NOW
Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie

Hydrogen and fuel cell technologies – key pillars of the energy transition 2.0

Further development of the
National Innovation Programme for Hydrogen and Fuel Cell Technology
(NIP)

Nationales Innovationsprogramm
Wasserstoff- und
Brennstoffzellentechnologie

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The board is tasked with supervising and advising on strategic content and is responsible for the preparation of the Development Plan (NEP). Board members represent the more than 300 companies and organisations participating in the NIP. Further information can be found online: http://www.now-gmbh.de/de.html

I Summary

The adjustment of our energy supply to the highest efficiency, to an increasing share of renewable energies with low energy consumption and low emissions (climate gases and harmful emissions), is a common goal of industry and politics. In order to achieve this, we need concepts which will intelligently link power generation with vehicles drive trains, fuelling infrastructure, as well as the energy supply of houses, ships and airplanes. Hydrogen and fuel cell technology provides just such a holistic approach, and can be used in a multifunctional manner.

Hydrogen can be simply produced from **renewable sources** and then stored. **Fuel cells** enable highly **efficient and emission-free conversion** to electricity and heat. In addition, with new products, services and applications, they contribute to securing added value and employment in Germany and to reducing the import of fossil fuels as a significant cost driver in today's energy supply. This technology will therefore assume an important **bridging function** in the interlinking of hitherto separate systems for **electricity generation** (from renewable energies) and **fuel supply** for transport.

Hydrogen and fuel cell technology in Germany has acquired a leading position by international standards. With several hundred research, development and demonstration projects, since 2007 the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) has created the technical conditions necessary to bring innovative products to market over the coming years. The federal government, federal states and industry are taking a concerted approach and are participating in the NIP with together more than 1.5 billion euro. The long-term NIP framework and the programme's organisation NOW GmbH – National Organisation Hydrogen and Fuel Cell Technology – are regarded both in Europe and globally as a success model to be emulated.

The first stage of proving the **everyday suitability and technological marketability** in vehicles and in the power and heat supply for buildings has been reached. Cars and buses with fuel cells have covered millions of kilometres under very different climatic and topographical conditions. From the 50 hydrogen fuelling stations planned in the first phase until 2015, over 20 are in operation. More than 500 fuel cell heating appliances have run reliably for over 4 million hours of operation.

Our task now is **to organise the second stage to commercial market breakthrough**. Experience from other innovative products like computers or mobile telephones has shown that their market introduction – whether competing with conventional products or also with other economies – must be prepared actively and in a well-planned manner. Hydrogen and fuel cell technology is also in direct competition with equipment and processes which have been optimised for generations. The latter are also often still directly or indirectly subsidised. At the same time Asian and North American competitors have already developed highly dynamic domestic markets in fuel cells and are now beginning to tap into the international market. For example thousands of fuel cell vehicles are coming onto the roads in the Far East over the coming years. In Japan there were already 40,000 fuel cell heating appliances installed in 2013. In the USA there are 500 fuel cell systems for cogeneration (CHP) with several hundred Megawatts installed capacity in operation. It is not only important for Germany to maintain the technological lead, it must also not miss the boat when commercialisation takes place globally.

The transition to the low-emission, efficient **products of tomorrow**, which support a growing and efficient use of renewable energies, also needs a stable framework in which **all players**

work together in goal-oriented way. Apart from technological further development and testing, creative implementation instruments and new business models are becoming more and more the focus here. Supplemented by the further technical development of the NIP and the goal-oriented cooperation between industry, science and politics until 2013, it is thus ensured that by the middle of the next decade **hydrogen and fuel cell technology will have become a key pillar of a sustainable and economic energy system in Germany** and a growing, future-oriented export market.

Over the past years businesses and governments worldwide have bolstered their investments in the development of hydrogen and fuel cell products. The remaining technical and economic challenges up to commercialisation are widely understood, though not all are overcome. In Germany many products and applications are nearing market readiness thanks to the common initiative of enterprise and politics. Building on this success, and in order to minimise the market risks of the next phase up to full market, the federal government will continue its successful involvement and adjust and supplement the current framework for research, development and demonstration projects with the aim of **accelerating market introduction**. To this end new initiatives and competitive instruments geared towards the important applications will be the focus, in order to achieve critical quantities of fuel cell heating appliances, fuel cell cars or buses.

Small- and medium-sized enterprises (SMEs) already today account for more than half of the added value in this area. An **integrated chain of suppliers** ensures further technical development and fosters the competitiveness of these companies over the medium-term. The use of **hydrogen to store energy** and the construction of **hydrogen fuelling stations** form the infrastructural prerequisites for a hydrogen economy and create synergies between market segments which are currently separate.

Against this background representatives from industry, science and the federal states in the NOW advisory board[1] recommend the further development of the NIP. It is now time to decide the content orientation as well as the type and scope of the necessary means and instruments, in order to guarantee a concrete lead-out from the existing programme and not to lose competitiveness in the international market. In this respect the following business areas and milestones are important until 2025:

[1]In the advisory board of the NOW all major branches and organisations involved in this topic are represented, see: http://www.now-gmbh.de/en/about-now/task/structure.html

- Fuel cells for electric vehicle drives and hydrogen infrastructure for comprehensive, emission-free mobility, with
  - more than 500 public hydrogen fuelling stations nationally,
  - over half a million fuel cell cars on the road and
  - 2,000 fuel cell buses in line service operation within the public transport system

