Hydrogen BAROMETER

Independent assessment of the hydrogen economy in Germany

Issue 1
May 2023

Preface

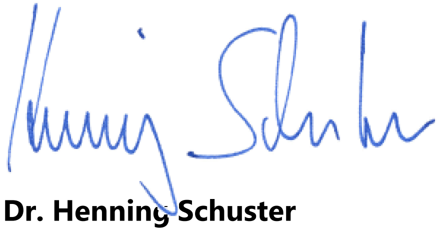
The hydrogen economy continues to gain momentum and the discussions about procurement, transport and application of the energy carrier that is so important for climate neutrality are becoming more concrete. As usual, we provide summaries of the most important developments on the way to the "coming of age" of the hydrogen economy in this issue of the H_2 Barometer.

This time, positive signals predominate, for example, for investors in electrolysis plants due to the revision of the RED II guidelines or for the (partial) development of the heat market due to the passing of the Building Energy Act.

With the Hydex, we have already designed a first price index, which is published regularly and is the basis of many valuable analyses. We have further developed this price index and are very pleased to present the HydexPLUS, an optimized full cost index that serves as a robust valuation tool for investors and regulators.

In the interview with Christian Ehret, Managing Director of Avacon Netz GmbH, it shows that hydrogen will play a significant role for power grid operators in the future, as this molecule-based energy carrier offers flexibility in the integration of high renewable energy outputs.

I hope you enjoy reading this H_2 Barometer and that we can once again provide some food for thought.



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

Theses and overall sentiment

Key findings from the H_2 Barometer

Regulation

The redesign of the criteria for recognizing hydrogen as a renewable energy source is a positive signal to the hydrogen industry and provides investors with greater legal certainty. The longer transition periods and deadlines also ensure that the market ramp-up of the hydrogen industry is not "snuffed out in its infancy"..

Upstream

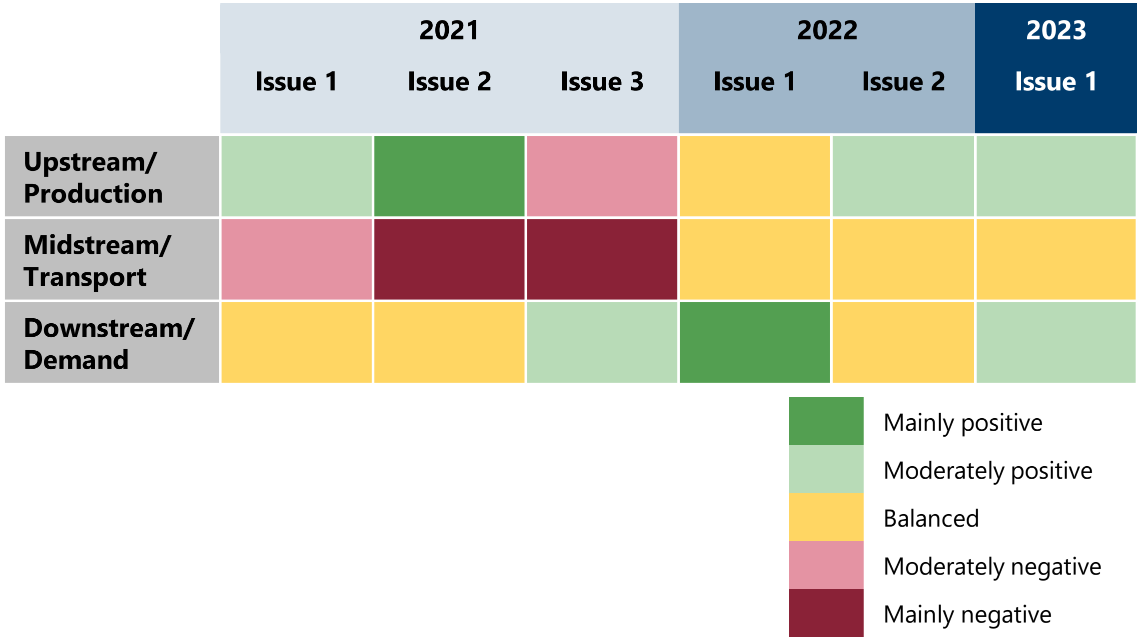
1. Due to the increasing renewable energy feed-in and higher expected gas and CO_2 prices, green hydrogen will gain competitiveness in the future. If the utilization of the electrolyser is optimized at 50% per year, the marginal costs already demonstrate competitiveness compared to conventional H_2.
2. The new HydexPLUS serves as a robust assessment tool for investors to determine the cost-optimal design and operation of hydrogen production facilities. Over time, there is indeed a cost increase due to the energy crisis, but volatile fluctuations remain absent..

Midstream

1. A hydrogen network company should be established without the initially proposed government participation. A national hydrogen network company would slow down the ramp-up of a hydrogen economy. Additionally, incentives for investments in hydrogen networks by the transmission system operators (TSOs) would be eliminated.
2. The overseas transport of ammonia is more cost-effective than the alternatives of liquid hydrogen (LH_2) and liquid organic hydrogen carriers (LOHC). However, the energy requirements for conversions occur at different points in the infrastructure. Therefore, depending on the energy availability in each specific case, it needs to be examined which transportation option is cost-optimal.

Downstream

1. The amendment of the Building Energy Act takes significant steps towards climate protection. The decision particularly has positive implications for the future of hydrogen (H_2) in Germany. Both the heating sector ("H_2-ready systems") and the mobility sector (H_2 refueling stations) are thus being developed for hydrogen use.
2. Hydrogen can be an important component for sustainable energy supply in certain application areas of the mobility sector. However, the forecast of hydrogen demand in transportation varies significantly due to external factors and regional conditions. Therefore, conducting individual studies on regional areas is meaningful in order to assess the specific needs and potentials.



The significant increase in commodity prices presents both opportunities and challenges for the competitiveness of green hydrogen. The HydexPLUS full-cost index allows for optimizing electrolysers in terms of design and operation costs. The competitiveness and increased legal certainty provided by the updated RED II Directive offer favorable conditions for the ramp-up of the hydrogen economy.

