NATIONALER WASSERSTOFFRAT

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Research and development requirements for the use of hydrogen in the chemical industry

The chemical industry is facing the major challenge of transitioning from fossil raw materials and energy sources to climate-neutral alternatives. Hydrogen can and will play a prominent role in this. However, in order to implement this, several questions still need to be solved. For example, not only does availability have to be ensured, but technological challenges within the chemical process chains have to be considered as well. The complexity of this transformation lies in particular in the adaptation of industrial processes, some of which have been established for decades, with high (currently also unique) hydrogen requirements, such as methanol and ammonia syntheses. In addition, it is also necessary to develop completely new technologies and industrial processes for the defossilisation of the chemical industry. These will also trigger a correspondingly high future demand for climate-neutral hydrogen. The focus is particularly on the development of process technologies for the production of synthetic naphtha or alternatives as a basis for the primary industry.

The resulting multitude of research and development topics will need to be addressed in parallel. In order to define this, a three-stage process was launched within the framework of the Working Group 1 of the National Hydrogen Council. Relevant experts were selected, and future needs and fields of action were discussed with them. The results of this process are summarised below and reflect the state of affairs, research and development needs as well as initial recommendations.

1 CURRENT STATE

It was possible to identify various aspects of the current status through the experts' input and discussions. The most relevant aspects are listed below.

The role of hydrogen in achieving the climate goals is substantial, but in the current consideration of the chemical industry it is still underrepresented. There are the additional tasks of developing and establishing new process technologies, which include the development of new sources for relevant elements such as sulphur and carbon.

The German electrolysis industry is in the process of transitioning to industrial scale, which is essential for the large-scale technical use of green hydrogen in chemical processes. Consequently, the market ramp-up must be accompanied by a technological realignment of chemical industry processes.

Currently available LCA tools and modelling used to assess climate impact trends do not at present allow for a complete future projection based on existing data and developments. This leads to a distorted representation of the actual state, the development over time and to highly diverging forecasts.

2 RESEARCH AND DEVELOPMENT REQUIREMENTS

2.1 FUNDAMENTAL R&D ASPECTS

This section highlights the research and development activities that serve as the basis for implementing climate neutrality in the chemical industry by 2035, combined with the goal of creating a green, hydrogen-ready petrochemical industry. Relevant factors include the effects on the assured supply of aromatics and other basic chemicals.

The developing energy-efficient technological innovations should be able to be incorporated in a modular 'drop-in' manner to ensure that existing process chains can continue to be used to the greatest possible extent. In this context, it is also important to create integrated systems and optimise process control in such a way that efficiency and resilience are increased continuously. A contribution to this is made, for example, by development progress in the field of hydrogen compression with the goals of achieving improved energy efficiency, shorter idle times and greater operational flexibility.

2.2 TECHNOLOGIES ON THE THRESHOLD OF INDUSTRIALISATION (TRL 7-8)

In order to achieve these optimised processes, the electrolysis technology established today must first be quickly implemented on the market on an industrial scale, with no restrictions on technology. This also includes a consistent reduction in the costs of electrolysis plants and components through industrialisation and consistent ongoing evolutionary development.

2.3 TECHNOLOGIES THAT REQUIRE R&D

The requirements arising from integration into renewable energy systems are a key focus, particularly with regard to dynamic operation, which generates alternating loads that cause stress to processes and materials.

Storage technologies for (green) electricity are an additional important link in the chain. Green carrier molecules for hydrogen or raw materials should be considered more closely in the material network and in the context of holistic value chains, with a focus on transport and cost efficiencies and their availability as well as regional supply security. This also applies in particular to hydrogen derivatives such as ammonia.

There is a fundamental need for materials research, especially in the area of freely tested sealing materials and hydrogen concepts. A topic of equally high relevance is the replacement of rare and questionable materials. Examples include the production of electrodes without platinum metals or fluorine-free membranes. The further development of such technologies aims to bring independence from strategic or questionable resources in the long term.

