GERMANY

Opportunities for **Hydrogen Energy Technologies** Considering the National Energy & Climate Plans

H2

FCH
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

Contract details
Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU)
Study on Opportunities arising from the inclusion of Hydrogen
Energy Technologies in the National Energy & Climate Plans
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fch-ju@fch.europa.eu

Prepared by

Trinomics

ludwig bölkow systemtechnik

Graphic Design:
Ático, estudio gráfico® - aticoestudio.com

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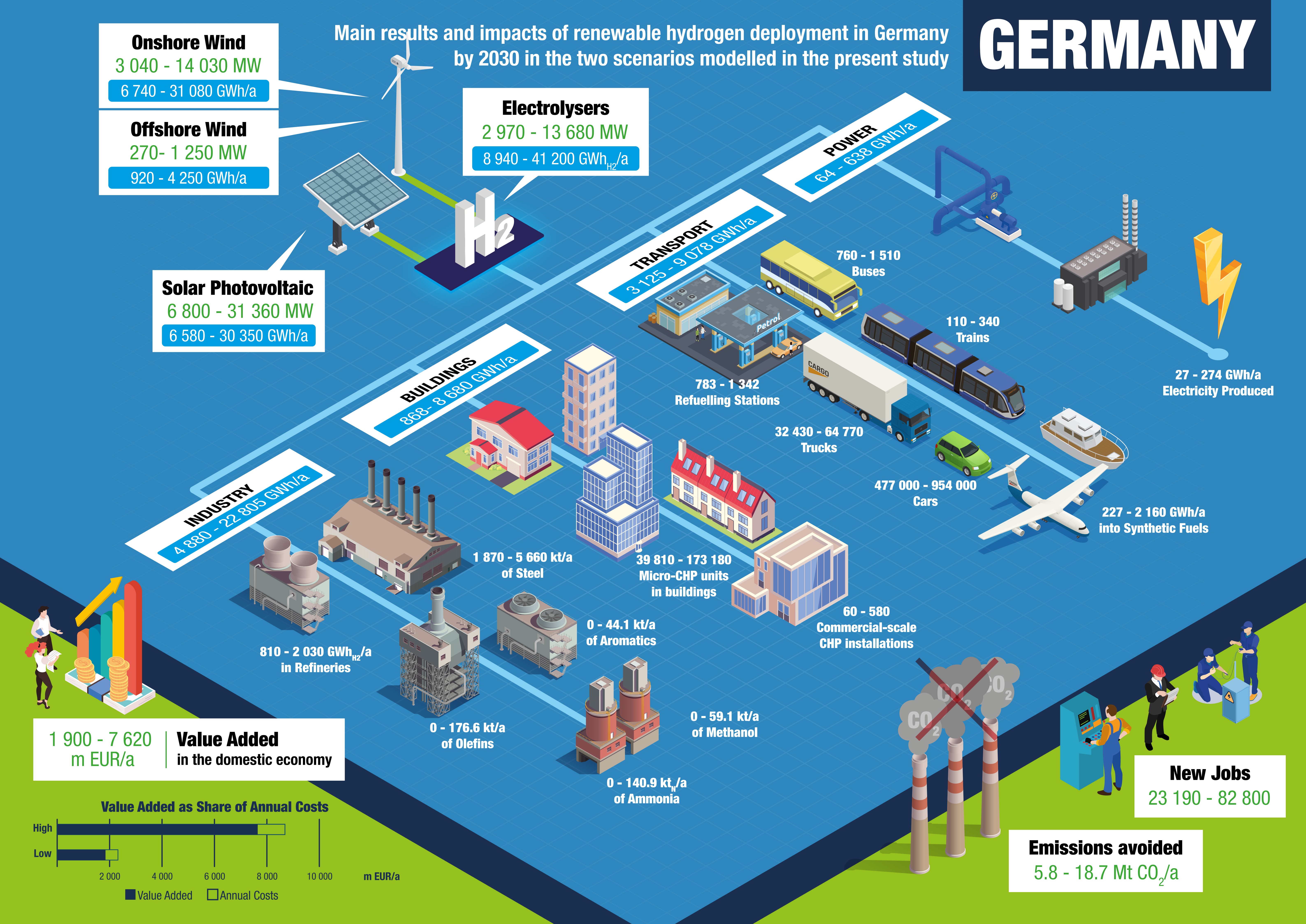
Introduction

The **Fuel Cells and Hydrogen Joint Undertaking** (FCH JU), in close cooperation with the **European Commission - DG Energy**, has commissioned a study on the "Role of Hydrogen in the National Energy and Climate Plans". This study is being conducted by the consultancies **Trinomics and LBST**.

This fiche represents one of the outputs of the study; it comprises two major parts:
- Analysis of **national opportunities for hydrogen deployment**, based on the national hydrogen production and demand potential, the gas infrastructure and the enabling environment. In this context, the role of hydrogen in the current National Energy and Climate Plan is in particular analysed.
- Assessment of **national economic, environmental and technical impacts of hydrogen deployment** under a high and a low scenario.

This information is expected to provide useful information to EU Member States that are considering to include renewable or low-carbon hydrogen deployment in their decarbonisation policies or roadmaps.


GERMANY
Main results and impacts of renewable hydrogen deployment in Germany by 2030 in the two scenarios modelled in the present study
Onshore Wind
3 040 - 14 030 MW
6 740 - 31 080 GWh/a
Offshore Wind
270- 1 250 MW
920 - 4 250 GWh/a
Electrolysers
2 970 - 13 680 MW
8 940 - 41 200 GWh_{H2}/a
Solar Photovoltaic
6 800 - 31 360 MW
6 580 - 30 350 GWh/a
H_2
POWER
64 - 638 GWh/a
TRANSPORT
3 125 - 9 078 GWh/a
BUILDINGS
868- 8 680 GWh/a
INDUSTRY
4 880 - 22 805 GWh/a
760 - 1 510
Buses
110 - 340
Trains
783 - 1 342
Refuelling Stations
Petrol
CARGO
32 430 - 64 770
Trucks
477 000 - 954 000
Cars
27 - 274 GWh/a
Electricity Produced
227 - 2 160 GWh/a
into Synthetic Fuels
1 870 - 5 660 kt/a
of Steel
39 810 - 173 180
Micro-CHP units
in buildings
60 - 580
Commercial-scale
CHP installations
810 - 2 030 GWh_{H2}/a
in Refineries
0 - 44.1 kt/a
of Aromatics
0 - 176.6 kt/a
of Olefins
0 - 59.1 kt/a
of Methanol
0 - 140.9 kt_N/a
of Ammonia
CO_2
1 900 - 7 620
m EUR/a
Value Added
in the domestic economy
Value Added as Share of Annual Costs
High
Low
2 000
4 000
6 000
8 000
10 000
m EUR/a
Value Added
Annual Costs
New Jobs
23 190 - 82 800
Emissions avoided
5.8 - 18.7 Mt CO_2/a

EXECUTIVE SUMMARY

Germany's commitment for hydrogen deployment according to its NECP

Germany has the ambition to "become a global leader in hydrogen technologies"[1] and "intends to invest €100 million annually in research of hydrogen technologies. This could be the business of the future, as well as the country's next top export product". Already in its National Innovation Programme on Hydrogen and Fuel Cell Technology (NIP) published in 2006[2], Germany considered that "Hydrogen and fuel cell technology will play an essential role in the future of mobility and energy supply". Germany mainstreamed hydrogen and fuel cells in its Mobility and Fuels Strategy[3] in 2013.