The ongoing political discussion regarding a possible national hydrogen network emphasizes the importance of a national hydrogen infrastructure. However, state participation should not hinder investments from network operators.

Technology neutrality in the heating and mobility sectors is a positive signal, but an individual regional assessment for the technically and economically viable use of hydrogen remains essential


INTERVIEW

Interview with Christian Ehret, Managing Director of Avacon Netz GmbH (I/II)

The Avacon Netz GmbH is the regional grid operator in Lower Saxony, Saxony-Anhalt, Hesse, and North Rhine-Westphalia. From the North Sea coast to southern Hesse, it ensures the secure energy supply of municipalities, industry, commerce, and households through its more than 85,000 kilometers of electricity and gas networks. As a grid operator with an extensive 110 kV network, it is already a significant player in the energy transition. With 23 GW of installed renewable energy capacity indirectly and directly feeding into the high-voltage grid, nearly one-fifth of Germany's current renewable energy capacity is connected to the Avacon network

Mr. Ehret, what developments in the hydrogen economy are you currently considering in the planning of your power grid?

We are well aware of the capacity of our power grid and therefore understand the implications of the expansion figures resulting from the Easter Package for our network and network expansion plans. As a major gas network operator, we also know that the gas infrastructure offers significantly more capacity in direct comparison. Unfortunately, this potential is hardly considered in the discussion on how to implement the energy transition. We firmly believe that the energy transition can only succeed if we fully incorporate the existing infrastructure into the plans. Our gas network can become H_2-ready on a comprehensive scale with relatively low effort.

We have the ingredients to incorporate green molecules into the solution concept through pipeline transport as well. We need to have the courage to believe in a genuine hydrogen market with domestically produced and imported green molecules in order to also have a good answer to how we can make renewable energies available throughout the year and how we can utilize the installed renewable energy capacity of over 600 GW by the mid-2030s.

We see this potential and believe that the planning of power and gas grids needs to be even more closely integrated with electrolyzers. However, these are currently our perspectives, as the network planning itself is still based on "conventional" grid expansion due to the yet undefined framework conditions for electrolyzers and H_2 injection into the gas grids

Christian Ehret, Managing Director Avacon Netz GmbH

Interview with Christian Ehret, Managing Director of Avacon Netz GmbH (II/II)

In your view, what role can hydrogen play in meeting current challenges in the power grid?

With the study "Netzstrategie 2035" conducted in collaboration with E-Bridge, our initial goal was to project the figures from the Easter Package onto our network area. However, as the study progressed, we discovered that we have network regions with very high feed-in into the high-voltage grid. In these areas, electrolyzers converting several hundred megawatts of power can make a significant contribution to reducing network expansion. This would bring numerous benefits: we could quickly absorb energy in specific locations without the time-consuming construction of power lines, it could provide an important solution for energy storage during periods of high wind and solar availability, and our simulations have shown operational hours of up to 7,000 hours, indicating economic viability as well. As network operators, we see our role as providing "search areas" for suitable electrolyser locations, while the operation of the facilities should be ensured by market-oriented participants.

In your view, does the current legal and regulatory framework provide the right incentives or do you see a need for action?

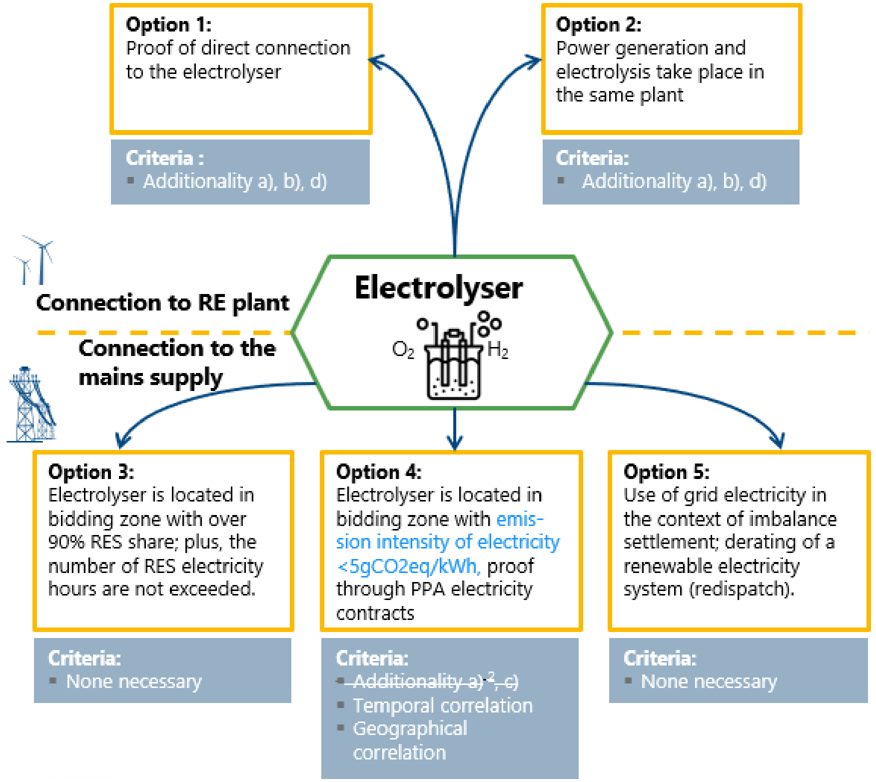
Of course, many things are still uncertain at the moment. When it comes to the development of hydrogen, we find ourselves in a "chicken and egg" dilemma. Many customers want to decarbonize but don't know when hydrogen will be available and at what price. On the other hand, network operators don't know what the framework conditions for gas networks or hydrogen networks will be. The question of the future of the gas network is also too unclear to take the necessary steps decisively at this point. Although I sense some movement in the discussion, I believe that there is still too much dogmatic reasoning. Considering hydrogen as the "champagne of the energy transition" is one of these points. The misconception that we can primarily meet the energy demand of the electricity sector, transportation sector, and heating sector through the power infrastructure is another. As for the availability of hydrogen, I believe that where there is a market, there will also be supply. In that case, the step to incorporate a capable existing infrastructure like the gas network into future plans is not far away.

