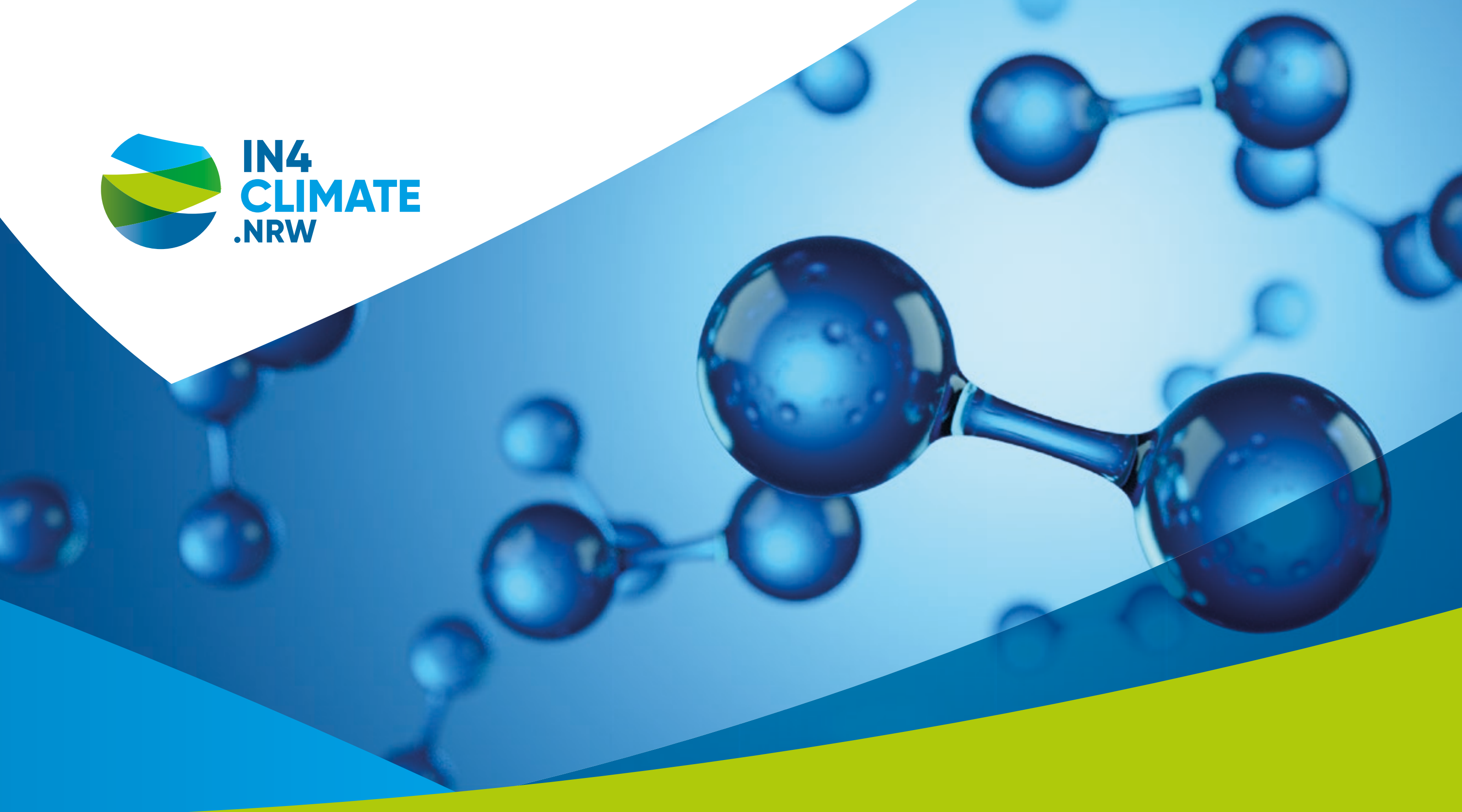

# HYDROGEN AS THE KEY TO A SUCCESSFUL ENERGY TRANSITION: SETTING THE COURSE NOW

**A contribution by the IN4climate.NRW working group on hydrogen to the development of the national hydrogen strategy**


Developed within the IN4climate.NRW initiative – with contributions from:

An initiative of the state government of NRW

Ministry of Economic Affairs, Innovation, Digitalization and Energy of the State of North Rhine-Westphalia

**Bibliographic references**

| | |
|---|---|
| Publisher: | IN4climate.NRW GmbH |
| Published on: | October 2019 |
| Coordination: | Dr. Anna Leipprand (Coordination IN4climate/SCI4climate, Wuppertal Institute) and Dr. Stefan Herrig (Project Manager, IN4climate.NRW) |
| Contact: | anna.leipprand@wupperinst.org, stefan.herrig@in4climate.nrw |

Please refer to as: IN4climate.NRW 2019: Hydrogen as the key to a successful energy transition: setting the course now. A contribution by the IN4climate.NRW working group on hydrogen to the development of the national hydrogen strategy. Gelsenkirchen.

# OUR KEY MESSAGES

- National and global energy and climate protection scenarios show that **carbon neutral hydrogen will be key for the energy transition** and for climate protection **in the future**. Achieving a largely carbon neutral economy is not possible without the direct and indirect use of hydrogen.