In February 2020, the first draft of a national hydrogen strategy has been released; it foresees that at least 20% of Germany's hydrogen consumption will be produced from renewable energies by 2030, by installing three to five gigawatt electrolyser capacity. Germany foresees to address the entire value chain including hydrogen generation, storage, transport, distribution and end-use. NOW GmbH[4], the National Organisation for Hydrogen and Fuel Cell Technology, is involved in the development of the hydrogen strategy. NOW is responsible for coordinating and managing the German Hydrogen and Fuel Cell Technology National Innovation Programme and other related Initiatives. NOW initiates projects, coordinates German funding and support, establishes international cooperation and raises awareness.

Germany is in a favourable starting position for hydrogen deployment given its industrial and research players active since many years, its industrial leading position in several technologies, its current investments in hydrogen research and pilot & demonstration projects, its extensive gas transport and distribution infrastructure, and the involvement of several cities and regions in hydrogen initiatives[5]. Germany is involved in the Green Hydrogen @ Blue Danube[6], Green Flamingo[7], Green Octopus[8], Green Spider[9], Silver Frog[10], White Dragon[11], H2Go[12], Zero-emission Urban Delivery @ Rainbow UnHycorn[13] and Blue Dolphin[14] IPCEI potential projects. Germany was also involved in the HyLaw[15] project, which identified and assessed major regulatory barriers in view of prioritizing measures to address them. The German participation in Mission Innovation, especially in the Innovation Challenge no 8 on renewable and clean hydrogen[16], will support the development of a global hydrogen market by identifying and overcoming key technology barriers.

According to its draft NECP, Germany expects to cover about 0,1% of its transport needs with hydrogen by 2030, and around 0,2% by 2040. The NECP does not provide hydrogen production targets nor specific hydrogen-related measures, which are expected to be included in the upcoming hydrogen strategy.

The scenario assessment shows substantial potential benefits of hydrogen deployment in Germany by 2030

Hydrogen demand

Two (high and low) scenarios of hydrogen demand in 2020-2030 were developed, based on different levels of ambition linked to the national context. The resulting values are summarised in the scheme in the previous page. For Germany, a significant development of hydrogen demand is assumed in the considered scenarios in **transport**, especially for passenger cars, buses, trucks and trains, and to a limited extent in aviation (through hydrogen-based liquid fuels or PtL) and navigation[17]. A significant development of hydrogen demand is also assumed in the scenarios in **industry**, especially in the iron and steel sector. Some industries use fossil-based hydrogen as feedstock or reducing agent, which could be replaced by renewable hydrogen. Switching high temperature heat processes fuels to renewable hydrogen could represent another important potential use in the considered scenarios.

In the **building** sector, hydrogen can replace part of the current use of natural gas and can be distributed via existing gas grids through admixture to natural gas. The building sector is expected to have in the Low scenario a limited demand of hydrogen by 2030 but would have a stronger demand in the High scenario.

The scenarios assume only a marginal share of electricity generation from hydrogen by 2030, coming from combined heat and power installations.

Hydrogen production

To cover the estimated hydrogen demand from new uses and from substitution of fossil-based hydrogen, 10.1 to 46.6 GW of dedicated renewable electricity capacity would have to be installed to produce green hydrogen via electrolysis. While "surplus" electricity might be available in times of high renewable electricity production, the main share will have to be covered by dedicated sources. In the two scenarios, part of the 2030 hydrogen demand would still be covered by fossil-based hydrogen produced via steam-methane reforming using fossil fuels.

In the European EUCO 3232.5 scenario[18], the installed capacity of variable renewable electricity sources in 2030 is estimated at 84 GW in wind and 81.7 GW in solar PV, generating about 271 TWh of electricity. The technical potential for renewable electricity production in Germany seems however significantly higher[19]. Building additional renewable electricity capacity dedicated for hydrogen production thus could be a feasible scenario.

Estimated socio-economic and environmental impacts

The annual costs to produce green hydrogen (including the cost of dedicated renewable electricity sources), to develop the transport infrastructure (or adapt the existing one) and end-user applications would in the considered scenarios reach respectively 2 341 and 8 573 million EUR. These activities will generate value added in the domestic economy, amongst others by creating jobs in manufacturing, construction and operation of hydrogen technologies and will contribute to greenhouse gas emission reductions. This is in particular important in hard-to-decarbonize industries. According to the EUCO3232.5 scenario[20], the German GHG emissions should be reduced by 290 Mt CO_2 in 2030, compared to 2015. In the scenarios considered, the deployment of hydrogen could contribute 5.8 – 18.7 Mt CO_2 to this goal, which is equivalent to 2% - 6.5% of the required emission reduction.

[1] https://www.euractiv.com/section/energy-environment/news/germany-eager-to-become-global-leader-in-developing-hydrogen-technologies/
[2] https://www.now-gmbh.de/en/national-innovation-programme
[3] https://www.vda.de/en/topics/innovation-and-technology/fuel-strategy/the-mobility-and-fuel-strategy.html
[4] https://www.now-gmbh.de/en/about-now/tasks
[5] https://www.fch.europa.eu/news/hydrogen-regions-get-further-support-germany
[6] https://static1.squarespace.com/static/5d3f0387728026000121b2a2/t/5d9b5e81e73c03421d1dd837/1570463369453/Green+HH2+Blue+Danube+poster_print.pdf
[7] https://static1.squarespace.com/static/5d3f0387728026000121b2a2/t/5e208b85ba1b7664a1933b7d/1579191174296/Green%2BHH2%2BGreen%2BFlamingo%2B-poster_print.pdf
[8] https://www.hydrogen4climateaction.eu/s/Green-Octopus.png
[9] https://static1.squarespace.com/static/5d3f0387728026000121b2a2/t/5d9ee2ee0bbfa367a02565c5/1570693882860/Green+Spider+poster.pdf
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[14] https://static1.squarespace.com/static/5d3f0387728026000121b2a2/t/5d9c7b1d9ada8b5691aa0536/1570536236724/Blue+Dolphin+poster.pdf
[15] https://www.hylaw.eu/sites/default/files/2018-10/National%20Policy%20Paper%20-%20Denmark%20%28EN%29.pdf
[16] http://mission-innovation.net/our-work/innovation-challenges/renewable-and-clean-hydrogen/
[17] Detailed assumptions are available in the methodology annex of the report, that can be consulted via the following link : http://trinomics.eu/project/opportunities-for-hydrogen-in-necps.
[18] In the time of writing this report, the final version of German NECP was not yet available and the draft NECP does not present any concrete relevant figures.
[19] The technical potential for renewable electricity production is based on the study commissioned by DG ENER Impact of the use of the biomethane and hydrogen potential on trans-European infrastructure (Trinomics, LBST, E3M; 2019).
[20] EC, 2019. Technical Note on Results of the EUCO3232.5 scenario on Member States. Available at https://ec.europa.eu/energy/sites/ener/files/technical_note_on_the_euco3232_final_14062019.pdf