Additionally, we are currently experiencing the painful realization of the risks of relying too heavily on individual energy sources. Therefore, solely focusing on the power grid is not ideal in my opinion, even from this perspective. So, what do we need from my point of view? A reliable ramp-up curve for hydrogen, a clear commitment that the gas network will play an important role in a major transformation, reliable economic framework conditions that allow for long-term investment decisions, and, last but not least, pragmatic regulation for hydrogen networks.

I have great concerns about the considerations of the Commission and Council regarding unbundling at the European level. It does not seem sensible to create such high barriers for the transformation of gas networks into hydrogen networks.


REGULATION

Green hydrogen production options (Draft Delegated Act RED II)



The redesign of the criteria for recognizing hydrogen as renewable energy is a positive signal to the hydrogen industry and provides more legal certainty for investors.

The longer transition phases and deadlines additionally ensure that the market ramp-up of the hydrogen industry is not "snuffed out" prematurely.

Update
Status 2022

Feb. 2023: EU Commission presents revised rules for renewable hydrogen

- **Additionality:** Capacity expansion up to 36 months instead of 24 months after the electrolyser`s commissioning.
- **Temporal correlation:** Hourly resolution starting from 2030 instead of 2027.
- **Geographical correlation:** In principle, the renewable energy facility and electrolyser must be located in the same bidding zone, although member states can define smaller areas for sites to ensure compatibility with network planning..

Additionality:[2]

a) Commissioning of the electrolyser within a maximum of 36 months after the power plant.
b) Capacity expansions for electrolysis at the site up to 24-36 months after commissioning.
c) No ongoing subsidies for operational or investment costs.
d) Capacity expansions for electrolysis at the site up to 24-36 months after commissioning.
e) No electricity procurement from the power grid for hydrogen production; proof through an intelligent metering system.[1]

Correlation over time (Options):

a) Electrolysis in the same hour as the renewable energy power generation[3]
b) Electricity procurement from a storage system located behind the same grid connection point as the electrolyzer, charged within the same hour it was generated in the Power Purchase Agreement (PPA) facility[3]
c) Electricity procurement during a one-hour period; electricity price ≤ 20 €/MWh or electricity price < 0.36 times the current CO_2-certificate price

Geographical correlation (fulfillment of one variant required):

a) The power plant (contracted through the PPA) is/was located in the same bidding zone as the electrolyser at the time of commissioning.
b) The renewable energy facility is located in an adjacent bidding zone if there is an equal electricity price between the bidding zones in the same hour, or if the electricity price in the zone where the renewable energy power is generated is lower than in the bidding zone where the electrolyser is located.
c) The renewable energy facility is located in an adjacent offshore bidding zone. However, member states can define smaller areas for sites to ensure compatibility with network planning

[1] Does not apply to (partial) installations for the purpose of research, testing and demonstration
[2] Comes into force from 01.01.2028 and does not apply to plants commissioned before that date.
[3] Comes into force from 01.01.2030, unless plant is promoted within the framework of a transitional phase. Until 31.12.2026 2029 temporal correlation is limited to one calendar month.

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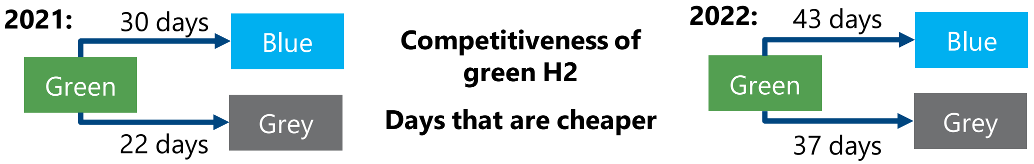
Hydex - Development of hydrogen production costs from 2021 onwards

- In 2022, the Hydex cross-border cost-based hydrogen price index increased significantly on average across all generation technologies and was also significantly more volatile than in 2021. This can be explained in particular by the increased and more volatile electricity, gas, and CO_2 input prices (Figure 1).
- Annual average values in comparison::

Hydex	Green	Blue	Grey
Mean value 2021 EUR/MWh	158	96	90
Mean value 2021 EUR/kg	5.26	3.20	3.02
Mean value 2022 EUR/MWh	358	209	202
Mean value 2022 EUR/kg	11.93	6.96	6.73

- In times of high RE feed-in, green hydrogen (Hydex Green) is competitive with conventional H_2 based on natural gas (Hydex Blue and Hydex Grey).



- Assuming full-load hours of 4000 h/year in the production of green H_2 and considering only days with the lowest electricity input prices, green hydrogen becomes competitive compared to conventional hydrogen (Figure 2). This results in a production cost of 7.27 EUR per kg of green hydrogen.

> Due to growing RE feed-in and higher expected gas and CO_2 prices, green H2 will gain competitiveness in the future. If the utilization of the electrolyser is optimized to 50 % per year, the marginal costs already show a competitiveness compared to conventional H_2.

