Executive Summary

Roadmap for the Realisation of a Wind Hydrogen Economy in the Lower Elbe Region

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Wind Hydrogen: a Key Factor for the German Energy Turnaround

In joint cooperation with a large number of companies, associations, administrative districts and chambers and by providing the starting signal for this project, the federal states of northern Germany, Schleswig-Holstein, Hamburg, and Lower Saxony, have decided to take another preparatory step for the successful implementation of the **energy turnaround** in the north of the country. Using the Lower Elbe region as a model, a commercial implementation concept for the generation, storage, transport, and use of wind hydrogen was examined under the auspices of ChemCoast e.V. and the accounting firm Ernst & Young GmbH in the period from February to June 2013. For this study, Ernst & Young were collaborating with the independent technology consultancy firm Ludwig-Bölkow-Systemtechnik (LBST) and the leading energy law firm Becker Büttner Held (BBH).

The economy of the Lower Elbe region, with Hamburg as its centre of growth and the second largest metropolitan region of Germany is characterised by the establishment of companies in the manufacturing sector which are using waterway transportation routes to import and export their goods. 60% of the employment and almost 70% of the gross value added effects of the Port of Hamburg are generated within the Hamburg metropolitan region. Moreover, a large number of companies active in the development and manufacture of plants used to generate renewable energies have settled in and around Hamburg.

The Lower Elbe region is ideal for the generation and storage of hydrogen produced from wind energy – not only from an economic point of view. It also has a high wind potential and features geological salt formations that constitute a necessary prerequisite for the construction of underground salt caverns used to store the wind hydrogen in a cost-effective manner at industrial scale. As a result of the associated industrial provision of raw materials from renewable energies, in particular to the chemical and the primary industry, but also as a fuel for transportation purposes, the development of a wind hydrogen network can, in perspective, help strengthening the industrial location with regard to sustainable economic activities. In this sense, the Lower Elbe can become a flagship region for this sector.

The German federal government has defined a **reliable, economic, and environmentally friendly energy supply** as guidance for its energy policy. Against this background, a number of ambitious goals for the year 2050 have been set within the framework of the German energy concept and the energy turnaround:

- the reduction of greenhouse gas emissions by 80% to 95% compared to the value of the year 1990 (2020: 40%);
- the expansion of renewable energies to a share of 60% of the gross final consumption of energy and 80% of the gross electricity consumption (2020: 18% and 35%, respectively); and
- a reduction of the primary energy consumption by 50% compared with the year 2008 (2020: 20%).

In light of the significantly increasing fluctuating power generation from renewable energies expected, the access to **powerful, efficient, and economically operable energy storage systems** will be of eminent strategic importance for the future energy supply of Germany. However, in the field of energy storage systems various and partly still substantial economic obstacles, also addressed in this study, have yet to be overcome.

In order to absorb large amounts of excess electricity and to also store such amounts as a long-term power reserve, if need be, not only **electrical and thermal storage, but also chemical storage facilities** will play a role: in times when electricity supply is high, flexible electrolysers are planned to be used to store large amounts of hydrogen in caverns. In the course of transforming the energy system this chemical energy can then initially be used in particular in the heating or transport sector, or even as an industrial gas. Once a certain (high) proportion of PV and wind energy is in the system, it might also make sense in the medium term to also use these energy reserves to generate electricity in times of high loads. Nevertheless, all this requires the availability of low priced and powerful electrolysers.

This study is the first one to consider a realistic use of the excess electricity saved in hydrogen from an economic point of view for one special region. This was done taking into account the expected generation of renewable energies, the plans for the expansion of the electricity grid in Northern Germany, the resulting excess electricity quantities, as well as the transport and storage infrastructure associated with the hydrogen. The focus here was on the material use of hydrogen. In this context, the analyses took into account the entire hydrogen offer in the Lower Elbe region, not only from the electrolysis of wind power, but also **from other production processes**, as well as the total demand in order to consider **possible economies of scale** for production and infrastructure. For this purpose, a large number of interviews was held players from the value added chain in the region. The result was a comprehensive potential demand for hydrogen in material form for both industry and transport.

The business plan prepared on this basis takes into account specific projects and measures to produce regeneratively generated hydrogen in the period from 2015 to 2025. Starting from a base case scenario, different economic and political design approaches are identified which may facilitate starting a competitive wind hydrogen energy economy in the region and which may serve as suggestions for an associated political decision-making process. The report starts with forecasts regarding the power quantities available as well as technical possibilities to produce and store wind hydrogen in the period under consideration.

Framework Conditions: Systemic Storage Demand Due to Excess Power Generation still limited until 2025

For the purpose of analysing potential excess electricity quantities, in particular from wind power generation, which might be used in electrolysers, the system boundary for our assessment was drawn around the federal states of Schleswig-Holstein, Hamburg, Bremen, and Lower Saxony, taking into account both the existing and the projected power transmission capacity into the neighbouring countries and federal states. In this context, two scenarios were defined within the framework of the present study delineating a plausible development corridor for a likely development. The "Low RE Expansion" scenario is characterised by a moderate increase in renewable energy deployment (assumptions in accordance with Scenario B of the German Grid Development Plan NEP[1]), while the "High RE Expansion" scenario is based in particular on the expansion plans of the individual federal states (NEP Scenario C).

The effect of the electricity grid expansion on the excess electricity quantities was examined within the framework of a sensitivity analysis implying different grid transmission capacities for each individual scenario and base year:

- no electricity export: all electricity remains in the examination room;
- existing electricity grid: electricity export on the basis of the existing grid;
- Existing grid + “starting grid measures” (Startnetzmaßnahmen): electricity export on the basis of the current grid expansion realisation and the “starting grid measures” of the NEP;
- Existing grid + “starting grid measures” + priority need: additional inclusion of the federal requirement plan[2]

Calculation of the excess electricity quantities has been made by an hourly simulation for the region for 2015, 2020, and 2025. For the two scenarios with higher and lower increase in renewable energy deployment, the different grid expansion scenarios result in the bandwidths shown in the following diagrams for the excess electricity as well as the number of hours during which excess electricity is generated in the year 2025.