HYDROGEN IN THE NECP OF GERMANY

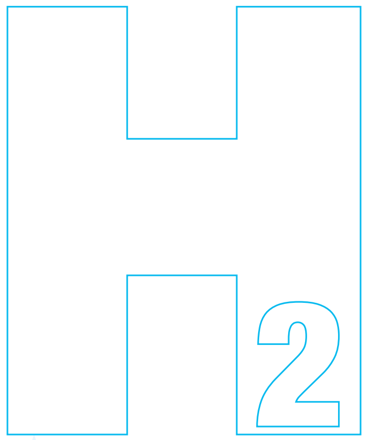
In order to support the development of Hydrogen and fuel cell technologies, the German authorities, industry and scientists have set up in 2006 a strategic alliance called the National Innovation Programme (NIP) for Hydrogen and Fuel Cell Technology.[21]

According to its draft NECP, Germany will further develop the NIP 2 to continue strengthening its technology expertise and supporting the market ramp-up phase of hydrogen. Germany will particularly focus on developing fuel cells for electric powertrains, deploying hydrogen refuelling stations infrastructure, generating hydrogen from renewable energies, integrating hydrogen into the energy system and deploying fuel cells for stationary energy supply. In 2016, Germany adopted a decision regarding the implementation up to 2025 of a framework programme on hydrogen and fuel cells.

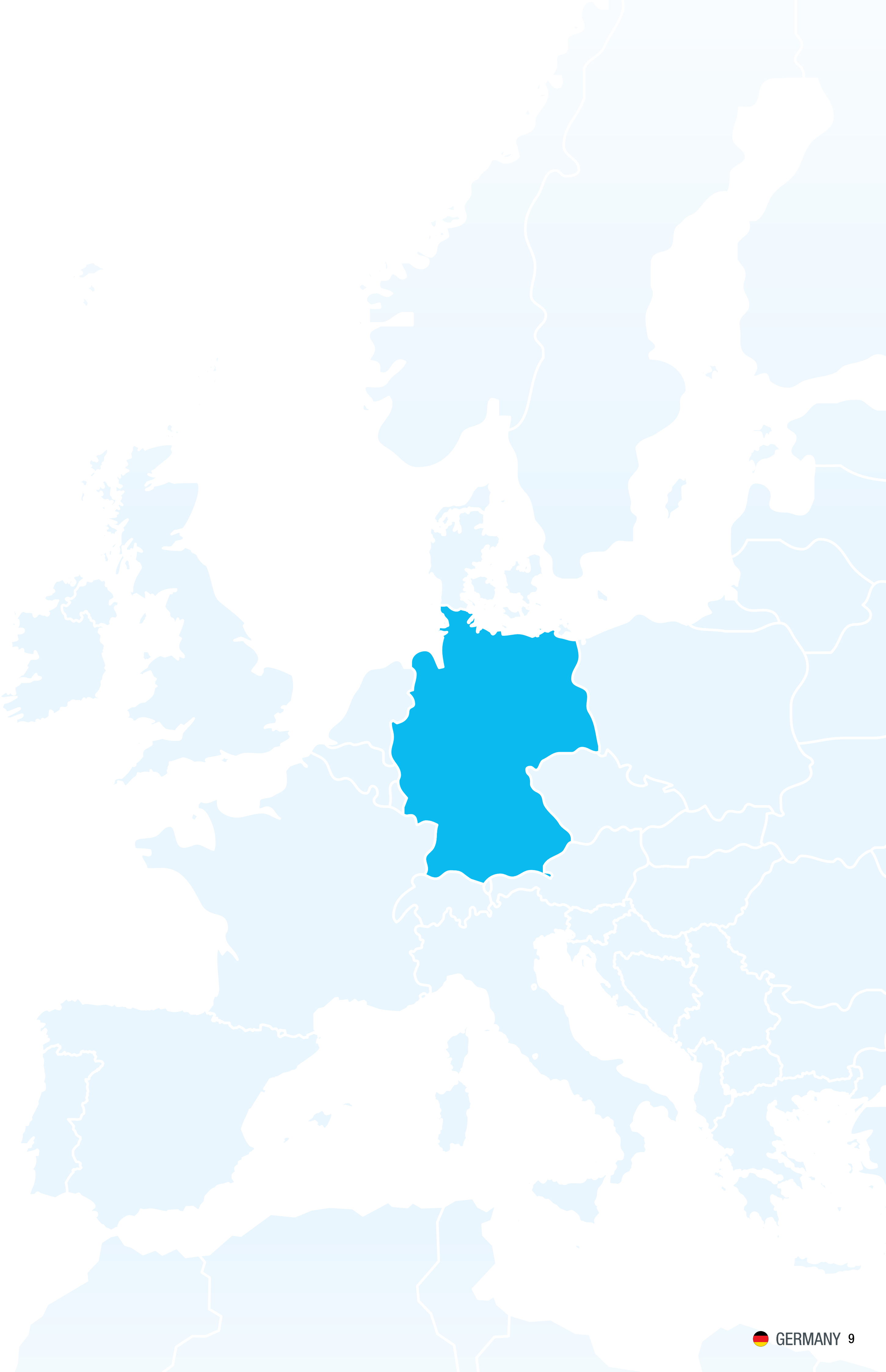
According to Germany's draft NECP, NOW GmbH coordinates and steers the Federal Government's National Innovation Programme for Hydrogen and Fuel Cell Technology and the funding guidelines on e-mobility and charging infrastructures. NOW also conducts technology watch up, analyses hydrogen related position papers of relevant stakeholders, coordinates projects with German participation, and supports the technology export initiatives in the field of hydrogen and fuel cell technology, as well as the German-Japanese cooperation in the field of power-to-gas technology. Among its priorities, NOW initiates hydrogen projects, evaluates their application and pools topics and activities in order to exploit synergies. In addition, NOW also undertakes interdisciplinary tasks such as establishing international cooperation, training and education, communication across politics, industry and science, and general public awareness to improve the perception of hydrogen and promote its various perspectives.

