Dovetailed innovation opens up new possibilities for hydrogen production at sea

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Wind turbine with positioning of an electrolysis platform © Siemens Gamesa Renewable Energy

The German Federal Ministry of Education and Research (BMBF) has launched three hydrogen flagship projects which reinforce the German National Hydrogen Strategy. The H2Mare flagship project is one of them, bringing together 33 partners from industry and science.

In the scope of this project, Fraunhofer IWES is investigating the scientific basis for quasi-autonomous offshore hydrogen production along a sustainable value chain. The offshore production of hydrogen demands a novel, compact form of PEM water electrolysis. At the same time, both a corresponding means of offshore water treatment for the electrolysis and a storage option for the hydrogen gas produced are being investigated. In parallel, a simulation platform is being developed that can be used to connect all the models and data created in the subprojects.

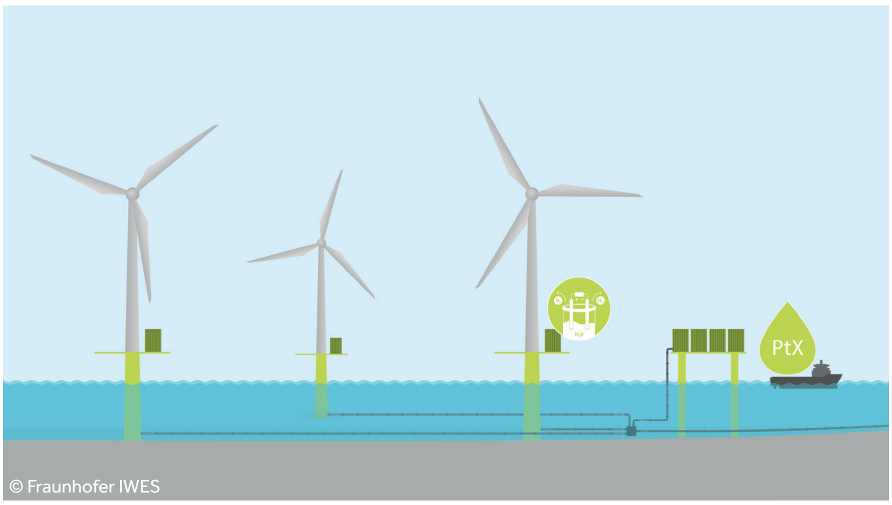
Efficient and stable offshore water electrolysis

For the planned, large-scale, offshore production of hydrogen, Fraunhofer IWES is investigating solutions for optimal interplay between the PEM electrolysis and directly coupled offshore wind turbines. When doing so, IWES is focusing on two main areas of research under the challenging offshore conditions. Firstly, the investigation, analysis, and modeling of stack components and their degradation behavior under dynamic partial load operation including development of the appropriate test infrastructure. Secondly, techno-economic simulations for optimal system dimensioning, which includes the electrolyzer itself and other defined system components like wind turbines, hydrogen storage systems, desalination units, and so on.

Fraunhofer IWES is collaborating with four other institutes for support in these areas: Fraunhofer Institute for Machine Tools and Forming Technology IWU, Fraunhofer Institute for Microstructure of Materials and Systems IMWS, Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB and Fraunhofer Institute for Chemical Technology ICT.

In the field of stack component analysis, IWES is carrying out chemical, electrochemical, and mechanical test series on specific material properties, performance, and their degradation behavior under simulated offshore conditions on laboratory cells and stacks measuring 25 cm^2, as well as with the research stack in the project. The changes in the material properties are evaluated on a microstructure level and correlated with the macroscopic measured variables as well as operating and ambient conditions in order to identify causal relationships with the help of models and derive recommendations for action for membrane and material optimization.

In electrolysis, special focus is always on the membrane or membrane electrode assembly (MEA). Particularly with regard to the requirements on the operating parameters/ conditions for offshore operation, it is expected that the MEA must demonstrate increased robustness and durability.



