BREMEN
BREMERHAVEN
HOME OF INNOVATION

HYDROGEN STRATEGY
THE STATE OF BREMEN

Ministry of Economic Affairs, Ports and Transformation

Ministry for Environment, Climate and Science

Ministry for Building, Mobility and Urban Development

The Hydrogen Strategy was drawn up in 2021 under the auspices of the Ministry of Economic Affairs, Ports and Transformation in consultation of the Senate Chancellery, the Ministry for Environment, Climate and Science, the Ministry for Building, Mobility and Urban Development and the companies WFB Wirtschaftsförderung Bremen GmbH, BIS Bremerhavener Gesellschaft für Investitionsförderung und Stadtentwicklung mbH, bremenports GmbH & Co. KG and the University of Bremen.

HYDROGEN STRATEGY
THE STATE OF BREMEN

FOREWORD

There is broad agreement about the need for an energy transition toward renewable energies and a climate-neutral economy. Corresponding resolutions have been taken on different levels in order to support for this transition and achieve net zero carbon emissions.

The Senate of the Free Hanseatic City of Bremen has adopted its Climate Protection Strategy 2038 that encompasses those measures which are necessary to achieve its emission reduction targets. Furthermore, the Climate Protection Strategy makes the Free Hanseatic City of Bremen more resilient in terms of energy supply and contributes to the transformation of its economy and infrastructure required to achieve climate protection objectives. One important aspect consists in using hydrogen for applications which, from today's perspective, cannot otherwise be decarbonised. Examples here include steel production or individual segments of the transport sector, where hydrogen offers technical and economic advantages. The state of Bremen adopted the North German hydrogen strategy in November 2019 in conjunction with the other four North German states. It has been implemented jointly since then. The national and European strategies followed in 2020. In December 2021 the Bremen senate adopted the "State of Bremen Hydrogen Strategy", at almost the same time as the Northwest Metropolitan Region adopted its strategy.

In just a few years, infrastructure projects such as Hyperlink and Clean Hydrogen Coastline will have connected the state of Bremen to the European hydrogen pipeline system, which will allow for rapid implementation of hydrogen projects on an even larger scale. Our departments are working with great dedication alongside partners from industry and science on these and other parts of the hydrogen value chain, including the use of hydrogen in industry and transport. It is a case of exploiting the many opportunities presented by building new and expanding large parts of the energy infrastructure.

The current use of hydrogen in Bremen's industry is mainly characterised by major projects in steel production or aircraft manufacturing, where the challenges consist in finding and developing viable solutions for the fossil fuels used up until now The particular challenge at Bremen's steel works is the huge quantity of hydrogen needed to produce so-called green steel and reduce the site's emissions. Current developments in Bremen into the role that liquid hydrogen can play in aviation are making a contribution to reducing emissions in the mobility sector.

Bremerhaven is becoming an established test region and centre of excellence in the north for hydrogen production and conversion, as well as fuel cell technology. Numerous research and development projects are already in progress. The lighthouse project "Hydrogen – Green Gas for Bremerhaven" is laying the foundations for a hydrogen industry as part of the seaport's "Green Economy". The "Innovation and Technology Centre for Hydrogen Mobility in Aviation and Shipping" combines the core expertise of Bremerhaven and Bremen.

One particular advantage in the state of Bremen is its research infrastructure and expertise. The Bremen University, the universities of applied sciences and the research institutes offer many years of experience with renewable energies. Bremen's scientists have distinguished themselves with a wealth of expertise in material research, prototype studies, and trials under real-life conditions, together with interdisciplinary research projects. Hydrogen research in the state of Bremen excels with its inter- and trans-disciplinary approach, in addition to close cooperation with regional and supra-regional companies.

Bremen's ports are a central shipping hub for cars and containers as well as conventional general, heavy, and bulk cargo. They can therefore also play an important role in importing and distributing hydrogen and its derivatives. This is a crucial location advantage, particularly in combination

with Bremen Cargo Distribution Center (GVZ) in Bremen, one of the largest and most efficient of its kind in Europe. As central logistics facilities, the ports, the GVZ and the private-sector logistics companies will also be using the new fuels. The "Study on developing and establishing a port-related hydrogen economy" provides analysis among others of possible future options for the port-related hydrogen economy in Bremen.

Special efforts will be necessary to ensure that qualified skilled workers are available to perform the many new tasks. An ongoing challenge consists in providing further vocational and academic training on all levels of the value chain, as well as integrating new content in existing training schemes and implementing acceptance-building measures at an early point in time.

The state of Bremen faces great challenges in implementing the first lighthouse projects and incorporating numerous other activities. Even so, it has already established a lead over other states and regions, a lead that must be expanded and exploited on a regional and international scale in the interests of a climate-neutral economy. The state of Bremen hydrogen strategy with its specific goals and measures conveys an overall picture of the chances and challenges and allows a coordinated approach.

The strategy has been compiled and implemented on an inter-departmental basis and can thus rely on broad support on the political and administrative level. It will be brought to life by the involvement of companies and scientific institutions as well as associations and chambers. We invite all stakeholders to take part in implementing the strategy as contributors and multipliers.

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Senator for Economic Affairs,
Ports and Transformation

Source: Jan Rathke

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Senator for Environment,
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Source: Tristan Vankann

Özlem Ünsal
Senator for Building, Mobility
and Urban Development

Source: SWH

ENERGY CONSUMPTION AND EMISSIONS 2019

Structure of energy consumption	in TJ	in TWh
Primary energy consumption	143,153	39.8
Losses, differences etc.	36,930	10.3
Final energy consumption	106,223	29.5

Energy consumption by fuel	in TJ	in TWh	as a %
Coal	28,303	7.9	26.6
Lignite	2,287	0.6	2.2
Oil/oil-based products	24,350	6.8	22.9
Natural gas	23,491	6.5	22.1
Other gases	6,002	1.7	5.7
Electricity	16,225	4.5	15.3
District heating	3,892	1.1	3.7
Renewable energies	1,672	0.5	1.6
Total	**106,222**	**29.5**	**100**

Energy consumption by sector	in TJ	in TWh	as a %
Manufacturing	56,822	15.8	53.5
Households, commerce, trade, services	29,734	8.3	28.0
Transport	19,666	5.4	18.5
Total	**106,223**	**29.5**	**100**

CO_2 emissions from final energy consumption (originator balance)*	in million tonnes	as a %
Manufacturing	5.1	58.6
Households, commerce, trade, services	2.2	25.5
Transport	1.4	15.9
Total	**8.8**	**100**
Electricity share	**1.8**	**20.2**

TRANSPORT AND TRAFFIC 2019

- approx. 38 million tonnes of cargo handled by maritime transport
- approx. 32 million tonnes of cargo handled for hinterland transport
- approx. 3 million trucks for hinterland transport
- approx. 36,000 trains for hinterland transport
- approx. 7,200 barges
- approx. 7,000 seagoing vessels
- approx. 14,700 take-offs at Bremen airport

* CO_2 emissions based on the originator balance. Includes emissions of final energy consumption in the state. The source balance includes all CO_2 emissions generated in the state, including exported electricity, for example.

Statistical Office of the State of Bremen, Statistical Yearbook 2021, pages 354-358; https://www.statistik.bremen.de/sixcms/media.php/13/Jb2021_pdfa.pdf

1 INITIAL SITUATION AND FRAMEWORK CONDITIONS

The aim of the Paris Agreement on Climate Change (2015) is to keep global warming well below two degrees Celsius above pre-industrial levels. The aim in Germany is to achieve climate neutrality by 2045. As a result, there is a need for resolute, constant reductions in the emissions of climate-damaging gases.

Climate protection and the energy transition must therefore be consistently implemented and accelerated. A fundamental change is needed in order to expand renewable energy generation, decarbonise all sectors of industry alongside the transport sector, and improve energy efficiency. The use of fossil fuels should be replaced completely by an energy system based on renewable energies.

With CO_2 emissions of approx. 9 million tonnes (2019), the federal state of Bremen makes a relatively large contribution to Germany's CO_2 emissions compared to its economic output, so that special efforts will be required to reduce these emissions.

At the same time, this transformation process should be used to establish sustainable and competitive economic, industrial and transport structures in Bremen.

Fossil fuels will have to be replaced by electricity from renewable sources and also by other fuels based on renewable energies. Green hydrogen provides a universal basis as a source of energy, a means of storage, a sector coupling element and raw material for the chemical industry.

Bremerhaven

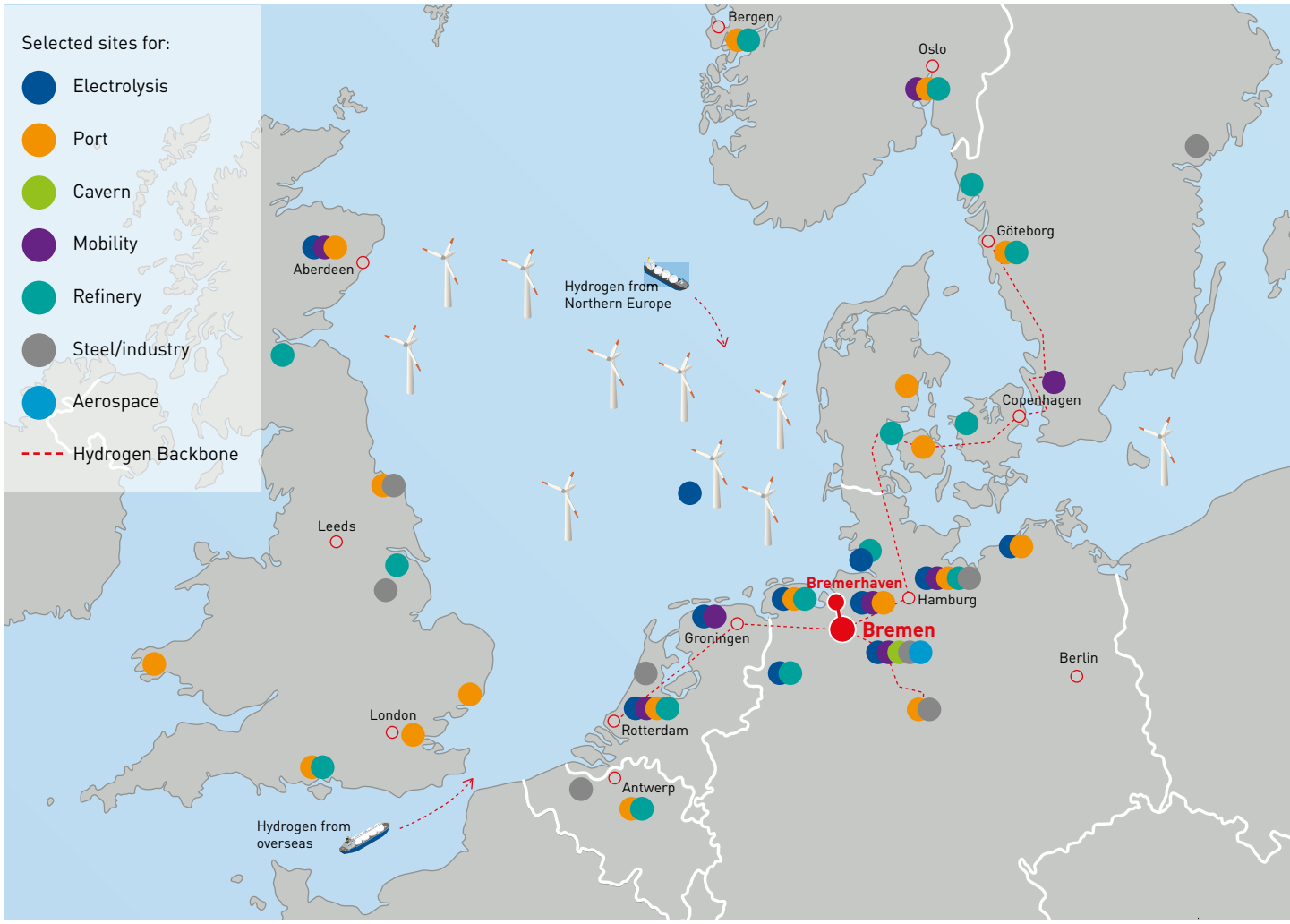
Green hydrogen[1] thus plays a central role in the energy transition for Bremen/Bremerhaven and offers many possibilities and business options for the state economy when it comes to creating and safeguarding sustainable, future-oriented jobs in the hydrogen economy[2].

