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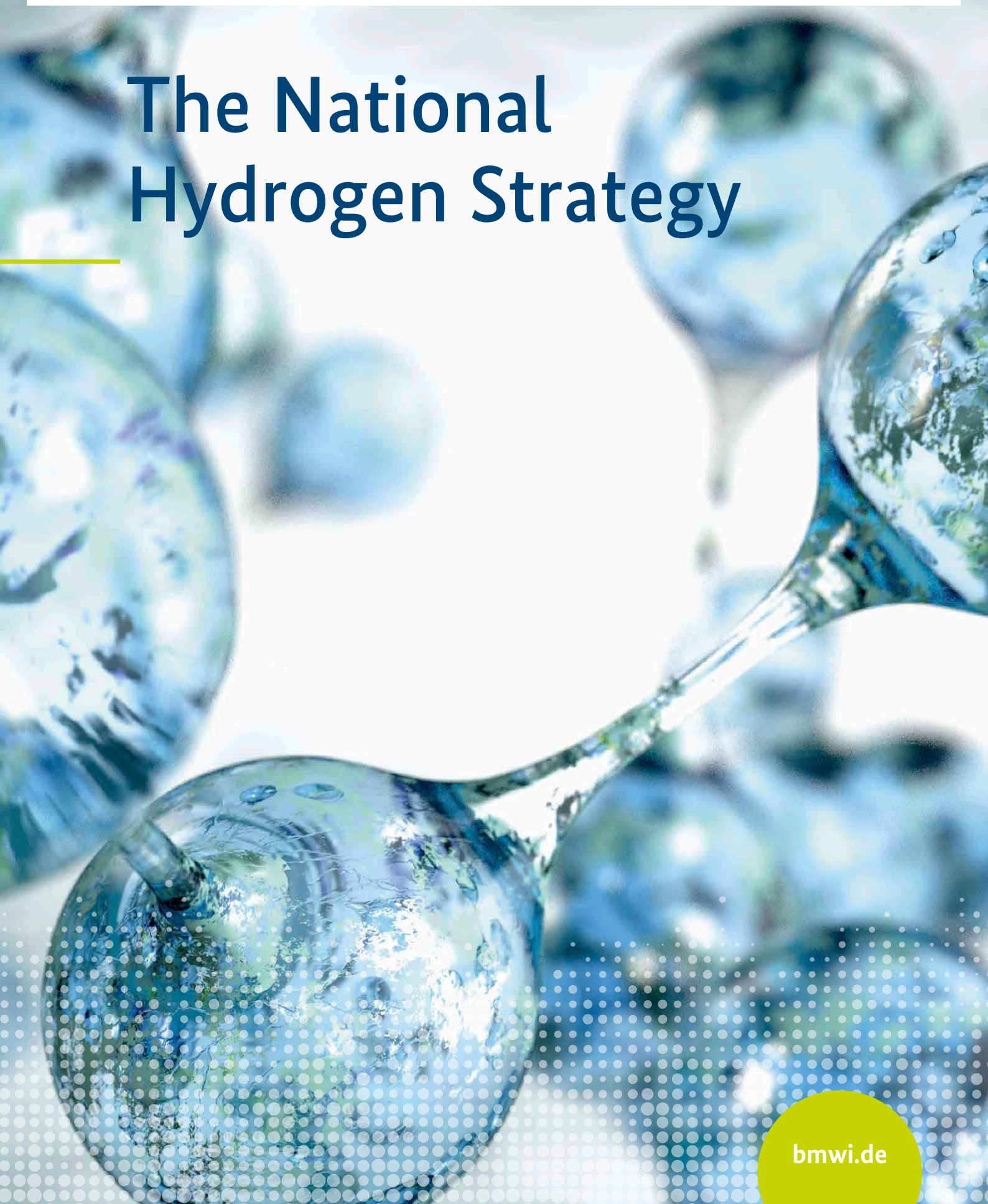
The
Federal Government

NATIONALE
WASSERSTOFF-
STRATEGIE
Schlüsselelement
der Energiewende

The National Hydrogen Strategy



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Content

Content 1

I. Recognising the potential and harnessing the opportunities of hydrogen

The energy transition – which represents the efforts undertaken and results achieved on renewable energy expansion and energy efficiency – is our basis for a clean, secure and affordable energy supply, which is essential for all our lives. By adopting the 2030 Climate Action Plan, the Federal Government has paved the way for meeting its climate targets for 2030. Its long-term goal is to achieve carbon neutrality in line with the targets agreed under the Paris Agreement, which seeks to keep global warming well below 2 degrees and if possible below 1.5 degrees. In addition, Germany has committed itself, together with the other European Member States, to achieving greenhouse gas (GHG) neutrality by 2050. Apart from phasing out coal-fired power, for which Germany has already taken the relevant decisions, this means preventing emissions which are particularly hard to reduce such as process-related GHG emissions from the industrial sector.

In order for the energy transition to be successful, security of supply, affordability and environmental compatibility need to be combined with innovative and smart climate action. This means that the fossil fuels we are currently using need to be replaced by alternative options. This applies in particular to gaseous and liquid energy sources, which will continue to be an integral part of Germany's energy supply. Against this backdrop, hydrogen[1] will play a key role in enhancing and completing the energy transition.

- Hydrogen can be used as an **energy source**. For example, it can be used in fuel cells to drive forward hydrogen-powered transport or as a means to produce synthetic fuels.
- Hydrogen is an **energy storage medium** that allows for renewable energy to be stored in a supply-based and flexible manner and therefore helps balance energy supply and demand. This makes hydrogen an important ingredient of the energy transition.
- Hydrogen plays a key role for **sector coupling**. In areas where renewable electricity cannot be used directly, green hydrogen and the products derived from it (power-to-X) open up new ways to decarbonise our energy supply.
- Already today, many chemical and industrial processes depend on the use of hydrogen. For example, it is used as a **base substance** for producing ammonia. Going forward, the fossil-based hydrogen currently used for this is to be replaced by green hydrogen. In addition, hydrogen in its pure form can be used to decarbonise a wide range of industrial production processes for which currently no decarbonisation technologies are available. For example, in order to allow for the GHG-free production of primary steel, hydrogen is currently considered to be the most promising solution for replacing hard-coal coke.
- **Hydrogen will be required if certain types of carbon emissions from the industrial sector** such as process-related emissions from the cement industry are to be eliminated in the long term. By capturing carbon emissions from the industrial sector and combining these with hydrogen, useful chemicals can be produced (CCU) and new value chains for the basic chemicals industry opened up.

In order to make hydrogen a key element of our decarbonisation strategy, our entire value chain – from

1 The Federal Government considers only hydrogen that has been produced using renewable energy (green hydrogen) to be sustainable in the long term.

technologies, generation, storage, infrastructure and use, including logistics and important aspects of quality assurance – need to be looked at.

In order for Germany to become GHG-neutral and meet its international obligations under the Paris Agreement, hydrogen needs to be established as a decarbonisation option. The Federal Government considers only hydrogen that has been produced using renewable energy (green hydrogen) to be sustainable in the long term. The Federal Government therefore seeks to use green hydrogen, promote its rapid market rollout and establish the necessary value chains. The Federal Government believes that both a global and European hydrogen market will emerge in the coming ten years and that carbon-free (for example blue or turquoise) hydrogen will be traded on this market. Given Germany's close integration in the European energy supply infrastructure, carbon-free hydrogen will be relevant for Germany and, if available, will be temporarily used.

In addition to this, hydrogen creates fresh potential for industrial policy and can help the German and European economy deal with the consequences of the coronavirus pandemic. The National Hydrogen Strategy therefore also seeks to use the economic opportunities opening up as a result.

The Federal Government has been aware of the potential of hydrogen technology for many years. Between 2006 and 2016, around 700 million euros in funding was approved under the National Innovation Programme on Hydrogen and Fuel Cell Technology, and between 2016 and 2026, a total of 1.4 billion euros in funding will be provided. In addition to this the Federal Government has made use of the financial resources provided under the Energy Research Programme to build an excellent research landscape. Between 2020 and 2023, 310 million euros will be provided under the Energy and Climate Fund for practice-oriented basic research on green hydrogen and there are plans to provide another 200 million euros over this period to strengthen practice-oriented energy research on hydrogen technology. In addition, 600 million euros will be provided between 2020 and 2023 to foster the 'Regulatory Sandboxes for the Energy Transition', which help speed up the transfer of technology and innovations from the lab to the market, not least for hydrogen solutions. As part of Germany's decarbonisation programme, funding is provided for investment in technologies and large-scale industrial facilities which use hydrogen to decarbonise their manufacturing processes. More than 1 billion euros will be provided for this between 2020 and 2023. There are also programmes that promote the use of hydrogen in manufacturing and for the purpose of eliminating and utilising carbon emissions in the base materials industry. These seek to encourage the industry to invest in hydrogen solutions. On 3 June 2020, the Coalition Committee adopted a 'package for the future' which makes available another 7 billion euros for speeding up the market rollout of hydrogen technology in Germany and another 2 billion euros for fostering international partnerships. The precise amounts available for each of these programmes depend on the budget estimates made by the responsible ministries.

