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Introducing Hydrogen as a Future Fuel: Strategies and Activities in Germany

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1 Introduction

Hydrogen as a future fuel for road transport promises substantial cuts in greenhouse and other emissions, and reduced dependency from imports of mineral oil and other fossil fuels. Hydrogen can be produced from a multitude of energy sources, including wind and biomass, at competitive costs. Both fuel cell and hydrogen technologies imply attractive economic prospects. To support technological development and prepare for the market entry, the German Federal government set up the *National Innovation Programme Hydrogen and Fuel Cell Technology* (NIP). The *National Organization Hydrogen and Fuel Cell Technology* (NOW) assumes responsibility for programme management and assessment of funding applications. The study *GermanHy* answered the question how the future demand for low or no-carbon hydrogen for transport can be met at competitive costs. A strategy paper further discussed hydrogen supply paths and recommended future technology support activities. Studies and demonstration projects have started, regarding hydrogen produced from wind energy, hydrogen from biomass, and by-product hydrogen. The paper discusses the above issues, focusing on strategic developments and demonstration projects.

2 Innovation Programme and Programme Management

The NIP was set up by the German Federal Government in May 2006 [1]. The overall task of the programme is to support preparations for the market introduction of hydrogen and fuel cell technologies in the mobile and stationary sectors, as well as in special markets. The *Federal Ministry of Transport, Building and Urban Development* (BMVBS) contributes €500 million for demonstration projects to the NIP. The *Federal Ministry of Economics and Technology* (BMWi) commits €200 million for research and development (R&D) projects. The combined public funds worth €700 million are to be matched by roughly the same amount contributed by the industry and other bodies running the projects. Thus, the NIP mobilizes a total of €1.4 billion spread across the programme duration from 2007 to 2016. The *National Development Plan 2.1* (NEP) of April 2007 spells out the NIP and suggests a more precise agenda for technological development [5]. 54 percent of the NIP budget is allocated to mobile applications, including hydrogen production and infrastructure. The role of hydrogen is seen as a transport fuel and a storage medium for leveling out fluctuations in wind energy.

NOW was founded as the primary programme management organization in February 2008. Funding applications for demonstration projects are processed in close collaboration with the *Project Management Organization Jülich* (PTJ). NOW is in charge of the overall coordination of the NIP and the evaluation of project proposals in terms of content. PTJ is responsible for

R&D projects and formal aspects of demonstration projects. An important task of NOW is the development of strategies for technology development in collaboration with politics, science and industry [4]. Since March 2009, NOW also assumes responsibility for the *Model Regions Electric Mobility Programme* of the BMVBS (www.now-gmbh.de).

3 Hydrogen Production in the NEP

The *transport* chapter of the NEP recognizes the need to further develop the portfolio of hydrogen production technologies. Improvements in energy efficiency, cuts in carbon dioxide emissions, the diversification of the primary energies used for hydrogen production, and cost reductions are core programme goals. However, the NEP lacks detail where hydrogen production is concerned. Also, these issues are discussed as aspects of the wider transport chapter, rather than features in their own right.

Thus, it proved necessary to conduct a study investigating hydrogen production pathways, and to develop a strategy towards realizing the potentials once identified. In September 2009 the industry announced to introduce significant numbers of fuel cell vehicles (FCVs) in 2015 and to work towards building up large-scale infrastructure in initiatives such as *H₂ Mobility* (www.daimler.de). This calls for strengthening the profile of hydrogen production in the NEP.

4 The Study GermanHy

The study GermanHy answered the question ‘Where Will the Hydrogen in Germany Come from by 2050?’ [2]. It established the volumes of hydrogen required to satisfy expected future transport fuel demands. GermanHy used different scenarios and calculated the share of the total production that individual pathways can account for between 2010 and 2050. The study considered established production technologies and such close to commercial availability only. A political imperative was that at least 50% of the total energy used had to be renewable.

The study showed that by 2050 up to 70% of all cars and light-duty vehicles in Germany could be equipped with fuel cells and that enough low or no-carbon hydrogen to fuel the vehicles could be made available. GermanHy also concluded that mobility based on fuel cells and hydrogen will be possible at today’s costs if the development targets for vehicles are met. The study estimates that hydrogen will cost between 4 and 5.5 €/kg in 2020, and between 3.5 and 4.5 €/kg in 2030. Carbon dioxide (CO₂) emissions of cars and light duty vehicles can be drastically reduced down to 40g CO₂/km (well to wheel) and 20g CO₂/km (tank to wheel) by 2050 (fleet average).

GermanHy showed how large volumes of hydrogen can be supplied as a transport fuel. However, it did not discuss in detail the technological, economic and environmental characteristics of the different supply paths. Moreover, the study did also not supply recommendations for action as to how the potentials identified could be realized. A Strategy Paper Hydrogen Production addressed these issues and is introduced below. The GermanHy findings with regard of the potential of individual production pathways - namely wind, coal, biomass, by-product and natural gas – are taken as a base.