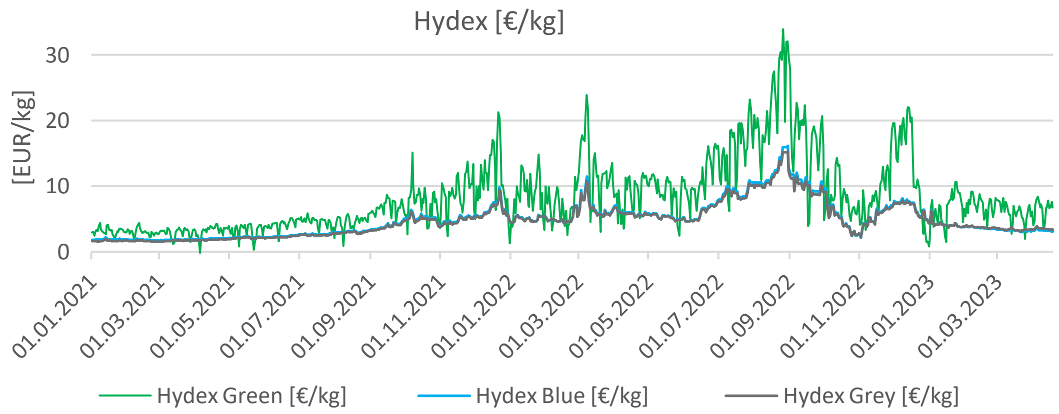


Figure 1: Hydex - Historical price development 2021 - 2023

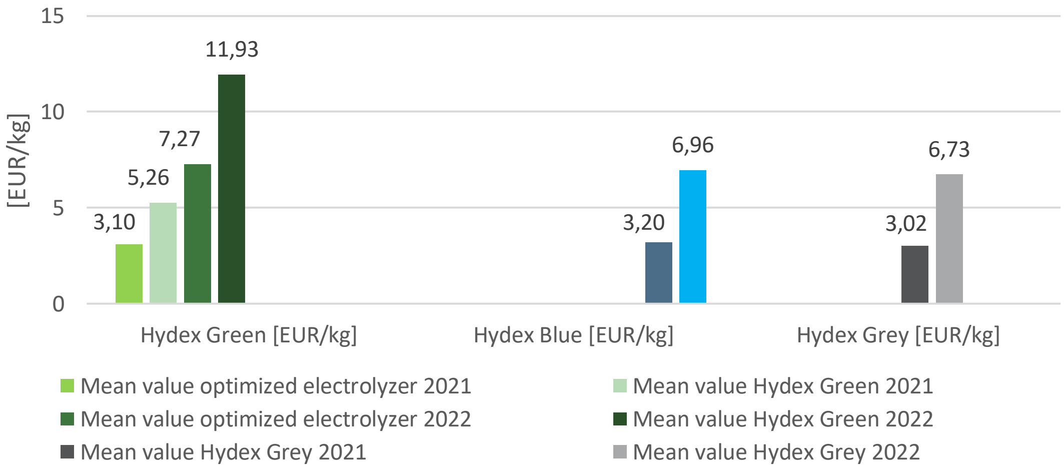


Figure 2: Hydex - Average prices 2021/2022 and using 50% of the cheapest days for green hydrogen production.

HydexPLUS - Introduction of an optimized full cost index (I/II)

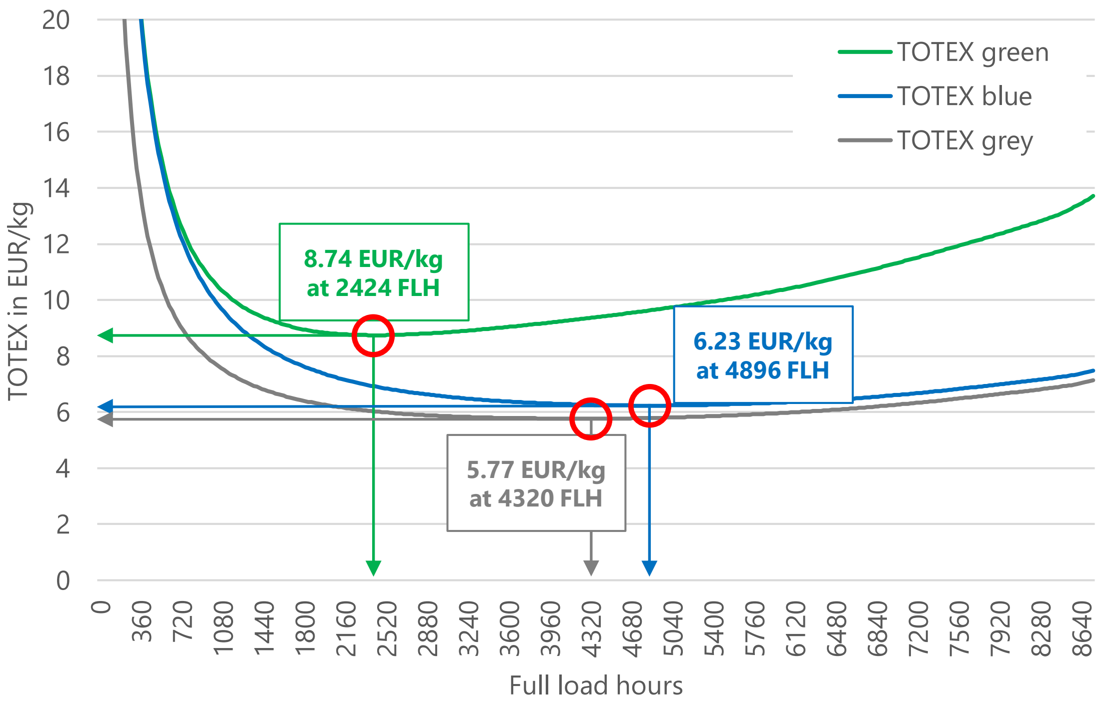
Motivation and Methodology

- The marginal cost index Hydex can be used as an indicator and simple pricing instrument based on electricity, gas, and CO_2 prices. However, for investment decisions, a full cost index is required, which takes into account optimized operation of the electrolyser..
- The full costs of hydrogen production include the investment costs for electrolysis or reforming, as well as an operationally optimized full utilization hour count.
- The variable operating costs of green, blue, and grey hydrogen production are calculated based on the commodity prices of the past year (t - 365 days) and then sorted in ascending order (following the principle of an "annual duration curve").
- For each day, the cumulative operating costs of hydrogen production are calculated in a daily resolution (24-hour intervals). Depending on the respective full utilization hours, the full costs of hydrogen production are determined.