Furthermore, activities relating to high-temperature electrolysis are to be assessed as useful for the integration capability of thermal process chains. Relevant research topics in this context include maximising efficiency and efficient ways of utilising the resulting waste heat. Lifespan-extending innovations should also be promoted.

In order to achieve all climate targets on time, energy consumption must also be fundamentally reduced. Currently, many technologies still heavily rely on steam. With the help of suitable catalysts, this can be used for CO_2 capture and storage processes and thus contribute to both increased energy efficiency and reduced emissions. Alternative processes, such as oxy-combustion or use for heat supply, are also conceivable and should be considered as part of holistic process chain development.

In addition to further technological developments and material research, it is important to use the existing infrastructure in the course of an economic implementation and to integrate the new hydrogen value chain effectively and, if necessary, in a staged manner. For components and parts that come into contact with hydrogen, for example, there is a particular need to consider service life and material compatibility at pressures above 200 bar. In this regard, the burner technologies whose burners and furnaces must be converted for pure or highly concentrated hydrogen need to be explicitly researched and made ready for industrial operation. In addition to ensuring the basic fit, the gradual conversion from natural gas to hydrogen must also be taken into account.

In industrial use, special safety precautions are required, e.g., under cryogenic conditions. This is also reflected in research and development for the improvement of safety technology, for instance through the industrial detection of hydrogen leaks.

Important enablers of targeted implementation include standardised components as well as planning and evaluation methodologies. There is a need for corresponding component catalogues and/or standardised information on, among other things, mean time between failures (MTBF) and other values (based on experience). In addition, generally accepted recommendations for component ageing, cycle strengths and material interactions (for example, ageing/running tests) are to be provided in the form of qualification work. Both go hand in hand with the goal of building up a common industry knowledge and thus meeting EU-wide quality standards. In some cases, this can be implemented using existing systems, but these must be re-evaluated under consideration of the increased use of hydrogen. The focus is on improved technical solutions for hydrogen product quality assurance, e.g., cost-effective online measurements in accordance with accepted quality standards.

Research contributes to the hydrogen cycle economy through targeted needs assessments. In this way, development scenarios will be set up that show the influence of a functioning circular economy and thus enable accurate forecasts of hydrogen demand. In addition to correcting previous assessments, which underestimated the requirements of the chemical industry as a whole, the area of chemical recycling also needs to be analysed. This will close a gap in the waste hierarchy between mechanical recycling and reuse. While it is not yet fully established in the market as such a technology, it could act as a complement to the need for new carbon sources in future. Other technologies whose maturity will be scaled up to TRL 8 in the coming years must also be taken into account in the development scenarios. This also applies to the use of the accumulated electrolysis oxygen or additional by-products resulting from other optimisation processes.

Increased need for research and development is evident in cost reduction, which must be consistently considered in TRL 8 technologies as well as those with lower levels of maturity – in the latter case from the very beginning. Further activities are therefore needed to increase cost efficiency along the hydrogen value chain, especially with regard to the use of by-products and process optimisation. The costs and impacts on chemical parks in the field of methanol, ammonia, LOHC, etc. will be investigated, especially with a view to sustainable security of supply. Technologies that have been largely unexplored to date, such as ammonia cracking, also need to be investigated with regard to their economic viability and sufficient quantitative impact to achieving the climate targets. The National Hydrogen Council recommends pilot projects that derive cost degressions and business models based on the technology and development scenarios to be explored, taking into account operating costs. The focus will also be on process chains with regional structures, with regard to system and cost efficiency and general molecule options. Extensive modelling and the calculation of cost degression curves are needed to develop these business models.

In the area of cost reduction, techno-economic and life cycle cost analysis are of particular importance. In addition to the cost degression curves, questions include the use of existing gas grids for hydrogen, economic application scenarios for membrane technologies and the impact of service life on viability.