- In view of its central location in Europe and the unique potential it offers in terms of industry and research, **NRW can become a model region for developing a hydrogen economy.**

- As a blueprint for other industrial regions, NRW can offer inspiration in Europe and beyond for an energy supply based on carbon neutral hydrogen and can place itself in an ideal position on the growing climate protection markets.

- The production, transport and use of climate friendly hydrogen, and the export of technologies in an international hydrogen market offer **great opportunities for economic growth in NRW and Germany.** For NRW, this represents a potential for added value running into billions and a high potential for future-proof jobs.

- **The future demand for hydrogen in Germany could reach a magnitude of more than 600 terawatt-hours a year, according to current scenarios.** Even conservative estimates point to a substantial demand in the future. NRW will represent a key area of consumption.

- The development of a hydrogen economy requires an **entry strategy.** Key elements of this are the gradual development of transport, storage and production infrastructure, coordinated action of stakeholders, and collaboration with international partners.

- The partner companies of IN4climate.NRW, who are working together in the initiative to create a climate neutral industrial sector, want to contribute to this development. **Numerous projects focused on the use, production and transport of hydrogen are already being implemented or in the planning stage,** supporting the state's aspiration to play a leading role.

- Policy-making at the national level is required to support the implementation of these projects by creating the necessary **regulatory conditions and economic incentives.** The following measures are deemed necessary and urgent by several or all of the companies involved in the working group on hydrogen:

  - creating favourable framework conditions for the provision of **sufficient additional capacity for the generation of electricity from renewable energy sources,**

  - the development of **tradable certificates of origin,** which provide information on the contribution of green and blue hydrogen to the reduction of greenhouse gas emissions,

  - adjustment of the system of **taxes and charges in the electricity sector** to meet the requirements of sector coupling,

  - the creation of **positive incentives for producing and using carbon neutral hydrogen through implementation of new policy instruments,**

  - **rapid implementation of the Renewable Energy Directive,** which guarantees the eligibility of carbon neutral hydrogen for greenhouse gas reduction quotas in transport,

  - consistent **consideration of hydrogen in the relevant legal framework,**

  - **extension of the Gas Network Development Plan** (i.e. forecast for hydrogen) and combined planning for the electricity and gas infrastructure.

# 1. OUR SHARED VISION: HYDROGEN AS THE KEY TO A CLIMATE NEUTRAL FUTURE FOR INDUSTRY

## We are facing enormous challenges

Global warming due to anthropogenic greenhouse gas emissions is one of the major challenges of our time. A substantial transformation of industrial supply chains and production processes is needed to overcome this problem.

In past decades, a predominantly economically optimised development of value chains took place, where the dominant criterion was to improve energy and resource efficiency. The high energy density stored in fossil fuels was taken for granted. In the course of this development, attention was for a long time not focused on the ecological consequences for the entire system. With increasingly tangible changes in the climate and scarcity of resources, these consequences are now coming to the fore; increasing economic performance and the rise in world population increase the pressure to act.

A thriving, future-oriented economy requires a comprehensive approach to sustainability; the set of criteria for optimising economic activity must be expanded to include climate protection and the conservation of resources. The economy is currently more strongly subject to social scrutiny and justification pressure. It is necessary to examine existing value chains and industrial processes and to make a new assessment of political target assumptions.

## Hydrogen can make a key contribution to addressing these challenges

Globally the renewable energy potential especially from sun and wind is immense, and this energy is likely to become cheaper. It is the backbone of our future energy supply. Losses in efficiency from transforming one form of energy into another can be minimised where electricity can be used directly. However, energy transition in the power sector alone is not sufficient to achieve the carbon emission reductions envisaged for industry in the federal government's climate action plan and to realise the transition to a largely carbon neutral energy supply. In addition, the potential for storing electrical energy is limited in Germany and the transport and storage of electricity is sometimes associated with very high costs. Therefore, an expansion of the system of future energy trading is necessary. Hydrogen is the key to a successful energy transition, since it offers the following technical advantages:

- Hydrogen has a wide range of applications, it can be transported and stored in large quantities and used in a stationary or mobile context. It thus offers the possibility of stabilising the fluctuating supply of electricity from renewable energy sources and improving its integration into the power system.

- Carbon neutral hydrogen[1] is an essential element of climate neutral production in the raw materials industry. Hydrogen is not just an energy carrier but also a feedstock for the chemical industry and a potential reducing agent in the steel industry. It can also be used to chemically bind unavoidable greenhouse gas emissions from industrial processes such as those in the cement industry and return them to the value chain ($CO_2$ recycling).

1 Here, the term "carbon neutral hydrogen" denotes hydrogen produced without emitting $CO_2$ into the atmosphere that is green and blue hydrogen. For definitions see Table 1.

- As an energy carrier, carbon neutral hydrogen can substitute fossil natural gas in many applications. The existing infrastructure could therefore continue to be used in many cases. Hydrogen can contribute to the de-fossilisation of the transport and heating sectors and link the energy, transport, industrial and heating sectors in an intelligent way.

- From an economic policy perspective, any number of stages of industrial added value can be based on hydrogen. Compared to importing higher grade synthetic fuels and raw materials, hydrogen offers more options as a basic material in the industrial, energy and mobility sectors to preserve industrial value creation in Germany.

