A Hydrogen Roadmap for Germany

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EXECUTIVE SUMMARY

1.1 MOTIVATION

To meet the worldwide challenge of limiting global warming to less than 2 degrees Celsius, the proportion of fossil fuels in the global energy mix must be reduced to a minimum. Fossil energy sources must therefore be replaced by the implementation of a sustainable circular energy economy, which will be heavily based on hydrogen. Large quantities of hydrocarbons will still be used in some sectors, but these will be produced using renewable energy sources and greenhouse-gas-neutral hydrogen and carbon. Thus, energy systems cannot be decarbonized, but must instead be tailored to meet the goal of greenhouse-gas emissions neutrality. In Germany, this process began in the year 2000 with the enactment of the Renewable Energy Sources Act and continued with the adoption of the German federal government's energy concept in 2010. This increased the proportion of renewable energy sources in the energy mix to around 38 percent (2018). However, it is now becoming increasingly clear that hydrogen and its synthesis products will play a key role in achieving greenhouse-gas emissions neutrality in all the energy-consuming sectors, such as transport, industry and buildings, for example. As well as being used directly in a range of applications, hydrogen is also taking on increasing importance in the system integration of renewable energies due to the fact that it is easy to be stored and transported.

Electrolysis of water will become a crucial component of industrial policy in Germany, not only as a means of generating a proportion of the hydrogen that is required, but also as an option for providing flexibility in the German power grid and as a core technology of the transition to renewables for the international export market. Hydrogen can make an important contribution to achieving greenhouse-gas emission neutrality in the industry and transport sectors. It can also be part of the solution in buildings and for back conversion into electricity if sufficient market-based policies incentives are put in place to clearly push sectors in that direction.

1.2 NATIONAL AND GLOBAL SIGNIFICANCE OF HYDROGEN

Studies anticipate that, in Germany alone, the market ramp-up of electrolysis will lead to a production capacity of between 50 and 80 gigawatts by 2050. To reach this capacity, electrolyzers in double-digit megawatt volumes would need to be installed now and growth rates of around one gigawatt per year achieved by the end of the 2020s. Electrolyzers are likely to be used most widely in those regions of the world where the cost of generating electricity from solar PV systems and wind farms is less than 3 cents per kilowatt-hour and where those plants are operating for at least 4,000 full load-hours a year. This will open up access to a global renewable energy trading market since both hydrogen and synthesis products based on hydrogen can be produced at internationally competitive costs.

Thus, as well as facilitating the achievement of national industrial policy and sustainability goals, hydrogen can also help drive forward the global energy transition. Ultimately, the supply of electricity by solar and wind farms in regions that are favorable to this form of energy generation must be brought into line – on a global level – with demand for energy sources, fuels and basic chemicals in industrial regions. Hydrogen can be transported in liquefied form similar to liquefied natural gas (LNG), or chemically bound as ammonia, methanol or as liquid organic hydrogen carriers (LOHC).

Many regions of the world are preparing for this form of trading in sustainably produced energy carriers and basic chemicals, which will enable Germany to expand its energy partnerships beyond the previous fossil energy partnerships. A key role in establishing such trading routes will be played by international ports and their nearby industrial regions, since these not only tend to include refineries, but also the logistics routes that make up a suitable distribution infrastructure for hydrogen products.

1.3 RESEARCH NEEDS BY SECTOR

Electrolysis is the key technology for hydrogen production. The cost of this technology needs to be reduced to less than 500 euros per kilowatt through ongoing R&D efforts, economies of scale and automation of production facilities. Research and development is currently focusing on adapting cell materials to increase power density, efficiency and service life, as well as on reducing specific requirements for critical materials and optimizing energy demand in flexible and dynamic operation. Germany would need to establish a gigawatt market by 2030 to achieve successful market penetration. This would include establishing supply chains and a competitive electrolysis industry capable of serving both the national and international market. Political steps could also be taken to boost the success of the German hydrogen industry, including modifying the regulatory framework defining how electrolyzers are installed and used to provide electricity, creating instruments to increase demand for green hydrogen, and transposing RED II into national law.