[1] NEP: Netzentwicklungeplan

[2] Bundesbedarfsplan (Nabeg II)

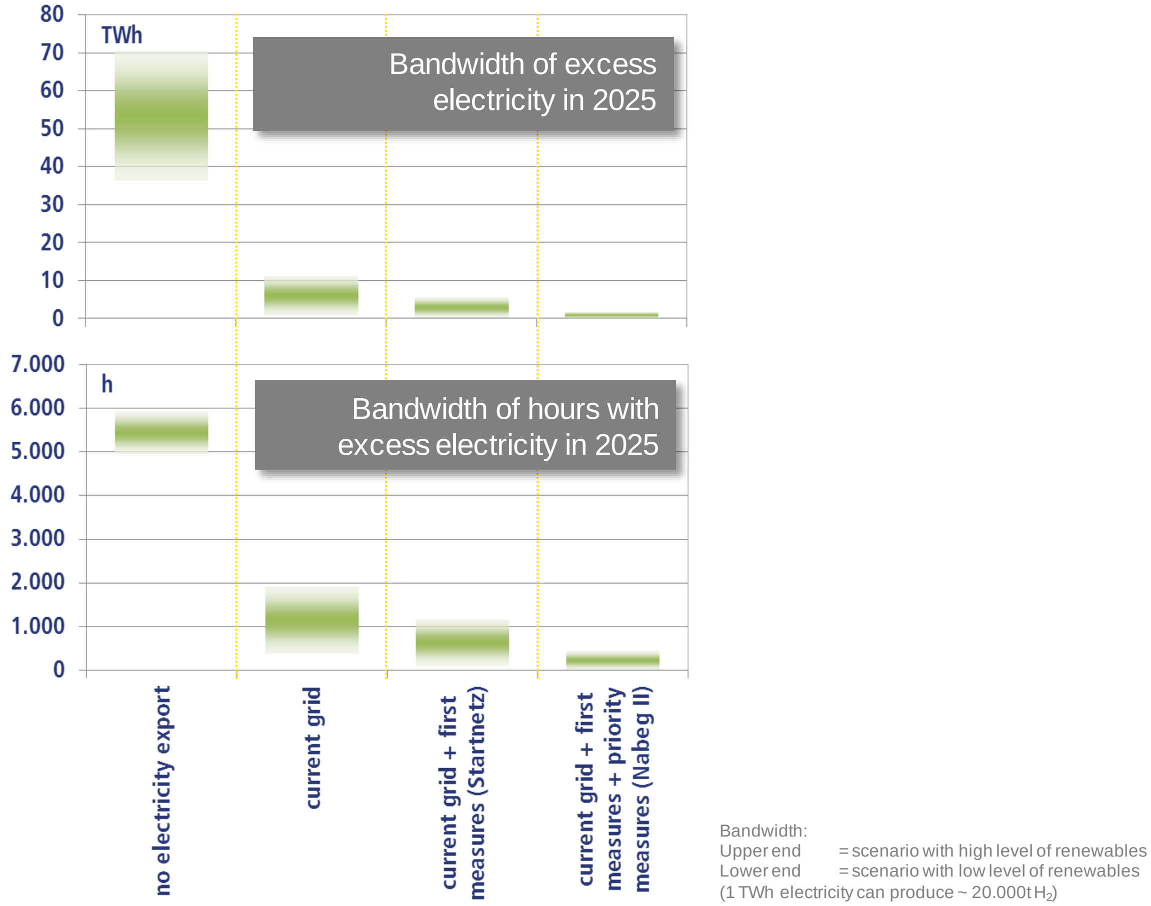

Illustration 1: bandwidths of the excess electricity and number of hours with excess electricity in the year 2025 (top end = scenario with high renewable energy deployment; bottom end = scenario with low renewable energy deployment)

The results very clearly show the sensitivity of the excess electricity to the parameters chosen, in particular to the scope of the expected grid expansion and the permitted electricity export. As the option "no electricity export" illustrates, already in 2025 the target region will over extended periods produce more electricity than it will consume.

The low excess electricity quantities in the case of the comprehensive grid expansion are not surprising. The current premise for the grid expansion plan in German virtually is to be able to absorb all renewable electricity directly into the grid ("copper plate Germany").

The likely development is expected to be in the range of the two middle scenarios. Accordingly, excess electricity quantities in the year 2025 will only be generated during approximately thousand hours of the year. For an economic operation of the electrolysers, however, it would be preferable to have a higher capacity utilisation. As a result, it can make sense in the course of an overall optimisation to also convert a certain share of electricity into hydrogen, which is not strictly excess electricity.

Increasing Demand for Green Hydrogen is Foreseeable

Nowadays, hydrogen is primarily generated and consumed on a global basis as an industrial gas at the place of use, i.e. especially in refineries and in the chemical industry. Only a fraction of approx. 5% of the hydrogen generated worldwide is transported and traded. In principle, this also applies in a very similar way to the Lower Elbe region.

Based on the interviews conducted a dedicated industrial hydrogen demand of 52,700 t/a (2015), 77,500 t/a (2020), and 92,700 t/a (2025) was determined (see Illustration 2). According to the evaluation of the players concerned, these quantities can take part in a regional hydrogen market by means of a common infrastructure. Captive quantities that are consumed right away at the place of production and, according to the players concerned, should not be taken into account for a future market are not included in the demand above. It cannot be excluded, however, that these partly considerable quantities might also participate in a common market in the future.

In this context, the by far largest share of demand in the period under consideration comes from the industry. Regarding the demand from the transport sector, it was assumed that public transport providers in Hamburg will only procure zero-emission buses from 2020 in accordance with the requirement set forth by the Hamburg Senate in its Clear Air Plan. By 2030, it is assumed that 1,000 to 1,200 fuel-cell buses will be operating. In addition, we also expect that in 2020 approximately 10,000 fuel-cell cars will be in operation and approx. 44,000 in 2025. Extrapolating these developments further, demand for hydrogen as a transport fuel would in the year 2030 amount to more than 25,000 t/a in total, i.e. roughly one fourth of the industrial demand.

The production process used to generate hydrogen has significant effects on the resulting costs, but also on where it can be used. It does not seem appropriate to use hydrogen that has not been generated within the framework of a zero-emission production in "green" applications, such as fuel-cell buses or renewable food production.