Political framework/context for Bremen's hydrogen strategy

Promoting green hydrogen was already anchored by Bremen state government in the **coalition agreement** of August 2019. This was further extended in the 2023 coalition agreement. The aim is to make significant progress with hydrogen technology and the hydrogen economy. Active support is to be provided for building electrolysis units and using hydrogen in the manufacturing industry and in the transport sector including the ports, as well as funding studies into using hydrogen for storage and other applications. The prerequisites are to be created for successfully implementing a hydrogen-based industry, as well as opening up future markets by using hydrogen as energy storage medium in sector coupling.

[1] The transformation process may possibly involve interim solutions, particularly for industry-focused uses, including so-called "blue" and "turquoise" hydrogen to compensate for predictable bottlenecks in hydrogen availability or in the interests of economically viable transformation.

[2] Hydrogen economy refers to the development of an economy with hydrogen as the main source of energy, alongside electricity. Furthermore, a hydrogen economy focuses particularly on hydrogen replacing the fossil fuels that form the basis for the current energy sector.



Future scenario "Hydrogen Hanse"

In 2020, Bremen's state parliament decided to set up a **Committee for the "Climate Protection Strategy in the State of Bremen"** to draw up a climate protection strategy by late 2021. The Committee published it in December 2021. It laid out a target for climate neutrality in which the electricity generation from fossil resources is replaced completely by regenerative electricity and green hydrogen. Accordingly, green hydrogen will play a major role in achieving Bremen's climate goals. The report predicts a considerable surge in demand for hydrogen within Bremen, mainly for the steel works green steel production line. Other industrial uses will scale up their consumption as well, i.e. to supply cogeneration power stations to keep the district heating and power grids operating while no power is generated by renewable energy sources. In 2023, the Senate of Bremen is in the process of implementing its Climate Protection Strategy, including various measures on hydrogen. The strategy extends to a funding scheme including so called "Fastlane" measures derived from the report.

In spring 2020, the state of Bremen established the **Bremen Fund to deal with the consequences of the Covid-19 pandemic**. The study commissioned in this context[3] came to the conclusion that the state has expertise and basic aspects for stimulating positive economic development in future areas such as the development of hydrogen technology. This applies particularly to using hydrogen-based processes to transform steel production, as well as supporting a general hydrogen economy, which is currently in the process of being established. As a result, options are available for the future of currently carbon-intensive sectors of the economy, such as the steel and chemicals industry, logistics, the port industry or shipping.

The current *Innovation Strategy of the State of Bremen* "Key to Innovations 2030 – Strategy for Innovation, Services and Industry" sees hydrogen technology as an innovation driver and central element for sustainable economic management and efficient use of resources.

By establishing a hydrogen economy and using hydrogen in sector coupling, the state of Bremen gives itself and its regional, national and international partners great cross-sectoral potential for sustainable value creation and competitive advantages.

The five coastal states in North Germany have taken the initiative and compiled the **North German hydrogen strategy**. which was adopted and published in November 2019 by the Conference of Coastal Ministers of Economic Affairs and Transport.

The strategy presents 15 goals for North Germany. The key aim is to establish a green hydrogen economy in North Germany by 2035 with almost complete provision for all consumers interested in green hydrogen. An electrolysis output of minimum 500 MW is to be set up by 2025 (2030:5 GW) for the production of green hydrogen. Steps and timelines are defined in four areas of action:

- Taking stock of the situation for hydrogen hubs and multi-modal filling stations together with the import and pipeline infrastructure, as well as other steps;
- Drawing up a location, settlement and marketing concept, as well as examining possible cooperation with neighbouring regions;
- Reviewing regulations, authorisation procedures, technical standardisation and funding programmes, and drawing up proposals;
- Elaborating suggestions for public relations and measures and for integrating hydrogen as a topic in syllabuses.

The **national hydrogen strategy** of the Federal Government (June 2020) contains altogether 38 measures for the production of hydrogen, for applications in transport, industry and heat, for infrastructure/supply, for research, education and innovation as well as the need for action on a European level, the international hydrogen market and external economic partnerships. The aim is to achieve electrolysis output of five gigawatt for green hydrogen by 2030. €9b in funding have been earmarked for the period through to 2027.

In July 2020, the EU presented the **"Hydrogen Strategy for a Climate-Neutral Europe"** as part of the European Green Deal, alongside the "EU Strategy on Energy System Integration". The central goals of the European strategy are as follows: a CO_2-neutral economy in Europe by 2050 and the phased expansion of production for green hydrogen in a scope of at least 40 GW electrolysis output by 2030.

Parallel to the development of Bremen's hydrogen strategy, in 2021 a **hydrogen strategy for the Northwest Metropolitan Region** was elaborated, with the participation of representatives from Bremen. The hydrogen strategy for the Northwest Metropolitan Region aims to visualise the great potential of diverse regional expertise and the particular suitability as a hydrogen region, contributing towards the further development.

The state of Bremen hydrogen strategy

The state of Bremen has drawn up its own hydrogen strategy, given the already mentioned special significance that the development of the hydrogen economy has for the state. It supplements the state's innovation strategy. The hydrogen strategy is to be seen in the context of the measures described on the North German, national and European level. The aim is to make the measures successful, to put them to strategic use and to tap into national and European funding possibilities.

Furthermore, Bremen's hydrogen strategy aims to contribute to a shared understanding of the initial situation, to set out objectives, to continue the development of measures that have begun and to prepare additional ones.

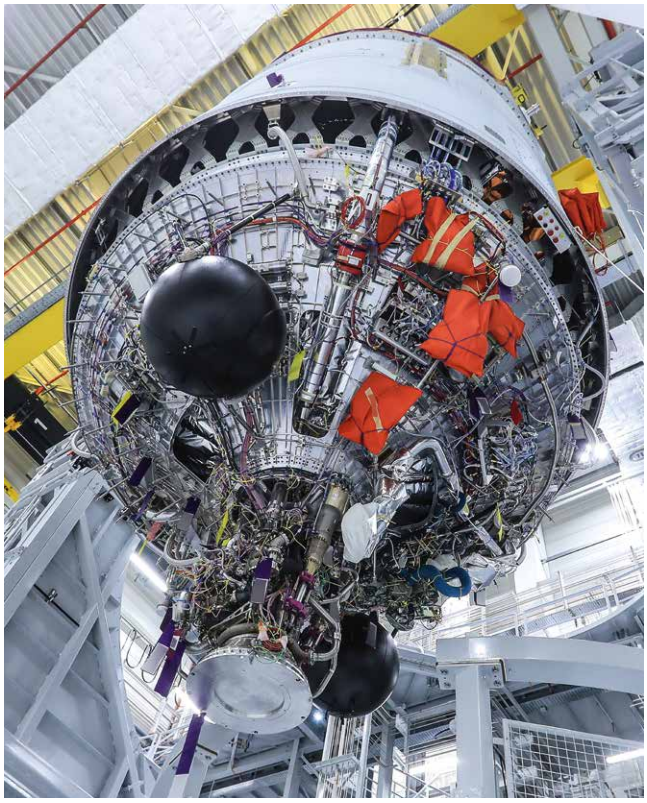
At the same time, developments on the hydrogen sector are highly dynamic and depend in the medium and long term on many variables such as general conditions in the energy sector and cost aspects. Furthermore, it is currently uncertain if and when important projects can be implemented. This current paper therefore intends to take stock of the current situation and to propose a strategic framework and starting point for further developments.

[*] https://www.bremische-buergerschaft.de/index.php?id=722

[3] Bremen Fund – Selection of medium- and long-term measures for a restart after the crisis. Study by IW Consult GmbH in conjunction with Prof Dr Jens Südekum (31 August 2020).

2 STRENGTHS AND CHANCES OF THE LOCATION

The location of Bremen/Bremerhaven in Northwest Germany presents ideal conditions for regional production, distribution and use of green hydrogen, and also for importing hydrogen from European and global sources, together with synthetic fuels made from hydrogen. The location offers applications in industry and other sectors, outstanding port infrastructure for importing hydrogen, a good research landscape, access to offshore and onshore wind energy from the region with current further expansion in this sector, efficient infrastructure for the gas transmission and distribution grid and large-scale storage options in the vicinity. The unique selling points stated in the North German hydrogen strategy apply in particular to the state of Bremen and its surroundings. Working on the basis of the national hydrogen strategy, the state of Bremen is pursuing cross-sectoral development of applications and the preparation of Europe and international import options for hydrogen.



Upper stage of the Ariane 6 rocket

Sectors of industry and maritime companies have experience with hydrogen and offer considerable potential

Hydrogen is already being used on a smaller scale by various sectors of industry in the state of Bremen. The aviation industry, for example, has expertise with liquid hydrogen that has been used as rocket fuel for decades. Hydrogen is used in the local steel industry to create an inert gas atmosphere and is produced on site from natural gas by steam reformation. In the food and bever ages industry, hydrogen plays a role as packaging gas or propellant. In future, the potential of hydrogen as an energy source is to be developed on a cross-sectoral basis.

Implementing the hydrogen economy will be accelerated primarily in those sectors of industry where the consumption of fossil fuel cannot be efficiently replaced with power from renewable energy sources. In the state of Bremen, this includes above all the steel industry which is expected to have a high demand for hydrogen Hydrogen will also replace fossil fuels in the shipping, aviation and HGV sector, all important players in Bremen's economy.

Bremen's location advantages come from the physical proximity of the planned electrolysis facility to the steel works as potential major hydrogen consumer and to the industrial ports, Neustadt port and the freight village, together with the general proximity of the sea ports to the offshore wind farms in the North Sea.

Furthermore, the state offers a wealth of energy-sector know-how that also applies to hydrogen, thanks to efficient energy utility companies in Bremen, Bremerhaven and the surrounding areas as well as a differentiated range of power stations with a broad generation mix.

Ports as economic centres and transport and logistic hubs

For shipping that comes from the North Sea, Bremerhaven is easily accessible for importing hydrogen, with just a short estuary approach (particularly once the pending adjustment has been completed). It is an ideal location for constructing import terminals to meet the growth in demand. Many solutions are conceivable, from small-scale transport in containers through to large-volume landings of hydrogen, synthetic methane, methanol or ammonia as hydrogen carriers. Ongoing transport to bulk consumers in the hinterland and also the availability for shipping will have to be organised in order to assume an important role for supplying industry.

In principle, import options include pipelines and also port-based shipping terminals. Possible hydrogen imports from North Sea states such as the Netherlands, Norway, Iceland and the United Kingdom offer further potential when the hydrogen is transported by sea. The necessary port infrastructures and specific development options are currently the subject of the study "Analysis of the port-related hydrogen economy". By providing shipping with zero-emission fuels, the ports can become a hotspot of hydrogen usage for the port industry and the logistics sector. Linking hydrogen imports with current port projects to develop CO_2 transport chains from local and supra-regional CO_2 capture facilities offers good local prerequisites for organising the production of the required synthetic fuels.

Underground formations for storing hydrogen

The storage caverns in Lesum and in nearby Huntorf are part of Northwest Germany's infrastructure for large-scale storage of gas, which is unique in Europe. Individual caverns can be converted to hydrogen. The storage facility can be used to compensate on a larger scale for fluctuations in the provision and usage of renewable energies. Together with the excellent regional pipeline network for natural gas, which can also be partly converted to hydrogen, there are excellent prerequisites for a future integrated energy sector based on green electricity and green hydrogen.

