Hydrogen BAROMETER

Independent assessment of the hydrogen economy in Germany

Issue 2
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Preface

A functioning hydrogen economy is an essential prerequisite for a successful national economy in Germany. This realisation has become much sharper in recent weeks and months and is currently determining political action.

At the same time, green hydrogen is becoming increasingly competitive due to the dynamic market development. Legislative and regulatory prerequisites must now be created to enable the practical ramp-up of the hydrogen economy.

In this Barometer issue, we once again take the pulse of the hydrogen economy and provide content overviews of planned LNG terminals and their impact on a future hydrogen import, the EU Commission's current REPowerEU plans, storage potential in Germany as well as a cost analysis for hydrogen in road transport and a critical look at H_2 use in gas-fired power plants.

We are particularly proud that we were able to win Andreas Schierenbeck, a member of the board of HH2E AG, one of the most important drivers of the hydrogen economy, for a short interview in this issue.

I hope you enjoy reading this issue and that we can once again provide some food for thought.

Dr. Henning Schuster
Managing Director E-Bridge Consulting GmbH
Baumschulallee 15 | 53115 Bonn
www.e-bridge.com
Tel. +49 228 90 90 65 0

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Theses and mood

Key statements from the H_2 Barometer

Upstream

1. Due to the growing feed-in of renewable energy and the high prices of basic materials, green hydrogen will become even more competitive in 2022 and 2023. If the utilisation of the electrolyser is optimised to approx. 50%, it is already possible to achieve competitiveness with conventionally produced H_2 today.
2. The current design of the renewable power purchase criteria needs to be revised so that the multitude of requirements does not become a showstopper for the ramp-up of the hydrogen economy.
3. The import of LNG is necessary to secure the natural gas supply in the short term. For economic reasons, however, the terminals should be designed directly for the import of LH_2 so that a conversion to hydrogen is economical in the medium term.

Midstream

1. To implement the REPowerEU plans, there is a need for a significant increase in sector-specific H_2 targets, a pragmatic regulatory framework for the conversion of gas to H_2 grids and a short-term increase in the permissible blending rate of hydrogen in the gas grid.
2. The salt structures in Germany offer attractive potential for the development of H_2 storage facilities on the required scale. The installation of large-scale H_2 storage enables a significant gain in self-sufficiency.

Downstream

1. The current high prices for fossil fuels are also making hydrogen competitive in the transport sector much sooner than expected. Green hydrogen is also becoming increasingly attractive. Thus, the dependence on imports for fossil fuels can be reduced.
2. H_2 gas power plants can serve as a reserve for cold dark slack periods, but compared to possible alternatives (RE expansion, grid expansion), the reconversion of hydrogen into electricity only makes sense in exceptional cases, as it is not very efficient and cost-intensive.

The current dynamic market development accelerates the "out" for fossil fuels and increases the competitiveness especially for green hydrogen. This increased competitiveness becomes clear when looking at the transport sector. Hydrogen is still too expensive for large-scale reconversion to electricity.

At the same time, legal criteria and an unpragmatic regulatory framework slow down the expansion of electrolysis capacities and the conversion of gas to H_2 networks. Using the underground storage potential could increase national self-sufficiency and simplify the integration of green hydrogen.

Interview with Andreas Schierenbeck, Member of the Board of HH2E AG

HH2E AG is a cleantech company that aims to build large-scale power plants of the future in many regions. These HH2E plants convert peaks of solar and wind power into a continuous flow of heat, carbon-free electricity and green hydrogen. The aim is to use them to supply regionally based, manufacturing companies or even the municipalities themselves. The power plant obtains the wind and solar energy during the hours with the lowest prices - in order to be able to make competitive offers overall.

Mr Schierenbeck, where do you see the biggest development in hydrogen demand in the short term (the next 5 years)?

We are currently seeing a highly dynamic development in the energy industry. Industry in particular, but also other sectors that are difficult to electrify, are pursuing the goal of substituting grey hydrogen with green hydrogen. However, due to the price increases for fossil fuels and the new GHG quota regulation, we expect the greatest increase in demand in the transport sector. Massive investments in hydrogen trucks and hydrogen refuelling stations are planned here. The race in heavy-duty transport between battery-electric and fuel cell drives has not yet been decided. Especially here, the competitive motivation for converting to hydrogen is great. Because it makes sense, I am sure that both technologies will coexist.

