STUDY

HYDROGEN POTENTIAL IN BERLIN 2025

An analysis on behalf of the initiative H2BERLIN

July 2020

Executed by umlaut Energy Transition Consulting

Foreword

The IEA (International Energy Agency) has taken the G20 summit in June 2019 in Japan as an opportunity to discuss the future of energy supply with hydrogen as an energy carrier. Without hydrogen the energy turnaround and the achievement of the Paris climate goals will not succeed. Now is exactly the time to seize the opportunity. The world's metropolises play a key role in this.

The health crisis triggered by Sars-CoV2 can be seen as an additional accelerator for this development. The Berlin state administration has provided considerable funds to help companies survive the lock-down quickly and unbureaucratically. Now the city's economy needs to be revitalized. In view of the considerable pandemic-related expenditure, it seems all the more urgent to focus budget funds commercially and carefully on promising economic sectors.

Linear economic processes, in which resources are irrevocably burned or products are simply thrown away after use, are an outmoded waste. The future belongs to cyclical economies, in which our environment is returned to what was taken from it after consumption. The prime example of such a cyclic economy is hydrogen from renewable energies. Produced from water with the help of electricity, the energy carrier hydrogen is used across all sectors of the economy and, when consumed, releases water again without further emissions.

In addition, green hydrogen also has considerable climate potential as a raw material in areas that were previously considered virtually impossible to decarbonize, such as the steel and chemical industries. That is why hydrogen is one of the cornerstones of the European Green Deal and will play a central role in the ramp-up of economic activity after the pandemic-related lock-down.

With its ambitious goal of climate neutrality within the framework of the Berlin Energy and Climate Protection Program, Berlin is also focusing on the broad use of suitable and innovative technologies such as digitization, applications with direct electricity use and sector coupling technologies such as synthetic gas and hydrogen.

Even in an energy system with a high proportion of renewable energies, we need energy and electricity around the clock, even in winter periods. Hydrogen as an energy carrier has the potential to secure peak load situations and to enable seasonal storage, thus ensuring security of supply. Hydrogen is an energy storage medium that can be transported and used in any quantity, without emission of CO2, NOx or particulate matter, using existing infrastructures across all sectors of the economy.

The purpose of this study is to determine the demand for hydrogen in Berlin until 2025 in the context of the defined climate targets until 2030. The results form the basis for the H2Berlin Initiative to develop a cross-company show case for Germany's largest metropolis and thus provide the impetus for the establishment of a hydrogen economy in Berlin.

The study is a first step towards the development of a regional hydrogen roadmap for Berlin and is intended to provide impulses for the strategic consideration of future hydrogen demand in the capital city.

I wish you an insightful reading.

Jörg Buisset

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Summary

Activities in metropolitan areas have a major impact on global greenhouse gas emissions and are also strongly affected by climate change. Many cities have therefore taken on a leading role in climate protection and are showing innovative ways of achieving a low-emission economy and society. Berlin also claims to be a pioneer and has decided to become climate neutral by 2050 at the latest.

In 2017 Berlin's emissions amounted to approximately 19 million tons of carbon dioxide. The biggest polluter is the electricity and heat supply to households and the commercial, trade and service sector (GHD), which accounts for 64% of total emissions. The transport sector is responsible for 29% and the industrial sector for 6% of the total emissions. This makes the electricity and heat supply and the transport sector the most important areas for climate protection in Berlin.

According to the monitoring report (2019) of the Berlin Energy and Climate Protection Program, the achievement of Berlin's climate goals in the areas of transport and heating in 2020 is at risk. In the heat sector, instead of the 26% set in the BEK 2030, an emission reduction of only 10 - 13% is expected to be achieved by 2020. This is due, among other things, to population growth and the low rate of building refurbishment, which falls short of the 2.1% target.

The Land of Berlin must reverse the trend in emissions by adapting its transport policy. The transport sector has even recorded a 13.2% increase in CO2 emissions since 2012 to 5.6 million t CO2 (2017) [1]. The interim target of 3.8 million t in 2020, as formulated in the BEK 2030, will probably not be reached. This is due on the one hand to the increased number of registered passenger cars, the increased logistics volume and, above all, the increased CO2 emissions from air traffic.

Hydrogen will play an important role in the green energy system!

With the publication of the European and German hydrogen strategy, green hydrogen was recognized in the international and national context as an important building block of the energy turnaround. Both strategies aim to make green hydrogen available at attractive prices in a timely manner by building up generation capacity and by imports.

Against the background of the achievement of the climate target and the booming hydrogen market, the role of hydrogen applications must be clarified immediately in Berlin. Although the feasibility study Climate Neutral Berlin 2050 calculated a consumption of green hydrogen of about 52,500 t in 2050, there is no analysis of the development of the short and medium term hydrogen demand in Berlin as a basis for further planning and strategies.

To estimate the demand for low-emission hydrogen in the year 2025, which would arise on the way to achieving the climate target, a scenario of the Research Centre Jülich was transferred to Berlin. The scenario of a national ramp-up describes the development of the demand that would arise if a **cost-optimal transformation path to emission neutrality** is followed.

Hydrogen demand Berlin

If the Berlin demand follows the scenario of the Research Centre Jülich for the development of national demand, a demand of approx. 9,000 t will arise in 2025. To produce this amount of green hydrogen an electrolysis capacity of approx. 170 MW would be necessary. If this scenario is continued, a demand of 24,000 t would already result for the year 2030.

The calculated demand can be seen as an indication of Berlin's overall needs on the way to achieving climate targets. However, it was not possible to go into detail about Berlin's special urban characteristics in this study. This should be part of further investigations and the basis for a hydrogen roadmap for Berlin.

In order to assess the real developments, a survey among Berlin companies analysed intentions and projects for hydrogen use. Although low-emission hydrogen was given high priority for decarbonization, a **projected hydrogen demand of only about 37 t for the year 2025** was found. Despite high interest in the application of hydrogen technologies, the attitude of the companies is wait-and-see. This results in a large gap between the theoretical necessary demand and the actual planned demand.

The European H2 strategy highlights the urgency of the need for action: "The time to act is now!”

The difference between the two scenarios or estimates results from several factors: On the one hand, many hydrogen applications have been extensively tested in pilot projects, but are still in a transition phase to mass production and broad market maturity. Secondly, there are not enough incentives for companies to become emission-free and use hydrogen for this purpose. This means that at present the framework conditions and incentives for the integration of hydrogen into the energy system and the transport sector are not yet sufficient.

There are already 25 "HYLAND" hydrogen regions in Germany, where the integration of green hydrogen in the transport sector and energy system is being pursued. These include cities such as Frankfurt, Ulm and the Rhine-Neckar metropolitan regions and the North-West region with Bremen and Bremerhaven.

To enable Berlin to maintain its pioneering role in climate protection, increased efforts in climate protection should be made and in this context suitable measures for the integration of hydrogen should be developed and implemented. The radiance of the German capital can also promote the use of hydrogen nationally and increase the international visibility of green technologies.

Fields of action

The national hydrogen strategy provides for the ramp-up of hydrogen demand via industry and transport. Berlin's industrial sector is unlikely to trigger a strong demand impulse due to its structure or comparatively small number of industrial companies. Due to the high number of old buildings with partly poor thermal insulation, the currently large share of gas-fired CHP plants or gas heating systems and areas without heat networks, decarbonization of the heat supply is difficult to implement without gaseous energy carriers.

Berlin's special challenges in the area of emission-free heat supply can be used as an opportunity. The IEA recommends adding low-emission hydrogen to the existing natural gas network in order to promote the ramp-up of hydrogen and at the same time prepare the infrastructure for the upcoming decarbonization of the gas network. The supply infrastructure can be scaled up through a plannable purchase quantity in the heat sector, the hydrogen price will fall in the medium term and trigger use in other areas. The climate protection scenario of the feasibility study "Coal phase-out Berlin" also assumes that as early as 2031 synthetic gas will be able to replace coal heat (from the coal-fired power plants Moabit and Reuter West) to a certain extent. The study calculates a 5% share of the synthetic gas used for this purpose, which is produced using green hydrogen.

At the same time, the **use of low-emission hydrogen in mobility must be enabled and promoted** in suitable applications in order to reduce emissions from the transport sector. The focus should be on those vehicles that are difficult to replace by battery, especially in the areas of fleets, commercial/utility vehicles, logistics and shipping. At the same time, emissions from aviation, which accounts for approximately 20% of the transport sector, must also be reduced. To this end, the German government should promptly introduce a quota for synthetic fuels.

Next Steps

The integration of hydrogen into the transport and energy system requires joint efforts by politics, society and industry.

On the part of the companies, it is now a matter of bundling the numerous individual initiatives in order to leverage common synergies.

A cross-sector network as a platform for exchange, information and connection with technology manufacturers can help in the planning and implementation of projects. By pooling needs and, if necessary, by jointly procuring technologies, hydrogen projects can be implemented more easily. Furthermore, especially in the early phase of the ramp-up, it is important to transfer experiences from the design and operation of hydrogen applications from other cities or regions in order to benefit from best practices. Today, hydrogen-powered trucks, buses, refuse collection vehicles, cab fleets and heat supply technologies are already in use in Europe.

Positive scaling effects can be exploited by **creating hydrogen hubs** to supply several consumers. To this end, incentives for the conversion and procurement of hydrogen vehicles must be created, if necessary in a supraregional context. Public companies could take a pioneering role in the conversion of commercial vehicles and thus promote the private-sector ramp-up.

The Land of Berlin faces the challenge of achieving the climate goals it has set itself and maintaining its pioneering role in climate protection. In this respect, the Land administration should, in dialogue with companies, identify the germ cells of hydrogen use and evaluate the necessary framework conditions for its realisation. The Land and above all the federal government are called upon to create attractive framework conditions for the appropriate use of hydrogen technologies within the scope of their regulatory responsibilities.

In order to make the substitution of fossil technologies predictable for companies, the current national sector-specific goals should be examined and, if necessary, adjusted for Berlin. Separate sectoral decarbonisation targets and, where legally possible, gradually increasing penalties or levies or charges on CO2 emissions could be used to push the city's targets.

Following the Swiss example, a (city) toll for heavy goods vehicles could make the use of H2 trucks financially attractive. In the same way, an environmental charge on electricity generators for construction sites and events would promote the substitution of diesel generators.

To support the economic viability of hydrogen applications in the ramp-up phase, individual financing models should be designed, taking into account supraregional funding programs. Through a commitment to the European Clean Hydrogen Alliance, Berlin could, for example, increasingly work towards European co-investments, which are now being rolled out as part of the EU Green Deal. Large pilot projects along the complete value chain with temporary guarantees will trigger the learning curve in the private sector and diversify risks.

A Berlin Hydrogen Roadmap with concrete intentions for the use and promotion of hydrogen will contribute to increasing investment security. A public commitment to the use of hydrogen can also be used to increase the perception of the capital and Germany as a pioneer in climate protection and as a location for innovation. The process of determining demand is not yet complete and should be carried out in a detailed analysis as part of the preparation of a hydrogen roadmap.

Current projects and intentions

A survey of 21 private and public Berlin companies shows that many companies have very ambitious decarbonisation targets and some of them want to become emission-free by 2030. Reliable and high-performance technologies are being sought in order to make the energy supply and business processes sustainable. For this purpose, a high potential is seen for the use of hydrogen, as it can often be integrated into existing infrastructures and applications.

The energy company GASAG AG advocates the addition of hydrogen to the natural gas network and is examining whether the use of the Grunewald gas storage facility is suitable for storing hydrogen. Vattenfall Wärme also wants to decarbonise district heating generation by using hydrogen, among other things, and intends to add hydrogen to the Marzahn CHP plant as a first step.