Graph: A container for electrolysis is positioned on the turbine´s platform. End Products are transferred via pipeline or vessel

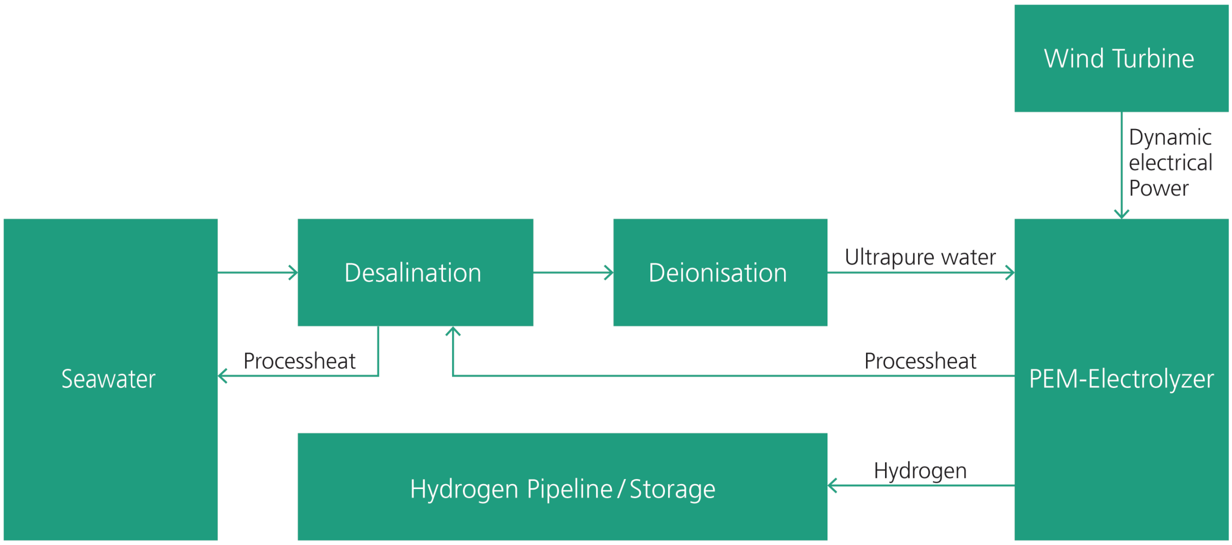


Figure 1 Schematic representation of hydrogen production with coupled seawater desalination

To this end, investigations are planned to determine the service life of the membranes with the aid of accelerated stress tests (AST) with regard to chemical and mechanical resistance. Optimized membrane compositions, e.g., stabilization structures, can play an important role in this.

In the course of the research work, and to achieve the project goals, numerous qualification tests will be carried out on laboratory test benches in order to identify target-oriented MEA compositions, analyze the effects of complex offshore scenarios, e.g., with regard to the challenging treatment of seawater and ion load), and advance fundamental findings in the material area of the cell components.

For this purpose, the experimental test infrastructure for the prototype level will be developed and set up in the first project phase, among other things. Since this is to be an independent and open system for the scientific characterization and evaluation of PEM stacks, in addition to the flexible test bench of 46 kW, 1.5 kA, 30 bar, balanced and differential pressure, a research stack of 300 cm^2, 1 to 10 cells, will also be developed together with the partner institute IWU. This will enable the scientifically independent investigation and development of components, test protocols, and analytics.