In your view, what measures are now necessary to enable a rapid ramp-up of the hydrogen economy?

The main problem lies in the "introduction" of the hydrogen market. Suppliers can offer green hydrogen at a certain price, but the delivery date is still one to two years in the future. For this period, the supplier needs a purchase guarantee and the consumer has to commit to a fixed price without being able to predict the price development on the market.

For a supply in the future, a present commitment with risk is therefore required. The market is thus in a state of limbo. The market needs an "initial spark", similar to the H2Global programme, which is intended to promote the international import of hydrogen. We would like to see similar market-supporting measures for domestic production in order to accelerate the market ramp-up and first utilise the domestic potentials.

What role do you see for HH2E in the development of the hydrogen economy?

HH2E is the first company to produce hydrogen from renewable energy on a large scale. The use of electricity generation peaks that might otherwise have to be capped without further use supports and accelerates the expansion of renewable energies and also serves to stabilise the electricity grid. At the same time, HH2E is a frontrunner in green hydrogen production according to the European Renewable Energy Directive RED II. Our goal here is pure sector coupling, as we produce only green heat and green hydrogen from renewable electricity. In this way, HH2E contributes to the efficient use of renewable energies and thus to the success of the energy transition.

Andreas Schierenbeck, co-founder and Member of the Board of HH2E AG


HYDROGEN
FUEL
H2
UPSTREAM

Development of hydrogen production costs in 2022 based on the Hydex

- The Hydex in 2022 has increased significantly across all generation technologies compared to the previous year and is also significantly more volatile than in 2021. This can be explained in particular by the increased electricity, gas and CO2 prices (Figure 1).
- In times and days of high RE feed-in, green hydrogen is cheaper than conventional hydrogen based on natural gas.
- In the first half of 2022, green hydrogen was cheaper than blue hydrogen on 26 days and cheaper than grey hydrogen on 23 days. In contrast, green hydrogen was cheaper than blue hydrogen on 30 days and cheaper than grey hydrogen on 22 days in the entire year 2021.
- If one assumes usage hours of 4000 h/a for the production of green hydrogen and only considers the days with the cheapest electricity input prices, green hydrogen becomes competitive compared to conventional hydrogen (Figure 2). This would result in a production price of 6.53 EUR per kg of green hydrogen..
- Comparison of annual averages:
  - Hydex Green:
    - 2021: 157,77 €/MWh (5,26 €/kg) vs. 2022: 290 €/MWh (9,66 €/kg)
  - Hydex Blue:
    - 2021: 95,97 €/MWh (3,20 €/kg) vs. 2022: 174,17 €/MWh (5,81 €/kg)
  - Hydex Grey:
    - 2021; 90,48 €/MWh (3,02 €/kg) vs. 2022: 170,24 €/MWh (5,67 €/kg)

Due to the growing feed-in of renewable energy and the high prices of basic materials, green hydrogen will become even more competitive in 2022 and 2023. If the utilisation of the electrolyser is optimised to 50%, it is already competitive with conventionally produced H_2.