- Hydrogen generation from renewable energies and integration in the energy system as a link between sustainable mobility and energy supply
  - 1,500 MW capacity electrolysers for the generation of hydrogen from renewable energies
  - definition and implementation of successful business models for power to gas
  - development of hydrogen storage mechanisms to store renewable electricity

- Fuel cells for stationary energy supply using decentralised cogeneration in house and building supply, industry and a secure power supply for public safety communication systems, telecommunications, etc.
  - more than a half a million fuel cell heating appliances in operation
  - more than 1,000 MW fuel cell CHP installations in operation
  - more than 25,000 secure power supply installations in place

Thus in the area of stationary fuel cells alone, with altogether over 1,000 MW capacity, CO_2 would be cut by up to three million tonnes. With the production and operation of systems in Germany up to four billion euro turnover would be gained and – with a high proportion of German added value at an export quota of over 50% - well over 10,000 jobs would be secured. Taking all hydrogen and fuel cell activities together, the above figures can be multiplied by a factor of three.

In the estimation of the authors, a total outlay of approx. 3.9 billion euro from 2016 to 2023 is required to achieve the technical and economic goals. The largest share of the expenditure will be borne by industry in the amount of approx. 2.3 billion euro. The requirement in public funding by 2023 totals 1.6 billion euro or on average approx. 160 million euro per year. From this it is expected that 0.7 billion euro will be needed for intensifying research and development up to full market maturity, as well as almost 0.9 billion euro for market activation measures in the areas of transport, electricity and heat[2].

[2] Market activation figures on the basis of analyses of the respective industry initiatives H2 Mobility, IBZ, performing energy

II Hydrogen and fuel cell technologies – key pillars of the energy transition 2.0

Today's energy system is not sufficiently centred on the future demands of a secure, affordable and environmentally-friendly provision and use of energy. Solutions which facilitate a sustainable energy supply are key to ensuring the well-being of future generations in Germany.

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Requirements for a future-oriented energy supply for electricity, heat and transport:

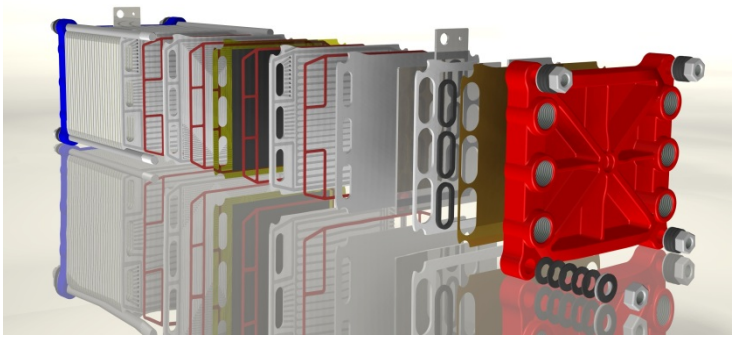
- **Secure energy supply:**
  Reduction in the dependency of energy imports (approx. 85% in the transport sector), tapping into new energy sources which are not bound to finite mineral deposits, development of renewable energies and their integration into the energy system, improvement of energy efficiency and energy savings through technical advancements.
- **Efficient and affordable energy supply:**
  Development of commercial business models for efficient energy technologies, assurance of energy costs, which remain affordable for all citizens and businesses.
- **Environmental- and climate-friendly energy provision:**
  Reduction and avoidance of emissions harmful to the climate, especially CO_2 as well as noise and environmental pollutions. Accomplishing European framework standards in for example, air quality in cities, ship emissions or noise.

The changeover of the energy system is happening in a complex environment of energy-economic as well as industrial- and climate-political framework conditions. Goal conflicts arise here, for example between innovation risk and security of investment, business costs and economic benefit, which can be dissipated with goal-oriented interlinking of different technologies, as well as a cross-sector optimisation of the entire energy system. At the same time energy also must and can remain affordable for all in the future.

Hydrogen as an energy source and storage mechanism and fuel cells as highly efficient energy converters illustrate key technologies for a pioneering and, in using renewable energies, emission-free provision of electricity and heat. They unlock new potential in the design of sustainable mobility as well as in stationary energy supply. Hydrogen can be produced with electrolysis from wind or solar power and stored, particularly when fluctuating renewable power cannot be consumed and the electrical grid hits its capacity limit. Hydrogen can not only be stored for reconversion, but can also be used as a fuel. Hence on the one hand, new business areas arise at the interface of the electricity and transport sectors, and on the other, hydrogen demonstrates an ideal link between electricity and natural gas networks as a gaseous energy source.

Hydrogen and fuel cell technologies make key, essential contributions to the energy transition 2.0 in the electricity, heat and transport sectors.

Emission-free local public transport with fuel cells and hydrogen from renewable energies (Source: Clean Energy Partnership)



Fuel cells and their components (exploded CAD drawing) (Source: ZSW) and a fuel cell system for a vehicle drive train (Source: Daimler AG).

III Market preparation in NIP – stage reached

NIP cooperation model: common strategy of politics, industry and science

In 2006 the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) was launched by stakeholders from the worlds of politics, science and industry. With the programme initially set to run until 2016 and a pioneering, unique organisational structure embodied by the programme organisation, NOW, and through the corresponding technological successes achieved in testing in the field, the course was set for a thorough implementation of fundamental innovations in various market segments. The NIP follows the guiding principle that a successful implementation of new technologies, aside from basic research and applied research and development in the classical sense, also needs testing in practice involving all players.