In the following, we will thus differentiate hydrogen into four categories highlighted in different "colours".

- "Brown hydrogen": hydrogen obtained with the help of fossil raw materials, for example by means of a steam methane reforming or similar processes or as a by-product in combined production fed with fossil fuels (e.g. in chlorine-alkali electrolysis, i.e. chlorine production by electrolysis of a sodium chloride solution).
- "White hydrogen": by-product hydrogen that is not used materially, but exploited thermally near the source. In principle, this white hydrogen is also available for other material applications; the thermal use on site can be substituted, for example, by natural gas.
- "Green hydrogen": hydrogen obtained directly from renewable electricity by electrolysis, in particular from wind power.
- "Yellow hydrogen": hydrogen obtained by electrolysis from electric energy of mixed origin that has been obtained via the European Energy Exchange (EEX) electricity exchange.

Primarily, the main focus of the present study was the production of hydrogen from electric energy. Nevertheless, brown hydrogen generated by fossil means defines the benchmark price for industrial use. In addition, we also consider the possibility of “greening” the chlorine-alkali electrolysis production process to a certain extent by use of wind power.

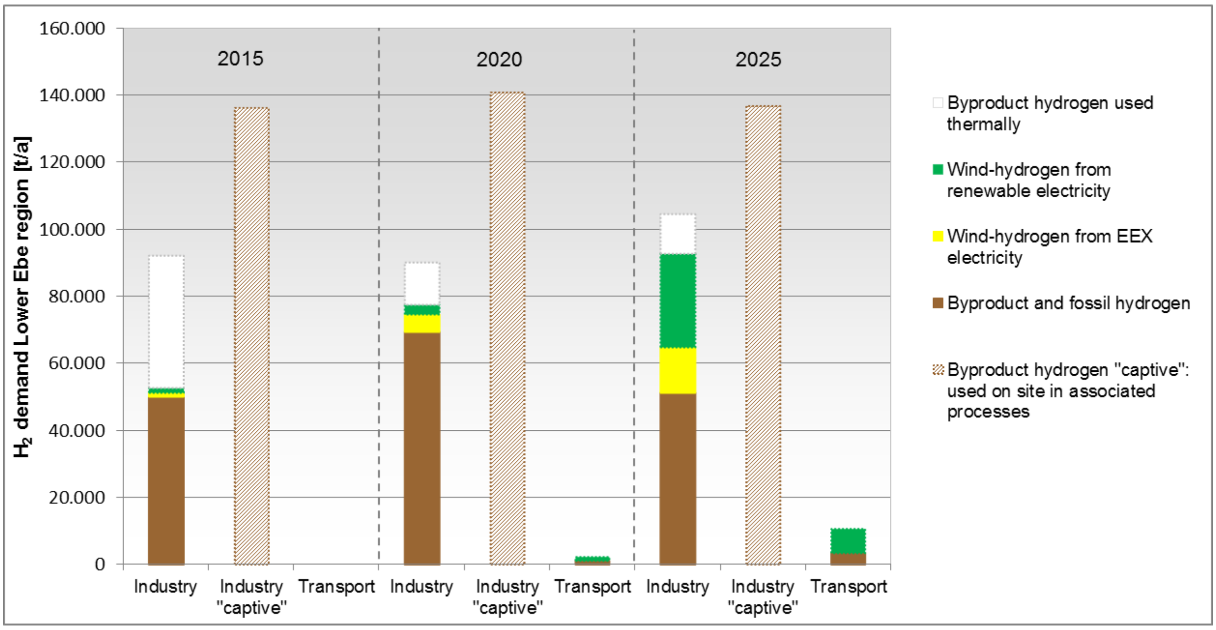

Illustration 2: potential change in hydrogen demand in the Lower Elbe region from today to 2025.

In the Lower Elbe region, about 50,000 t of hydrogen is currently produced annually as a by-product (approximately one tenth of the global German hydrogen production in the year 2011). Nowadays, this is largely used in internal processes for thermal use in gas turbines or industrial furnaces. Only part of this quantity is placed on the free market by a gas company. In addition, the industry established in the region still has unused capacity for the production of hydrogen from fossil fuels. Altogether, the Lower Elbe region has a free hydrogen production capacity in the amount of at least 50,000 t per year that can be made available to other consumers by means of an appropriate distribution infrastructure. Nevertheless, there are options to use wind hydrogen: we assume that it will be possible in the future to substitute conventional hydrogen by wind hydrogen. The development of the market for this green hydrogen will largely depend on the pricing mechanisms and the willingness of users to pay for this.

An essential prerequisite for making this hydrogen available to a common market is, however, the development of the necessary distribution and storage infrastructure. Only this infrastructure will enable hydrogen use on an industrial scale with corresponding market mechanisms. The development of this infrastructure is a key element of the measures proposed within the present study.

The Roadmap

On the basis of current producers and consumers and the existing plans with the resulting increase in demand for hydrogen in the Lower Elbe region, we propose the approach described below to establish a wind hydrogen energy economy along the Lower Elbe. For this, focus our analysis on three so-called "value added paths" in three initially separated market places, where infrastructure for the generation and distribution of hydrogen is built. These will then progressively grow together as the infrastructure expands (Illustration 3).

- Value added path I: Hamburg
- Value added path II: Brunsbüttel – Heide cluster
- Value added path III: Stade region

Here, the smallest value added path I in Hamburg has a certain project character and will be completely absorbed by value added path III in the year 2025 when connected to the infrastructure in the Stade region.

By 2015: laying of the foundation for renewable wind hydrogen use by industry
In 2015, the foundation for the wind hydrogen energy economy in Hamburg will be laid (value added path I). The investments amounting to EUR 16.3 million are made in an industrial electrolysis plant with 20 MW electric input power of. In a first step, it will exclusively produce yellow hydrogen to meet industrial demand on-site.

Within value added path II, electrolysis capacity with an electric input power of 20 MW will be built up at the Brunsbüttel site. The yellow and green hydrogen produced there can be made available to consumers by means of an existing pipeline between Brunsbüttel and Heide.