The National Strategic Framework for the Expansion of Alternative Fuel Infrastructures (implementing Directive 2014/94/EU) includes goals and measures to build charging infrastructure for electric vehicles, natural gas supply infrastructure (compressed and liquefied natural gas) and hydrogen supply infrastructure for fuel cell vehicles.

The draft NECP mentions that Germany would cover about 0.1% of its transport needs with hydrogen by 2030, and around 0.2% by 2040.



[21] https://www.now-gmbh.de/en/national-innovation-programme



OPPORTUNITY ASSESSMENT

Hydrogen production potential & its role in energy system flexibility

The technical variable renewable electricity generation potential in Germany is about twice as high as the electricity consumption forecasted in the EUCO 3232.5 scenario for 2030. There is thus an opportunity to use part of this renewable electricity potential to produce hydrogen via electrolysis. According to the EUCO 3232.5 scenario, Germany would by 2030 use 26% of its technical potential in renewable electricity generation, so there is a great margin for building up additional dedicated renewable electricity generation capacity for hydrogen production.
Given the technical limitations of the German electricity transmission system (bottlenecks in the north-south connection) and problems with infrastructure build-up due to lack of public acceptance, local conversion of power to hydrogen would help to ease the systemic constraints and to avoid curtailment of renewable energy production.

The indicators also show an opportunity to use power-to-hydrogen conversion and storage as a flexibility provider to the energy system. Due to the aforementioned constraints of the domestic transmission system, the flexibility needs might indeed be higher than suggested by the indicators. The flexibility needs will anyhow substantially increase as the installed capacity of variable renewable electricity generation in 2030 is expected to be significantly higher than the average load.

	Technical variable renewable electricity potential (TWh/yr)	Technical renewable electricity generation potential compared to forecasted gross electricity consumption in 2030 (NECP)	NECP estimate of variable renewable electricity production in 2030 (TWh/yr)	NECP estimate of variable renewable electricity production in 2030 compared to its technical potential	Ratio between variable power generation capacity in 2030 and average load	Readiness for CO_2 storage
Germany	1 046	188%	270.95	26%	based on NECP 261%	High

Germany has a quite advanced readiness for wide-scale deployment of CCS. It is in this domain one of the most advanced countries in the European Union, with a strong geological CO_2 storage potential and well advanced research programme.

Energy infrastructure

Blending hydrogen into the natural gas network is still under debate in Germany.

As the share of polyethylene in the distribution network is relatively high, it could be converted to hydrogen at relatively low cost.

	Technical and economic feasibility of converting gas distribution networks to hydrogen (share of polyethylene pipelines in distribution grid)	Natural gas demand in residential and services sectors / length of gas distribution network (GWh/km)	Existing salt cavern natural gas storage sites (TWh)	Suitable geological formations (potential for future hydrogen storage)
Germany	51%	0.7	153.5	YES
EU	MS range 16%-99%			

There is an important salt cavern natural gas storage capacity in Germany (the highest in EU), that could be used for hydrogen storage. Moreover, Germany has large underground salt layers that could provide additional hydrogen storage opportunities. The availability of suitable formations to develop sites for seasonal hydrogen storage represents an opportunity for Germany and offers it a competitive advantage compared to other Member States.

Current and potential gas & hydrogen demand

In Germany, hydrogen could play a major role in the transition to a low-carbon energy system. Germany has a very large industrial sector with a vast amount of energy consumption and hydrogen is one of the low-carbon energy carriers that can be deployed to decarbonise numerous applications in the German industry. Renewable and low-carbon hydrogen can replace existing fossil-based hydrogen use in refineries and ammonia factories and on the medium to long term, hydrogen-based processes can replace coal-based production processes in the German steel industry, which is one of the major steel suppliers in Europe. Next to that, hydrogen can decarbonise the existing natural gas use in industry as well as the energy use for the generation of high-temperature process heat. The built environment, where natural gas is a dominant fuel as well, hydrogen can also decarbonise the gas supply. Moreover, there are large opportunities for the deployment of hydrogen in transport, with road transport and rail transport being the largest markets.

Opportunities for hydrogen demand in industry

Germany is one of the industrial motors of Europe, accounting for a quarter of the value added created in European industry and for more than a fifth of the total energy consumption of industry in Europe. As a consequence, there are strong opportunities for the deployment of hydrogen in Germany's industry. Germany's ammonia and refineries sectors have a large market share in Europe and there is an opportunity in the short to medium term to replace the existing fossil-based hydrogen use in these sectors by renewable or low-carbon hydrogen. The same holds for hydrogen-based methanol production in the country. Germany's steel industry is responsible for 30% of the primary steel production in the EU. This sector on its own accounts for 14% of the industrial energy use.

On the medium to short term, the conventional steelmaking process via the blast furnace / basic oxygen furnace route which consumes hard coal, could be replaced with the production of direct reduction iron using hydrogen. Recently, Arcelor Mittal has announced to build a demonstration plant in Hamburg, which will annually produce 100 000 tonnes of direct reduction iron using hydrogen produced through SMR, which can be replaced eventually with renewable hydrogen. Next to these specific sectors, Germany's industry uses vast amounts of natural gas, accounting for 36% of all energy use in industry. Deployment of renewable and low-carbon hydrogen can decarbonise the fossil gas supply and thereby reduce the GHG emissions in industry.

	Presence of ammonia industry / share of ammonia production capacity in EU28 total	Presence of refineries / Share of German refineries in total captive hydrogen production by refineries in the EU28	Share of Germany in total primary steel production in the EU28	Share of natural gas in industrial energy demand (2017)	Share of high-temperature (>200°C) process heat in industrial energy demand (2015)
	16%	26%	30%	36%	40%
	MS range 0%-16%	MS range 0%-26%	MS range 0%-30%	Average 32% MS range 0%-43%	Average 38% MS range 9%-60%

Opportunities for hydrogen demand for heating and cooling in the built environment

In Germany, natural gas accounts for 36% of the final energy demand in households and the services sector and for over 40% of the demand for heating. Hydrogen represents one of the solutions to decarbonise this part of the energy use in the built environment. Hydrogen is an attractive solution as it can be transported through the existing transmission and distribution system. Only when hydrogen concentrations exceed certain limits, investments in adjustments of the gas infrastructure and end-use appliances are needed. Next to natural gas, oil-fired boilers still account for about a quarter of the heat generation in Germany's built environment. Hydrogen is one of the solutions for the decarbonisation of this part of the heat demand as well.