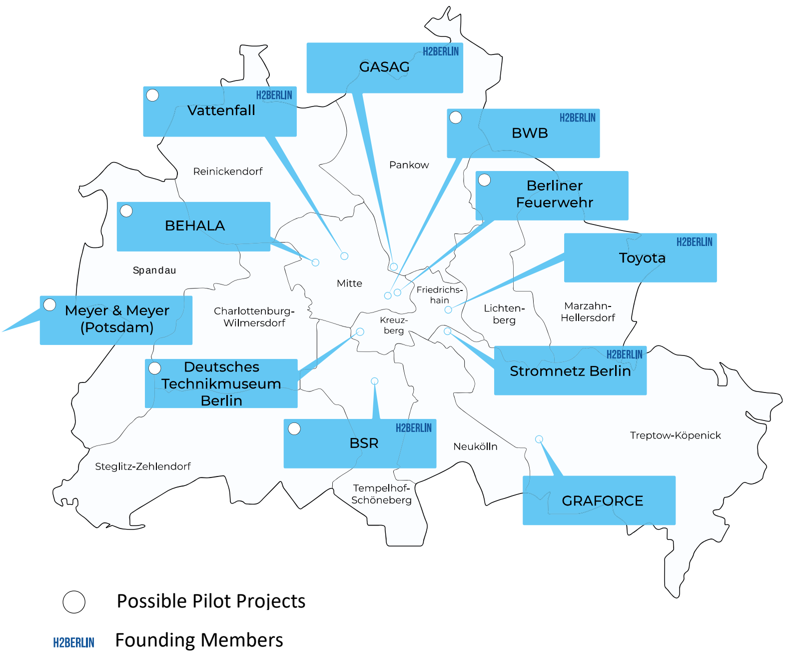
Berliner Wasserbetriebe, together with Graforce, want to implement a new innovative process for producing hydrogen from wastewater and use the resulting gas for their commercial vehicles. Toyota Kreditbank is planning a holistic mobility concept for the Neulichterfelde district, which will include the use of hydrogen.

As a result of the decarbonisation of public fleets, as called for in the Berlin Energy and Climate Protection Program (BEK), public companies such as the Berlin city cleaning service (BSR), the fire department and the police also see great potential in the use of hydrogen vehicles and are examining possible applications. The BVG (public city transport) is also examining the use of hydrogen-powered buses to achieve an emission-free bus fleet by 2030.

The timely planned deployment of the battery and hydrogen-powered push boat "Elektra" shows that there are also pioneers in the city in the field of shipping whose experience could be transferred to passenger transport on Berlin's waterways.

The following potential projects have been identified for rapid implementation by 2025: Fuel cell cars at the Berlin fire department, Project Everywh2ere with fuel cells at events, the hydrogen-powered push boat "Elektra" of the Behala (harbour site) and, eventually the excursion boat with fuel cell propulsion of the German Museum of Technology "KAISER FRIEDRICH". All projects together generate a **projected probable demand of approx. 37 t hydrogen per year.**

Projects with high potential for greater demand for hydrogen from 2030: conversion of commercial vehicles of the Berliner Stadtreinigung (BSR), conversion of the emergency vehicle fleet of the Berlin fire department, conversion of the Marzahn combined heat and power plant to hydrogen operation These projects add up to a potential **hydrogen consumption of about 6,500 t.**



Actors of the hydrogen network in Berlin & possible pilot projects

Conclusion

The interviewed Berlin companies show a strong interest in low-emission hydrogen and are willing to participate in pilot projects. However, current projects are still far from tapping into existing potential.

The use of hydrogen in heat and energy supply is recommended because, according to the coal phase-out feasibility study, Berlin has comparatively few low-emission heat potentials and yet a low-emission heat supply must be ensured. Action must be taken now so that hydrogen applications can contribute to achieving the climate targets in 2030. Experience in the field is needed to make technologies more reliable, prepare the necessary infrastructure and exploit possible economies of scale.

As the capital and internationally renowned metropolis, Berlin could use its radiance to position itself as a location for further innovative energy turnaround projects. A cross-sector strategy could help Berlin companies to integrate the ramp-up of hydrogen applications into the city's climate strategy and offer investment prospects.

1. Initial Situation

Climate Targets Berlin

To halt climate change and limit global warming to well below 2° C, the German government has decided to reduce its greenhouse gas emissions by 80-95% by 2050 compared to 1990 levels [2]. The Berlin state government recognised early on the importance of large cities for the energy turnaround and agreed as early as 2011 to develop Berlin into a climate-neutral city by 2050. The interim targets for reducing carbon dioxide emissions set out in the Berlin Energy Transformation Act are shown in Figure 1 [3]. Berlin's climate protection goals, especially for 2030, are more ambitious than the national goals of the German government, which is pursuing a reduction of carbon dioxide emissions by at least 55 % over the same period [2].

In addition to the legally stipulated reduction of 85% by 2050, the State of Berlin has committed itself in the Berlin Energy and Climate Protection Program (BEK) to undertake further efforts to reduce CO2 emissions by 95% by 2050 compared to 1990 [4].

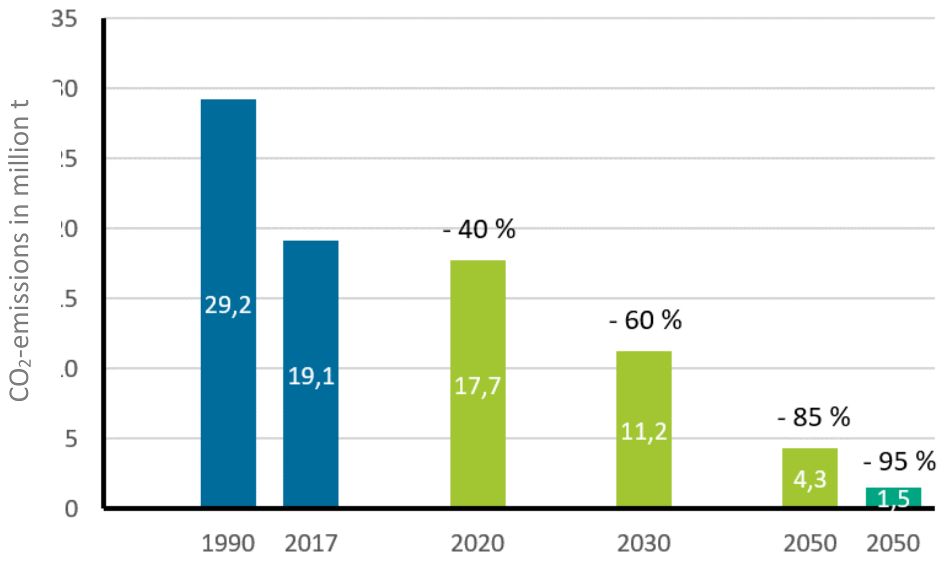


Figure 1: Berlin's climate protection goals and declaration of intent [3].
(blue: history, green: goals according to EWG Bln; turquoise: declaration of intent)

Overview of the current energy supply

Berlin's final energy consumption by energy source is shown in Figure 2. The high share of energy sources for heat supply, such as district heating, natural gas and heating oil, which accounted for 48.2 % of final energy in 2017, should be highlighted [5]. District heating has a share of over 33 % of the total heating market in Berlin.

Berlin's industrial sector is relatively small, accounting for 5% (3.29 TWh) of final energy consumption compared to the national average of 29%. The relative shares of final energy consumption of the household and GHD sectors and transport are much higher. Compared to the national average, the transport sector is slightly above average with a 32% share of final energy consumption, while the household and GHD sector is strongly above average with a share of 62.9% [5, 6]. This is due to Berlin's economic structure. As in many major cities, a large part of Berlin's gross domestic product (GDP) is generated in the service sector.

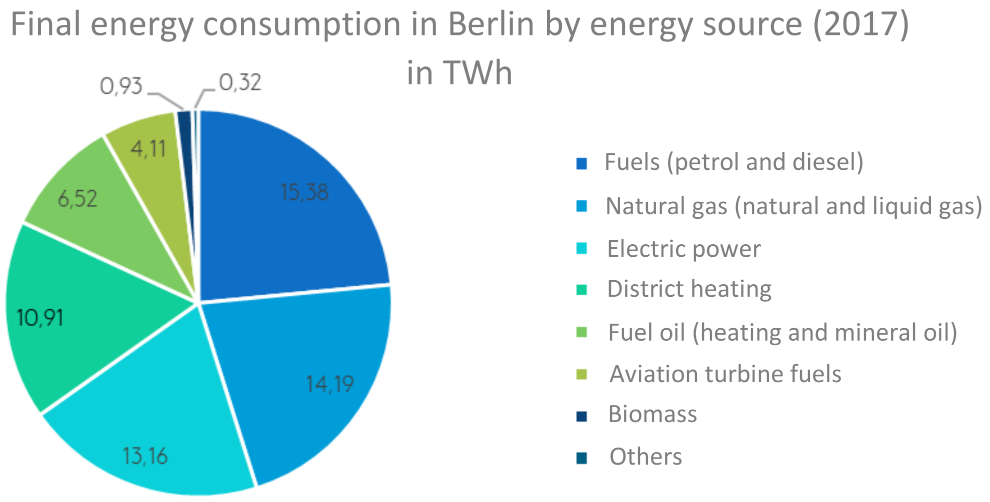


Figure 2: Final energy consumption in Berlin 2017 by energy source in TWh [5].

Greenhouse gas emissions

In 2017, Berlin emitted a total of 19.08 million tonnes of CO2, a decrease of 37.8% since 1990. Figure 3 shows the polluter-pays balance of CO2 emissions in Berlin by sector. The Households and GHD sector includes the supply of heat and electricity to private buildings as well as the supply of heat and electricity to commercially used buildings for trade and services. With 12.3 million t CO2 or 64% of total emissions, this is the largest CO2 emitting sector in Berlin. Accordingly, the sector plays a key role in achieving climate protection targets. In the polluter-pays balance of the households and GHD sector, about 55% of emissions are caused by the heat supply (including 37% by district heating) and the rest by the electricity supply [5].

The second major polluter is the transport sector with a 29% share of total emissions. Road transport accounts for 3.9 million tonnes of CO2, air transport (Tegel airport) for 1.1 million tonnes and rail and inland waterway transport for 0.6 million tonnes.

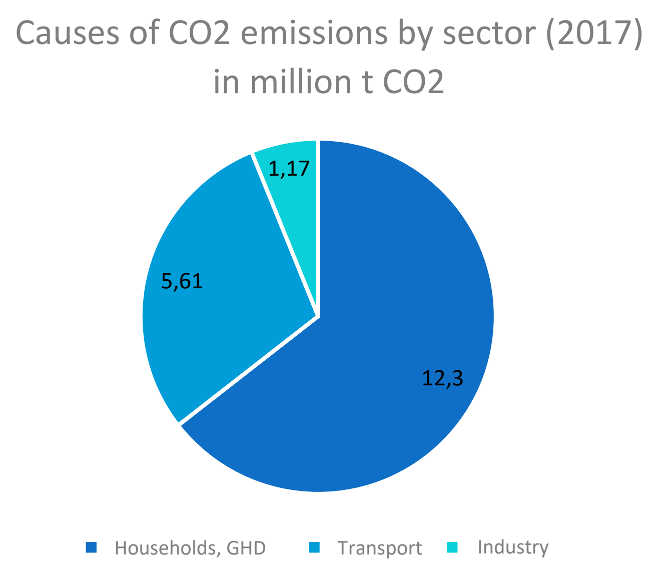


Figure 3: Causes of CO2 emissions in Berlin by sector, in million tonnes (2017) [5]

Berlin decision on climate target achievement: BEK 2030

Based on the Berlin Energy Turnaround Act (EEC Bln 2016), the Berlin Energy and Climate Climate Protection Programme 2030 (BEK) [4] sets out measures and strategies for implementation by 2021 for all fields of action.

The monitoring report of the BEK from 2019 shows the development of greenhouse gas emissions in the individual fields of action up to 2017. If the average annual emission reductions from 2010 are extrapolated, the climate protection target for 2020 would only just not be reached with a deviation of 0.6%. The emission targets in the fields of energy supply (transformation sector), the economy and in the area of households and consumption are on track to meet the targets for 2020. However, the interim targets for the sectors in the areas of buildings and urban development and transport for 2020 will probably be missed by a wide margin [1]. Moreover, the monitoring report only compares the emissions trend with the emissions targets specifically laid down in the Energy system transformation law, which ultimately do not yet lead to the envisaged emissions neutrality. This will require a tightening of the targets in the future.