Cost parameters	Unit	Hydex green	Hydex blue	Hydex grey
		Electrolysis	Natural gas with CCS	Natural gas without CCS
Lifetime/Depreciation period	a	20	20	20
WACC	%	8	8	8
Specific investment costs	EUR/kW_{el} or EUR/kW_{H2}	1000	1450	800
Operation & Maintenance (O&M)	% of invest	2.20	3.00	4.70
Efficiency (with respect to lower heating value Hi)	%	65	70	75
Full load hours	h/a	4000	7000	7000
Electricity and gas levies (cumulative)	EUR/MWh	16.95	9.94	9.94

- As full utilization hours increase, the impact of investment costs decreases, but in return, hydrogen is also produced on days with comparatively high commodity costs.
- A parameter variation in 24-hour steps results in a cost-optimal operating point or a number of hours of full use with the lowest possible full costs (see figure below).

Full costs of hydrogen production depending on full load hours for 2022



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HydexPLUS - Introduction of an optimized full cost index (II/II)

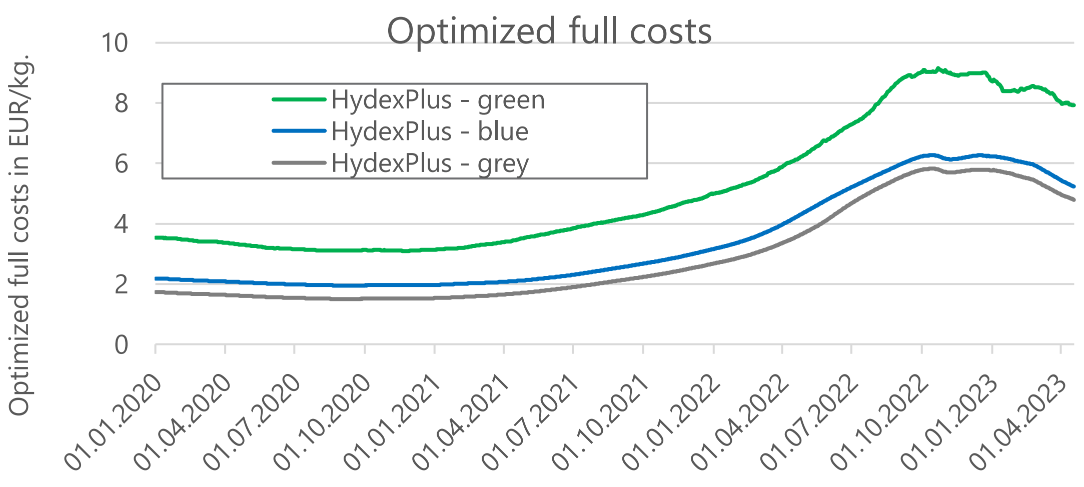
Evaluation over time

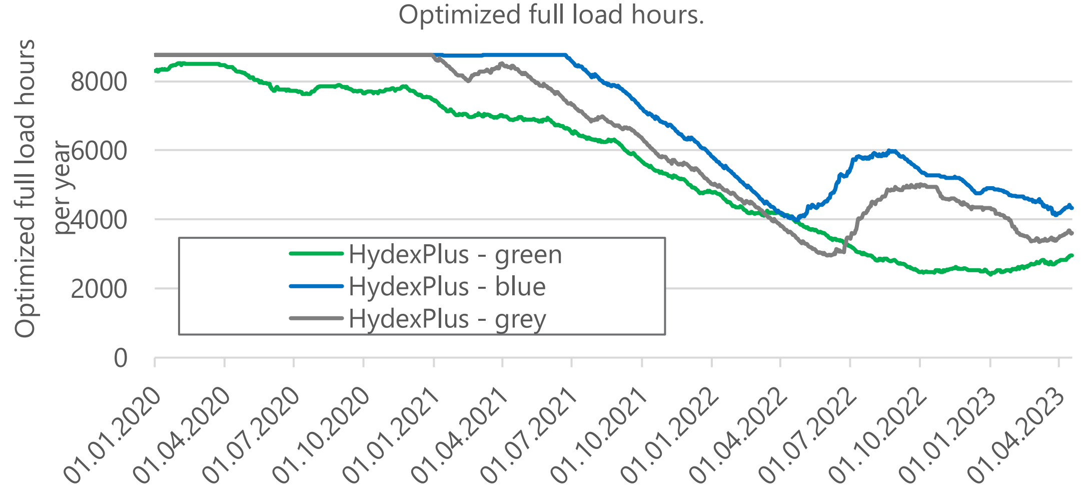
- Cost-optimal operating point (full costs and opt. full load hours) is calculated on a daily basis for the respective past year. Right: Course from January 2020 to April 2023
- By January and July 2021, maximum reformer utilization for gray and blue hydrogen, respectively, was cost-optimal due to low commodity prices.
- Increase in generation costs since mid-2021, especially from the beginning of 2022 due to energy crisis. Only slight easing on the markets at the end of 2022 leads to a short stagnation of the HydexPLUS indices. Since the beginning of 2023, the values decrease slightly again.
  - **HydexPLUS green:** Since the beginning of 2023, electricity prices have been slightly decreasing, while at the same time full load hours have been slightly increasing..
  - **HydexPLUS blue & grey:** Since the beginning of 2023, optimal full costs have been decreasing. However, optimal full load hours are also decreasing as gas prices are slightly decreasing, but this decrease is offset by an increase in CO_2 certificate prices.

Fields of application and services

- Benchmark for the full cost of H_2 generation to shape the support and regulatory framework.
- Individual forecasts for the future development of hydrogen generation costs
- Cost-optimal capacity design & operational management of H_2 generation plants
- Business model verification, deployment & revenue planning of H_2 generation plants
- Optimization of power and gas procurement (tailormade PPA) based on optimized operation and future power price forecasts.

The new HydexPLUS serves as a robust assessment tool for investors to determine the cost-optimal design and operation of hydrogen production plants. Over time, there is an increase in costs due to the energy crisis, but there are no volatile fluctuations.