	Share of natural gas in the household and service sector energy demand (2017)	Share of heating in the household and service sector energy demand (2015)	Share of cooling in the household and service sector energy demand (2015)
	35%	81%	2%
	Average: 34% MS range: 0% - 60%	Average: 74% MS range: 41% - 82%	Average: 3% MS range: 0% - 46%

Opportunities for hydrogen demand in transport

In the transport sector, the largest opportunities for the deployment of hydrogen are in road transport and in the rail sector. Like in most EU countries, road transport is still largely dependent on fossil fuels. Together with electrification, hydrogen can contribute to the decarbonisation of the energy use in this sector, especially in heavy-duty transport, which is responsible for 30% of the energy use in road transport. Hydrogen can also play a role in the decarbonisation of passenger car transport, especially in the larger car segment and for consumers who need cars with large driving ranges. The rail sector in Germany is largely electrified, but diesel trains still account for 273 ktoe of energy consumption on an annual basis. Hydrogen trains are one of the solutions to replace diesel trains. In 2018, Germany opened the first commercial hydrogen railway line in the world, in the north of the country.[22] Additionally, the rail operator RMV in the Hessen region ordered 27 hydrogen-fuelled trains. Although the shipping sector does not have a large share in the total energy use in the German transport sector, it is a sector that is relatively hard to decarbonise and hydrogen and derived fuels can be deployed as a low-carbon solution. On the medium to long run hydrogen and derived fuels can also be deployed to decarbonise the aviation sector.

	Share of heavy transport (trucks, buses & vans) in total energy demand in road transport in 2020	Share of fossil fuels in energy use of rail transport (and absolute consumption) in 2017	Share of inland shipping in overall energy demand for transport in 2017	Energy use by international shipping relative to total (domestic) final energy use in transport in 2017	Share of domestic and international aviation in overall energy demand for transport (incl. energy use int. aviation) in 2017	Share of fossil fuels in energy use of road transport in 2017
	30% (153 225 GWh)	21% (3 173 GWh)	0.4% (2 839 GWh)	4.0% (26 623 GWh)	15% (113 630 GWh)	95% (604 536 GWh)
	Average 32% MS range 18%-48%	Average 30% MS range 0%-95%	Average 1.5% MS range 0%-9.8%	Average 14% MS range 0%-1011%	Average 14% MS range 1%-25%	Average 95% MS range 79%-100%

[22] https://www.theguardian.com/environment/2018/sep/17/germany-launches-worlds-first-hydrogen-powered-train

Enabling environment: national hydrogen policies and plans, projects and industry

The assessment shows that Germany is in a favourable position for the deployment of renewable hydrogen, also thanks to its research and innovation community and strong industry which are tackling the challenges of this early stage technology. The fact that Germany is preparing a comprehensive hydrogen plan, along with its important RD&I investments and existing or planned hydrogen-related projects, provide a positive enabling framework to support and develop renewable or low-carbon hydrogen as a cross-sector decarbonisation solution.

Existence of (or concrete plans for) national hydrogen roadmaps or strategies — Positive environment ✓

In February 2020, the first draft national hydrogen strategy has been released. It foresees that by 2030 at least 20% of Germany's hydrogen should be produced from renewable energies, by installing three to five gigawatt electrolyser capacity. Germany foresees to address the entire value chain from generation, over storage, transport and distribution to end-use.
Germany will further develop and implement its National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP 2) to provide a solid technological basis and support the market ramp-up phase.

GHG mitigation gap in non-ETS sectors (need for additional GHG reduction measures) — Positive environment ✓

Germany's 2030 target for greenhouse gas (GHG) emissions not covered by the EU Emissions Trading System (non-ETS) is -38 % compared to 2005, as set in the Effort Sharing Regulation (ESR). With the existing policies and measures outlined in the draft NECP, Germany is not on track to achieve this target. Therefore, hydrogen could be considered in the context of additional policies needed to fill in the mitigation gap.

Existence of (active) hydrogen national association — Positive environment ✓

Current and planned hydrogen refuelling infrastructure for the transport sector

Alternative fuels infrastructure directive (2014/94/EU)

In its draft NECP, Germany recalls it has set up a National Strategic Framework for the Expansion of Alternative Fuel Infrastructures, which includes specific targets and measures to build hydrogen supply infrastructure for fuel cell vehicles. The German National Policy Framework (or NPF set in the context of the alternative fuel infrastructure directive (2014/94/EU)) supports a potentially ambitious market uptake of hydrogen vehicles and contains a comprehensive list of measures. Germany is coordinating its plans on alternative fuels infrastructure with other Member States and collaborates with them in this field. The Mobility and Fuel Strategy of Germany was published in 2013, and already covered alternative fuels, among which hydrogen and fuel cells.[23]

	Inclusion of hydrogen in national plans for the deployment of alternative fuels infrastructure (2014/94/EU)	Existence of hydrogen refuelling stations (2019)	which is equivalent to 1 refuelling station per … cars
Germany	YES	80	580 932
EU		Total 156	Average 1 677 543

Existence of (investment on) hydrogen-related projects

More than half of the refuelling stations in the EU are located in Germany; they are an important building block in the deployment of an hydrogen corridor along the TEN-T Core Network.
The yearly German R&D budget for hydrogen is the second-highest in the EU-28, showing the strong commitment to invest in research and innovation in this versatile technology.
There are already 32 projects in operation, offering Germany a strong position and experience in the production, delivery and use of hydrogen.

	Existing R&D and pilot projects directly related to hydrogen	RD&D annual expenditure on hydrogen & fuel cells (m EUR) (average 2013-2017)	Activities and projects in industry to use hydrogen as feedstock	Number of power-to-gas projects (existing and planned)
Germany	YES	22.4	YES	47

[23] https://www.vda.de/en/topics/innovation-and-technology/fuel-strategy/the-mobility-and-fuel-strategy.html

Existence of national tax incentives (CO_2 pricing mechanisms & car taxation)

Positive environment: ✖

Germany has set up a CO_2 pricing mechanism and introduced a carbon related taxation for vehicles; both measures are key to support the progressive shift to low carbon vehicles (including on hydrogen).