2015 to 2020: market growth through a maturing traffic sector
In 2020, value added path I will be further expanded. There, an additional customer increases industrial demand for yellow hydrogen. To be able to satisfy that additional demand, a pipeline of three kilometres length will be built. In the 2020 base year, the industry in value added path I will have a total demand of 2,228 t of yellow hydrogen. To meet such demand, the water electrolysis plants at the Hamburg location will be expanded to an electric input power of 34 MW.

In the Brunsbüttel – Heide cluster, the industrial demand for hydrogen will increase to approx. 6,000 t per year. The demand for green hydrogen will be almost equal to the one for yellow hydrogen. To be able to satisfy that demand, investments in new electrolysis plants will increase total electrolysis capacity to 82 MW electric input power. In addition, the existing pipeline will be complemented by a parallel connection in order to create further transport capacity.

Starting in the Stade region (value added path III), a pipeline infrastructure will be established, which will not only connect different consumers within this value added path, but will also integrate the infrastructures of the first two value added paths. Apart from that, further electrolysis capacity as well as a storage cavern will be established there. Thanks to the electrolysis plants having an electric input power of 20 MW, the initial hydrogen demand from the Hamburg transport sector will be served. In this context, the Hamburg Transport Association will be supplied through a pipeline, while the hydrogen refuelling stations will be served with by truck.

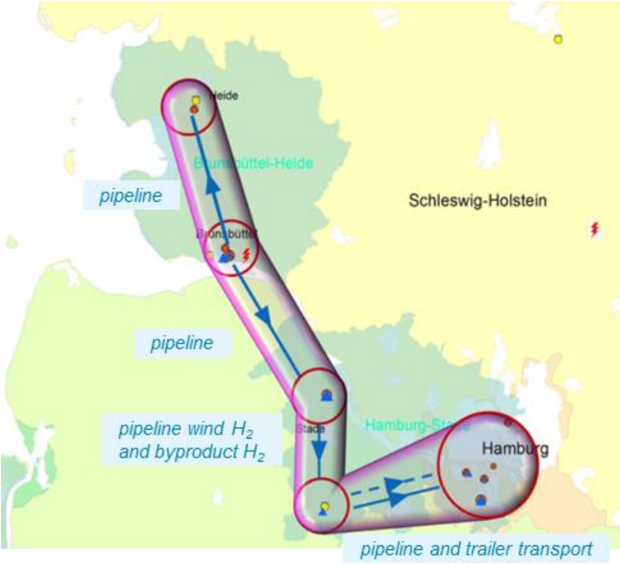

Illustration 3: hydrogen energy economy in the Lower Elbe region in 2020

2020 to 2025: shift towards a supplier market through decreasing production costs
The key activities to be performed by 2025 will be developed in the "Hamburg – Stade" and "Brunsbüttel – Heide" clusters. In 2025, value added path I and value added path III will be integrated. The transport sector will be the main consumer of green hydrogen with an expected annual demand of more than 7,000 t due to 44,000 fuel cell cars and 540 buses in greater Hamburg. To meet the demand from industry and transport, the Stade region will by then have an electrolysis capacity with 156 MW electric input power.

In value added path II, the demand for hydrogen will increase to approx. 31,000 t, the largest part of which will be green. A large part thereof can be generated as a by-product from sodium-chloride electrolysis, part of which will, in addition, be fed with green electricity. Besides this, Brunsbüttel will have installed electrolysis plants with a total electric input power of 231 MW in 2025.

Looking ahead, it is assumed that green hydrogen demand will continue to show strong growth potential until 2030 due to a considerable increase in market penetration with fuel-cell buses and cars, continuously strengthening the market in the Lower Elbe region.

In the Base Case Scenario, a Substitution of Brown Hydrogen by Green Hydrogen Does Not Pay Off

An evaluation of the economic efficiency of the prices for wind hydrogen will only make sense in relation to competing sources of energy and production paths. For the industry, the relevant benchmark is mainly the price of natural gas. Nowadays, hydrogen can be produced by steam methane reforming for approx. EUR 1.68 per kg, without taking into account logistics, margin, taxes, or CO_2 certificates (based on a natural gas price of EUR 0.023 per kWh). The sensitivity analyses carried out within the framework of this study show that this price level will not be achievable for wind hydrogen in the period under consideration without any recourse to state aid.

For the transport sector, the benchmark is the diesel or gasoline price, resulting in an energetic equivalent of approx. EUR 5.07 per kg of hydrogen (at a diesel price of EUR 1.30), requiring a separate and differentiated analysis.

Exemption from the EEG Apportionment
The consideration of the electricity prices for green and yellow hydrogen in the year 2013 shows the influence of the additional power costs on the selling price.

base year		2013	2013	2013	2013	2013	2013	2013	2013
full-load hours	Std.	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000
~~EEX-power~~	~~EUR/MWh~~	~~32~~	~~37~~	~~42~~	~~47~~	~~52~~	~~57~~	~~62~~	~~67~~
wind power	EUR/MWh	90	90	90	90	90	90	90	90
grid charges	EUR/MWh	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0
EEG-apportionm	EUR/MWh	52,8	52,8	52,8	52,8	52,8	52,8	52,8	52,8
KWK-markup	EUR/MWh	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Offshore-levy	EUR/MWh	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
~~§ 19 levy~~	~~EUR/MWh~~	~~0,5~~	~~0,5~~	~~0,5~~	~~0,5~~	~~0,5~~	~~0,5~~	~~0,5~~	~~0,5~~
concession levy	EUR/MWh	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1

Table 1: EEX electricity price and wind power price as well as extra charges

As can be seen from the sensitivity calculations made in this study, projects to generate wind hydrogen would practically not be realisable without their exemption from the EEG apportionment. This is why an exemption from the EEG apportionment has already been assumed in the base case scenario. Nowadays, such an exemption can principally result from the self-supply privilege of Section 37 Para. 3 EEG or from a reduction of the EEG apportionment from the special compensation scheme in Sections 40 et seqq. EEG. However, these situations do not refer to electrolysis as a storage technology as from the point of view of generating wind hydrogen, their intervention is "adventitious".