Further research is required to promote increased use of *hydrogen in industry*. Examples of areas where research is needed include plants that can operate flexibly and cope with changes in feedstock and volume flow rates, methane pyrolysis, and analyses of the effects of changing feedstock on cross-industrial material flows. Processes for capturing CO_2 are not yet sufficiently understood. To support industrial use, it is also necessary to expand the hydrogen pipeline network, in particular along the areas of the Rhine where large, central consumers are located (chemicals industry, refineries, steel industry, etc.). At the same time, large-scale demonstration plants could be built to carry out industry-related research projects addressing key aspects of scaling up PtX processes and integrating them in existing industrial infrastructures. The regulatory framework must be adapted to ensure that cost-effective operation with green hydrogen is viable. The market launch of new manufacturing processes on an industrial scale also requires a very high degree of regulatory planning certainty.

Hydrogen in transport will require significant further development of fuel cell powertrains and establishment of a refueling infrastructure. To achieve this, key R&D aspects of production and storage technologies and system testing could be combined into “national technology platforms” in order to pool public funding. The refueling infrastructure should be expanded for both passenger vehicles and trucks, bearing in mind that trucks have significantly different requirements in terms of the quantities of hydrogen they need and the frequency with which they cross borders. Various political steps could be taken, including promoting fuel cell mobility and hydrogen refueling and allowing the public sector to take a pioneering role in procuring fuel cell vehicles. Regulatory approval of hydrogen as a fuel instead of as an industrial gas is also still pending.

Hydrogen-based power generation is not a key driver for developing the hydrogen economy. This sector can deploy gas turbines, which are already highly developed, as well as fuel cells, assuming they become available at low cost through developments in other sectors. It is also important to appreciate the full significance of hydrogen. Its value stems from the fact that electrolyzers can be operated flexibly and large amounts of hydrogen can be stored easily – two factors that can help promote system integration of renewable energies. Hydrogen can also make a useful contribution to securing energy supplies.

The *building sector* will not generate any significant demand for hydrogen over the short to mid-term. Over the long term, there may be an increasing demand for climate-neutral hydrogen in the building sector under certain conditions, such as slow expansion of the wind turbine sector and limited availability of CO_2-neutral electricity imports.

1.4 ECONOMIC ASSESSMENT AND POSSIBLE COURSES OF ACTION

The regulatory framework – consisting of duties, levies and taxes on electricity, gas and other energy sources – plays a very significant role in any economic assessment of hydrogen. Up to now, the regulatory framework has generally been defined on a sector-specific basis, with some sectors experiencing very different levels of regulation to others. This is exacerbated by the fact that today's regulatory frameworks typically pursue a multitude of objectives that end up making the respective framework highly complex.

The high taxes and duties payable on electricity create a significant burden that, at least for now, limits the use of renewable hydrogen from an micro-economic perspective, although this may well be very different from a macroeconomic perspective. So what might a possible target model for the regulatory framework aim for? Based on the above, it should ideally result in an economically efficient overall system and a far-reaching internalization of the environmental cost (e.g. from CO_2 emissions) and be fundamentally open to different technological solutions.

There are also some important requirements with regard to technology funding. Renewable hydrogen involves a substantial demand for infrastructure and path dependencies, both of which create significant barriers to market entry. Diffusion may therefore be delayed even where there are specific cost benefits from an overall system perspective. This is where regulatory interventions to promote technology are conceivable and should be examined. This should enable further innovations and cost reductions to be achieved.

The following key issues must be considered in efforts to achieve an international trading mechanism in renewables for hydrogen-based products:

- The technology base already exists for the entire value chain, but further investment is required in research in order to reduce costs and continue improving the durability of the products.

- Internationally harmonized and certified standards for hydrogen-based energy sources and chemicals must be developed.

- System analysis can provide important information on the expected business models in the overall chains.

- Energy partnerships with countries that have high potential to expand renewable energies create an attractive long-term investment environment.

- International research cooperation and energy partnerships are key prerequisites for long-term trade relations.

In addition, regulatory frameworks should always take into consideration industrial policy effects and the competitive situation internationally. Early technology development can lead to competitive advantages and export opportunities which, in turn, have a positive effect on industrial policy. Germany is currently well positioned along the entire hydrogen value chain – from production to fuel cell use – and it should therefore exploit this market position.

The following roadmap shows the key research and development steps on the journey toward a hydrogen economy in Germany.

Roadmap for the hydrogen economy in Germany