Sector coupling could aid energy transition

Words: Prof. Andreas Reuter and Prof. Jan Wenske

Since the 2015 Paris Agreement, there has been a global consensus that the transition to a CO_2-neutral energy supply needs to be achieved worldwide within the next few decades. At the same time, considerable technological progress has been made with both onshore and offshore wind energy, for example, and, as a result, the energy generated in this way is now able to compete with conventional forms of energy largely without subsidies. Nevertheless, the market for wind turbines is stagnating worldwide.

This suggests that low generation costs alone are not the key to the rapid transition of the energy system and that other factors also have a role to play. Based on current developments in Germany, the article below aims to show that the speed of transition is limited, but alternative paths for the use of renewables in sectors that have undergone only little decarbonization to date can lead to a new dynamic through the use of green hydrogen, i.e. hydrogen produced from renewable energies, as a parallel form of energy transportation. This could create new market impulses for the wind industry, nevertheless the associated technical challenges also need to be tackled.

Current status of the energy system transition

By 2030, the aim is to reduce Germany's climate-damaging CO_2 emissions by 55% compared to the reference year of 1990. Moreover, a reduction of 40% by this year has been set as an interim goal. And, although this short-term goal is once again within reach, due to the economic impact of the COVID-19 crisis, it is likely that the long-term targets will not be met without significant additional efforts.

The decarbonization of mobility and the building sector in particular present a problem; the measures taken to date fall far short of the requirements.[1] What's more, the further expansion of renewable energy production is reaching its limits. One of the limiting factors at present is the sluggish expansion of the grid and the question of how to distribute renewable electricity.

Against this background, solutions are being discussed which will accelerate the linkage of energy sectors and also create parallel distribution and utilization paths. One approach which is currently enjoying significant backing is the intensive use of hydrogen.

1 The impact of greenhouse gas reduction of the climate protection program 2030 (short report) partial report from the 'Greenhouse Gas Projection: Further Development of Methods and Implementation of the EU Effort Sharing Decision in the 2019 Projection Report ('Policy Scenarios IX')' project by Ralph O. Harthan et. al. commissioned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and the German Federal Environment Agency

New approaches to sector coupling with hydrogen

The current enthusiasm for hydrogen as an energy carrier is based on the multiple possible applications of the gas, which also address a number of the challenges posed by the transition of the energy supply:

- Power recovery: hydrogen as a store

  Large amounts of renewable energy are already curtailed now on windy and sunny days because the distribution infrastructure cannot guarantee its use. There are also insufficient electricity storage facilities available for such days. This renders the use of surplus electricity highly attractive for the production of hydrogen with the possibility of direct usage in other sectors or, if necessary, storage for subsequent reconversion.

- Mobility with fuel cells: storage with high power density

  Hydrogen stored under high pressure can be used for mobility applications which are currently not viable with the existing battery technology. In combination with fuel cells, storage systems can be developed with the requisite high-power density, e.g., for heavy-duty transport.

- Mobility with synthetic fuels: a solution for the aviation sector

  The use of batteries is not feasible for certain applications due to weight and capacity restrictions and, in addition, the supply of hydrogen at high pressures is not possible for safety reasons. For these cases, especially in the field of aviation, synthetic, hydrogen-based fuels which can be handled just like conventional fossil fuels make an ideal choice.

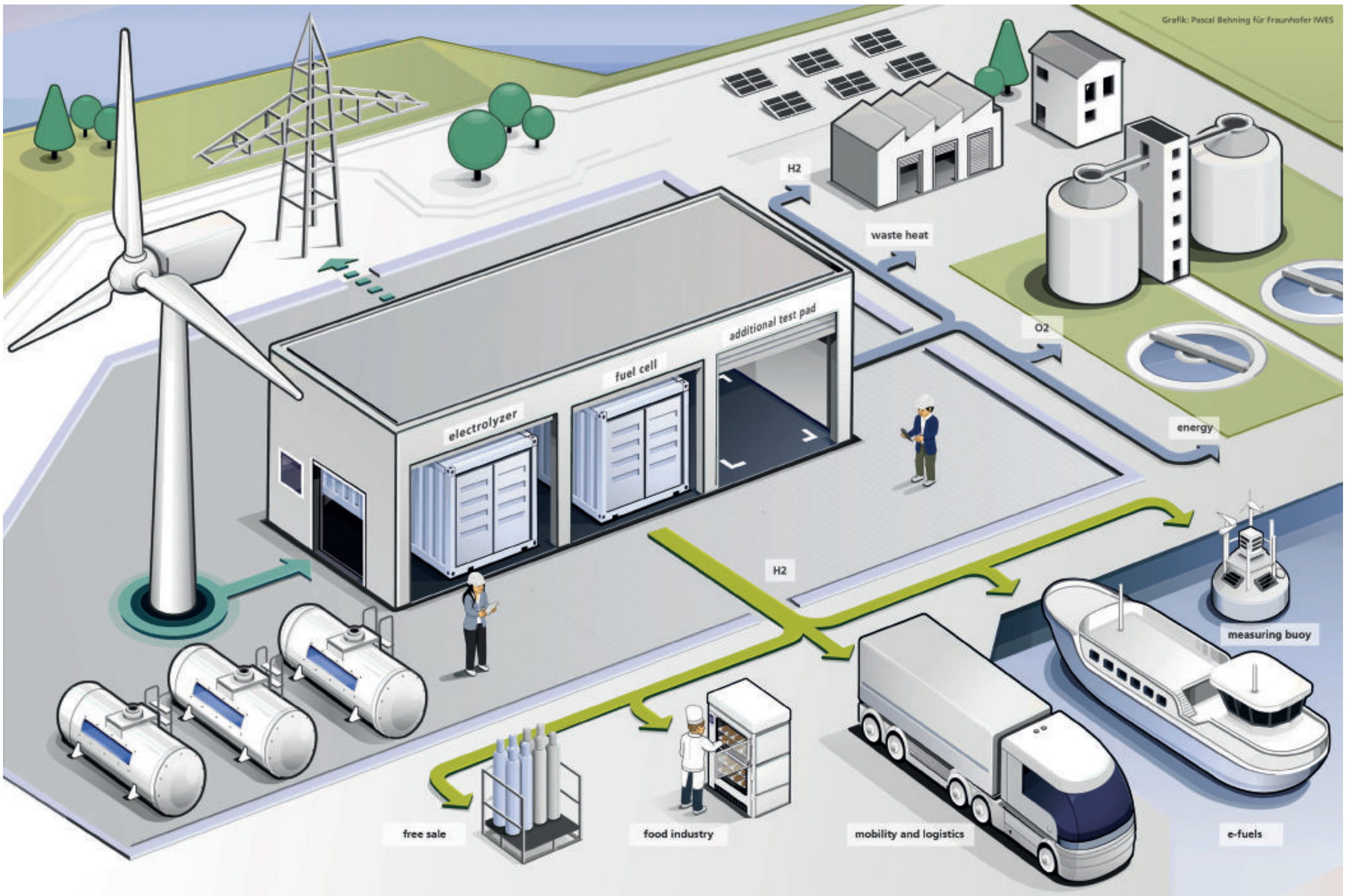
In the medium term, the question of replacing oil and gas for material use also arises. Here, too, green hydrogen represents a truly viable basis as an alternative, climate-neutral raw material for the chemical industry.

The advantages of the parallel use of hydrogen in an industrial nation

One of the greatest challenges faced by the energy transition is the time it will take to reshape a highly industrialized society, given that the changes to the energy infrastructures are associated with considerable planning efforts and costs. In this respect, the development of a parallel path for the use of renewable energies is expedient even if this path, as in the case of the use of hydrogen, is not ideal in terms of energy.

In the specific German context, there are further advantages to this sector coupling approach:

- Germany has a well-developed gas network combined with large caverns as storage facilities, which can be adapted, at least in part, for use with hydrogen.



Example of the qualification of electrolyzers in combination with wind energy. Fraunhofer IWES test field in Bremerhaven

- The spatial separation of production and use is possible; looking at medium-term planning in particular, it is foreseeable that it will not be possible to establish enough local renewable generation structures. Accordingly, one solution would be to fall back on energy imports in the form of hydrogen produced in the world's windy and sunny regions.
- Furthermore, the increased use of hydrogen means that transitional solutions can be applied, e.g., with blue hydrogen, which is produced on the basis of natural gas with subsequent compression of the carbon dioxide. This means that the availability of hydrogen and the development of wind and solar energy capacities will be partially decoupled for a certain time.

Technical challenges

From a research perspective, it can be said that the expansion paths for the production and application of green hydrogen currently under discussion by politicians are undoubtedly ambitious and indeed, in part, visionary. The current status of the requisite technologies, production processes, capacities, and integration capacity in the electrical supply grids is assessed in a less differentiated and overly optimistic manner. There is no robust ramp-up strategy for the necessary technological development of reliable, large-scale, series products in materials research, systems engineering, storage technology, and process and manufacturing technology on both the production and application side.

The systems available today, e.g., for electrolysis cannot be freely scaled and, for the most part, only have TRLs of between 5 and 7. Furthermore, product- and application-related technical guidelines and standards and, as a result, validation and certification processes based on them are lacking. Only alkaline electrolysis, which boasts the longest development history, could currently meet the requirements for large electrolyzers.

It is a well-known development policy error linked with overambitious objectives to wish to omit important and essential intermediate steps when scaling from the kW to the MW range. There is a real danger of an effect as seen in the initial stages of large-scale wind energy turbine development in the 70s and 80s with the then unsuccessful large-scale systems in Germany, Sweden, and the USA. The history of offshore wind energy also shows parallels of critical scaling and ramp-up steps as well as their temporarily negative consequences, which could still be avoided in the context of the industrialization of green hydrogen technology. A far from exhaustive list of overriding technical issues and challenges for a hydrogen-based sector coupling is given below:

- **Technical maturity and costs of electrolyzers and fuel cells**

  This remains comparatively low for systems in higher power classes, compared to PV and wind turbines and still fails to meet the demands for use in public energy supply systems and the transport sector, heavy-duty traffic, shipping. To date, not enough research has been conducted into degradation mechanisms under the expected highly dynamic load, due to preferred green generation and operating conditions, temperature and pressure fluctuations, as well as the specific environmental conditions e.g., offshore. It goes without saying that there are various highly developed solutions, yet these only exist for niche applications: space travel, submarines, weather stations, laboratory applications.

  However, these are neither technically easily scalable nor do they fit into the necessary cost structure for large-scale commercial, industrial applications. The

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efficiency ranges of all the systems show considerable potential. This potential must be exploited for future applications over the course of the ramp-up. PV technology is an apt example of successful optimization over the last decades. Thanks to successive cost reductions and efficiency increases, it has become one of the most cost-effective forms of energy generation.

- **Process and production technology**

  The production of stacks for electrolyzers and fuel cells remains barely industrialized. This goes both for the production of individual components e.g., bipolar films and membranes as well as the mechanical stack assembly. Today, complete systems are created in a kind of manufacture / prototype production process, which, in terms of production capacities and quality as well as costs, is not designed for high volumes and large-scale production.

  Looking at this today, there is only limited potential for automation with this system production, but the cost level for medium volumes of multi-megawatt turbines is similar to that of the wind industry. Over the past decades, the wind industry has also achieved an astonishingly low level of production costs at system level. Other mobility applications, fuel cells, on the other hand, require a high degree of automation with a high mechanical packing density for significantly higher quantities and smaller system outputs.

- **Robustness**

  The systems are designed at their interfaces for the highest purity levels, e.g. water supply for ELY, hydrogen at the FC, i.e., the investments required for the corresponding treatment of the supplied operating materials and end products: filtration, deionization, drying, etc. are still very high.

  Subsystems for integration into energy sectors, such as compressor stages, fail all too frequently in sample applications e.g., H2 filling stations, so that subsystems to meet high availability requirements would have to be designed redundantly today. For cost reasons, large-scale offshore hydrogen production with capacities in the GW range would be facilitated by the option of direct seawater electrolysis or, at least, operation with only weakly treated water. This direct offshore hydrogen production would also take the strain off electrical transmission grids or save the otherwise necessary additional expansion.

- **Integration into the public electrical supply network**

  Especially on the side of the electrical grid, the grid interface, the electrolyzers are currently not very advanced. The use of controlled rectifiers, preferably in thyristor technology, with input voltages in the low voltage range and DC output voltages for the electrical stack supply in a range of around 100 V represents the state of the art.

  The principle behind this type of grid connection results in comparatively high grid perturbations. A planned, large-scale integration of these systems with a total power of x0GW would be neither compatible with the grid nor cost efficient since considerable additional measures/investments would be required to stabilize the grid. The electrical interfaces of the electrolyzers must be designed to serve the grid to allow these systems to play an active role in grid stabilization and support Here, too, there are no appropriate standardization and certification regulations for future, converter-based equipment in grid parallel operation which would satisfy the resulting converter shares, in some cases up to 100%, in future electrical supply grids.

- **Transport and distribution logistics**

  The transport and distribution logistics of the generated green hydrogen represent a considerable cost factor in the context of the future hydrogen economy. Decentralized generation puts additional strain on the supply grids. Centralized generation, e.g., offshore or close to the coast, poses the question of further transportation.

  There is already a very well-developed pipeline-based natural gas supply and transmission structure throughout Europe offering sufficient capacity. There are also significantly smaller, yet dedicated hydrogen transmission grids. Nevertheless, a variety of questions arise with regard to compatible admixture, degradation by hydrogen corrosion of the materials used and suitable and cost-effective materials and principles for intermediate storage. Often, the focus here is not on general feasibility, as this is a given, but rather on the realization of compatible CAPEX and OPEX.

- **Adaptation of the applications**

  A further aspect requiring research and development should also not be neglected. The switch to hydrogen, for example in the area of steel production, also demands considerable, and, in part, serious adjustments in terms of further processing and refinement for specific end applications, e.g., the automotive industry. The properties of the starting products of conventional steel production and hydrogen-based steel production differ considerably. Such adjustments can also be expected in other future applications, e.g., with the switchover to essentially CO_2-neutral wastewater treatment plants using electrolysis, methanization, and high-temperature fuel cell technology.

These technological challenges should not be interpreted as fundamental 'obstacles' to a future hydrogen economy which works to further sector coupling, but rather as a chance to develop climate-friendly high technology. This means jobs and the bolstering of Europe as an industrial location in the field of green technology and could serve as an example for sustainable social and industrial development which does not involve sacrifices, yet which also preserves natural resources.

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