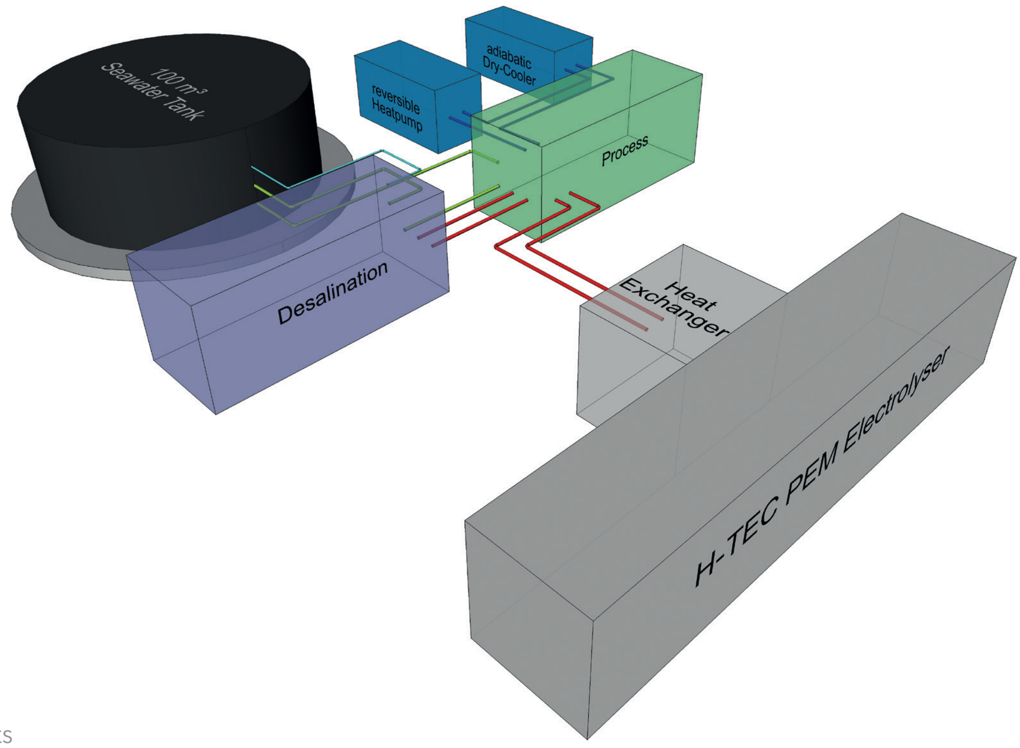


Figure 2 Schematic representation of the test bench for seawater desalination using waste heat from a PEM electrolyzer

A coordinated and networked experimental and digital infrastructure will be developed, set up, and validated in parallel for the implementation of this work. When doing so, particular importance will be attached to the preparation and definition of interfaces so that the results obtained can be linked between the experimental and theoretical research topics and levels. Furthermore, the scalability from small to large, from the laboratory level to the prototype level and the industrial level, will play a decisive role.

Seawater desalination

The production of sustainable hydrogen can be based on a variety of procedures. At present, the splitting of water by means of a proton exchange membrane (PEM) electrolyzer represents an approach with great potential, as it does not require much space and contains no liquid electrolyte needing to be replaced over the course of time. PEM electrolysis requires pharmaceutical-grade, ultrapure water with very low conductivity.

However, as only natural seawater, which has very high conductivity, is available offshore, the water must be processed first of all. In addition, aquatic organisms naturally present in seawater represent an obstacle for the downstream process steps, so it must first be ensured that all contaminants are removed from the water.

Seawater processing systems have already been in use in industrial settings for many years now, for example for the production of drinking water aboard cruise liners. Although these technologies have already been employed for decades, there are significant differences where the processing of water for PEM electrolysis is concerned. The processed water must be considerably purer in order to be split into its components in a subsequent step.

In addition, the scales of operations such as the available electrical and thermal capacity are very dynamic and subject to the prevailing wind conditions. Furthermore, environmental compatibility also plays an important role. Process chemicals and the introduction of heat at specific points within a wind farm must urgently be avoided.

Within the project, Fraunhofer IWES is constructing a test bench for testing seawater desalination systems with direct coupling to a PEM electrolyzer. The idea is to utilize the waste heat produced during the electrolysis to supply the requisite process heat for a desalination system, which could significantly increase the overall efficiency of the hydrogen production.