5 Strategy Paper Hydrogen Production

The Strategy Paper Hydrogen Production was drafted by NOW and presented to the *Advisory Council* to NOW in September 2009. The Council is staffed by 18 representatives of politics, science and industry, and defines the agenda for technological development NOW has to pursue. A core task of the Council is to update the NEP. In December 2009 the Council decided to take the Strategy Paper as the base for revising the relevant parts of the NEP.

The Strategy Paper furnishes a detailed discussion of the GermanHy production pathways. Core items are the potential contribution individual paths can make, the state of the art of technologies, needs for further R&D and demonstration projects, and the activities of NOW. The paper aims at guiding activities ensuring that hydrogen production minimizes carbon emissions, relies on at least 50% renewable energy, increases energy efficiency, and achieves competitiveness of costs. Below the main pathways of the paper are discussed, taking account of recent comments of the Council.

According to all GermanHy scenarios electricity from off and on-shore wind power generators will play a central role in hydrogen production. Excess electricity that currently cannot be harvested due to insufficient capacities of the electricity grid can be used for electrolysis. The hydrogen produced can be used either as a vehicle fuel or be stored and reconverted into electricity at times of high demand. Wind hydrogen systems are especially important in light of plans to massively enhance wind power capacities in the future. Due to the high gravimetric storage capacity of hydrogen, large-scale underground storage of compressed hydrogen offers storage capacity for fluctuating energy unrivalled by other storage media. Several recent studies suggest that hydrogen is the only medium capable of storing the large volumes of fluctuating energy that will follow from increased wind power [6]. Electrolysers as the central components of wind hydrogen systems represent a key area for projects and studies supported by NOW. Large scale underground storage is another central issue for support in the future work of NOW.

GermanHy establishes that coal might evolve in an important source for hydrogen production as well; depending on the scenario either in conjunction with, or without, Carbon Capture and Storage (CCS). However, relevant technologies such as Integrated Gasification Combined Cycle power stations and CCS are not proven as yet. Both on the German and the European level clean coal technologies receive substantial governmental support. Given pronounced technological risks and existing support programmes, coal gasification is not regarded a priority theme for the NIP.

In all GermanHy scenarios biomass assumes relevance for hydrogen production, though its potential remains limited due to the relative scarcity of feedstock. Apart from generally low emissions, hydrogen production from biomass offers the advantage of the lowest costs of all pathways based on renewable energy. There is a multitude of different production processes with different characteristics, which complicates technology assessment. Gasification processes are generally regarded most promising, but also the reforming of substances such as biogas represents an interesting option [3]. A comparative evaluation of production processes is required. Today several small-scale R&D projects are running internationally,

but just a few larger demonstration projects. There is a clear need for NOW to support relevant activities.

According to GermanHy, by-product hydrogen from the chemical industry can be readily made available at low costs. The volumes are small, but can be important in the early years of the market introduction of FCVs. A study suggests that there is enough hydrogen in the state of North Rhine Westphalia to fuel 6000 buses or 300.000 cars. Most technological components are state of the art and do not require major technological innovations. However, due to the importance by-product hydrogen can assume in facilitating the market entry of FCVs, NOW supports the production pathway.

In some GermanHy scenarios steam reforming of natural gas (SMR) makes a limited contribution to satisfy the hydrogen demand. In the light of expected rising gas prices and higher distribution costs associated with central SMR, GermanHy regards decentral SMR as the more viable option. However, there are pronounced technological and economic uncertainties. Therefore, SMR is not regarded a priority theme for the NIP.

6 Demonstration Projects and Studies on Hydrogen Production

In March 2010, 16 demonstration projects and studies regarding hydrogen production, worth € 68 million, are in discussion with NOW. 3 demonstration projects and 1 study with a combined budget of € 14 million received their final approval and have started.

The demonstration project *Renewable Hydrogen RH₂* shows the working of a wind hydrogen system set up and operated by the firm Wind-projekt and a subsidiary. Hydrogen is generated via electrolysis from wind energy, stored, and reconverted into electricity used to satisfy the power demand of wind generators during periods of calm (www.wind-projekt.de).

A study establishes the state of the art of water electrolysis, the central component of wind hydrogen systems. The main technologies AEL, PEMEL and HTEL are being evaluated in terms of performance, costs and requirements for technological improvements. Key players are being identified and recommendations for action are given.

A project on *Glycerin Reforming* by the gas company Linde uses glycerin produced as a by-product of bio-diesel production to generate hydrogen. Glycerin is purified, pyrolysed and reformed in a pilot plant. The synthesis gas is then treated to hydrogen in existing industrial facilities for use in transport applications (www.linde.com).

The project *Chemergy* demonstrates how industrial by-product hydrogen can be made available for transport applications. The project run by the city of Hürth and partners treats by-product hydrogen from chlorine electrolysis to fuel cell standards, and dispenses the hydrogen in a filling station. The hydrogen is used in fuel cell buses operated in a complementary project funded by the state of North Rhine Palatine and the Netherlands (www.hycologne.de).

The demonstration projects and studies described above underline the priority NOW gives to hydrogen production from wind and biomass in strategy formulation and project activities. The activities target reduction of CO₂ emissions, reliance on renewable energy, high energy efficiency, and cost competitiveness.

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