Within NIP public and private sectors are investing 1.4 billion euro. The Ministry of Transport, Building and Urban Development (BMVBS) is providing 500 million, and the Ministry of Economics and Technology (BMWi) 200 million euro in funding. Industry is participating in the projects with at least the same amount. Furthermore industry and science are developing technology with their own means.

The Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU) and the Ministry of Education and Research (BMBF) are involved in strategic programme supervision and coordination in addition to their own, complementary funding opportunities. Furthermore different federal states are carrying out their own programmes and are included in the current coordination processes in the NOW advisory board via a working group.

The areas of transport, stationary energy supply, off-grid as well as secure power supply were stipulated as the focal point in the National Development Plan Hydrogen and Fuel Cells (NEP)[3] and updated in 2011, following the decision of the federal government on the energy transition. The issue of hydrogen as an energy storage mechanism and as a bridge between electricity from renewable energies and the provision of fuel for emission-free mobility was subsequently lent considerably more weight. With representatives from the scientific world as well as all sectors involved, a continuous adjustment to strategic, scientific and technical requirements is ensured through the advisory board.

Comprehensive cooperation in lighthouse projects

Within NIP, industry partners of all sizes and sectors are working together. Coordination by NOW ensures that public funds prioritising applied research and development as well as system testing for everyday suitability are put to use effectively. Here the focus is on projects with critical mass and clear economic orientation, which as lighthouse projects could develop strategic importance in terms of market preparation and achieve high visibility with the public as well with potential partners in the evolving supply industry.

[3] See http://www.now-gmbh.de/en/ueber%20die-now/aufgabe/publikationen-download.html

Current lighthouse projects:

- **Clean Energy Partnership (CEP)**
  Operation of vehicle fleets (buses and passenger cars) with fuel cell e-drives and construction of 50 hydrogen fuelling stations along the German road network

- **Callux**
  Over 500 installed fuel cell heating systems in the area of home energy supply

- **E4Ships**
  Testing of fuel cell systems for on-board electricity supply of passenger ships

- **Clean Power Net (CPN)**
  Secure, off-grid power supply systems at 250 locations

The lighthouse projects play a decisive role not only in product development, but also in creating a broad acceptance among the public. They build a bridge between research/development and later markets – they are the seeds of subsequent commercialisation and are designed to start and prepare this process. With products and services, the first practical experiences will be gained and infrastructures, supply industry and operational systems developed. Lighthouse projects have broad appeal in the technological and/or the geographical sense. Public funds and finances from private investors and users are concentrated in such a way as to attain the necessary minimum amount of technological competence and financial power for efficient research and development as well as successful demonstration. In this way potential for synergies are exploited and interdisciplinary cooperation fostered.

Interim goal reached

Through the NIP, the everyday suitability and fundamental marketability of fuel cell and hydrogen technologies have been proven successfully. In addition, the potential with respect to energy efficiency, use of renewable energies, environmental and climate protection has been demonstrated. Examples of this are the local fully emission-free use of fuel cell vehicles, the production of hydrogen from wind energy, or the proven reduction of carbon dioxide by more than 30% using fuel cell heating devices for the supply of buildings with electricity and heat.

With its application- and market-oriented focus, the NIP is unique. Its broad programmatic focus, the networking of different industry sectors, its more stable, longer-term programme framework, as well as the implementation structure over an independent programme organisation have proved their worth. The results of the NIP make a decisive contribution to accelerating the market preparation of hydrogen and fuel cell technologies, creating the energy markets of the future, and strengthening Germany as an industrial base.

NOW is recognised across sectors and federal states as a professional programme organisation

With the founding of the federal NOW GmbH National Organisation Hydrogen and Fuel Cell Technology[4] a competent programme organisation with an excellent network at the interface of politics (on federal and state level), industry and science was created. Its important tasks are the coordination and supervision of the implementation of the NIP[5], coordination between demonstration programmes and technological developments and cross-sectional tasks, cooperation with European and international initiatives, public communications, as well as knowledge management in the assessment of results achieved and further measures.

With its efficient implementation structures, the NIP is seen globally as a pioneering model for a coordinated market preparation of hydrogen and fuel cell technologies. The NIP development plan was formulated approximately at the same time and in keeping with the content of the *Fuel Cells and Hydrogen Joint Undertaking* (FCH JU)[6] of the European Commission. In the technical implementation of the programme an intensive exchange takes place through the NOW with the local projects (including with Austria, France, UK, Netherlands, and Scandinavia). In addition the findings from the NIP activities are discussed with other relevant programmes on national and international levels as well as bilaterally (including USA, Japan, and China) and in the framework of the *International Partnership for Fuel Cells and Hydrogen in the Economy* (IPHE)[7]. Successful programmes in other countries, such as the introduction of fuel cell-based heating devices in Japan, or industrial trucks with fuel cell systems in the USA are analysed and experiences for local activities adapted.

An independent evaluation of the NIP carried out in the meantime came to the conclusion that the optimisation of components, system integration as well as production technology could be substantially strengthened through the NIP. Nevertheless it is important to improve the industrial manufacturing penetration in Germany and to increase availability of components, in particular in the medium-sized supply industry. Furthermore specific gaps in added value for example in the area of fuel cell stacks, must be closed. In some cases we risk dependency on foreign manufacturers for key components. Moreover NIP industry partners expect a temporary and digressive, but nonetheless consistent support at market introduction phase in an internationally distorted competition environment. In this way equality of opportunity will be created against generations of optimised or often state-subsidised technologies elsewhere.