3 SECURING THE SUPPLY OF SKILLED WORKERS

As a newly developing and evolving field of activity, the use of hydrogen in the chemical industry offers special challenges for future specialists and managers. The aim must therefore be to acquire new competencies and to help shape the transformation activities towards green chemistry in a targeted manner. The possibility of being able to contribute as a trained specialist in the respective home country can counteract brain drain, especially through continuing vocational training. In addition to general training needs, there is a particular need for retraining in plant construction and in technical process competence with a focus on increasing the attractiveness of working in a green chemical industry of the future. For example, new chemistry and electrochemistry processes have to be established in the areas of compatibility, alternating load (lifetime) etc. Fundamentally, however, new offers are needed along the hydrogen value chain to achieve process optimisation and interconnection.

4 RECOMMENDATIONS OF ACTION

The use of hydrogen in the chemical industry requires separate research and development activities along the value chain. The National Hydrogen Council recommends building the individual technologies along this very chain, both in hydrogen production and in the context of converting chemical plants and processes. This also applies in particular to the targeted development of technology suppliers, who will play a decisive role in scaling.

The Technology Readiness Level (TRL) should serve as a guideline for assessment:

- The main focus should initially be on making TRL 8 technology ready for series production (in particular the industrialisation of electrolysis).
- Lower TRL technologies should be promoted, and mid-TRL technologies should be scaled up to pilot plant scale to mitigate development risks and enable realistic business models.
- Research activities on the replaceability of rare and questionable materials are to be intensified in order to achieve strategic resource independence.

- Regional structures and process chains that map the respective supply strategies and product chains as a whole are to be given special consideration.

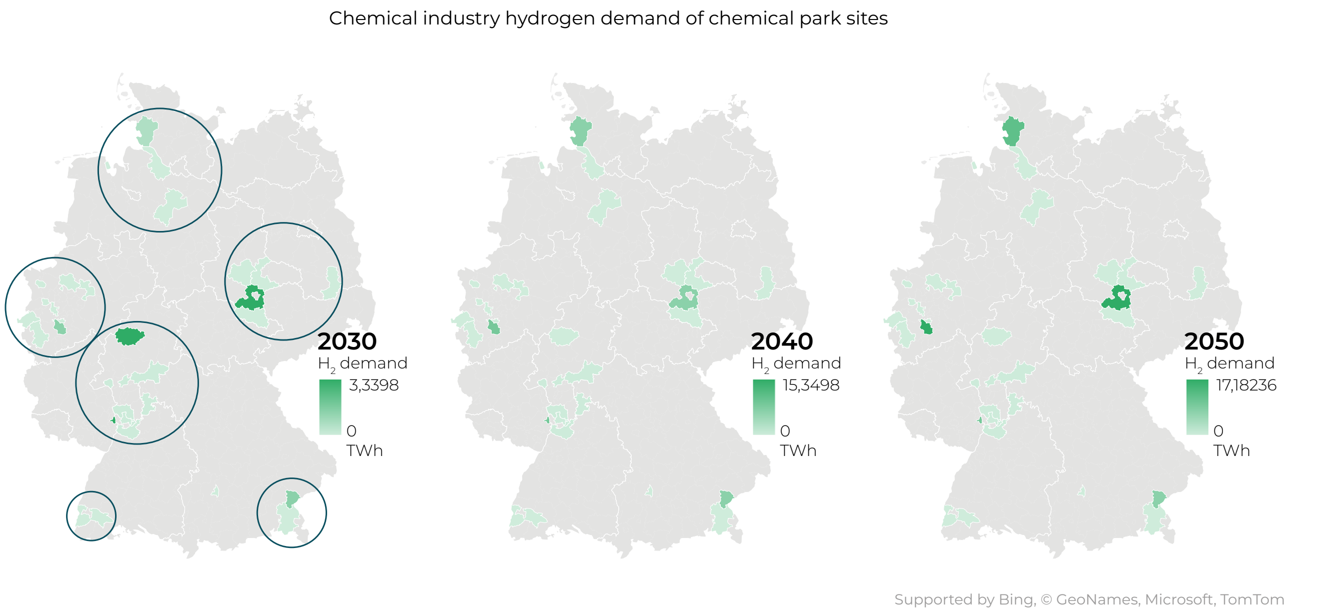
Correspondingly, the focus lies on rapid implementation of processes that are foreseeably relevant, industrialisable and scalable in accordance with the principle of 'demonstrate, scale, apply'. The area of application does not only refer to the conversion of regional structures, but it also includes the export of holistic process chain concepts.