A considerable increase in the demand for hydrogen is expected in the medium to long term. In order to harness the full potential of hydrogen technology, the next steps need to be taken to speed up the rollout of this technology together with the private sector. The National Hydrogen Strategy provides the basis for private-sector investment in hydrogen generation that is both economically viable and sustainable, and in its transport and use.

Considering the status quo, it is unlikely that the large quantities of hydrogen that will be needed for the energy transition can be produced in Germany alone, as Germany's renewable energy generation capacity is limited. This means that Germany will continue to import much of its energy from abroad. We will foster and intensify international cooperation and partnerships on hydrogen.

Hydrogen has gained in importance on the European and international agenda in the last few years. In Sep-

tember 2018, the Federal Government together with 27 other European nations and the European Commission adopted a European hydrogen initiative and declared hydrogen technology and systems a value chain of strategic interest. The Federal Government will make use of this momentum to continue to advocate hydrogen technology during its upcoming Presidency of the Council of the EU and in line with the principles set out in this strategy.

It will be for the competent ministries to ensure that the measures are implemented and financed on the basis of the existing budget estimates and financial plans.

II. The National Hydrogen Strategy – goals and ambitions

By tabling the National Hydrogen Strategy, the Federal Government is providing a coherent framework for the generation, transport and use of hydrogen, encouraging the relevant innovations and investment. The Strategy sets out the steps that are needed to meet the German climate targets, create new value chains for the German economy and foster energy policy cooperation at international level. It focuses in particular on the following goals:

Assuming global responsibility

The Federal Government recognises Germany's responsibility to reduce greenhouse gas emissions globally. By developing the hydrogen market and promoting hydrogen as a decarbonisation option, our country can make a key contribution to climate change mitigation around the world.

Making hydrogen a competitive option

The current framework does not allow hydrogen to be generated and used in an economically viable manner. Fossil fuels in particular continue to be much cheaper as the cost of carbon emissions is not included in their price. In order for hydrogen to become economically viable, we need to continue to bring down the price of hydrogen technology. In order to drive forward technological progress and economies of scale and promptly obtain the critical mass of hydrogen needed for some initial sectors to switch to the new technology, the production and use of hydrogen need to be sped up globally. A particular focus is being placed on areas that are already close to commercial viability and where major path dependencies can be avoided, or which cannot be decarbonised in other ways, as is the case for process-related emissions in the steel or chemicals industry, or in certain parts of the transport sector. In the longer term, parts of the heat market will also be focused on.

Developing a domestic market for hydrogen technology in Germany, paving the way for imports

The first step that needs to be taken to speed up the rollout of hydrogen technology is establishing a strong and sustainable domestic market for the production and use of hydrogen at home. A strong domestic market will send an important signal, encouraging other countries to use hydrogen technology as well. Germany will design the incentives for speeding up the rollout of hydrogen technology in Germany and particularly for the establishment and operation of electrolysers in a way that is compatible with the energy transition.

The Federal Government expects that around 90 to 110 TWh of hydrogen will be needed by 2030. In order to cover part of this demand, Germany plans to establish up to 5 GW of generation capacity including the offshore and onshore energy generation facilities needed for this. This corresponds to 14 TWh[2] of green hydrogen production and will require 20 TWh of renewables-based electricity. It needs to be ensured that the demand for electricity that is created by the electrolysers will not lead to an increase in carbon emissions. The Federal Government has included a monitoring mechanism in the National Hydrogen Strategy which will be used to track the development of green hydrogen demand in detail. An additional 5 GW of capacity are to be added, if possible by 2035 and no later than 2040.

However, the domestic generation of green hydrogen will not be sufficient to cover all new demand, which is why most of the hydrogen needed will have to be imported. There are several places across the EU where large quantities of renewables-based electricity are being generated. These offer great potential for producing green hydrogen. The Federal Government will work to ensure that this potential is tapped and that the generation capacities are further expanded. To this

2 Assumption: 4,000 hours full-load hours of electrolyser operation and an efficiency ratio of 70%.

end, it will intensify its cooperation with other European Member States, particularly those bordering the North and Baltic Sea, but also with the countries of southern Europe. The use of offshore wind energy will play an important role. The Federal Government will work with the North and Baltic See border states to push forward hydrogen production by establishing a reliable regulatory framework for offshore wind energy. It also aims to systematically develop production sites in other partner countries, for example as part of development cooperation. The Federal Government seeks to provide suppliers, consumers and investors in Germany and abroad with the security to plan ahead.

This will require working with the relevant partner countries to launch an investment and innovation campaign. The Federal Government will use its Hydrogen Strategy to promote the establishment of production capacity and new supply chains and provide our partner countries with the relevant technology and targeted solutions. This will boost employment both in Germany and our partner countries and pave the way for long-term economic growth.

The Action Plan for the National Hydrogen Strategy and the current budget and financial estimates serve as the basis for speeding up the rollout of hydrogen technology. Should it become clear that the demand for hydrogen will develop more strongly than expected, the National Hydrogen Strategy will be enhanced as part of the evaluation process.

Establishing hydrogen as an alternative for other energy sources

Hydrogen technology and the alternative sources of energy derived from it are an integral part of the energy transition and contribute to its success. Some sectors such as air and maritime transport or industries in which process-related emissions are unavoidable will be impossible or very difficult to electrify, even in the long term. This applies in particular to aviation, parts of heavy-duty transport, mobile systems for the defence of our country and the Alliance, and maritime transport, where many routes and applications cannot be operated using electricity alone. This is why the fossil input and fossil fuels need to be replaced by renewables-based alternatives, for example jet fuel produced through PtX.

Making hydrogen a sustainable base material for the industrial sector

Hydrogen is an important base material for the German industrial sector (it is used for example in the chemicals industry or steel production). Around 55 TWh of hydrogen – most of it produced from fossil energy sources – is used for industrial applications in Germany each year. These need to switch to a production based on green hydrogen to the extent possible. In addition to this, hydrogen and hydrogen-based PtX commodities need to be used to drive forward the decarbonisation of emission-intensive industrial processes, which will open up new fields of application for hydrogen and PtX commodities. For example, it is estimated that more than 80 TWh of hydrogen would be needed to make German steel production GHG-neutral by 2050. Around 22 TWh of green hydrogen would be needed for German refinery and ammonia production to switch to hydrogen. Germany's industrial sector already has demand for hydrogen and this demand is expected to grow heavily in the future. This means that the industrial sector is well-placed to become one of main factors speeding up the market rollout of hydrogen and a global pioneer for hydrogen technology.

Enhancing transport and distribution infrastructure

Developing and putting in place the right transport and distribution infrastructure is key in order to be able to import and develop the sales markets for hydrogen and the products derived from it. Germany has a well-developed gas infrastructure consisting of a tightly-knit natural gas network and the gas storage

units connected to it. In order to harness the full potential of hydrogen, we will enhance our transport and distribution infrastructure and continue to ensure that the use of hydrogen applications is safe. This includes building and expanding a dedicated hydrogen network. The Federal Government will revisit and develop the regulatory framework and the technical requirements for the gas infrastructure. For example, it will examine whether natural gas pipelines which are no longer needed to transport natural gas (for example L gas) can be converted into hydrogen infrastructure and investigate whether the compatibility of existing or upgraded gas infrastructure with hydrogen can be ensured.

Fostering science, mobilising skilled labour

Research is a strategic element underpinning energy and industrial policy. Only by developing long-term research and innovation programmes that cover the entire hydrogen value chain – from storage, transport and distribution all the way to its use – will it be possible to establish hydrogen as a key technology for the energy transition. Hydrogen solutions need to be systematically developed to the stage of practical use at industrial scale by 2030. In order to further strengthen the good position of German companies and research institutes on hydrogen, we should recruit, train and foster outstanding scientists, new talent and skilled staff and engage in close dialogue with other leading research nations. The government also plans to place a stronger focus on establishing new research institutes, setting up centres of excellence and building educational and research capacity aimed at regions which are particularly affected by structural change.

Shaping and accompanying transformation processes

The energy transition and the increased use of renewable energy mean that all stakeholders need to adapt in many ways. We will work with businesses, scientists and the general public to look at how hydrogen can make a contribution to the energy transition. We will start a dialogue process to accompany the necessary transformations and provide assistance to the stakeholders where necessary.

Strengthening German industry and securing global market opportunities for German firms

Germany now has the chance to play a key role in international competition for the development and export of hydrogen and Power-to-X (PtX) technologies. The broad-based community of German stakeholders in the hydrogen technology field, with their good international connections, will not only be a key factor for the successful market ramp-up of hydrogen technologies in Germany, but will also improve the opportunities of German firms on this forward-looking market. The manufacture of components for the generation and use and for the supply of hydrogen will contribute to regional value creation and strengthen the companies active in these fields. For this to happen, attention is being paid in the implementation of the hydrogen strategy and in particular in the funding measures to ensuring that all of Germany's regions benefit from the new potential for growth deriving from the hydrogen economy. The fostering of the market ramp-up of hydrogen technologies also makes an important contribution towards coping with the economic impact of the coronavirus pandemic, and lays a further foundation stone for a sustainable orientation of German industry.