[4] The shareholder of the NOW GmbH National Organisation Hydrogen and Fuel Cell Technology (NOW) is the federal government, represented through the Federal Ministry for Transport, Building and Urban Development (BMVBS). Furthermore, on the board of directors of the NOW the Departments of Economics and Technology (BMWi), Environment, Nature Conservation and Nuclear Safety (BMU) as well as of Education and Research (BMBF) are represented. Aside from representatives of the named federal ministries, participating industry sectors, science and the federal states are involved - www.now-gmbh.de

[5] In addition NOW was tasked in 2009 by the BMVBS with the implementation of the Model Regions Programme in the area of battery-electric mobility.

[6] www.fch-ju.eu

[7] www.iphe.net

IV Further development of the NIP – the road to market

The NIP is scheduled to run until 2016 as a research and development programme of the federal government. For the step towards a broad market introduction of hydrogen and fuel cell technology, additional, specific measures and instruments are required in order to stabilise the state of development achieved and to convert this into market success over the coming years.

Because hydrogen and fuel cells are competing with technologies which have been optimised over generations and often subsidised, full economic viability can only be developed on a step-by-step basis. Achieving this goal is helped by the fact that fuel cells already today are noted for their high multi-functionality under different mission profiles. Added to this are further advantages such as low emissions, the simple integration of renewable energies or the replacement of imported fossil energy (representing in Germany today more than 100 billion euro p.a.). Aside from market goals and apart from tapping into technical optimisation potential, a long-term commitment to stable investments is required, e.g. in the organisation of serial production in the supply industry, as well as a growing infrastructure, for example regarding hydrogen fuelling stations. However because revenue will only slowly increase by selling products, a longer, financial dry spell must be overcome. It is exactly for this interim period that a stable framework as the foundation for intensive cooperation and coordination of all market players is essential. Creative, temporary and strongly digressive market incentives, which orient themselves around technological milestones and new business models contribute to securing market success, as our competitors from Asia are already demonstrating.

All funding instruments and measures must thus be focussed on the key economic application areas in order to guarantee the best possible effectiveness of the funding. A comprehensive monitoring and regular analysis of the technical and economic development steps ensures a goal-oriented approach.

For the continuation and further development of the NIP, a strongly focussed course of action with the three following programmatic focuses is recommended:

- Fuel cells for electric drives and fuelling station infrastructure
- Hydrogen production from renewable energies and integration into the energy system
- Fuel cells for the stationary energy supply (home energy supply and decentralised systems for cogeneration as well as secure power supply)

In these application areas, a commercially sound market with many new jobs, economic growth, as well as competitive cost structures in international business will be achievable by 2025.

Fuel cells for electric drives and hydrogen fuelling station infrastructure

Target market Germany 2025:

- More than 500 public hydrogen stations nationwide
- Over half a million fuel cell cars on the road and
- 2,000 fuel cell buses in line service of the local public transport system in operation

The reduction of greenhouse gas emissions and energy consumption in street traffic are important goals for the European Commission and the federal government, which have only recently been incorporated in the German Mobility and Fuel Strategy (MKS). Without efficient electric drives and fuels from renewable energies, neither long-term climate goals, nor independence from fossil fuels can be achieved. With no range constraints and remaining highly flexible and productive in operation, cars and buses can contribute to considerably reducing noise and emission pollution in urban environments with hydrogen and fuel cells. Complementary to battery-electric vehicles, fuel cell vehicles thus constitute an important pillar for electromobility in the context of sustainable transport concepts.

It is expected that from 2015 the first thousand series passenger cars with fuel cells will come into operation[8], followed by a rapid further development of the market. By 2018 the latest, the first production facilities for components, systems and vehicles in Germany will go into series production. From 2020 fuel cell cars from about 30,000 euro will exist competitively on the market[9].

In order to achieve these goals, beyond the research and development funding frameworks thus far, additional measures must be taken which will allow vehicles to be continually brought onto the road. After the first 20 hydrogen fuelling stations were already constructed within the framework of the CEP, now sufficiently building up infrastructure for German or European-wide use will be advanced in parallel by both public and private means. In the H2-Mobility[10] Initiative, plans for basic coverage are specified, defined as corridors between metropolitan regions along the federal motorways, in order to thus achieve a synchronized ramp up of vehicles and fuelling stations. Because the operation of a comprehensive hydrogen infrastructure can only be profitable over the longer term, it is essential to bear the start-up risks together. Apart from industry and the federal government, many federal states are committing themselves in this regard.

[8] Hyundai and Toyota have announced the market introduction of fuel cell cars for 2015 in their key markets. Daimler, together with Nissan and Ford, plans the start of series production from 2017. BMW and VW are participating in research and development activities in the NIP. Together with Honda and GM/Opel, the aforementioned vehicle manufacturers (with the exception of Nissan), are partners of the CEP.

[9] Source: *A portfolio of power-trains for Europe: a fact-based analysis* (McKinsey, 2011); the cost example refers to a car in the compact class; with fuel cells, larger vehicles in particular are anticipated.

[10] The partners of the H2 Mobility Initiative (Air Liquide, Daimler, Linde, OMV, Shell and Total) work on a business model for a comprehensive network of hydrogen fuelling stations in Germany. The initiative is accompanied by BMW, Honda, Hyundai, Intelligent Energy, Nissan, Toyota und Volkswagen as well as NOW as the interface to the federal government. http://www.now-gmbh.de/en/mobility/mobility-of-tomorrow/cars-buses-and-public-fuelling-stations/h2-mobility-development-of-a-network-of-hydrogen-refueling-stations-in-germany.html

The car sector is a key industry for Germany as an industrial base. Its successes in global competition are in part thanks to a medium-sized supply industry. This lead can be secured through a timely orientation towards the expected technology changeover, when it is accompanied by a proportional but continuous and committed adjustment. However, a gradual conversion requires substantial effort in order to facilitate the changeover in the supply industry along the entire added value chain, and also to remain competitive and capable of meeting demand in future.