## The production, transport and use of hydrogen offer economic opportunities

The production, transport and use of climate friendly hydrogen offer great opportunities for economic development in NRW and in Germany. For NRW, a potential added value running into billions is expected (LBST 2019). Great opportunities also arise for North Rhine-Westphalian and German companies based on the export of technologies to an international hydrogen market. Germany is currently the largest exporter of electrolysis systems in the world. A growing global market for Power-to-X technologies (PtX) could create a potential added value of around 36 billion euros a year for Germany and give rise to up to 470,000 additional jobs in Germany (IW Köln and frontier economics 2018).[2]

## The development of a hydrogen economy requires considerable efforts and a collaborative approach

Despite all the obvious advantages of hydrogen, enormous efforts are required to develop a hydrogen economy. From today's perspective, it is clear that this transformation must be consistently implemented in order to meet the climate targets agreed at the COP21 conference. In the light of the technical, infrastructural, regulatory and financial challenges, a high level of commitment and a collaborative approach are needed from all the stakeholders involved.

The supply of sufficient quantities of hydrogen is of central importance and the question arises where these large quantities can be produced. A sustainable economy in line with the envisaged climate neutrality and resource conservation will use large quantities of energy. Planet Earth does have sufficient sources of non-fossil (renewable) energy, but these energy sources are distributed in a very hetero-geneous way. Germany (and Europe according to current understanding) is not anticipated to become energy self-sufficient in the future and will still have to import a percentage of its energy demand from other continents. At the same time, domestic energy production will continue to play an important role in the future.

Traditional energy-based trade relationships need to be taken into consideration when developing future demands for renewable energy to ensure that foreign-policy stability, which is a prerequisite for sustainable economic development, is not weakened. In the future, hydrogen can be supplied from countries that currently serve the international markets for fossil oil and gas, but other countries with sparsely populated areas and high solar and wind energy potential may participate in the new economic developments based on energy partnerships. Alongside these geopolitical aspects and the basic need for compatible energy supply systems, regional socio-economic development and safety issues in partner regions also need to be taken into consideration when creating partnerships.

2 These figures include derived demand effects and do not refer exclusively to hydrogen technologies but to PtX in general.

### The hydrogen economy requires a smart entry strategy

In view of the social challenges, it is essential to set the course towards a future energy supply that includes hydrogen in a timely manner. As an industrial country, Germany should create the nucleus for this transformation, thereby demonstrating the seriousness of its intention to develop international partnerships and paving the way for global implementation.

In the necessary communication with the relevant social and political stakeholders there is great potential for presenting the concept of hydrogen in a positive light. To achieve this, comprehensive public information and transparency will be essential. The initial points of contact with hydrogen in the areas of private transport (re-fuelling stations) and public transport already exist. Public acceptance is decisive both for the future large-scale development of the projects and for the political viability of the regulatory framework conditions for a sustainable hydrogen economy. A smart entry strategy is needed in order to take advantage of the huge opportunities associated with the hydrogen economy.

# 2. SETTING THE COURSE TOWARDS A HYDROGEN ECONOMY

## 2.1 Scenarios on the role of hydrogen in the future

### Large quantities of hydrogen will be needed for a climate neutral future

Carbon neutral hydrogen will play a significant role in the future, if the target of a 95 per cent reduction in greenhouse gas emissions compared to 1990 levels is to be achieved (BDI 2018, dena 2018, UBA 2019, LBST 2019). It is to be expected that, in a future (largely) carbon neutral energy and industrial system, hydrogen will mainly contribute to covering final energy requirements in the industrial and transport sectors and will be used as a material feedstock for the chemical industry. Yet unquantifiable amounts could also be used for reconversion to electricity and possibly also to provide heating in the building sector. Hydrogen will thus be used primarily in areas in which the direct use or the timely coupling of the supply and demand of electricity is more difficult, technically impossible or not cost-effective.

A climate neutral raw materials industry is inconceivable, from today's perspective, without the use of hydrogen. Primary steel production can be made largely $CO_2$ neutral, for example, by using hydrogen. In the chemical industry, too, hydrogen can make a significant contribution to climate protection. Using green hydrogen for ammonia production, for example, where large quantities of hydrogen are employed, allows a significant reduction of greenhouse gas emissions. In addition, hydrogen will be needed as a feedstock in the future to produce primary materials containing carbon without using ocarbons is extracted, for instance, from biomass, waste materials or by means of recycling (e.g. chemical recycling in the plastics sector). Hydrogen can also be used to produce process heat at high temperature levels for energy-intensive sectors. Carbon neutral hydrogen can be produced in several ways ("green", "blue") which are differentiated from the currently dominant form of production of "grey" hydrogen, see table 1.

| "Grey" hydrogen | "Blue" hydrogen | "Green" hydrogen |
|---|---|---|
| Produced using fossil fuels, releasing $CO_2$ into the atmosphere in the process | Produced using fossil fuels (by means of reforming or pyrolysis) with subsequent capture and storage of the $CO_2$ or carbon produced | Produced from renewable energy sources |

Table 1: Definition of hydrogen according to origin and greenhouse gas effect

Scenario calculations also assign an important role to hydrogen in the area of transport. In addition to battery electric cars, hydrogen fuel cells can be an option in future markets for passenger cars. In a largely carbon neutral world, hydrogen and hydrogen-based synthetic fuels are expected to play a key role in the goods transport sector, in public transport, in the shipping sector, in non-electrified rail and in air transport. In the building sector, fuel cell cogeneration plants – replacing old central or decentralised heating systems – could have a very large market potential under certain circumstances, particularly if they are used together with other hydrogen-powered electricity generators to stabilise the power grid. In the building sector, hydrogen is mainly advantageous in interlinked projects that integrate different technologies into the system. Battery and hydrogen storage facilities can provide a helpful addition for the storage of photovoltaic and wind power. The waste heat resulting from hydrogen production can be used in district heating systems on site and thus increase system efficiency.