The building stock in Berlin is characterised by numerous old buildings, some of which are listed, with poor thermal insulation and a high proportion of rented flats. In order to achieve the target, a total of 85% of emissions must be saved here, which corresponds to a reduction to 1.6 million t CO2 in 2050. An important contribution is made by the energy-related refurbishment of the building stock, with the specific final energy consumption to be reduced from 207 kWh/m^2 (2012) to an average of 77 kWh/m^2. In addition, the fossil primary energy demand is to be reduced considerably, on the one hand by the direct use of renewable energies, but also by successively increasing the share of renewable energies in gas consumption. In addition, the flexibilisation of the overall system, in particular by means of combined heat and power plants with heat storage facilities, the expansion of storage technologies and the intelligent linking of generation and consumption is of central importance [4].

For 2020, emissions in the building sector are expected to fall by around 26% compared to 2012, to 7.6 million tonnes of CO2. However, the actual reduction by 2016 is only 6.5%. This is due on the one hand to the moderate population growth of 5.8% in the same period, but also to the low renovation rate of currently only 1%, which corresponds to the national level. In order to achieve the objectives, the rate of building renovation must be increased to 2.1% as quickly as possible in a socially acceptable manner, and the depth of renovation must be increased.

The transport sector recorded a 13.2% increase in CO2 emissions to 5.6 million tonnes of CO2 (2017) [1], similar to the nationwide trend since 2012, despite the efforts of Berlin's transport policymakers. On the one hand, this is due to the increased number and size of registered passenger cars, the growth in general mobility services and increased logistics volumes, but above all to the attributable CO2 emissions of air transport. So far, only the emissions of Tegel Airport have been considered. With the opening of Berlin-Brandenburg Airport (BER), 70% of the energy consumption of which is attributed to the city of Berlin for the purposes of this study, emissions in the Berlin transport sector will continue to rise in the medium term [7].

The interim goal formulated in the BEK 2030 of reducing emissions in the transport sector to 3.8 million tonnes in 2020 will thus probably not be achieved. It is therefore important that the Land of Berlin works towards reversing this trend by means of an appropriate transport policy. In addition to a change in the mobility of private transport, increased efforts to convert public transport and public and private commercial vehicle fleets to alternative drive systems are necessary.

Role of hydrogen in the future Berlin energy system

In order to reduce greenhouse gas (GHG) emissions and meet climate change objectives, greater integration of renewable energy into the energy system and efficiency improvements in all sectors are needed. In this context, liquid or gaseous energy sources will probably continue to be used in the future for applications that require an energy source with a high energy density (e.g. aviation). The use of hydrogen will allow to make a decisive contribution to decarbonisation in those applications where electrification or the direct use of renewable energies is difficult to implement. The German government also draws this conclusion in its hydrogen strategy published in June 2020 [8].

What role hydrogen will play in Berlin and how the necessary hydrogen infrastructure can be created has not yet been adequately answered. Although the Feasibility Study Climate Neutral Berlin 2050 [9] outlined a hydrogen consumption of about 52,500 t for 2050 and possible applications in various sectors, the BEK 2030 contains hardly any concrete measures for the ramp-up of hydrogen demand and supply. However, it is planned to update the BEK in 2021.

Based on a national scenario of future hydrogen demand, this study outlines how much low-emission hydrogen would have to be integrated in the individual sectors in Berlin in order to achieve the climate protection targets. For comparison purposes, a ramp-up of hydrogen demand in Berlin is worked out on the basis of regional indicators and technological availability. A detailed company survey describes the current intentions, goals and challenges of Berlin companies regarding the use of low-emission hydrogen in energy supply or mobility applications. A final qualitative assessment of the projects included in the survey provides indications for the development of possible pilot projects and their linking.

Summary Initial Situation

The GHD & household sector plays a key role in the achievement of climate targets, accounting for 64% of total emissions. The heat supply of buildings plays a particularly important role. Berlin is facing particular challenges in this respect due to the old building stock and the dense housing situation. The high proportion of district heating offers opportunities to integrate alternative energies into the heating supply at an early stage.

The second important field of action is the transport sector, where the trend of rising emissions must be reversed. At the same time, solutions should be found to meet the increasing demand for mobility and inner-city transport volumes.

As an energy carrier with a high energy density and long-term storability, hydrogen will play a major role in achieving energy system transformation. However, the Land of Berlin has so far hardly any concrete plans for measures to ramp up the market and scale up hydrogen applications.

2. Hydrogen Demand in Berlin 2025

The aim of this chapter is to theoretically estimate Berlin's hydrogen demand for the year 2025. The approach for quantifying hydrogen demand focuses on achieving Berlin's climate targets. To this end, a scenario for the Federal Republic of Germany which shows the development of an energy system that is as cost-optimal as possible while simultaneously reducing emissions by 95 % by 2050 is transferred to Berlin [10]. The result of the approach represents Berlin's hydrogen demand in 2025, when demand in Berlin follows the ramp-up of the national scenario.

2.1. Methodology

At the end of 2019, Forschungszentrum Jülich published the study "Cost-efficient and climate-friendly transformation strategies for the German energy system up to the year 2050" [10]. The most important aspect of this study is the minimisation of transformation costs and the design of the German energy system in 2050 and in the support years 2030 and 2040. In the optimisation process, all available technology options compete against each other and are evaluated according to efficiency and cost criteria. In Scenario 95 (S 95), the study thus describes a cost-optimal transformation strategy for reducing total German greenhouse gas emissions by 95 % compared to 1990.

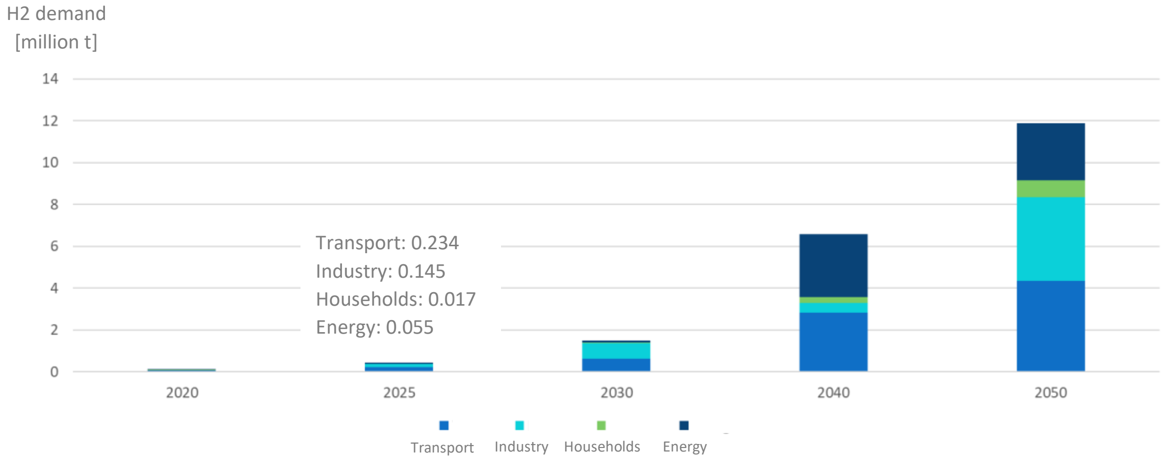
For the year 2030, the cost-optimal transformation path envisages a 61% reduction in emissions and is thus very close to the targets of the Berlin Energy Transformation Act for the year 2030 (60% reduction), which is why it was used as the basis for the following assessment.

In order to determine Berlin's hydrogen requirements in 2025, taking into account the achievement of the climate targets, the hydrogen requirements forecast by the Jülich Research Centre in its optimisation for the German energy system, assuming a 95 % reduction in emissions, are transferred to Berlin. The national hydrogen demand in 2025 is interpolated from the support years, assuming an exponential increase. It is also assumed that national hydrogen demand will be distributed among the Länder in proportion to their respective shares in national energy demand. Accordingly, Berlin's share in national final energy consumption per sector is used to determine Berlin's hydrogen demand in 2025.

National H_2-Demand

Figure 4 shows the development of national hydrogen demand with a 95 % reduction in emissions compared to 1990 on the cost-optimal transformation path according to Robinius et al. [10].

Figure 4: Germany's hydrogen demand in the 95 % scenario of Forschungszentrum Jülich [10].



The calculation of an exponential increase in demand between 2020 and 2030 results in the following sector-specific hydrogen demand for Germany for the year 2025:

Sector	H_2-demand [t/a]
Transport	234.000
Industry	145.000
Households	17.400
Energy/ Electricity recovery	55.000

Table 1: Sector-specific hydrogen demand for Germany in 2025 [10].

In principle, it is clear that by 2030 the majority of hydrogen use in Germany will probably be in the transport and industrial sectors. In this national scenario, the demand for hydrogen to supply heat to buildings will only arise on a larger scale later. This is because, according to the optimisation of the Jülich Research Centre, in the scenario with a 95 % emission reduction, 83 % of residential and non-residential buildings will be equipped with electric heat pumps and the final energy demand in the building sector will fall by about 50 % due to extensive renovation.

However, emission reductions in the heat supply via refurbishment and the large-scale use of heat pumps are countered by unfavourable conditions in Berlin. Due to the high proportion of CHP gas-fired power plants in district heating and many buildings with unfavourable conditions for the use of heat pumps, it remains to be examined whether the decarbonisation of the heat supply in Berlin can take place in the near future without hydrogen as a substitute for natural gas.

Derivation of the H2 demand in Berlin

First, the sector-specific shares of Berlin in Germany's final energy demand are determined. Table 2 compares the final energy consumption of Berlin and Germany in the transport, industry and buildings sectors.

	End-energy consumption [TJ]		Berlin share [%]
	Germany	Berlin	
Transport	2.765.245	75.514	2,7
Industry	2.665.969	11.860	0,4
Households	3.773.579	148.432	3,9

Table 2: Berlin's share of German final energy consumption by sector, reference year: 2017 [5, 11]

Table 2 makes it clear that energy- and emission-intensive industry plays a subordinate role in Berlin and accounts for only 0.4 % of the total German final energy demand in this sector. The Berlin building sector has the highest share of national final energy consumption.

To determine Berlin's share of national hydrogen demand in the energy sector, the installed power plant capacities are considered. Table 3 lists the gross electrical capacities of power plants with a nominal capacity of more than 100 MW, on the basis of which the Berlin share of the national power plant capacity is calculated.

	Germany	Berlin	Berlin share
Power plant capacities - gross electrical output	89.054 [MW]	2.005 [MW]	2,3 %

Table 3: Berlin's share of installed power plant capacity in Germany, status: 2020 [12]

A detailed analysis of the power plant capacities in Berlin shows that gas-fired power plants account for an above-average share of slightly more than 50 % of installed power plant capacity. Against the background of Berlin's plans to phase out coal use by 2030, it can be assumed that this figure will rise further in order to secure the supply of heat in Berlin [1, 13]. There is already a wide range of development activities throughout Germany to convert gas-based CHP plants and gas-fired power stations to the admixture or complete use of hydrogen, which is why the potential for a medium-term entry in this area in Berlin is seen as particularly promising.

Total demand is calculated by multiplying the national hydrogen demand per sector (cf. Figure 4) by Berlin's respective shares in final energy consumption or power plant capacity.

2.2. Overall need according to the model-based approach

If the hydrogen demand in Berlin follows proportionately the national scenario of the Jülich Research Centre, the total demand for the year 2025 will be 8,936 t. Since the national scenario used corresponds to Berlin's climate targets, the quantity determined is an indication of the demand for low-emission hydrogen. If the approach presented is applied in the same form to determine Berlin's hydrogen demand in 2030, the demand totals 23,959 t per year. The distribution of demand among the sectors changes only slightly compared to 2025.

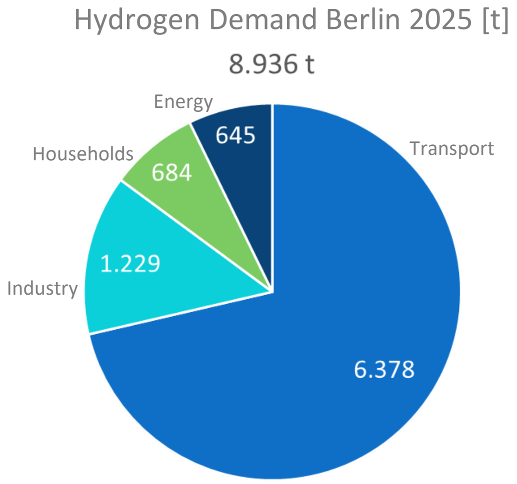


Figure 5: Berlin's theoretical hydrogen demand in 2025

Figure 5 shows the distribution of hydrogen demand among the sectors considered. According to the national scenario, it can be seen that hydrogen will be used mainly in transport in 2025. The special situation of Berlin with 2/3 of CO2 emissions in the heat sector would have to be further examined, but could significantly shift the distribution in favour of this sector.

