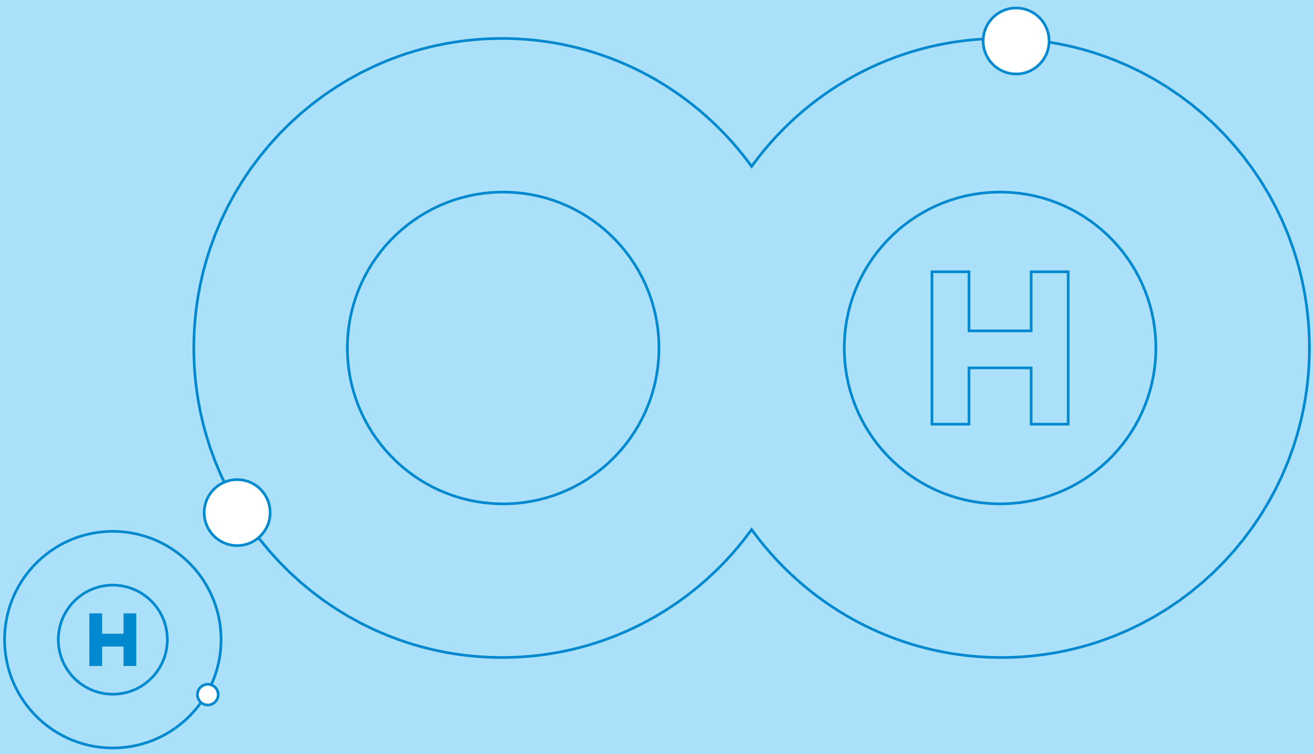
Norwegian Ministry of Petroleum and Energy
Norwegian Ministry of Climate and Environment

Strategy

The Norwegian Government's hydrogen strategy

towards a low emission society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Preface

Norway is to become a low emission society by 2050. The government has a target for greenhouse gas emissions in 2050 to be reduced by between 90 and 95 per cent compared to 1990 levels. As announced in the government's low emission strategy for 2050, the government is working on changing the climate act's target for 2050 to 90-95 per cent. In the nationally determined contribution under the Paris Agreement, the government has submitted a more ambitious climate target of reducing emissions by at least 50 and towards 55 per cent by 2030, compared to 1990 levels.

The government is pursuing an ambitious climate and environmental policy, with measures to reduce greenhouse gas emissions. If we are to achieve the ambitious climate targets, we must develop and start using new technology which reduces these emissions. It is for this reason that the government for a number of years has been facilitating infrastructure and funding to enable the development and adoption of new climate solutions by the research community and businesses. This work must continue even as we emerge from the economic challenges created by the Covid-19 virus outbreak. In the crisis package presented to Parliament in May 2020, the government announced an increased focus on hydrogen-related research and technology development as a way of meeting these challenges.

This hydrogen strategy is a contribution to the process of developing new low emission technologies and solutions. An increased focus on hydrogen in Norway is in line with the goal of having internationally competitive businesses which develop the technology and solutions addressing tomorrow's challenges. We will grasp the opportunities presented by the green transition.

Hydrogen is an energy carrier with a significant potential for reducing local, national and global emissions, and for creating economic value for Norwegian businesses. If hydrogen is to be a low or zero emission energy carrier, it must be produced with low or zero emissions, for example through natural gas reforming combined with CCS, or from electrolysis of water using renewable electricity. Hydrogen presents exciting opportunities for Norway, as an energy nation and a technology nation.

This strategy lays the foundation for the government's future work with hydrogen. Technologies and new solutions develop quickly. The government will keep up to date on developments and will adapt its policies where needed, in order to facilitate the further development of hydrogen solutions, both in order to reduce emissions and contribute to value creation.

Tina Bru
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Sveinung Rotevatn
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Introduction

Hydrogen has a number of applications and could be relevant in several sectors as part of the transition to a low emission society. The sectors and applications in which the use of hydrogen will be relevant in Norway will depend on a variety of factors. Hydrogen could be a solution for applications for which there are currently few or no other zero emission alternatives. At the same time, hydrogen production and the development of hydrogen technology could contribute to value creation in Norway.

Hydrogen is an energy carrier, not an energy source. Just like other energy carriers such as petrol, electricity and district heating, hydrogen must be produced from an energy source. These production processes require energy and involve energy losses. This makes hydrogen more expensive than the direct use of energy carriers, for example electricity. Hydrogen can store energy in a flexible and compressed manner.

Around 70 million tonnes of hydrogen are used annually globally, mainly in the chemical industry and in oil refining. Around 90 per cent of the hydrogen used in Europe is currently produced from natural gas, which generates significant emissions.

If hydrogen is to be a low or zero emission energy carrier, it must be produced with zero or low emissions. This can be achieved either through electrolysis of water using renewable electricity, or from steam reforming processes involving natural gas or other fossil fuels combined with CCS. In this strategy, low and zero emission hydrogen is described as *clean hydrogen* or simply *hydrogen.*

Interest in hydrogen solutions internationally has been increasing in recent years. In the EU's low emission strategy towards 2050[1]hydrogen is presented in several scenarios, and many nations including the Netherlands, Germany, Japan and Australia have developed or are developing their own hydrogen strategies. The International Energy Agency (IEA) points out in an analysis of the hydrogen market[2] that there has never been more interest shown by businesses or the authorities in commercialising hydrogen, and that the conditions for developing scalable, cost-efficient solutions have never been more ideal.

On 27th May, the EU presented its long-term budget (multiannual financial framework – MFF) for the 2021–2027[3] period. At the same time, the EU presented a package of measures in *"Europe's moment: Repair and Prepare for the Next Generation"*[4]. Together, the budget and package of measures are intended to jump-start development and the transition process in Europe. The Covid-19 crisis has reinforced the European Green Deal's message about the importance of investing in sectors and infrastructure that have a positive impact on human health and the environment, and ensuring that we have a robust supply of environmental goods and services.

The package of measures is intended to increase investments in renewable energy and offshore wind, but it also includes batteries and has an increased focus on hydrogen. The use of

1 European Commission, Directorate-General for Climate Action (2018), A clean planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, COM 2018 (773) (2018, Brussels)

2 IEA (2019), The Future of Hydrogen, IEA (2019, Paris), taken on 25 May 2020 from https://www.iea.org/reports/the-future-of-hydrogen

3 "The EU budget powering the recovery plan for Europe" (COM(2020) 442 final).

4 Europe's moment: Repair and Prepare for the Next Generation" (COM(2020) 456 final)

technology such as carbon capture and storage (CCS) is also included. The Horizon Europe research programme will also be boosted.

Several major projects are taking place internationally. For example, in the north of England, in the H21 North of England project, Equinor, Northern Gas Networks and Cadent are looking into opportunities to decarbonise 3.7 million homes and 40,000 businesses by using hydrogen instead of natural gas for heating. The Swedish company Vattenfall is working on a project in the Netherlands involving the conversion of a gas-fired power station to hydrogen. Vattenfall is also involved in the HYBRIT project in Sweden, where it is working on emission free steel production using hydrogen. In North America, Nikola Motors plans to establish a network of 700 fuelling stations for hydrogen-powered trucks[5]. In Switzerland, a consortium of truck owners has joined forces to acquire 1,600 hydrogen trucks by 2025[6]. Hyundai is one of the companies supplying the trucks. The train manufacturer Alstom will deliver hydrogen-powered trains to companies including LNVG in Germany by 2022[7]. Similar initiatives to replace diesel trains are also under way in the United Kingdom[8]. In Japan, Kawasaki has been working with Shell to develop and launch the world's first transport ship for liquid hydrogen[9].

The development and use of hydrogen-based solutions can contribute to both value creation and important emission cuts in Norway. The versatility of hydrogen means that it can be used in a range of sectors. In Norway, parts of the heavy manufacturing and transport sectors, including shipping and heavy goods transport, stand out as the sectors most suitable for hydrogen. These are areas in which there are currently few or no zero emission alternatives, and in which it can be challenging to replace fossil energy sources with renewable electricity and batteries, or sustainable bio-based solutions.

Conditions for hydrogen in Norway are ideal, and Norwegian businesses are well positioned to participate in this potentially growing market.

- Norway has many years of industrial experience across the entire hydrogen value chain, and conditions for the production and use of clean hydrogen are ideal. Many Norwegian companies and technology communities are already developing and supplying equipment and services for the production, distribution, storage and use of hydrogen for various sectors.
- Norway has large gas reserves and the potential to increase energy production from renewable energy.
- Converting natural gas to clean hydrogen requires the capture and storage of CO_2. The Norwegian continental shelf could potentially act as a CO_2 storage.
- Through the petroleum industry, we have robust experience of everything from processing gas to tackling major industrial projects.
- Norway has competitive knowledge and technology communities and a maritime industry that includes large segments of the maritime value chain. The industry already has experience in developing and implementing new high-technology solutions in maritime transport, including the use of batteries and liquefied natural gas (LNG). Several projects in the industry are already looking closely at hydrogen or ammonia as energy carriers.

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5 https://www.trucks.com/2019/04/22/nikola-ambitious-plan-hydrogen-service-network/ (taken on 25 May 2020)

6 https://hyundai-hm.com/en/2020/02/06/hyundai-hydrogen-mobility-ag-hhm-selects-auto-ag-truck-as-service-partner-in-switzerland/ (taken from website on 25 May 2020)

7 https://www.alstom.com/press-releases-news/2019/1/alstom-presents-hydrogen-train-six-federal-states-germany (taken from website on 25 May 2020)

8 https://www.bbc.com/future/article/20200227-how-hydrogen-powered-trains-can-tackle-climate-change (taken from website on 25 May 2020)

9 https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20191211_3487 (taken from website on 25 May 2020)

The strategy builds on, and must be seen in context with, other relevant action plans, strategies and reports to Parliament that the government has presented or with which it is working. These include the 2021–2030 climate plan, action plan for green shipping, action plan for infrastructure for alternative fuels and the plan for fossil-free public transport by 2025. The action plan for green public procurements and the action plan for fossil-free construction activity in the transport sector, both of which are currently being prepared, will also be relevant.

Much of the factual basis of the strategy is based on the report prepared by DNV GL "Production and use of hydrogen in Norway"[10] commissioned by the Ministry of Petroleum and Energy and the Ministry of Climate and Environment, and other relevant reports. Meetings have also been held, in which companies and organisations have had the opportunity to provide input, verbally and in writing.

In addition to the introductory section, the strategy has three sections:

1) Safe use and production of hydrogen with low emissions

2) Hydrogen in Norway

3) Norway and hydrogen internationally

Main elements of the government's hydrogen strategy

The government wants to prioritise efforts in the areas in which Norway has a particular advantage, where Norway and Norwegian companies and technology communities can influence development, and where there are opportunities for increased value creation and green growth.