The changing needs of industry are a decisive factor for the development of a hydrogen infrastructure. This is to a large extent because the industrial demand for hydrogen occurs in distinct hot spots. Current scenarios for Germany, which depict a 95 per cent reduction in greenhouse gas emissions by 2050 compared to 1990 levels, all feature a high demand for hydrogen in the future industrial sector. According to these forecasts, the demand for hydrogen in the steel industry alone (in the case of a complete switch of primary steel production to direct reduction using hydrogen and e-furnaces) could amount to around 70 to 80 terawatt-hours in 2050[3] (UBA 2019, LBST 2019). According to these scenarios, the annual demand for hydrogen in other industrial sectors amounts to up to 40 terawatt-hours (dena 2018, UBA 2019) – with the exception of the "-95% $H_2$" scenario in the LBST study, which even estimates the additional demand in the industrial sector at 150 terawatt-hours. The demand for hydrogen in 2050 in the energy transformation sector (for reconversion in gas turbines or fuel cells and – in the BDI study – for the production of synthetic methane) amounts to between twelve (dena 2018) and 36 terawatt-hours (BDI 2018) depending on the scenario. In the transport sector, current scenarios see the demand for hydrogen (without synthetic fuels) in a world with a 95 per cent reduction in greenhouse gas emissions as being between 25 (BDI 2018) and 120 terawatt-hours per year (dena 2018). Calculations by Wuppertal Institute show that the industrial demand for hydrogen could be even higher if extensive use is made of hydrogen as a feedstock for the chemical industry. In order to replace 50 or 100 per cent of the fossil-based raw materials currently used, between 112 and 225 terawatt-hours of hydrogen per year would be needed. When considering the upper range of the stated potential demand in each case for the steel/direct reduction sector, other industrial sectors, the transport sector, the transformation sector and the chemical industry (feedstock), the maximum annual demand for hydrogen in Germany could add up to around 600 terawatt-hours.

The potential future demand for hydrogen in the industrial sector is characterised by a high geographical concentration. Based on the structure of current production, about half of this demand would be accounted for by locations in NRW alone. If carbon neutral hydrogen is used on a large scale in industry in the future, NRW would in any case be a key centre of consumption. According to the Wuppertal Institute's estimates, the total demand for hydrogen in NRW would account for around 40 per cent of the demand for hydrogen in Germany as a whole. NRW could therefore constitute a key focal point for the development of a hydrogen infrastructure covering Germany and Europe.

## Carbon neutral hydrogen is produced in Germany but also imported

Where carbon neutral hydrogen is produced will depend on a wide range of conditions. These include the availability of renewable resources, for example, solar, wind or hydropower, the availability of land areas and infrastructures, and the speed with which projects can be implemented, which in turn is influenced by the industrial environment and regulatory framework. Transporting large quantities of hydrogen can offer substantial advantages compared to transporting additional electricity. This is particularly the case when existing natural gas pipelines can be converted to transport hydrogen, and when electricity from renewable energy resources that could otherwise not be integrated into the power grid can be used. It is

3 The figures stated here refer in each case to the quantity of hydrogen, *not* to the amount of electricity required to produce the hydrogen. For reasons of comparability, the quantities of hydrogen are given in terawatt hours (based on the net calorific value).

therefore likely that green hydrogen will be produced to a large extent in the vicinity of renewable energy facilities, for example in the North of Germany and neighbouring European countries (particularly those on the North Sea) where conditions for producing electricity from renewable energy sources are good. From there, the hydrogen will be transported to consumers by pipeline or possibly by ship. It can be assumed that a global market for green hydrogen will emerge in the future, and that hydrogen will also be imported to Germany from regions further afield with favourable production conditions (e.g. from the MENA region, Chile, Argentina or Australia).

Blue hydrogen, which is produced from natural gas either via steam reforming with capture and storage of the accruing $CO_2$ (Carbon Capture and Storage: CCS) or via pyrolysis with storage of the accruing carbon, can play a decisive role to meet the overall demand for carbon neutral hydrogen in the transitional period. CCS must therefore be included in the discussions and the necessary appraisal processes as an option for action. The use of blue hydrogen can particularly facilitate the development of an efficient hydrogen infrastructure in the early stages, when sufficient quantities of green hydrogen are not yet available. This "blue" hydrogen production would most likely take place in the vicinity of $CO_2$ storage facilities, for example on the North Sea coast, in order to use the saline aquifers that are located off the coasts of the Netherlands and Norway to store the $CO_2$. The hydrogen would then also be transported to Germany via pipelines. It would also be conceivable to produce hydrogen (from natural gas) in the vicinity of areas of high demand and transport the captured $CO_2$ via inland waterways to suitable $CO_2$ storage facilities abroad. The hydrogen could in turn be transported to consumers, for example through converted natural gas pipelines.