Establishing international markets and cooperation for hydrogen

We need to prepare the future supply of hydrogen and its downstream products and design it to be sustainable. This is because, in the medium to long term, Germany will import substantial quantities of hydro-

gen. We share with other future importers an interest in the swiftest possible establishment of a global hydrogen market. In view of their potential for renewable energy, the countries currently producing and exporting fossil fuels also have attractive opportunities to convert their supply chains to the use of renewable energy and hydrogen, and thus to become potential suppliers of hydrogen. In this way, these countries will be also able to benefit in the long term from existing trade relations. Here, it is important to ensure that local markets and a local energy transition in the partner countries are not impeded, but are fostered by the production of hydrogen.

International trade in hydrogen and synthetic downstream products will not only create new trade relations for Germany and the EU, but also facilitate a further diversification of energy sources and transport routes, and will thus improve the security of supply. International trade in hydrogen and its downstream products will thus become a significant industrial and geopolitical factor which creates a need for strategic objectives and decisions, but also offers fresh opportunities for all sides.

Regarding global cooperation as an opportunity

There is a sense around the world that hydrogen technologies are on the verge of exciting progress, and we wish to work with our partners around the world to utilise this positive mood and make rapid technological progress. At international level, the cooperation with potential suppliers and other importers promotes their contribution towards climate change mitigation and creates opportunities for sustainable growth and development. Possibilities for joint projects and trialling of technology exist in the area of the North Sea and in southern Europe in particular, and also in the context of the Federal Government's energy partnerships and cooperation with the partner countries in German development cooperation.

Building up and securing the quality assurance infrastructure for hydrogen production, transport, storage and use, and building trust

The special physical and chemical properties of hydrogen mean that a robust quality assurance infrastructure for the development and in particular the monitoring of facilities to produce, transport, store and use hydrogen is essential. The chief components of this measurement and quality assurance infrastructure which needs to be built up and networked at national and European level are metrology and physical and chemical safety technology. In particular, there is a need for scientifically accepted and regulated measurement methods and assessment criteria, and internationally accepted standards and technical standards. Further to this, a high level of safety needs to be established. Negative events and accidents can undermine public acceptance of hydrogen technology. There is a need to build trust amongst the users.

Improving the policy environment and addressing current developments on an ongoing basis

The implementation and further development of the National Hydrogen Strategy is an ongoing process. The status of implementation and target achievement is subject to regular review by a new committee of state secretaries for hydrogen from the various ministries; this body will also decide on the further development and implementation of the Strategy. The state secretaries' committee is supported and advised by a National Hydrogen Council with high-level experts from science, business and civil society. The Strategy will be subject to a first evaluation after three years. On this basis, the Federal Government will then consider the further development of the Strategy, including the necessary measures for this.

III. Hydrogen: status quo, fields of action, and markets of the future

The status quo and expected trends for hydrogen and its downstream products

Domestic hydrogen consumption currently amounts to roughly 55 TWh. The greatest demand for hydrogen is linked to material production processes in industry and is evenly distributed between the basic chemicals (production of ammonia, methanol, etc.) and petrochemicals sector (production of conventional fuels). The bulk of the hydrogen being used in these processes is 'grey' hydrogen. About 7% of demand (3.85 TWh) is being met via electrolysis (chloralkali) processes. Since some of the hydrogen used in the petrochemicals industry, in particular, does not have to be produced from scratch, but is available as a by-product of other processes (e.g. catalytic reforming), the current level of hydrogen consumption of around 55 TWh cannot entirely be substituted with 'green' hydrogen.

The future development of the hydrogen market in Germany, but also globally, will fundamentally depend on the level of ambition displayed by climate action policy and the attendant strategies being pursued. In the light of the Paris Agreement and the Federal Government's commitment to the goal of achieving greenhouse gas neutrality by 2050, the hydrogen market is likely to exhibit the following trends in the future:

By 2030, following market penetration, hydrogen demand is set to experience an initial increase – especially in the industrial sector (chemicals, petrochemicals, steel) and, to a lesser extent, in the transport sector. According to conservative estimates, the demand in industry will rise by 10 TWh. In addition, growing demand is expected to come from fuel-cell-driven electric vehicles. Other consumers (e.g. parts of the heating sector, in the long term) might follow.

If the 2050 carbon neutrality goal is to be reached, hydrogen technologies will also have to play an important role in Germany. According to the scenarios analysed by various studies that consider the effects on the entire energy system in the case of a 95% reduction of GHG emissions against the 1990 baseline, the forecast consumption of electricity-based energy sources in 2050 will be between 110 TWh (*Klimaschutzszenarien* [Climate Action Scenarios] by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) and roughly 380 TWh (*Klimapfade* [Climate Paths] by the BDI, the Federation of German Industries). Alongside the industrial and transport sectors, long-term demand will also arise in the transformation sector. The shape of the future policy framework, particularly as regards climate action ambitions and the attendant strategies being pursued, will have a decisive impact on the development of overall demand and consumption levels in the individual sectors.

The National Hydrogen Strategy is targeted at the following strategic markets of the future:

Hydrogen production

To enable the market penetration and export of hydrogen technologies, a domestic market is indispensable – one that provides a strong and sustainable base for the production and use of hydrogen while furthering the energy transition. If hydrogen is to have long-term prospects of being used in a sustainable and economical way, capacities for generating electricity from renewables (particularly wind power and photovoltaics) must be systematically improved.

Industrial sector

In certain industrial sectors, the transformation towards carbon neutrality will not be possible using conventional technologies. In these sectors, gaseous and liquid sources of energy have to be gradually replaced by alternative technologies, paving the way for the use of alternative resources or processes with either zero or very low carbon emissions. Many of these processes will, in the long term, enable the use of hydrogen and products derived from it. In refineries and parts of the chemical industry, in particular, it

is already possible today to substitute green hydrogen for 'grey' hydrogen without any adjustments being necessary. Moreover, existing infrastructures of the chemical industry, e.g. hydrogen networks, can continue to be used and possibly be expanded or optimised for other applications such as in the steel sector. For example, hydrogen will soon be used within pilot projects in the steel industry, where it can help substitute high-emission blast furnace processes with the direct reduction of iron ore. The aim is, wherever possible, to channel upcoming investments in production facilities on an industrial scale into climate-friendly technologies. Therefore, hydrogen is set to play an important long-term role in safeguarding the attractiveness of Germany's industrial sector.

Transport

Mobility applications offer great potential for hydrogen uses. The transport sector must be committed to technological progress if it is to reach the sector-specific climate and renewables targets. Hydrogen-based or PtX-based mobility can be an alternative option for those applications where using electricity directly is not reasonable or technically feasible. This includes military applications that must be able to ensure interoperability between allies.

In the long term, air and maritime transport in particular will develop a demand for carbon-neutral fuels which can be supplied in the form of hydrogen-based energy sources from PtX processes. Both air and maritime transport rely on synthetic fuels to achieve decarbonisation. In air transport as well as coastal and inland navigation, fuel cells and battery-powered drives may also be an option for certain mobility needs. However, technological advances are still necessary in this field.

In a wide range of sectors – such as local public passenger transport (buses, trains), parts of heavy-duty road transport (trucks), commercial vehicles (e.g. for use in construction work or agriculture and forestry) or logistics (delivery traffic; other commercial vehicles such as forklift trucks) – the introduction of fuel cell vehicles can complement battery-powered electric mobility and help significantly reduce air pollutant and carbon emissions. In certain segments, hydrogen may also provide an alternative for cars. If hydrogen is to be used in road transport, refuelling infrastructure must be expanded as needed.

It is important to provide constructive and targeted support for the German automotive and supplier industry as it undergoes this structural transformation. With a view to fuel cell technology, for example, the goal is to strengthen Germany's machinery and plant manufacturing sector and to aspire to global leadership in the endeavour to improve the cost, weight, and performance parameters of fuel cell components (stacks, pressure tanks, etc.).

Heat market

Even after the efficiency and electrification potentials for process heat generation and the building sector have been harnessed, there will continue to be long-term demand for gaseous fuels. In the long run, hydrogen and its downstream products can help in various ways to decarbonise parts of the heat market.