At present, however, there are considerable uncertainties with regard to the question as of whether any and all **grid charges payable "in a broader sense"** (CHP apportionment[3], offshore apportionment[4], Section 19 Electricity Grid User Charge Ordinance[5], concession levies[6], Regulation on Interruptible Loads[7]) are actually covered by the exemption provision in Section 118 Para. 6 German Energy Industry Act (Energiewirtschaftsgesetz, EnWG) to the extent that this provision is applicable. Due to the currently existing legal uncertainty, the base case scenario described in the present study has been based on the "worst case", i.e. that any and all grid charges payable in a broader sense (including grid charges) will have to be paid.

Hydrogen Prices in the Lower Elbe Region

The following table summarises the results obtained from the business plan calculations for the different value added paths in the base case scenario. The quantities and prices have initially been compiled on the condition that the demand for yellow and green hydrogen is completely inelastic, i.e. that the consumers are thus willing to pay virtually any price for hydrogen. The reason for this may be that the **CO_2 emissions associated with the hydrogen production** can only be reduced when green electricity is used and, thus, against the backdrop of the energy turnaround consumer do not have any alternatives to green hydrogen, for example in the commitment for sustainability in public passenger transport.

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[3] KWK-Umlage: Apportionment for the promotion of electricity from combined heat and power in accordance with Section 9 Para. 7 KWKG

[4] Offshore Umlage: Apportionment for the cost of grid connections of offshore wind energy plants in accordance with Section 17 et seq. Para. 1 EnWG

[5] § 19 Stromnetzentgeltverordnung Umlage: apportionment in accordance with Section 19 Para. 2 Sentence 2 StromNEV for financial burdens arising out of individual grid charges in accordance with Section 19 Para. 2 Sentence 1 StromNEV as well as due to grid charge exemptions in accordance with Section 19 Para. 2 Sentence 2 StromNEV

[6] concession levies with regard to fees to be paid by electric utility companies to be granted the right to use the public ground to install and operate lines

[7] Verordnung zu abschaltbaren Lasten, AbLaV: apportionment in accordance with the Regulation on Interruptible Loads

Overall view Region Unterelbe			
base year 2015	**quantity in to**	**percentage**	**price in EUR/kg**
green	1.393	2,6%	6,78
yellow	1.348	2,6%	3,46
brown	49.955	94,8%	1,98
total	**52.695**	**100,0%**	**2,15**
base year 2020	**quantity in to**	**percentage**	**price in EUR/kg**
green	3.908	4,9%	7,82
yellow	5.463	6,9%	4,72
brown	70.162	88,2%	2,82
total	**79.533**	**100,0%**	**3,19**
base year 2025	**quantity in to**	**percentage**	**price in EUR/kg**
green	35.094	34,0%	5,83
yellow	13.657	13,2%	3,45
brown	54.438	52,8%	2,37
total	**103.190**	**100,0%**	**3,69**

Table 2: prices and quantities in the base case scenario

Table 2 illustrates that even in 2025 the base case scenario does not yield sufficiently attractive prices for the market to expect a substitution of brown hydrogen by green hydrogen. Due to the increasing consumption of green and yellow hydrogen, the imputed average price even goes up over the years. In the light of this, it is more than questionable whether a wind hydrogen energy economy on an industrial scale can get off the ground at all.

Illustration 4 shows a typical composition of the price for hydrogen produced electrolytically in 2025 using value added path II as an example. It can be clearly seen that the electrolytic production is by far the most important cost driver in the three value added stages, i.e. electrolysis, storage, and logistics, and that within this stage electricity costs are the most decisive parameter[8].

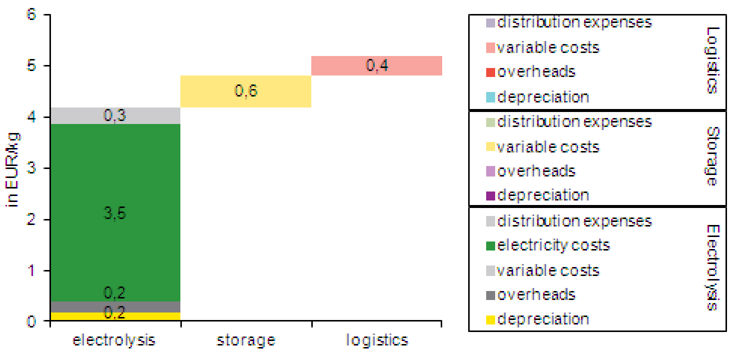

Illustration 4: composition of the hydrogen prices weighted with the production quantities for green and yellow hydrogen from electrolysis in 2025 for value added path II

[8] Assuming 4,000 annual full load hours of operation, 66.7% electrolysis efficiency, and the corresponding electricity costs according to Table 1

Investments in Infrastructure Can Only Be Made Jointly by State and Industry

Significant Investment in Electrolysis Plants with 387 MW Input Power by the Industry

The total the hydrogen demand identified requires establishing electrolysis plants with a total electric input power of approx. 387 MW in the Lower Elbe Region over the course of time. We assume that until 2025 the specific investment for alkaline electrolysers will decrease from € 800 up to € 600 per kW in several technology development steps. In the long term, it should be possible to also apply these cost targets to PEM pressure electrolysers. Electrolyser installation requires a total investment volume of approximately EUR 310 million in the period under consideration. In the base case scenario, we assume that these investments will be made within PPP projects.

Annual operating costs of one electrolyser amount to approx. 4 - 5% of its investment costs also taking into account the incurring overhead costs. The significant investment volume will generally require a high number of operating hours in order to achieve low H_2 production costs. Additionally, electricity availability and prices will vary. Particularly, excess electricity from wind power will only be available temporarily so that the advantage of this potentially very cheap electricity would be levelled by a small number of operating hours. Since industrial consumers of hydrogen tend to have a rather constant demand, they allow the electrolysis plants to operate at a high capacity level, thereby contributing significantly towards reducing the price of hydrogen production.

Storage Cavern Safeguarding the Energy Turnaround will be Realised by PPP with the German Federal Government as Guarantor

Salt caverns have the lowest specific storage costs. Potential sites in the Lower Elbe region are near Stade, Brunsbüttel or Heide. In our analyses, we chose a location in the Stade region due to its proximity to the future centres of consumption.