Fuel cells in transport will in all likelihood go into series production firstly in passenger cars and in city buses, as well as in delivery vans. In principle special-purpose vehicles and other means of transport such as commercial vehicles, airplanes, ships and trains are also suitable for conversion to this future technology. Therefore the relevant systems will be developed and tested early within the NIP. In future all means of transport possible must be taken into account in a national support programme in order to create the required economies of scale. This happens not least, when common production capacities and logistical chains are used.

Mercedes Benz B-Class with fuel cell e-drive refuelling with hydrogen and a public bus with fuel cells in everyday operation (Source: EnBW and CEP)

Hydrogen: production, storage and distribution – the link between sustainable mobility and secure energy supply

Target market Germany 2025

- 1,500 MW electrolysis capacity for hydrogen from renewable energy
- Establishment of successful business models for power to gas
- Development of hydrogen storage systems in order to store sufficient amounts of renewable electricity

The reorganisation associated with the energy transition creates many challenges. Among them is for example, the reconciliation of production and demand for electricity from renewable sources or the overcoming of large geographical distances between production and demand. It is anticipated that from 2020 at least 20 TWh of renewably produced electricity per annum will not be able to be used directly. This is a considerable cost driver and reduces the overall efficiency of the energy system. In order to resolve this disadvantage over the medium term, sufficiently large energy storage systems are needed in order to integrate electricity from wind or photovoltaic systems safely, reliably and in a stable manner into the supply system and thus use it economically. One of the most promising options, in particular for the storage of larger energy amounts over longer time periods, is conversion into hydrogen. Not only can it be stored, but it can then be made available for a large number of different applications, such as feeding into the gas network, as a fuel for vehicles, or as raw material for industrial processes. Over the medium term new business models will be derived with substantial potential for regional added value and the creation of more jobs.

Hydrogen production from renewable energies with electrolysers. (Source: Enertrag)

In addition to ongoing activities for wind-hydrogen systems within the NIP, as well as in the framework of the storage initiative of the federal government, initiatives for technological developments and testing of key components of such systems are needed in practice. This especially relates to new, high-performance and dynamic electrolysers and hydrogen storage systems, as well as integration into the power grid and the management of the energy system. Renowned representatives of industry, science, as well as organisations from the area of environment and the advancement of technology have joined forces in the *Performing energy – alliance for wind-hydrogen*[11] in order to create the conditions for a future economic integration of storage systems with hydrogen into the energy economy.

One of the goals is the reduction of investment costs for electrolysis to a fourth of its current value in the next 10 years, as well as the further development of today's performance capacity of under 1 MW to more than 50 MW, and increasing efficiency by 20 percentage points. Under these conditions the electrolysers' overall output of 1.5 GW by 2023 seems achievable.

Fuel cells for stationary energy supply: home energy supply, decentralised co-generation and secure electricity supply

Target market Germany 2025:

- More than a half a million fuel cell heating devices in operation
- More than 1,000 fuel cell cogeneration units installed for home energy, industry and ships
- More than 25,000 secure electricity supply units produced

Home energy supply

Through cogeneration, fuel cells in home energy supply save up to 50% CO_2 in supplying residential buildings. They distinguish themselves in this application area from other CHP units such as Stirling or combustion engines through their high efficiency, as well as an almost fully emission-free and noiseless operation. Fuel cell CHP systems can already achieve high savings in existing buildings with relatively small investment and limited building work. The impressive CHP coefficient makes it interesting also for new buildings. Operating with organic natural gas – possibly also with hydrogen – it converts renewable energy sources into electricity and heat highly efficiently.

[11] The partners of the *Performing energy* initiative are: The Brandenburg University of Technology, DBI Gas- und Umwelttechnik GmbH, Deutsche Umwelthilfe e.V, German Aerospace Center (DLR), ENERTRAG AG, Fraunhofer Institute for Solar Energy Systems, GASAG Berliner Gaswerke Aktiengesellschaft, hySOLUTIONS GmbH, Linde AG, NOW GmbH National Organisation Hydrogen and Fuel Cell Technology, Siemens AG, Total Deutschland GmbH, Vattenfall Europe Innovation GmbH, Vattenfall Europe Windkraft GmbH

Fuel cell CHP devices will be operated in the low-voltage networks, as is the case with photovoltaic roof systems (PV); they can be linked to virtual power plants through simple communication technologies in order to stabilise the fluctuating, renewable electricity supply from wind and sun. Fuel cells and PVs are ideal for home use and together help effectively solve the enormous challenges in the development and stability of electrical grids.

Within the *Callux* lighthouse project and further activities there have been over 500 units installed so far. In over four million operational hours, they have proven their suitability for everyday use and an already high technical maturity. Teaching programmes for the trades who install and service the units are already intensively used. The first manufacturers begin market introduction in 2013, in which they offer end customers appliances together with a full maintenance contract. The Fuel Cell Initiative (IBZ) and the German Engineering Federation (VDMA) Fuel Cell Working Group (AG BZ) predict that commercial marketability can be achieved without funding from 2020. Then up to 75,000 units could be sold annually. This represents 15 to 20% of the German heating appliance market.