Hydrogen as a collaborative European project

The issues and conditions that have to be addressed in order to foster the domestic ramp-up of hydrogen technologies and to build up an international hydrogen market can only be successfully handled within the context of the European internal market and regulatory framework. As hydrogen technologies gain ground in other EU Member States, it is becoming increasingly important to develop a European internal market for hydrogen. The EU benefits from the North Sea's ideal locations for wind energy and the great potential for photovoltaics and wind energy offered by southern Europe. This potential can represent a great long-term opportunity for generating renewable hydrogen. Also, Europe's well-developed gas infrastructure may provide possibilities for the

transport of hydrogen. In order to lay the foundations for an internal market, we need a strong European framework. Key challenges can only be meaningfully addressed in the context of the EU. Thus, cross-border collaboration is indispensable in order to find solutions for the generation of wind and solar energy in the respective areas and for the distribution of hydrogen. It is also essential as regards regulatory law, investment conditions, and the sharing of experience. Furthermore, action at European and international level is required to establish clear sustainability standards for the production and transport of hydrogen, and to set the stage for the systematisation and environmental classification of electricity, hydrogen, and synthetic downstream products. By starting out early to develop standards and a policy environment in this field, the EU can play a pivotal role in shaping the basic international framework. Progress also needs to be made on the state aid framework to take account of the rising operating costs linked to the use of hydrogen in the steel and chemical industries, for example. Germany will take on an active role in setting up a market for hydrogen and establishing sustainability standards, share its experience with the energy transition, and use its Council Presidency to place a central focus on the framework for sector coupling and the development of an EU internal market for hydrogen. Within the EU, the Federal Government will advocate that key aspects of this strategy influence the development of a European hydrogen strategy.

International trade

If Germany is to reach its climate targets for 2030 and its GHG neutrality target for 2050, importing renewable energy from beyond the European internal market will become a medium and long-term necessity. International trade in hydrogen and its downstream products is therefore a significant industrial and geopolitical factor.

At international level, cooperation with potential suppliers and importers, if based on the partners' needs, can promote their contribution towards climate change mitigation, speed up the ramp-up of hydrogen technologies, and create opportunities for sustainable growth and development. It is possible, for example, to agree on ambitious standards for certification and for the sustainability of hydrogen production, and to increase market volumes. Existing forms of collaboration, notably with the energy partnerships of the Federal Government, but also with the partner countries in German development cooperation or the International Climate Initiative, offer prospects for joint projects and for testing import routes and technologies. Besides these, further initiatives for international cooperation may emerge. Current fossil fuel exporters may play a particularly prominent role if they offer great potential for hydrogen production. In developing countries in particular, it is vital to ensure that the export of hydrogen will not be detrimental to possibly inadequate energy supply systems in the exporting countries concerned and thus incentivise local investment in even more fossil fuels. Therefore, the production of green hydrogen is to act as a stimulus for these countries to rapidly expand their capacities for generating renewable energy – these will, after all, also benefit local markets.

The trade relations needed for the hydrogen market raise complicated geopolitical questions that policymakers have to address as early as possible. But they also provide many opportunities – for example for expanding the EU's internal energy market, establishing new international value chains, furthering cooperation with those partner countries within German development cooperation that offer great renewable energy potential for PtX production, and for expanding existing or creating new trade relations with energy exporters.

Transport and distribution infrastructure in Germany and abroad

In order to be able to import and develop sales markets for hydrogen and its downstream products, the right transport and distribution infrastructure, especially as regards transmission systems, must be in

place. Germany has a well-developed gas infrastructure consisting of a tightly-knit natural gas network and the gas storage units connected to it. In future, part of this infrastructure is to be usable for hydrogen as well. Further networks are to be created exclusively for the transport of hydrogen. Given Germany's geographical location and its role as an important transit country within Europe, these transformation processes can only be successfully shaped in cooperation with its European neighbours and associated third countries. Consistent quality and sustainability standards and suitable documentation procedures have to be established not only for the production, but also the transport of hydrogen and associated emissions. As in other countries, building up a hydrogen market in Germany entails technical challenges for several components of the infrastructure and for certain devices and installations employed by end users. That is why the necessary transformation processes ('hydrogen readiness', etc.) must be enabled and initiated as early as possible. In order to avoid misallocated investments, however, this transformation process should be oriented to the demand that can be expected in view of the 2050 carbon neutrality goal.

Especially as far as international trade is concerned, important options for transporting hydrogen include PtX downstream products or LOHCs (Liquid Organic Hydrogen Carriers). Liquid hydrogen, PtL/PtG downstream products, and LOHCs can be transported easily and safely over long distances. Here, existing transport capacities and the relevant infrastructure may be used and new capacities created (e.g. pipelines, methanol and ammonium tankers). Under the motto 'Shipping the sunshine', research could provide an unprecedented opportunity to tap new potential for the large-scale generation and transport of green hydrogen. Long-distance trading of PtX products can complement the transport of hydrogen via pipeline systems. It is important to avoid greenhouse gas emissions in connection with the transport of hydrogen.

Research, education, innovation

Research is a strategic element underpinning energy and industrial policy. Thanks not least to the long-term approach and reliability of the Federal Government's research funding, German companies and research establishments are pioneering hydrogen and other PtX technologies. Across the world, German institutional funding finances outstanding research facilities and infrastructures and helps to transpose cutting-edge research into practice.

We are committed to providing research funding for key enabling technologies and new approaches that cover the entire hydrogen value chain – from generation and storage, transport and distribution all the way to application. By integrating forward-looking basic research with targeted application-based research, we can set the stage for key enabling technologies such as electrolysis-based or bio-based processes of hydrogen production, methane pyrolysis ('turquoise' hydrogen), artificial photosynthesis, and fuel cells. It is important to take into account the particularities of individual sectors such as air transport, maritime transport, and industry, and to harness potential spill-over effects across the various fields of application. We are also assessing the opportunities that may arise with regard to natural hydrogen resources.

We fund research in the knowledge that the findings made today will be the innovations of tomorrow. Bridges must be built between research and practice. Apart from the regulatory sandboxes for the energy transition, we also rely on the tried-and-tested format of collaborative projects with strong partners from the business and science communities. Due to the long run-up periods from research to application, it is necessary to foster application-based energy research so that we can reach our targets in time.

We are strengthening the pre-competitive cooperation between science and business also in the field of

applied basic research. Flagship projects such as Carbon2Chem and the Kopernikus projects demonstrate how cutting-edge science and innovative companies can successfully cooperate. We use these experiences to develop internationally visible and exportable 'showcase' initiatives for hydrogen technologies. Among other things, our research focuses on hydrogen applications such as direct reduction as a means of reducing carbon emissions in the steel and chemical industries.

Now is the time to put laboratory innovations into practice – faster than we used to in the past – and to enable their industrial roll-out. To speed up the transfer of innovation for key enabling technologies, particularly in the field of hydrogen, and to help these technologies become marketable more quickly, the regulatory sandboxes for the energy transition have been established as a new funding pillar of energy research. The National Decarbonisation Programme also helps to speed up the way innovative climate technologies that rely on hydrogen are made available and used throughout industry.

Hydrogen is also an education issue: the hydrogen industry needs skilled workers, both in Germany and abroad. This is why we will explore new horizons for the cooperation between education and research.

IV. Governance for the National Hydrogen Strategy

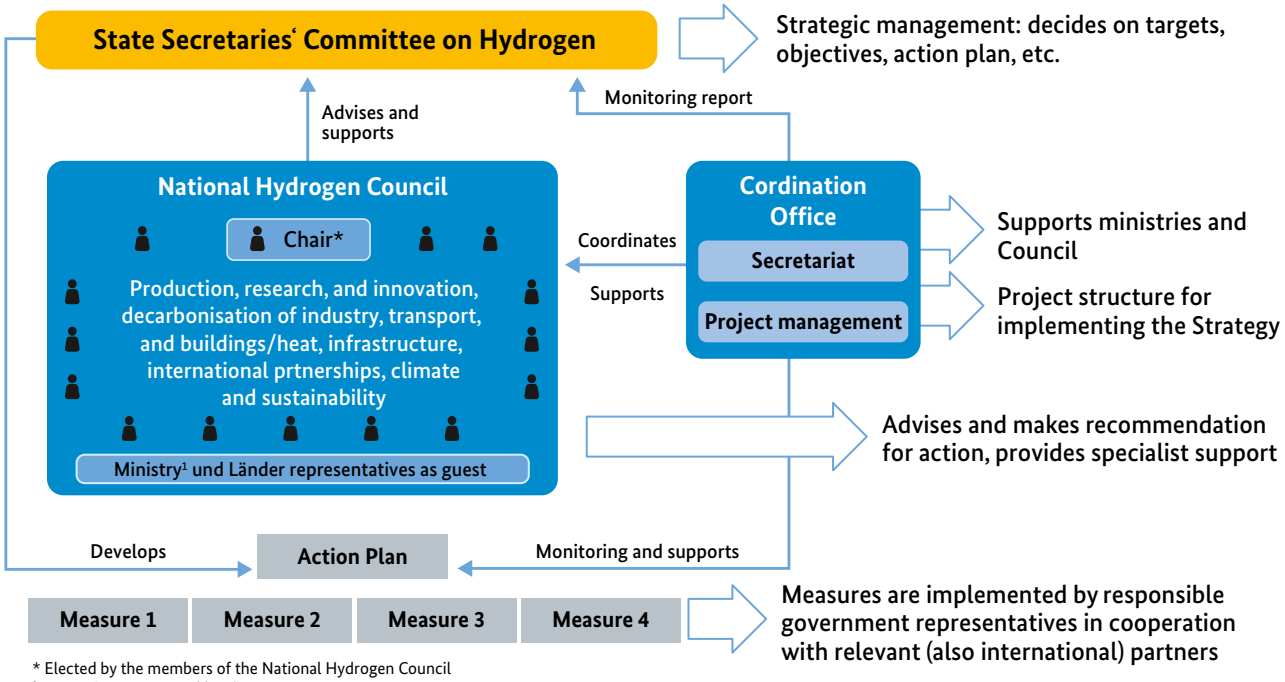
A flexible and results-oriented governance structure will be created to monitor the implementation of the strategy and develop it further (cf. Figure 1).