For the storage options, we conducted a semi-quantitative analysis of the load profile dynamics on the supply and the user side for each value added chain and then combined them to form an adapted overall system. In principle, the pipeline network also has a certain storage capacity; however, this is only small and can be safely neglected here. As a result, an underground salt cavern storage facility with a geometric volume of approximately 500,000 - 750,000 m³ was chosen, able to store more than 4,000 t of hydrogen. The storage volume is sufficient to satisfy the maximum storage demand in 2025 and ensure continuous supply. The associated investments required amount to EUR 35.6 million for the cavern construction and EUR 112.8 million for the above-ground installations, i.e. a total of EUR 148.4 for the entire storage facility.

This investment will contribute to a special purpose vehicle and will be operated and maintained by a general contractor. The federal government will act as the contracting authority for the infrastructure investment and will help to finance the project. By forfeiting the receivables towards the government a favourable interest rate can be achieved, improving financing costs and thus decreasing investment costs. In return, the infrastructure user will pay to the government a variable fee depending on the use. This way, it creates advantageous conditions for the investment in an infrastructure measure, which is an essential prerequisite for the success of the German energy turnaround.

Northern States PPP to lay the Foundations of a Hydrogen Energy Economy at the Lower Elbe

The key element of the scenarios analysed is the establishment of a distribution infrastructure for hydrogen which will create a common market in the region under study. Our investigation showed a major interest on the part of the industry to feed the by-product hydrogen, which, at present, is for largely used thermally ("white" hydrogen), into applications where it can be used materially, making best use of its intrinsic higher quality. We believe that making these hydrogen quantities available to the market will open the way for the rapid development of a common transport and distribution infrastructure. Pipelines are the most cost-effective option when transporting hydrogen beyond a minimum distance and annual quantity, and avoid transports by road. Once installed, the more hydrogen is transported through the network, the higher its utilisation rate and the lower its annual operating costs. By 2015, it can be assumed that the hydrogen pipeline formerly operated as an oil pipeline between Heide and Brunsbüttel will remain the sole pipeline over public property. Already from 2015 however, a capacity expansion of the existing pipeline capacity should be considered depending on market growth and economic conditions. There is additional need for a pipeline within Hamburg and in the medium to long term from Stade to Hamburg in order to transport the available by-product hydrogen or wind hydrogen. Altogether, investments totalling EUR 61.8 million will have to be made for the pipelines provided for in the value added paths. We suggest assigning the task of distributing the hydrogen to a PPP company owned by Schleswig-Holstein, Hamburg, and Lower Saxony.

Contribution of the State to the Development of Infrastructure
The development of an infrastructure for the transport and the storage of wind hydrogen is crucial to creating a market place as well as economic options for the use of (wind) hydrogen in the medium and long term. However, the development of an infrastructure for wind hydrogen will probably succeed only if – like in the case of other infrastructures – the government assumes a share of the responsibility. The difficulty of developing such infrastructure mainly lies in the considerable initial investments to be made, and which, in light of the uncertainty regarding the development of wind hydrogen use, are not without risk. Only when these initial difficulties are overcome, it will be possible to strive for a solution in which the infrastructure development costs are completely passed on to its users and are thus refinanced.

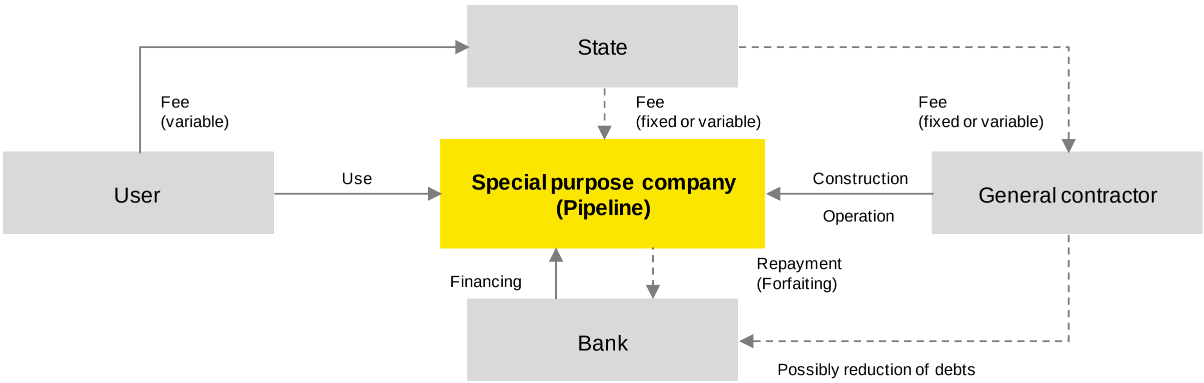

Illustration 5: conceptual illustration of a Public-Private Partnership (PPP)

Governmental involvement in establishing an infrastructure for wind hydrogen, for example in the form of a Public-Private Partnership (PPP), would, in particular, generate the following advantages: by giving the sole responsibility for the development of the infrastructure to an independent company involving governmental participation, the erection of the infrastructure would not be carried out by the same companies aiming to use it at a later point in time – this, in turn, will ensure unbundling of network and distribution. The creation of an **infrastructure involving governmental participation** also shows that it is in the interest of a large number of market players. As a consequence, the infrastructure investment secures the market place in the long term and provides for a high degree of continuity. If solely a few individual companies would be cooperating for the development of an infrastructure, this might possibly also be problematic from an anti-trust law perspective. In the base case scenario, the initial investments will be made by a PPP company, which receives income from fees related to the hydrogen amount transported or stored.

Green Hydrogen Needs Additional Promotional Measures to become Economically Attractive

In order to effectively promote the economic attractiveness of wind hydrogen, an appropriate combination and timing of different measures in line with market development progress is required.

Basically, the measures are intended to be cumulative. They address different levers along the value chain of generation, distribution and use of wind hydrogen. The particular interaction between these measures helps to establish a targeted overall concept as well as a legal framework for wind hydrogen.

Moreover, even if the support measures can be taken in a cumulative manner, the authors of the study also considered a **prioritisation** of the corresponding measures. Such prioritisation results, in particular, from our current assessment regarding the likelihood of the respective measure actually being realised on a political level – despite all the general unpredictability of political, especially parliamentary developments. Thereby, the measure given the best chances of being implemented is given priority.