The above-mentioned examples underline the need for a national hydrogen strategy which pools, utilises and further develops the interests of all the consumer industries involved as customers and the technological expertise in the raw materials industry. Being open to international collaboration is imperative to guarantee the supply of hydrogen for the future. NRW has excellent preconditions to take on the role of a pilot region for a wide range of projects. The importance of hydrogen for the energy transition has been recognised for a long time also at the international level. The International Energy Agency (IEA), for example, emphasises the need to establish an international trade structure for hydrogen based on existing gas pipelines and shipping routes (IEA 2019). Some countries such as Japan, South Korea, Australia and the Netherlands are working – like Germany – on developing and implementing hydrogen strategies. It therefore seems likely that an international market for climate friendly hydrogen and hydrogen-based synthetic fuels, which will help to supply the German energy market with hydrogen, will be established. This would allow NRW to rely on a wide portfolio of national and international sources of hydrogen. Just as importantly, this will also create the opportunity for German industry to supply technology for building the required infrastructure to the exporting countries.

It needs to be stressed that hydrogen can only be used in Germany on the scale outlined above if an efficient infrastructure is established early enough. Areas of very high demand must be linked to the areas where hydrogen is produced by means of pipelines and/or to the respective ports. Since there are technical limitations to blending hydrogen into natural gas grids and since many industrial consumers require pure hydrogen, a transport network for pure hydrogen must be developed, exploiting the existing infrastructure as far as possible to minimise investment costs.

## Infrastructure is gradually developed

Any use of hydrogen in companies requires an appropriate transport infrastructure to be developed. As outlined above, there is currently still uncertainty regarding the magnitude of future demand and the future sources of supplies of green or blue hydrogen and their geographical distribution. The challenge is therefore to gradually develop an infrastructure starting with robust small-scale elements which can be expanded over the course of time. In view of the existing state of technology, this transformation process would amount to an evolution rather than a revolution. The first stage of development could take place in industrial centres in Germany (for example in the Rhine-Ruhr area and Lower Saxony), by implementing no-regret-measures as first steps towards a comprehensive reduction of industrial greenhouse gas emissions. Wide-scale expansion into other sectors could be achieved by gradually developing and converting the existing gas infrastructure at a speed of implementation that corresponds to the respective capabilities and requirements.

The use of hydrogen is intended to contribute to reducing greenhouse gas emissions across the entire system and ultimately towards achieving climate neutrality. During the transition to a completely $CO_2$-free system, it is necessary to ensure that the production of green or blue hydrogen is not accompanied by an unwanted increase in greenhouse gas emissions elsewhere. At the same time, it is important that hydrogen technologies be developed rapidly and be successively brought into the market so that they are available early enough. As long as supplies of green electricity or green hydrogen are insufficient (even with the inclusion of imports), the use of grey and, to limit emissions, also of blue hydrogen may make sense for a transitional period. Irrespective of this, the generating capacity of renewables-based electricity must be increased as a matter of urgency so that green hydrogen can be produced in sufficient quantities. Electrolysis plants must allow for flexible operation (which they do as current state of the art), so that they can help balance the fluctuating production of electricity from renewable energy sources. Negative impacts on the power system and the growth of the demand for flexibility from the further expansion of renewable energies can thus be limited.

The following scenario describes potential expansion phases for a hydrogen system from an industry point of view. In the first phase, scalable innovative pilot applications for hydrogen are developed in industry (for example in the steel industry). Parts of the current hydrogen production based on fossil raw materials can be converted at this stage to produce carbon neutral hydrogen. Carbon neutral hydrogen is also used in refineries. Through conversion of existing natural gas pipelines, the first pure hydrogen pipelines emerge that transport hydrogen to the centres of consumption. The first pipelines to be converted could be those that become available due to the phasing out of low calorific gas imports from the Netherlands and the medium-term shift in demand from natural gas to hydrogen, and that link the areas of high-demand in western Germany with the main production areas and ports on the North Sea coast. At the same time, under bi- or multilateral cooperation agreements, first projects arise aimed at accessing international hydrogen sources and developing the corresponding shipping and import logistics.

Following this initial phase, a widespread hydrogen system is developed, in addition to the electricity system, that – starting from the main industrial areas – gradually covers increasingly large numbers of regions. Via the ports, hydrogen is obtained from international sources, which increasingly complements the domestic production of hydrogen. The demand for hydrogen increases sharply, since primary steel production is converted to hydrogen direct reduction and hydrogen is used on an increasingly large scale as a feedstock in the chemical industry and in refineries. Alongside this, a network of hydrogen fuelling stations, predominantly for long-distance freight trucks and public transport, is developed, as well as a hydrogen infrastructure for shipping and non-electrified rail services. Synthetic fuels, which are produced in Germany also based on hydrogen or imported, compete with electricity and hydrogen, offering an option of reducing $CO_2$ emissions particularly for air travel.

In the wake of this increase in the use of hydrogen, a Germany-wide transport network for hydrogen emerges, where the existing natural gas infrastructure is converted and increasingly replaced by a hydrogen infrastructure, as the percentage of fossil fuels in use decreases steadily. Pipelines predominantly serve the routes between the main production areas and ports and the centres of consumption in the primary industries. Other regions may be supplied by smaller pipelines. Re-fuelling stations and other smaller consumers of hydrogen are not necessarily connected to the network but are supplied for instance by smaller on-site electrolysis units and/or by trucks. In order to meet the additional demand for electricity to produce hydrogen in Germany, the generation of renewable energy must increase. Here, the limits of renewable potential of 800 to 1,000 terawatt-hours per year (BDI 2018) and issues of public acceptance need to be considered. The extent of this growth also depends on the share of hydrogen that is imported. A global market for hydrogen develops which increasingly determines the price of hydrogen.