The diagram in Figure 1 shows the whole process with coupling of the electrolyzer and seawater processing system. The waste heat from the electrolysis provides the process heat for the processing of the seawater.

This, in turn, supplies ultrapure water as a raw material for the electrolysis. The resulting oscillating circuit must be precisely tuned to ensure the water processing system and electrolysis do not have negative effects on each other. Research is currently being carried out into the coordination of the components and the investigation of the system behavior with a highly dynamic electrical output from a wind turbine.

The test bench planned by Fraunhofer IWES is to have a 100m^3 seawater tank, which can be filled with different qualities of water such as self-mixed standard water or seawater from the respective deployment site. A process container with an integrated thermal unit makes it possible to control the test procedures and run reproducible test scenarios. The electrical connection of the PEM electrolyzer is initially intended for simple electrical tests, but the possibility should present during the project term to couple actual wind turbines to the test field or perform dynamic electrical tests with a Hardware in the Loop (HiL) simulation.

In addition to testing of the technical facilities, topics such as the filtration of bio organisms, deposits in pipelines, the stability of the seawater, and maintenance aspects also play a role. In this way, the planned test bench can produce a fully comprehensive overview of the autonomous, long-term, offshore operation where modifications to optimize the whole process can be quickly applied.

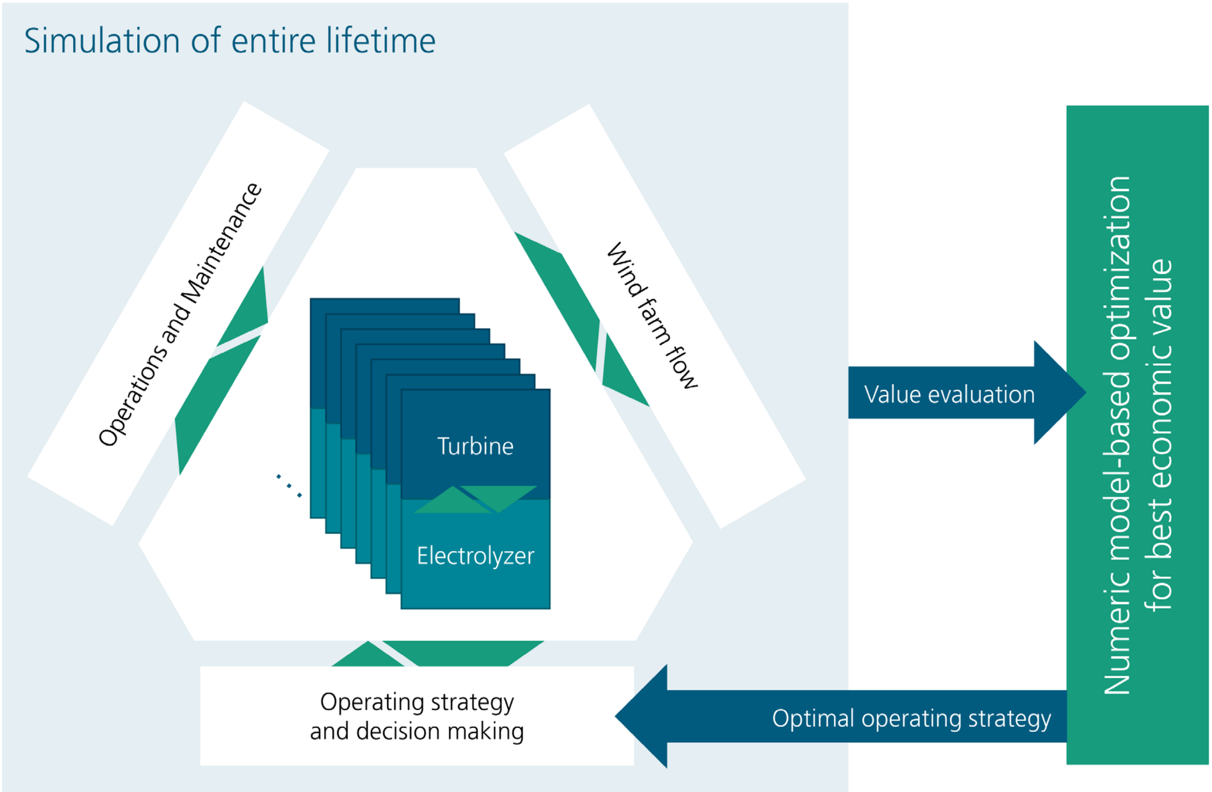


Figure 3 IWES' simulation platform allows for integrated simulation of turbines, electrolyzers, and overarching aspects in multiple dimensions. The system model is used for system simulation, optimization, and value evaluation

The goals are essential findings and demonstrators for directly coupled hydrogen electrolysis in preparation for a MW-scale demonstrator and initial projects in the North Sea in the second half of this decade.

Simulation platform for co-simulation

There are many factors which determine the price of offshore hydrogen. In addition to the investment costs, these predominantly include the operating and maintenance costs, which depend particularly on the form of operational management chosen. In contrast to conventional wind energy use for the generation of electricity, direct offshore hydrogen production is a completely novel operating scenario.

The optimal operation of a hydrogen wind turbine is different to that of conventional wind turbines, as there is no grid connection and the electrolyzer places different demands on the turbine within a local hybrid system. There are also additional components which must be considered in a service and maintenance concept. This value chain for hydrogen is to be mapped and optimized in the project.