When reading the prioritisation table, please note that any and all measures will have their own economic effect on the generation and the use of wind hydrogen. According to the actual need for economic promotion of the wind hydrogen technology over time, recourse may need to be made to more or less of the measures proposed. Depending on the economic efficiency of the technology, the table can thus be read to show to what extent one or all of the measures specified will have to be taken in order to achieve the intended promotional impact. The higher the promotional requirements are from an economic point of view, the more of the measures specified have to be taken. Here, measures are labelled M1 to M7 (see **Error! Reference source not found.**) according to their position in the prioritisation scheme. In the base case scenario, measures M(-)2 and M(-)5 have already been included in the economic calculation. The contribution of the remaining measures depends to a great extent on their particular design. Moreover, in the case of the approaches M3, M6, and M7, it is either difficult to quantify their contribution or it will depend on market conditions at the time.

Priorisationof Measures	In the basic scenario	In estimationof measures
1. Exemption from all grid fees and similar fees/cost allocations (KWK apportionment, Offshore apportion-ment, concession apportionment …)	x	?
2. Exemptionfrom EEG apportionment in particular extensionin favour of wind hydrogenas transportfuel)	?	?
3. Exemptionfrom the prohibitionof multiplesales	x	?
4. Supply of surplus electricityfrom congestion management	x	?
5. Infrastructurebuildupby Public-Private-Partnership-Projects	?	?
6. Marketincentive programme	x	?
7. Pricemechanism (EEGasGwithdirectmarketing)	x	?

Illustration 6: overview and prioritisation of the promotional instruments

In the time frame between 2013 and 2020, an **initial promotion** will be able, in particular, to balance the currently high technology costs until the expected economies of scale in electrolyser production have taken effect. Moreover, an initial promotion will also take into account that, looking forward, scenarios for the economic use of electrolysers will only develop later on in those periods when a high share of fluctuating renewable energies in the energy mix results in a considerable amount of excess electricity.

The initial promotion is supposed to foster technology development and, moreover, to already result in the installation of a relevant electrolysis capacity to prepare the energy system for these future requirements, which are already now visible, especially in grids with existing bottlenecks. In order to develop an economic scenario for the generation and use of wind hydrogen in an initial period, the scope of the approaches regarding the initial promotion would thus have to be designed in such a way that the remaining gap to economic efficiency can be compensated at least to a large extent so that companies are willing to make investments.

At a later period in time – i.e. after 2020 – further instruments could be used to achieve a significant promotional effect for the generation and the use of wind hydrogen. This relates, in particular, to the **quadruple crediting of renewable fuels**, such as wind hydrogen, towards the European target quota for renewable energies in the transport sector. The corresponding efforts to introduce such an advantageous crediting are already under way. Nonetheless, given the absence of the corresponding infrastructure as well as the relevant number of hydrogen vehicles, it can rather be expected at a later point in time that this measure will promote the market for wind hydrogen to a relevant degree.

Moreover, this measure merely applies to the transport sector and, thus, does not consider the possibilities of generating and using hydrogen in the industrial field, which is also part of the focus of the present study. In a later phase, the participation of electrolysers in the **electricity balancing market**, in future **capacity markets**, or in the provision of load management might additionally prove useful. To promote the use of electrolysers, recognising their vital role in future markets, it seems appropriate to take measures aiming at enabling participation of electrolysers in the relevant markets in the first place. Depending on the market development, the instruments will sooner or later come into consideration and may, where appropriate, also be taken into consideration for the phase of initial promotion (instead of the instruments mentioned above, i.e. market incentive programme or EEGasG with direct marketing option), always provided that they are designed in a suitably open and simple way.

Instruments for the 2nd phase
1. Quadrupled crediting against the rates of biofuels
2. Use as balancing energy, preferential participation in the balancing energy market, capacity markets, load management

Illustration 7: further promotional instruments for the time beyond 2020

The measures specified above have a direct influence on the green hydrogen price. Therefore, the prices derived in the base case scenario for green hydrogen (base price) of the region will be taken as a basis to quantify the corresponding **effects of the measures of the 1st phase M1 to M7** and to illustrate them for the year 2025. Since the instruments of the 2nd phase are still fraught with considerable uncertainties (e.g.: Will there be capacity markets? Where will biofuels be positioned in ten to fifteen years?), these measures will not be considered from a quantitative point of view.

The base case scenario has been calculated exclusive of EEG apportionment, grid charges (in the strict sense) and by taking into account two PPP projects for the infrastructure (pipeline and storage facility). Based on this base case scenario, prices for green hydrogen have also been calculated including the EEG apportionment (M-2) and, in addition, without the aid of any PPP project (M-5). In the latter case, any and all investment costs for pipeline and storage facility are allocated to the hydrogen quantities, resulting in considerably higher specific cost estimates per kg of hydrogen, in particular in the case of smaller volumes.

For the other assumptions M1 to M7, the calculation has been based on the following assumptions:

- M1 – Exemption from **grid charges in the broader sense**: the calculation of the price for green hydrogen has been performed without taking into account apportionments, fees, or charges. In this context, a net electricity price of EUR 90 per MWh (cf. electricity price list) has been taken as a basis.
- M2 – Exemption from the **EEG apportionment**: the exemption has already been taken into consideration in the base price, thus separate disclosure will not take place. To visualise the scale of the effect, M-2 can be used, in which the EEG apportionment has then been taken into account.
- M3 – Exemption from the EEG-**prohibition of multiple sale**: It was assumed that green electricity might be obtained at the price of EEX electricity; the power producer may thus claim the EEG market premium without the hydrogen then losing its green quality. In this context, the EEX price used is determined by the number of full load hours (cf. electricity price list).

- M4 – Delivery of excess electricity free of charge from **feed-in management**: in quantifying the effect of this measure, it was assumed that 3.5% of the electricity comes from feed-in management measures and that this electricity will be delivered to the electrolysers free of charge. By way of calculation, only 96.5% of the electricity costs are taken into account in the hydrogen price.
- M5 – Development of the infrastructure by means of projects within the framework of a **Public-Private Partnership** (PPP): the consideration of the PPP project has already been taken into account in the base price. M-5 visualises the scale of the effect.
- M6 – Initial support: Within the framework of a **market incentive programme**, it was assumed that 1/3 of the investment costs necessary for the electrolysers is financed and that thus only 2/3 of the corresponding investment costs will affect the hydrogen price.
- M7 – **Subsidised pricing regime**: this regime is supposed to compensate the difference between the remaining price for green hydrogen and the market price for brown hydrogen.