Industry, which still contributes significantly to the demand for hydrogen in the national ramp-up, only accounts for about 7 % of hydrogen demand in Berlin, as the sector is not very well developed in Berlin. It is assumed that **hydrogen in industry** will be used mainly in the operation of company-owned combined cycle power plants or CHP plants, i.e. in **heat and power generation**.

In total, the energy, buildings and industry sectors theoretically have a demand of 2,558 tonnes, representing 29% of total demand. This demand could arise in the electricity and heat supply by **using hydrogen to decarbonise the gas-fired power stations**. Due to the large number of CHP plants and the high share of district heating in Berlin's heat supply, this area is considered to have great consumption potential. In contrast to the national scenario, the use of hydrogen for heat supply is ascribed a much greater potential in the medium term.

3. Evaluation on actual H2 Activities in the Capital

In order to determine an up-to-date practical evaluation on the use of hydrogen applications and to assess the real development of demand, 21 local companies were interviewed. The results of the surveys give an impression of the importance of hydrogen in relation to the goals and measures for emission reduction of the companies. Figure 6 shows an overview of the interviewed participants, sorted by application fields for hydrogen in the respective company.

Mobility	Logistics	Electric Power & Heat Supply
1. H2-Mobility	1. Berliner Feuerwehr	1. Vattenfall Wärme
2. Clever Shuttle	2. Berliner Stadtreinigung	2. Vattenfall Innovation
3. Deutsches Technikmuseum Berli	3. Berliner Wasserbetriebe	3. GASAG
4. Toyota Tsusho	4. Behala	4. Stromnetz Berlin
5. Toyota Financial Services	5. DB Energie	5. B.E.M
	6. Meyer & Meyer	6. Berlin Event
		7. Charitè
		8. Fuchs & Hirsch
		9. Bayer AG
		10. Vivantes

Figure 6: Overview of interview partners sorted by possible hydrogen applications

The focus of the ramp-up of hydrogen applications in the transport sector found in the theoretical analysis in Chapter 2 is also reflected in the opinions presented. With regard to the short- to medium-term significance of hydrogen for the decarbonisation of energy supply and corporate business processes, the surveyed companies see a comparatively high potential in the use of hydrogen-powered vehicles in the areas of mobility and logistics (Figure 7). In the area of electricity and heat supply or the application areas of combined heat and power generation, on the other hand, the significance is only rated as less high to neutral.

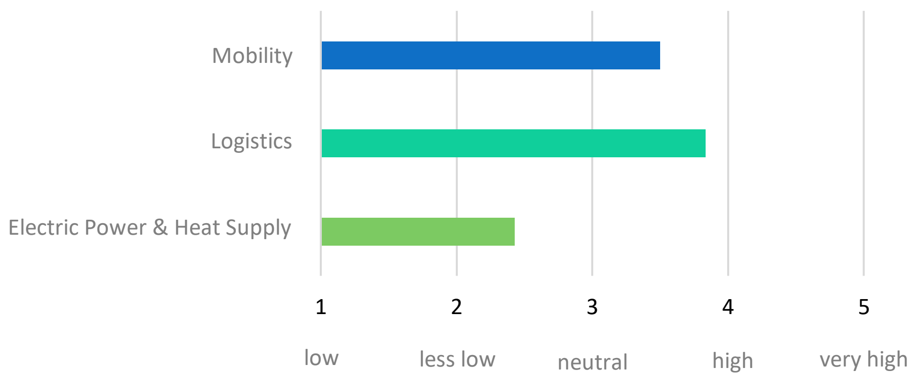


Figure 7: Importance of hydrogen technologies with regard to decarbonisation (broken down by fields of application)

In the following, the current situation and the assessment of the companies in the mobility & logistics sectors and the electricity and heat supply for the use of hydrogen are presented. Intentions and concrete projects identified in the interviews are listed in detail in Chapter 4.

3.1. Mobility & Logistics

In the area of mobility & logistics, the assessments of the means of transport in road, rail and shipping traffic are summarised. The statements focus on the conversion or new procurement of commercial vehicles with fuel cell drive.

Fields of application and current projects

As regards passenger transport vehicles, the majority of the companies surveyed said that they had already converted part of their fleet to battery electric vehicles or planned to do so in the near future. At the same time, there are examples of hydrogen-powered vehicles at the fire brigade, or at CleverShuttle (GHT Mobility GmbH).

Figure 8: H2 car at the Berlin fire brigade [40]

At the time of the study's preparation, the mobility company CleverShuttle in Berlin had 20 hydrogen-powered vehicles and 130 battery electric vehicles in taxi-like ridepooling operation. According to the latest news, however, this company is now withdrawing from Berlin. In the field of hydrogen-powered vehicles, the company relied on the Toyota Mirai model. In order to expand the fleet, the company was thinking about hydrogen-powered large-capacity vehicles in the future.

The taxi company Hype in Paris, a consortium of several companies from the mobility and technology sector, shows how successfully hydrogen-powered vehicles can be used in public mobility and help develop the hydrogen infrastructure. A fleet of 100 hydrogen taxis is already in operation in the French metropolis, which is to be increased to 600 vehicles in the future.

The Berliner Stadtreinigung (BSR), Berliner Wasserbetriebe and the Berlin fire brigade were asked about potential fields of application for hydrogen in relation to urban infrastructure and municipal services of general interest. In addition to purely economic interests, the surveyed companies have the political mandate, as public companies of the State of Berlin, to invest in alternative drive technologies.

To this end, Berliner Stadtreinigung has already electrified around 75% of cars and vans and converted half of the 330 waste collection vehicles currently in use to biogas. In addition, in 2013, in cooperation with Heliocentris Academia GmbH and FAUN Umwelttechnik GmbH & Co. KG, the use of a hybrid waste collection vehicle with a hydrogen-powered superstructure was already tested in cooperation with Heliocentris Academia GmbH and FAUN Umwelttechnik GmbH & Co.

At the Berlin fire brigade, the administrative regulations for procurement and the environment (VwVBU) state that investments must be made in technologies that comply with the latest emissions standards. In this context, four hydrogen passenger cars are currently being operated and the use of other hydrogen-powered rescue and fire-fighting vehicles is being examined.

Berliner Wasserbetriebe see a possible future use for hydrogen both for the operation of their sewer vehicles, trucks and other utility vehicles (a total of approx. 600 units), as well as for heat supply. In order to gain experience in use, two utility vehicles are currently being converted for operation with hydrogen as pilots.

In public transport, hydrogen-powered buses have significant advantages in terms of range and performance over purely battery electric buses. BVG faces the challenge of converting its bus fleet of 1,400 vehicles to emission-free drive systems by 2030 [14]. For the high-performance vehicles such as double-decker buses, the drive or at least the extension (as a range extender) with a fuel cell is a suitable option. The implementation of a possible fleet of hydrogen-powered buses of the BVG, however, is still under review and could not be determined during the interviews.

An innovative mobility concept is to be implemented in the planned Neulichterfelde district with a total of 2,500 residential units, for which Toyota Kreditbank GmbH is responsible as innovation partner. Specifically, the use of electric cars, hydrogen-powered buses, bicycles, pedelecs and electric two-wheelers at rental stations (mobility spots) are planned for the connection to public transport. The use of hydrogen in mobility is also to be evaluated in the modernisation and expansion of the Siemens campus in Berlin, the Siemensstadt 2.0 project[1].

The logistics companies Behala GmbH and Meyer & Meyer Holding SE & Co. KG are currently electrifying parts of their short- and medium-range commercial vehicles. Behala GmbH is also converting three tractor units to run on natural gas. The two companies are also very interested in using hydrogen-powered trucks for medium to long distances. For example, Meyer & Meyer Holding SE & Co. KG sees a first possible application for a hydrogen-powered truck for the Berlin-Osnabrück route, provided that a suitable hydrogen infrastructure and the technology to use green hydrogen at a competitive price would be available.

In rail transport, hydrogen-powered trains come into question where there are long non-electrified lines on which the use of a battery electric rail vehicle is not economical. Currently, the operation of a hydrogen train by Niederbarnimer Eisenbahn AG on the regional railway line RB27 (Heidekrautbahn) to Berlin Gesundbrunnen is planned. The new trains are scheduled to enter service in 2024 and will serve the approximately 60 km long non-electrified line north of Berlin [15]. The production of hydrogen and the refuelling of the train will initially take place in Brandenburg.

Other non-electrified lines in the Berlin area that may be suitable for hydrogen-powered trains are the regional express line RE6 (Prignitz Express) and the regional railway line RB55 on the Berlin (Gesundbrunnen) to Wittenberge, which is only electrified on part of the 140 km long line. However, the use of further hydrogen-powered trains in the Berlin-Brandenburg transport association is not yet planned.

On the Spree and the Berlin lakes there are numerous excursion boats, some of which are based on relatively old technology. Hydrogen propulsion via fuel cells is a suitable means of decarbonising shipping traffic in the near future. The drives are powerful enough to ensure continuous use, and vibrations and noise emissions can also be reduced. According to the Museum of Technology in Berlin, the propulsion system of the passenger ship KAISER FRIEDRICH is to be converted to fuel cells. The project is described in more detail in chapter 4.2.

[1] Due to the early planning stage, the H2 applications could not be described more precisely

The push boat "Elektra" of Behala GmbH is currently being built for logistics traffic on the water. Behala GmbH, in cooperation with the Technical University of Berlin, has ordered the push boat from the Barthel shipyard in Elbe Parey in Saxony-Anhalt. The push boat will be powered by a combination of batteries and three fuel cells with a nominal output of 100 kW each. Regular operation as a push boat is scheduled to start by the end of 2024 on the Berlin - Hamburg route. According to the company, the propulsion concept can also be transferred to other cargo transport vessels within the development and construction of the Elektra. The project is presented in chapter 4.2. as a pilot project.

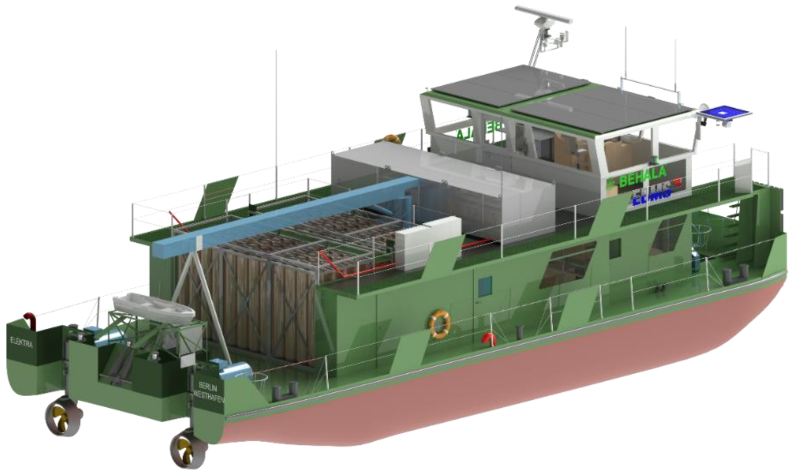


Figure 9: Concept illustration push boat Elektra of Behala GmbH [16]

Summary Mobility & Logistics

The majority of the companies surveyed are currently relying on battery electric vehicles to decarbonise their fleets. The main arguments against including hydrogen-powered vehicles in fleets were the lack of economic efficiency and the currently still limited choice of models available on the market. Nevertheless, some companies already have H2 cars in operation, for which Berlin, with currently five H2 filling stations, offers good conditions.

Contrary to the current challenges, many companies are very interested in converting their commercial vehicles to run on hydrogen, as in their view the technical advantages outweigh the battery electric drives. There are also already concrete projects for the conversion of ship propulsion systems and rail transport.