## 2.2 Companies in NRW are already leading the way

The companies working together in the IN4climate.NRW initiative on a climate neutral future for industry in NRW are planning a range of projects that will help set the course towards an energy future with hydrogen. The projects include innovations for reducing companies' emissions by using hydrogen, the carbon neutral production of hydrogen, as well as the development of the necessary transport infrastructure.

With the **GET H2** initiative, several partners from the industrial, transport and energy sectors are aiming to implement a cross-regional pure hydrogen infrastructure based on the existing gas network. In collaboration with Nowega and other partners, **RWE** is planning to establish a Power-to-Gas plant on an industrial scale (105 megawatts) to generate green hydrogen in Lingen and to deliver it to consumers in Emsland and northern NRW using the existing gas infrastructure. In addition, they plan to demonstrate various areas of application. For example, operation of a hydrogen pipeline storage facility will be optimised with regard to electricity supply, storage capacity and hydrogen demand, the waste heat from electrolysis will be used to supply the town of Lingen with district heat and customers for the oxygen that is generated will be found. It is expected that almost 17,000 tonnes of hydrogen per year can be produced using the electrolysis plant. Depending on how the hydrogen is used, between 113,000 and 261,000 tonnes of $CO_2$ emissions per year could thus be avoided.

The **hybridge** project put forward by **Amprion** and **Open Grid Europe** is intended to promote sector coupling at system level and to coordinate operation of the electricity and gas systems in an optimal way. An electrolyser in the area of Lingen is planned to convert up to 100 megawatts of electrical power into hydrogen starting in 2023. This hydrogen can then be transported to consumers in the region using a natural gas pipeline that is converted to transport pure hydrogen. In extension of the project, existing gas storage facilities could also be used, and the hydrogen pipeline extended as far as the Ruhr area in order to connect further potential users. The project aims to test all prospective uses of hydrogen: transporting pure hydrogen in existing gas networks, blending-in hydrogen in the natural gas network and the methanation of hydrogen. Investigating the benefits of electrolysis for the energy system and minimising greenhouse gas emissions in the overall system are the project's focus.

These projects could make a significant contribution to the development of the technology for electrolysis in the gigawatt range and to building infrastructure. This would allow for the long-term de-fossilisation of those parts of the national economy that are likely to continue to be dependent on the use of gas.

**BP** is involved in the planning of several projects where green hydrogen is to be used in refineries. For instance, BP is collaborating with Uniper on a project aimed at using Power-to-Gas technologies to produce green hydrogen from wind and solar power. In the refinery process, green hydrogen replaces grey hydrogen obtained from natural gas. By exploiting the huge potential for the use of hydrogen in refineries it would be possible to achieve considerable economies of scale and thus avoid greenhouse gas emissions. BP also plans to carry out projects in the area of Lingen which would create interfaces with other planned electrolysis and hydrogen infrastructure projects in the region, including hybridge and GET H2. In the future, BP also intends to engage in the production of synthetic fuels from hydrogen.

**Shell** and ITM Power, in partnership with SINTEF, thinkstep and Element Energy in a European consortium, are building the biggest PEM hydrogen electrolysis plant in the world at the Shell refinery Rheinland, Werk Wesseling. The project **REFHYNE** was launched in January 2018, construction began in June 2019, so that the plant will go into operation in the second half of 2020. The plant will have a capacity of ten megawatts and supply around 1,300 tons of green hydrogen per year. This hydrogen is to be used for processing in the refinery. In addition, the technology will be tested for potential application in other sectors. The total investment of the project, including integration into the refinery, amounts to around 20 million Euro, with the European "Fuel Cell Hydrogen Joint Undertaking" contributing ten million. Moreover, Shell and the Ministry for Economic affairs, Innovation, Digitalisation and Energy of NRW together have started a feasibility study on the production of liquid fuels from electricity.

**thyssenkrupp** is starting to substitute hydrogen for coal dust in steel production at a blast furnace in Duisburg. Small quantities of hydrogen are being used in a test phase; subsequently the entire blast furnace will be operated with hydrogen injection. Alongside this, research is to be carried out into a steel production procedure involving the alternative process of direct reduction using hydrogen. **Air Liquide** is supplying hydrogen to the blast furnace, initially delivering the gas by tank trucks and subsequently by constructing an approximately six-kilometre-long extension to the company's existing pipeline network. The first phase of the project is funded by the state government of NRW under the IN4climate.NRW initiative with 1.6 million euros. The second phase of the project was accepted in mid July 2019 by the Federal Ministry for Economic Affairs and Energy as one of 20 projects in the context of its tendering process for real-world laboratories. In addition, thyssenkrupp has been working for several years on technologies that utilise hydrogen and industrial emissions for synthetic chemical products. Part of this research is funded by the Federal Ministry for Education and Research within the scope of the **Carbon2Chem** project. The "Carbon2Chem" approach aims to make economic use of the 20 million tonnes of $CO_2$ emissions that are produced each year by the German steel industry. This corresponds to 10 per cent of the yearly carbon emissions produced by German industrial processes and manufacturing industries. To this end, a water electrolysis system by thyssenkrupp with a performance of two megawatts that can be scaled up (>100 megawatts) is operated in a pilot plant opened in Duisburg in April 2018. The processes have already reached a high level of maturity and their market readiness is planned for 2025. By means of the various measures taken, thyssenkrupp aims to achieve virtually carbon neutral steel production in the long term. Until 2050, this transition could involve investments amounting to ten billion euros. Very large quantities of hydrogen in the range of around seven billion cubic metres per year will prospectively be needed in the final expansion stage in 2050.