Fuel cell heating devices in residential buildings ensure an efficient heat and electricity production. (Source: Callux)

It is important in the context of NIP's further development to establish a self-sustaining market for highly-efficient CHP facilities with fuel cells. To achieve this, the number of installed units must be substantially increased. A coordinated market initiative of manufacturers, suppliers and trade is being prepared. Parallel to this series production will be developed and manufacturing costs reduced to a competitive level through technical optimisation and rising demand. As the first manufacturers from Germany will already market products, apart from a stable framework for research, development and demonstration projects, a digressive, temporary, technical and economic criteria-focussed, market introduction programme is also needed here, which is subject to competition law.

[12] The Fuel Cell Initiative is the competence centre for fuel cell heating devices in home energy supply. Together leading energy companies, major appliance manufacturers, the German Energy Agency as well as the NOW GmbH National Organisation Hydrogen and Fuel Cell Technology are committing to the innovative technology. – www.ibz-info.de

The German Engineering Federation (VDMA), through the Fuel Cell Working Group, is supporting over 60 leading manufacturers and suppliers of fuel cells in the development of the industry network for the optimisation of systems and components as well as representing political interests.

In this way on the one hand, the high initial investment expenditure for customers and end users will be reduced, and on the other, the feeding-in of efficiently generated electricity rewarded. In addition to this, technological further development, including in the area of production technologies, are also required to achieve cost targets.

Industrial applications

Fuel cell systems of a higher power class have similar advantages to home energy units and are currently being converted for initial applications. The multiplicity of possible uses - from shopping centres and industrial facilities to ships, together with the power capacity of the systems allow the overall installed output of the systems to be rapidly increased and become significantly important to the energy industry. A prerequisite to this is to overcome high costs. In addition decentralised CHP fuel cell systems - with an electrical output of up to 10 MW due to their high degree of electrical efficiency, their high overall efficiency rates, as well as their low degree of harmful emissions – have attractive market potential in a changing energy system characterised by increasingly decentrally-optimised supply structures. In the case of high temperature fuel cells the usable heat also accumulates to a temperature level which facilitates the use of process heat, e.g. in the food industry on site.

Highly efficient fuel cell systems in decentralised and/or autonomous applications then make sense also when initially gas or other carbon hydrides are beings used as a fuel. Because of the high electrical efficiency, fuel consumption can be reduced by about 30%. Along with synthetic fuel cells from biomass or renewable energies, even further reduction of emissions is possible. The high fuel cell costs will be cushioned by the improved efficiency. Discarding components for emission reduction lowers the operational and investment costs. This is particularly significant for applications in ship-building and marine technology, in which Germany has a leading global position.

In the e4ships lighthouse project, the technological further development and testing of systems for power supply and heat/refrigeration supply on ships will be supported in particular. This will be accompanied by the launch of an initiative for the adjustment of framework conditions of the International Maritime Organisation (IMO) for the use of gas on ships, etc., which ensures that particularly efficient products from Germany are supported in the future. Because of the high demand for power and heat in port operation first and foremost, the focus is on systems with a 500 kW capacity. Systems from 5 up to several 10 kW will be developed and demonstrated alongside for commercial buildings such as shopping centres.

The greatest challenges to commercial use so far are the high manufacturing costs of such systems. They have already been reduced by approx. 60% since 2003, and a further 30% is anticipated due to demand-related economies of scale. Demonstration projects on the megawatt scale can counteract uncertainties on the user side; a marketable development of further CHP capacities can be supported through an efficiency bonus for systems with high electricity efficiency.

Secure and off-grid power supply

Industrial nations today greatly depend on a stable and secure power supply. Power outages incur high economic and operational costs, with the result that major facilities are secured through their own emergency power supply – independent from the public electrical grid. Aside from such solutions for an uninterrupted power supply, above all safety-sensitive systems such as mobile telecommunications and public safety communication networks, traffic control systems and control stations, as well as data centres, environmental and monitoring technology and emergency power supply to public, critical infrastructure facilities are among potential users.

Compared to back-up systems based on batteries and diesel generators, fuel cell-based systems are much more efficient and generate considerably lower emissions, especially in combination with renewable energies and electrolysis, and all this with availability levels similar to the electrical grid. Moreover, fuel cell systems provide the option, as a secure, buffer solution in using renewable energies more intensively, of relieving the public electrical grid and of providing balancing energy very quickly. An additional benefit is the reduction in peak loads, which further reduces power plant reserves.

In leisure applications, such as the power supply of mobile homes, sailing yachts or mountain cabins, as well as in industrial applications like transport, safety and monitoring technology for sensors, measuring and radio systems, fuel cell systems allow a decentralised electricity supply, which is independent from the public electrical grid. Compared to battery systems or diesel generators, fuel cells have the advantage of being environmentally-friendly, grid-autonomous, with a high level of availability and efficiency. Added to this is emission-free and quiet operation, as well the in part substantially reduced logistical and service outlay of remote stations. Within NIP such fuel cell systems could already be developed in Germany up to near commercial viability stage. The first systems are commercially available from different manufacturers or are on the brink of commercialisation. About 30,000 small fuel cell systems with a power capacity of 100 watts have already been successfully brought to market. Germany is the global market leader here.

Secure electricity supply with fuel cell in telecommunications and public safety networks
(Source: Heliocentris, CPN)

As in home energy supply, the joint initiative of all stakeholders is required here also in order to demonstrate the cost reductions of fuel cell systems and to achieve the 25,000 units forecast by the suppliers in the *Clean Power Net* (CPN)[13] in the larger power range with several kilowatts per system by 2017.