A State Secretaries' Committee on Hydrogen, composed of the relevant ministries, will provide continuous support for the activities under the National Hydrogen Strategy. In the event of delays in implementation or a failure to meet the targets of the Strategy, the State Secretaries' Committee will immediately take corrective action in coordination with the Federal Cabinet, adapting the action plan to the new requirements. The aim is to ensure that the National Hydrogen Strategy remains in line with market developments and delivers on its overall targets.

The Federal Government will appoint a National Hydrogen Council. The Council is made up of 26 high-level experts from business, science, and civil society who are not part of the public sector. The members of the Council should have expertise in the fields of production, research and innovation, decarbonisation of industry, transport and buildings/heat, infrastructure, international partnerships, as well as climate and sustainability. In its first meeting, the Council elects one of its members as Chair.

The task of the National Hydrogen Council is to advise and support the State Secretaries' Committee through proposals and recommendations for action in implementing and enhancing the Hydrogen Strategy. The Council and the State Secretaries' Committee hold regular joint meetings in order to facilitate coordination between the Federal Government and the Council and to ensure the Council's work ties in closely with the activities of the various ministries during the implementation of the National Hydrogen Strategy. Also, designated representatives of the ministries concerned (e.g. from the competent Directorates-General) attend the Council's meetings as guests. At the request of the Länder, two Länder representatives may attend the meetings as guests. The National Hydrogen Council meets at least twice a year.

Figure 1: Governance structure of the National Hydrogen Strategy



* Elected by the members of the National Hydrogen Council
¹ e.g at Director-General level

The 'Green Hydrogen' Innovation Officer of the Federal Ministry of Education and Research (BMBF) is a permanent guest of the State Secretaries' Committee and the National Hydrogen Council. The Officer is in charge of the organisation of research and development activities conducted by the BMBF, and coordinates their implementation in cooperation with the government, business, and science representatives that are involved in the process. Furthermore, the Officer ensures that promising innovative approaches and stimuli arising from the research that is conducted under the responsibility of the BMBF enter the political realm and are taken up by public debate.

The Federal Government is establishing a Hydrogen Coordination Office alongside the National Hydrogen Council. On behalf of the Federal Government, the secretariat of the Coordination Office assists the ministries in implementing the Hydrogen Strategy, and the Hydrogen Council in coordinating and drafting recommendations for action. The Coordination Office is also responsible for monitoring the National Hydrogen Strategy. Furthermore, it actively supports the ministries in the implementation of the Strategy by providing a flexible project management structure. To this end, thematic task forces are established at the Coordination Office.

An annual monitoring report provides a basis for recommendations and decisions to be made by the Hydrogen Council and the State Secretaries' Committee. The report not only gives an account of the overall progress made on the creation of a hydrogen economy, but also outlines any unexpected challenges that may have arisen during the reference period and identifies the steps that have to be taken. It also places particular focus on the European and international dimensions. The relevant indicators on which the report is based are continuously collected and evaluated as pertaining to the various fields of action (e.g. the electrolysing capacity installed in Germany, Europe, and other relevant countries; the amount of hydrogen and production methods across different fields of application). These monitoring reports form the basis for an extended report, to be prepared every three years, which provides an overall evaluation of the strategy and action plan and suggests how these can be developed further. The aim on this basis is to ensure the National Hydrogen Strategy is kept in line with market trends and delivers on its targets.

Cooperation between the Federal Government and the Länder

Aside from the measures taken at federal level, the Länder have also been planning and implementing their own hydrogen-related measures that are just as important in terms of the creation of a hydrogen economy and the leadership of German companies. Close cooperation between the federal and state levels helps to coordinate activities, use synergies, avoid path dependencies, share valuable experience, and define further steps of action. For this purpose, the Federal Government will soon (during the first half of 2020) establish a suitable platform format (e.g. in the form of a Federation-Länder Working Group on Hydrogen) and make sure the Länder governments are kept informed about the activities of the Hydrogen Council. Existing networks, initiatives, and working groups focusing on hydrogen will be taken into account and, where appropriate, serve as a basis for further activities.

V. Action Plan: steps necessary for the National Hydrogen Strategy to succeed

In tabling this Action Plan for the National Hydrogen Strategy, the Federal Government is laying the basis for private investment in hydrogen generation, transport and use that is both economically viable and sustainable. This can also play a part in mitigating the impact of the COVID-19 crisis and reviving the German and European economies. In a first ramp-up phase until 2023, the Federal Government will take a number of measures in the fields listed below. It will be for the competent ministries to ensure that the measures are implemented and financed on the basis of the existing budget estimates and financial plans. However, there is also a cross-cutting dimension to the National Hydrogen Strategy and there will be a strong focus on a systemic approach. This means that supply and demand will always be considered together.

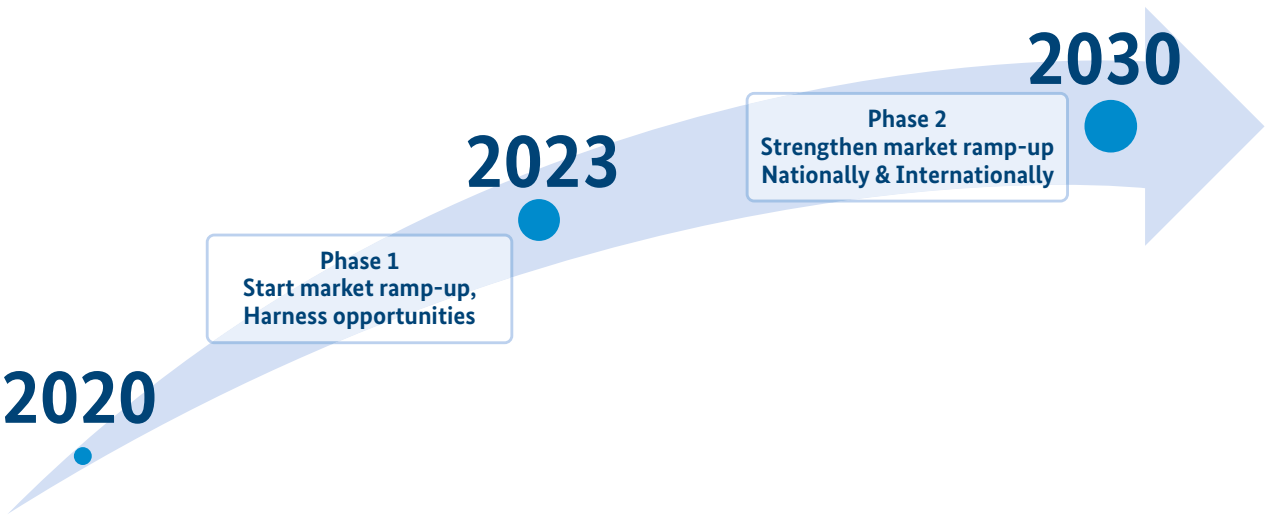
The measures set out in the Action Plan are those for phase one of the National Hydrogen Strategy, i.e. the phase up to 2023, by which time the ramp-up is to begin and the basis for a well-functioning domestic market to be laid. Parallel to this, essential issues such as research and development and international aspects are to be tackled as well. The next phase, which is due to begin in 2024, is about stabilising the newly emerging domestic market, moulding the European and international dimension of hydrogen, and using it for German industry. This shows that continuous development is a built-in feature of the National Hydrogen Strategy.

Hydrogen production

Reliable, affordable, and sustainable ways of producing hydrogen are essential for its future use. Now is the time to construct demonstration plants at an industrial scale and scale these up further to ensure that the cost of hydrogen production degresses considerably.