Furthermore, the principle of open technology should be applied. All technologies that serve to achieve the climate targets should be considered. At present, H_2 should not be treated as the sole option as a carrier molecule; instead, alternatives (ammonia, LOHC) should also be considered in R&D. In order to maintain and increase Germany's technological lead in the long term, the further development of existing technologies should take into account their global applicability in order to enable comprehensive technology exports.

To support scaling up to the targeted TRL 8, the National Hydrogen Council recommends the rapid establishment of reference plants. For this purpose, integrated locations should be selected to promote a stronger interconnection between research and development and industrial implementation. These locations should feature at least the 10-MW-EL level for the investment decision as well as different regional structures in the process and supply chains. Using 10,000 to 100,000 t of hydrogen per year, it can be demonstrated that the technology works on a larger scale. From the perspective of plant construction, the implementation of corresponding ('first-of-a-kind') reference plants and interconnection strategies can also demonstrate their marketability beyond Germany as a location. It is advisable to set up large-scale research facilities and to couple the dynamics on the generation side (renewable energies) with the dynamics-free consumer side.

Figure 1 presents reference locations (coastal/offshore, port proximity/ship deliveries, inland location/regional supply) and their hydrogen demand in the years 2030, 2040 and 2050 on a map of Germany.

Figure 1: Reference locations (coastal/offshore, port proximity/ship supply, inland/regional supply) and their hydrogen requirements



When taking into account the current regional structure of the chemical industry as well as its forecast based on the scaling of the current state, regional clusters emerge. Based on this finding, it would be advisable to focus on experimental spaces with corresponding special features: Clusters near the coast with direct coupling for the development and expansion of H_2 offshore structures; locations near ports form reference structures for coupling with ship supplies (H_2, derivatives and intermediate products); inland locations form structures with regional supply. In this way, different technological approaches could be tested up to industrial implementation and could be considered and evaluated in terms of their sustainability. This assessment should also account for the aspects of efficiency, costs and climate neutrality.

Locations with refineries that require little specific basic research alongside upscaling and the rapid realisation of alternative process technologies represent a unique case. The decisive factors here are suitable framework conditions and a binding legal basis for investment decisions, which cannot be the direct subject of the assessment of research needs.

It takes a holistic analysis of the meaningful use of electrons to establish hydrogen technologies in the chemical industry. A comparison of electrification and alternative pathways for process heat, for instance, is needed. Similarly, the standardisation of components and their requirements in the form of component catalogues and fatigue tests is still pending.

Since many scaling and research questions have not been answered yet, there are currently no best practices in the area of business model development. It is important to create these, especially in the area of cross-sectoral activities, by using reference plants and sites as concept blueprints for the transformation of the chemical industry. This should be done with a view to where these topics are located in the industrial context. An application-derived top-down approach, which is then applied to different applications, is recommended. This requires close collaboration between research and industry to identify missing building blocks along the value chain, differentiate them according to research priority and then implement them in an application-oriented manner.

THE GERMAN NATIONAL HYDROGEN COUNCIL

On 10 June 2020, the German Federal Government adopted the National Hydrogen Strategy and appointed the German National Hydrogen Council. The Council consists of 26 high-ranking experts in the fields of economy, science and civil society. These experts are not part of public administration. The members of the National Hydrogen Council are experts in the fields of production, research and innovation, industrial decarbonisation, transportation and buildings/heating, infrastructure, international partnerships as well as climate and sustainability. The National Hydrogen Council is chaired by former Parliamentary State Secretary Katherina Reiche.

The task of the National Hydrogen Council is to advise and support the State Secretary's Committee for Hydrogen with proposals and recommendations for action in the implementation and further development of Germany's National Hydrogen Strategy.

Contact: info@leitstelle-nws.de, www.wasserstoffrat.de/en