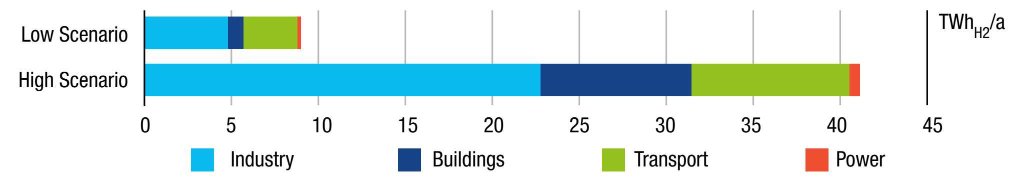
Fossil energy import bill

Like many EU Member States, Germany is strongly dependent on imports for its natural gas as well as its oil consumption. Switching from fossil fuel to nationally produced hydrogen for industrial processes, heating and transport applications will contribute to reducing the energy import dependence and bill.

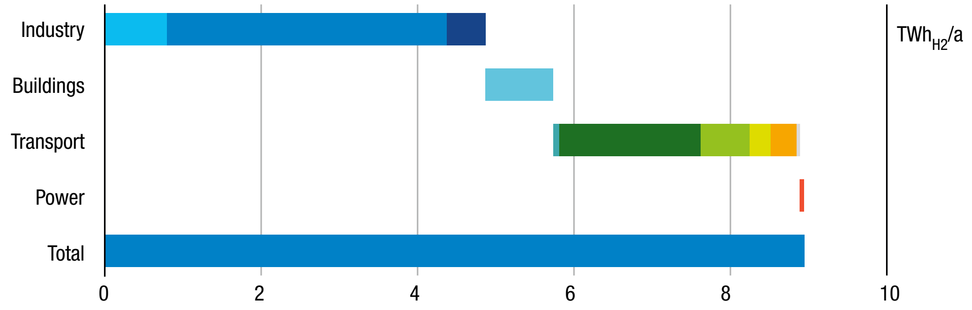
	Import bill for natural gas as share of national Gross Value Added	Import bill for all fossil fuels
Germany	**0.5%**	**1.9%**
EU	Average: **0.6%** MS range: 0% - 1.5%	Average: **2%** MS range: 0% - 7%

SCENARIO ASSESSMENT
Estimated renewable/low carbon hydrogen demand for Germany by 2030

Hydrogen demand in the year 2030 has been estimated in a low and a high scenario covering the range of uncertainty. Today, conventional hydrogen mainly used in industry is produced from fossil fuels (e.g. through steam methane reforming) or is a by-product from other chemical processes. Both scenarios assume that in 2030 renewable hydrogen will be provided to partially substitute current conventional production and to cover additional demand (e.g. from transport sector).

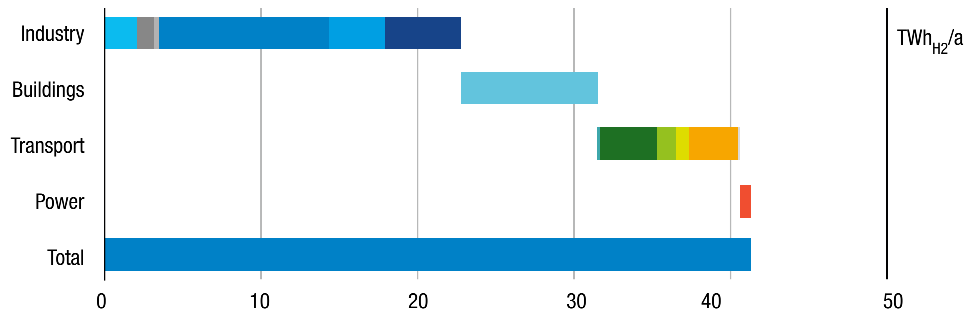


Low scenario



In the low scenario, renewable hydrogen accounts for 0.4% of final total energy demand (i.e. 8.9 out of 2 029 TWh/a) or 1.8% of final gas demand (505 TWh/a) according to EUCO3232.5.

High scenario



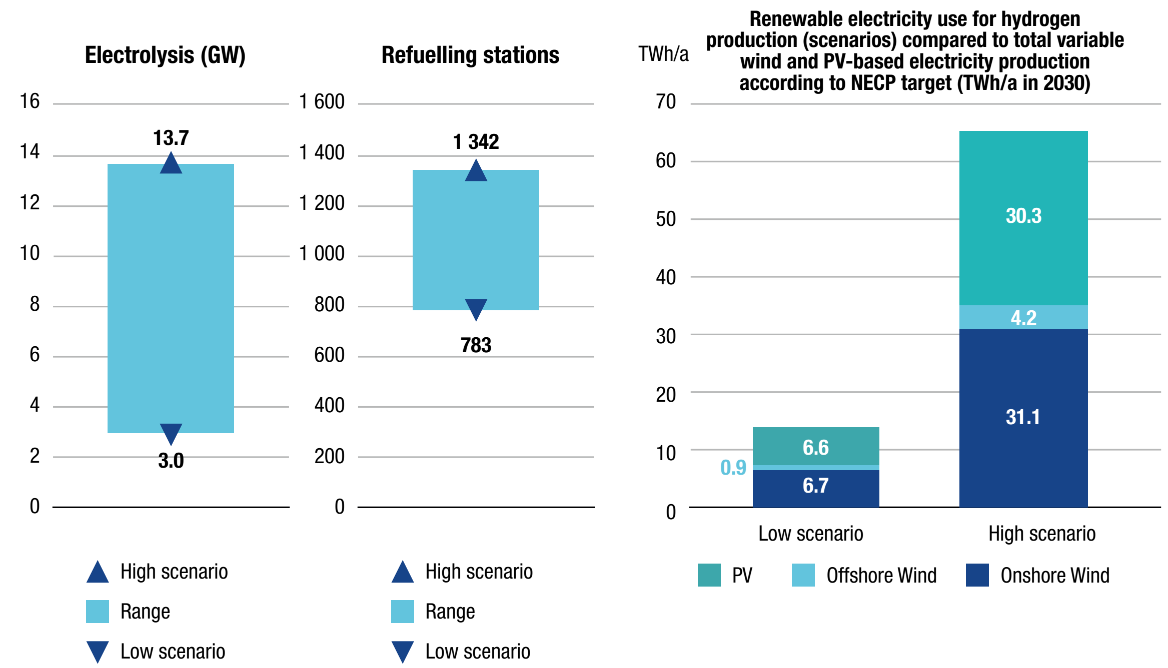
In the high scenario, renewable hydrogen accounts for 2.0% of final total energy demand (i.e. 41.2 out of 2029 TWh/a) or 8.2% of final gas demand (505 TWh/a) according to EUCO3232.5.

Refinery, Ammonia, Methanol, Iron & steel, Olefins/Aromatics, Industry energy, Buildings, Buses, Cars, Trucks, Rail, Aviation, Inland navigation, Power

Hydrogen generation, infrastructure and end users in Germany by 2030

The analysis of renewable hydrogen generation, infrastructure and end use is based on the demand estimates presented above. Renewable hydrogen is generated from variable renewable power using electrolysis. The analysis covers only national hydrogen production to satisfy domestic demand and does not take into account any cross-border trade of hydrogen (i.e. hydrogen imports and exports are not included in this analysis).