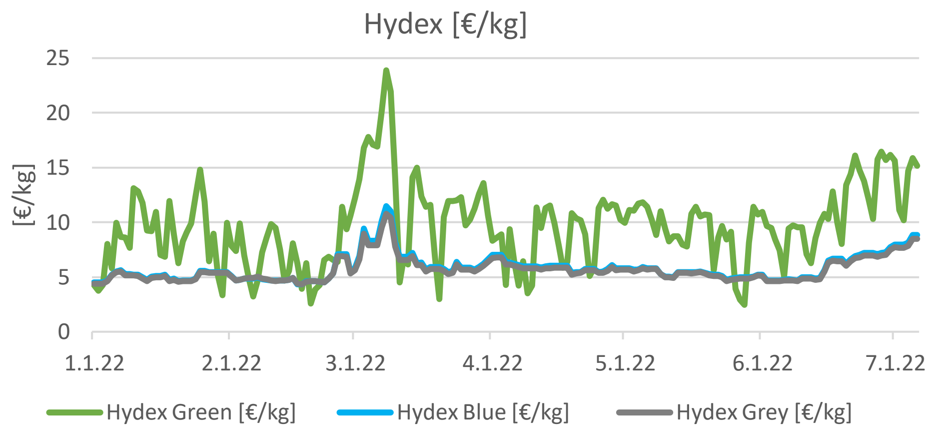

Figure 1: Hydex - Historical price development 2022

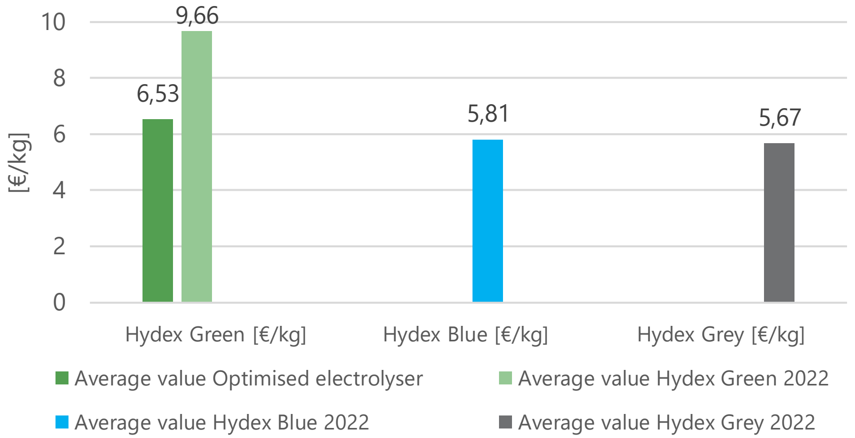

Figure 2: Hydex average prices 2022 and with 50% of the cheapest days for green hydrogen production

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Green hydrogen production options (Draft Delegated Act RED II)

Option 1:
Proof of direct connection to the electrolyser

Criteria :
- Additionality a), b), d)

Option 2:
Power generation and electrolysis take place in the same plant

Criteria:
- Additionality a), b), d)

Connection to RE system

Electrolyser

O_2 H_2

Connection to the mains supply

Option 3:
Electrolyser is located in bidding zone with over 90% RES share; plus the number of RES electricity hours are not exceeded.

Criteria:
- None necessary

Option 4:
Electricity from 100% RE, proof through PPA (volume of PPA ≥ required amount)

Criteria:
- Additionality a)[2], c)
- Temporal correlation
- Geographical correlation

Option 5:
Use of grid electricity in the context of imbalance settlement; derating of a renewable electricity system (redispatch).

Criteria:
- None necessary

Criteria for renewable electricity procurement

Additionality:
a) Commissioning of electrolyser max. 36 months after electricity plant
b) Capacity expansions for electrolysis at the site up to 24 months after commissioning
c) No subsidies received for operating or investment costs[1]
d) Capacity expansions for electrolysis at the site up to 24 months after commissioning[2]
e) No electricity drawn from the electricity grid for the production of hydrogen; proof via intelligent metering system[1]

Temporal correlation (Options):
a) Electrolysis in the same hour as RES electricity generation[3]
b) Electricity purchased from storage located downstream of the same grid connection point as electrolyser and charged within the same hour it was generated in PPA plant[3]
c) Electricity purchase, during a one-hour period; electricity price ≤ 20 €/MWh or electricity price < 0.36 times the current CO2 certificate price.

Geographical correlation (Options):
a) Power plant (under contract via the PPA) is/was located in the same bidding zone as the electrolyser at commissioning.
b) RES plant is located in adjacent bidding zone if the same electricity price exists between the bidding zones in the same hour or the electricity price in the zone where RES electricity is produced is lower than in the bidding zone where the electrolyser is located.
c) RE plant is located in a neighbouring offshore bidding zone.

The current design of the criteria for renewable electricity procurement needs to be revised so that the multitude of requirements does not become a showstopper for the ramp-up of the hydrogen economy.

1 does not apply to (partial) installations for the purpose of research, testing and demonstration.
2 shall enter into force on 01.01.2027 and shall not apply to installations commissioned before that date
3 shall enter into force on 01.01.2027, unless the installation is supported within the framework of a transitional phase. Until 31.12.2026, temporal correlation is limited to one calendar month.

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LNG terminals: Catalysts or barriers for the H_2 economy?