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Publication
Energate Messenger: https://www.energate-messenger.de/markt/gas-oel-und-wasserstoff/
E-Bridge Consulting: https://e-bridge.de/kompetenzen/energy-markets/wasserstoff/


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MIDSTREAM

Discarded plan of the federal government: National Grid Company for Hydrogen

Core contents of the strategy paper of the German federal government in December 2022

- Key contents of the December 2022 strategy paper of the German federal government:
  - Intention to establish a national hydrogen network company
  - The company would acquire existing hydrogen and convertible natural gas pipelines to facilitate a coordinated and system-oriented development of a hydrogen network, ensuring its financial viability
  - Target to construct a minimum of 1800 km of hydrogen pipelines by 2027

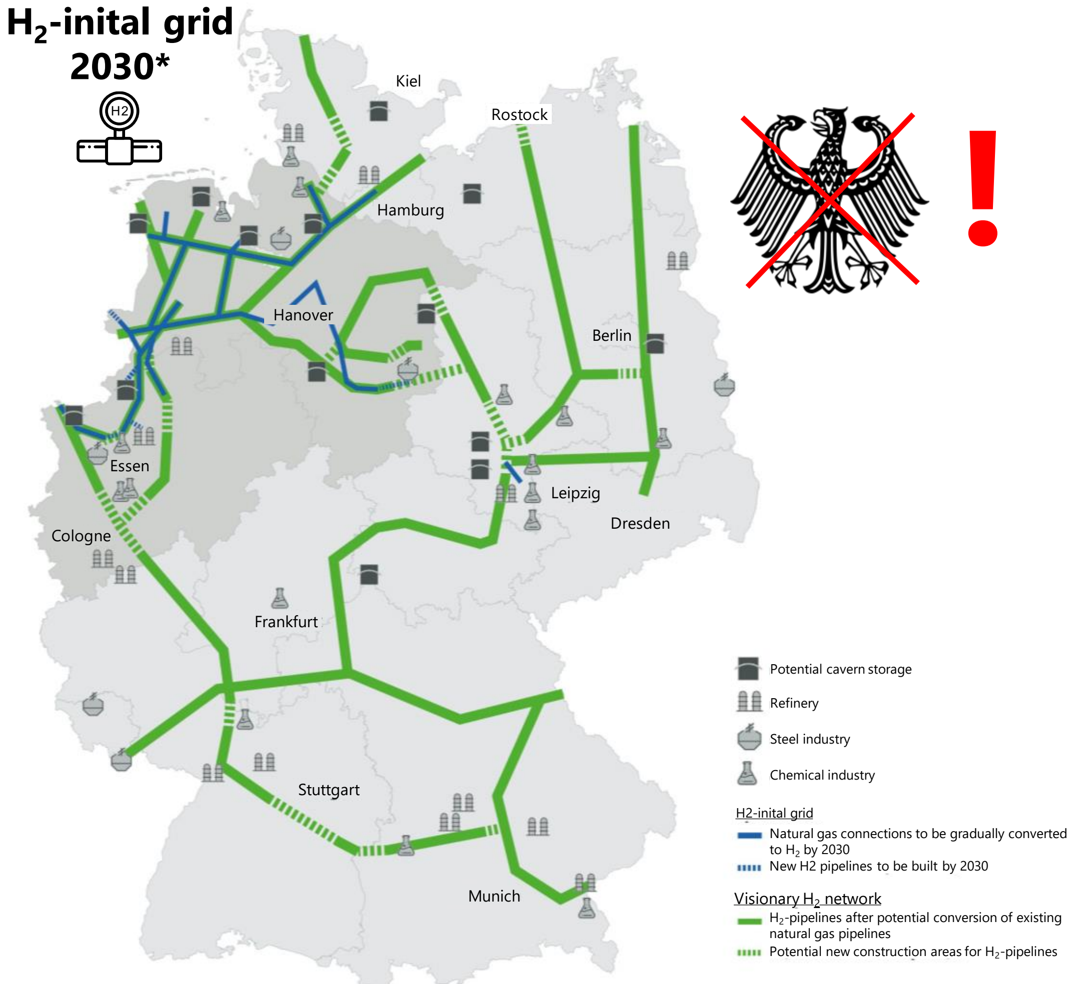
Government-owned hydrogen company off the table as of March 2023.

- The federal government does not intend to participate in the planned hydrogen network company.
- SPD, FDP, and opposition parties (especially CDU) are skeptical.
- The Federal Ministry of Economics (Green Party) considers the network company to be meaningful.
- However, the hydrogen network company is still planned to be established without government participation and to take over the existing pipelines to ensure transportation by 2030.

Reasons for the failure: Criticism from the Bavarian state government and the FDP

- The proposal of the federal government for a national hydrogen network company hinders the ramp-up of a hydrogen economy
- Incentives for investment in hydrogen networks by the transmission system operators (TSOs) would be eliminated
- The future business foundation of the network operators would be destroyed, and the perspective towards a carbon-neutral future of their business sector would be lost.
- Sufficient private companies are ready to ensure the establishment of the hydrogen infrastructure.

A network company for hydrogen should be established without the initially proposed government participation. A national hydrogen network company would slow down the development of a hydrogen economy. Furthermore, incentives for investments in hydrogen networks by the transmission system operators (TSOs) would be eliminated.



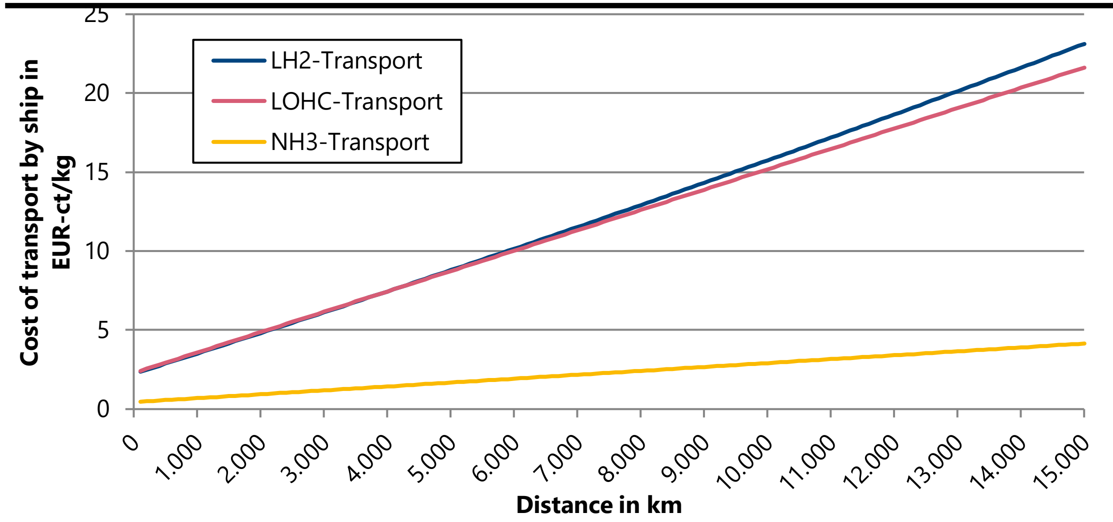
*The map is a schematic representation that does not claim to be complete with regard to the storage facilities and consumers shown [Link]