The illustration below shows the effects of the said measures on the price for green hydrogen in 2025.

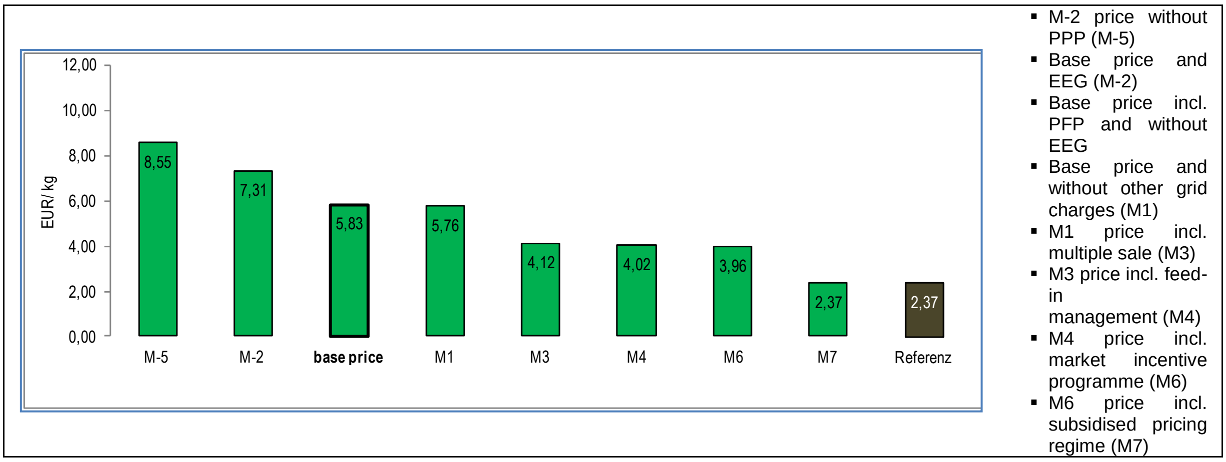

Illustration 8: effects of the different measures on the price for green hydrogen in 2025

Without any supporting measure, the price for green hydrogen (M-5) is not economically attractive. Starting from the base price, measures M1 and M3 show the greatest potential. Thanks to these measures, the price for green hydrogen will decrease by about 30% from EUR 5.83 to EUR 4.12. This is conclusive in as much as both measures are directly addressing the electricity price, which is the main factor influencing the hydrogen price. The remaining measures play a minor role – with regard to both their absolute and their relative effect. By definition, measure M7 comprises a subsidised pricing regime, which compensates the remaining difference to the brown hydrogen price.

Market Launch of Green Hydrogen by Mixed Products

Finally, it should also be pointed out that the proposed instruments can basically also be varied in such a way that whenever the initial focus is on the use of wind power, the statutory requirements for support are still fulfilled either when the green hydrogen or, if appropriate, yellow hydrogen is part of a **hydrogen-mix** and is thus only used in a share with hydrogen obtained by other production processes (brown hydrogen). Thus, unlike in current regulations of the EEG for the generation and the conversion of biogas into electricity, the authors do not propose a general principle of exclusivity for the generation of green or even yellow hydrogen. Precisely as a result of this option to use wind hydrogen in "mixed products", it will be possible to **limit promotion requirements and market interventions**, on the one hand, and to also **effectively eliminate market entry barriers** for wind hydrogen in the field of industry and transport, on the other hand.

In order to follow this idea, the mixed prices below have been calculated on the basis of the price for green hydrogen in accordance with measures M1 to M6 for 2025.

	part of brown hydrogen										
part of green hydrogen	**100%**	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**	**0%**
0%	2,37										
10%		2,53									
20%			2,69								
30%				2,85							
40%					3,01						
50%						3,16					
60%							3,32				
70%								3,48			
80%									3,64		
90%										3,80	
100%											3,96

Illustration 9: mixed prices calculated on the basis of the price for green hydrogen with measures M1 to M6 for 2025

Results show a mixed price of considerably less than EUR 4.0 per kg at a ratio of 50:50 in 2025; in 2015, these prices are also already below of EUR 4.0 per kg. If this is compared with the diesel equivalent for fuels (diesel price assumption: EUR 1.3, multiplier for the same calorific value: 3, hydrogen propulsion efficiency: 30%), this 50:50 mixed price in 2015 is already below a comparable imputed price for diesel (EUR 5.07). Without taking into account any price increase for diesel until the year 2025, already the price for green hydrogen (100%) M3 will undercut the price level of diesel in 2025. By mixing green hydrogen with brown hydrogen, the use of hydrogen in the transport sector can thus be designed in an even more economically attractive way for the corresponding consumers when compared with diesel.

Looking ahead

Already today, hydrogen finds widespread use in the Lower Elbe region. Due to the high density of hydrogen producers and consumers the area is in a key position for establishing a common hydrogen market benefitting all players. A pipeline and an underground storage cavern will be the backbone of the required infrastructure. Initially, by-product hydrogen will have a large share, enabling a market start with attractive hydrogen prices and advantages for all players. Successively, the share of green hydrogen will increase in the mix. Certain amounts thereof can also be generated cost-effectively as a by-product from sodium-chloride electrolysis when fed with green electricity.

We propose to fund the core infrastructure, pipeline and storage cavern, through Public-Private Partnerships. Additionally, a stable legal framework for hydrogen with green admixture is important to safeguard further market development. Corresponding measures are identified and described.

In the wake of creating this hydrogen market several factors combine in creating exciting perspectives for further future growth of the region:

- Location-securing effects for the local chemical industry
- Further development of internationally leading pilot activities in the use of hydrogen in the transport sector
- Fundamental support of the German energy turnaround by systemically relevant energy storage capacities

The present study thus lays the foundation for trendsetting decisions.

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