Extensive expertise at universities and scientific research institutes

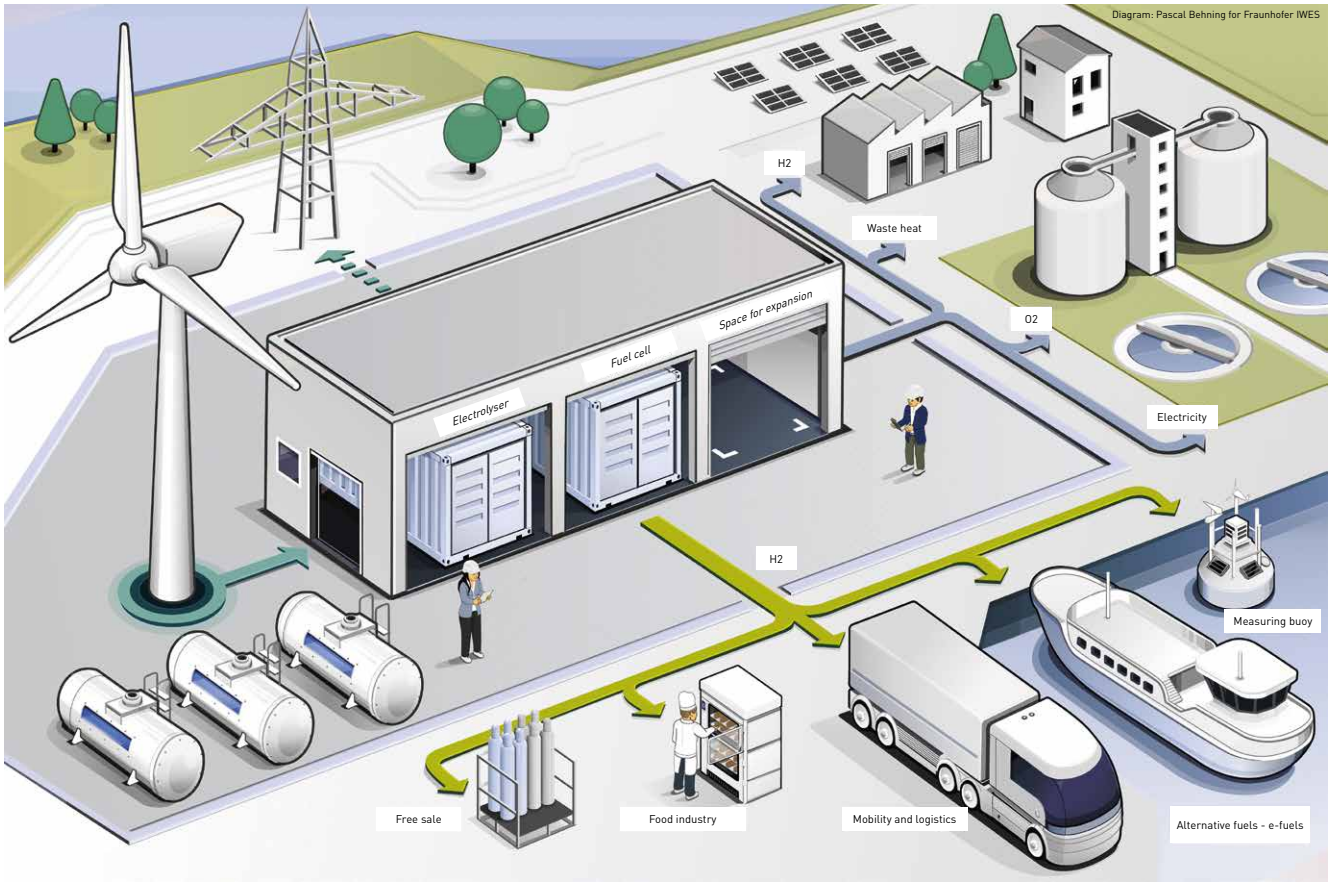
Many research institutes and universities in the state offer a wealth of expertise in research into and with hydrogen. Among others, research topics include producing hydrogen from green electricity and reconverting hydrogen to electricity, as well as integrating wind power into the electricity grid and hydrogen into the gas grid. Expertise exists in terms of simulating and optimising energy systems, together with material science expertise for developing new, hydrogen-resistant materials that can be used in a broad range of applications. The development of economic applications for hydrogen in logistics, transport, shipping, manufacturing and the offshore industry rounds off the research profile. The research institutes maintain outstanding research relationships with local, regional and supra-regional industrial companies so that industry and society at large benefit directly from the research results.

Regional and supra-regional networking

Business and science are well networked in both cities. Hydrogen working groups have already been set up in the existing cluster organisations for wind energy, the maritime industry and aviation.

The "Hyways for Future" project and the compilation of the hydrogen strategy for the Northwest Metropolitan Region have resulted in intensive hydrogen-related networking within the Metropolitan Region. Representatives from Bremen and Bremerhaven are actively involved in dealing with the above-mentioned areas of action for implementing the North German hydrogen strategy. The "North German Hydrogen Coordination Group" has existed on the ministerial level since the North German hydrogen strategy was compiled. A special hydrogen event at the North German Conference of Ministers of Science in 2020 clearly intensified networking on the North German level, particularly in the science sector. International contacts exist especially with the Netherlands and other North Sea states.

3 ACTIVITIES IN MORE THAN 20 PROJECTS



Hydrogen – green gas for Bremerhaven

The Free Hanseatic City of Bremen made a comparatively early start with hydrogen-related activities along the value chain. The senate and many other players in the state of Bremen have begun to initiate and support specific measures and made substantial contributions towards setting up a green hydrogen economy. These measures have set important milestones and starting points for the development as a hydrogen location.

Moreover, work is about to being on implementing certain major hydrogen projects in Bremen, primarily with federal funding, that have central significance for this strategy (see chapter 4.2).

Microgrid container of Bremerhaven University of Applied Sciences

Hydrogen filling station Bremen

Future scenario electrolyser in machine room

The following section looks at some of the key projects in the implementation phase:

Hydrogen – green gas for Bremerhaven

The former airfield at Bremerhaven's fishing port and the adjoining areas are being used to set up an electrolyser test site (Hydrogen Lab Bremerhaven), and also for developments into industrial applications for the hydrogen produced in this way. The project is in the hands of the Fraunhofer Institute IWES, Bremerhaven University of Applied Sciences and the ttz Bremerhaven. It is being funded with €20m from the state of Bremen's ERDF programme, and is the first component for a "Hydrogen Centre of Excellence" in Bremerhaven.

HyBit (decarbonisation of steel production)

HyBit "Hydrogen for Bremen's industrial transformation" is a project that marks the start of decarbonisation in Bremen's steel production. The on-site production (electrolysis) of green hydrogen, initially with an output of 10 MW, for use in the steel works and in the transport sector generates significant reductions in emissions and is creating the basis for a hydrogen economy in the industrial ports and adjoining areas. The senate has granted a sum of €10m for this project from the Bremen Fund. HyBit is one of the largest projects of its kind in Europe

Research infrastructure

In the framework of the Bremen Fund, a comprehensive research infrastructure is being made available to strengthen research into material and manufacturing, thus preparing the use of hydrogen technology in industrial applications, particularly in aviation. The Leibniz Institute for Materials Engineering (IWT), the Fibre Institute Bremen (FIBRE) and the Bremen Institute of Applied Beam Technology (BIAS) are being equipped with the necessary infrastructure. This enables them to investigate the effect that hydrogen has on materials made of metal, man-made fibres and carbon, develop materials for hydrogen applications and optimise the production processes for electrolysis and fuel cells components, thus bringing down the manufacturing costs. The senate has made funds amounting to €13m for this purpose.

Test region mobile hydrogen applications Bremerhaven

The project includes the following measures: procurement of a plasma analyser to test how hydrogen can be produced from wastewater (project partner: ttz Bremerhaven, Bremerhavener Entsorgungsgesellschaft); retrofitting public vehicles to run on hydrogen (police vehicle, Unimog truck; project partners: ttz Bremerhaven, Bremerhaven University of Applied Sciences, Bremerhaven police authority, fishing port operating company; construction of a technical centre

Research and Technology Centre ECOMAT

as basic infrastructure for a future H2 test facility for prototype applications, including a 3D test rig (so-called swell simulator). The project has a financial volume of €5m.

Office for the hydrogen economy, other agencies

In order to coordinate hydrogen-related activities in Bremen, a corresponding office has been set up in early 2022 by the senate under the auspices of the Senator for Economic Affairs, Labour and Europe, since July 2023 Senator for Economic Affairs, Ports and Transformation. It implements Bremen's hydrogen strategy and the North German hydrogen strategy and monitors activities being carried out in the context of the national hydrogen strategy and the national hydro-gen council. It works with companies and other relevant organisations to develop and initiate measures for establishing a hydrogen economy in the state of Bremen with the participation of research institutions, networks, economic development agencies, the political sector, chambers and associations.

An office to coordinate port-relevant hydrogen topics has been set up under the auspices of the Senator for Science and the Ports.

Analysis of the port-related hydrogen economy

In March 2021, the senate decided to commission a study to develop and establish a port-related hydrogen economy (total volume €640,000), for which the Senator for Science and the Ports is responsible. Among others, the study looks at potential transport routes, the role of Bremen's ports and the corresponding requirements to be met by the port location.

SHARC

As part of the 7th Energy Research Programme, the Federal Ministry for Economic Affairs and Climate Action (BMWK) provided funds amounting to approx. €2.5m for the SHARC project: Smart Harbour Application Renewable Integration Concept. The project examined Bremerhaven's international port to ascertain the demand for energy, the possibilities for changing over to renewable energy sources, and approaches to fostering sector coupling with hydrogen technologies. The project also drew up an investment concept.

A list of main hydrogen projects can be found in the Annex.
Together these projects prepare the ground for other activities.

4 AREAS OF ACTION AND STRATEGY

4.1 AREAS OF ACTION

The transformation to a carbon neutral economy based on hydrogen has an impact on many aspects and important areas of the economy in the state of Bremen. This section lists the essential areas of action to be treated with priority. The areas of action result from the sectors of the industry that form the backbone of Bremen's economy, which are also marked by high CO_2 emissions. Many of the areas of action, such as the steel industry, ports, logistics and transport, are featured in the so-called hydrogen hubs detailed in chapter 4.3 Development in other areas of action, such as the aviation sector, is expected to be relatively independent of the hydrogen hubs.

4.1.1 STEEL INDUSTRY

The transformation of the steel industry in Bremen plays a central role in developments towards a hydrogen location. Notable CO_2 reductions needed for climate protection can be achieved here mainly by using hydrogen and by replacing the conventional blast furnaces in the long term.

The steel works is Bremen's worst polluter with emissions amounting to around 4.2 million tonnes of CO_2 per year, corresponding to about 50% of total emissions in the state. Most of the emissions are caused by the blast furnace route (there are two blast furnaces in the steel works), with smaller contributions from galvanising and the rolling mills, together with other processing steps. The furnace gas resulting from steel production is converted into electricity in a power station operated by swb (block 4) in Mittelsbüren.