Renewable hydrogen generation and infrastructure



The required renewable power production accounts for 1.7% of the overall technical renewable. The required renewable power production accounts for 1.7% of the overall technical renewable power potential in the low scenario and for 7.7% in the high scenario. Alternatively hydrogen produced from SMR + CCS would require 13 – 59.7 TWh/a of natural gas at a SMR+CCS capacity of 1.1- 5 GW for the low and high scenarios, respectively.

End users

End user	Unit	Low scenario	High scenario
Passenger cars	Nº	477 000	954 000
Buses	Nº	760	1 510
Lorries	Nº	18 400	36 700
Heavy duty vehicles	Nº	14 030	28 070
Trains	Nº	113	340
Substituted fuel in aviation	GWh/a	219	2 083
Substituted fuel in navigation	GWh/a	8.1	77.3
Micro CHP	Nº	39 810	173 180
Large CHP	Nº	60	580
Iron&Steel	% of prod.	4%	13%
Methanol	% of prod.	0%	5%
Ammonia	% of prod.	0%	5%

According to the estimations, the hydrogen refuelling station network will by 2030 encompass between 780-1 340 stations for 510 000-1 020 000 fuel cell vehicles on the road.

In addition, the analysis estimates substitution of up to 13%of the conventional steel production by renewable hydrogen-based steelmaking.

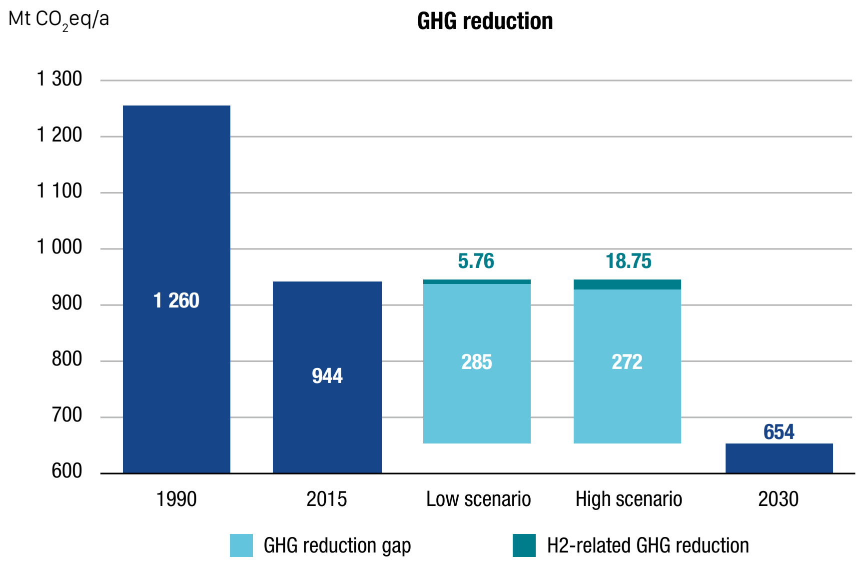
Futher use of renewable hydrogen is foreseen in methanol production (up to 5%) and in ammonia.

Finally, the introduction of 39 870-173 760 stationary fuel cells for combined power and heat production is estimated.

Environmental and financial impact in Germany by 2030

Greenhouse gas (GHG) emission reductions were calculated by estimating the fuels replaced by hydrogen, and their respective greenhouse gas footprint. Comparing these to the 2030 GHG reduction targets results in the contribution of hydrogen to achieving these targets.

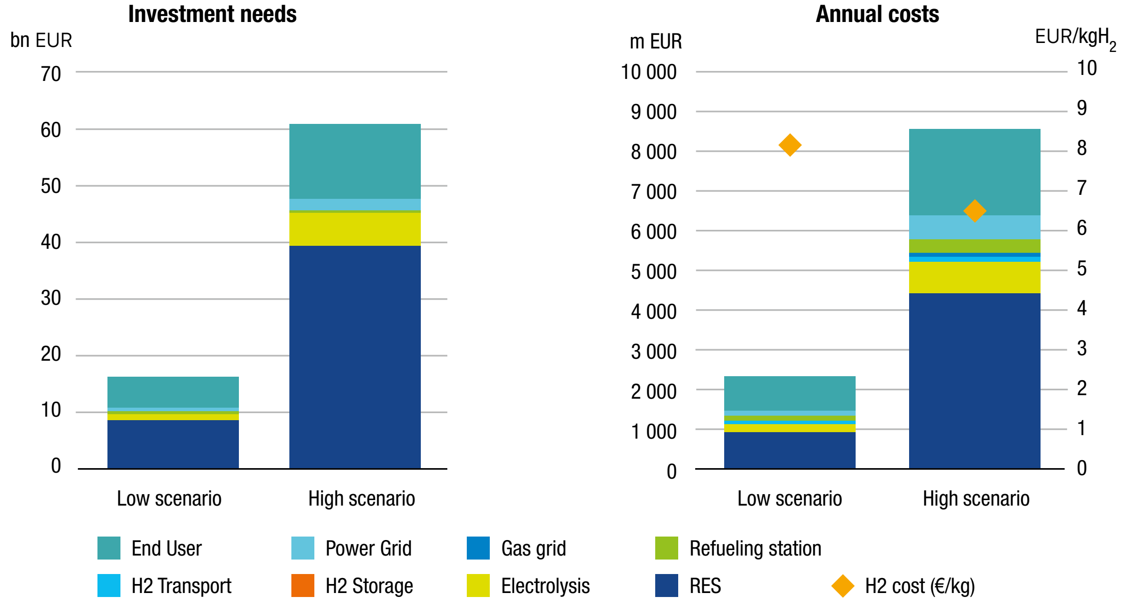
Environmental impact



An additional GHG emission reduction of 5.8-18.7 Mt CO_2 is estimated in 2030 corresponding to 2.0%-6.5% of the overall GHG emission reduction gap towards 2030 target (based on EUCO3232.5).

Financial impact

The financial scenario assessment includes investments (CAPEX) until 2030 and operating expenses (OPEX) per year in 2030. Cumulative investments in hydrogen technologies are estimated at 16.2-60.7 billion EUR until 2030, while annual expenditure would amount to 2 340-8 570 million EUR (including end user appliances as well as power and gas grids).