Overall, there is strong interest and a positive outlook for the inclusion of hydrogen-based drives in mobility and logistics concepts for decarbonisation.

3.2. Electric Power & Heat Supply

In the electricity & heat supply sector all applications of combined heat and power generation were analysed.

Fields of application and current projects

In order to decarbonise the electricity & heat supply, hydrogen as a green, storable energy carrier is of great importance. GASAG AG is currently pursuing the goal of operating Berlin's natural gas network with a mixture of natural gas and 20 %-vol. hydrogen by 2030. In view of the coal phase-out by 2030, Vattenfall intends to convert the existing coal and gas power plants of Vattenfall Wärme Berlin AG in the coming years and make them H2-ready, which should enable the use of hydrogen gas mixtures in district heating generation. Individual new gas turbines of the CHP plants are to be operated completely with hydrogen in the future (e.g. the Marzahn CHP plant). For this, however, a dedicated hydrogen pipeline would have to secure the supply in addition to possible local production. Due to the current market and framework conditions, the conversion of power plants to pure hydrogen operation is currently not foreseeable before 2040.

Several large companies in the industrial and service sectors cover their heat and electricity needs to a large extent through their own CHP plants. Bayer AG, Charité and Vivantes, for example, set particularly high standards for the availability and reliability of their energy supply. As soon as proven technologies are available on the market and a competitive hydrogen supply is guaranteed, these companies would also be prepared in principle to convert current natural gas applications. Bayer AG has set itself the group-wide target of achieving balance sheet climate neutrality by 2030 and is evaluating suitable paths to achieve this. The decarbonisation of public and semi-public institutions such as the Charité and Vivantes is driven primarily by the specifications and procurement regulations for energy management which are drawn up by the state. Here, flagship projects in the heat and power sector could be developed.

With regard to the supply of electricity and heat to districts, the Neulichterfelde district and Siemensstadt 2.0 were considered in the interviews. In the Neulichterfelde district, 2,500 housing units for around 6,000 people are to be implemented with an emission-neutral heat supply through the use of heat pumps and biogas CHP units. The new Siemens Campus in Siemensstadt 2.0 is also to become a CO2-neutral residential and technology location with around 3,000 flats by 2030. According to Siemens, hydrogen is particularly relevant for mobility, given current knowledge and the given implementation period of the project. In the heat and power supply of Siemensstadt 2.0 and in Neulichterfelde, concrete hydrogen applications up to 2025 could not be described more precisely.

Summary Electric Power & Heat Supply

According to statements by the companies questioned, the use of hydrogen in the heat supply is of no significance in the short term due to the currently favourable energy and CO2 prices. Nevertheless, companies see the substitution of natural gas as essential for the decarbonisation of the electricity and heat supply. Companies with their own CHP plants are generally open to gaining experience in pilot projects and to making any necessary investments to adapt the technology.

3.3. Obstacles for H_2-Applications

In addition to current intentions, the study also included the obstacles to the use of hydrogen in the mobility, logistics and electricity and heat supply sectors. These are shown graphically in Figure 10.

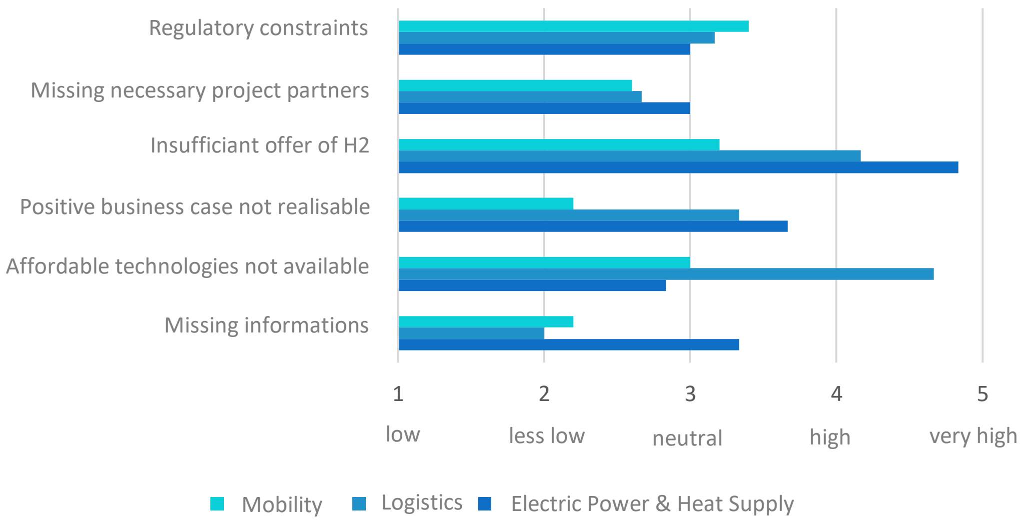


Figure 10: Assessment of the obstacles and necessary framework conditions for the use of hydrogen

Mobility & Logistics

As shown in Figure 10, the barrier factor of missing technologies in the logistics sector is rated as high to very high. In this context, the majority of the interviews highlighted the problem that there are currently no economic concepts and standardised hydrogen-powered vehicles on the market in the commercial and utility vehicle sector. However, initial research and pilot projects, such as the development of the push boat Elektra (see Chapter 4), show a progressive development.

When looking at the obstacle factors, it is striking that in the mobility and logistics sector the factor *No economic business model* is only rated neutral to high, but the factor *No sufficient hydrogen supply* is rated high to very high. The purchase and temporary storage of green hydrogen is initially subject to high investment in infrastructure if connection via the local gas network is not possible. In connection with the acquisition of new vehicles and the purchase of green hydrogen, the companies surveyed do not believe that this is currently an economically viable option. Under the factors *Obstacles to the regulatory framework* and *Lack of information*, national and regional regulations and requirements in connection with funding models are also expected to facilitate investment in hydrogen technologies by companies.

Electric Power & Heat Supply

For decentralised electricity and heat supply as well as central CHP power plants, the energy source is usually obtained by direct connection to the natural gas grid. This means that a substitution of the energy source in the gas network will inevitably lead to decarbonisation at the consumer. The technologies required for this are generally considered to be available; in this context the barrier of missing technologies was only rated as less high to neutral.

However, the factor *No economic business model* is rated as neutral to high, since hydrogen cannot compete with fossil fuels in electricity and heat supply from today's perspective. Since the decarbonisation of gas applications by hydrogen appears necessary in any case, heat and energy suppliers are nevertheless preparing for it. In order to raise the decarbonisation potential in a timely manner, suitable framework conditions would have to be created which make feeding hydrogen into the gas grid or decentralised use for electricity and heat supply economically attractive.

4. Projects, Intentions & Options

Company	Realisable by 2025	Realisable by and after 2030
BEHALA GmbH	Push boat Elektra	
Berliner Feuerwehr		Conversion of the existing fleet to hydrogen power trains
BSR		Conversion of utility vehicles to hydrogen power trains
Vattenfall Wärme Berlin AG		Conversion of the Marzahn thermal power station to H2
Berliner Wasserbetriebe	Conversion of two utility vehicles to hydrogen	Conversion of utility vehicles to hydrogen power trains
BEHALA GmbH		Conversion of utility vehicles to hydrogen power trains
Berliner Wasserbetriebe		Substitution of heat supply by hydrogen gas
BSR		Heat supply via hydrogen
Stiftung Deutsches Technikmuseum Berlin	Conversion of Kaiser-Friedrich ship to hydrogen	
Project Everywh2ere	Use of fuel cell power supply at events	
Meyer & Meyer Holding SE & Co. KG		Use of an H2 trucks in medium and long distance transport

	Projected Consumption	Intended Consumption
	37,1 t H_2/a	**6.480,9 t H_2/a**

Assuming that the most important actors in the implementation of hydrogen projects in Berlin were consulted**, the large delta between the identified projected hydrogen demand for 2025 of 37.1 t H2 and the model-based demand of approx. 9000 t H2 is striking**. This suggests that the necessary framework conditions must be further developed to create opportunities and incentives for the use of hydrogen.

4.1. Breakdown of Identified Projects

Based on the information gathered in the interviews, the identified projects and intentions were analysed and differentiated into current (planned until 2025), currently medium-term (planned after 2025) and potential projects (no planning available so far).

Project ideas that require further investigation for evaluation

Due to a lack of information or concrete plans, some potential projects could not be examined more closely in the study.

	Project Ideas
Potential Projects	Conversion of parts of the bus fleet to H2 operation (Model Cologne and London)
	Conversion of parts of passenger shipping to H2 operation
	Conversion of heavy goods vehicles to H2 propulsion (diesel tolls for the city, introduction of a pay-per-use model like in Switzerland)
	Conversion of stationary power generators to H2 operation (diesel ban in the city, Amsterdam model until 2025)
	H2 taxi operation (successful model Hype in Paris)
	Conversion of parts of the airport ground fleet to H2 power trains (Hamburg model, climate-neutral in 2021)
	Replacement of diesel locomotives in railway operation with H2 railcars
	Conversion of combined heat and power plants to H2 operation
	Production and use of H2 on Reuther West site (BSR-Vattenfall)
	Use of the energy source H2 in the new quarters Siemensstadt 2.0 and Lichterfelde Süd

4.2. Description of Current Projects

BEHALA

Brief description of the push boat ELEKTRA

In cooperation with the TU Berlin, shipyard Hermann Barthel, Ballard Power Systems, Anleg, Schiffselektronik Rostock, EST-Floattech and Imperial Logistics, Behala is developing a push boat that will in future commute between Hamburg and Berlin. There is also a willingness to convert the vehicle fleet (250,000 litres of diesel per year) to hydrogen.

Profil

Parameter	Value	Comment
Expected demand until 2025	20 – 25 t_{H2}/a	Push boat Elektra in normal operation
H_2 demand potential	92 – 98 t_{H2}/a	Push boat Elektra including conversion of the entire fleet to hydrogen
Potential for decarbonisation	12.133 t_{CO2}/a	Related to overall potential
Scalability	70 t_{H2}/a	• Related to the H2 potential of Berlin's ships in 2030 • Container traffic is also expected to increase in the Berlin region due to the opening of the Elbe-Havel Canal

Transfer of the technology of the push boat to:

- passenger ships
- Police boats

Transfer of technology from commercial vehicles to:

- heavy transport
- Special vehicles

How can this potential be exploited?

- Provision of the necessary technology
- Ensuring a resilient supply infrastructure within Berlin
- Financial assistance in technology procurement (80%- 90% of the gap between technologies)
- Hydrogen price under 5 €/kgH2

Berliner Wasserbetriebe

Utlity Vehicles	Overall Potential 330,08 t H_2/a
Brief description of the project idea	Berliner Wasserbetriebe are currently working on converting two commercial vehicles for operation with hydrogen. A total of approx. 600 different commercial vehicles are in operation, which in the future can be operated with hydrogen.
How can this potential be activated?	• providing the necessary framework conditions for an economically viable use of hydrogen

Stiftung Deutsches Technikmuseum Berlin

Passenger Shipping	Overall Potential 0,6 t H_2/a
Brief description of the project idea	The German Museum of Technology wants to convert the Berlin steamer KAISER FRIEDRICH to hydrogen operation. In future, the steamer is to be used for conferences and training courses and to promote hydrogen technologies. A positive feasibility study is already available. Currently, a financing possibility is being sought to implement the project.
How can this potential be activated?	• Financial support for the implementation of the project

Everywh$_2$ere

Stationary Power Generators	Overall Potential 2 t H_2/a
Brief description of the project idea	For the Lollapalooza Festival 2020, it was planned to use two fuel cells from the Everywh2ere project to supply electricity. The project sees an immense potential in supplying festivals with fuel cells, as the diesel generators are designed for peak loads, which are only needed at peak times. The rest of the time the units will be run at 15 % - 20 % of the maximum load, which is already an economic business case for hydrogen. Partners are explicitly sought to exploit this opportunity in the hydrogen environment.