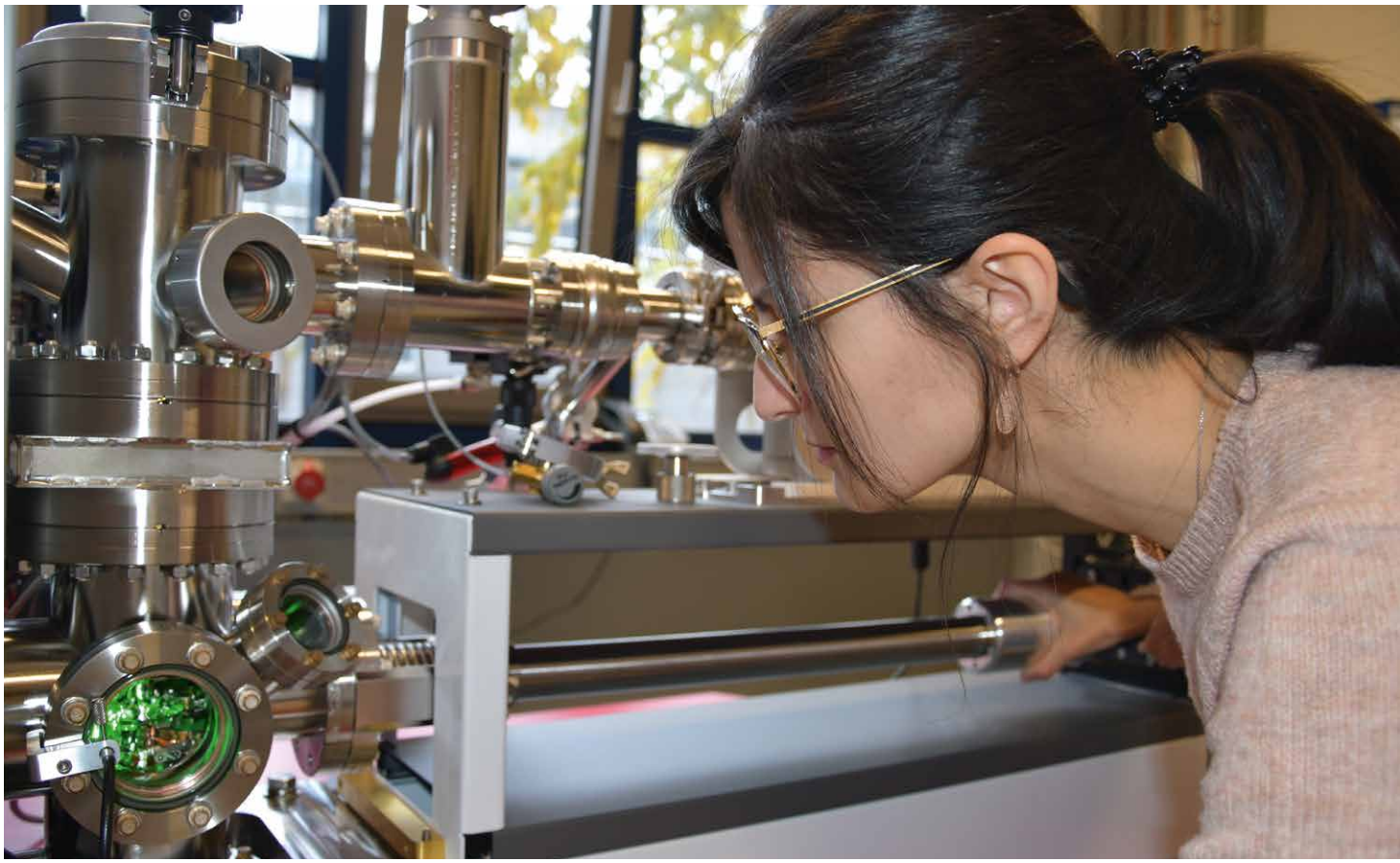
To transform the steel works, the blast furnace route will be operated partly with hydrogen to start with, before the blast furnaces are replaced with a green hydrogen-powered direct reduced iron plant (DRI) and an electric arc furnace (EAF) in the long term.

Steel production in Bremen

According to the company's current plans, the direct reduced iron plant and the electric arc furnace should replace the smaller blast furnace 3 as from 2026 (the DRI plant is part of the IPCEI project DRIBE2, see chapter 4.2.1). The larger blast furnace 2 should be replaced by expanding the DRI-EAF route in 2032 at the latest. In the meantime, emissions will be reduced by using hydrogen and natural gas, before completing the fundamental change to direct reduction and electric steel production in blast furnace 2.

The advantage of a DRI plant is that it can be operated with natural gas to begin with if the hydrogen supply on site is not sufficient at that point in time. ArcelorMittal intends to produce 1.5 million tonnes of crude steel with the DRI plant and the electric arc furnace by 2026 in the first stage, compared to the current total output of around 3.5 million tonnes of crude steel p.a.).

Part of the infrastructure needed for producing hydrogen is already available at Mittelsbüren power station near the steel works. In the first phase, by 2023 an electrolyser with output of up to 12 megawatts (MW) will be installed in one of the power station buildings to produce hydrogen for use



Atom probe tomography at Leibniz Institute for Materials Engineering – IWT

in the blast furnace, in galvanising, in other processes and for transport. The investment is being supported from the state's Bremen Fund as part of the "hyBit" project. The intention is for the electrolyser to operate with green power from offshore wind parks. The electrolysis capacity should eventually be increased to 300 MW.

Additional infrastructure will have to be adapted or acquired for full decarbonisation of steel production. The output of the power grids and electrical systems on site will have to be upgraded for scaling the electrolysis process and operating the EAF and DRI plant. More details can be found in chapter 5.4 Infrastructure.

Furthermore, the site will have to be connected to a supra-regional hydrogen pipeline grid and a hydrogen storage facility (e.g. Huntorf) so that the hydrogen supply is not totally dependent on production on site, and also in the interests of redundancy and flexibility options.

4.1.2 RESEARCH AND INFRASTRUCTURE

The hydrogen economy is still in its very early days. Further expansion depends crucially on research and technology development. The structural change to a hydrogen economy will succeed if the process is accompanied by scientific monitoring, analysis and reflection.

The universities in the state and numerous independent research institutes have accumulated many years of extensive know-how in energy research. Recently they have greatly expanded and pooled their expertise in terms of hydrogen research and sector coupling, giving the state of Bremen a broad research landscape for hydrogen research. Bremen Research Centre for Energy Systems (BEST) is the energy research backbone at the University of Bremen. The universities of applied sciences in Bremen and Bremerhaven have also put hydrogen research on their agenda. Independent research institutions looking into hydrogen include the Fraunhofer IWES and the Fraunhofer IFAM, the Fibre Institute, Bremen Institute of Applied Beam Technology (BIAS), the Leibniz Institute for Materials Engineering (IWT), the Institute of Shipping Economics and Logistics (ISL) and the Technology Transfer Centre (ttz) at Bremerhaven University of Applied Sciences.

Tensile measuring machine for measurements in liquid nitrogen at -196 °C at Bremen Fibre Institute

Hydrogen tanks in the future A380 ZEROe flight test demonstrator

A fundamentally important part of the research infrastructure is the Hydrogen Lab Bremerhaven, which is currently being set up by Fraunhofer IWS as part of the project "Hydrogen – green gas for Bremerhaven". The hydrogen lab is an electrolysis test site that plays a central role in expanding the hydrogen hub in Bremerhaven. Synergy effects can be expected from the vicinity to the neighbouring IWES nacelle test site (DyNaLab): the connection to one of the world's most efficient dynamic power grid emulators makes it possible to investigate the impacts of grid fluctuations on the electrolysers and define their electrical characteristics.

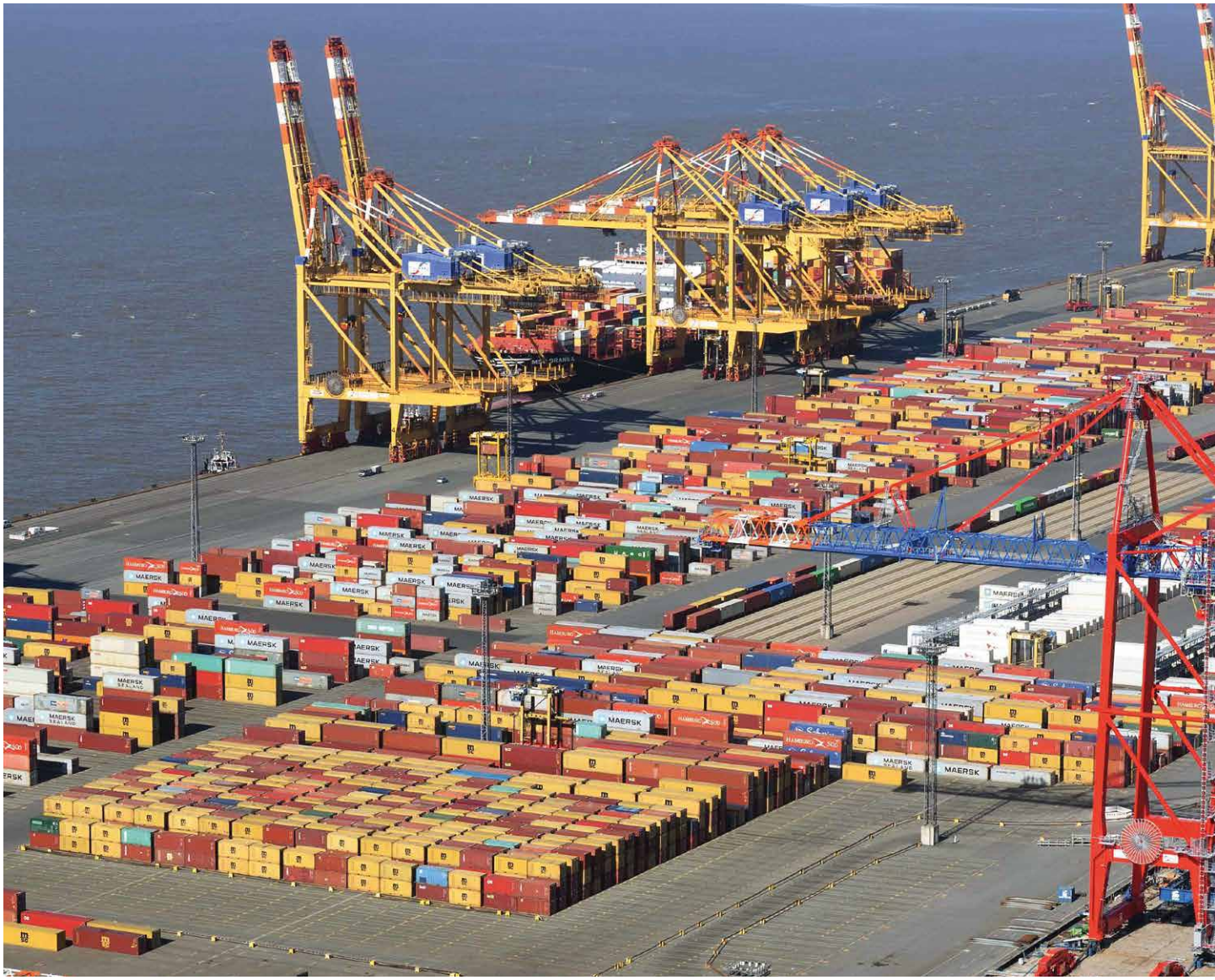
Another important part of the infrastructure in Bremerhaven is the Hydrogen Test Centre that is to be set up for prototype applications on an industrial scale. Besides workshops for commercial vehicles, trucks and buses, it should also include a 3D test rig (so-called swell simulator) for testing maritime applications on an industrial scale.

Material research is another focus at Bremen's research institutes. The equipment used by the material science institutions is currently being supplemented with a hydrogen test facility to test materials made of metal and carbon fibres in terms of hydrogen applications, with technology-specific development of production methods suitable for mass production. The aim is to upgrade large-scale industrial applications for hydrogen technology (e.g. the steel industry), to establish hydrogen applications in other areas (particularly the mobility sector with aviation, vehicle construction, trains and shipbuilding), and to accelerate the production of components for hydrogen technology while reducing their costs at the same time. The focus here is on researching the influence of hydrogen – particularly deep-frozen liquid (cryogenic) hydrogen – on the long-term behaviour of materials. Another focus is on developing and testing processing possibilities above all for low-cost construction materials, particularly in terms of industrial scalability.