A continuation of the NIP should make centre-stage the development of sustainable business models which especially offer export opportunities for German companies. In newly industrialising countries such as India and South Africa, grid-independent energy supply facilities are the key to connecting large portions of the population to the worldwide information and telecommunications infrastructure, and thereby the key to economic, in which German companies can also participate.

Apart from the reduction in manufacturing costs by at least 50%, including through the creation and strengthening of series production processes, it is important to increase the availability of critical components and technologies together with the supply industry, as well as to build on a supply concept for the different fuels. Market introduction can also be accelerated through simplifications in the regulatory area as well as through standardisation in approval procedures.

In this way in the area of stationary fuel cells alone, with together over 1,000 MW of installed capacity, up to three million tonnes of CO_2 will be saved per year. With production and operation of systems in Germany up to four million euro revenue will be achieved and – with a large proportion of German added value with an export quota of over 50% - many more than 10,000 jobs secured.

[13] The partners of the NOW-initiated CPN are: b+w Electronic Systems GmbH & Co. KG, BOS Digitalfunk Brandenburg, E-Plus Mobilfunk GmbH & Co. KG, Elcore GmbH, ELTEK DEUTSCHLAND GMBH, Emerson Network Power | Knürr GmbH, FCPower GmbH, fischer eco solut ions | fischer group, Forschungszentrum Jülich GmbH, Fraunhofer-Institut für Solare Energiesysteme ISE, FutureE Fuel Cell Solutions GmbH, Heliocentris Energiesysteme GmbH, HOPPECKE Batterien GmbH & Co. KG, HyPower GmbH, ITM Power GmbH, MODL GmbH, new enerday GmbH, PASM Power and Air Condition Solutions Management GmbH & Co. KG, Proton Motor Fuel Cell GmbH, Rittal GmbH & Co. KG, SFC Energy AG, The Fuel Cell Research Center (ZBT GmbH), The Center for Solar Energy and Hydrogen Research (ZSW)

V Recommendations for implementation

Much has been achieved thanks to the NIP in terms of the technical development and testing of highly efficient plants and systems. Further efforts are necessary for market readiness however, to not lag behind competitors from Asia or North America in the second phase. In particular, this involves actively continuing to utilise the investments made thus far and develop these further even if the risks of market introduction go above and beyond the commercial risks of incremental innovation. Above all, a reliable framework to support the very long-term investments of industry is required in order to support market activation. If successful, this would guarantee a significant level of security for the future and a predominant position for German industry in the global market.

Today, the NIP covers applied research, development and demonstration activities primarily in the areas of transport, power and heat. Further initiatives must still precede the wide scale market introduction of hydrogen and fuel cell technology from around 2020 to actively ensure its successful development. Application-specific instruments complementing research and development need to be established in this regard, that enable the development of a complete and stable added-value chain in Germany – developing new business models along the way if required – that are of appeal to users not only for marketing reasons but also due to economic considerations. The future programme structure in terms of the continued development of the NIP should therefore both **secure the technological basis** as well as **support market activation**.

Securing the technological basis

To secure research and continued development in the area of hydrogen and fuel cell technology in Germany and thereby to secure a globally competitive supplier industry as well as the establishment of an end-to-end added-value chain, the following measures must be swiftly prepared and implemented:

- BMVBS measures with a focus on demonstration activities and market preparation (e.g. intensifying and continuing to develop existing lighthouse projects, the development of new lighthouse projects)
- Continuation of BMWi measures within the framework of the government's energy research programme with a focus on applied research and development (e.g. cost-reducing components and increasing system reliability, recycling, production research)
- Increased involvement of existing BMBF programmes and intensified networking with non-university research facilities; where appropriate by establishing specific research and development measures (e.g. catalysis research, electrochemical components, production processes)
- BMU programmes and where appropriate, establishing new measures with a focus on the use/integration of renewable energy (e.g. wind-hydrogen systems for the production of fuel, large-scale storage and the integration of hydrogen into the grid)

Supporting market activation

Based on the successful testing activities within the NIP lighthouses, the following specific measures were identified as being necessary for market activation:

- Support for the market launch of fuel cell vehicles, particularly through the development of the required hydrogen infrastructure
- Ensuring sufficient production capacity of hydrogen from renewable sources to relieve the existing electrical grids and to supply a renewable fuel for the transport sector
- Definition of a digressively defined and temporary technology introduction programme for highly-efficient, climate-friendly combined heat and power fuel cell systems, in particular for home energy supply

Monitoring and analysis of the energy systems

A programmatic approach demands that the technology-specific research and development activities along with application-specific introductory programmes (fuel cell vehicles/hydrogen infrastructure, electrolysis and storage technologies, introduction of combined heat and power system technology) are coordinated and managed in a holistic manner. This requires that specific technical and economic goals – derived from the target markets – are jointly defined and regularly monitored for success. A knowledge database is to be established to monitor success. Through comprehensive monitoring and a detailed analysis of the issues and correlations relating to energy and economic aspects, a target-oriented approach will continue to be maintained, thereby ensuring that funds are effectively used.