4.3. Presentation of Current Medium-Term Projects

4.3.1. H_2-Vehicles, Transport and Logistics

Berliner Stadtreinigung (BSR)

Brief Description Conversion of Utility Vehicles to H2 Power Trains

Berliner Stadtreinigung (BSR) has been active in the field of sustainability for a long time. For several years now, it has been operating half of its waste collection vehicles with biogas from its own biowaste fermentation. Similarly, around 75 % of cars and vans are already powered by batteries. In the next step, for the decarbonisation of further commercial vehicles, the BSR only considers the use of hydrogen to be realistic, in addition to the use of biogas, since, for example, with the weight of a battery-powered vehicle, the required payload can only be achieved with considerable effort. As early as 2013, BSR carried out a pilot project to operate partial functions of a waste collection vehicle with hydrogen. With a view to BEK 2030, BSR is striving to decarbonise not only its fleet of cars but also the operation of its utility vehicle fleet.

Profil

Parameter	Value	Comment
Expected demand until 2025	0 t_{H2}/a	No short-term technical applications for hydrogen are currently envisaged
H_2 demand potential	898 t_{H2}/a	Conversion of the utility vehicle fleet to hydrogen
Potential for decarbonisation	8.022 t_{CO2}/a	Related to overall potential
Scalability	2.229 t_{H2}/a	Based on Berlin's H2 potential of commercial/utility vehicles and trucks in 2030

Transfer of the technology to:

- Heavy transport
- Special vehicles
- Utility vehicles

How can this potential be exploited?

- Provision of the necessary technology
- Ensuring a resilient supply infrastructure within Berlin
- Minimisation of susceptibility to faults
- Financial assistance in the procurement of the technology

Berliner Feuerwehr

Brief description of hydrogen-powered emergency vehicles

Against the background of the BEK requirements to implement CO2-neutral fleets in municipal/public companies by 2030, the Berlin fire brigade is actively looking for ways to make its fleet climate-neutral. In the course of its regular activities, the Berlin fire brigade's fleet (928 vehicles in total) consumes up to approx. 2 million litres of diesel per year. Against the background of the administrative regulation on procurement and the environment (VwVBU), the fire brigade is required to comply with the most demanding exhaust gas standard. In addition, the Berlin fire brigade is encouraged to decarbonise its fleets via BEK 2030. The Berlin fire brigade sees a great deal of potential in the use of hydrogen, as battery technologies alone do not meet the requirement profile of emergency vehicles. Currently, the Berlin fire brigade has four hydrogen passenger cars.

Profil

Parameter	Value	Comment
Expected demand until 2025	0,5 t_{H2}/a	Currently, four passenger cars are powered by hydrogen
H_2 demand potential	582 t_{H2}/a	Conversion of the entire fleet to hydrogen
Potential for decarbonisation	5.200 t_{CO2}/a	Replacing 2 million litres of diesel with hydrogen
Scalability	2.229 t_{H2}/a	Based on Berlin's H2 potential of commercial vehicles and trucks in 2030

Transfer of the technology to:

- Heavy transport
- Special vehicles
- Utility vehicles

Use of mobile care infrastructure in health care or for events

How can this potential be exploited?

- The Berlin fire brigade is looking for partners who can provide the appropriate technology. At present, hydrogen emergency vehicles (RTW etc.) are not available on the market.
- A secure supply infrastructure must be available to also be able to guarantee disaster control (H2 is brought to the emergency vehicles)
- Financial support for investment in fleet development

BEHALA

Harbour Supply	Overall Potential 72,83 t H_2/a
Brief description of the project idea	The Behala is currently already working on the project push boat Elektra. In addition to this project, other hydrogen technologies are also being sought (for construction machinery, traction and other port vehicles, commercial vehicles or even technology for rail transport) to reduce diesel consumption. Preference will be given to avoiding diesel fuel where technically and economically feasible.
How can this potential be activated?	• It is expected that OEMs will drive the development of hydrogen technologies, with the exception of the push boat, no own developments are foreseen • A hydrogen price below 5 € /kg H2 • Availability of a resilient and fail-safe supply infrastructure within Berlin to avoid detours

Meyer & Meyer

Long Haul Transport	Overall Potential 11 t H_2/a
Brief description of the project idea	The Meyer & Meyer Group has been working for several years on decarbonising its commercial vehicle fleet in the local transport sector (distribution fleets) and its medium and long-distance transport. Hydrogen is of interest to Meyer & Meyer in medium and long distance transport; internal studies currently do not see a business case for hydrogen-powered trucks in local distribution operations. As a first application scenario a truck in shuttle traffic between Berlin and Peine Osnabrück was identified, whose consumption potential is exemplarily recorded here.
How can this potential be activated?	• Visibility of a technology development regarding hydrogen by the OEMs • Promotion of investment in hydrogen-powered fleets

Taxi Company

Overall Potential **12,04 t H_2/a**

Brief description of the project idea	CleverShuttle used twenty hydrogen-powered cars by June 2020, which require about 12 t H2/a. Large-capacity taxis seemed particularly attractive for the procurement of further hydrogen vehicles. However, according to the latest developments, the ridepooling service **will be discontinued in Berlin**.
How can this potential be activated?	• Availability of an economic business case (e.g. through support measures) • Trouble-free operation of hydrogen technologies

4.3.3. Heat Supply

Vattenfall Wärme

Brief Description
Conversion of the CHP Plant Marzahn on H2 Operation

Vattenfall Wärme is gradually preparing for the use of hydrogen. It is intended to prepare new and existing gas turbines for partial to complete conversion to hydrogen. The operation of power plants with pure hydrogen is not considered realistic under the foreseeable conditions until 2040. In view of the supply infrastructure (pipelines and H2 electrolysis plants), the Marzahn CHP plant offers the prospect of being one of the first power stations to be converted to hydrogen.
The construction of a 30 MW electrolyser is planned by 2030 as a pilot project for the proportional supply of hydrogen to the Marzahn CHP plant.

Profil

Parameter	Value	Comment
Expected demand until 2025	0 t_{H2}/a	No use of hydrogen is currently envisaged until 2025
H_2 demand potential	3.600 t_{H2}/a	Proportionate operation of the Marzahn CHP with hydrogen, supplied by the 30 MW electrolyser[2]
Potential for decarbonisation	2.112 t_{CO2}/a	Realated to overall potential
Scalability	53.243 t $_{H2}$/a	Based on the GASAG scenario, 20 %-vol. hydrogen to be fed into the gas network by 2030

Transfer of burner technology to other applications:

- Combined heat and power plants

How can this potential be exploited?

- Provision of the necessary technology (it is currently not clear from what point in time it will be possible to operate with high hydrogen contents)
- Flexibility in the use of hydrogen and natural gas, as a constant availability of hydrogen is not assumed
- Ensuring a resilient supply infrastructure within Berlin

[2] Electrolyser assumptions: 70 % electrical efficiency; 4,000 full-load hours (based on the German government's hydrogen strategy)

Berliner Wasserbetriebe

Heat Supply **Overall Potential** **660,53 t H_2/a**

Brief description of the project idea	Berliner Wasserbetriebe see a perspective for the use of hydrogen in heat supply, for example in combined heat and power plants.
How can this potential be activated?	• It is necessary to ensure a reliable supply infrastructure for hydrogen

Berliner Stadtreinigung

Heat Supply **Overall Potential** **300,07 t H_2/a**

Kurzbeschreibung der Projektidee	Berliner Stadtreinigung sees a potential of up to 10 GWh for heat supply via hydrogen in CHPs. The exclusive use of heat pumps for heat supply is not economically optimal, as the pumps would have to be operated outside their efficient operating point.
How can this potential be activated?	• Provision of a technically reasonable (efficiency) and economically justifiable solution

4.4. Additional Potential beyond the projects considered

In the previous chapter, Berlin companies were asked about their intentions regarding the use of hydrogen. The survey did not cover Berlin bus transport and aviation, which appear to have great potential in terms of technology and decarbonisation. For this reason, these applications are assessed theoretically below.

Double-decker buses of the BVG

BVG (Berlin public transport services) intends to convert its entire bus fleet to alternative drive systems by 2030 [14]. Due to the high weight and correspondingly high fuel consumption, decarbonisation of the double-decker buses using battery electric drives is a particular challenge. However, a hydrogen drive with relatively high power density appears advantageous for this purpose. If all 383 double-decker buses of the BVG were to be converted to hydrogen propulsion, the annual demand would be approximately **2,970 tonnes of hydrogen**.

In 2018, Wrightbus presented a hydrogen-powered double-decker bus for the first time at the Euro Bus Expo 2018, of which 15 were ordered the following year by the city of Aberdeen in Scotland and others for London [16, 18]. Based on these examples, an implementation in Berlin seems realistic. In addition to the market availability of the buses, their economic efficiency must also be taken into account, including the required refuelling infrastructure. Whether and what proportion of the buses will be converted to hydrogen is currently open.

Use of E-Fuels in air traffic

Air traffic was responsible for around 20% of total emissions in 2017 and has led to significant increases in recent years [5]. Due to the high demands on the energy density and handling of aircraft fuel, the decarbonisation of air traffic is likely to require the use of synthetic fuels (E fuel), which are produced on the basis of electricity-based hydrogen and carbon monoxide.

A consortium around the Dresden start-up Sunfire has announced the construction of one of the first commercially operated plants for the production of e-fuels for 2023, which is expected to produce 100 million litres of e-fuels per year after two years [19]. The commissioning of further major e-fuel production facilities in Norway and Morocco has been announced for the next five years [20]. Provided that the general conditions develop favourably, it can be assumed that the production of synthetic fuels will increase sharply and will be available to a large number of consumers.

To produce **0.38 % of BER's kerosene** consumption from e-fuels would require **760 tonnes of hydrogen in 2025**. It is assumed that the fuel requirements of BER (new Berlin Airport) are made up of the requirements of Tegel and Schönefeld airport and, in addition, it is assumed that 70 % of this is attributed to the Land Berlin. The German Government is currently discussing a mandatory e-fuels quota of 2% of fuel consumption. To meet this quota in 2030, 0.38% of the 470 million litres of kerosene could be replaced by e-fuels in 2025 in a moderate ramp-up scenario. The hydrogen demand would not be generated directly in Berlin, as synthetic fuels are produced in refineries close to CO2 sources. Nevertheless, Berlin, as a major consumer, can influence trend-setting decisions on the introduction of e-fuels and the development of the necessary infrastructure.

Blending the natural gas network with hydrogen

Due to their high efficiency, heat pumps are often the most sensible alternative to decarbonising the heat supply of buildings from an economic and ecological point of view [21]. However, since heat pumps only reach comparatively low temperatures, they are particularly suitable for supplying heat to buildings that have good insulation and large radiators (ideally underfloor heating). In Berlin, however, there are numerous old buildings, some of which have poor thermal insulation and therefore unfavourable conditions for heat pumps [1].

It is therefore assumed that the domestic heat supply will foreseeably be based on gas heating and district heating, among other things. According to the feasibility study on the coal phase-out, district heating will continue to be provided largely by gas CHP plants and to some extent by direct use of renewable energies and waste heat. The coal phase-out and sustainable district heating supply in 2030, in the scenario of a 95 % reduction in emissions, envisages the use of 5 % synthetic gas (produced with green hydrogen) in the remaining gas power plants in the western district heating network of Vattenfall in 2031 as a substitute for coal heat, with the share rising to 100 % by 2050 [13].

For the reasons mentioned above, it can be assumed that hydrogen will play an important role in Berlin's heat supply. Even if the business case for adding hydrogen to the gas network is difficult under the current framework conditions, **the special requirements of Berlin's heat supply must be taken into account**. If emission-free produced hydrogen is fed into the natural gas network, both buildings whose heating systems are based on natural gas and gas-fired power stations or combined heat and power plants (CHP) that obtain their fuel from the natural gas network can improve their emission balance. If there are no critical consumers in the gas networks, 10% vol. hydrogen can be fed into the natural gas grid [22]. If these are available in individual network strands, the admixture may have to be limited to 2% vol.

In the spirit of a gradual conversion of the gas system, GASAG AG's declaration of intent was included, which states that by 2030 the addition of up to 20 % vol. hydrogen into the natural gas network by 2030 [23]. Due to the large quantities of gas and the current legal restrictions, a moderate ramp-up was assumed, resulting in a hydrogen content of **2 % vol. for 2025**. Based on the gas throughput in the Berlin gas network in 2019 of 31 TWh, a 2 %-vol. hydrogen would result in an **annual consumption of 5,046 t hydrogen**.