4.1.3 AEROSPACE

The development of the upper stages for the Ariane rockets has given the ArianeGroup has more than 40 years of experience with cryogenic hydrogen. This experience is of particularly sustainable benefit when it comes to developing concepts for aviation. There are basically three technological approaches to decarbonising aviation: using SynFuels (synthetic kerosene using sustainably generated energy), hybrid fuel cell concepts (e.g. propeller aircraft) and direct combustion of hydrogen in turbines. The energy density required to fly means that all three concepts need cryogenic hydrogen (LH2, temperature of –253 °C). On this basis, Airbus intends to offer the first commercial passenger aircraft powered with liquid hydrogen by 2035.

The corresponding industrialisation of tank system integration and possible rating of the LH_2 storage systems together with operation and certification concepts are to be developed and demonstrated in Bremen. Among others, a laboratory for cryogenic material research is being set up in the ECOMAT (Bremen Centre for Eco-efficient Materials and Technologies) for necessary further development work. Furthermore, Airbus has already set up its



Container terminal Bremerhaven

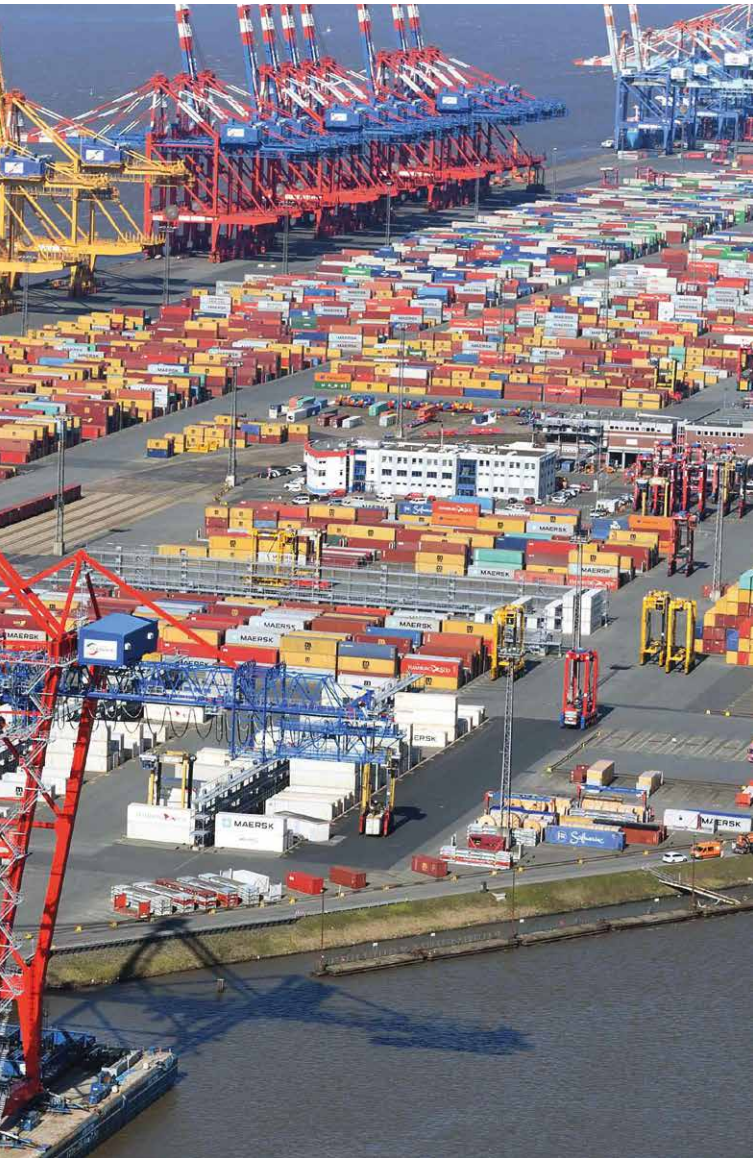
own cross-division #H2Lab for adapting hydrogen-based aerospace technology and developing concepts for civil, commercial zero-emission aviation in the future.

Research institutes involved in these developments include the Fibre Institute, the German Aerospace Centre (DLR), the Fraunhofer IFAM and the Leibniz IWT. As well as characterising materials, work at the ECOMAT focuses on the testing and certification of materials, construction methods and components in terms of future fire safety requirements, which should lead in the medium term to establishing a cross-sectoral Fire Safety Certification Centre.

4.1.4 PORTS

The ports are seen as playing a central role in setting up hydrogen value chains, also in the context of the North German hydrogen strategy. The ports are where maritime goods are handled and loaded onto downstream transport vehicles such as barges, trains, trucks and possibly pipelines. This area is therefore closely linked to the area of action for logistics and transport. The transport hub function and the economic activity of the local companies result in a multitude of possible uses for hydrogen and its derivatives, alongside other synergy effects.

Basically, there are good possibilities for developing the port-related hydrogen economy. The options are being investigated in a current study to develop and establish a port-related hydrogen economy, and to provide a resilient basis.



For example, the ports could also be used for production of locally needed green hydrogen to run fleets of working vessels in the port area. The fossil-free fuels methanol and ammonia that are needed for shipping can also be produced and handled here.

The SHARC project funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK) has already ascertained the principles needed to establish a smart grid in Bremerhaven's international port for better integration of renewable energy. The upcoming implementation phase should include setting up a local smart micro-grid as well as local production of green hydrogen by electrolysis and its direct use in the port area.

In the long term, local and above all supra-regional demand for hydrogen can only be covered from international sources. Importing hydrogen from countries with more favourable production conditions offers chances if it is possible to bring about significant reductions in transport costs and if the large-scale handling and transport of hydrogen products is technically feasible. In setting up these new transport chains, Bremen's ports have the unique opportunity of becoming established as a hub for these new cargoes. Integration with CO_2 transport chains results in ideal conditions as a site for local production of synthetic fuels.

4.1.5 LOGISTICS AND TRANSPORT

Bremerhaven and Bremen are logistic hubs. Hinterland transport by road and rail shapes the economy, and use is also made of inland shipping. One of Germany's most important multi-modal freight villages is in Bremen, with direct access to shipping (Neustadt port), road, rail and air transport. Green hydrogen is seen as a highly promising option for carbon neutral long-distance and heavy goods traffic. It supplements battery-based electromobility that seems particularly suited to short- and medium-distance journeys in individual vehicles and for regional distribution and delivery services.

In contrast to battery electric commercial vehicles, little progress has been made hitherto with the development of heavy-duty fuel cell commercial vehicles. No standard has become established yet for which form of hydrogen is needed (gaseous 350/700 bar or liquid). Ongoing developments* must therefore be closely monitored to ensure that the necessary refuelling and maintenance infrastructure is established and possibly adapted in good time in the state of Bremen.

* Arrival of the FAUN Group and EDAG focus on tank solutions

Vehicle of the Enginius Bluepower series by the Faun Group

Production of hydrogen fuel cell HGV in Bremen

Conventional towing vehicles or locomotives, particularly for shunting, could be converted on site for pilot projects and tested in operation in the short and medium term. The state of Bremen offers a wealth of know-how in the conversion and maintenance of road and railway vehicles. bremenports is involved in a preliminary survey in Bremerhaven to prepare the use of corresponding shunting locomotives in ports in Bremen, Lower Saxony and also Hamburg.

4.2 MAJOR PROJECTS AS INITIAL STIMULUS

Up to now, companies and scientific institutions in the state of Bremen have been highly successful in competing for tenders issued by the Federal Ministries to implement the national hydrogen strategy.

Several major projects were chosen in the early tender phases and have very good chances of being implemented. These include three IPCEI projects and a number of other projects which are presented below. Taken together, the volume of investment in these major projects well exceeds €1b.

IPCEI projects

"Important Projects of Common European Interest (IPCEI)" are a European instrument for funding strategically significant developments in industry and the economy in compliance with state aid law.

An IPCEI must make a contribution to the strategic objectives of the European Union and must be conducted by more than one Member States. It must include co-financing from the participating companies/institutions, disseminate positive spill-over effects across the whole EU and pursue very ambitious targets for research and innovation which explicitly exceed international state-of-the-art technology in the corresponding sector.

Companies participating in an IPCEI can receive considerable state funding for the project, coming from national and state funds.

In December 2020, 22 EU Member States including Germany and Norway decided to conduct an IPCEI for hydrogen.

Germany then requested an expression-of-interest procedure for participation in the IPCEI for hydrogen, which came to an end on 19 February 2021. This was the closing date for companies to submit project outlines.

On 28 May 2021, the Federal Ministry for Economic Affairs and Climate Action (BMWK) which was responsible for the IPCEI procedure in Germany and the Federal Ministry for Digital and Transport (BMDV) that deals with mobility issues announced that 62 major German projects were qualified for the ongoing procedure (with altogether 439 projects in 18 countries selected throughout Europe).

These include three major projects in which Bremen is involved.

Bremen is involved in three major IPCEI projects: "Direct Reduced Iron Bremen and Eisenhüttenstadt" (DRIBE2), "Clean Hydrogen Coastline" and "Hydrogen for Aviation Infrastructure and Production in North Germany" (WopLin).

With substantial participation from the following companies based in Bremen: ArcelorMittal Bremen (DRIBE, Clean Hydrogen Coastline), swb (Clean Hydrogen Coastline) and Airbus (WopLin). (More details about the projects are provided in the following sections).

The total volume of the three projects in which Bremen is involved amounts to around €2.4b, based on the submitted project outlines. The share of investment earmarked by the companies for Bremen is around €1.1b.

The IPCEI projects mentioned above offer a great chance for developing the hydrogen economy in Bremen with climate-friendly transformation of the steel works, the aviation industry and other sectors of the economy. The leverage effect of IPCEI funding by the state must be seen as outstanding in relation to national funding and to private investment.

Implementation of these IPCEI projects could result among others in considerable quantities of hydrogen being produced and put to industrial use on a permanent basis, with considerable reductions in direct CO_2 emissions. The DRIBE project by ArcelorMittal Bremen alone could save up to 2.3 million tonnes of CO_2 every year from 2026 onwards (corresponding to about 20% of Bremen's current CO_2 emissions).

Commercial use of hydrogen in steel production and the new innovative direct reduction plant would open up industrial perspectives for ArcelorMittal Bremen to secure jobs and ensure value creation here in the long term. Flexible hydrogen supplies for the steel works, heavy goods traffic and other sectors of the economy would also be safeguarded in the long term by being linked up to a cavern storage facility converted to hydrogen in Huntorf and a supra-regional hydrogen pipeline system.

The aviation industry with its important role in Bremen's economy would be strengthened by the WopLin project which could make a considerable contribution to the development and realisation of zero-emission flying based on hydrogen, which is part of the corporate strategy adopted by Airbus.

The IPCEI projects promote developments and infrastructure to prepare the ground and create a wealth of experience for other hydrogen applications in the physical vicinity of the sites, in the energy industry, logistics and other sectors of the economy.

Furthermore, the high investment in the IPCEI projects also has significant indirect effects on the regional economy. Above all, the CO_2 savings that can be achieved with green hydrogen in industrial and other processes have a direct impact on climate protection.

The IPCEI projects are also an excellent means of continuing the already existing hydrogen activities in Bremen and Bremerhaven and leading them into an industrial dimension.

Other tenders by the BMBF and the BMDV

The project "hyBit: initial stimulus for the Hydrogen Hanse" by Bremen University is currently in the selection process of a hydrogen research project grant scheme for fundamental research by the Federal Ministry of Education and Research (BMBF).

Furthermore, the cities of Bremen, Bremerhaven, Hamburg and Stade were selected for funding in the competition to select a site for an innovation and technology centre "Hydrogen Technology for Mobility Applications" (ITZ Nord) by the Federal Ministry for Digital and Transport (BMDV).