Measure 1

A better framework for the efficient use of electricity from renewables (e.g. by means of sector coupling) and a fair design of the energy price components induced by the state, in line with the climate targets and the targets for the energy transition (fostering grid stability), so as to create greater scope for the production of green hydrogen. The introduction of CO_2 pricing for fossil fuels used in transport and the heating sector is an important element here, and will be complemented by a reduction of the EEG surcharge as envisaged in the



2030 Climate Action Programme. This, however, will not be sufficient in the long and mid-terms to ensure a viable business environment for companies operating plants for the production of green hydrogen in Germany. Beyond what has been agreed in the Climate Package, we will therefore explore the possibility of additional reform of the price components induced by the state whilst continuing to establish CO_2 pricing as a key guiding instrument. Our analysis will also include the question as to whether it might be possible to largely exempt electricity used for the production of green hydrogen from taxes, levies, and surcharges. In particular, we are working towards exempting the production of green hydrogen from the EEG surcharge. As we do so, we will ensure that the EEG surcharge dues not rise.

Measure 2

Also being explored are possibilities for new business and cooperation models for operators of electrolysers and for grid and gas network operators in line with the principle of regulatory unbundling (results expected in 2020). We want to launch one or two model projects to test highly promising approaches that could significantly ease the burden on the grids at an affordable price without distorting the hydrogen market. Work to explore any potential need for amending the regulatory framework to make this possible is being undertaken.

Measure 3

As part of our Climate Action Innovation Pact, we are also supporting the switchover to hydrogen in the industrial sector by providing funding for investments in electrolysers (implementation starts in 2020, for more details on the Climate Action Innovation Pact and the support for hydrogen applications in the industrial sector cf. Measure 14). We are also exploring potential tendering schemes for the production of green hydrogen, e.g. to help decarbonise the steel and chemical industries. If necessary, the financing that has been earmarked for the National Decarbonisation Programme will be topped up as needed.

Measure 4

Due to the high number of full-load hours, offshore wind energy is an attractive renewables technology that can be harnessed for the production of green hydrogen. The framework for this is being developed further to ensure that investments in this area pay off. Potential adjustments that will be discussed include the designation of additional areas that can be used for offshore production of hydrogen/PtX, the infrastructure necessary for this, and the potential for additional auction rounds for the production of renewables (implementation starts in 2020).

Fields of application

Reliable demand and greater use of hydrogen are both needed for the hydrogen market to continue to develop. There are economic reasons why the hydrogen ramp-up must proceed in a targeted way and incrementally. For this reason, its use as an alternative fuel in some areas of the transport sector and as a base substance for recycling and a reductive in high-priority industrial applications is to be increased. High-priority in this case will be fields in which the use of hydrogen is close to being economically viable in the short or medium term, in which no major path dependency is being created, or in which there are no alternative options for decarbonisation.

Transport

Measure 5

The use of green hydrogen for the production of fuel and as an alternative to conventional types of fuel is to be embedded as part of a swift and ambitions transposition of the EU Renewable Energy Directive (RED II) into German law (implementation in 2020). Key levers here include:

- An ambitious GHG reduction ratio will increase the share of renewables in transport. If combined with specific other measures, it can provide incentives for the use of hydrogen or hydrogen products as an alternative fuel for transport. For this reason, the Federal Government has decided to make its objective to increase the minimum share of renewables in Germany's final energy consumption in transport significantly beyond what is required under EU rules by 2030. A target will be set in the Federal Immission Control Act; this Act stipulates a greenhouse gas emissions reduction rate for the transport sector which is to be developed further as laid down in the Coalition Agreement.

- The use of green hydrogen for the production of conventional fuel is a sensible way of harnessing hydrogen and makes a real contribution to the efforts to reduce greenhouse gas emissions from transport. We will therefore be using the opportunity presented by the transposition of RED II into German law to allow for the use of green hydrogen for the production of fuels to be counted towards the greenhouse gas reduction rate. Furthermore, we will seek to design the legislation transposing the RED II into national law in such a way that green hydrogen can be used for the production of fuel as soon as possible. We want to create clear incentives for investments in electrolysers so that the ramp-up can start soon. Our goal is to have electrolysing capacity of around 2 GW installed in Germany. If necessary, we will also provide financial support for this.

- As air traffic, in particular, will continue to rely on liquid fuel for the foreseeable future, kerosene from renewables has an important role to play for climate change mitigation. In principle, it would therefore seem to make sense to impose a requirement on suppliers to use electricity-based jet fuel, for the production of which green hydrogen is needed. An analysis is needed to find out what amounts of kerosene can be technically and sustainably produced by what time. In the interest of an ambitious market ramp-up, a minimum quota of 2% is being discussed for 2030. When adopting a legal requirement, it is important to avoid a situation whereby the German aviation industry would find itself at a competitive disadvantage. The Federal Government will therefore work with its European partners to advocate a multilateral requirement.

- Across all fields of application, a uniform and transparent methodology for establishing the carbon footprint of energy products and for assessing their level of sustainability is essential for the national, European, and global trade in alternative energy sources. We will be getting actively involved in these discussions at European level at an early stage.

All of the other measures listed below are ongoing and will continue through 2020. This notably applies to the development of new funding guidelines that can be used as a basis for calls for funding applications. Some measures have yet to be notified to the European Commission and approved by them. Calls for funding applications are due to take place regularly, beginning in 2020.

Measure 6

The funding measures under the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) will continue. The additional funding available from the Energy and Climate Fund (ECF) until 2023 leaves greater scope for hydrogen and fuel cell technology.

- Market activation to boost investments in hydrogen-powered vehicles (light and heavy-duty vehicles, buses, trains, inland and coastal navigation, car fleets); in addition to the NIP funding, funding from the ECF is also available for all technologies including hydrogen applications (until 2023):
  - €2.1 billion in purchase grants for electric vehicles;
  - €0.9 billion in purchase grants for utility vehicles powered by alternative, climate-friendly driveline technology;
  - €0.6 billion for the purchase of buses with alternative drivelines.
- R&E activities with the objective of achieving further cost reductions (e.g. for utility vehicles, small aircraft);
- "HyLand – hydrogen regions in Germany" as a three-tiered approach for the development, finetuning, and implementation of integrated regional hydrogen concepts. The plan is to extend this funding strategy that was successfully implemented in 2019.

Measure 7

Development of and funding for installations for the production of electricity-based fuels, in particular electricity-based kerosene, and advanced biofuels. For this measure, €1.1 billion from the Energy and Climate Fund (ECF) has been earmarked until 2023.

Measure 8

Funding for the construction of a needs-based refuelling infrastructure for vehicles, including heavy-duty road haulage vehicles, vehicles public transport and in local passenger rail services (cf. Measure 20). In total and for all alternative technologies combined, €3.4 billion in grants for the construction of a refuelling and charging infrastructure can be made available from the Energy and Climate Fund (ECF). If necessary, the funding for the hydrogen infrastructure will be made available at an earlier time. Under its 2030 Climate Programme, the Federal Government wants to develop concepts for the construction of hydrogen refuelling stations for commercial vehicles. As part of the efforts to promote the use of green hydrogen in heavy-duty road haulage, the network of hydrogen refuelling stations will be quickly expanded.

Measure 9

Advocacy for an ambitious development of the European infrastructure facilitating cross-border transport powered by fuel-cells; recast of the European Alternative Fuels Infrastructure Directive (AFID) (implementation begins in 2021).

Measure 10

Support for the establishment of a competitive supply industry for fuel-cell systems (fuel cells and related components) including an industrial basis for large-scale fuel-cell stack production for vehicle applications, exploration of the possibility of creating a centre for hydrogen technology and innovation to facilitate the emergence of vehicle platforms for fuel-cell drivelines and support for the establishment of a fuel-cell systems supplier for logistics/intra-logistics.

Measure 11

Target-driven transposition of the Clean Vehicles Directive (CVD) to support zero-emissions vehicles in local transport.

Measure 12

Advocacy for a carbon-based differentiation of the truck toll with reduced rates for climate-friendly drivelines under the Eurovignette Directive.

Measure 13

Advocacy for an international harmonisation of standards for mobility applications for hydrogen and fuel-cell-based systems (e.g. refuelling standards, hydrogen quality, official calibration, hydrogen-powered car type approval, licencing for ships etc.).

Industrial sector

Measure 14

The international competitive environment makes it impossible to fully pass on the cost of investment in zero-carbon technologies to the customer. This is why the Federal Government has launched several programmes under which it rewards the switchover from conventional fossil-fuel based technologies that come with inherent emissions to industrial processes that are low in greenhouse gas emissions or even climate neutral. The switchover to hydrogen as a base substance and fuel is key to this, particularly in the steel and chemical industries. The tools available for this are the fund for 'Decarbonising the industrial sector' and the programmes for 'hydrogen use in industrial production' (2020-2024) and 'avoiding and using CO_2 in industries relying on base substances'.

Measure 15

As part of the efforts to promote climate-friendly industrial procedures, we are not only providing investment grants, but also supporting the use of electrolysers. For this purpose, the Federal Government will launch a new pilot programme entitled 'Carbon Contracts for Difference (CfD)', which mostly targets the steel and chemical industries with their process-related emissions. Under this programme, the Federal Government will guarantee that it will provide funding amounting to the difference between the actual cost of avoiding emissions/a project-based contractually agreed carbon price per amount of greenhouse gas emissions avoided, and the ETS prices for the construction and operation of decarbonisation technologies to achieve greenhouse gas neutrality. Should the future ETS price rise above the contractually agreed carbon price (i.e. the cost of avoiding emissions for the respective technology), companies would be bound to pay back the difference to the Federation. This type of programme delivers a reliable investment environment and creates incentives for the early implementation of climate projects which in turn will create indirect incentives for the production of hydrogen and the ramp-up of hydrogen technologies. Once the pilot phase has been successfully completed, it will be possible to expand this type of instrument to other industrial sectors. We are aiming for close coordination with the European Commission.

Measure 16

Increasing the demand for industrial products manufactured using low-emission processes and hydrogen. The Federal Government wants to encourage work at national and European level to explore solutions as to how the markets for climate-neutral and recycled products can be boosted in energy-intensive industries. A demand quota for climate-friendly base substances, e.g. green steel, is being considered. Such measures would require a

clear and ambitious label to mark out the more climate-friendly or sustainable intermediate and end products in a way that is easy to understand.

Measure 17

Develop hydrogen-based long-term decarbonisation strategies together with stakeholders – particularly from the energy-intensive industries – within sector-specific dialogue formats (beginning in 2020 for the chemical, steel, logistics, and aviation sectors, with others to follow step-by-step).

- Chemical industries: The chemical industries already have a high demand for hydrogen as a feed material, and mostly use grey hydrogen for this purpose. One of the aims of the discussions with this sector is to explore ways in which grey hydrogen could increasingly be substituted. This is to be achieved in a way that respects the supply chains in the chemical industries and does not create any lock-in effects. For instance, it is envisaged that the hitherto used fossil-based materials could be replaced with new carbon sources (CCU, DAC etc.), which in turn would provide for a carbon-neutral raw materials basis for chemical reactions and chemical production. By the same token, there are also areas where there is excess hydrogen production, for instance in chlorine-alkali-electrolysis, which releases hydrogen as a by-product. This type of untapped potential should be registered and reviewed for potential usability.

- Steel industry: Dialogue with this industry will focus on the following issues (among others): Alternative processes, such as injecting hydrogen into blast furnaces to avoid greenhouse gas emissions in a transitional period, and, more importantly, direct H_2 reduction in dedicated installations, can make an essential contribution towards decarbonising steel production. Carbon capture and use (CCU) is also being tested in exploratory projects. Bearing in mind the investment cycles, we want to provide for a secure basis for planning. This particularly applies to the framework and to potential support for direct investments.

- Logistics: The use of hydrogen technology in haulage will depend on adjustments along the entire supply chain. Dialogue on the prospects for hydrogen in the logistics sector is to take place shortly within the innovation commission for the 'Innovation Programme for Logistics 2030'. The focus will be on how vehicle manufacturers, and suppliers of infrastructure, energy and fuels can work with logistics companies to coordinate their product ranges with one another so that hydrogen technologies can be used for decarbonising heavy-duty transport.

- Aviation: As part of the 'Round Table for the Aviation Industry', the challenges for aviation that stem from the Paris Agreement will be discussed. This is another area in which hydrogen technologies can play a part.

- Other sectors: Other applications that will not be able to rely completely on renewables, even in the long term, or which are associated with unavoidable and high process emissions, will have to be powered by alternative sources of energy or close their carbon cycles (e.g. by using hydrogen-based CCU options). Again, dialogue is needed to prepare for the necessary adjustments to make the regulatory framework – including the one at EU level – sustainable (e.g. development of a method to count CCU towards carbon reduction targets).

Heat

Measure 18

As far as the building sector (residential and non-residential property) is concerned, we have had our Energy Efficiency Incentive Programme for highly-efficient fuel-cell heating systems in place since 2016. The Federal Government will continue to provide this funding and, if necessary, top it up. Furthermore, the scope of application of this funding is assessed with a view to expanding it. For the period from 2020-2024, up to €700 million has been earmarked within the Energy Efficiency Incentive Programme and the future Federal Compensation Act, and this money can also be used for funding fuel-cell heating systems.

Measure 19

With a view to strengthening the long-term shift of the heating sector towards the use of renewables, the Federal Government is looking at ways of providing funding for 'hydrogen readiness' installations under the Combined Heat and Power Act.

Infrastructure/supply

A secure, reliable and needs-based hydrogen supply that is efficient overall will be key to the future hydrogen market. This can be achieved by drawing on the potential of existing infrastructure as needed, and initiating the construction of new elements of the supply infrastructure if necessary. The following measures are to be taken in this respect:

Measure 20

The need for long-term action within this transformation process is being assessed together with the relevant stakeholders and a report compiled, complete with recommendations for action. This means that the possibilities for using existing structures (dedicated hydrogen infrastructure as well as parts of the natural gas infrastructure than can be adjusted and backfitted to make it H_2-ready), starting with the supplier to the end consumer, need to be discussed and initiated in time. The same applies for possibilities to re-dedicate and re-use pipelines etc. for future hydrogen supply. The necessary regulatory basis for the construction and expansion of a hydrogen infrastructure will be prepared swiftly. For this purpose, a market exploration procedure is to take place shortly.

Measure 21

Efforts to better link up the electricity, heat, and gas infrastructure will continue. The aim is to shape the planning, financing, and the regulatory framework in a way that makes it possible to coordinate these different parts of the infrastructure and develop them as required in line with the needs of the energy transition and in a cost-efficient way. In this context, it is necessary to consider the potential of the existing hydrogen infrastructure whilst also ensuring its compatibility in the EU context (work in progress; outcomes of a long-term study commissioned by the Federation will be available in 2nd semester 2020).

Measure 22

As a new infrastructure is being created, special attention must be given to a needs based expansion of the network of hydrogen refuelling stations in road transport, at suitable locations within the railway network (e.g. Municipal Transport Financing Act), and for the waterways (cf. fields of application). Target groups here include individual users and operators of a large fleet of hydrogen-powered or fuel-cell-powered vehicles.

Research, education, innovation

New funding initiatives for research and innovation along the entire hydrogen value chain are to lay the basis for future success on the market. We are bundling together several targeted funding measures to make research and innovation a strategic element of the Federal Government's energy and industrial policy. This work is rooted in the 7th Energy Research Programme. The focus for the short and medium term will be on the following measures:

Measure 23

A joint hydrogen roadmap that is to serve as guidance: Germany wants to position itself as a lead provider of green hydrogen technology on the global market. For this purpose, a roadmap for the German hydrogen industry will be developed together with the science and business communities and civil society. This roadmap is designed to have international ripple effects. The application scenarios therein will be used to decide where there is need for research and action. (Begins: 1st semester 2020).

Measure 24

In the short term, demonstration projects on green hydrogen will be set up with the help of research being conducted into international supply chains. The aim here is to address some fundamental questions and aspects: ideal and typical supply and technology relations are to be developed; robust and modular solutions to be tested globally. Production sites located in our partner countries under our development cooperation are to be included in this (begins 1st semester 2020).

Measure 25

A new cross-ministry research campaign entitled 'hydrogen technologies 2030' will see a strategic bundling together of research activities into hydrogen-related key-enabling technology. (Implementation begins in Q2 2020). Key elements of the research campaign include:

- 'regulatory sandboxes for the energy transition' so as bring up PtX technologies that are close to market to an industrial scale and accelerate the process of innovation transfer;
- large-scale research projects entitled 'hydrogen in the steel and chemical industries' that pave the way for climate neutrality;
- projects in the transport sector that will use research, development and innovation to further bring down the cost of hydrogen technologies;
- feasibility studies and atlases of potential to help pinpoint economically suitable global locations for a future, green hydrogen industry. This work will take into account future developments of energy needs and of the natural resources available in the various countries;
- international networks and R&E cooperation to prepare new markets for German technology exports;
- the establishment of a new research network on hydrogen technologies to foster networking and an open dialogue between business and science that can inform public funding policy.

The research campaign will also support the National Innovation Programme for Hydrogen and Fuel Cell Technologies (cf. Measure 6).

Measure 26

A pro-innovative framework is to pave the way for the use of hydrogen technologies in real life. Assessments are being done to test if and what measures such as research and experimentation clauses could help test the market entry of hydrogen technologies and facilitate their transfer into practice. Within the short term, a pioneering project for scientific policy advice is to be set up. The project is to lay the basis for practical work to further develop the national and European legal framework to allow for a large-scale roll-out of applications for the production, storage, transport, and use of hydrogen and for related business models that are economically viable. This includes the development of a quality-assurance infrastructure that meets all the security requirements, complete with an assessment of the systems' and installations' efficiency, and of a billing system that is in compliance with calibration law and is based on reliable metering procedures. Any obstacles existing under the national or European legal framework must be identified and proposals for its development made (begins Q2 2020).