At Fraunhofer IWES, the entire value chain is modeled in specific component models, which are individually wrapped as function mock-up units (FMU) and are connected in co-simulation. FMU is a standardized exchange format for models that allows for the coupled simulation of different simulation tools, timescales, and granularities. These component models are joined in a simulation platform with integrated interconnection strategy for models and optimization, which has been specifically developed for this purpose.

Co-simulation plays a central role in the project. It makes it possible to reuse component models and connect them in a new context without considerable extra work. Overall, operation and maintenance, wind farm flow and wake calculation, operational management, and the wind turbine-electrolyzer system are the central components, see figure 3. These are augmented with more specific component models, e.g., for auxiliary systems within the turbine-electrolyzer system.

All component models interact with each other. At the core is the coupled wind turbine and electrolysis system for which the hydrogen yield is to be optimized. The wind turbine operation perturbs the wind flow by producing wakes, which reduce the wind speed and increase turbulence. This, in turn, affects the loads of individual turbines downstream and results in unfavorable operating conditions. Furthermore, individual components of the wind turbine-electrolyzer system can fail and require replacement. This is mapped by the O&M model Offshore Times. These factors must be taken into consideration in the overall operational management concept in order to define a robust operating strategy.

The operating strategy determines the optimal way to operate the wind turbines, i.e., defines when and how much hydrogen they should produce at any given time. Each unit of hydrogen produced is accompanied by damage caused to the system components. The relationship between hydrogen yield and damage depends on the external conditions. Ultimately, this results in an optimization problem, as damage that has not occurred allows for a longer service life and thus allows for an increased cumulative hydrogen production.

The development process of the operational strategy requires two different timeframes. Simulation of a detailed models for a short timespan to evaluate the trade-off between hydrogen production and induced component damage. These results are then mapped to fast-running surrogate models. Using fast-running models of all components, evaluation and mathematical optimization of the operational management concept over 20 years also becomes possible.

Ultimately, co-simulation in the H_2Mare project is a central tool for the development of modular energy systems. The replaceability of component models thanks to a uniform interconnection strategy offers shorter development times and increases the reusability of simulation models.

Optimized operational management strategies allow for increased power or hydrogen production with increased revenue and reduces risks and uncertainty.

Outlook

The H_2Mare flagship project was launched in April 2021 and will be completed in 2025.

The goals are essential findings and demonstrators for directly coupled hydrogen electrolysis in preparation for a MW-scale demonstrator and initial projects in the North Sea in the second half of this decade.

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