With an admixture of 2 %-vol. hydrogen in the natural gas grid can save approx. 0.64 % of emissions (36,161 t CO2). With an admixture of 20 %-vol. hydrogen, emissions are reduced by approx. 7.3 %. Measures to reduce emissions in domestic heat supply are caught between rising energy prices due to substitution of the energy source and rising rents due to investments in energy-related refurbishment. It is necessary to examine in detail which combination represents the most socially acceptable compromise.

5. Legal Framework for Hydrogen in Berlin

For the development of a hydrogen infrastructure, licensing regulations for construction and operation (electrolysers, filling stations, pipelines, etc.) as well as specifications and quotas for the use of alternative drives or energy carriers in the mobility sector and regulations regarding the feed-in of hydrogen into the natural gas grid play an important role.

5.1. Approval of Hydrogen Infrastructure Elements

A central element of any licensing procedure is effective co-operation between the applicant and the competent licensing authority. In Berlin, the competent authorities for the licensing of hydrogen infrastructure plants are basically the State Office for Occupational Safety, Health Protection and Technical Safety (LAGetSi) and the Senate Administration for Environment, Transport and Climate Protection. Hydrogen filling stations already realised fell within the scope of the LAGetSi, which is why it can be assumed that the licensing procedures for other elements of the hydrogen infrastructure will also be dealt with by the LAGetSi in future [24].

The nature of the approval procedure for hydrogen refuelling stations depends essentially on whether the hydrogen is to be produced locally. If the filling station is planned with onsite production (e.g. electrolysis), a formal approval procedure must be carried out in accordance with the requirements of the Federal Immission Control Act (BImSchG). If it is a filling station where the hydrogen is not produced on site, a simplified procedure under the BImSchG can be carried out in any case. If the storage capacity of the filling station for hydrogen is less than three tonnes, no procedure according to the requirements of the BImSchG is necessary and the Building Regulations for Berlin (BauO Bln) and the Ordinance on Industrial Safety and Health (BetrSichV) are decisive [25].

According to one of the plant manufacturers surveyed, LAGetSi needs to build up further expertise and establish standardised processes in the hydrogen sector in order to ensure efficient approval processes in future. The same applies to TÜV Berlin, which will probably play a central role in accompanying the approval process and the acceptance of infrastructure elements of the hydrogen economy in Berlin.

NOW GmbH has drawn up a generally applicable guideline for the clear presentation of the individual process and planning steps that must be taken into account when approving a hydrogen filling station. The guideline offers assistance both to the applicant and to the competent licensing authority and can help in the efficient performance of the licensing process [26].

5.2. Promotion of Hydrogen Applications in the Transport Sector

The use of alternative propulsion systems in the transport sector is promoted and encouraged by various legal requirements and regulations. Two European Union directives play a central role in this respect. Directive 2018/2001 on the promotion of the use of energy from renewable sources (RED II) initially formulates the goal of increasing the share of renewable energies in the Union's gross final energy consumption across all sectors to at least 32% by 2030 (cf. Art. 3). With regard to transport, the EU Member States should ensure that the share of renewable energies in the sector's final energy consumption rises to at least 14% by 2030 (Art. 25(1)) [27]. In the recently published National Hydrogen Strategy, the German government reaffirms its commitment to a timely and ambitious implementation of RED II. For example, the minimum share of renewable energies in final energy consumption in the transport sector in Germany in 2030 should be significantly higher than the EU target. The German government also announces that the use of green hydrogen, as an alternative and for integration into conventional fuels, will play a special role in the implementation of RED II in national law. It is to be expected that the national laws still to be passed to fully implement RED II will create new incentives for the use of green hydrogen.

In addition to RED II, the "Clean Vehicles Directive" (CVD) can also contribute to the increased use of hydrogen-powered vehicles. For example, the CVD sets minimum quotas for the procurement of zero-emission or low-emission vehicles through public procurement contracts, which must be met for the periods up to 2025 and 2030. The following minimum quotas for "clean vehicles" apply to Germany:

Vehicle Class	Minimum Quota
Light commercial vehicles	38,5 % until 2025 and 2030
Trucks	10 % until 2025 and 15 % until 2030
Buses	45 % until 2025 and 65 % until 2030

Table 4: Minimum quotas for the procurement of zero-emission/low-emission vehicles through public procurement under CVD (Clean Vehicle Directive)

Light commercial vehicles are considered "clean" for the period until 2025 if they emit no more than 50 g CO_2/km. From 2026, this limit drops to 0 g CO_2/km. For trucks and buses, on the other hand, vehicles are considered "clean" if they run on alternative fuels. In addition to electricity, hydrogen and synthetic fuels, the Directive includes natural gas among the alternative fuels. In addition, for public procurement of buses, the CVD requires that at least half of the clean vehicles must have zero emission propulsion for both periods. In fact, only vehicles with purely electric propulsion (battery or hydrogen fuel cell) can be considered as emission-free buses [28].

In the course of the adoption of the Berlin Mobility Act, the Berlin Senate has issued regulations that go far beyond the requirements of the CVD, particularly in the area of bus transport. Section 26(9) of the Act states that "the provision of public transport services by rail and road [...] is to be gradually converted to full operation with alternative drive systems or non-fossil fuels by 2030 at the latest" [29].

It can therefore be stated that various legal requirements promote or stipulate the increased use of alternative drives in public authorities and public companies. In Berlin, the public sector in particular is obliged to take particular account of emission-neutral forms of propulsion when making purchases. This applies above all to the purchase of buses, but also to light commercial vehicles and trucks. Hydrogen-powered vehicles can play a central role in meeting the required quotas. With the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) and the Energy and Climate Fund (EKF), two funding sources provide financial resources to support the acquisition of fuel cell vehicles [8].

5.3. Blending Hydrogen into the Natural Gas Grid

Under section 34 and section 19(1) sentence 3 of the Gas Grid Regulation, biogas is entitled to priority feed-in to the gas grid and exemption from grid fees. Under section 3(10c) of the German Energy Industry Act (EnWG), electrolytically produced hydrogen is covered by the rules for biogas if at least 80% of the electricity used for electrolysis comes from renewable energy sources [30].

In Germany, the permissible hydrogen concentration in the natural gas network is not regulated by law. However, gas network operators are obliged to ensure that fed-in gas is compatible with the network infrastructure and downstream applications. The technical requirements for this are laid down in two DVWG worksheets (G 260 & G262). According to the DVWG worksheets, feed-in is permissible as long as the hydrogen concentration in the network section does not exceed 10 % vol. and there are no restrictions due to specific end applications. In a press release last year, the DVWG made it clear that a target of about 20 % vol. hydrogen feed-in is targeted for the future regulations [31]. The necessary consideration of consumers with significantly lower tolerances, such as gas turbines and natural gas vehicles, currently means that in practice in many grid areas the permissible hydrogen addition limit is limited to 2 % vol. or less [27].

6. Possible Supply Option for Hydrogen

The hydrogen currently used in Germany, which is mainly produced by natural gas reforming, is mainly used in industry for the production of basic chemical substances such as methanol or ammonia and in refineries. Further consumption results from special applications such as glass processing or steel treatment. Currently, there is no major industrial hydrogen consumer in Berlin. If the demand for hydrogen were to increase, an infrastructure would have to be built up in the city to supply and possibly also produce hydrogen.

In the theoretical estimate of hydrogen demand in Berlin, an annual hydrogen demand of approx. 9,000 t hydrogen was determined for the year 2025. To produce this amount of green hydrogen, an electrolysis capacity of about 170 MW would have to be built up[3].

6.1. Supply in the City

When setting up an inner-city hydrogen supply, it is possible to plan the infrastructure directly for different consumers and to design it modularly. Logistically favourably located, multimodal hydrogen hubs for the production, storage, refuelling and distribution of green hydrogen could supply several hydrogen consumers. This would create cross-sectoral synergy and economies of scale right from the start. Larger hydrogen sinks, such as depots or neighbourhoods, could be established near larger consumers and, from there, serve smaller consumers by trailer.

Due to the concentrated electricity consumption of an electrolyser at certain points in the power grid, the grid connection conditions play a major role in the location of the plant. In order to use the flexibility of an electrolyser to the advantage of stabilising the grid and thus to benefit the grid, the installation and operation must be agreed with the electricity grid operator in good time.

At present, five hydrogen filling stations in Berlin are operated by H2Mobility and two more are planned to be operational by 2023. Depending on demand, the number of filling stations will be further increased in subsequent years. The filling stations will be supplied with hydrogen as required, which in perspective should be 100 % green.

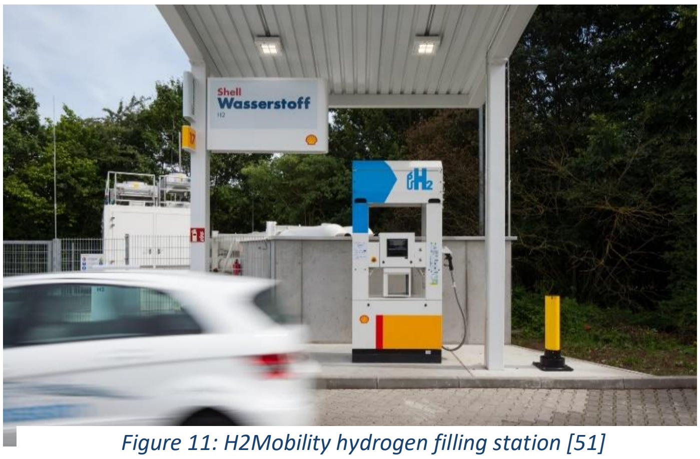


Figure 11: H2Mobility hydrogen filling station [51]

A further filling station is located at BER, which has its own electrolysis plant with a capacity of 200 - 300 kg hydrogen per day and is therefore self-sufficient. It is possible to expand this plant to a modular production capacity of up to 1 t per day using the existing infrastructure [32].

As an alternative to the production of green hydrogen via water electrolysis, there is a process for obtaining hydrogen from wastewater. In so-called plasmalysis, hydrogen is extracted from the nitrogen and hydrocarbon compounds present in the wastewater. Since elementary nitrogen and carbon are produced as waste products, this method is even a CO2 sink in terms of process

[3] Annahmen für Elektrolyseur: 70% elektrische Effizienz; 2.500 Volllaststunden

engineering. The Graforce company has developed a corresponding plant and is in the process of setting up a pilot plant with Berliner Wasserbetriebe at the Waßmannsdorf sewage treatment plant, which will initially produce 25 kg of hydrogen per day. According to Graforce, the total potential from the waste water produced in the sewage treatment plant is approximately 650 t of hydrogen per year. In addition, other sources of wastewater in the city could be tapped.

For the operators of Berlin's combined heat and power plants, it is time to reduce the use of fossil natural gas after the phasing out of coal use. In order to prepare for the gas phase-out, Vattenfall Wärme plans to gain experience in the operation of its CHP plants with hydrogen-natural gas mixtures in the near future and to demonstrate the technological feasibility. A pilot project for the operation of a 200 MW turbine with a H2 mixture is planned at Marzahn CHP plant. The hydrogen required for this is to be provided directly on site by a 30 MW electrolyser from 2030. In the future, the hydrogen intended for the power station could also be used in part to supply other hydrogen applications in the city.

Currently, Berlin's electricity consumption is around 13.2 TWh, 60% of which is produced in Germany. With the Solarcity master plan, the Berlin Senate has set the goal of significantly increasing the expansion of photovoltaic systems in the city area. By 2050, a quarter of electricity consumption is to be covered by domestically produced solar electricity, which requires the installation of solar systems with a capacity of 4.4 GWp [33]. There is no significant potential for wind energy. In addition to generation by solar installations, the remaining 75 % of electricity demand will in future be covered mainly by CHP plants and purchases from neighbouring Länder [9].

The production of hydrogen by electrolysers in the urban area is thus caught between the limited possibilities of electricity generation from renewable energy in Berlin and the advantageous location close to urban consumers.