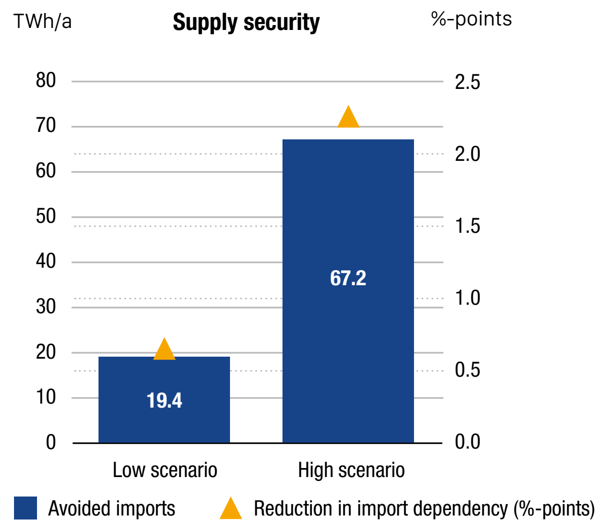
Alternatively hydrogen produced from SMR + CCS would require 7.1-19.1 billion EUR of investments or annual costs of 1 521-4 825 million EUR.

Impact on security of supply, jobs and economy in Germany by 2030

Hydrogen contributes to the energy supply security objective by reducing fossil energy import dependence and enhances energy supply diversification by facilitating deployment of renewable energy sources. This is assessed by estimating imported fossil fuels that will be replaced by hydrogen based on domestic renewable sources.

Security of energy supply

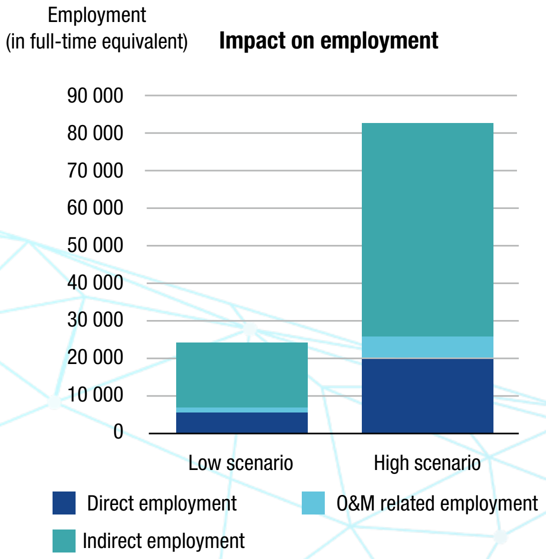
Deployment of renewable hydrogen would lead to 19.4-67.2 TWh/a of avoided imports, and thus reduce import dependency by 0.7-2.3% (in volume terms) in 2030, depending on the scenario.

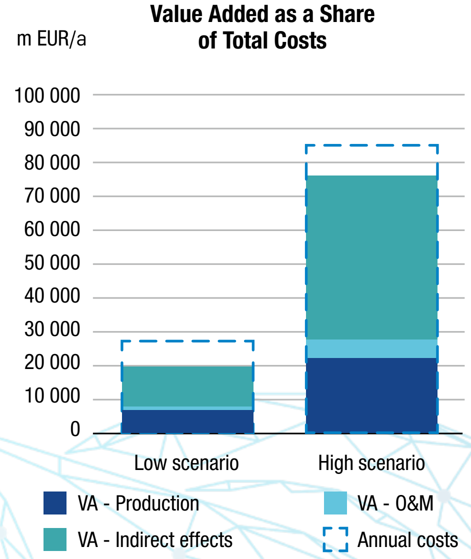


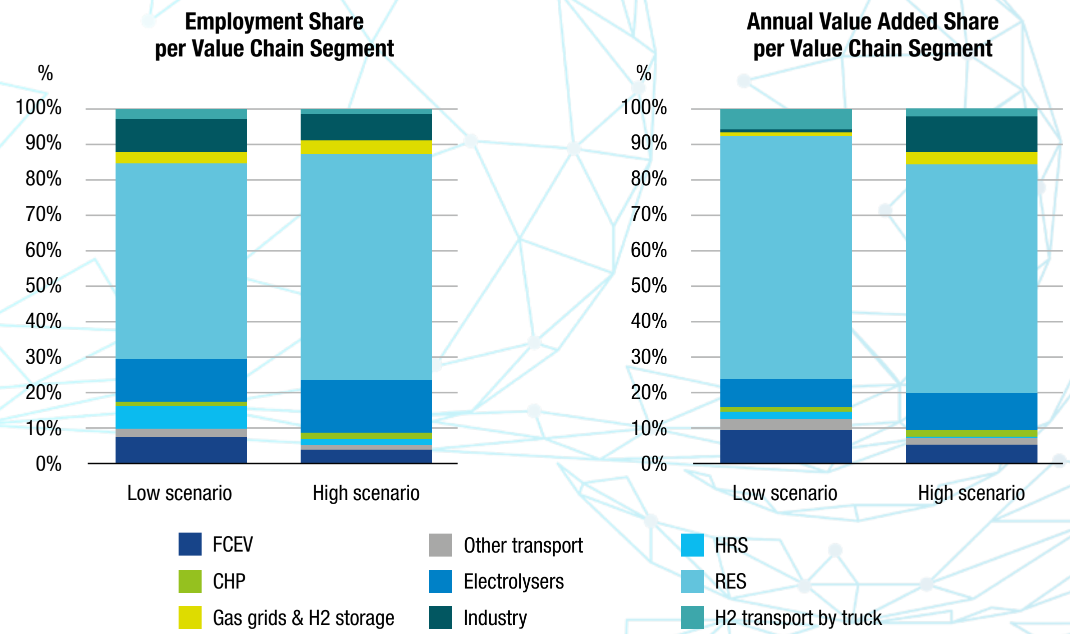
Impact on employment and value added

This analysis shows that in the years 2020-2030 around 790 million EUR can be retained annually in the domestic economy as value added in the low scenario, and almost 2 810 million EUR in the high scenario (value added is defined here as sum of wages for employees, margins for companies and taxes). If the indirect effects induced by the investment in and operation of hydrogen technologies are also taken into account, around 1 920 million EUR (low scenario) and almost 7 620 million EUR (high scenario) of value added can be created in the German economy annually, which is almost equivalent to the amount of annual investment needed. Most of this value added is expected to be created by building and operating dedicated renewable electricity sources and electrolysers for hydrogen production, and in the automotive and steelmaking industry.

The hydrogen-related expenditures in 2020-2030 are estimated to generate employment of 6 560 – 25 300 direct jobs (in production and operations & maintenance) and contribute to a further 16 630 – 57 500 indirectly related jobs, depending on the scenario. Most of these jobs are expected to be created by building and operating renewable electricity sources, electrolysers and hydrogen refuelling stations, and in the automotive and steelmaking industries.







GERMANY

Opportunities arising from the inclusion
of **Hydrogen Energy Technologies**
in the National Energy & Climate Plans

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING