NATIONALER WASSERSTOFFRAT

Hydrogen Action Plan Germany 2021–2025

The National Hydrogen Council

With the adoption of the National Hydrogen Strategy (NWS), the German government established the National Hydrogen Council NWR) on 10 June 2020. The Council consists of 26 high-ranking experts from business, science and civil society who are not part of the public administration. NWR members have expertise in hydrogen generation, research and innovation, decarbonisation of industry, transportation and building/heating, infrastructure, international partnerships, and climate and sustainability. The NWR is chaired by Katherina Reiche, former Parliamentary State Secretary.

The task of the NWR is to advise and support the State Secretary's Committee for Hydrogen with proposals and recommendations for action for the implementation and further development of the hydrogen strategy.

Please note that the NWR is an independent panel of experts. Publications of the NWR do not necessarily reflect the opinion of the German federal government.

The Hydrogen Coordination Office

The NWS provides for the establishment and operation of the Hydrogen Coordination Office to support the implementation and further development of the NWS. The Office the following tasks in particular: providing support for government departments in implementing the NWS, assisting the NWR in coordinating and formulating recommendations for action and monitoring the NWS.

The Hydrogen Coordination Office is managed by the following organisations:

Deutsche Energie-Agentur GmbH (dena)
Chausseestraße 128 a
10115 Berlin, Germany
Tel.: +49 (0)30 66 777-0
Email: info@dena.de
www.dena.de

NOW GmbH
Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie
Fasanenstraße 5
10623 Berlin, Germany
Tel.: + 49 (0)30 311 61 16-100
Email: kontakt@now-gmbh.de
www.now-gmbh.de

Projektträger Jülich (PtJ)
Forschungszentrum Jülich GmbH
Wilhelm-Johnen-Straße
52428 Jülich, Germany
Tel.: +49 (0)2461 61-2626
Email: ptj@fz-juelich.de
www.fz-juelich.de/ptj

Zukunft – Umwelt – Gesellschaft (ZUG) gGmbH
Köthener Straße 4
10963 Berlin, Germany
Tel.: +49 (0)30 700 181 100
Email: kontakt@)z-u-g.org
www.z-u-g.org

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Preamble

In June 2020, the German government published the National Hydrogen Strategy (NWS), setting specific targets for Germany's entry into the hydrogen economy for the first time. It also established the National Hydrogen Council (NWR), whose members from business, science and civil society support the federal government in further formulating and implementing the NWS. The following Hydrogen Action Plan Germany 2021-2025 is part of efforts to fulfil this mandate. It summarises the discussions and analyses of the NWR in recent months and, on this basis, derives recommendations for action for the next legislative period.

The recommendations of the NWR are based on a variety of analyses. One of these is the Hydrogen Metastudy conducted by Fraunhofer ISI, ISE and IEG. It demonstrates future generation and consumption scenarios as well as associated infrastructure requirements. In addition, Council members have provided an array of industry-specific information and data. The NWR and its working groups have intensively discussed each of the analyses. Where the existing information situation does not allow sufficient specification, the NWR has drafted recommendations to improve the availability of information and data.

Developments in the field of hydrogen and its derivatives are extremely dynamic. However, fields of application are emerging in which significant demand for hydrogen is considered certain. The recommendations of the NWR are to be understood against the backdrop of current knowledge at this time. Should the studies and basis for analysis change, the NWR will also make adjustments to the recommendations in due course.

The action plan is divided into three main parts. First, the initial situation is discussed in terms of climate protection targets, industrial potential and the legal framework. The second part summarises the discussion about the expected ramp-up of the hydrogen economy by 2030, broken down by demand, supply (generation) and required infrastructure. Alongside these categories, the third and final part deduces detailed recommendations for action for efficient implementation and, if necessary, adaptation of the NWS, prioritised in each case based on urgency. The action plan thus not only presents a technology-specific perspective on the topic of hydrogen, but also incorporates it in the overarching energy, climate and industrial policy framework.*

* Also see also the dissenting opinion issued by Klima Allianz Deutschland and Bund für Umwelt und Naturschutz Deutschland (BUND) at the end of the document.

Contents

List of abbreviations

AFID	Alternative Fuels Infrastructure Directive
BAFA	Federal Office for Economics Affairs and Export Control
BImSchG	Federal Immission Control Act
BImSchV	Federal Immission Control Ordinance
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMVI	Federal Ministry of Transport and Digital Infrastructure
BMWi	Federal Ministry for Economic Affairs and Energy
BOS	Security authorities and organisations
BUND	German Federation for the Environment and Nature Conservation Germany
CAPEX	Capital Expenditures
CCfD	Carbon Contracts for Difference
CHP	Combined heat and power generation
CO_2	Carbon dioxide
CVD	Clean Vehicles Directive
DRI	Direct Reduced Iron
DVGW	German Technical and Scientific Association for Gas and Water
EastMed	Eastern Mediterranean Natural Gas Pipeline
ECH2A	European Clean Hydrogen Alliance
EEG	Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz)
EFTA	European Free Trade Association
EnWG	Energy Industry Act
EU	European Union
EU-ETS	European Union Emissions Trading System
Fraunhofer IEG	Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems
Fraunhofer ISE	Fraunhofer Institute for Solar Energy Systems
Fraunhofer ISI	Fraunhofer Institute for Systems and Innovation Research
FuE	Research and development
G20	Group of the 20 most advanced economies and emerging market economies
G7	Group of Seven
GW	Gigawatts
H_2	Dimerised form of molecular hydrogen
IEA	International Energy Agency
IPCEI	Important Project of Common European Interest
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IRENA	International Renewable Energy Agency

LOHC	Liquid Organic Hydrogen Carriers
MEDREG	Association of Mediterranean Energy Regulators
Med-TSO	Association of the Mediterranean Transmission System Operators
MPa	Megapascal
NIMBY	Not in my backyard
NSEC	North Seas Energy Cooperation
NWR	National Hydrogen Council (Nationaler Wasserstoffrat)
NWS	National Hydrogen Strategy (Nationale Wasserstoffstrategie)
OPEX	Operational Expenditure
PCI	Project of Common Interest
PFAS	Per- and Polyfluoroalkyl Substances
PtL	Power-to-Liquid
PtX	Power-to-X
REACH	Regulation: Registration, Evaluation, Authorisation and Restriction of Chemicals
RED I	Renewable Energy Directive I
RED II	Renewable Energy Directive II
RED III	Renewable Energy Directive III
SME	Small and medium-sized enterprises
t	Metric ton (unit of measurement)
THW	German Federal Agency for Technical Relief
TWh	Terawarr hour
UN	United Nations (United Nations)
USA	United States of America (United States of America)
WTO	World Trade Organisation

1 Initial situation

1.1 Climate protection targets

The European Union (EU) is pursuing the goal of climate neutrality by 2050 at the latest, while Germany is aiming to be climate neutral by as early as 2045.

Greenhouse gas neutrality is the prerequisite for limiting global warming to well below 2°C compared to pre-industrial levels and – as stipulated in the Paris Agreement – if possible to 1.5°C.

With its Climate Act, the EU has enshrined climate neutrality by 2050 in law and instituted a comprehensive package of measures with the European Green Deal to achieve this goal. Accordingly, the interim target in 2030 has increased significantly to reflect more ambitious goals. Greenhouse gas emissions are now to be reduced EU-wide by 55 per cent instead of 40 per cent compared to 1990. Over the past three decades, the EU Member States have only been able to reduce their emissions by around 25 per cent. Significant efforts will therefore be required in the period up to 2030.

With an amendment to the Climate Protection Act, the German government has also increased its national greenhouse gas reduction targets for 2030: Greenhouse gas emissions are now to be cut by 65 per cent instead of 55 per cent compared to 1990. The legal basis for the national and European targets was already established at the federal level in December 2019. Germany has committed itself to achieving an above-average reduction in greenhouse gases as part of the EU's burden-sharing agreement and its national climate protection targets. The new, more stringent EU climate targets also require Germany to achieve a higher level of emissions reductions, with new interim targets set for 2030 and 2040 for all sectors.

In general terms, hydrogen will take on a more central role as a result of these new targets. This is because continuous technology advancements made during the ramp-up of a hydrogen economy will enable emissions to be reduced more and with greater efficiency. Hydrogen that is largely climate-neutral will play a key role in this transformation. Investing in facilities that are climate-neutral, cost-effective and provide a secure supply of hydrogen should serve as the guiding principle. To avoid lock-in effects, the principle of H_2 readiness should be applied.

To ensure continuity during the initial phase in the transition to a hydrogen economy, natural gas will play a central role in replacing coal as an energy source at the start. However, the aim is to gradually replace natural gas with largely climate-neutral hydrogen as soon as possible.

1.2 Economic motivation

Hydrogen technologies not only play a central role in achieving climate protection targets, but also hold enormous potential for Germany in the global economy. If Germany succeeds in becoming an international pioneer in the development of hydrogen technologies, zero-emission technologies have the potential to create added value and boost exports for the German and European economies. In this way, Germany can contribute to decarbonisation in other regions of the world on the one hand and strengthen its domestic economy on the other.

Hydrogen is part of an industrial policy response to the Paris Agreement. For some core German industries, hydrogen is the only way to maintain domestic production in view of the ambitious climate targets. For Germany to become a climate pioneer and remain an industrial nation at the same time, the domestic market ramp-up of hydrogen technologies along the entire value chain - from production and storage to transport and use - must succeed. This includes, in particular, building up a professional and efficient supplying industry for economical mass production.

With its SMEs, industrial clusters, existing energy infrastructure, decades of advance development work focusing on hydrogen technologies in industry and academia, and top-notch research expertise and scientific community, Germany is ideally positioned to become a role model for other countries by having a sustainable hydrogen economy. However, this is not a foregone conclusion: This is made clear not least by the example of photovoltaics. Germany was seen as the leading technology developer, but was quickly overtaken in production by other countries. Developments like this must be avoided in the field of hydrogen by having and maintaining a lead in innovation. The global race for technological supremacy in hydrogen has also long since begun.

Internal hydrogen projects/strategies, involvement in publicly funding projects and the formation of alliances demonstrate German industry's willingness to act. However, effective climate protection based on hydrogen technologies and a successful transition can only be achieved if the international competitiveness of the user industries and thus also the value chains in Germany can be assured, and if climate-neutral technologies are also economically competitive on the global marketplace. In the medium term, this requires both an economic environment that gives climate-friendly business models an advantage over fossil fuel alternatives and an attractive financing ecosystem – which provides access to venture capital. The coordination of numerous actors across multiple sectors urgently requires an increase in the effectiveness of market-based incentives. To this end, (1) CO_2 pricing must be strengthened across all sectors, (2) the price of electricity in particular must be exempted from surcharges imposed under the Renewable Energy Sources Act (EEG) as part of a reform of taxes and surcharges and (3) the electricity tax must be significantly reduced. This would relieve the burden on households and companies and, at the same time, create incentives for most groups of actors to invest in sector coupling. For the private and public sector, eliminating the surcharge to finance the EEG would mean a reduction in bureaucratic costs. Since high electricity prices are a barrier to investment for many stakeholders, a general regulation is preferable to a large number of special exemptions. For individual applications, faster individual solutions are necessary due to the time lead of such a reform.

Strong incentives to scale activities – through subsidies and adjustments to the real economic environment are drivers of reducing costs as quickly as possible. Lower costs, in turn, lead to broad market penetration and faster greenhouse gas reductions. In order to help innovations achieve a breakthrough and scale up, it is also crucial that companies have easy access to (venture) capital. In order to take a pioneering role internationally, Europe must (1) act as a united front, (2) form partnerships, (3) support the real economic environment and (4) strengthen the capital market. The view must go beyond national borders because it is clear today that initial steps towards a hydrogen economy can only succeed as a collective effort.

From the perspective of the NWR, the period up to 2030 is the decisive stage for climate protection and Europe's industrial competitiveness. In this context, accelerated industrialisation must go hand in hand with further research activities. Research will continue to be important - both in developing further generations of new technologies and in scaling up production, for example in the areas of fuel cells and electrolysis.

1.3 National Hydrogen Strategy

The German government and the EU Commission have recognised the necessity and potential of hydrogen technologies. To leverage this potential, the German government has adopted the NWS and the EU Commission a European hydrogen strategy. The NWS defines the framework for action for the future production, transport, utilisation and further use of hydrogen and thus for corresponding innovations and investments.

In particular, the NWS pursues the following goals:

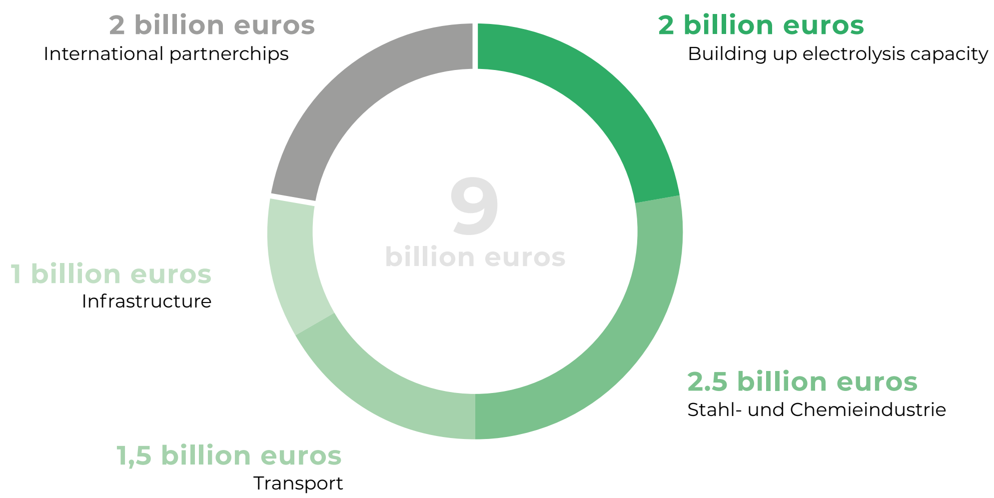
- Establish hydrogen technologies as key technologies of the energy transition
- Create the regulatory framework for market ramp-up of hydrogen technologies
- Increase international competitiveness and boost exports of German companies
- Secure future supply of climate-neutral hydrogen and its derivates

The German government has thus set ambitious goals. With the NWS, Germany wants to create a domestic market with strong domestic production and use and, at the same time, open up export opportunities for technologies “Made in Germany”. This requires the establishment of an industry for the production of electrolysers and fuel cells in Germany, where hydrogen is to be established as a competitive energy carrier in all sectors. At the international level, Germany intends to play a leading role in multilateral projects.

As part of the 2020 stimulus package, the federal government has earmarked €9 billion in federal funding for the NWS (see Figure 1). These funds are intended to finance the first stage of the market ramp-up by 2023. Of these funds, €7 billion are earmarked for the national ramp-up of a hydrogen economy and €2 billion for international hydrogen partnerships. This includes the development of an import infrastructure and the production of hydrogen in third countries.

Figure 1

Distribution of NWS federal funds by use (in €)



Of the €7 billion earmarked for national projects and funding, €2 billion will go towards building up electrolysis capacity, €2.5 billion towards converting the steel and chemical industries to hydrogen-based processes, €1.5 billion towards transport and €1 billion towards setting up a hydrogen infrastructure. (Data: NWS)

1.4 Current legal framework

Climate-neutral hydrogen is not an end in itself. It supports the decarbonisation of all sectors. It is therefore essential that companies can count greenhouse gas reductions from hydrogen technologies towards their climate protection targets. In some sectors, quotas specify certain implementation paths to incentivise the use of climate-neutral hydrogen and derivatives. The measures to ramp up the hydrogen economy cannot take place in a regulatory vacuum. Quite the opposite is true. They require a regulated framework that specifically promotes and propels them forward. Several existing regulations have already been amended and adapted to reflect the NWS, while others are still being coordinated. The proposed amendment to the EnWG, for example, lays the initial critical groundwork for the transport of hydrogen. However, changes like these should only be the beginning. There is still a need for comprehensive reform at both national and European level.

The path to the hydrogen economy requires the coordination of a large number of activities across different sectors. Individual links in complex new value chains will have to emerge independently of one another, though at the same time, so that in the end each company involved also has a business model that produces profits. Even if funding will be necessary at various points at the beginning, the activities must be profitable in the medium term. The challenge of coordinating all players increases the urgency of bolstering the effectiveness of market-based incentives.

Consistently rising CO_2 prices, for example, will produce real benefits for climate-neutral business models over fossil fuel alternatives in the future. The prerequisite is effective carbon leakage protection that assures international competitiveness. The introduction of CO_2 prices across all sectors as described above should be accompanied by an exemption of energy prices from distorting levies and surcharges wherever possible and the removal of all direct and indirect subsidies for fossil energy sources. The elimination of state-imposed levies and surcharges on electricity prices, for example, would be a suitable way of offsetting the burden on households and companies by strengthening CO_2 pricing. At the same time, incentives for investments in sector coupling would be increased. The use of largely climate-neutral electricity for mobility, heat generation and industry would thus become more attractive.

A fundamental and politically viable reorganisation of the economic framework with a view to CO_2 pricing, the elimination of added costs to electricity prices caused by government mechanisms and the dismantling of distorting subsidies will give business and consumers planning security and create confidence. A robust, predictable regulatory and market environment will enable forward-looking investments, strengthen market coordination and competition, and stimulate the emergence of appropriate value chains. The expectation of an attractive and secure market environment can thus create the dynamic conditions required.

Especially at the beginning of the ramp-up of the hydrogen economy and in the first phase of the above-mentioned reforms, however, further accompanying mechanisms will remain necessary. In the context of these reforms, however, the necessity, scale, narrow scope and, if necessary, the duration of additional support programmes can and should be significantly reduced and concentrated on those areas in which substantial CO_2 reductions can be achieved in the near future by means of a technology change. This will accelerate the timelines, improve or enable the integration of value chains and the corresponding competition, and reduce the regulatory risks for all market participants. The risk that the necessary momentum will not be achieved despite the deployment of substantial resources can be significantly reduced. The combination of a credible, far-sighted as well as strategic reform of the market and regulatory environment with complementary, but narrowly defined accompanying measures focused on the essential areas can significantly accelerate the ramp-up of hydrogen-based business areas and make them more robust. This can and will also improve Germany's and Europe's competitive situation with regard to those regions of the world that also pursue leadership in hydrogen economy technologies and business models as a strategic goal.

In order to achieve the EU climate protection targets for 2030, the EU has mandated an increase in the share of renewable energies in energy end consumption with the RED II. This does not yet take into account the more stringent climate protection targets for 2030. Paragraph 25 of the directive stipulates a minimum quota of 14 per cent renewable energies for road and rail transport, which must be achieved by 2030 through an obligation when putting fuels into circulation in each EU Member State. As with the previous directive (RED I) from 2009, Germany is implementing the requirements of RED II via amendments to the Federal Immission Control Act (BImSchG) and the downstream regulation (BImSchV). In particular, the concrete definition of the conditions for the recognition of electricity-based fuels under RED II can have a significant impact in other application areas and will be available at the end of 2021.

2 Ramp-up of the hydrogen economy

The German government has set ambitious goals with the NWS. In order to achieve the outlined climate and industrial policy objectives in Germany with positive effects on CO_2 emissions, value creation, technology development and export potential, the ramp-up of the hydrogen economy must be initiated quickly.

The period up to 2030 or 2035 is the decisive stage for the establishment of a hydrogen economy in Europe and Germany. This will determine whether Germany will assume its envisaged role in the hydrogen economy as the lead market and technology exporter for H_2 and PtX technology or whether other countries will take on this role on the European and international market. By 2030, Germany must achieve ambitious climate protection targets that cannot be met without an ambitious ramp-up of the hydrogen economy.

This will require:

- a sufficient volume of largely climate-neutral hydrogen,
- suitable transport and storage infrastructures and
- a comprehensive, nationwide use of hydrogen in all sectors.

In addition, complementary measures such as the development of hydrogen hubs along European rivers will be necessary.

The medium-term targets for the ramp-up of the hydrogen economy for the years 2030, 2035 and 2040, which are reasonable, will be presented below. In view of the climate policy and economic goals formulated in the NWS, the respective conceivable ranges of use hydrogen in the industrial, mobility, heating and energy sectors are outlined and set against the expected quantity of hydrogen available from domestic production and imports that may be required. In addition, the resulting infrastructure requirements will also be described.

2025

2.1 Hydrogen demand

Largely climate-neutral hydrogen is to be used in sectors where it can be used more efficiently than green power in the decarbonisation of the relevant application for technical, economic or energy system-related reasons, or where this is the only possible option.

2.1.1 Industry

Hydrogen is already widely used in industry, particularly as a base material for the production of basic chemicals such as ammonia and methanol and as a process gas in refinery processes.

The current hydrogen demand in the chemical industry is about 1.1 million metric tons per year (37 TWh). Most of the hydrogen is produced from natural gas by way of steam reforming (as grey hydrogen). Currently, demand here is expected to remain constant in the coming years and substitution with green hydrogen will not occur until after 2030, in part because new plants will have to be built to produce green hydrogen. To achieve greenhouse gas neutrality, the grey hydrogen used today must be replaced by green hydrogen by 2050, and the petroleum-based feedstocks used to date must be decarbonised. The chemical industry today uses 21.5 million metric tons of carbon-based feedstocks, predominantly naphtha, which in the medium term can be synthesised from recycled CO_2 that does not pollute the atmosphere. The hydrogen used for naphtha synthesis will increase demand several fold by 2050 to nearly seven million metric tons (227 TWh) per year for the chemical industry as a whole, reducing CO_2 emissions by 54 million metric tons. This eliminates roughly ten metric tons of CO_2 emissions per metric ton of hydrogen (or 284 metric tons of CO_2 per GW of hydrogen).

From 2040, in particular, demand for green hydrogen for the production of synthetic naphtha will increase rapidly. Whether and to what extent chemical intermediates such as naphtha can or should be supplied via international markets in addition to hydrogen will require more in-depth discussion.

New areas of application for hydrogen will arise in the short to medium term especially in the steel industry. Here, strong demand for green hydrogen will arise by 2030, as the central technology is already available in principle in the form of direct reduction on a hydrogen basis. Direct reduction based on natural gas is already state of the art. Natural gas can and will also have a central role to play in the rapid and substantial move towards decarbonisation from 2025, provided that this is a prelude to the transition to renewable hydrogen.

The current target is to convert ten million metric tons of production to the direct reduction process (DRP) by 2030, provided the policy framework is created. If these plants are operated 100 per cent with green hydrogen, just under 17 million metric tons of CO_2 can be saved. That would be 30 per cent less than in 2018, which would require around 600,000 metric tons of green hydrogen (20 TWh). As long as green hydrogen is not sufficiently available, natural gas can also be used as a first step and in the transition, thus already reducing CO_2 emissions by two-thirds. Flexible hybrid concepts with natural gas and hydrogen can also be pursued with the plants, depending on the availability of hydrogen. As availability increases, the direct reduction plants need to be modified only slightly or not at all by the time climate neutrality is achieved in 2050. A full conversion of primary steel reduction from 30 million metric tons in Germany to hydrogen-based direct reduction by 2050 would require around two million metric tons of green hydrogen (70 TWh). This would allow CO_2 emissions to be cut by around 50 million metric tons, representing a reduction of 28 metric tons of CO_2 per metric ton of green hydrogen or 830 metric tons of CO_2 per GW of H_2.

Moreover, this relatively high savings potential can be leveraged at a few clearly defined and easily monitored locations. Due to their production processes, the industrial sectors with high process emissions have no alternative to using hydrogen to achieve climate neutrality.

In addition, green hydrogen offers the cement industry the opportunity to indirectly reduce emissions via the conversion of captured CO_2 into chemical feedstocks or synthetic fuels.

In total, the industrial sector (excluding refineries) is expected to require 1.7 million metric tons of hydrogen per year (57 TWh) by 2030, 35 per cent thereof will be green hydrogen in the steel sector, which could increase to almost nine million metric tons by 2050.

The steel and chemicals industry will require roughly 2.3 million metric tons (77 TWh) of hydrogen in 2035 and 2.8 million metric tons (93 TWh) in 2040. Of this, about 50 per cent will be green hydrogen. There is no discernible competition for use of green hydrogen between the aforementioned industrial sectors, especially in the period up to 2030, as it will only be in demand in the steel sector. Transitional technologies such as natural gas are an indispensable option in terms of volume availability and costs to achieve flexibility on the way to achieving climate neutrality.

2.1.2 Mobility

With no other alternative technologies emerging with potential for mass deployment, the NWR is convinced that the focus in land-based transport will be on battery-powered vehicles and those powered by hydrogen and fuel cells. In addition, e-fuels will be used in some applications and will be needed in the long term, that is for more than 40 years from today (see glossary).

The drivers for new drive technologies are the existing energy efficiency and CO_2 emission standards for manufacturers' new vehicle fleets, which are in place in Europe and worldwide for road vehicles until 2030 and will be updated for the period thereafter. This results in CO_2 reduction targets being achieved for newly registered road vehicles which, if not met in Europe, will lead to penalties of between €400 and €500 per metric ton of unavoided CO_2 emissions in 2030. While the focus of manufacturers in the passenger car sector is on battery-electric mobility technology and a majority of their investments are being allocated there, in the heavy commercial vehicle sector investments are currently occuringin battery and hydrogen storage technologies.

For other modes of transport, there are further targets that provide incentives for the use of climate-friendly drive systems and energy sources. The resulting demand for hydrogen over time is driven, among other things, by the time required to develop the relevant vehicles. For example, the development of a new road vehicle takes five to eight years, while more than ten years is required to develop an aircraft, especially in the development of new propulsion systems. In addition to largely climate-neutral hydrogen production, the use of hydrogen in the transport sector requires the setup of a high-quality hydrogen filling station network with a focus on heavy good vehicles. It is necessary to determine whether the ramp-up of hydrogen-based mobility will require that hydrogen be made available for use in the form of compressed gas and/or as cryogenic liquid hydrogen or that the infrastructure for various forms of hydrogen has to be developed. Development of this infrastructure must be started well in advance and aligned to the ramp-up of hydrogen consumption in the transport sector.

In addition, it must be possible to manufacture the hydrogen system components economically, ultimately leading to cost parity with fossil fuel-based drive systems. At present, however, the necessary high-rate technologies that would enable production to be scaled up to industrial mass production are unavailable. Their development would open up a unique opportunity for Germany not only to consider the topic of hydrogen in terms of climate policy, but also to establish it in terms of sustainable value creation. In particular, the automotive industry as well as the mechanical and engineering sector in Germany could play a role here.

In terms of mobility, Germany is integrated in Europe. In shipping and air transport, the transport links extend beyond Europe. For this reason, all developments in Germany must be able to be integrated into European or international transport operations and must also track developments there. Also, the new drive technologies in road cargo transport will not offer the same range as existing concepts. As a result, the number of refuelling and loading operations will increase compared to today and will inevitably lead to an increase in domestic German energy demand.

In addition to road transport, technologies for air, rail and maritime transport are also continuing to evolve. It is not possible to say at present which fuel technologies will become established in international maritime transport. Climate-neutral technical solutions for maritime transport are based primarily on the use of e-fuels, e-ammonia, e-methanol and e-methane, but also on the direct use of hydrogen for short distances.

Long-haul aviation will largely use carbon-neutral, hydrogen-based fuels to minimise greenhouse gas emissions there. In short- and medium-haul aviation, the direct use of liquid hydrogen could also lead to CO_2 emission reductions by around 2035.

The use of conventional diesel in rail transport is increasingly being rolled back. Hydrogen and fuel cells are important alternatives here, although they will only lead to low levels of hydrogen demand in the foreseeable future and must be embedded accordingly into European developments, especially against the backdrop of the new trans-European networks.

In 2030, 75 per cent of all existing vehicles on the road will likely still be equipped with an internal combustion engine. A market ramp-up of largely climate-neutral, hydrogen-based fuels, which is necessary for aviation and shipping, can achieve further greenhouse gas reductions here during the transition phase. For all applications that are difficult to electrify, where neither vehicles nor an infrastructure for direct hydrogen use are available or where avoidance and modal shifts are not possible, electricity-based fuels could also be used.

Based on the quantity framework previously laid out in its opinion on the implementation of RED II,

roughly 25 TWh is deemed a reasonable estimate in the view of the NRW for hydrogen demand in the mobility sector in 2030. This demand is divided into hydrogen used directly in fuel cell electric drive (approx. 17 TWh) and for the production of synthesis products (approx. 8 TWh).

Driven not least by even more ambitious CO_2 reduction targets from 2030, demand for hydrogen in the mobility sector will again increase dramatically by 2035. In the heavy-duty commercial vehicle sector in particular, the NWR expects consumption to be three to four times higher than in 2030 according to current estimates. This significant increase requires the carefully planned, long-term development of infrastructure, a decision on which must be made before 2025. In addition to road transport, national and intra-European air transport could also start to use liquid hydrogen as an energy carrier from around 2035, which could lead to the use of 400,000 metric tons of hydrogen (13 TWh) by 2040. The production of synthetic products is assumed to be between 14 TWh and 36 TWh in 2035 and between 23 TWh and 84 TWh in 2040, though this includes production sites outside of Germany.

Table 1

Summary of demand in the transport sector

	Total demand of transport		of which e-fuels for land transport		of which e-fuels for air transport	
	million t H_2	TWh	million t H_2	TWh	million t H_2	TWh
2030	0.8	25	0.17	5.7	0.1	2.7
2035	2.0	67	0.24	8	0.2	6.3
2035*	2.8	92	0.9	30	0.2	6.3
2040	3.8	128	0.3	11	0.4	12.1
2050*	6.1	203	2.2	72	0.4	12.1

* Scenario with high e-fuels production (internal data).

2.1.3 Heating

The heating sector is responsible for more than half of Germany's final energy demand, and it is an important segment in terms of achieving climate protection targets. Decarbonisation options are needed for both space heating and the expansive field of process heat. In addition to electrification and the use of district heating in metropolitan areas, the use of climate-neutral gas is an option for this. Besides biogas and biomethane, this also includes hydrogen and synthetic methane.

Pilot projects are currently underway on the use of hydrogen in the heating market, which are investigating and demonstrating the compatibility of hydrogen with heating appliances and the pipeline infrastructure in various blends in the distribution network. In addition to blends of up to ten per cent, which are already possible with existing appliances, and up to 20 per cent with new appliances, the use of pure hydrogen is also being investigated. Corresponding heating devices are already being developed and will be available in a few years.

An important consumer of climate-neutral gases will be central heat generation at CHP facilities, where it is possible to make a major contribution to decarbonisation and sector coupling by replacing previously fossil fuel-based energy sources and through the efficient use of hydrogen. Hydrogen and climate-neutral gases will also play an important role in the process heat sector, especially in high-temperature applications.

While large-scale generation projects in this decade initially target large-scale consumers, hydrogen or its derivatives can be fed into the gas grid at the local level, especially in close proximity to emerging hydrogen clusters or through decentralised smaller-scale generation projects. In this way, initial blending or first conversions of sub-grids can already begin in the period up to 2030.

Overall, the heating market is multifaceted and is characterised by local differences. For reliable sales forecasts, there is no detailed analysis that takes local conditions into account. Possible sales corridors vary widely. In 2019, building heating demand was just over 780 TWh. As previously described, the use of climate-neutral gases is one of the possible decarbonisation options. For the period up to 2030, sales of climate-neutral gases – including biogas – are expected to range from 10 to around 100 TWh in the heating sector. Looking forward at the years up to 2040, demand is estimated to be in the range of between 10 and 154 TWh, with an increasing share of hydrogen.

2.1.4 Energy

According to the NWR, the use of hydrogen in the energy sector for the production of electrical energy will play only a minor role in 2030. Depending on the contours of the EU taxonomy, however, this could change for new power plants added in the 2020s, as CO_2 targets can only be met in part with large-scale co-firing of hydrogen. At the same time, the completion of the nuclear phase-out and the ongoing phase-out of coal mean that investments are needed in secure power plant capacity up to 2030 and beyond. To ensure that these capacities can also guarantee security of supply in a fully climate-neutral energy system in 2050, H_2 readiness and the feasibility of retrofitting are two factors that need to be considered. It can be assumed that these power plants will be operated with an increasing share of hydrogen or even fully with hydrogen, also in order to be able to fulfil the framework conditions for the financing of any projects arising from the EU taxonomy requirements.

In addition, the gradual conversion of the necessary pipeline infrastructure requires sufficient lead times. A reliable long-term regulatory framework is needed by 2025 at the latest. Against this backdrop and in order to ensure the feasibility of H_2 readiness measures or corresponding hybrid solutions, a sector for the use of largely climate-neutral hydrogen in the area of central supply of heating via CHP facilities should be developed in connection with accompanying measures for CHP and climate-neutral district heating.

For the subsequent periods, the level of direct electrification in the demand sectors is a key driver for demand for hydrogen in the energy sector. Therefore, the NWR expects demand of up to 20 TWh for the year 2030 and up to 288 TWh for the year 2040.

2.2 Hydrogen production

The NWR currently sees a highly dynamic development on the supply side, both in terms of technological development and individual projects. Hydrogen and hydrogen derivatives for Germany will be supplied by various sources; a large part of demand will have to be met by imports. In principle, we assume that reliable demand for hydrogen in Germany will lead to corresponding projects on the supply side. The exact growth and distribution of hydrogen on a volume basis depend on a variety of factors, not least the political framework in Germany and abroad.

Currently, we see the following basic sources of largely climate-neutral hydrogen for Germany:

- Domestic production of green hydrogen of at least 5 GW targeted in the NWS for 2030. Significantly higher electrolysis capacity should be targeted, unpinned by the expansion of additional renewable energies.
- Import of green hydrogen from other European countries, which can be carried out via cost-effective infrastructure connections that can be used at short notice (time frame: 2030/2035).

- Imports of green hydrogen beyond the 2030 time horizon from supply regions that require greater technical and economic investment for infrastructural development.
- Generation or import of blue hydrogen as a bridge option.[1]
- Generation or import turquoise hydrogen for the market ramp-up phase beyond 2030.[1]
- Import of hydrogen derivatives for energy and material use from supply regions with favourable production conditions for renewable electricity and climate-neutral CO_2, which could become possible on an increasing scale from around 2030.

The supply of sufficient quantities of green hydrogen must be ensured by 2040.[1] In addition to creating the appropriate technological, infrastructural, economic and political foundations for the production and import of hydrogen, the establishment of a robust certification and tracking system (certificates of origin) is a necessary prerequisite for hydrogen applications in Germany. This also applies to imports from countries outside the European judicial area.

Particularly with regard to the creation of the regulatory framework and the necessary funding instruments, there is a major and urgent need for action to develop a uniform or harmonised European system of certified and standardised certificates of origin for largely climate-neutral hydrogen. This should be done in the period from 2021 to 2023. Certificates of origin must contain, among other things, validated information on the amount of energy, the plant, the method as well as the period of production, the greenhouse gas footprint, information on further sustainability criteria and, if applicable, the use of subsidies. They must be transferable and creditable across borders.

Even though preliminary work has already been done on the development of such a system, there is still need for conceptual and methodological clarification at crucial points, as well as gaps with regard to legislation.

Certificates of origin for largely climate-neutral hydrogen are indispensable in the early phase of market ramp-up in order to create the basis for various support measures on the supply and consumption side. They should concurrently be made available for physical trading at this stage. For this to happen, a robust, reliable registry must be created quickly. At what point certificates can be traded independently of physical hydrogen flows, without counting emission reductions twice, is an issue that will be addressed separately in a second step and should not delay the rapid development of a robust and reliable system in any way.

A high-quality, robust system of validated certificates of origin for largely climate-neutral hydrogen in the EU, established as quickly as possible, can also promote and possibly shape the necessary development of corresponding international systems. Therefore, the development of the system of origin and certification in the EU should take into account the requirements for international imports in order to avoid creating a two-class or multi-class system. At the same time, Germany's and the EU's activities to create a high-quality and robust system for certificates of origin for largely climate-neutral hydrogen should be promoted and bolstered internationally, for example via the G7 presidency, the G20,the IPHE or the IEA.

[1] Also see the dissenting opinion issued by Klima-Allianz Deutscchland and Bund für Umwelt und Naturschutz Deutschland (BUND). at the end of the document.

2.3 Hydrogen infrastructure

The hydrogen infrastructure has a central role to play in the timely development of a hydrogen economy organised along the lines of a market economy and competition. By using pipelines, it is possible to transport large quantities of energy cost-effectively from the producer to the consumer, even across borders in a European hydrogen system. Particularly in view of the fact that Germany will meet a large portion of its hydrogen needs via imports in the long term, it is important to integrate the German hydrogen network into a cross-border European network and to connect import terminals for import routes other than through pipelines. An interconnected infrastructure is the basic prerequisite for the emergence of a liquid hydrogen market.

Germany can draw on an existing foundation for the development of a hydrogen infrastructure. Natural gas pipelines can be converted to hydrogen. This, supplemented by individual new pipelines, will enable a rapid and cost-efficient path for the development of the hydrogen infrastructure. For inner-European transport involving distances of at least 3,500 kilometres, even newly built pipelines are by far the most cost-effective form of transport.

In order to be able to import hydrogen also from countries for which, due to the distance, delivery via pipelines is not possible or economically unviable, marine transport offers an alternative. For this purpose, hydrogen must either be converted into another aggregate state (liquid hydrogen) or into other energy carriers (for example, ammonia or LOHC). The necessary conversion process is energy- and cost-intensive and accounts for a significant part of the total costs. Nevertheless, imports from more distant sources may also become attractive for Germany due to the often highly favourable local production conditions and the dynamic technology development in marine transport. Therefore, potential export countries should not be rejected out of hand on the basis of distance, but the potential of all possible hydrogen partnerships should be utilised. On the other hand, the reduction of marine transport costs, especially with regard to conversion and reconversion, is a central factor for success in the import of hydrogen from more distant production regions.

The development of the hydrogen infrastructure should be based on the requirements and needs of hydrogen producers and users, and anticipated needs should be taken into account at an early stage in grid planning. In the Gas Grid Development Plan 2020 2030, German grid operators have shown how a start grid for hydrogen can be created. First, initial regional hydrogen clusters are formed in which the hydrogen required is produced relatively close to where it is consumed. These will then be connected to form a larger grid by 2030, including an initial link-up to neighbouring countries. With the European Hydrogen Backbone, an initial concept has been developed for creating a Europe-wide interconnected hydrogen network with links to third countries by 2040.

In addition to the transmission networks, the gas distribution grids are also important for supplying hydrogen customers. The gas distribution network supplies not only heating customers in the household and commercial sectors, but also a large proportion of industrial customers in Germany. Therefore, the gas distribution grid will also have to be upgraded, at least in part, for hydrogen transport.

Germany has large underground storage facilities that are connected to the cross-regional transport infrastructure. By 2030, it will be necessary to put the first hydrogen storage facilities into operation, thus enabling decoupling in terms of when hydrogen is produced and consumed as well as seasonal storage. Especially in the ramp-up phase, storage in pipelines can play a role if storage requirements are too large for pressure vessels on cost grounds, but still too small for caverns for utilisation reasons.

In addition, other hydrogen infrastructures need to be created, such as a refuelling infrastructure for hydrogen-powered vehicles and for marine and aviation applications. These applications have special requirements in terms of the supply of hydrogen as well as infrastructure density. These requirements should also be incorporated early in the demand planning phase for hydrogen infrastructure development.

3 General conditions

In order to achieve the outlined targets for the years 2030, 2035 and 2040, a corresponding regulatory framework for hydrogen must be created. The current framework is tailored to the energy carriers available to date. With hydrogen and its derivatives, the coupling of numerous sectors can be achieved. For this to succeed, numerous existing laws, regulations, programmes and standards must be adapted or reformulated. The adjustments to the framework conditions for the production, use and infrastructure of hydrogen and the accompanying research that are necessary in the short, medium and long term from the perspective of the NWR will be described below.

The hydrogen economy is a global goal, and Germany's ambitions and dependencies extend beyond its national borders. Therefore, numerous frameworks must also be established internationally. It is therefore of the utmost importance to cross-link national developments within the framework of the NWS with close European and global collaboration on objectives, strategies and measures. A coordinated ramp-up of a European hydrogen economy is necessary for German industry to succeed domestically - and even more so internationally - as well as for it to create markets on which to sell its products. Germany should use its full political weight within the EU to create the necessary framework conditions for the success of the hydrogen economy on both an economic and ecological level.

2030

3.1 National Hydrogen Strategy

3.1.1 Emergence of hydrogen

For a successful ramp-up of the hydrogen economy, a sufficient and reliable supply of hydrogen, at a reasonable cost, must be available. The costs on the production side must be reduced, which can be achieved, among other things, with the help of cost degression effects through a higher number of facilities, larger plants and the development of low-cost production sites in Germany and abroad. However, it is also necessary to take into account that potential import options that could be available within the 2030 time frame are subject to clear limitations for infrastructure reasons, among other things, in particular due to the domestic requirements of possible exporting countries.

IMPLEMENTATION IN THE NEAR TERM (2021/2022):

E.1 Make policy decision on the role of blue and turquoise hydrogen as a bridge option during market ramp-up (Germany)

In view of hydrogen being credited towards climate targets in the consumer sectors and the use of differential cost subsidies for hydrogen, the federal government must make a policy decision regarding the role to be played by blue and turquoise hydrogen. The extent to which these forms of generation qualify for subsidies on the production and use side will have significant implications in terms of how the various funding instruments will be structured. This decision will also have a significant impact on potential volumes to be imported and the associated potential CO_2 savings.[2]

E.2 Target values for hydrogen production and imports (Germany)

In the long term, widespread use of hydrogen produced in a largely climate-neutral manner depends on whether it is possible to significantly reduce its costs. On the one hand, these costs are the result of technological and economic developments (economies of scale, innovations, international location-specific advantages, etc.), and, on the other hand, they are also directly and indirectly dependent on government regulation. The German government should do everything within its influence to accelerate these cost reduction efforts while taking sustainability criteria into account as well as explicitly state this as a goal.

E.3 Integrate green electricity criteria into RED II methodology and transpose into national law (EU/Germany)

Investment security can also be improved by a timely implementation of the RED II. In this context, the German government should approach the EU Commission with proactive proposals and press for a Commission decision as early as possible. Wherever possible, these proposals should take into account flexibility for new business models. An overly narrow interpretation of individual criteria for power procurement or the operation of electrolysers would hamper investment in generation capacity.

In addition, a consistent definition of green electricity criteria is needed so that hydrogen production can be legally exempted from the EEG levy in accordance with EU regulations. Certainty also urgently needs to be created for the purchase of electricity from hydrogen production plants.

The methodology must then be transposed into German law as soon as possible within the framework of the 37th BImSchV and the Renewable Energy Sources Act (EEG) (NWS measure 5).

[2] Also see the dissenting opinion issued by Klima-Allianz Deutschland and Bund für Umwelt und Naturschutz Deutschland (BUND) at the end of the document.

E.4 Align the EU framework on subsidies to CAPEX and OPEX funding requirements (EU)

To ensure the timely construction of generation facilities, a framework on subsidies is needed that allows for higher CAPEX subsidy quotas and amounts as well as OPEX or sales-related subsidies. This includes, for example, CCfDs to enable cost parity and to protect against higher operating costs on the user side. This is to be implemented in the reform of EU state aid law due in 2021. The German government should weigh in and proactively position itself vis-à-vis the EU Commission at an early stage. The German government's goal should be a separate section devoted to hydrogen and industrial transformation technologies in EU state aid law, similar to the one that already exists for renewable energies. This should explicitly include production, sales and operating cost subsidies and create legal certainty when combining national and European subsidy instruments. A comprehensive European approach could also help avoid time-consuming and resource-intensive individual notifications regarding national subsidies (various NWS measures on subsidy programmes, including 6, 7, 8, 14, 15, 18, 19 and 37).

E.5 5 Broaden expansion corridors for renewable energies (Germany)

In view of the planned expansion of generation capacities, the expansion corridors for additional renewable energies and those intended for hydrogen use must be increased in the EEG, and measures must be taken to tap additional potential in all areas of renewable electricity generation in the short term. This is a necessary prerequisite in order to produce green hydrogen in Germany.

E.6 Get broad funding scheme off the ground quickly (Germany)

To promote the generation, utilisation and infrastructure for hydrogen, the corresponding and previously announced funding instruments must be fully developed by the end of 2022. These include programmes for PtL funding by the BMVI and the BMU, several programmes to fund electrolysis initiatives in Germany and abroad (led by the BMWi) and for the rollout of CCfDs by the BMU and BMWi (including NWS measures 6, 7, 8, 14, 15, 18, 19 and 37).

E.7 Speed up decision-making process regarding IPCEIs (EU)

It is particularly important that the IPCEI applications for expressions of interest be processed promptly and prioritised, and that EU-wide coordination and the matchmaking process be expedited. The German government should lobby the EU Commission to ensure that a decision is taken before the end of 2021 (NWS measure 31).

E.8 Extend availability of budgetfunds for market ramp-up (Germany)

The budget funds earmarked from the economic stimulus and future package for the ramp-up of the hydrogen economy should be extended and made more flexible. In order to support the international measures of the NWS, such as H2Global, in the long term and to create planning security for investment projects with long payback times, the funds must also be available well beyond 2023. An off-budget- instrument in the form of a decarbonisation fund, for example, should be considered.

E.9 Establish European certificates of origin for hydrogen (EU)

The German government must also apply pressure during the ongoing processes to create European certificates of origin (cf. section 2.2). Uniform certificates of origin enable the production conditions of largely climate-neutral hydrogen to be tracked, including certification of the different colours of hydrogen. This is considered an essential prerequisite for ensuring the efficient use of funding.

E.10 Implement and enhance H2Global quickly (International)

H2Global must be implemented quickly so that international projects can be realised on the basis of sales-related subsidies. In this way, projects can be initiated promptly and investment decisions can be made. The funds from the economic stimulus package can thus have the desired effect of stimulating the economy. The H2Global concept should be regularly reviewed and further developed. This also includes ensuring that the governance of H2Global is consistently geared towards transparency and legitimacy in terms of the use of funds, the import of sustainable products and the opening up of long-term, strong prospects for the emergence of hydrogen supply in Germany.

IMPLEMENTATION IN THE COMING LEGISLATIVE PERIOD (2021–2025):

E.11 Establish interdepartmental institution for coordination activities (Germany)

After the 2021 federal election, an institution should be established for cross-ministry NWS coordination and to ensure its consistent implementation (complementary to NWS measure 33).

E.12 Ensure and support enhanced expansion of renewable energies (Germany)

With the adjustment of the expansion corridors for renewable energies (see E.5), a comprehensive package must be adopted that supports the further expansion of renewable electricity generation facilities. This package should include the use of offshore wind power for hydrogen production, taking into account marine and nature conservation, and should designate additional areas for renewable energies as well as electricity and gas infrastructure connections. In the area of offshore wind energy, cooperation with the countries bordering the North Sea and the Baltic Sea should be intensified (NWS measure 4).

E.13 Conclude long-term import agreements with suitable supply regions (Germany)

In order to create incentives for international production and secure the quantities of hydrogen that will foreseeably be needed, state-backed long-term contracts should be concluded for the import of largely climate-neutral hydrogen, ideally with a term of 15 to 20 years. It would also be possible, for example, to establish international trading platforms. To this end, the German government should initiate a dialogue with potential supplier regions (NWS measures 34 to 38, supplemented by new measures; not yet addressed in NWS).

E.14 Implement European hydrogen society (EU/International)

With H2Global, there is an international reference model that can also serve as a model for the European analogue. The development of the European auction mechanism should be supported.

E.15 Harmonise national hydrogen strategies across the EU (EU)

There are still significant differences between the hydrogen strategies of the EU Member States, for example in the areas of classification, infrastructure development, blending rates and uses. The German government should quickly address these differences at the EU level and bring about harmonisation, also with a view to partners outside the EU.

E.16 Focus EU initiatives on cross-border steps in the value creation process and their implementation (EU/International)

There are now several EU initiatives on hydrogen, such as ECH2A. These must be applied in a coherent manner. In addition, institutions at the EU level, but also bilaterally and regionally, must be established quickly in order to implement infrastructure planning, transport and supply chains. The IPCEI programme for hydrogen should also be extended to neighbouring regions in order to carry out a market ramp-up and create corresponding import capabilities in a timely manner (not yet addressed in NWS).

E.17 Establish intra-European cooperation structures (EU/International)

Hydrogen cooperations within the EU and in the areas adjacent to Europe should be promoted via the pentalateral forum NSEC. Clusters should be established in other regions at the same time. In the future, these could be combined to form a European Hydrogen Union (not yet addressed in NWS).

E.18 Establish international standards for market components (International)

Approval procedures must be expedited for the ramp-up of national production and the necessary cost reduction efforts. In this context, standards for hydrogen production plants and the corresponding infrastructures (grid connections, etc.) that are as internationally compatible as possible should be set as quickly as possible. This not only simplifies the national approval processes but also increases the export opportunities for the technologies developed in Germany (NWS measure 13).

E.19 Create legal basis for CO_2 transport and storage (Germany/EU)

If the German government makes the decision to also use blue hydrogen to build a hydrogen economy, (international) legal foundations for the transport and storage of CO2 must be created. These are particularly relevant for coastal locations from which CO2 can be transported to offshore storage sites (not yet addressed in NWS).

E.20 Reform state-imposed price components for energy (Germany)

With regard to funding instruments, a consistent and incentive-based reform of taxes, levies and reallocation charges is required.

E.21 Readjust and implement CO_2 pricing mechanisms and EU energy tax system (EU/Germany)

Regulatory cost drivers for hydrogen production must be reduced. In this sense, the German government should play an active role in efforts to amend the various direct or indirect CO2 pricing mechanisms at EU level.

E.22 Provide incentives for use of hydrogen technologies via EU emissions trading (EU)

The EU-ETS is a central instrument of European climate policy. However, it can and should provide stronger incentives for the replacement of conventional technologies with transformational hydrogen-based technologies. This can be done, for example, through more stringent pricing of hydrogen production from fossil fuels. In addition, new approaches to the free allocation of emission allowances can provide incentives for relevant industrial facilities. However, this will require some rule changes compared to the current system. Additional incentives as well as funding for investments in hydrogen-based processes must also be established using other instruments such as investment assistance, CCfDs and lead markets.

A reform of the EU-ETS should be designed in such a way that, on the one hand, effective protection against carbon leakage is maintained for those plants that cannot yet be modernised through a wide range of existing and, if necessary, new mechanisms. On the other hand, the reform should create strong incentives as well as provide sufficient funding for the transition to climate-neutral technologies and feedstocks within the context of the modernization cycles.

These changes need to be implemented in the pending EU-ETS reform process for them to take effect in the second half of the fourth trading period of the EU-ETS, that is from 2026 onwards (complementary to NWS measure 1).

E.23 Conceptually differentiate funding mechanisms (Germany)

Consistent, differentiated and legally robust concepts for subsidies and non-subsidies must be created. These should take into account a holistic view of investment costs, operating costs and product/sales-related subsidies. However, a distinction should be made between hydrogen production near the point of consumption (potentially differentiated between green/blue hydrogen, etc.) with the aim of replacing grey hydrogen (lower cost parity gap), hydrogen production near the point of consumption (potentially differentiating between green and blue hydrogen, etc.) with the aim of replacing fossil fuels (higher cost parity gap) and hydrogen production far from the point of consumption (additional measure; not yet addressed in NWS).

E.24 Provide for funding instruments in the federal budget for the decade (Germany)

On the budget side, the federal government must provide for the necessary funding instruments for a period of at least ten years. This can be done, for example, through commitment appropriations or other funding instruments (variety of measures).

E.25 Mobilise institutional capital to finance market ramp-up in Germany and Europe (Germany/EU)

In order to finance the massive investment required for the hydrogen market ramp-up, it makes sense to mobilise highly competitive private capital from institutional European investors, such as pension funds or insurance companies, in addition to government support. This would significantly lower the cost of market ramp-up. A prerequisite for mobilising institutional capital is that policymakers create a regulatory framework for the market ramp-up that justifies a low-risk capital backing in line with Solvency II rules. In addition to CCfDs, the so-called double auction model touted in H2Global could be extremely well suited for this purpose (see E.8).

E.26 Establish internationally recognised certification and tracking system for production and imports (International)

Internationally recognised certification and tracking models must be advanced in appropriate multilateral bodies. Clear standards and sustainability criteria are needed for the necessary differentiation between largely climate-neutral hydrogen from the EU, EFTA and the European Energy Community and largely climate-neutral hydrogen imported from other regions. The German government must initiate a debate on this topic at international level and expedite the process by way of pilot projects (NWS measures 13 and 30, cf. section 2.2).

E.27 Model market for hydrogen supply (Germany)

In the coming legislative period, a market model for hydrogen supply must be developed. The market model for natural gas already offers a regulatory framework.

3.1.2 Industry

The use of largely climate-neutral hydrogen in industrial production processes is critical for the decarbonisation of industry and, moreover, there are no alternatives available in many areas. At the same time, industry, as a large consumer with the capacity and flexibility to absorb supplies rapidly, can be a key driver in the establishment and ramp-up of the hydrogen economy with simultaneous benefits for the other sectors where it is used. To this end, largely climate-neutral hydrogen must be made available.

Insofar as the use of hydrogen in industry is associated with a fundamental shift in technology, hydrogen must be made available at conditions that are acceptable to the industries who compete internationally. In addition, it is necessary to support investments in these new technologies and technology chains and to close the economic viability gap.

IMPLEMENTATION IN THE NEAR TERM (2021/2022):

A.1 Making largely climate-neutral hydrogen available (Germany)

The hydrogen demand of the steel and chemical industries, to which demand from other sectors must be added, are already significantly higher than the quantities of green hydrogen that can be expected from the electrolysis capacities stated in the NWS in the foreseeable future. Therefore, additional efforts are needed to produce green hydrogen. Hydrogen demand can be met during the transition period in the steel industry, for example, by using other gases such as natural gas with a significant CO_2 reduction effect.

A.2 Introduction of certificates of origin for largely climate-neutral hydrogen (Germany/EU)

A prerequisite for the use of hydrogen and hydrogen-rich gases such as natural gas in industrial processes that mitigate CO_2 emissions is that the CO_2 footprint of the gas being used is documented; this refers to the total CO_2 emissions generated during its production, transport and use (scopes 1 to 3). This provides transparency with regards to how much CO_2 can actually be saved by using the relevant hydrogen or hydrogen-rich gas such as natural gas. If this is demonstrated and can be credited to the reduction of CO_2 emissions, industry can quickly switch to hydrogen-based and low CO_2 industrial processes and flexibly purchase large quantities of hydrogen, despite the shortage of green hydrogen. To this end, a robust system of certificates of origin must be created at the beginning of the next legislative period (cf. INT.6).

A.3 Suitable system to demonstrate use of green electricity for the production of hydrogen

Due to the fluctuating volumes generated and increasing demand in many sectors, electrolysis capacity as well as the quantities of available green electricity in Germany will be scarce for the foreseeable future. In order to maximise the production of hydrogen using electrolysis, it should be possible to use renewable electricity to a sufficient degree, both physically and on the balance sheet, by means of certificates of origin.

A.4 Bring hydrogen to the customer

In addition to the availability of sufficiently large quantities, it is important that hydrogen can be reliably delivered to customers. Industrial customers must be quickly connected to a networked infrastructure that provides access to hydrogen sources in Germany and abroad as well as to hydrogen storage facilities. The necessary pipelines and other infrastructures must be built as quickly as possible. At the same time, the large volumes sold at industrial sites are an excellent starting point for the development of a hydrogen infrastructure, as they ensure a minimum utilisation rate. At the same time, investments in electrolysis plants at high-demand locations allow for an early start to hydrogen use.

For industrial customers, it is very important, especially in view of the large sums involved in investment decisions, to have a reliable perspective for connection to the hydrogen network and, at the same time, customer-friendly grid access with stable, plannable transport fees. It must be ensured that the pilot customers of hydrogen in industry are not penalised with high fees for their pioneering work.

The framework must be designed in such a way that the development of domestic hydrogen production is as grid- and system-friendly as possible. At the same time, industrial hydrogen production must also be made possible at locations with low renewable energy generation potential, where this makes sense both ecologically and economically for process-related reasons, for example due to synergies. With regard to the German power grid, this means that possible bottlenecks in the grid are presented in a transparent manner and evaluated with this issue and the the overall electricity and hydrogen system in mind.

A.5 Promote hydrogen-based and H_2-ready production processes

To make hydrogen-based low CO_2 and CO_2-free production processes economically viable and to provide an incentive for corresponding investments, the expected higher investment and additional operating costs compared to established CO_2-intensive processes must be offset. This must be done through a combination of government support and the development of lead markets for green feedstocks. The CCfDs for process industries announced in the NWS are of central importance in this regard. At the same time, CAPEX support should also include plants that are H2 ready, i.e., ones can be operated fully with hydrogen, at the time of commissioning.

A.6 Ensure combinability of funding programmes (EU)

Conflict-free combinability of the various regional, national and European funding programs must be ensured.

A.7 Make medium-term funding commitments via special funds binding (Germany)

Companies need planning security for their investments over a long period of time, which cannot be achieved based on funding in line with the current budgetary position. For this reason, a mechanism must be developed that allows binding assurances regarding funding commitments. To this end, a special fund for industrial transformation should be set up and a framework created for legally established entitlements to subsidies during the depreciation period. The first step in setting up such a special fund is to determine the funding requirements for industrial transformation for OPEX and CAPEX costs up to 2030. Since climate protection is a task for society as a whole, the costs must be distributed in a socially equitable manner, for example through tax-based financing. The introduction of a climate levy on CO_2-intensive basic materials, which would be charged for every metric ton of basic material produced or imported, should also be examined. In order to create a reliable investment framework, it is essential that the expansion of renewable energies be reliably refinanced in the long term.

A.8 Bring broaden use of CCfDs (Germany)

CCfDs are a key tool to offset the higher operating costs (including interest payments) of hydrogen-based, low-carbon industrial production processes. The pilot programme for CCfDs must therefore be quickly launched and further developed towards broader applicability.

Accordingly, the state or a state-appointed institution concludes a contract with the companies on guaranteed prices for innovative, low greenhouse gas or greenhouse gas-neutral products or correspondingly facilitates production at competitive prices by providing compensation for the additional costs for the hydrogen-based process. The differential costs between conventional and low GHG or GHG-neutral EU production on the world market are reimbursed until distortions of competition or carbon leakage risks can be eliminated or a market for green feedstocks has emerged so that climate-neutral production processes can recoup the associated additional costs. CCfDs should be used primarily to facilitate the conversion of industrial production with process-related emissions or high-process temperatures. For that reason, they should be applied on the demand side.

CCfDs should make it possible to offset the total additional costs, especially the added costs for the largely climate-neutral hydrogen. The funding of other support mechanisms and any additional revenues should be taken into account. Compensation only for the nominal difference to the ETS price would not be sufficient; only real revenues from CO_2 certificates that can actually be sold should be deductible from the funding under the CCfDs. The possibility of compensation for additional operating costs for low-CO_2 or climate-neutral industrial production through CCfDs must be established in the EU framework for state aid in the near term. In the long term, EU harmonisation should be sought.

When developing the CCfDs during the ramp-up of the hydrogen economy, it is critical that compensation of additional operating costs takes place within the overall context and that the CO_2 reduction effects during the gradual ramp-up of the hydrogen economy are also taken into account accordingly.

In order to create a sufficiently robust planning basis for industry investments, CCfDs must include long terms with binding funding commitments over the depreciation period of the relevant assets.

A.9 Establish green lead markets through government incentive schemes (Germany/EU)

For climate-neutral basic material production to be self-sustaining in the long term, the higher costs of climate-neutral production processes must also be reflected in the prices of end products. In addition to government subsidy programs, the establishment of green lead markets for basic materials in selected sectors should therefore begin at the start of the next legislative period to support the ramp-up of investments in climate-neutral processes and thus also reduce the need for subsidies. Wherever possible, in view of the shortage of green hydrogen for the time being, the German government should rely on government incentive systems among feedstock users to create demand for climate-neutral but expensive feedstocks with a corresponding willingness to pay.

A.10 Look into quotas for materials manufactured using green hydrogen (Germany/EU)

In addition, however, regulations for the mandatory use of green materials should also be drawn up without delay. The German government must develop a binding regulatory framework for this. Starting points could be found, for example, in the standards for public procurement or the EU CO_2 standards for passenger cars, as well as in the EEG tenders. In addition, the introduction of quotas and standards for the mandatory use of materials should be closely examined. For a rapid rollout, the framework for lead markets should first be created at national level; in the longer term, from 2030 at the latest, EU regulations will be required. As a prerequisite for green lead markets, suitable definitions and verification systems for climate-neutral basic materials must be established. Last but not least, the shift to green basic materials must be made across the board in public procurement processes.

3.1.3 Mobility

Key activities in the period up to 2030 will include the ramp-up of the necessary technologies and the entry into force of the framework regulations. The development of the technical and market framework as well as the necessary infrastructures accompanied by a simultaneous reduction of production costs through upscaling are therefore essential requirements for the use of hydrogen and hydrogen-based energy carriers in transport.

IMPLEMENTATION IN THE NEAR TERM (2021/2022):

M.1 Define standards for use by means of technical regulations (international)

In view of the technical lead times, it is essential to create reliable technical regulations for the approval of heavy commercial vehicles and rail vehicles as well as for hydrogen refuelling stations as soon as this year and next year (NWS measure 13). Due to the lower level of technological development, the complexity of aircraft development and the coordination processes at an international level, a more protracted process is to be expected for the creation of technical regulations. Therefore, the technical framework, amongst others for the development of hydrogen-powered aircraft, must begin as soon as possible.

M.2 Prepare a service station infrastructure concept embedded in Europe (Germany/EU)

The development of the necessary infrastructure for hydrogen use in the transport sector takes time. Following the process currently underway to plan a high-performance charging infrastructure for commercial vehicles, a detailed infrastructure concept for a hydrogen filling station network embedded in Europe must also be developed in the short term to enable rapid implementation of the expected amendment to the Alternative Fuels Infrastructure Directive (AFID). The concept should take the needs of the transport sector outlined in section 2 as the basis.

M.3 Use of pilot projects to test different technological options (Germany)

In the short term, fully integrated pilot projects for hydrogen use in commercial vehicles and in rail transport should be carried out on a large scale along the value chain with major support from the German government in order to test various technology options for refuelling and storing hydrogen in vehicles.

M.4 Develop the supplying industry for hydrogen lead markets in the mobility sector (EU)

The development of a competitive supply industry for fuel cells, fuel cell systems and their components must be supported. Of particular importance in this context is the timely and prioritised processing of IPCE applications for expressions of interest in the field of mobility as well as the promotion of the EU-wide coordination and matchmaking process. The aim should be to establish intra-European project partnerships in the comprehensive value chain for lead markets such as heavy-duty mobility applications. In particular, the needs of industrialisation and high investment costs of the component supply industry as well as fuel cell and fuel cell system manufacturers should be taken into account. Investment security for this medium-sized industry should be significantly improved. The German government should lobby the EU Commission to ensure that a decision is made before the end of 2021 (NWS measures 10 and 31).

M.5 Set international standards for fuel cells and related key components (international)

In order to achieve the defined cost targets and scaling for market-oriented production of key components, it is expedient to adopt internationally compatible standards at an early stage. The Hydrogen Technology Innovation and Technology Centre must assume a leading role in this and the German government must ensure that it starts work quickly. This will also increase the export opportunities for fuel cell systems and components developed in Germany (NWS measure 10).

M.6 Play active role in shaping regulatory framework at an EU level (EU)

Within the framework of the European Green Deal, relevant decisions will be taken in the period up to 2022, in which the NWR considers it vitally important that the federal government play an active role:

- Amendment of the Energy Tax Directive: In the NWR's opinion, the amendment of the Energy Tax Directive should result in a shift to components that are linked to the emission of greenhouse gases and not to the consumption of energy. In doing so, the necessary funding requirements for infrastructure resulting from taxing energy should continue to be taken into account and guaranteed.
- Amendment of the Eurovignette Directive: In the NWR's perspective, the German government should support the establishment of a CO_2 component in the Eurovignette Directive, which would allow external costs of CO_2 emissions from vehicles to be taken into account in the toll charges levied.
- Introduction of a separate EU emissions trading system for the transport and heating sectors as of 2025: In the NWR's opinion, the German government should advocate for an EU-wide CO_2 pricing system that guarantees a price for the transport sector that is significantly more ambitious than €55 per metric ton of CO_2 from 2025. Possible effects on other sectors of the economy should be taken into account.
- Amendment of the AFID: Upgrade the directive into a regulation with mandatory requirements for the minimum number and capacity of charging stations as well as hydrogen refuelling stations for all EU Member States.
- Review of CO2 emission standards for passenger cars and light as well as heavy commercial vehicles.
- Amendment of RED II (RED III).

IMPLEMENTATION IN THE COMING LEGISLATIVE PERIOD (2021–2025):

M.7 Integrate hydrogen drive systems as a key priority in the commercial vehicle strategy and promote initial applications (Germany)

In the NWR's opinion, hydrogen use and fuel cell propulsion should be designated as priority technologies of the 'overall concept for climate-friendly commercial vehicles' alongside electric battery drives. Especially in the field of mobility, a value-adding hydrogen economy can be achieved as a low-threshold entry scenario, if it is possible to carry out research on and develop production technologies for the necessary components as quickly as possible and subsidise these activities.

The development of a competitive supply industry for fuel cell systems and the creation of an industrial base for large-scale production of fuel cell stacks (NWS measures 3 and 10) should be supported by the establishment of a reference platform. This could serve as a technological orientation for the industry and provide a development platform for an innovative ecosystem and the related value chain creation. With the rapid implementation of the Clean Vehicles Directive (CVD) into national law, there is also a need to use zero-emission vehicles in municipal transport. In addition, further pilot projects for hydrogen use in transport should be promoted on a large scale. These measures should be implemented, taking into account the needs for industrial development in the supply sector.

M.8 Adopt a reliable market framework for climate-friendly transport (Germany)

To increase the competitiveness of climate-neutral road vehicles, a regulatory and tax framework should also be created in the coming legislative period, at the very latest for the second half of the decade, which takes into account the main externalities of transport. This includes measures such as the rapid integration of CO_2 emissions into the national road toll charge calculation as well as a CO_2 component in the taxation of fuels that is systematic and increases annually, taking into account the necessary infrastructure funding. This will create a market framework that ensures the competitiveness of climate-friendly transport carriers in the foreseeable future and thus stimulates investment in more climate-friendly technologies..

M.9 Promote hydrogen use in shipping (Germany)

Public contracts for climate-neutral fuels and propulsion systems for government ships, research vessels, etc., can demonstrate the marketability of new technologies and act as pilots to generate corresponding demand for largely climate-neutral hydrogen and hydrogen derivatives.

IMPLEMENTATION FOR THE PERIOD AFTER 2025:

M.10 10 Establish lead markets for transport carriers with new drive systems (Germany/EU)

Other sector-specific topics to be addressed for the second half of the decade include the creation of a lead market for various applications in the transport sector. For commercial vehicles, the establishment of a lead market with a target size of 30,000 units by 2030 is recommended. This should be accompanied by defined benchmarks, decreasing overall costs and a further expansion of the refuelling station infrastructure.

M.11 Plan terminals and ship transport as key components of an import concept (Germany)

An infrastructure concept for imports of green molecules (gaseous, liquid hydrogen, LOHC, e-ammonia, e-methanol, etc.) as part of the future hydrogen supply should include the role of terminals and ship transport. It should also be noted that different transport carriers require hydrogen in different forms (for example, 35 MPa, 70 MPa or liquid form). The network of hydrogen refuelling stations being developed should also take into account the different applications for reasons of acceptance, cost and investment, with a focus on long-distance road cargo transport.

M.12 Align import planning at an early stage with rising demand in the transport sector (Germany)

The technologies introduced in road-based transport prior to 2030 will sharply increase demand for hydrogen in the coming decade. In addition, there will then be increasing demand from other modes of transport such as trains and aircraft. In the development of import infrastructures, these increasing volumes for the transport sector, for example in the form of liquid hydrogen, must be taken into account separately. Finally, before 2040, the sectors that emit large amounts of CO_2 could be converted on a large scale to battery and hydrogen-based mobility.

M.13 Establish hydrogen in aviation

In addition to innovative aircraft and propulsion concepts, sustainable energy sources (synthetic fuels, hydrogen, etc.), altered flight routes and modal shifts also play an important role. New technologies are under development that also make the direct use of hydrogen in aircraft appear possible by the middle of the next decade.

This requires the development of a long-term, politically backed Europe-wide plan that reflects the potential of hydrogen and, at the same time, takes into account the complexity of aviation, international integration in this area as well as the stringent safety requirements that apply. In addition R&D activities and the accompanying funding should be initiated, focusing on key areas of the components required for short- and medium-haul aircraft and making maximum use of synergies with other fields of application. This requires not only the development of the relevant technologies as well as the establishment and expansion of production, infrastructure and the supply of liquid hydrogen, but also its technical integration at airports.

At the same time new aircraft and airport infrastructure are being developed, research into the climate impact of water vapour emissions must be intensified. The state of knowledge with regards to both modelling and the effect in the upper atmosphere is crucial for a sustainable contribution of aviation to the required reduction in emissions.

These measures should should go into a demonstrator programme, the decision on which should be made as early as possible during the next legislative period, as well as support the implementation of a pilot project. In addition, for the decarbonisation of long-haul flights, a suitable programme for the provision of sustainable aviation fuels and the additional hydrogen required for this should be initiated together with the petrochemical industry.

M.14 Ensure the supply of hydrogen and e-fuels to German security authorities and organisations (BOS) and the armed forces

Although hydrogen technologies can and will be increasingly used also by BOS and armed forces in the future, these institutions operate systems and vehicles that will be dependent on combustion technology and thus e-fuels for a long time. For these and similar cases, domestic generation and stockpiling capacities must be maintained in order to be able to guarantee a reliable and long-term supply and thus operational capability even in the event of a crisis or disaster.

3.1.4 Heating

The heating market in Germany accounted for around 53 per cent of end consumption of energy in 2019. In 2020, the heating sector exceeded the annual emission levels set out in the Federal Climate Protection Act. For years, renovation rates in the building sector have been far below the levels needed to achieve a climate-neutral building stock by 2050. In view of the targets defined for the sector, much more ambitious objectives must be set for the building sector. In the next ten years, CO_2 emissions must be reduced by the same amount as in the past 30 years. On the one hand, this illustrates the challenge this sector poses for decarbonisation in Germany. On the other hand, there is enormous savings potential in the heating market that can be leveraged by gradually substituting fossil fuel-based energy sources.

The heating market is characterised by a wide variety of technologies and heating requirements. It is necessary to take into account that heating often has regional, local as well as significant seasonal aspects. The sector includes space heating for residential and commercial buildings, hot water heating as well as process heat for industrial applications. However, space heating and hot water applications differ significantly from those for process heat. Temperature differences and technical specifications require the development of individual decarbonisation solutions for the respective heating sectors. These must be both cost-effective and affordable for the relevant users. In addition to key economic aspects, the issues of acceptance, security of supply and resilience of the transformation path are also of critical importance.

IMPLEMENTATION IN THE NEAR TERM (2021/2022):

W.1 Avoid technological preconceptions for decarbonisation paths for the building sector (Germany)

Electrification of space heating is an efficient way to decarbonise new buildings. In 2020, electric heat pumps have been installed in around one third of new buildings. There are also excellent opportunities for using heat pumps in (renovated) existing buildings, provided that sufficient renovations have been made, including change of technology in the heating sector. However, statistics from recent years illustrate that renovation of existing buildings is progressing at a very slow pace. If it is not possible to increase the renovation rate from one to about two per cent annually and double the efficiency gains made as part of these measures, additional options will be needed. New and existing buildings could also be decarbonised in suitable supply structures by expanding green district heating (heat pumps, biomass, solar and geothermal, use of hydrogen). Other variants with decarbonised gaseous energy sources for existing buildings are also an option for decarbonisation, especially since a large part of the required infrastructure (transmission and distribution networks) is already in place and the corresponding heating technology can be modularly adapted to the relevant gas quality which makes it possible to avoid lock-in effects. A gradual adjustment of blending rates would also contribute to the goal of reducing greenhouse gas emissions. This raises the question as to the availability of hydrogen and, in general, the issues of cost, feasibility, resilience and security of supply.

W.2 Commission analysis of possible decarbonisation pathways for the heating market (Germany)

The initial situation in the heating market is extraordinarily complex and first requires further analysis in order to deduce suitable measures for decarbonisation. It is therefore not advisable to adopt measures in the current legislative period. Instead, a detailed bottom-up study should be commissioned as soon as possible, taking into account typical urban and rural regions and including municipalities and municipal utilities. It is particularly important to consider high-temperature process heat, most of which is supplied via the distribution grid to industry, and the implications for existing infrastructures, such as the impact on the electricity distribution grid with a concomitant increase in electrification in the transport and heating sectors.

In the context of this study, the underlying premises and scenarios must first be defined and transparently presented on the basis of the latest cost and technology data. Subsequently, a manageable number of different ‘types’ of urban and rural areas as well as high-density and industrialised regions, so-called heat avatars, are to be defined. The heat avatars are to be analyzed in detail in order to deduce and evaluate alternative transformation paths of decarbonisation with regard to costs, social compatibility, security of supply, pace of transformation, infrastructure tipping points in case of low grid utilisation rates and so forth. Given the significant uncertainties that exist, it is critical to maintain a range of options.

IMPLEMENTATION IN THE COMING LEGISLATIVE PERIOD (2021–2025):

W.3 Prioritise implementation of NWS measure 19 (Germany)

The German government should examine the possibility of promoting H_2-ready CHP plants. This measure should be prioritised, provided that the plants are compatible with full climate neutrality (NWS measure 19).

W.4 Ensure H_2 readiness in heating systems (Germany)

The German government must examine whether the conversion of heating systems and associated network components to hydrogen or climate-neutral gases should be set out in the funding guidelines of the German Federal Office of Economics and Export Control (BAFA). This would prevent possible lock-in effects.

W.5 Use distribution grids also for decarbonisation of process heat (Germany)

With regard to process heat, the potential for electricity-based decarbonisation is low (especially in the area of high-temperature applications). Here, the electrification of the applications is often either technically unfeasible or not financially viable.

Companies operating in this sector will continue to be dependent on a gaseous energy source in the future. The connections to the gas distribution network that often already exist offer economically efficient opportunities for switching to decarbonised gases. This would significantly reduce the need to expand and build new connections to the power grid, which can be cost-intensive.

3.1.5 Infrastructure

The infrastructure forms the basis of a secure, reliable, demand-based and fully efficient supply of hydrogen. To harness the benefits of hydrogen and enable the development of a competitive market for it, it is necessary to set up a hydrogen infrastructure. Cross-regional hydrogen transports connect producers and consumers and integrate the German hydrogen market into a European hydrogen network. A large portion of the hydrogen used in Germany in the medium term will come from abroad. Therefore, early integration into a cross-border, European hydrogen infrastructure and the connection of ports for import by ship are very important.

Hydrogen storage facilities connected to the cross-regional transport grid supplement the system as seasonal storage facilities, increase security of supply and enable generation and consumption to be decoupled over time. The use of caverns to store hydrogen has already been tested and would enable a switch to hydrogen. The extent to which pore storage can be used is being investigated in pilot projects.

The gas distribution networks supply a large proportion of end customers, including industrial consumers and the heating market. In Germany, 31.5 million private consumers and 1.8 million commercial and industrial customers are currently connected to the gas distribution network.

The local supply function, developments in the heating market, the use of decentralised hydrogen generation plants, the possibilities for supplying energy to commercial and industrial customers and the availability of hydrogen at economic prices are factors that will have a major impact on the role of the distribution grids, which has yet to be clarified. Depending on these factors, this may result in the required distribution grid capacities being maintained and, in individual cases, expanded or significantly scaled back.

The hydrogen infrastructure can be built largely by converting existing, unused natural gas pipelines, supplemented by individual newly built pipelines. This will enable rapid and cost-efficient implementation, while at the same time minimising the impact on nature. As with the current natural gas infrastructure, non-discriminatory grid access with a flexible entry-exit model, affordable and stable transport fees and efficient, transparent planning would also be desirable for the hydrogen infrastructure. The appropriate legal, economic and technical framework must now be established quickly. Transport customers and grid operators require planning and investment security.

IMPLEMENTATION IN THE NEAR TERM (2021/2022):

I.1 Create legal framework via the German Energy Industry Act (EnWG)

The EnWG must be amended before the end of this legislative period to include hydrogen as an energy carrier and to ensure that existing permits, easements and rights of use to land for natural gas pipelines remain valid even in the event of conversion to hydrogen. The same must apply to new hydrogen pipelines to be constructed. Without this, pipelines will not be converted to transport hydrogen. The proposed amendments to the EnWG contained in the cabinet resolution are suitable for this purpose and must now be adopted quickly.

I.2 Establish funding for hydrogen network

Hydrogen can be transported in large quantities via pipelines at low cost. Initially, higher specific costs are to be expected due to low utilisation of the pipelines. Affordable and stable charges for transport customers as well as investment security for grid operators can be ensured immediately by including hydrogen in the existing and proven cost-revenue regulation for natural gas networks. The total system costs will change only slightly due to the relatively low costs for the hydrogen network at the beginning, and a seamless transition from natural gas to hydrogen with no change in fees will be possible for transport customers. The German government should lobby for this in the upcoming talks on the EU gas package. In the next legislative period at the latest, it will be necessary to create a reliable long-term framework for the regulatory approval for H2 readiness conversion in gas distribution networks. Transitional solutions for private-sector hydrogen infrastructures and pipelines that developed organically over time must be provided.

If hydrogen is not immediately included in the cost-revenue regulation for natural gas networks, the first transport customers could face higher transport charges than for natural gas, and grid operators will encounter investment risks. These risks can and should be temporarily reduced via suitable funding instruments such as IPCEI (NWS measure 31). Otherwise, the cost risks threaten to significantly delay the transformation process in the application areas.

IMPLEMENTATION IN THE COMING LEGISLATIVE PERIOD (2021–2025):

I.3 Facilitate cross-border trading and transport [Germany/EU].

In the future, large quantities of hydrogen will be traded and transported across borders in Europe. Some standards from the DVGW regulations, which are currently being adapted for hydrogen, are relevant for cross-border transport, for example regulations on gas quality. The German government must create a suitable platform that supports the European harmonisation of such standards.

I.4 Ensure efficient grid planning and promote interconnection of electricity, heat and gas infrastructures

For a seamless and secure supply to customers, the hydrogen network of the future – as in the past decades with natural gas – requires close cooperation between transport grid, distribution grid and storage facility operators, while at the same time taking into account integration into an international grid structure. For electricity and natural gas, there is already an established process for infrastructure planning in the form of the grid development plan. Hydrogen should be included in this process on an equal footing to enable efficient and transparent network planning. Due to the close link between gas and hydrogen infrastructure, a joint process for grid development planning should be set up. Hydrogen storage facilities on the transport level and hydrogen projects on the generation and consumption side on all grid levels, including the distribution grid, should be taken into account.

At the same time, the interlinking of electricity, heat and gas infrastructures should be promoted in order to achieve sector coupling. As part of a system development plan, joint future scenarios for electricity, gas and hydrogen should be prepared by an independent body. Simplified modelling derived from this can then provide the basis for establishing potential for improvements within the system and the relevant demand-based grid development planning. For example, bottlenecks in the electricity grid can be eliminated by shifting to the hydrogen grid, or suitable locations for electrolysers can be identified. In addition, the time-related reference points for the grid development plans for electricity as well as gas and hydrogen should be aligned to each other.

I.5 Speed up establishment of cross-border infrastructures

To achieve the goal of a European hydrogen market, cross-border infrastructure planning must be optimised. Expected European import corridors should be integrated into infrastructure planning at an early stage. The German government should promote corresponding coordination at the EU level.

LONG TERM (UNTIL2030 OR 2035, IF APPLICABLE)

I.6 Establish a national hydrogen reserve

In addition to optimising the overall economic costs, the security of the energy supply is another very important goal. Beyond the upcoming legislative period, Germany should take appropriate measures to ensure security of supply for hydrogen as well. The establishment of a national strategic hydrogen reserve should be analysed and evaluated with regard to the corresponding time frame (not adequately addressed in the NWS so far).

3.1.6 Research and development, innovation and education

The safe handling and cost-effective use of the technologies described in this action plan require that the current conceptual phase of the use of hydrogen will be heavily supported by a great deal of creativity being unleashed by an R&D offensive on a sustained and long-term basis. This is essentially the view of the NWS and is currently being promoted primarily by the Federal Government. Support is needed in the long term, since highly challenging tasks lie ahead and the sustainability and safety of the solutions found must be proven in demonstrators over about a decade. In global terms, Germany has a top-notch research ecosystem in the field of hydrogen technologies, which has played a major role in making it possible to tap the potential of the hydrogen economy over the coming years. The new phase, which has now begun and which will be characterised by the industrial application of the technologies, requires considerable adjustments in the research priorities. This involves, among other things, verification of processes along the value chain (production, transport and use of hydrogen), system integration, production technologies and new materials. At the same time, the use of renewable gases triggered by sector coupling will lead to significant changes in the economic sectors outlined above. Products and production processes will have to be completely revised in some cases. Research on numerous individual challenges to the hydrogen economy, the construction of the demonstrators and their rollout will have a significant impact on the future job specifications as well as on the underlying vocational and university education. Fast, comprehensive transfer of relevant research results into the educational sphere and the recruitment of additional employees at all levels of the research and implementation process are essential. A shortage of qualified employees that is already perceivable today could become an obstacle to achieving the climate targets, which can only be eliminated in the medium term.

IMPLEMENTATION IN THE NEAR TERM (2021/2022):

F.1 Communication

Because of its impact on the energy system, hydrogen can only be successful if there is clear, comprehensive communication with the users before and during its rollout. In the history of energy transitions, this has not always been the case. There is an urgent need for a research programme focused on identifying the causes, developing concrete proposals for effective communication and applying them into practice. There are numerous communication initiatives to accompany the energy transition, but these are neither active in a coordinated manner nor with sufficient methodological certainty and monitoring of the successes. A package of measures is needed consisting of financial support to provide autonomy, methodological and conceptual assistance, appropriate coordination activities as well as the monitoring of quality and success that feeds back into the measures. To achieve the optimal impact quickly, an integrated interdepartmental approach is required to implement this task.

F.2 Identify research priorities

An important element of the rapid ramp-up of the hydrogen economy is speeding up the transition from research and development to industrial implementation of key hydrogen technologies. For example, the timely completion of H2Kompass (NWS measure 23) is of great importance to identifying important research and development areas for industry and science. H2Kompass identifies measures and barriers to market ramp-up as well as research requirements and can serve as a guide for science and industry in defining what research and development activities to prioritise and in identifying important measures for large-scale implementation. The German government should establish an interdepartmental platform for hydrogen research. This should act as an operational institution coordinating between demand drivers and solution providers. In an ongoing process to monitor the progress and deficits in research, critical issues of industrialisation along the hydrogen value chain will be identified and, if possible, resolved through cooperation among the members (vehicle manufacturers and automotive suppliers). Where this proves unsuccessful, suggestions for new research programmes will be put forward to the funding agencies. Sufficient, independent and critical policy advice ensures that the necessary updates take into account the current state of knowledge and technology and the socio-economic situation. The platform maintains contact with European research programmes and provides information on current developments on both sides. A key to the success of a hydrogen economy is ensuring the safety, durability, reliability and resilience of hydrogen technologies. Hydrogen technology made in Germany stands for safety at the highest level worldwide. Germany must set international standards here in order to increase confidence in safety and thus generate social acceptance. Operators must also be convinced of the economic efficiency through long service life and high reliability. The widespread use of hydrogen in new fields of application requires a high level of ongoing research and development with regard to these aspects, which must be explicitly taken into account when developing the funding programmes.

F.3 Identify and initiate international supply chains

In addition, international potential atlases to identify locations that are suitable for the production of largely climate-neutral hydrogen from an economic, ecological and social perspective must be developed and updated now. The knowledge gathered should serve as a basis for initiating international energy partnerships and as a launching pad for initiating large-scale demonstration projects involving international supply chains (NWS measure 24). These demonstration projects should be coordinated across ministries, be consistent with the findings of H2Kompass and identify optimal supply chains and key technologies. The analysis should not be limited to the transport of hydrogen and its derivatives. Consideration should also be given, for example, to the development of suitable markets and the requirements for raw and basic materials (such as iridium or water) for other hydrogen production technologies. In addition, the impact of a partial shift of value creation to the supplier countries should be systemically researched. This involves technical research, for example, on the quality and transportability of the resulting precursors (for example, polymers). Furthermore, non-technical aspects of national sovereignty and long-term geopolitical security play a major role and should be analysed farsighted. One example model would be the production of e-fuels for aviation and shipping as a storage medium for largely climate-neutral hydrogen. Since shipping consumes more than 200 million metric tons of conventional fuels worldwide every year, this offers an opportunity to establish the market for climate-neutral fuels due to the international aspect of the industry.

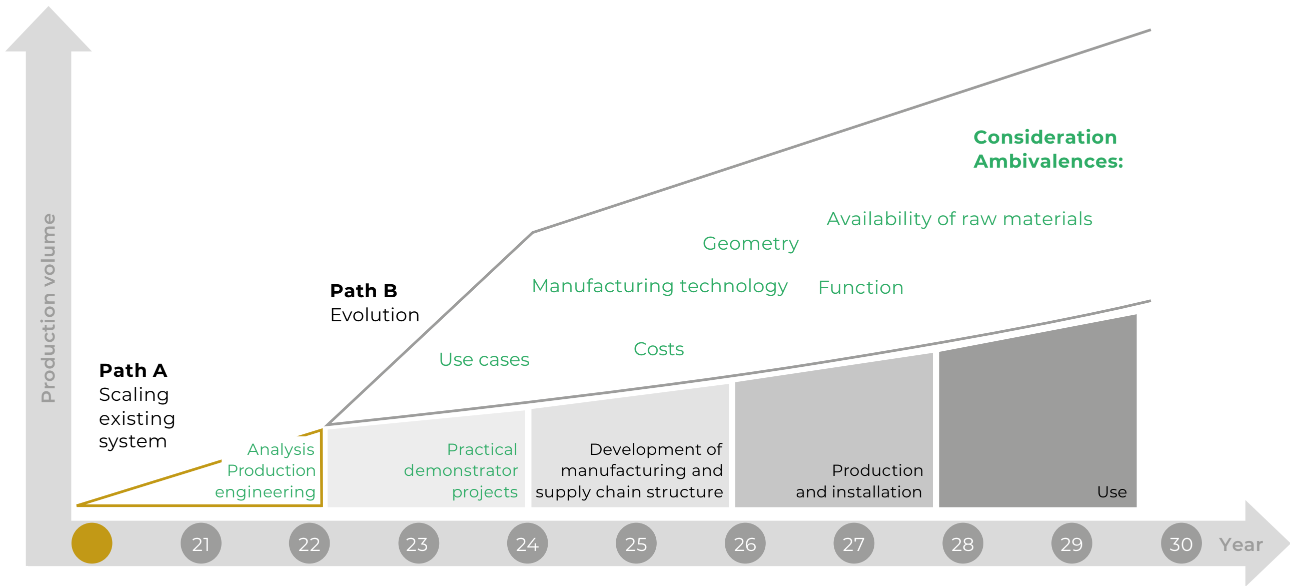
F.4 Develop roadmaps for substantial upscaling the production of hydrogen systems and their components

Key technologies in the hydrogen value chain exist today on scales that are insufficient for global deployment. There are clear concepts as to where and how these technologies can be developed. For this purpose, technology-specific roadmaps can be developed. They can be worked off by industry-led consortia. These must be accompanied by effective basic research. This could involve, for example, ongoing research into replacing hazardous or rare materials and gaining insights into the fundamental physics underlying the technologies. The NWR will help to identify these technologies. One example is electrolysis which is presented below with the results from work conducted by the NWR.

To make largely climate-neutral hydrogen competitive, significant cost savings are necessary in its production. The main potential for reducing costs lie in both OPEX and CAPEX of electrolysers. A systemic roadmap needs to be implemented in two coordinated and systematic action paths – path A and B (Figure 2). In step one (path A), the development of a scaling concept for the production on the basis of existing products will be planned. At the same time, path B, which examines evolution with an analytical optimisation of electrolyser design and the accompanying manufacturing technologies, will be extended. The framework for path B must be developed now to ensure the long-term viability of path A and, ultimately, the most cost-effective, sustainable production of the largely climate neutral hydrogen as an alternative to fossil fuels. Furthermore, synergies in fuel cell production can be exploited thanks to technology compatibility. The rapid implementation of the roadmaps through the targeted development of an efficient industry, including the corresponding supply chains, is also critically important.

Figure 2

Upscaling of electrolyser production – chart showing action paths A and B



F.5 Examine the EU Chemicals Regulation (REACH) with regards to key chemicals such as PFAS

To secure value chains for hydrogen, there is an urgent need to reexamine REACH in terms of the possible impact of restrictions or bans on the use of chemicals, in particular the possibility of a ban on PFAS. PFAS are found in many key components for hydrogen, such as proton exchange membranes and sealing systems. In a national dialogue between industry, science and policymakers, suitable solutions for hydrogen applications should be promptly examined and introduced within the framework of REACH in order to safeguard the future viability of the hydrogen economy in Germany and Europe. To this end, the NWR will develop recommendations for action aimed at ensuring the availability of strategic materials by the German government. In a longer term dialogue, other material classes critical to the energy transition (e.g., batteries and catalysts) should also be considered in the context of possible REACH regulations (not yet included in the NWS).

F.6 Develop standards and norms for Hydrogen systems

Standardization, norming, certification and approval procedures for hydrogen systems must be included as a further field of action for NWS measure 26. In this context, the scientific findings must be translated into the corresponding binding regulations in a timely manner through close cooperation with the responsible institutions. In particular, test centres for the examination of hydrogen system components must be established for certification purposes. Further prerequisites, such as the certification of hydrogen based on its CO_2 footprint or its purity by means of special hydrogen labels, should also be drawn up or existing ones expanded accordingly. This will result early in standards for components or systems that will guide development. In addition, the benchmarks that determine the safe and sustainable handling of all forms of largely climate-neutral hydrogen are derived from this on an international level. Germany's leading role in this important field of the hydrogen economy is underpinned by the technological competitiveness of domestic research and development.

F.7 Develop circular economy systems

Sustainable energy systems and the use of hydrogen require the establishment of circular systems for all critical materials. In addition to numerous mineral materials, the cycle of carbon as a material (polymers) and energy carrier (E-Fuels) is extremely important here. Linear economic processes (use and dump) must be replaced by circular processes. For this to happen, numerous operational and scalable technologies are lacking. Complex issues related to chemistry will need to be resolved in some cases to establish them. Examples could include the extraction of pure CO_2 from gas streams (air), the use of polymer waste products and the production of synthetic fuels without unavoidable by-products (kerosene without diesel). It should be noted that the quality of the recycled materials should not reduce the function of the resulting products. Despite numerous approaches, scalable processes, which are also to be designed in an energy-saving way, are largely lacking here. This requires focused research programmes that are guided by sound fundamental knowledge of the reactions and are validated by means of documented life cycle analyses. The results must then be met by an industry that is ready to implement them. Any cost disadvantages that arise must be suitably offset, at least at times.

IMPLEMENTATION IN THE COMING LEGISLATIVE PERIOD (2021–2025)

F.8 Create framework conducive to innovation

In order to create investment incentives and accelerate the market launch of hydrogen technologies, an environment that is conducive to innovation is needed for small and large companies (NWS measure 26). This includes not only funding that is open to all technologies, but also the reduction of bureaucratic redtape when it comes to access to funding and establishing a suitable legal framework.

An expansion of tax-funded research is intended to encourage broader participation of the overall business sector in R&D activities and to encourage SMEs to invest more heavily in the hydrogen sector. Simplifying and expediting tendering and approval procedures should enable faster and less bureaucratic access to funding. In addition, it should be ensured that funding programmes (where possible under state aid law) can be combined at a regional, national and international level without this resulting in conflicts.

Furthermore, low-cost, accessible test infrastructures for SMEs and an expansion of open-technology start-up funding should promote the development of and research into innovative hydrogen technologies in a simple and unbureaucratic manner (NWS measure 10).

To create a willingness to invest in innovative key technologies (hedging the first-mover risk), the legal framework for increasing CAPEX funding quotas should be expanded and initial, temporary OPEX funding for pilot operations/demonstration projects should be made possible. The assurance of funding quotas should be binding in order to additionally increase planning security.

The implementation of larger-scale demonstration projects and the transfer of the results obtained in these projects into commercial practice are facilitated to a large extent by the involvement of operating companies for demonstration projects (investors, users, customers). In addition, demonstrating the financial viability of the solutions found will facilitate rapid adoption of the solution on the market. To meet this and the other requirements set out under F.4, a suitable liberalisation of legal frameworks is needed, for example in the area of state aid law. This cannot be achieved with sufficient legal certainty and reliability by means of individual exceptions and experimental clauses. Reform of the relevant frameworks must be done quickly and decisively.

F.9 New fields of technology

The efficient use of renewable energy necessitated by the cost structures alone will not only lead to a shift from known technologies to green energy, but will generate entirely new alternatives, especially for energy-intensive and waste-generating products. Research into such options (such as hydrogen in the steel industry, biotechnology in fine chemicals, new food technologies to replace energy-intensive agriculture in times of climate change) and their rapid transformation into marketable technologies are both challenges and opportunities for the German research ecosystem. Germany can and should position itself successfully on this highly competitive international market in these emergent fields. Since these are new fields of technology, they are not developed through established procedures, but must be identified and supported with concepts. The impetus for identifying such research topics could come from the Federal Government's foresight processes, from start-up companies and from the portfolio development of established companies. These should be selected in a process that determines the first steps in a coordinated effort on national and European level. This requires platforms and dialogue formats, followed by rapid and subsequent funding initiatives provided with the critical resources needed. After an initial development phase, these technologies should move into the development process described in F.1.

F.10 Interlinked research

The measures already planned and initiated in the 'Hydrogen Technologies 2030' research offensive (NWS measure 25) should be continued at a brisk pace and implemented in an interdepartmental manner. Networking and the open exchange of experience between industry and science in the Federal Government's Hydrogen Research Network also play an important role here. In addition to scenario analyses harmonised on a cross-sectoral level, regulatory sandboxes and other large-scale research projects should also be coordinated and serve to test and implement key technologies geared to market requirements and to collect empirical data in accordance with H2Kompass and the needs of industry.

In addition, research projects and plants for the demonstration or use of largely climate-neutral hydrogen should be exempted from the state-imposed cost shares for electricity from renewable energies. Furthermore, OPEX costs should be properly taken into account in R&D projects. Corresponding measures can only be developed on an interdepartmental basis and in accordance with EU regulations in such a way that they guarantee planning security for the business models necessary for the development projects.

Finally, technological openness in the R&D sector must be made possible and a stable, continuous interlinking of basic and applied research through to the industrialisation of hydrogen systems and their use must be ensured.

F.11 Secure supply of specialists

In order to cover future demand for specialists in the hydrogen economy, there is a great need for action now due to the latency of education and training activities, i.e., the time required to develop training and teaching programmes as well as the training period (NWS measure 29). There is a need for an immediate and comprehensive definition of future demand for specialists by the Federal Government, which should also include the need for specialists in current training programmes. The skills profiles required of future specialists play an important role here. The findings should be used directly to expand training and further education activities in the skilled trades and in academia as well as to create new training and study programmes. In the academic field, incentives and continuous access to adequate funding for corresponding chairs and university institutions are suitable for this purpose.

A major challenge will be to secure a sufficient number of well-educated, highly trained and motivated specialists, especially for the production of hydrogen system components. For this reason, special programmes are needed for certification, training and continuing education for industry, focusing in particular on teaching appropriate skills. Thus, practical training courses should be developed on the basis of standards for training. In view of the expected dynamic development of technologies, excellent digital skills must be developed in training and the use of effective learning platforms for education and training must be supported.

In addition, international cooperation as part of energy partnerships in education and research should serve to qualify the necessary specialists locally. Consideration should be given to providing financial incentives for training in professions that are relevant to the transformation of the energy system. In any case, a targeted and ongoing promotional and communication campaign at schools and for companies should be developed and promoted.

F.12 Generate acceptance

Acceptance within society as a whole is a cornerstone of the rapid and sustainable ramp-up of the hydrogen economy. An indispensable prerequisite for the acceptance of hydrogen technologies by the general public is their safe and reliable operation with a minimum number of incidents. The development of appropriate technological solutions, standards and regulations must therefore be sped up.

Despite general acceptance, however, a NIMBY mentality can emerge in specific projects, which can delay the implementation of energy projects and make them more expensive. Trust in the players involved and prior knowledge can influence acceptance. However, knowledge and expectations about hydrogen technologies are currently heterogeneously distributed and predominantly low. Therefore, there is a need for comprehensible and transparent communication as well as cross-technology knowledge transfer by a public agency that will need to be established, which on the one hand demonstrates the potential of hydrogen and places this in the overall context of the cross-technology energy transition. At the same time, however, the challenges and negative effects, for example changes to the landscape or negative income effects due to price increases, must be addressed and possible conflicts over distribution and ways to avoid them must be discussed.

Establishing local value chains will help hydrogen technologies to become a tangible experience and to reduce possible reservations. It has also been shown that energy projects in which the public has a financial stake, especially in "citizen energy parks", have a major positive impact on acceptance. Therefore, a funded decentralised ramp-up of the hydrogen economy can help promote acceptance across society. Socio-economic research in regulatory sandboxes in different regions of the country can lay the foundations for targeted communication, provide well-founded information to policymakers and give impetus to the R&D process for non-technically motivated upgrades prior to the ramp-up of a technology (not yet included in NWS).

Table 2

Priority measures in the R&D area

No.	Reference text	Content
1	F1	Communication research
2	F4	Roadmaps
3	F6	Standards, norms
4	F8	General conditions
5	F10	Organisation of research

This selection does not reduce the relevance of the remaining items, but primarily serves to indicate prioritisation in terms of time.

3.2 Positioning of Germany in the international context

More than 20 countries worldwide either already have a national hydrogen strategy or are planning to publish a strategy paper in the coming months.

It can thus be stated that the strong focus on future hydrogen production and use is not just a German or European phenomenon, but an international one. Although Germany can and will make a decisive contribution to the global provision of industrialised electrolysis technology and equipment, it will not be able to produce the required quantities of hydrogen itself for the most part, but will have to import them from other European and non-European countries. The implementation of the NWS must therefore be based on three pillars that are interlinked: (1) the national pillar, (2) the European pillar and (3) the international pillar.

In addition to the contribution to global climate protection and the potential of renewable energies, important criteria for the implementation of projects include transport costs, existing infrastructures, governance and compliance with sustainability standards. Governance includes legal or regulatory convergence, as this the case in the European Economic Area and the Energy Community, as well as good governance and institutional capacities. According to these criteria, the United Kingdom and Norway in particular, but also the North Sea, Baltic Sea and Mediterranean regions, are suitable for rapid implementation. In addition, the countries in the EU neighbouring regions (North Africa, Ukraine, the eastern Mediterranean area) offer low to medium transport costs. However, in order to leverage the potential for cooperation with these countries, the institutional framework (Energy Community, Eastern/Southern Partnership Platform and Western Balkans) must also be further developed, and it must be ensured, that projects deliver benefits to the local population and comply with international standards. Furthermore, countries with fewer barriers to trade (e.g., Australia, Chile, Canada, the US) but with high transport costs are also potential project partners. The group of countries with high transport costs and governance challenges spreads widely. Today's fossil fuel producers with good infrastructure links, such as Russia, deserve special attention. There are external and climate policy reasons for this.

Due to the many sources of supply for largely climate-neutral hydrogen, there are various options for establishing new international partnerships and transforming existing ones. The import of hydrogen offers opportunities for new partnerships with countries that have major potential for renewable energies and thus for the production of hydrogen. There is an opportunity to help shape the international energy landscape politically and to incorporate climate, industrial policy and strategic interests, for example, in the enforcement of standards or the development of an international marketplace. At the same time, Germany competes with other hydrogen importing countries for limited resources (electricity, hydrogen, hydrogen derivatives).

Furthermore, it makes sense to interlink European and international hydrogen activities more closely across ministries and to strive to achieve consistency in terms of the instruments used.

3.2.1 Generation

IMPLEMENTATION IN THE NEAR TERM (2021/2022):

INT.1 INT.1 Expand intra-European cooperation on hydrogen (Germany/EU)

In recent months, Germany has entered into bilateral hydrogen partnerships with Australia, Saudi Arabia, South Africa, Chile and Morocco at government level. It has become clear that the existing international energy partnerships can be leveraged to great practical effect for this purpose. In the EU, institutional responsibilities in the various areas need to be clarified quickly. These include regulation, infrastructure planning, regional coordination, external relations and so forth (not yet included in NWS).

IMPLEMENTATION IN THE NEXT LEGISLATIVE PERIOD (2021–2025)

INT.2 Harmonisierung von Standards und Aktivitäten auf EU-Ebene (EU)

There are still significant differences within the national hydrogen strategies of the EU Member States, for example in the areas of classification, infrastructure development, permissible blending values and utilisation pathways. The German government should quickly address these differences at EU level and bring about harmonisation.

In the next legislative period, Germany should work towards within the EU that the hydrogen activities of the EU Member States, which are currently running in parallel, are more effectively coordinated. The EU Member States should not compete internationally with their projects, but create synergies for an EU hydrogen market. To this end, it is necessary to coordinate the instruments. In this context, it must be clarified whether and how the "European Hydrogen Society" described in the NWS (NWS measure 33) fits into the emerging landscape of instruments.

INT.3 Extend instruments for priority infrastructures to neighbouring regions (EU)

Close coordination should take place with the countries bordering the North Sea, the Baltic Sea and the Mediterranean Sea in the context of offshore wind planning. Interconnectivity is an important medium- and long-term goal in the context of hydrogen. For example, the European hydrogen IPCEI could be extended to neighbouring regions in order to carry out a market ramp-up and realise corresponding import potentials in a timely manner (complementary to NWS measure 34).

INT.4 Integrate hydrogen into EU neighbourhood policy (EU)

Hydrogen must be established as part of the European Neighbourhood Policy. This applies in particular to the Ukraine and the Western Balkans, but also with regard to shape the Southern Neighbourhood Policy. Here, it makes sense to use existing platforms such as MEDREG and Med-TSO. From a foreign policy perspective, the Eastern Mediterranean also deserves attention. In the Eastern Mediterranean, interconnectivity should be more integrated into planning. EastMed, once conceived as a PCI, is no longer compliant with the goal of a climate-neutral Europe. Electricity and hydrogen should therefore be at the heart of connecting this region to Europe.

INT.5 Expand international coordination efforts (Germany/EU/G7/G20)

Particular attention should be paid to current fossil fuel exporters whose national budgets are highly dependent on fossil fuel sales (for example, Russia, Algeria and Egypt) (NWS measure 38 expanded). The transformation of energy trading should be proactively addressed with these countries. Analysis and modelling or development of common target scenarios could be pursued within the framework of the IEA and (regional) UN organisations. Other countries that deserve special attention are the Gulf Arab States, which have significant internal resources, technological know-how or a geographic and strategic position between the EU and Asia.

The USA, Canada, Australia, and countries in Latin America are examples of potential partners in establishing a functioning global market. Japan and South Korea, for example, are considered to be major potential demand centres. The topic of hydrogen should be placed within the framework of the EU-Africa partnership (complementary to NWS measures 34 to 38). IRENA could also be used and strengthened here as a knowledge and best practice hub.

Market development must be done in stages: physically, on the trade side and via certificates of origin/certificates (cf. section 2.2). This should initially be done bilaterally in the EU and internationally (physically and via certificates), and at the same time regionally within the EU and at a global level. Germany should use its G7 presidency in 2022 to address this issue. Efforts should be made to establish a working group with Indonesia, which simultaneously holds the G20 presidency. The issue of parallel institutions for international standards and certification should also be addressed to avoid the risk of competing organisations and hence fragmented markets. The G7/G20 framework can also be used to coordinate criteria for international investment promotion via the World Bank or regional development banks. Trade issues related to hydrogen should be initiated early within the WTO framework. The new WTO dialogue mechanism on trade and sustainability should be strengthened for this purpose (complementary to NWS measures 30 and 36).

Climate, energy, economic and development policy approaches should go hand in hand in the partner countries. However, conflicting goals must always be addressed within the specific country and project context. Involvement of the local population as well as participation in local value creation in the potential supplier countries are essential to creating acceptance for hydrogen production as well as energy and hydrogen exports. In addition, the achievement of ambitious climate protection targets in the project countries must also be accelerated locally through hydrogen projects.

3.2.2 Classification and certification mechanisms

IMPLEMENTATION IN THE COMING LEGISLATIVE PERIOD (2021–2025):

INT.6 Establish international standardisation and classification (Germany/EU/International)

International certification and classification should be actively pursued in parallel with the corresponding processes in Germany and the EU (cf. section 2.2).

3.2.3 Infrastructure

IMPLEMENTATION IN THE COMING LEGISLATIVE PERIOD (2021–2025):

INT.7 Planung europäischer Importinfrastruktur (EU/International)

To ensure that the EU and Germany are internationally connected and that as many options as possible are available for diversifying the sources of hydrogen supply, the necessary infrastructure must be created as quickly as possible, including, for example, landfall points at ports, regasification terminals and pipelines. Planning for this infrastructure should be done at the European level and in line with Hydrogen Europe's 2 x 40 GW strategy. Regulation of this infrastructure should be harmonised across Europe, following the existing gas market regulation (cf. sections 3.1.2 and 3.1.5). Existing network codes should be adapted for the cross-border transport of hydrogen. It is essential that quality standards and permissible blending ratios are harmonised at the European level. Market fragmentation must be avoided. Germany should advocate pure hydrogen networks in European hydrogen transport. In addition, safety and environmental standards should be coordinated at the international level (not yet sufficiently addressed in NWS).

Overall, in the course of increased sector coupling, but also to ensure security of supply and resilience, grid and demand planning at European and national level for electricity, gas, hydrogen and, in the future, CO_2 must be closely interlinked (not yet sufficiently addressed in NWS).

INT.8 Further development international energy security mechanisms

At present, the strategic oil reserves managed via the IEA and other regional security mechanisms for gas supply - in the case of Germany, in particular, via the EU - form the basis for security of supply in the area of fuels and indirectly other energy sources as well. As hydrogen grows in importance and in the course of a shift in the trade flows of energy products, the question arises as to how this mechanism can be properly further developed. This also applies to further provisions, including in the area of cooperation between the military and security forces. The German government should proactively engage in the relevant forums here in order to quickly identify relevant issues and find solutions (not yet included in the NWS).

INT.9 Transport costs

As a general rule, hydrogen transport via pipeline is by far the least expensive transport route. In order to be able to import hydrogen from countries for which pipeline delivery is not possible due to the distances involved, it must either be converted into a different aggregate state or into other energy carriers such as ammonia or methanol. This results in considerable costs, as this also the case with the conversion back into hydrogen. However, direct marketing of the transported materials can open up economically interesting options from a marketing perspective. Furthermore, however, developments in conversion costs and on the ship transport side are dynamic. Therefore, it is important not to exclude any potential exporting country a priori due to distance, but instead to examine the potential of all possible hydrogen partnerships, taking into account that imports from remote regions should primarily go to nearby consumption centres for reasons of efficiency.

4 Breakpoints in the implementation

For the ramp-up of the hydrogen economy to succeed, key basic energy policy requirements must be established. Without this, the market ramp-up and the desired effects on climate and industrial policy goals will not be possible. The measures outlined in the areas of generation, industrial application, mobility, infrastructure and heating will also not be able to achieve the desired impact without these breakpoints.

In the NWR's opinion, the following points are absolute prerequisites without which ambitious goals presented by the German government cannot be achieved. In the negative scenario, this not only affects the national ramp-up of the hydrogen economy, but also puts Germany's international role in the field of key hydrogen technologies at risk.

More ambitious expansion of renewable energies in Germany and Europe

The outlined ramp-up of the hydrogen economy in Germany can only take place if sufficient renewable energies are available at an economical cost. This is also a prerequisite for exploiting the great climate potential of the hydrogen economy. The expansion corridors for renewable energies in the Renewable Energy Sources Act (EEG) must be revised significantly upward at the beginning of the coming legislative period.

The envisaged 5 GW electrolysis capacity in 2030 alone corresponds to an electricity demand of 20 TWh at 4,000 full load hours. Against the backdrop of the future integrated value chain for hydrogen and in view of the simultaneous expansion of electromobility, the increased use of heat pumps and the growing pace of digitalisation taking place in all industrial sectors, the German government's electricity consumption forecast must be urgently updated.

2035

Industrialisation and development of an efficient electrolyser industry, including a supplier ecosystem, as along with systematic research, development and industrialisation of production technologies for hydrogen system components

The industrial policy response to the Paris Agreement can only succeed if high-rate manufacturing technologies are available for industrial production of hydrogen systems (for example, electrolysers and fuel cells) or their components. At the same time, an industry must be established that can make this technology available practically and in a sufficient scale, quantity and at an affordable price. In addition to the system manufacturers themselves, an efficient supplying industry is also indispensable. Without the establishment of this value chain, the systems required for the large-scale production of green hydrogen in particular will not be available. With its market and technology leaders as well as its exceptional R&D expertise in the hydrogen sector, especially in large-scale electrolysis technology, Germany has a special obligation here, internationally as well as domestically. Furthermore, this is also a prerequisite for exploiting the great economic potential of the hydrogen economy for companies in the German manufacturing industry and in mechanical and plant engineering. Therefore, the research, development and industrialisation of new manufacturing technologies, which are necessary for the mass production of hydrogen systems or their components, must be urgently accelerated. The development of the hydrogen economy and, in particular, the electrolysis industry must be promoted. With their ramp-up, it is possible to use economies of scale and achieve economical production near or at cost parity with fossil fuel alternatives.

Production technology research, development and industrial implementation of hydrogen system manufacturing can create the conditions that will allow Germany to secure significant shares of the rapidly developing global hydrogen market in the future, while at the same time fulfilling the responsibility that arises from its current technological leadership. In this way, this sector can be developed into a central field of expertise for German companies, which guarantees national technological sovereignty constantly while also further increasing the country's export capabilities, especially in the manufacturing industry and in mechanical and plant engineering. In addition, Germany would have a unique opportunity not only to consider the topic of hydrogen in terms of climate policy, but also to establish it in terms of sustainable value creation.

Reform of the tax, duty and levy system

Electricity costs remain the biggest price driver in green hydrogen production. With the current structure of German electricity price components, the ramp-up of the hydrogen economy is blocked or at least made much more difficult. The cost delta between fossil fuels and renewable energy sources such as green hydrogen is largely based on regulatory-driven price components. A reduction in the effective price of electricity is a prerequisite for a market-driven ramp-up of the hydrogen economy. A reform of the tax, duty and levy system must take place in the coming legislative period.

For the mobility sector, it is necessary to introduce a CO_2 pricing system by the mid-2020s – for example, via the truck toll scheme or emissions trading systems – which will lead to an overall cost advantage for electric vehicles for customers.

Development of a nationwide infrastructure must begin in parallel with lighthouse projects

A hydrogen market can only develop if an existing hydrogen infrastructure is in place. Transport, storage and distribution facilities are prerequisites for bringing supply and demand together and for market forces to take effect. The development of infrastructure must begin immediately in the first phase of the market ramp-up so that the subsequent broad market ramp-up phase can take place with numerous players.

In addition to pipeline-based infrastructure, the development of import terminals and ship-based transportation such as tankers must be ensured at the same time.

Making infrastructure financing favourable to market ramp-up

No unreasonable cost barriers for hydrogen users must be imposed in the financing of the hydrogen infrastructure. A funding instrument must be found immediately that does not place the burden of infrastructure costs solely on early hydrogen users. This would jeopardise the transformation to climate-neutral processes and also the ramp-up of the hydrogen economy in general.

European harmonised technical rules and regulatory frameworks

The German government must work towards that a uniform European technical framework and regulatory conditions are put in place as quickly as possible. A single European market for hydrogen is needed so that economies of scale can be achieved quickly and Germany and Europe can assume technological leadership in hydrogen. This includes technical standards, specifications on purity levels for hydrogen as well as green electricity and green gas criteria. It must be ensured, for example, that green hydrogen retains its green properties when crossing the border from the Netherlands to Germany. Germany should advocate for dedicated hydrogen pipelines at the transport level and, in addition, uniform upper limits for the admixture of hydrogen should apply to the European natural gas network so that inter-European gas and hydrogen trade is not jeopardised.

Getting investments in climate-friendly application technologies off the ground

In order to achieve the ambitious targets for CO_2 reduction and the ramp-up of direct reduction technology in the steel industry, a political framework is needed in view of the long lead times with regard to the planning, approval, construction and commissioning of plants by the beginning of 2022, which will allow appropriately sized investment decisions to be made in good time. In addition, the economic conditions for these investments must be created. In particular, the existing support framework for investment subsidies and additional operating costs (contracts for difference) must be significantly expanded and secured for the long term. Work must also begin on establishing a regulatory framework for lead markets for green steel.

In the interest of rapid introduction of hydrogen in industry, the construction of near-consumer electrolysis plants should be pursued strongly in regulatory and political terms in the first half of the 2020s.

Social security in transition

The implementation of the NWS will mean profound changes for employees in the affected industries. This change requires social protection. Co-determination is a key to social compatibility. Existing, high-quality, collectively agreed and co-determined jobs should be secured or new, high-quality, collectively agreed, co-determined and future-proof jobs created. Jobs at all skill levels are needed in the long term. This will ensure a positive employment balance.

5 Timeline for the action plan

The action plan laid out in the NWS stipulates that in a first phase, the market ramp-up of the hydrogen economy and the foundations for a functioning domestic market will be initiated by 2023. By 2030, the second phase will consolidate the domestic market and shape the European and international dimensions of hydrogen. Hydrogen demand in 2030 from the perspective of the NWR is presented in section 2.

The upcoming legislative period is crucial for the implementation of the NWS goals. During this period, the framework conditions must be created to initiate the market ramp-up of the hydrogen economy and to establish the market with the expected volume frameworks. To this end, a number of concrete recommendations for action along the entire value chain have been listed in the preceding sections.

The measures formulated are to be considered of equal importance to the fulfilment of the NWS. However, the recommendations for action differ in terms of the urgency of their implementation. Therefore, the formulated recommendations for action are divided into two categories: The first category includes measures that, in the view of the NWR, should be implemented in the short term by the new federal government by the end of 2022. The measures in the second and third category should be implemented by the end of the coming legislative period or thereafter.

The first category includes measures that are necessary for the short-term (further) development of hydrogen technology and the initiation of the market ramp-up of the hydrogen economy. The second and third category include measures aimed at anchoring hydrogen use in the sectors in the medium and longer term and consolidating the hydrogen economy in Germany.

In addition to the concrete recommendations for action for the ramp-up of the hydrogen economy, section 4 also describes the central basic energy policy conditions without which the ramp-up of the hydrogen economy with its desired climate and industrial policy effects will not be possible. These breakpoints form the basic prerequisites for the recommendations for action described to have the desired effects. Compliance with and implementation of the breakpoints should also be part of government action in the coming legislative period.

The goals formulated in the NWS can only be achieved within the framework of a European and international networking of goals and measures. Therefore, the German government should work at the international level to create the necessary framework conditions for the economic and ecological success of the hydrogen economy.

2050

Figure 3

Presentation of measures by priority and sector

SECTOR	IMPLEMENTATION by the end of 2022	up to the end of 2025	post 2025
Generation	E.1, E.2, E.3, E.4, E.5, E.6, E.7, E.8, E.9, E.10	E.11, E.12, E.13, E.14, E.15, E.16, E.17, E.18, E.19, E.20, E.21, E.22, E.23, E.24, E.25, E.26, E.27	
Industry	A.1, A.2, A.3, A.4, A.5, A.6, A.7, A.8, A.9, A.10		
Mobility	M.1, M.2, M.3, M.4, M.5, M.6	M.7, M.8, M.9	M.10, M.11, M.12, M.13, M.14
Heating	W.1, W.2	W.3, W.4, W.5	
Infrastructure	I.1, I.2	I.3, I.4, I.5	I.6
Research and development, innovation and education	F.1, F.2, F.3, F.4, F.5, F.6	F.7, F.8, F.9, F.10, F.11, F.12	
International	INT.1	INT.2, INT.3, INT.4, INT.5, INT.6, INT.7, INT.8, INT.9	

Glossary

Largely climate-neutral hydrogen

Climate-neutral hydrogen is defined as hydrogen whose production does not release any greenhouse gases into the atmosphere. This can be assumed to be the case if production is based on additionally provided emission-free energy sources or if the carbon produced during hydrogen production cannot be permanently released into the atmosphere. In view of the manifold uncertainties for the proof of additionality of the climate-neutral energy carriers used and the residual emissions, if any, during hydrogen production and also in the different process chains, the NWR uses a pragmatic definition in the context of this paper. On the one hand, hydrogen produced with electricity is referred to as largely climate-neutral if the electricity can be classified as climate-neutral according to the applicable legal rules. On the other hand, hydrogen that is produced on the basis of fossil fuels but whose production releases a maximum of ten per cent of the carbon contained in the fossil fuels into the earth's atmosphere as greenhouse gas is also described as largely climate-neutral.

Limited application of e-fuels

By “some areas of application” for e-fuels in land-based mobility, the following applications are meant: In construction and agriculture, a relevant proportion of vehicles cannot be electrified due to the technical requirements; in the long term, this sector will also rely on internal combustion engine drive concepts with liquid fuels or hydrogen. In addition, in the long term, there is a requirement to use e-fuels for special vehicles and municipal services, such as fire engines, special transports and emergency vehicles for the police, military, and THW. There are differing estimates in the NWR about the magnitude and timing of when e-fuels in the existing fleet of cars and trucks will contribute to climate protection. The action plan is based on a demand for e-fuels of up to 9 TWh for the year 2030 together with air and maritime transport. This demand for land-based mobility increases to a range of just under 8 TWh to 30 TWh for 2035 and 11 TWh to 72 TWh in 2040.

Appendix: Dissenting opinion

Dissenting opinion issued by Klima-Allianz Deutschland and Bund für Umwelt und Naturschutz Deutschland (BUND) with regard to section 2.2

The NWR was established by the German government as part of the NWS. Its members from business, academia and civil society support the federal government in implementing and further developing the NWS through proposals and recommendations for action. With regard to recommendations for action for the coming legislative period, the NWR adopted an action plan on 20 May 2021, containing a comprehensive package of concrete recommendations. Klima Allianz Deutschland and the Bund für Umwelt und Naturschutz Deutschland (BUND) issued the following dissenting opinion on the resolutions adopted:

The NWS states that it is the explicit goal of the federal government 'to use green hydrogen, to support a rapid market ramp-up for it and to establish corresponding value chains'. It also states that 'only hydrogen produced on the basis of renewable energies ("green" hydrogen) is sustainable in the long term'. This directional decision for green hydrogen, which has already been made, must now be backed up financially and in terms of planning. Only green hydrogen - produced on the basis of renewable energies - is compatible with the goal of a climate-neutral energy system in the long term. Against this backdrop, we criticise the resolution of the NWR which recommends 'subsidising the generation and use' of fossil hydrogen to the future federal government as a decisive option for action. Blue and turquoise hydrogen must not be established as equivalent source of hydrogen. A consistent and comprehensible definition of climate-neutral hydrogen should not include it. Only hydrogen that can actually be produced without residual emissions and climate impact should be considered climate neutral..

At the same time, we are aware that with regard to the investment decisions of industry, a sufficient supply of green hydrogen must be ensured by accelerating the expansion of additional renewable energies. The main political focus should therefore be on quickly developing the required additional renewable energy capacities, primarily within Germany and Europe. Political planning should also take into account scientific scenarios that assume a majority of domestic hydrogen production and reduce international imports accordingly. The scarcity of green hydrogen must be resolved concomitantly by strictly prioritising the areas of application, with the aim of enabling in particular those investments in climate-neutral industrial processes that are crucial for avoiding bad investments. Overall, deployment must be clearly prioritised where direct electrification is not possible. The existing economic viability gap for green hydrogen must be bridged by an increasing CO_2 price for fossil hydrogen and a differential cost subsidy for a transitional period. The financial subsidies used must be concentrated on these areas; their misallocation to non-sustainable forms of hydrogen production should be avoided.

In order to achieve the ambitious 1.5°C target of the Paris Agreement, all sectors must be made climate neutral as quickly as possible. The introduction of new, so-called bridge technologies, which are operated without any fixed time limits, hinders and slows down this transformational process. It is particularly highly debatable with regard to hydrogen production because the climate-neutral alternative, hydrogen from renewable sources, already has the necessary technological maturity today.

For the mobility sector, we believe it is important to highlight that the use of hydrogen must be limited by strict efficiency requirements. In the passenger car sector, e-mobility is a more efficient drive alternative to fuel cells, which has established itself as a leading technology and whose market launch has gained considerable momentum. The concurrent development of an infrastructure for refuelling hydrogen cars should therefore be halted altogether.

List of figures

List of tables