- To secure the supply, alternative import possibilities for gas are necessary in the short term. Through own LNG terminals, a more flexible supply of natural gas and possibly hydrogen is possible.
- The terminals are so-called floating terminals - moored ships that receive the liquefied natural gas from the tankers, convert it into gas, pump it ashore via pipeline and feed it into the grid.
- The following import terminals are planned:
  - Wilhelmshaven: Start of construction May 2022, import target: 9 bcm gas per year
  - Brunsbüttel: Start of construction Sept. 2022, import target: 3.5 bcm gas per year
  - Stade and Lubmin: Start of construction probably end of 2023
  - There is already a future perspective for LNG terminals that are now being built to secure the gas supply in Germany and Europe. This usually envisages that the LNG terminals will also be used to import hydrogen-based energy sources as the supply of climate-neutral energy sources grows.

Claudia Kempfert, German Institute of Economic Sciences
"We don't need any new LNG terminals now, that made sense 15 years ago when they decided to build a pipeline. We need liquefied gas for the coming winter, and we can get it either via the existing liquefied gas terminals in Europe, i.e. via the Netherlands and Belgium, or via ships that have been ordered for the coming winter, but which do not mean a fixed terminal. Instead of LNG terminals, it would be better to build hydrogen terminals in order to be able to import green hydrogen in a few years' time."

German Association of Energy and Water Industries (BDEW)
"As natural gas is no longer transported to us only via pipelines, LNG contributes to further diversification and flexibilisation of the import sources for natural gas in Germany. With its logistical flexibility, LNG also ensures a strengthening of global supply security."

Martin Kaltschmitt, Professor of Environmental Engineering and Energy Economics at the TUHH
"If Germany's energy supply is to be realised in a climate-neutral way by 2045, it is very likely that this will only be possible through an additional import of green energy [...]. In the medium term, an LNG terminal can also be used "multifunctionally" for the landing of hydrogen. From a technical point of view, this is in principle feasible and also desirable, although different technical [...] adjustments are necessary for the individual cryogenic energy carriers compared to a classic LNG terminal."

Association of German Engineers (VDI)
"The LNG terminals planned in Germany should also be directly designed for the import of hydrogen. The terminals are long-term investments. Retrofitting at a later date is possible, but it does not make economic sense. This is because too many large components have to be replaced so that the terminals can be used for the import of liquid hydrogen (LH_2)."

The import of LNG is necessary to secure the natural gas supply in the short term. For economic reasons, however, the terminals should be designed directly for the import of LH_2 so that a conversion to hydrogen is economical in the medium term.

MIDSTREAM

Russian aggression accelerates the need for H_2 ramp-up

REPowerEU Plan of the EU Commission of 18 May 2022

- Dual objective: Restructuring the European energy system to end import dependency on Russia and for more climate protection.
- Hydrogen and biomethane emerge as the 4^{th} pillar and key to sustainable security of supply alongside energy efficiency (13% instead of 9% by 2030), renewables expansion (45% instead of 40% by 2030) and diversified common gas sourcing.
- 2030 target: EU-wide production of 10 million tons of green H_2 annually (333 TWh) & import of a further 10 million tons of green hydrogen by 2030.
- In addition to green hydrogen, other forms of generation should also be used for H_2 production, including hydrogen from nuclear power.
- Development of import corridors via country partnerships: among others, three corridors from the Mediterranean region and Africa as well as corridors from the North Sea region, the Baltic States and, in the future, Ukraine. For this purpose, partnerships are to be concluded with countries outside the EU.
- In addition, biomethane production is to be increased more than tenfold to 35 billion m^3 (350 TWh) by 2030.
- To achieve the desired independence from Russian energy imports, investments of around €300 billion are to be made.
- Furthermore:
  - Survey of Europe-wide hydrogen infrastructure needs (TEN-E Regulation) by March 2023, including with ENTSOG.
  - Accelerated completion of the first IPCEI project reviews by summer.
  - Increase investment in Clean Hydrogen Joint Undertakings in Horizon Europe to €200 million.

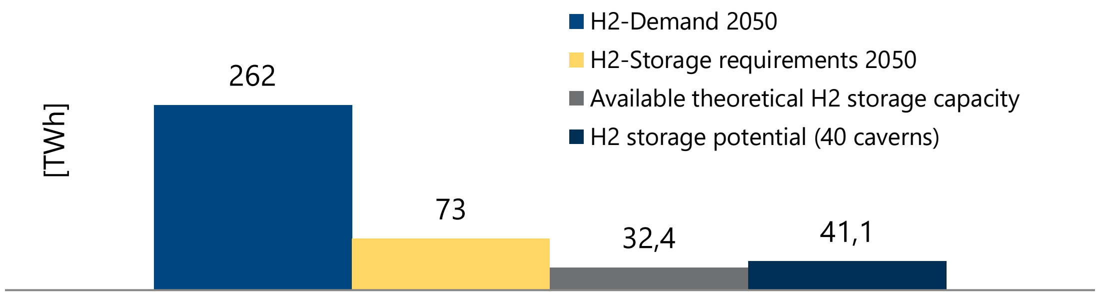
A real opportunity for the rapid development of the European hydrogen economy, but also a major challenge:

- In order to achieve the proposed doubling of the already ambitious H_2 targets for 2030, a significant increase in the sector-specific H_2 targets under the Renewables Directive is likely to be necessary, among other things.
- The rapid development of the necessary infrastructure will have to take place primarily through conversion projects from the natural gas to the H_2 grid and requires a - so far missing - pragmatic regulatory framework.
- The simultaneous redefinition of gas import routes, especially by switching to LNG supplies, and the accelerated development of the H_2 sector could lead to conflicts of use. Especially for the start-up phase of the hydrogen economy, an increase in H_2 admixture in the natural gas grid should therefore not be taboo.
- How serious the Commission is about the implementation of the REPowerEU plan and thus with the development of the hydrogen economy is shown by the intention to auction 250 million emission rights from the market stability reserve ahead of time to finance it, against the criticism of climate protection protagonists.

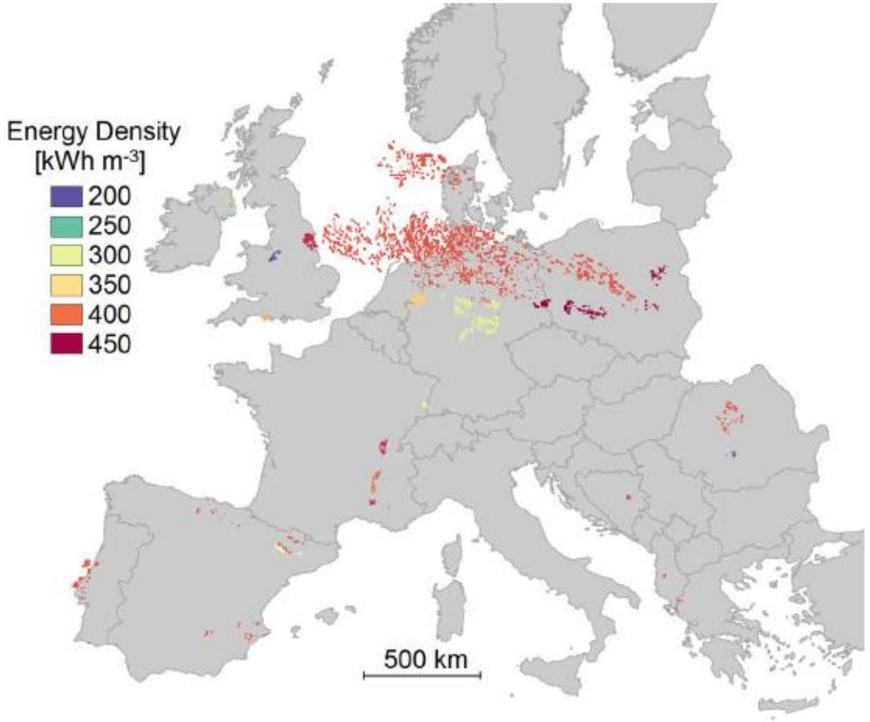
In order to implement the REPowerEU plans, there is a need for a significant increase in sector-specific H_2 targets, a pragmatic regulatory framework for the conversion of gas to H_2 grids, and a short-term increase in the permissible blending rate of hydrogen in the gas grid.

H_2 storage potential in Germany

- Currently, the level of gas storage in Germany is only about 65.2%. [1] Further future gas supply reductions require measures to ensure long-term security of supply.
- Dependence on Russian gas can be reduced in the future by tapping possible storage facilities for hydrogen at an early stage.
- Large-scale gas storage facilities have a maximum capacity of 255 TWh (242 TWh usable capacity plus cushion gas). 31 cavern storage facilities (including 4 pore storage facilities with a total of 1.7 TWh) can be converted to hydrogen, but the energy storage volume of the caverns drops from 162 to 31 TWh.
- The long-term scenario of the BMWK (TN electricity) expects a hydrogen demand of 262 TWh and a storage demand of 73 TWh by 2050.
- The construction of 40 new H_2 caverns with an investment volume of 12.8 billion euros can provide an additional storage capacity of about 41 TWh. [2]
- Salt structures in northern Germany (see figure on the right) offer potential for large-scale (cost-effective) hydrogen storage. In addition, the generated RE load peaks that do not flow into the electricity grid can be stored in the form of hydrogen.



Distribution of potential salt cavern sites in Europe with their corresponding energy densities [3].



The salt structures in Germany offer attractive potential for the development of H_2 storage facilities on the required scale. The installation of large-scale H_2 storage enables a significant gain in self-sufficiency.

[1] Status 25 July 2022, BNetzA
[2] DBI Gas- und Umwelttechnik (2022) Wasserstoff speichern – so viel ist sicher. URL: https://www.bveg.de/wp-content/uploads/2022/06/20220610_DBI-Studie_Wasserstoff-speichern-soviel-ist-sicher_Transformationspfade-fuer-Gasspeicher.pdf
[3] Caglayan et al. (2020) Technical potential of salt caverns for hydrogen storage in Europe. URL: https://www.sciencedirect.com/science/article/abs/pii/S0360319919347299


H2
DOWNSTREAM

Hydrogen supply costs at the filling station increasingly competitive

- **The hydrogen production costs were determined using the annual average costs of hydrogen prices in 2022 (full costs).**
- Basis is the hydrogen full cost index developed by E-Bridge.
- Green: 11,69 €/kg, Blue: 6,61 €/kg, Grey: 6,19 €/kg
- Three options* were presented and compared on the basis of the current hydrogen production costs :
  - Option 1: Cavern storage, transmission of hydrogen via pipeline and distribution via truck
  - Option 2: Cavern storage, transmission of hydrogen via pipeline and distribution via pipeline
  - Option 3: LH2 tank storage, transmission and distribution via truck
- All three options were compared with current diesel transport costs for passenger car: 1 kg H_2/100 km and heavy duty: 8 kg H_2/100 km.
- Figures 1 and 2 show that the hydrogen supply costs (incl. storage, transport and filling station operation) for conventional hydrogen in all three options are below those of the diesel reference value for both passenger cars and heavy-duty diesel transport..
- Green hydrogen is significantly above the full cost value of the previous year due to the tense situation on the basic material markets and the increased opportunity costs for green electricity. Optimising the electrolyser to the 4000 cheapest hours of the year would have delivered a cost saving of approx. 34% in 2022 so far (see p. 8).

The current high prices for fossil fuels are also making hydrogen competitive in the transport sector much sooner than expected. Green hydrogen is also becoming increasingly attractive. Thus, the dependence on imports of fossil fuels can be reduced.

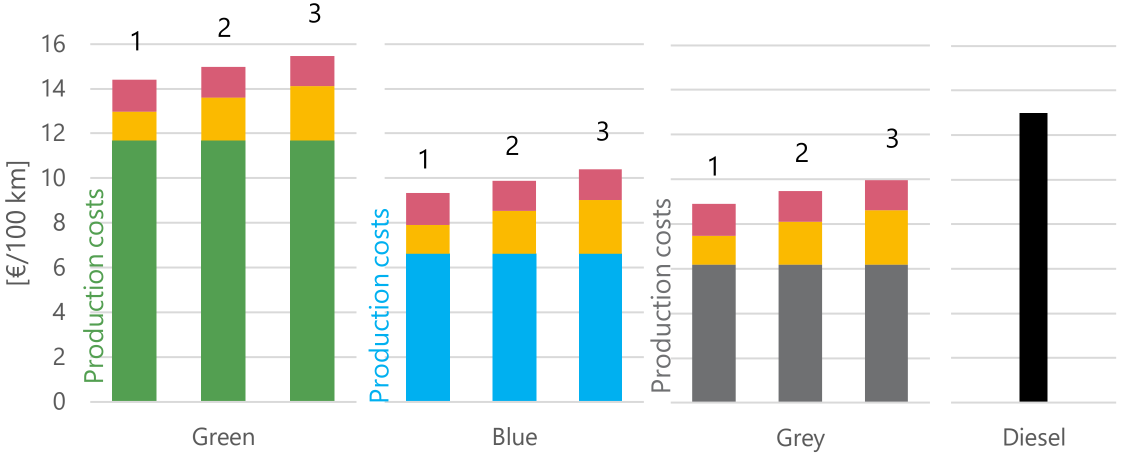


Fig. 1: Water supply costs with 3 different options for storage and transport compared to current diesel costs (car).

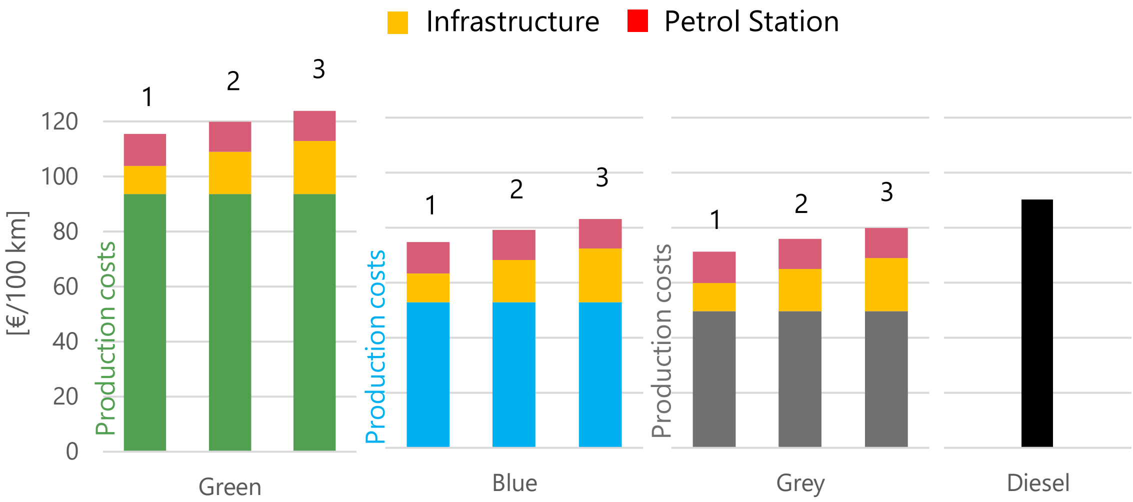


Fig. 2: Hydrogen supply costs with 3 different options for storage and transport compared to current diesel costs (heavy duty).

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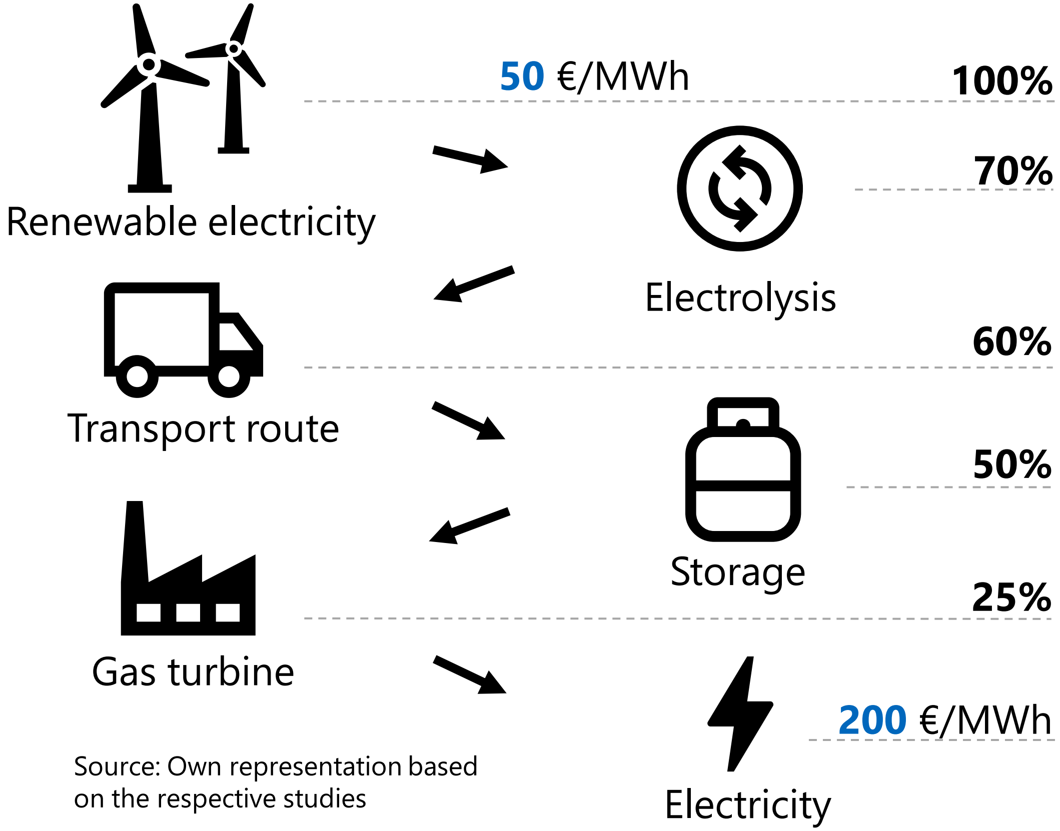
* Reuß et al. (2019) A hydrogen supply chain with spatial resolution: Comparative analysis of infrastructure technologies in Germany

Economic viability and efficiency of H_2 gas power plants

- The coalition agreement envisages gas-fired power plants in future for the reconversion of hydrogen into electricity. This is intended to contribute to climate-neutral security of supply.
- In this way, renewably generated electricity does not have to be fed directly into the grid or consumed immediately but can be used in a staggered manner in terms of time and space.
- The most important energy studies assume that hydrogen power plants will be used in the future. However, no study gives an outlook on the required capacities, efficiencies or costs. In the illustration on the right, the pure efficiency chain is roughly considered in order to show the order of magnitude of the efficiency losses and the costs (assumption: marginal RE generation costs of 50 EUR/MWh). A central storage facility fed by a pipeline is assumed. The hydrogen power plant is located at the storage site.
- The overall efficiency of the reconversion chain is only 25 % after the 4 process steps. This means that three quarters of the original electricity is lost, and the costs rise from 50 EUR/MWh to 200 EUR/MWh. Thus, the order of magnitude for efficiency and costs can be roughly classified.
- The efficiency analysis shows both a low efficiency and a cost-intensive quadrupling of the electricity supply. Hydrogen power plants should only be used for peak loads.



Source: Own representation based on the respective studies

H_2 gas power plants can serve as a reserve for cold dark periods. Compared to possible alternatives (RE expansion, grid expansion), however, the reconversion of hydrogen into electricity only makes sense in exceptional cases, as it is not very efficient and cost-intensive.

[1] Agora (2020), Klimaneutrales Deutschland;
[2] FZJ (2020), WEGE FÜR DIE ENERGIEWENDE-Kosteneffiziente und klimagerechte Transformationsstrategien für das deutsche Energiesystem bis zum Jahr 2050
[3] Prognos (2021), Klimaneutrales Deutschland 2045 Wie Deutschland seine Klimaziele schon vor 2050 erreichen kann
[4] Dena (2018), dena-Leitstudie Integrierte Energiewende
[5] Dena (2021), Klimaneutralität 2045 – Transformation der Verbrauchssektoren und des Energiesystems
[6] BMWi (2021), Langfristszenarien für die Transformation des Energiesystems in Deutschland
[7] LBST (2019), Wasserstoffstudie Nordrhein-Westfalen

Andreas Gelfort
agelfort@e-bridge.com

Dr. Christian Schneller
cschneller@e-bridge.com

Dr. Philipp Heuser
pheuser@e-bridge.com

Leona Jovy
ljovy@e-bridge.com

Philipp Steffens
psteffens@e-bridge.com

Vito Tisci
vtisci@e-bridge.com

E-Bridge Consulting GmbH
Baumschulallee 15
53115 Bonn
www.e-bridge.com
Tel. +49 228 90 90 65 0