects so far. Proposals for new projects can permanently be submitted to the IPHE secretariat through the national ILC delegates (in Germany this is coordinated by the NKJ). At present, 17 new project proposals have been submitted that are being evaluated by the Project Evaluation Team and will then accordingly be suggested for approval as IPHE projects. The final decision is always made by the Steering Committee at its autumn meeting. Amongst others, the EC has proposed the above-mentioned project HYCHAIN-MINITRANS. One of the prerequisites for approval by the IPHE is that two or more IPHE member states are collaborating and that the project resources are clearly identified and financial sources granted. Recognition as an IPHE project offers advantages in terms of improved international reputation, potential recruiting of new partners for research and development and additional applicants in demonstration projects.

**International Energy Agency (IEA)**

In addition to the integration of German participants from science, industry and politics into IPHE activities, the International Energy Agency (IEA) is an institution that has set up networks for technological cooperation [14]. Over the past years it has kept these networks going and has even extended them. Active cooperation projects concerning relevant issues – called IEA Implementing Agreements - have been running for years.
Germany actively participates in the project “Advanced Fuel Cells” and is currently preparing to join the “Hydrogen Implementing Agreement” (HIA).

NKJ is involved in IPHE as well as in IEA activities related to hydrogen and fuel cells and it contributes to the preparation and transfer of information to interested institutions. Information channels on international activities are thus opened up to the German hydrogen and fuel cell network that is thereby offered the chance to actively participate in international cooperation.

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