## 2.3 The political and regulatory framework can support implementation

The federal government and the state government of NRW are pursuing various activities aimed at gradually bringing the production, transport and use of hydrogen to market-readiness.

- In October 2019, the federal government adopted a programme of measures to achieve the 2030 climate targets (Klimaschutzprogramm 2030). This programme highlights the key relevance of hydrogen for the transformation of the economy. A national hydrogen strategy will be presented by the end of 2019.

- In its "Gas 2030" dialogue process, the Federal Ministry for Economic Affairs is currently discussing topics including the role of hydrogen in the gas market and in the future energy mix with businesses, associations, scientists and representatives of the political departments. First results published in October 2019 (BMWi 2019) emphasize the role of green and blue hydrogen for the move towards carbon neutral gaseous energy carriers.

- The current national network development plan for gas (Netzentwicklungsplan Gas 2020-2030) for the first time takes hydrogen and synthetic methane as "green gases" into account.

- The Federal Ministry for Economic Affairs' funding of real-world laboratories (Reallabore der Energiewende) focuses on hydrogen technologies and sector coupling. Eleven projects are designated for funding; an expansion of the funding framework is planned.

- With its new energy supply strategy, NRW among other things aims to build a supply structure based on hydrogen and synthetic fuels. The state assumes that the percentage of imports will be high in the future.

- The NRW Ministry for Economic Affairs is working on a hydrogen road map, which will address in particular the infrastructure needs for production and distribution. The state government also aims to intensify cross-border collaboration especially with the Netherlands and to support innovative and climate friendly infrastructure projects.

As described earlier, some of the companies involved in the IN4climate.NRW initiative are planning major investments in projects which serve to facilitate bringing carbon neutral hydrogen into the market, the construction of the necessary hydrogen infrastructure, the further development and establishment of Power-to-Gas technology and the build-up of new industry branches. Despite the above-mentioned activities undertaken by the federal and state governments, these investments currently face a series of regulatory and economic barriers. These must be removed to provide the companies with a supportive, reliable and economic basis for making decisions. If these projects are to be implemented and if thus key milestones in terms of the gradual development of a hydrogen economy are to be achieved, policymakers need to take further measures and remove persisting barriers in a targeted way.

The following sections present measures that several or all of the companies represented in the working group on hydrogen consider to be necessary and urgent.

**Creating additional capacity for electricity generation from renewable energy sources to produce hydrogen:** There will be an additional demand for electricity from renewable energy sources to produce green hydrogen in Germany. In order to prevent hydrogen production from impairing the reduction of greenhouse gas emissions in other sectors, additional capacity must be provided beyond the deployment corridor planned by the federal government. Electrolysis plants must allow for flexible operation (which they do as current state of the art), so that they can help balance the fluctuating production of electricity from renewable energy sources.

**Introducing tradable certificates of origin for hydrogen:** Certificates of origin are needed for hydrogen, which provide information on its contribution towards reducing greenhouse gas emissions and which can be offset against $CO_2$ reduction targets (for example under RED II). Appropriate systems are to be developed at European level. In terms of green hydrogen, it must be ensured that the renewable electricity used to produce the hydrogen cannot be offset twice (for example in the electricity sector and in the transport sector).

**Removing negative incentives by adjusting taxes and charges for electricity:** The system of taxes and charges for electricity needs to be adjusted to meet the demands of sector coupling. This also means that appropriate incentives must be provided for operating electrically powered hydrogen production plants. The system of taxes and charges that is currently in force, particularly the Renewable Energy surcharge (EEG-Umlage), places a considerable burden on the use of electricity to operate Power-to-X plants. This represents a significant barrier to the commercial operation of these plants. The regulations on switchable loads in the power grid need to be extended to make the use of surplus electricity from renewable energy sources also more attractive in Power-to-Gas plants.

**Providing positive incentives by supporting hydrogen technologies:** Carbon neutral hydrogen is currently not competitive compared to fossil fuels. Policy instruments are therefore required (for the introductory phase) to make investments in carbon neutral hydrogen economically viable and to create demand; this would allow for realisation of economies of scale, for learning curve effects and for establishing the market for hydrogen technologies and the necessary infrastructure (Smolinka et al. 2018). Various potential policy instruments are currently under discussion. These include temporary funding programmes for new technologies (see e.g. Power-to-X Alliance 2019), a quota for carbon neutral hydrogen e.g. in the form of tradable certificates (see Nymoen et al. 2019), OPEX funding via contracts for difference that guarantee a fixed price for achieved $CO_2$-reductions for specific projects (WWF 2019), and support for the use of hydrogen in specific sectors (Beckers et al. 2018). The decision on the introduction of any of these policy instruments requires careful consideration and comparison of the respective advantages and disadvantages.