4.2.1 IPCEI PROJECT DRIBE – DIRECT REDUCED IRON BREMEN AND EISENHÜTTENSTADT

The DRIBE project by ArcelorMittal Bremen and Eisenhüttenstadt aims to introduce innovative direct reduction processes for climate-friendly production of sponge iron, an interim product when manufacturing steel. A commercial plant is to be set up in Bremen and an industrial prototype in Eisenhüttenstadt. Both plant can run on natural gas initially, but should be operated with green hydrogen as soon as possible. The plant for Bremen could start operating in 2026 and replace one of the two blast furnaces (blast furnace 3). The DRIBE project is currently the largest individual investment project for hydrogen in the Free Hanseatic City of Bremen.

4.2.2 IPCEI PROJECT CLEAN HYDROGEN COASTLINE

The Clean Hydrogen Coastline project by EWE, swb, ArcelorMittal Bremen, FAUN, Tennet and others pursues the gradual integration of hydrogen in the existing energy system of the Bremen region and the Northwest. In Bremen, the electrolysis capacity on the premises of the steel works is to be increased to more than 100 megawatts; blast furnace 2 is to be converted to green hydrogen, and green hydrogen is to be made available for commercial vehicles with fuel cell drives. Furthermore, the location is to be linked up to the North German and cross-border hydrogen grid **with the IPCEI hyperlink project by Gasunie Deutschland**, which is being partly converted to hydrogen. All-in-all, this lays the foundation for producing, transmitting and using hydrogen and is aimed particularly at the steel and transport markets.

The project is an important stimulus for using hydrogen in the commercial traffic sector and aims to make hydrogen more competitive in this area.

4.2.3 IPCEI PROJECT WOPLIN – HYDROGEN FOR AVIATION INFRASTRUCTURE AND PRODUCTION IN NORTH GERMANY

WopLin is a joint project by the Airbus sites in Bremen, Hamburg and Stade to create the prerequisites for using hydrogen and fuel cell technology to produce a "ZERO emissions" aircraft. The intention is to demonstrate and industrialise the use of hydrogen in a commercial application.

In the framework of pilot production for a zero emission aircraft (ZEA), the Airbus site in Bremen will be responsible for two important elements in the certification and future production of aircraft powered by hydrogen. As part of a future North German production chain, Bremen's Cryogenic System Integration Centre will be involved in integrating and testing the cryogenic hydrogen supply system as a module for subsequent integration in the overall aircraft.

A similarly crucial component in the certification procedure for a ZEROe aircraft will be played by the Fire Safety Certification Centre (FSCC) that is to be established in Bremen. The aviation authorities are currently working on new certification criteria to cover the changeover from previous aviation fuels to hydrogen. This in turn will lead to other more extensive test methods for experimental fire safety certification. The work involved in the WopLin project is to include creating facilities and the testing infrastructure in the FSCC for large-scale structure, system and component testing.

4.2.4 HYBIT AS INITIAL STIMULUS FOR A NORTH GERMAN HYDROGEN ECONOMY

The project "hyBit – initial stimulus for developing a North German hydrogen economy" under the auspices of Bremen University was funded through to 1 September 2022 in the framework of the BMBF ideas competition "Hydrogen Republic Germany". The aim of the project was to understand the cross-sectoral transformation processes involved in setting up an integrated hydrogen economy, with a focus particularly on socio-technical transformation aspects of infrastructures and their interaction in North Germany. In the first phase, around €30m from federal funds were earmarked for the project consortium of altogether 21 partners. A second implementation phase was an integral part of the project concept.

The project acted as the starting point for the hydrogen hub in Bremen and was thus an important element in setting up a supra-regional hydrogen economy and in the transformation towards a sustainable, climate-neutral Europe.

Five project goals were defined by ten institutes at Bremen university and 20 other partner organisations: cross-sectoral hydrogen-induced defossilisation to achieve the climate goals; establishing a regional, integrated hydrogen economy; resilient organisation of the defossilisation process and sustainable energy and resources management; development of a digital transformation platform for monitoring and adaptive transformation management of industrial hydrogen hubs; setting triggers for networking with partners in the regional hydrogen economy.

4.2.5 INNOVATION AND TECHNOLOGY CENTRE AVIATION / MARITIME (ITZ NORD)

The cities of Bremen, Bremerhaven, Hamburg and Stade have been selected together with three other sites in Germany for funding in the BMDV competition to select a site for an innovation and technology centre "Hydrogen Technology for Mobility Applications". The North German Innovation and Technology Centre will have aviation and shipping as its focus. By the end of 2021, the four German sites drew up a detailed concept featuring key aspects

Northwest Germany: the heart of Europe's hydrogen economy

and budgets, organisation structure and functional direction, together with networking and cooperation. The intention is for the "ITZ Nord*" to be set up as a new services centre in the future network of the German Centre for Future Mobility.

Altogether up to €72.5m in national funding have been earmarked for all three North German sites including Bremen/Bremerhaven for the period through to 2026.

4.2.6 PROPORTIONATE STATE FUNDING FOR MAJOR PROJECTS AND RELATED TRANSFER

The state of Bremen will need to contribute funds towards the three named IPCEI projects and others such as the Hyperlink IPCEI project by Gasunie Deutschland Transport Services GmbH and possibly also the "Technology Centre for Hydrogen Mobility". The state funding involved here will probably be well in excess of €100m.

A corresponding consultation process in the senate is necessary and has been initiated in order to provide this support from the state. Furthermore, transferring the results of the major projects to the many other organisations in the state of Bremen that are actively involved with hydrogen will enhance synergy effects and developments.

* Project feasibility was confirmed by the project initiator in June 2022.

Project period and financial volume of hydrogen projects in the state of Bremen that are being or about to be implemented

Project periods / financial volume	2021	2022	2023	2024	2025	2026	Total volume €m	FHB funds €m
IPCEI projects							1,100	
Installation direct reduction plant (DRIBE)								
Installation electrolyser (Coastline)								
Blast furnace conversion at AMB (Coastline)								
Supplying hydrogen for aircraft (WopLin)								
Fire Safety Certification Centre (WopLin)								
ITZ Nord								
Maritime							12.1	–
Aviation							12.1	–
Regional funding projects								
hyBit 10 MW: electrolysis for steel works								10
Hydrogen – green gas for Bremerhaven							20	10
Equipment for H2 research (tests etc.)							13	13
Test region mobile hydrogen applications							5	5
Purchase of 7 fuel cell buses in BHV, partly funded by "Hyways for Future" project							5.6	5.6
Projects funded by third parties								
hyBit: industrial transformation (Uni HB)							30	–
Hyways for Future							up to 20	–
Studies								
SWH/ISL Port hydrogen economy							0.6	0.6
H2B, Uni HB, decarbonising the steel industry							0.7	0.7
SHARC – port concept for EE integration							2.5	–
H2Cool Prelude; H2 truck; HS BHV, ISL							0.2	0.1
Flexi green fuels – jet and shipping; HS BHV							4	–
hyTracks – platform H2 economy; Uni HB							0.9	–
H2BPMM; HS BHV							0.2	0.2

4.3 HYDROGEN HUBS AS THE NUCLEI OF A HYDROGEN ECONOMY

The concept of hydrogen hubs in the North German hydrogen strategy is intended to allow for spatial concentration of the activities involved in producing, distributing and using hydrogen. These hubs facilitate and accelerate interdisciplinary work on solutions along the value chain, as well as coupling various sectors such as industry and mobility. The measures in the hubs focus on several areas of action at the same time. The hubs are intended to gradually safeguard regional supplies of green hydrogen and are integrated right from the start with activities in the Metropolitan Region and North Germany, having an impact that goes over and beyond the state borders.

The hydrogen value chains are already present in rudimentary form in the hubs and should undergo further development to become supra-regional value chains. Hubs thus help to bridge the lack of supra-regional/national value chains until the market is up and running.

They have a supply function for the direct surroundings and beyond. It is a basic prerequisite for the hubs to include various sectors with differing demands, such as low quantities / high price acceptance (mobility) and large quantities / high price sensitivity (industry).

Close cooperation with the state's scientific institutions should help develop the high innovative capacity of the hubs. The hydrogen hubs offer the potential of securing jobs and opening up new, hydrogen-based areas of business, attracting companies to settle here and creating local jobs in innovative sectors.

The state of Bremen has two sites in Bremen and Bremerhaven that are suitable for successive stages in the value chain for green hydrogen, also demonstrating and implementing the possibilities for coupling the sectors involved in electricity, heat and refrigeration supply, industry, logistics and transport. These hubs form the nuclei of the hydrogen economy.

4.3.1 HYDROGEN HUB IN BREMEN

The industrial ports, the steel works, the Neustadt port and the freight village will in future be linked by the A281 motorway to form one of the largest cohesive industrial zones in Northwest Germany, offering ideal starting conditions for a hydrogen hub in Bremen.

The electrolyser being installed on the site of ArcelorMittal Bremen, initially with output of 10 MW that can be expanded to 300 MW, is the interface and key point of the hub. Initially, it will have a sector coupling function in supplying green hydrogen to the steel works and also to the transport sector. The need for hydrogen to produce steel in the steel works solves the problem of inadequate demand that is frequently encountered in new hydrogen projects. Furthermore, the oxygen generated as a side product in the electrolysis process can also be used directly for steel production.

In the medium term (also in the framework of the Clean Hydrogen Coastline IPCEI project), the site is to be connected to a hydrogen cavern storage facility in Huntorf and to the North German hydrogen pipeline which is currently in the planning stage, as a further means of safeguarding the supply of hydrogen.

The development of the hub is being monitored in conceptual terms by the project "H2B – Roadmap for gradual defossilisation of the steel industry and urban infrastructures by means of electrolysis hydrogen in Bremen" which began in January 2020. The aim is to produce an implementation strategy using green hydrogen for decarbonising industrial processes and mobility applications where electrification is difficult or impossible.

Moreover, the development of the hydrogen hub is also part of the university project described in chapter 4.2.4 "hyBit: initial stimulus for the Hydrogen Hanse" funded by the BMBF.

Lune Delta – sustainable economic management in Bremerhaven

4.3.2 HYDROGEN HUB IN BREMERHAVEN

Bremerhaven is aiming to become a test region and centre of excellence for hydrogen and fuel cell technologies in North Germany. The hydrogen hub with focal applications thus integrates two central sites for the hydrogen economy in the seaport:

The **Lune Delta commercial estate and the fishing port** in the south of the city focus on test infrastructures and mobility applications, with the project "Hydrogen – green gas for Bremerhaven" acting as an important stimulus. An electrolyser test site is being installed through to 2024 on the premises of the former Luneort airfield to test interaction between electrolysis units and wind turbines. Hydrogen applications are being developed at the same time. The first public hydrogen filling station in Bremerhaven is to be erected in 2023 in the direct vicinity of the BVV bus depot (Bremerhavener Verkehrsgesellschaft). In 2022, BVV purchased three fuel cell buses for its local public transport services. A sum of €5m has been granted in the framework of the Bremen Fund to implement a test region for mobile hydrogen applications.

Bremerhaven has comprehensive scientific expertise for hydrogen applications and has accumulated a wealth of project experience, such as using fuel cells on ships. Bremerhavener companies see another area of great potential.

An electrolyser is being installed at an existing wind turbine to supply among others a hydrogen filling station with green hydrogen. There are many other ideas for using wind/hydrogen. A fuel cell truck-mounted road sweeper is currently being purchased. Purchasing options are also being for hydrogen-powered refuse vehicles, buses and large HGV as well as forklift trucks for municipal services and logistics.

The **port areas in the north of Bremerhaven** offer scope above all for the following: carbon neutral port quarter, import site for hydrogen and other raw materials for producing e-fuels, test site for maritime hydrogen applications, particularly for the integration of new ship propulsion systems, together with transport and logistics. The developments of mobile applications are being supported by cooperation with many different partner organisations, particularly research institutions, based in the state of Bremen.

Bremen ports can play a major role in supplying the new fuels, as well as transporting raw materials and conversion products by sea and through the ports.

Vision of the "green" commercial estate Lune Delta in Bremerhaven

This must also be seen in the context of new business options emerging with positive impacts for employment in Bremerhaven. In order to sound out the related chances and create a basis for taking decisions to install the necessary infrastructure, the senate has commissioned a study to clarify important questions involved in establishing a hydrogen-related port economy (see Annex).

CCS technology (carbon capture and storage) could also play a significant role in the hydrogen economy during a transitional period. Bremen's ports could assume a central function for collecting and shipping CO_2 – to Norway, for example. At the same time, this CO_2 could be used locally to produce hydrogen derivatives such as methane or methanol to be supplied as e-fuels among others for shipping.

5 STRATEGIC ACTIVITIES

5.1 FUNDING POSSIBILITIES, SUPPLEMENTARY STATE PROGRAMME

The high investment and operating costs (also caused by the electricity price) when using green hydrogen currently prevents it from being economically efficient. Until the corresponding structural market issues have been overcome, incentives are required for investment in the production and use of green hydrogen so that potential application areas can develop. It is appropriate to make optimum use of European and national funding programmes, supplemented with state funds.

If the European Commission confirms the selection of major IPCEI projects (see chapter 4.2) with its overall investment volume of probably around €1b, this would give the state a decisive boost and set the points for future activities. The necessary financial participation by the state in the national funding programme makes it expedient for the funds to have the broadest possible impact, also for organisations that are not stakeholders in the projects.

It is therefore important to ensure that the results of the major projects are transferred to the many other organisations in the state of Bremen that are actively involved with hydrogen. First and foremost, federal measures should go towards using the results for other processes.

However, experience shows that additional funding support from the state of Bremen will be necessary, such as a specific state programme for small and medium-sized businesses (SME). The programme aims to support SMEs in using green hydrogen themselves or developing products and services to use hydrogen so that they can generally participate in developing a hydrogen economy.

At the same time, the programme should facilitate regional system-relevant investment, for example to safeguard the security of supply, together with investment in own priorities. Where possible, the programme should be made available at the same time as the co-funding towards the described national funding to ensure that all companies in the state are given comparable opportunities. This does not affect comprehensive use of federal and European funding programmes.

The existing funding guideline of the Free Hanseatic City of Bremen for funding pilot projects for hydrogen technology in the business economy (BreWaP, adopted on 15 June 2021) will continue to be developed insofar as the current reform of European state law opens up improved funding possibilities for the hydrogen sector.

5.2 CLUSTERS IN THE METROPOLITAN REGION AND NETWORKING IN THE NORTH SEA/BALTIC AREA

When clusters already exist, networking plays an important role in their further development in order to tap into all potential. At the moment, no conventional clusters exist as such for the hydrogen sector that could be used to build up corresponding structures. However, "cluster" is a frequently used synonym in this context, so that it can also apply here.

Right from the start, cluster development in Bremen and Bremerhaven has focused on networking with the Metropolitan Region and with North Germany, taking a European perspective.

Bremen and Bremerhaven are integral parts of the Northwest Metropolitan Region and play a key role in hydrogen developments in North Germany in general. This is illustrated by current projects such as e.g. the IPCEI project "Clean Hydrogen Coastline" (see chapter 4.2.2) which is being implemented in North Germany in the Northwest Metropolitan Region from the Dutch border across to just outside Hamburg. The DRIBE project at the steel works is also integrated in North German structures through the purchase of hydrogen. The aim is to make systematic use of such projects to expand and cultivate close relationships with neighbouring clusters, adjoining regions and beyond. The large quantities of hydrogen needed for the energy

transition will be produced and traded on a global scale in future. The national hydrogen strategy of the federal government expects the hydrogen demand for 2030 to reach 90 TWh, with planned national production capacity of 14 TWh. This leaves a considerable gap in supply that has to be covered by importing green hydrogen via offshore/onshore-pipelines or by tankers.

The North Sea and Baltic region can be expected to play a hugely significant role in the production and transport of hydrogen, and every effort must be made to take this into account. In consultation with the North German states, networking efforts are therefore being made in the North Sea/Baltic region in the context of a new "Hydrogen Hanse" (North German hydrogen strategy).

In the international context, close hydrogen-related cooperation with the North Sea and Baltic countries should open up possibilities for developing a broader core region for producing and trading in green hydrogen, also including hydrogen derivatives.

As far as North German cooperation is concerned, the aim is to develop a working structure to integrate the existing hydrogen clusters in the Northwest Metropolitan Region and other North German regions with corresponding representation of their pooled interests.

5.3 GOVERNANCE AND MONITORING

The responsibility for implementing Bremen's hydrogen strategy lies in the hands of the senate departments according to the senate's distribution of business. A cross-departmental steering group has been set up as governance structure. It encompasses the relevant departments of the Senator for Economic Affairs, Labour and Europe, the Senator for Science and the Ports, the Senator for Climate Protection, Environment, Mobility, Urban Development and Housing, the Senate Chancellery and the companies WFB Wirtschaftsförderung Bremen GmbH, BIS Bremerhavener Gesellschaft für Investitionsförderung und Stadtentwicklung mbH and the port management company bremenports. Other institutions are consulted when the need arises.

This steering group was involved in drawing up the hydrogen strategy and monitors implementation of the strategy and the whole process, regularly checking the respective priorities and developing measures and instruments when necessary.

The hydrogen office helps with coordination and operational control of the activities within the state in the framework of North German cooperation and with the federal government and the EU.

The intention is to provide information about progress in implementing the hydrogen strategy in the context of the planned reporting on the innovation strategy state of Bremen 2030".

Furthermore, progress reports on implementing the strategy were submitted to the senate through to the end of 2022.

5.4 ENERGY INFRASTRUCTURE

Natural gas and hydrogen grid

Based on what is known at present, the structure of the future hydrogen grid will differ from the existing natural gas grid. Many stationary energy consumers using natural gas at present will find green electricity more economical than hydrogen for energy purposes (e.g. heat pumps). The pipeline length of the future regional hydrogen grid can be expected to be shorter than the existing natural gas grid.

Besides the steel works, consumers of large quantities of hydrogen needing a corresponding grid connection could include industrial companies that require very high temperatures or companies with large areas to be heated. Other potential consumers include companies or infrastructures for logistics and ports (freight companies, larger logistics firms, local public transport companies, Bremen airport, etc.) for refuelling hydrogen trucks.

More hydrogen pipelines will be necessary if the already planned electrolysis installations are joined by additional ones not located on the premises of bulk hydrogen consumers.

Starting grid for hydrogen

The plan submitted in 2020 by the operators of the gas transmission grid for a starting grid for hydrogen shows good options for hydrogen pipelines in the immediate vicinity of Bremen and Mittelsbüren. However, the starting grid for hydrogen has not been recognised for the final version of the gas grid development plan 2020 - 2030 by the Federal Network Agency. Nevertheless, it can be presumed that the grid operators are pursuing or considering corresponding plans. For Bremen, being linked up to the starting grid would also ensure its connection to a national

and cross-border hydrogen grid. The state of Bremen must therefore actively monitor such processes and projects.

Electricity grid / electricity supply
As described above, the plan is to produce green hydrogen at the Mittelsbüren steel works site in electrolysers in a gradually phased process with an output of up to 300 MW. Furthermore, operations are to begin in 2026 with a direct iron reduction plant (DRI) and an electric arc furnace (EAF), followed by a second electric arc furnace by 2032 at the latest.

This will result in a considerable increase in the demand for electricity on site. Integration in the electricity grid will require extensive grid expansion measures. To cover the electricity demand in the long term, an additional link up to the transmission grid is necessary. This affects the planning of measures in the grid development plan of the transmission grid operators, and the Federal Network Agency will also have to be involved. The grid connection project is currently going through the concept development and preliminary planning stage. Corresponding consultations have been initiated.

5.5 SKILLS DEMAND

The forward-looking recruitment and retention of skilled workers includes the need to adapt existing job descriptions so that syllabuses and vocational training programmes take far greater account of climate protection issues. Hydrogen technologies will have to be included as an additional qualification in corresponding job descriptionsto cover the future demand for skills in this area.

Specific aspects of the hydrogen economy must be added to vocational training schemes and dual training programmes, in cooperation with the chambers.

A range of corresponding initial and further academic training will be put together in cooperation with the regional research and education institutions in the form of seminars, certified training courses and support for training and degree courses with modules and courses for senior executives in the various key application areas.

Existing degree courses offer a suitable basis, such as the specialisation in energy technology in the Faculty of Production Engineering at Bremen University, the degree courses in energy and maritime technology and in logistics and information systems at Bremerhaven University of Applied Sciences, and the degree courses in environmental engineering, electrical engineering, energy and process engineering as well as energy management at Bremen University of Applied Sciences.

Relevant opportunities to train and study must also be expanded in both vocational and academic training and education, while also ascertaining the need to develop new job descriptions, such as hydrogen technicians and engineers.

Priority must be given to further and advanced training of skilled workers for the hydrogen economy as a new market, making use of the possibilities presented by the Skills Development Opportunities Act for funding climate protection content in further or retraining programmes. In this context, responsibility also lies with the employers to make their companies a place of learning to help employees adjust to the new requirements and provide further training.

The pending transformation processes will demand increasing climate protection know-how and expertise in the new key technologies AI, IT and hydrogen. The Senator for Economic Affairs, Labour and Europe therefore advocates the introduction of a transformation short-time allowance as an entitlement in the German Social Code III (SGB III). The objective of the new short-time allowance variant is to safeguard employment while improving qualifications in the company undergoing transformation. As with the existing forms of short-time allowance, the transformation short-time allowance should offer the employees job security and also cover the full costs of further vocational training attended while on short time.

Fair stand of the North German HY-5 initiative

5.6 ACTIVE LOCATION MARKETING AND BUSINESS ACQUISITION

Compared to other regions, North Germany and Bremen/Bremerhaven offer unique location advantages for setting up a hydrogen economy, as described in the chapter on strengths and chances.

These advantages should feature in international communication addressing companies in the hydrogen economy and for the acquisition of shipping capacity (hydrogen and its derivatives).

The initiative "HY-5 – Green Hydrogen Initiative of Northern Germany", with the involvement of BremenInvest for the state of Bremen, was launched in December 2020 and uses the location advantages of North Germany when addressing international companies and investors. Going over and beyond initial jointly organised webinars, this initiative aims as far as possible to pool the international presence of the North German states and also to enhance the worldwide visibility of the location potential offered by the state of Bremen for the hydrogen economy.

Significant events included the "Hydrogen Technology Expo Europe" and "Carbon Capture Technology Expo Europe" trade-fairs in October 2021 and September 2022 in Bremen and scheduled also for September 2023.

5.7 PUBLIC RELATIONS AND ACCEPTANCE

The measures to set up a hydrogen economy demand active public relations to encourage broad acceptance in the population and in the economy. The public relations measures elaborated to this end in the North German hydrogen strategy must be actively implemented also in the state of Bremen.

The first practical examples include the annual Hydrogen Symposium, that has been held in the autumn in Bremerhaven since 2018, and the annual Hydrogen Week that has taken place since 2019. These events were and are used to provide information on site and online and to offer participation possibilities. Corresponding activities must be further expanded, supplemented and perpetuated by additional formats such as websites and newsletters.

In 2020, a virtual conference of the North German energy research associations was held at the initiative of the North German Conference of Ministers of Science, with a focus on hydrogen research. The conference format was continued in 2021 with hydrogen as a fixed item on the agenda, with the head of the department for energy policy – heat and efficiency at the BMWK highlighting North Germany's significance for hydrogen research in a keynote speech. In 2023, the conference of the North German energy research associations will be held in Bremen, with Bremen's energy research association BEST and its cooperation partners giving a prominent position to the hydrogen research activities in the state of Bremen.