Sources: [1] „Bund prüft Gründung einer Wasserstoffnetz-Gesellschaft ", Bayerische Staatsregierung [2022] Link; [2] „Kein staatliches Wasserstoffnetz ", FAZ [2023] Link; [3] „Ampel uneins bei Wasserstoffregulierung", Energate [2023] Link; [4] „Ampel-Koalitionäre kritisieren Pläne für staatliches Wasserstoffnetz", Handelsblatt [2023] Link

Comparison and Classification of Options for H_2 Overseas Transport

- Long-term, the import of green hydrogen or its synthesis products is considered necessary to meet a portion of Germany's future demand. Currently, various transportation options for overseas transport are being discussed.
- This brief analysis compares the transportation costs of liquid hydrogen (LH_2), liquid organic hydrogen carriers (LOHC), and ammonia (NH_3), as they offer advantages over the low volumetric density of gaseous hydrogen.
- It is evident that the transportation of ammonia (NH_3) is the most cost-effective option regardless of the distance. For transportation distances up to 4,000 km, the transport of liquid hydrogen (LH_2) is slightly cheaper than the transportation of liquid organic hydrogen carriers (LOHC). However, for longer distances, LOHC has a slight cost advantage.
- It should be noted that the dehydrogenation of loaded LOHC requires a source of heat at the destination, while the liquefaction of hydrogen requires a similar amount of energy at the starting point. Similarly, the production (including air separation for nitrogen) and cracking of NH_3 require energy at both the starting and destination points. Depending on where energy is available at a lower cost, the infrastructure needs to be adapted accordingly.
- The analysis demonstrates that a sole consideration of transport costs is not sufficient for optimizing the infrastructure design. Depending on the spatial availability of cost-effective energy at the starting and/or destination points, the infrastructure design needs to be adapted. In this way, import corridors and trade connections can be individually assessed and optimized for cost efficiency.

System	LH_2-Tanker	LOHC-Tanker	NH_3-Tanker	Comments
Invest	500 MEUR	330 MEUR	185 MEUR	LOHC: incl. Dibenzyltoluol for 2.50 EUR/kg
Capacity	11.360 t (160,000 m³)	120,000t (133,000 m³)	132,860t (182,000 m³)	New Panamax-Class
Capacity H_2	11,360 t_{H2}	7440 t_{H2}	23,383 t_{H2}	
Amortization	30 a	30 a	30 a	
O&M	2 %	2 %	2 %	In terms of investment costs
Losses (Boil-off)	0,2 %/d	-	-	LH_2: Inevitable transition to the gas phase due to heat input
Fuel consumption	35 t_{H2}/d	100 t_{Diesel}/d	100 t_{Diesel}/d	Efficiency rates: 35 % at 15 MW
Fuel costs	7000 EUR/t	500 EUR/t	500 EUR/t	
Speed	37 km/h	37 km/h	37 km/h	
Source	[1], [4]	[2], [4]	[3], [4]	



Ammonia transportation is more cost-effective than the alternatives of liquid hydrogen (LH_2) and liquid organic hydrogen carriers (LOHC) for overseas transport. However, the energy requirements for conversions occur at different points in the infrastructure. Therefore, depending on the availability of energy, it needs to be assessed on a case-by-case basis which transportation option is cost-optimal..

[1] Kamiya S., Nishimura M., and Harada E. Study on Introduction of CO2 Free Energy to Japan with Liquid Hydrogen. Physics Procedia 2015;67. p. 11 - 19.
[2] Teichmann D., Konzeption und Bewertung einer nachhaltigen Energieversorgung auf Basis flüssiger Wasserstoffträger (LOHC). 2014, Universität Erlangen-Nürnberg: Aachen.
[3] Kawasaki. Delivery of the world's largest MOSS-type LNG Transport Vessel PACIFIC BREEZE. Kawasaki Heavy Industries, Ltd., http://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20180308_3533; 2018
[4] Own assumptions


H2
DOWNSTREAM

Amendment to the Building Energy Act - a positive decision for the hydrogen economy

Amendment to the Building Energy Act April/2023:

- As of January 1, 2024, every newly installed heating system is required to be operated with a minimum of 65% renewable energy sources.
- It is important for homeowners to note that existing heating systems can continue to be operated and repairs can be carried out. There are also additional exceptions for individuals over 80 years old, for whom the conversion to renewable heating is not mandatory in case of emergencies.
- Pragmatic transitional solutions and multi-year transition periods are in place, allowing for a gradual shift to renewable heating rather than an immediate change..

Resolutions relating to hydrogen:

- Establishment of a hydrogen refueling infrastructure for trucks by 2025, as well as the development of infrastructure in depots and operating yards.
- Additionally, the installation of "H_2-ready" systems, which can be converted to run on 100% hydrogen, is allowed if there is a binding innovation and transformation plan for hydrogen networks. From 2030 onwards, a minimum of 50% biomethane/green gases will be required, and from 2035 onwards, a minimum of 65% hydrogen will be required.
- Furthermore, there is a goal to expedite the approval process for industrial plants, wind energy installations, and electrolyzers..

The amendment of the Building Energy Act takes significant steps towards climate protection. The decision particularly has positive implications for the future of hydrogen (H2) in Germany. It enables the development of H2-ready systems in the heating sector and the establishment of H2 refueling stations in the mobility sector.

Sources: [1] „Überblick über die Novelle des Gebäudeenergiegesetzes “, BMWK [2023] Link; [2] „Wirtschaftsministerium warnt vor Panikkäufen bei Heizungen“, Redaktionsnetzwerk Deutschland [2023] Link

Analysis of Future Hydrogen Demand in the Transportation Sector

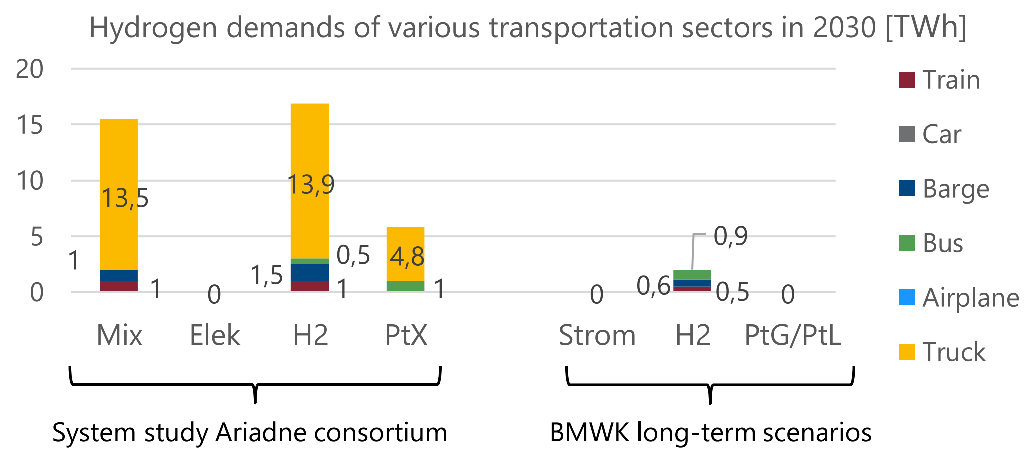
Forecast of Future Hydrogen Demand for Infrastructure Planning

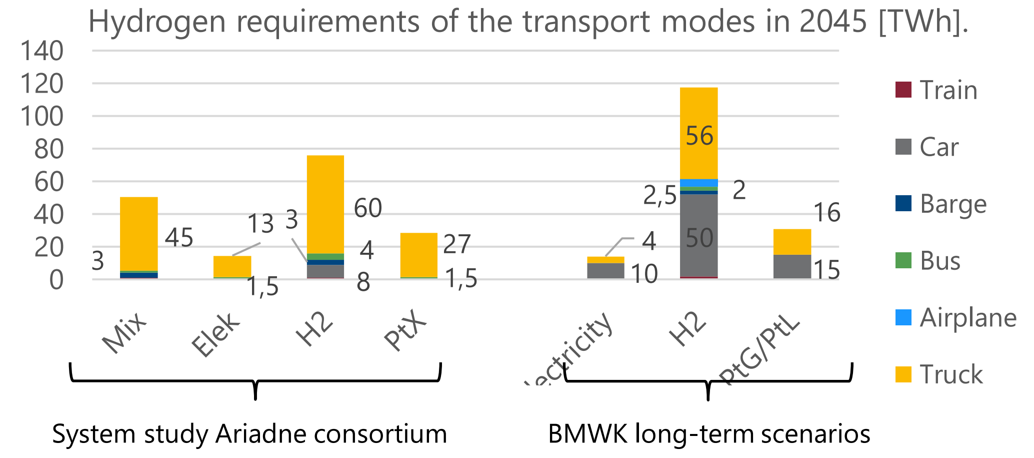
- Energy system studies provide possible pathways to achieve a carbon-neutral energy system in Germany by 2045. These studies explore various scenarios, providing a detailed overview of the mobility sector as well. In this analysis, we focused on the system studies commissioned by the Federal Ministry for Economic Affairs and Energy (BMWi) and the Ariadne Consortium..
- Forecasting hydrogen demand, particularly in the mobility sector, poses challenges due to the existence of different propulsion concepts for various modes of transportation. Each application offers different advantages depending on the specific use case..

Hydrogen demand in heavy-duty transportation and consumption clusters for aviation and maritime sectors

- Long-term, in every scenario, even under conditions unfavorable for hydrogen, the use of hydrogen in the mobility sector is projected. Therefore, the planning of hydrogen infrastructure must also take into account the transportation sector.
- It is evident that significant hydrogen demands in the mobility sector can emerge as early as 2030 under favorable conditions. Particularly in heavy-duty transportation, large demands may arise early on. However, a widespread refueling infrastructure is a prerequisite for this.
- In the long term, hydrogen propulsion for passenger cars is only expected to play a significant role under optimal conditions. Other modes of transportation, such as aviation and inland shipping, are projected to have relatively low hydrogen consumption compared to other sectors. However, significant demand can still arise regionally due to consumption clusters and specific regional needs.

Hydrogen can be a crucial component for achieving sustainable energy supply in specific areas of the mobility sector. However, the forecast for hydrogen demand in transportation varies significantly due to external factors and regional circumstances. Therefore, conducting individual assessments of regional areas is advisable to account for these variations.





[1] Luderer, et al., 2021. Ariadne-Report: Deutschland auf dem Weg zur Klimaneutralität 2045 zur Klimaneutralität 2045 Modellvergleich.
[2] Krail, et. al., 2021. Langfristszenarien für die Transformation des Energiesystems in Deutschland Treibhausgasneutrale Hauptszenarien - Modul Verkehr

Dr. Philipp Heuser
pheuser@e-bridge.com

Andreas Gelfort
agelfort@e-bridge.com

Leona Jovy
ljovy@e-bridge.com

Lorenz Valk
lvalk@e-bridge.com

Philipp Steffens
psteffens@e-bridge.com

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