BU: Fraunhofer IWES Hydrogen Lab Leuna: green hydrogen in the chemical industry

New ways to satisfy future demands with climate-neutral hydrogen

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In the future, hydrogen will be a fundamental building block for the transformation towards a climate-neutral economy. Its various production methods and possibilities for use will render it essential. For the conversion of the energy system, hydrogen offers the possibility of storing the volatilely produced renewable energies, and it will also play a key role in raw material use for the decarbonization/defossilization of the industry.

In the medium and long term, the development towards green hydrogen, with the electricity required for its electricity-based production coming exclusively from renewable energies, must therefore be adopted to comply with the reduction of greenhouse gases. As such, the task at hand is to work simultaneously and in an open-ended manner at different points in a new value chain. This is both exciting and challenging at the same time, especially since there is currently no market for green hydrogen.

At present, the market for climate-neutral hydrogen is still limited, with around 1.1 million t/a of hydrogen being used in Germany. This is almost exclusively in the chemical industry and based on gray hydrogen, that is to say hydrogen produced from natural gas by means of steam reforming.

The industry's future demands for climate-neutral hydrogen to implement respective decarbonization strategies have already been put into figures and assume a continuously increasing demand as of 2026, starting with the technological changeover to direct reduction in the steel sector. As early as 2030, demand across all sectors in Germany alone will add up to more than 3 million t/a[1], with continuous growth to around 20 million t/a in 2050+, subject to the continuation of current regional industrial structures and the parallel development of new areas of application such as in mobility and the heating market.

Similar growth is expected for the European and global markets, provided the envisaged climate goals are maintained. The current energy policy situation will lead to acceleration, as issues such as supply security are now increasingly coming to the fore.

We thus have the green light from climate-neutral hydrogen customers, but the challenges in terms of the development of the entire hydrogen value chain from an economic and ecological perspective will still involve a great deal of work.

First, the expansion of renewable energies is a fundamental prerequisite, but it will not be explored in more detail here. Rather, there is a need for rapid scaling of H_2 production capacities. As demand for green hydrogen grows, which consequently has priority in decarbonization strategies, this logically starts with the electrolyzer power conversion system and its coupling with renewable energy sources.

What does that mean for research needs in the short, medium, and long term? Essentially, the key to the success of a hydrogen economy is to ensure its safety, durability, reliability, cost reduction potential, raw material availability, and resilience along the entire value chain, from production to storage and transport right up to the respective area of use.

As a result, it is not only the technology itself which must be convincing, achieving trust and acceptance is also decisive. Naturally, new approaches must also be pursued in a technology-independent manner in order to achieve the greatest possible potential in all areas on the way to the clearly defined goal of sustainable climate neutrality. Achieving this goal under the current energy policy framework conditions increases the pressure for one thing, but above all the complexity.

Price of hydrogen production

The suitability of a technology for the production, transport, or even utilization of hydrogen is highly dependent on the location factors and the respective intended purpose. The quantity of climate-impacting emissions resulting from the production and use of a technology is the prominent evaluation criterion from a climate protection perspective.

However, the decisive aspect for the establishment of a sustainable green hydrogen economy will be the price of producing the hydrogen. This depends on the

1 Schattauer et al, NWR study 2022

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energy carrier employed, i.e green energy for green hydrogen, the investment costs for the conversion equipment including electrolyzers and both upstream and downstream infrastructure, and the availability and capacity utilization of the conversion equipment for volatility risk, including storage and transport strategies, as well as import strategies.

Gray hydrogen currently represents the benchmark, although the development will depend highly on political decisions, on the availability of raw materials, especially of gas at present, and gradually on the price of CO_2. However, the price development also highlights the dependence on considerable innovation progress in the areas of production, transport, and the conversion of the areas of application such as steel production, chemical industry, mobility, and heat.

In the field of green hydrogen, the availability of electrolyzers, regenerative power generation, and the process-engineering conversion of derivative production are particularly relevant. These areas of the hydrogen value chain must be developed and expanded quickly and simultaneously. Rapid transfer of research results to industrial implementation is essential here.