6.2. Supply from the surrounding Area

The north-east of Germany and also the surrounding area of Berlin offer excellent conditions for the generation of renewable electricity through solar and wind energy plants. Brandenburg already produces a lot of electricity for the Berlin conurbation. Wind turbines with a total capacity of 7.3 GW have been installed in Brandenburg, but only around 50% of the total wind energy potential has been exploited [34]. With declining coal-fired power generation and increasing expansion of renewable energies in Brandenburg, large-scale storage facilities to balance feed-in and grid load are becoming increasingly important. Brandenburg's energy strategy also provides for the use of power-to-gas technology, which is to be demonstrated on a large scale in a real-life laboratory in the Lausitz (Lusatia). The conversion of the salt cavern near Bad Lauchstädt for H2 storage is in preparation. There is also the potential to use other caverns operated by EWE Gasspeicher GmbH to store 446 GWh (13,380 t) of hydrogen [35]. In the future, Brandenburg could be the closest and thus first supplier of green hydrogen to Berlin.

In addition, the northern German states such as Schleswig-Holstein, Mecklenburg-Western Pomerania and Lower Saxony have great potential for producing green hydrogen by using both onshore and offshore wind power. These Länder have already agreed on a joint hydrogen strategy in 2019, which envisages expanding electrolysis capacity in northern Germany to 500 MW by 2025 and 5 GW by 2030 [36]. However, even this strategy makes it clear that imports from abroad will be necessary to supply the entire demand for hydrogen. Whether German Länder sell green hydrogen on the national market therefore depends to a large extent on the development of international markets in the long term.

6.3. Hydrogen Infrastructure

According to the current legal framework, the direct connection of electrolysers to renewable energy plants can save grid fees and levies. In addition, the proximity to electricity generation (or even to grid bottlenecks) can relieve the strain on the electricity grids. Large electrolysers are therefore often installed close to large renewable energy plants.

Starting from large decentralised electrolysers in the Berlin area, hydrogen would initially be transported to the consumers by truck trailer. However, transport by road is not economically viable over distances of a few hundred kilometres and for large quantities. In the long term, therefore, a gas network for the transport of hydrogen should be established, for which the existing infrastructure of natural gas pipelines and storage facilities can be used to a large extent. Initially, smaller regional pipelines are likely to connect large hydrogen producers and centres of consumption, before an increasing number of consumers are connected via an interconnected network. In this context, the use of the Berlin gas storage facility under the Grunewald for the storage of renewable energies using hydrogen is currently being examined.

At the beginning of 2020, the transmission system operators published a draft for the Gas 2020-2030 network development plan, which for the first time contains concrete plans for the development of a nationwide H2 transport network. According to the draft NEP, however, Berlin would only be connected to a nationwide H2 network after 2030.
Import routes must be established in order to cover the emerging hydrogen demand in Germany cost-effectively in the long term. Liquefied hydrogen is transported to Germany and Europe from countries with very low costs for renewable energies. The hydrogen is then landed at large terminals and distributed further by pipeline. Figure 12 shows the structure of a possible hydrogen network that is being built from the north.

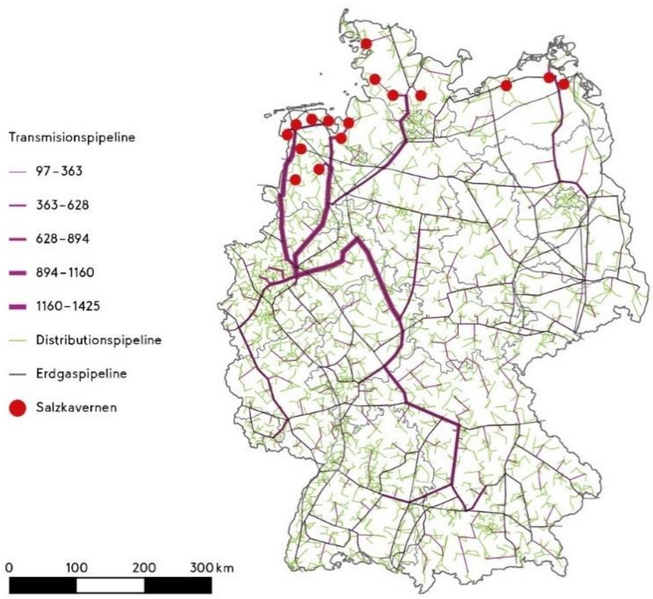


Figure 12: Possible pipeline infrastructure in Germany based on the natural gas grid [1]

7. Outlook

According to the plans of the national strategy, green hydrogen is an important element of energy system transformation. Germany is not alone in this opinion; green hydrogen is also a key element for the European Green Deal to achieve climate neutrality. The German capital should also help to shape the ramp-up of hydrogen use in the sense of setting a German, European and international example.

However, the projects and intentions of Berlin companies in the field of hydrogen analysed in this study show that there are still some obstacles (e.g. economic efficiency, lack of offers on the market, infrastructure development etc.) for Berlin companies to enter into hydrogen use on a large scale. There is a large gap between the predicted demand in Berlin according the Jülich Research Center model and the hydrogen demand actually projected for the year 2025. If Berlin's demand follows the assumed national development, there will already be a demand of about 9000 t of hydrogen in 2025.

In order to live up to its claim of leadership in climate protection, Berlin must take a pioneering role in the appropriate implementation of hydrogen in the energy and mobility system. Federal states such as Bavaria, but also city states such as Bremen and Hamburg have already adopted a hydrogen strategy.

Fields of Action

Due to Berlin's economic structure, the **heat supply of residential and office buildings** plays a particularly important role. The climate targets for 2020 will probably not be reached here. Due to the many CHP power plants and the large number of old buildings that are difficult to renovate, hydrogen will probably be part of the heat supply. In the feasibility study "Coal phase-out and sustainable district heating supply Berlin 2030" it is already outlined that gas-fired power plants will use 5 % synthetic gas in 2031 **to replace coal-fired heat and decarbonise district heating**. This already requires actions to be taken now to implement the fuel change.

Through the gradual decarbonisation of the heat supply, a stable demand will be built up, leading to the development and scaling of the generation and supply infrastructure, from which other consumers will benefit.

There is also a great need for action in the field of **transport**, which has also been recording rising emissions in Berlin for years. Vehicles with fuel cell drives will supplement battery electric vehicles where their performance is insufficient. This is particularly true in the areas of **commercial vehicles and logistics**. The intentions to retrofit commercial vehicles of the companies BWB, BSR and the fire brigade indicate a potential to be leveraged in the short term. BVG must also operate its bus fleet emission-free by 2030, for which hydrogen-powered buses, among other things, appear advantageous.

The increase in emissions in the transport sector was largely due to the growth in air traffic. Even if the regional implementation of a substitution of conventional aviation fuel seems difficult, Berlin must prepare for a supply of synthetic fuels in the long term.

Recommendation for action

Targeted measures will be needed in the coming years to realise the potential for climate protection and technology development. In addition to creating political and regulatory framework conditions at national and European level that sustainably support the use of hydrogen technologies, Berlin should actively promote the regional ramp-up of hydrogen applications.

In order to make optimum use of Berlin's radiance, **local "H2 lighthouse projects"** should be selected and promoted with the involvement of the local business network. Germany's claim to export clean tech worldwide, including hydrogen technology, should be supported by ambitious projects in the German capital.

Although Berlin has few incentives to use hydrogen technologies, companies are very interested in using hydrogen in the areas of commercial vehicles and logistics. It is now important to use the existing momentum to help companies' initiatives become reality. A **hydrogen roadmap** that creates a reliable framework for investment is helpful in this respect.

A consensus is needed to **set out the phase-out of fossil fuels** for Berlin. This should prioritise efficient substitutions and enable the entry into synthetic fuels through binding sustainability rules and incentive instruments. In this context, hydrogen is not an alternative, but a complement to applications with low conversion losses such as electric cars or heat pumps.

Further Investigations

The needs assessment has not yet been completed and must be continued. The present study shows the focus for further investigations.

Gaseous energy sources will continue to be needed in the future for electricity and heat supply. It remains to be investigated which synergies for the achievement of the climate target will be created by adding hydrogen to the natural gas network or by gradually converting individual neighbourhoods to hydrogen-based heat supply. Here, not only the pure effects of decarbonisation should be considered, but also the positive impact on the ramp-up of applications outside the heat supply.

In the field of mobility, Berlin's commercial transport is the focus of further studies. In perspective, BVG is one of the larger hydrogen consumers whose potential should be evaluated more closely. Furthermore, a concept must be developed with which commercial vehicles and emergency vehicles can be decarbonised in a timely manner. The experience gained from European pilot projects of the FCH-JU can be helpful in this respect.

For the relevant applications, specific profitability calculations should be carried out and the effects on regional value added and jobs should be investigated. This would require a detailed analysis taking into account the urban characteristics of Berlin, such as its economic structure, commercial transport and the existing gas infrastructure.

In order to guarantee the supply in the city, infrastructure analyses for networks and the investigation of existing natural gas pipelines for rededication as well as the identification of feed-in paths are necessary. Furthermore, a quantitative assessment of the potential for hydrogen supply from Brandenburg and a joint value-added chain should be carried out.

8. Introduction to H2Berlin

8.1. Partners of the Initiative

"After coal comes hydrogen" is the new mission statement of the Brandenburg state government. Brandenburg's strategic decision as the capital's traditional energy supplier to switch from coal to hydrogen in the future will have a significant impact on Berlin's supply and value chains. In addition, the experience gained in recent years shows that an energy industry in the city based solely on electricity will only satisfy the needs of consumers to a limited extent in an economically and technically justifiable manner.

In view of Berlin's fixed climate targets, this was the trigger for the capital's leading utilities and waste management companies, together with Toyota and Sustainable Hydrogen GmbH, to launch the H2Berlin initiative.

H2Berlin was given start-up aid by HyCologne, the hydrogen association from the Rhineland which has been successful for many years, the German Hydrogen and Fuel Cell Association DWV and NOW GmbH (National Organisation for Hydrogen and Fuel Cell Technology). In the meantime, the initiative has also been able to attract the Berlin Senate Department for Economics, Energy and Businesses and the Berlin Economic Development Agency, which have also supported the implementation of this study.

8.2. Objectives

The H2Berlin initiative pursues the following objectives in the capital region:

- promote and develop a hydrogen economy
- enable energy system transformation, the reduction of CO2 emissions and compliance with climate targets
- the promotion of a sustainable cyclical economy from renewable energy sources and the renunciation, as far as possible, of fossil fuels,
- contribute to the implementation of the National Hydrogen Strategy (NWS) and in particular to support the first phase of the market ramp-up of the hydrogen economy up to 2023 as formulated therein,
- use Berlin's radiance as an international location for young talents and start-ups, capital and largest metropolis in Germany, to bring innovative ideas and advantageous business models to the world and thus strengthen German and European activities for the use of hydrogen as an energy carrier,
- raise awareness in society of the importance of hydrogen and to demonstrate the important aspects of the technology to decision-makers in industry and authorities (fire brigade, public order office, police) (e.g. safety engineering),
- promote political decision-making,
- form a regional network of companies, scientific institutions and other bodies concerned with hydrogen and fuel cells.

8.3. First Activities

- Development of a first cross-company and cross-sectoral "show case", which is sufficiently large to stimulate a hydrogen economy in Berlin as a lighthouse project
- Development of a hydrogen roadmap for Berlin, which can be used by the Senate administration as a basis for the development of a hydrogen strategy for the capital

Abbreviations

BauO Bln	**Building regulations for Berlin**
BEK	**Berlin Energy and Climate Protection Programme**
BER	**Berlin Brandenburg Airport**
BetrSichV	**Ordinance on Industrial Safety and Health**
BHKW	**Combined heat and power station**
BImSchG	**Federal Immission Control Act**
CVD	**Clean Vehicle Directive**
DVWG	**German Society of Transport Sciences**
FCEV	**Fuel Cell Electric Vehicle**
GHD	**Industry, trade and services**
H_2	**Hydrogen**
KWK	**Power Heat Coupling**
LAGetSi	**State Office for Occupational Safety, Health Protection and Technical Safety**
NEP	**Network development plan**
NWS	**German National Hydrogen Strategy**
OEM	**Original Equipment Manufacturer**
ÖPNV	**Public Transportation Services**
RED II	**Renewable Energy Directive II**
GHG	**Green House Gas**
VwVBU	**Administrative regulation on procurement and environment**

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