Measure 27

The targets set out in the European Flightpath 2050 document are supported by Germany's Aviation Research Programme. This programme will continue with new funding for hybrid electric aviation. For the period between 2020 and 2024, a total of €25 million from the Aviation Research Programme has been earmarked for hydrogen technologies (measure has started):

- developing overall systems capabilities in the new field of hybrid electric aviation, e.g. on the basis of disruptive engine technology (e.g. fuel cells, hydrogen-powered generators, compact and reliable hybrid electric engines on the basis of hydrogen fuel cells) and sustainable ground power (multi-functional fuel cells).
- flight tests with hydrogen-powered and hybrid electric technologies (combination of hydrogen/fuel cells/battery technology) for regional aircraft and preparation of these technologies for commercial wide-bodied aircraft.

Measure 28

Continuation of the funding instruments for 'Maritime.Green' (green shipping) as set out in the Maritime Research Programme. At EU level, a partnership initiative for 'Zero-Emissions Waterborne Transport' is under preparation for the new HORIZON Europe programme. The target here is to develop a zero-emissions vessel with closed cycle of substances. Approx. €25 million has been earmarked for the Maritime Research Programme from 2020-2024, a portion of which can be used for hydrogen-related work. (measure has started)

Measure 29

Foster education and vocational training nationally and internationally: we are supporting and further developing vocational and scientific training and continuing education in the field of hydrogen technologies so as to pave the way for individual workers and companies to be able to handle hydrogen technologies efficiently and safely. This work is focused on imparting knowledge and skills to the staff that are to produce, operate, and do maintenance work in fields where hydrogen has so far played no more than a minor role. These include plant manufacturing and, in the transport sector, garage staff that are to service vehicles powered by fuel cells. In addition to skilled professionals, we also need outstanding scientists and upcoming scientists. This is why we are venturing into new ways of cooperation between training and research, for instance by setting up centres of excellence at non-university research institutions and institutes of higher education. We are also working with

export markets to foster cooperation on vocational training and are strengthening our efforts for capacity building with special programmes, for instance for PhD students (implementation starts 2021).

Need for action at European level

The German EU Council Presidency offers a good opportunity in the second half of 2020 to proactively progress key hydrogen-related dossiers, e.g. in the context of the preparations for the legislative package on sector coupling and gas market design. These particularly include the Hydrogen Action Plan envisaged by the European Commission and the strategy on Smart Energy System Integration.

Measure 30

To ensure that a market can develop which contributes to the energy transition and to decarbonisation, as well as boosting export opportunities for German and European companies, there is a need for reliable sustainability standards and for a sophisticated quality infrastructure, proof (of origin) for electricity from renewable energy and for green hydrogen and its downstream products. At European level, we want to set sustainability and quality standards in the field of hydrogen and PtX products, and thus to actively foster the establishment of the international hydrogen market. This includes support for the development of European regulations, codes and standards in the various fields of application which will form the groundwork for the international market and ensure that the market ramp-up in Germany takes place in line with the needs of the energy transition. In parallel to this, Germany will also intensify the dialogue on common standards with other countries in order to pave the way towards a universalisation in international organisations.

Measure 31

At EU level, we wish to intensify investment in research, development and demonstration of green hydrogen. One option is the creation of a new Important Project of Common European Interest (IPCEI) for the field of hydrogen technologies and systems as a joint project with other Member States. The focus here should be on the entire value and use chain for hydrogen (generation, transport, distribution, use). To this end, the Federal Government is proactively approaching the European Commission and EU Member States in order to attract support for such a project and to initiate its realisation (ongoing process).

Measure 32

Against the background of the European Green Deal, the Federal Government is not least working towards an accelerated implementation of the EU hydrogen initiatives. Further to this, on the basis of this strategy it is supporting the drafting of a Green Paper by the Commission mapping out the prospective content of an EU Hydrogen Strategy. A joint market ramp-up of hydrogen technologies will tap economies of scale and create the basis for a successful internal hydrogen market.

Measure 33

The establishment of a European hydrogen company to promote and develop joint international production capacities and infrastructure is being explored and will be progressed if there is sufficient European backing.

International hydrogen market and external economic partnerships

International cooperation in the field of hydrogen offers opportunities in the fields of economic policy, climate change mitigation, foreign policy and development policy. We aim to make use of this, and the coalition committee's "package for the future" of 3 June 2020 offers an additional €2 billion for this. We are therefore stepping up our efforts to build up and intensify international cooperation on hydrogen at all levels. In addition to the development of hydrogen technologies and markets together with the partner countries, the focus is also on possibilities and opportunities to convert production and the export of fossil fuels to hydrogen. The following measures contribute towards this:

Measure 34

The integration of hydrogen into existing energy partnerships and the establishment of new partnerships with strategic exporting and importing countries creates new prospects, e.g. by making it possible for partner countries to use German technology to export hydrogen products, to make their economies less dependent on fossil fuels, and to meet Germany's need for hydrogen. For example, use is to be made of existing energy partnerships with partner countries – particularly via the establishment of specific specialised working groups – in order to develop sustainable import potential for hydrogen-based fuels and sales markets for German hydrogen technologies. This also takes account of the future development of domestic energy requirements and the availability of natural resources such as water in the respective countries. Here, the energy partnerships will also be contributing to the decarbonisation and economic development of the countries exporting the hydrogen.

Measure 35

We will rapidly progress the cooperation with partner countries in the context of a hydrogen alliance in coordination with EU initiatives. The envisaged cooperation will focus on collaboration along the entire value chain. This will create a platform for German companies to position themselves on foreign markets. Also, German firms which need the fuel will find it easier to obtain climate-neutral hydrogen. (Launch of initiative in 2020)

Measure 36

We will strengthen the existing international activities, particularly in the context of the energy partnerships and of multilateral cooperation, such as that of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), the International Renewable Energy Agency (IRENA) and the International Energy Agency (IEA), and we will make use of them to progress the supra-regional aspects of hydrogen. Here, the compilation of atlases of potential for the generation of green hydrogen and its downstream products will help with the identification of future countries of destination and opportunities to export installations (cf. also Measure 25). To this end, information is to be compiled and pooled to show which forms of energy can be best produced in the partner countries in the light of their general parameters. A special focus will be placed on countries with active German development cooperation and their potential for hydrogen production. Account must also be taken of the growing need for energy and the availability of natural resources like water. Atlases of potential for selected countries of German development cooperation will be produced in time for the German EU Council Presidency. (Implementation from first half of 2020)

Measure 37

Pilot projects in partner countries, not least as part of German development cooperation involving German firms, are to show whether and how green hydrogen and its downstream products can be produced and marketed there on a sustainable and competitive basis. Concepts for this are to be developed, and specific implementation options drawn up. Here, attention will be paid to ensuring that an import to Germany of green hydrogen or energy sources based on it takes place on top of domestic energy production in the respective partner countries and does not impede the supply of renewable energy, which is inadequate in many cases, in the developing countries. Also, the sustainable supply of water in arid regions of these countries must not be impaired by the production of hydrogen. The aim is to achieve sustainable production along the entire supply chain. This project is to make use of the opportunities offered by the hydrogen market as a key component of partnership-based development cooperation, and thus to give the partner countries fresh opportunities for sustainable value creation, energy and jobs, as well as incentives for a decarbonisation of their economies and the establishment of sustainable supply chains (implementation from 2020).

Measure 38

In relations with the current exporters of fossil fuels, the Federal Government will intensify the dialogue with a view to a gradual global energy transition including hydrogen. Fresh opportunities are to be taken which are offered by an at least partial substitution of fossil fuels by hydrogen, not least with important energy policy stakeholders.

VI. Glossary

Grey hydrogen: Grey hydrogen is based on the use of fossil hydrocarbons. Grey hydrogen is mainly produced via the steam reforming of natural gas. Depending on the fossil feedstock, its production entails considerable carbon emissions.

Blue hydrogen: Blue hydrogen is hydrogen which is produced using a carbon capture and storage (CCS) system. This means that the CO_2 produced in the process of making hydrogen does not enter the atmosphere, and so the hydrogen production can be regarded on balance as carbon-neutral.

Green hydrogen: Green hydrogen is produced via the electrolysis of water; the electricity used for the electrolysis must derive from renewable sources. Irrespective of the electrolysis technology used, the production of the hydrogen is zero-carbon since all the electricity used derives from renewable sources and is thus zero-carbon.

Turquoise hydrogen: Turquoise hydrogen is hydrogen produced via the thermal splitting of methane (methane pyrolysis). This produces solid carbon rather than CO_2. The preconditions for the carbon neutrality of the process are that the heat for the high-temperature reactor is produced from renewable or carbon-neutral energy sources, and the permanent binding of the carbon.

Downstream products: Further products can be made from hydrogen (ammonia, methanol, methane, etc.). As long as these products are produced using "green" hydrogen, the overarching term "Power-to-X" (PtX) is used. Depending on whether the downstream products are gaseous or liquid, the term "Power-to-Gas" (PtG) or "Power-to-Liquid" (PtL) is used.