5.8 NECESSARY FRAMEWORK CONDITIONS

Development of the hydrogen economy requires improved statutory framework conditions and funding. The state of Bremen is working intensively and, as far as possible, in conjunction with the North German states, to make corresponding demands with the federal government and other relevant authorities.

For example, companies are currently investing billions of Euros in decarbonising the steel industry. Additional support is therefore needed from the federal government and from the European Union to ensure production remains profitable.

Bremen is therefore advocating fair framework conditions, including in particular:

- Creation of effective carbon border adjustment to prevent carbon leakage
- Introduction of climate protection contracts with the same approach as in the carbon contracts for difference (CCfD) to give incentives for investment in climate protection. The key points published in April 2021 by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) do not go far enough (see also resolution adopted by the Conference of Ministers of Economic Affairs in June 2021).
- Further expansion of trajectories for renewable energies, particularly for onshore and offshore wind energy, to cover the additional demand for hydrogen electrolysis in North Germany.
- Funding for the operating costs (OPEX) for pilot projects: hydrogen applications are currently not economically efficient, particularly in the industrial setting. Companies will have to receive support for the operating costs (OPEX) in addition to funding for the investment costs (CAPEX) so that the first projects can be implemented. Among others, this needs corresponding adjustment of European state aid law.
- Support to establish markets for green products. It is foreseeable that "green" products, e.g. green steel produced by using green hydrogen in the production process, cannot be offered initially at the same prices as corresponding products from conventional production. It is therefore important for the production of green hydrogen to be exempt from levies and other charges. It is also essential to successively reduce the subsidies on fossil fuels to establish fair competition conditions for green products.

6 MEDIUM- AND LONG-TERM GOALS

The following medium- and long-term targets should be achieved by 2025 and 2030 in the state of Bremen. Given the still uncertain framework conditions, the focus is initially on providing infrastructure to make it possible to forge ahead with other activities.

TARGETS BY 2025/2026

- The necessary port infrastructure for hydrogen is identified.
- Test region and centre of excellence for mobile hydrogen applications: the test centre has been set up as an institution with supra-regional awareness of its activities.
- The electrolyser test site in Bremerhaven has started operating at full capacity (10 megawatt output) and is acknowledged as a provider on the supra-regional level.
- The electrolysis capacity at the Mittelsbüren site has been increased from 10 MW to 100 MW output. The steel works and mobility applications are supplied with hydrogen.
- The steel works operates with hydrogen. A blast furnace has been replaced with a direct reduction plant and an electric arc furnace.
- Hydrogen vehicles are running in local public transport and in the port, accounting for a 10% share of the fleets operated by municipal organisations, companies such as bremenports and port infrastructure users.
- The IPCEI projects are being implemented or about to be concluded.
- Networking with the surrounding areas uses established structures.
- Initial and advanced training programmes for hydrogen are available.

TARGETS THROUGH TO 2030

- A first zero-emission ship has been built in Bremerhaven and has started operating.
- The test centre in Bremerhaven has started operating a seawater electrolysis plant with 1 megawatt output for test purposes and a pilot plant has been erected for the production of methanol fuel.
- The output of the electrolysers at Mittelsbüren power station has been expanded to 300 megawatts. A pipeline has been installed for connection to the cavern storage facility in Huntorf.
- A Fire Safety Certification Centre has been set up for the aviation industry and can also be used by other sectors.
- Companies in the hydrogen industry have settled in the area.

7 ANNEX: PROJECTS COMPLETED AND IN IMPLEMENTATION

This is a list of projects dealing with hydrogen in the state of Bremen that were known at the end of 2021. The headings are merely intended to give structure to the list: they do not limit the project contents.

TEST CENTRES AND CENTRES OF EXCELLENCE

Improving the infrastructure for hydrogen research – equipment infrastructure for hydrogen research.
Research institutes BIAS, FIBRE, IWT; project period 2021.
The objective is to procure, implement and use a test infrastructure for materials for hydrogen applications and a test infrastructure for laser production processes.

"Hydrogen – green gas for Bremerhaven".
Fraunhofer IWES, Bremerhaven University of Applied Sciences, ttz Bremerhaven; project period 2020 – 2022.
The project aimed to set up and operate an electrolysis test site on the grounds of the former airfield Luneort, and to develop application cases.
https://wind-wasserstoff-bremerhaven.de/

Project "Test region mobile hydrogen applications".
Project period: 2021. This project consisted of three partial measures: procurement of a plasma analyser to test how hydrogen can be produced from wastewater; retrofitting public vehicles to run on hydrogen (police vehicle, Unimog truck); setting up a test facility as basic infrastructure for a future 3D test rig (swell simulator).

Project "Feasibility study for a technology and innovation centre for hydrogen mobility".
BMDV, Bremen, Hamburg, Stade; project period 2021.
Besides feasibility studies for three centres in Bavaria, Brandenburg and North Rhine-Westphalia, the applications from Bremen / Bremerhaven, Hamburg and Stade for the aviation and shipping sectors underwent external evaluation.

Project "TTH2OR – R&D project to develop an IT tool for assessing and improving the resource efficiency of plants for generating green hydrogen".
Bremen University of Applied Sciences; project period 2021 – 2022.

PROJECTS IN THE INDUSTRIAL SETTING

Project "H2B – Roadmap for gradual defossilisation of the steel industry and urban infrastructures by means of electrolysis hydrogen in Bremen".
University of Bremen; project period 2020 – 2022.
The project elaborated an implementation strategy using regeneratively produced hydrogen for defossilising industrial processes and mobility applications where electrification is difficult or impossible.
The aim was to make a crucial contribution to the energy transition and to reducing greenhouse gas emissions in the state of Bremen and in the region.
https://www.uni-bremen.de/res/forschung/h2b

Project "hyTracks – development of a stakeholder-oriented interaction platform for shaping resilient transformation paths for a regional hydrogen economy".
University of Bremen; project period 2020 – 2023.
The aim is to work with stakeholders to model trans-formation paths along the hydrogen value chain according to the example of Bremen's industrial port and to develop possible solutions.

PROJECTS IN THE PORTS

Project "SHARC – Smart Harbour Application Renewable Integration Concept".
bremenports, Siemens, Technical University of Berlin, Institute for Energy and Circular Economy at Bremen University of Applied Sciences, German Research Centre for Artificial Intelligence; project period 2019 – 2021.
The project for a new port quarter supported the integration of renewable energies in the port infrastructure and

suprastructure, with energy optimisation in the port quarter and active management of flexible energy producers and consumers.
https://sharc-project.de/

Study "CO_2 neutrality: how ports can tap into hydrogen potential".
Kieserling Foundation, ISL; project period 2020. Logistics and the transport sector can draw considerable benefits from innovative concepts and climate-neutral procedures based on hydrogen technologies. This study laid the foundation for concepts and procedures.

Study on developing and setting up a port-related hydrogen economy looking at:
- transport itineraries to cope with a growing demand for hydrogen,
- the role of Bremen's ports with this new freight,
- identifiable requirements to be met by the port location (anticipated ships, port and handling facilities,
- safety precautions) and possible solutions for Bremen's ports. The study results were intended to enable the ports to take necessary decisions with regard to expanding the infrastructure for importing hydrogen.
  The results were to be available in August 2022.

Project H2Bx.MariTransGate.
Bremerhaven port as test site for hydrogen technologies in the maritime economy. The seven sub-projects in the joint project were developed as part of an IPCEI application and pursued by the respective partners. On behalf of Bremerhaven international port, bremenports is looking at setting up a smart microgrid with green hydrogen produced locally In the sub-project H2Bx.HyGrid; setting up a multi-modal hydrogen filling station to supply shunting locomotives, working vessels in the port and HGVs in the sub-project H2Bx.HyShunter; building three new working vessels powered by hydrogen fuel cells in the port (a trailing suction hopper dredger, a water police vessel and a harbour launch for the harbour master) and using mobile hydrogen-based power generators, e.g. for external supply of seagoing ships at berth in the sub-project H2Bx.HyShipSol, and setting up import and distribution facilities for hydrogen and its derivatives in the sub-project H2Bx.HyDistriTerm. The funding still needs to be clarified for all these projects. Talks are being held with investors and possible operators and funding possibilities are being examined.
https://bremenports.de/greenports/wasserstoff/

Project "H-AuTAq – autonomous water taxi with fuel cell drive for zero-exhaust and low-noise passenger transport in cities with potential for more".
There are plans in Bremerhaven's finishing port to operate a zero-emission autonomous ferry service for event-based passenger transport logistics in local public transport. Work is currently in progress on developing a corresponding system with the components ship and jetty. The next step will consist of a detailed project application in the framework of a feasibility study, in conjunction with a funding application.

LOGISTICS AND TRANSPORT PROJECTS

Joint project "KEROSyN100 – development and demonstration of a dynamic, efficient and scalable process chain for e-kerosene, sub-project.
System analyses and overall project coordination"; among others: University of Bremen (coordination), project period 2018 - 2022.
https://www.kerosyn100.de/

Thesis paper: "Hydrogen logistics is the key to the success of the national hydrogen strategy".
ISL; project period 2020. This thesis paper on hydrogen provided a differentiated view of the key topics.
https://www.isl.org/de/thesenpapier_wasserstoff

Project "Hyways for Future".
EWE / swb and companies of the Northwest Metropolitan Region; project period 2020 – 2023: the aim is to produce hydrogen for mobility applications locally with climate-friendly energy, and to use it locally as well. This includes setting up electrolysis capacities and hydrogen filling stations, and investing in fleets of buses, refuse vehicles, trucks and cars.
https://www.hyways-for-future.de/

Project "Hydrogen technology business process management modelling".
Bremerhaven University of Applied Sciences; project period 2020 – 2022.
The project aimed to support the establishment of the infrastructure necessary for hydrogen drive technology. Business process modelling was extended and tested with the example of the approval process for a hydrogen filling station.
https://wasserstoffprozesse.de/

Project "H2Cool Prelude – cool transport with hydrogen truck".
Bremerhaven University of Applied Sciences, ISL, akquinet port consulting; project period 2021 – 2021. The project examined the future use of hydrogen for transport by refrigerator truck. The project results are to be implemented in a subsequent project with the conversion of a refrigerator truck.
https://www.efre-bremen.de/projekte/h2cool-prelude-37273

Project "Flexi-Green Fuels – Flexible and resilient integrated biofuel processes for competitive production of green renewable jet and shipping fuels".
Among others, Bremerhaven University of Applied Sciences (project coordination); project period 2021 – 2023. The joint research and innovation project with 13 partners from 4 EU countries looks at producing the next generation of biofuels for shipping and aviation.
https://www.hs-bremerhaven.de/forschung/forschungsprojekte/flexi-green-fuels/

Purchase of fuel cell buses in Bremerhaven.
BremerhavenBus; project period from 2021. Besides purchasing and operating the fuel cell buses in Bremerhaven's local public transport system, a bus depot is be equipped for technical maintenance of these vehicles, with scientific monitoring of operations.

PROJECTS IN RELATED AREAS

Project Destismart.
Partners include Erlebnis Bremerhaven.
Project period since 2018
In the context of the European Interreg project on sustainable tourism, work is being carried out in Bremerhaven on using a hydrogen-powered harbour liner and the development of a climate-related tour.

Marketing initiative "HY-5".
Partners: five economic development agencies of the five North German coastal states, project period since 2020. The project is responsible for marketing North Germany as a hydrogen location. Activities included several international webinars, each attended by several hundred participants representation of the region at various international fairs e.g. in Paris and Tokyo, hosting delegation visits from e.g. Japan and UK as well as promoting the region to individual investors and other organisations.
https://www.hy-5.org/

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