Where funding instruments are introduced, it is also necessary to ensure that carbon neutral hydrogen production is not accompanied by an unwanted increase in greenhouse gas emissions elsewhere. In addition, potential risks of carbon leakage must be taken into account.

**Early implementation of the European directives (Renewable Energy Directive and Electricity Market Directive) in Germany and eligibility of carbon neutral hydrogen for the greenhouse gas reduction quota:** The Renewable Energy Directive (RED II) allows member states to credit the use of carbon neutral hydrogen in the refinery process against the renewable energy quota. This would provide an incentive for refineries to process green or blue hydrogen and thus reduce their emissions. For national implementation in Germany, this would mean that carbon neutral hydrogen must be made eligible for credit under the greenhouse gas reduction quota according to the Federal Imission Control Act (BImSchG). This implementation should occur as soon as possible in order to create legal certainty and make investments possible. The corresponding certificates of origin (see above) are a prerequisite for this.

**Consistent consideration of hydrogen in the relevant statutory provisions:** The technical rules of the DVGW (German Technical and Scientific Association for Gas and Water) must also be expanded to include pure hydrogen infrastructures.

**Extension of the network development plan for gas *(Netzentwicklungsplan Gas, NEP)* for the transparent development of the hydrogen infrastructure:** The NEP Gas has proven to be an efficient coordination and steering tool for the development of the natural gas network and also seems appropriate for the development of a transport infrastructure for the long-distance transport of hydrogen. It needs to be established whether adjustments to the process are necessary to accommodate the high momentum expected in the area of hydrogen. Basically, there is a typical "chicken or the egg" dilemma as regards developing the hydrogen network infrastructure, which will have to be overcome by appropriate measures and by the coordinated approach taken by companies with the support of the public authorities. As a first step it is very important that the Federal Network Agency take account of the declared large-scale industrial production and demand quantities for hydrogen when approving the scenario framework for the 2020 network development plan for gas, so that a start can be made as soon as possible. Combined planning for the electricity and gas infrastructure is also necessary.

**Simplification of permitting processes:** Regulatory barriers for the approval of electrolysis plants should be reduced, for example by harmonising the procedures between the federal states and by exchanging information on practices for permitting between the authorities involved.

# BIBLIOGRAPHY


- BDI (the Federation of German Industries) 2018: Klimapfade für Deutschland. Boston Consulting Group und Prognos commissioned by BDI.
- Beckers, Thorsten; Gizzi, Florian; Schäfer-Stradowsky, Simon; Wilms, Susan; and others 2018: Rechtliche Rahmenbedingungen für ein integriertes Energiekonzept 2050 und die Einbindung von EE-Kraftstoffen. Research report by BBH (Becker Büttner Held), LBST (Ludwig Bölkow Systemtechnik), ISE (Fraunhofer Institut für Solare Energiesysteme) and IKEM (Institut für Klimaschutz, Energie und Mobilität) for the Federal Ministry for Transport and Digital Infrastructure.
- BMWi (Bundesministerium für Wirtschaft und Energie) 2019: Dialogprozess Gas 2030 – Erste Bilanz – Oktober 2019. Berlin.
- dena (the German Energy Agency) 2018: Leitstudie integrierte Energiewende. Report by ewi Energy Research & Scenarios gGmbH for dena. Berlin.
- IEA 2019: The Future of Hydrogen. IEA, Paris.
- IW Köln (German Economic Institute Cologne) and frontier economics, 2018: Synthetische Energieträger – Perspektiven für die deutsche Wirtschaft und den internationalen Handel. Eine Untersuchung der Marktpotenziale, Investitions- und Beschäftigungseffekte. Study commissioned by IWO, MEW und UNITI.
- LBST (Ludwig Bölkow Systemtechnik) 2019: Wasserstoffstudie Nordrhein-Westfalen. Eine Expertise für das Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen.
- Nymoen, H., Sendler, S.C., Steffen, R. and Pfeiffer, R. 2019: Kurzstudie „Quote erneuerbare und dekarbonisierte Gase“. Kurzstudie im Auftrag der Vereinigung der Fernleitungsnetzbetreiber Gas e.V. (FNB Gas) Nymoen Strategieberatung GmbH, Berlin.
- Power to X Allianz 2019: Ein Markteinführungsprogramm für Power to X-Technologien.
- Smolinka, T., Wiebe, N., Sterchele, P., Palzer, A. and others 2018: Studie IndWEDe. Industrialisierung der Wasserelektrolyse in Deutschland. Chancen und Herausforderungen für nachhaltigen Wasserstoff für Verkehr, Strom und Wärme.
- UBA (Federal Environment Agency) 2019: Ressourcenschonendes und treibhausgasneutrales Deutschland. Szenario GreenEe. UBA, Dessau-Roßlau.
- WWF 2019: Klimaschutz in der Industrie. Forderungen an die Bundesregierung für einen klimaneutralen Industriestandort Deutschland. WWF Germany, Berlin

IN4 CLIMATE .NRW

**Contact:** **IN4climate.NRW**
Munscheidstraße 14
45886 Gelsenkirchen
GERMANY
phone +49 209 40 85 99-0
post@in4climate.nrw
www.in4climate.nrw/en

We print carbon neutral with natureOffice

FSC www.fsc.org MIX Paper from responsible Sources FSC® C001704