Research is needed

Innovation is an undisputed force behind sustainable economic development, especially when it comes to the establishment of new value chains, as will be required for the hydrogen economy. In the field of research, the need extends from ongoing basic research to applied research for industrial establishment, which is currently to be viewed as the priority, although the aspect of the qualification and further training of specialists must also be a focus at present.

Before green hydrogen can be distributed and used, it must first be produced in corresponding quantities and at competitive prices in the medium/long term. One key component here is the scaling of the production capacities of hydrogen systems and their components. Considering the urgency, this can initially occur on the basis of existing systems predominantly designed for factory production.

In parallel, however, there is an evolutionary need for research in the area of the analytical optimization of design and materials as well as their tailored manufacturing technologies in order to reach the next development stage in good time, including as far as costs, energy and material use, safety, and durability are concerned.

Further development and research infrastructure requirements aim to test MW electrolyzers as complete systems in order to be able to determine operating, performance, and degradation data under realistic operating conditions.

Further testing is required in particular for dynamic operation with simulated load fluctuations corresponding to the provision of renewable energies as well as with a view to the application areas regarding quality, that is hydrogen 3.5 or 5.0 and availability, ie. volatile production with continuous demand.

On the basis of these data, operating models can then be developed and economic analyses conducted in order to optimize the design and operation for industrial applications and enable integration into process steps. Furthermore, the integration of individual plants into complete energy systems, taking into consideration the resulting interactions on both the physical as well as the economic level, is also a central aspect.

In this respect, the interaction of electrolysis with wind energy in a dynamic context and the actual behavior of the technology units in the power grid deserve particular emphasis. Fraunhofer IWES now offers a comprehensive research infrastructure based on the three Hydrogen Labs in Bremerhaven, Leuna, and Görlitz for this purpose www.hydrogen-labs.fraunhofer.de/en.html

One previously underestimated area concerns the upcoming conversion of the existing plant infrastructure of the processing industry in the fields of the steel and chemical industries as well as, in the context of the development of synthetic fuels for defossilization of air and shipping traffic, in the field of refineries.

This is to be tackled in the short term in parallel to the ramp-up of climate-neutral hydrogen production and includes the thrilling task of decarbonizing decades-old production processes in ongoing operation by means of technological progress, for example, in the field of methanol and ammonia synthesis, or fundamental, new process technologies, as will be necessary in the field of synthetic naphtha. There is a broad technological basis for all processes, including steelmaking and e-fuels. The task increasingly concerns scaling up to industrial scale while taking all economic and ecological issues into account.

Ultimately, the topics of offshore hydrogen production and the digitalization of the energy system with the integration of a hydrogen value chain are also subject to a considerable need for technological development.

Prospects for offshore hydrogen production

The future demands for green energy in industry and the energy sector exceed the current hydrogen production capacity, which is largely based on fossil energy carriers at present. Identifying a location for sustainable hydrogen production is thus essential. However, the availability of onshore locations is limited. In contrast, offshore hydrogen production offers enormous potential for covering future green hydrogen requirements.

Offshore hydrogen production is in its infancy and faced with corresponding research and development challenges if it is to achieve the goal of cost-efficient offshore hydrogen production. These encompass the entire ecosystem: from the design and coupling of the components to the further development of individual technologies right up to the investigation of possible impacts on the marine environment.

At system level, the focus is on the total efficiency in terms of cost and efficiency. Correspondingly, system configurations in coupling the different technologies must and are being optimized in order to avoid unnecessary losses due to additional converter stages, for example. As regards the hydrogen components, the focus is particularly on the effects and stresses of the marine environment on materials.

The corrosion effects on the materials in the saline environment must be researched. With regard to the scaling up from the research laboratory to industrial scale, mechanical loads in both in-turbine concepts and hub concepts need to be investigated and taken into account during the development of the technology.

Electrolysis technologies must be optimized with respect to the generation profiles of the wind turbines so that they can be shut down if minimal signs of degradation appear. Harmful conditions must be researched to the extent that they can be avoided in accordance with appropriately designed control processes. Seawater treatment is a central research topic where media supply is concerned. A large quantity of these research topics is being addressed by the flagship project H2Mare, which can be described as a lighthouse project in the German research landscape.

A brief insight into current concepts and the present state of research of offshore hydrogen production is therefore exciting. In terms of volume and cost potential, offshore wind energy offers good conditions for energy-intensive hydrogen production compared with direct electricity use. Furthermore, compared with onshore wind energy, offshore wind energy also offers higher and more stable wind speeds, which is beneficial for more continuous operation of electrolyzers and results in lower hydrogen production costs.

Offshore hydrogen production can be divided into concepts for self-sufficient offshore hydrogen production which are not connected to the grid and hybrid concepts with a corresponding connection to the grid. The advantages of hybrid offshore hydrogen production result from the higher flexibility in operation and a greater abundance of usable electrical energy. In addition, with hybrid operation, provided there are no grid bottlenecks in the upstream power grid and sufficient transport and storage capacities are available for the hydrogen, the decision can be taken flexibly as to whether the electrical energy produced is fed directly into the grid or used for hydrogen production.

Drawing on corresponding model-predictive control procedures, it is possible to decide automatically during operation, on the basis of the contribution margins and other technical criteria, which form of operation is economically advantageous. In addition to participation in the conventional electricity market, that is electricity exchange or over-the-counter trading, a grid connection enables the provision of negative control energy. The addition of a fuel cell unit can expand a hybrid offshore hydrogen production system into a power storage system able to provide positive control energy. The disadvantages of this approach are the significantly higher investment costs.

The lack of a grid connection means self-sufficient offshore hydrogen production plants are associated with low investment costs and boast higher site flexibility. The hydrogen can be transported away either by pipelines or by vessels.

The advantage of pipelines is the high and continuous throughput volumes as well as the transport in gaseous state. The latter avoids further energy losses, which occur during liquefaction of the hydrogen, for example. Which transport solution is advantageous again depends highly on the distance to the coast and the volume to be transported. One challenge is the dimensioning and control of the wind turbines and the electrolysis or the individual plant components. Furthermore, the energy supply of the entire system, including the peripheral components, is provided by the wind turbines. This creates the need for new design concepts.

Conclusion

In all areas, staying ahead of the times is decisive in Germany when it comes to the implementation and transfer of the excellent scientific basis into innovations and essential for a climate-neutral economy.

However, time is becoming increasingly scarce. Consequently, many research issues must be tackled in parallel and in some cases in advance, and perhaps we may not always be on the right track in these fast-moving times, where framework conditions and requirements evolve drastically in unexpected ways, as the current energy crisis has shown, but the envisaged direction is still without alternative. Our first-rate research environment is in place and ready, and that is certainly a reassuring feeling.

Fraunhofer IWES: current projects

Investments in infrastructure worth approx. €70 million

Hydrogen Lab Bremerhaven: Electrolyzer system tests, coupling with multi-MW wind turbines, connection to virtual medium-voltage grid

Research facility from 2023

Hydrogen Lab Leuna: Green hydrogen production for the chemical industry, system testing of all types of electrolyzers up to 5 MW and auxiliary units, power-to-X

Research facility since 2021

Hydrogen Lab Görlitz: Testing of electrolyzer components, application in industrial manufacturing and decarbonization, test infrastructure with 12.3 MW

Research facility from 2023

H_2 Mare: Offshore production of green hydrogen

Project term: 2021–2025

H_2Giga: Serial production of electrolyzers for market ramp-up

Project term: 2021–2025

OntoHy: Fraunhofer competence platform for application-oriented hydrogen technologies

Project term: 2021–2025

H_2 Digital: Construction of a digital architecture for mapping of the green hydrogen economy

Project term: 2021–2022

More: www.hydrogen-labs.fraunhofer.de/en.html