Funding needs

The public sector assumes a decisive role for initial and continued training, research and development as well as for the establishment and continued development of an efficient energy infrastructure. For the period 2007 to 2016, the NIP has approximately 700 million euro of government funding available coming from the BMVBS (500 million euro) and the BMWi (200 million euro). For each specific funding project, industry must contribute an amount that is at least equal to the funding received as well as investing additional substantial funds for product development and the market preparation of hydrogen and fuel cell products. Combined annual BMVBS and BMWi funding that was allocated in the years 2010 to 2012 amounted to an average of approximately 80 million euro per annum. These funds are supplemented through expenditure incurred by the federal states as well as fundamental supporting work conducted by public research institutes not directly associated with the NIP.

The following table shows the funding needs for the development of the NIP for the period 2014 to 2023, as explained above. This amounts to 700 million euro to secure the technological basis and 900 million euro for market activation measures, particularly in the areas of transport, power and heat[14].

[14] Figures on market activation on the basis of analyses of the respective industry initiatives H2 Mobility, IBZ, performing energy

Securing the technological basis		
Continued development of BMVBS measures with a focus on demonstration activities and market preparation		**500**
BMWi measures within the framework of the energy research programme of the federal government with a focus on applied research and development		**200**
BMBF programmes and, if required, the establishment of additional specific R&D measures		**Still to be approved**
BMU programmes and, if required, the establishment of new measures with a focus on the use/integration of renewable energy		**Still to be approved**
	Total	***700***
Supporting market activation		
Support market launch of fuel cell vehicles, in particular via the development of hydrogen infrastructure (fuelling stations)		**200**
Ensuring sufficient production and storage capacity of hydrogen from renewable sources to relieve the electrical grids and to supply an renewable fuel for the transport sector		**300**
Establish a digressively defined and temporary technology introduction programme for highly efficient, climate-friendly combined heat and power fuel cell systems, in particular for home energy supply		**400**
	Total	***900***
Total public funding		**1,600**
Direct funds from industry	**at least**	**2,300**

Funding needs for further development of the NIP, in millions of euro (2014-2023)

The approximately 1.6 billion euro[15] of public funding to be allocated over ten years (an average of 160 million euro per annum) is complemented by direct investments from industry totalling at least 2.3 billion euro. This means, compared to the current NIP, industry will provide at least a tripling of funding if the technological basis and marketing activation can be secured together.

In addition, public bodies can initiate other important instruments to stimulate the market, such as in the area of public procurement. Joint efforts in this vein, including initiatives from the federal states, enable the development of a marketable hydrogen and fuel cell industry in Germany, which can also exist internationally.

It is important that the continuation of the NIP is assured in 2014 to guarantee that ongoing projects with a runtime of several years will continue beyond 2016. Such projects and requests from industry have already been submitted to NOW in a significant volume.

Adjust and maintain the proven structure for implementation

The diversity and complexity of measures from industry, research and government for the continued development of the NIP require extensive, comprehensive coordination. The structures of NOW with the associated bodies involved have proven their effectiveness for this purpose. They also guarantee that superordinate energy and technology-open consultation will continue in the future. The members of the advisory board from ministries (federal and state), industry, associations and research were nominated by the corresponding interest groups and selected with respect to their professional and business background.

The important and well-functioning cooperation with the involved ministries (BMVBS, BMWi, BMBF, BMU) is to be emphasised, along with that of the states and the EU, which ensures that the doubling up of funding from various sources is avoided and therefore guarantees the effective deployment of available funding.

NOW is not only coordinator of large government programmes, it also builds and maintains a network of contacts comprising all relevant players in the area of fuel cells on both a domestic and international level. It has proven itself as an effective platform for the exchange of information on developments in the sector on a national and global scale, and as the interface to politics, bundles the relevant issues for swift and appropriate decisions.

[15] In comparison: German crude oil imports in 2012 were 6.4 billion euro higher than in 2011 when they totalled 60.1 billion euro. (That represents an increase of 11.9% in value, with a 3.2% increase in volume.) http://www.bafa.de/bafa/de/energie/mineraloel_rohoel/engergieinfo_rohoel/2012/dezember.pdf

VI Conclusion

Hydrogen and fuel cells comprise key components for the successful realisation of the “energy transition” and for aligning German industry to products that will remain in demand in the future. The integration of renewable energy in the energy supply system will reach its limits in the mid-term should hydrogen not be deployed as an energy storage medium. In the areas of transport and the decentralised supply of energy, the fuel cell distinguishes itself due to its high efficiency and particularly low emissions. With its multifaceted areas of application, hydrogen and fuel cell technology can make important contributions to growing added value and employment in Germany and ensuring sustainability at this location.

With its current focus on applied research and development as well as demonstration, the NIP has an initial term until 2016. Building on this first phase, the focus should be expanded in future to include market activation. In addition, the continuation of research and development activities will help to ensure that a high level of quality, efficiency and practical suitability of products and applications is achieved. Furthermore, the continued development of the NIP with both elements – **(1) Securing the technological basis** and **(2) Supporting market activation** – is to be **prepared from 2014 in the government programme for the next legislative period**.

For the continued development of the NIP, activities in the following areas are to be emphasised:

- Fuel cells for electric drives in transport and fuelling station infrastructure
- Hydrogen production using renewable energy and integration in the energy system
- Stationary fuel cell applications (decentralised combined power and heat systems in the household and in industry as well as the secure supply of electricity)

These areas are to be flanked by continual research and development in order to realise the remaining technical and economic optimisation potentials and thereby actively exploit the associated added-value chains in Germany. This is to be underpinned by suitable instruments for market activation to ensure good products are also taken up by the market.

There is consensus among all involved players that the existing structure with NOW positioned as the implementing organisation, has proven itself very well. It should therefore also remain in place in the future, with correspondingly adjusted terms of reference and facilities.