If hydrogen is to become a viable zero emission alternative, both in Norway and globally, it must be safe and accessible, both technologically and financially. In many commercial applications, energy costs are important in terms of a company's global competitiveness. Based on the current costs of energy and emissions, the energy losses generated by producing hydrogen and the cost of storing it make the utilisation of clean hydrogen less profitable compared with fossil energy sources or other low and zero emission solutions. Hydrogen is currently not competitive in many of the areas of application that could be of interest.

Emissions pricing, through taxes and the Emissions Trading System, is designed to promote low emission solutions. A more stringent emissions trading market, combined with the increase in the CO_2 tax announced by the government, will make emission-intensive solutions more expensive. In the Granavold political platform, it was announced that the government will increase the flat CO_2 tax by 5 per cent every year for all sectors until 2025.

The necessary technological developments
As described in Climate Cure 2030, technology readiness level and high costs are central barriers to the use of hydrogen in the transport sector and as a chemical component in the manufacturing industry. If hydrogen and hydrogen-based solutions such as ammonia are to be adopted in new fields, the technology and solutions must be available. Demonstration and piloting of hydrogen and hydrogen-based solutions could lead to hydrogen being used

10 DNV GL (2019), Production and use of hydrogen in Norway, DNV GL Energy Markets & Technology N&MEA (2019, Høvik)

as an energy carrier in new areas of application. Developing technology could affect the supply side, through reduced production costs, and the demand side, through new markets. Technology development and innovation in a value chain perspective could assist in drawing on potential synergies between industries.

An important target for the government is to increase the number of pilot and demonstration projects in Norway, thereby contributing to technology development and commercialisation. This goal is backed by a range of policy instruments focusing on zero emission technologies and solutions. The Research Council of Norway, Innovation Norway and Enova contribute to developing and demonstrating energy-efficient and cost-efficient methods and value chains for the production, transport, storage and use of clean hydrogen, through among others, joint calls for proposals in the PILOT-E scheme.

- The government will, through current policy instruments, continue to support the necessary technological developments. The authorities will monitor developments and adjust the policy instruments if needed.
- The government will in conjunction with the Climate Plan for 2030 evaluate policy instruments to promote the development and use of hydrogen in Norway.
- The government will continue to support research into, and the development and demonstration of hydrogen technologies through relevant schemes, with a focus on projects of a high scientific quality and potential for commercial development.

Competitive production of clean hydrogen
If clean hydrogen is to become a competitive energy carrier, production costs must be reduced. For hydrogen from electrolysis, this means reducing the costs of the actual electrolysis plant, but also developing production facilities that convert electricity to hydrogen in a more energy-efficient manner. Through the Research Council of Norway, Innovation Norway and Enova, the public sector is helping to develop and demonstrate more energy-efficient and cost-efficient methods of producing clean hydrogen. Electricity supplied for use in electrolysis is currently exempt from the consumer tax on electricity.

- The government will contribute to developing technology for the capture, transport and storage of CO_2, and has ambitions to build cost-effective solutions for full-scale CCS plants in Norway, given that this will generate technology development in an international perspective. CCS is essential for the production of clean hydrogen from natural gas.

Emission-free transport
The government pursues a broad set of policies aimed at zero emission solutions in the transport sector. This also includes hydrogen. Hydrogen vehicles get the same tax breaks and user benefits as those of battery electric vehicles.

In the national budget for 2017, the Conservative, Progress, Liberal and Christian Democrat parties adopted a resolution to extend the benefits applying to electric vehicles to fuel cell vehicles until 2025 or 50,000 vehicles. ESA has been notified of and has approved the VAT exemption for fuel cell vehicles until 2023.

If hydrogen is to become a competitive zero and low emission alternative in the transport sector, solutions must be adopted after they have been piloted and demonstrated. In order to speed up the introduction and growth of hydrogen solutions in the commercial vehicle and vessel market, the government introduced the Zero Emissions Fund.

In 2019, the government set aside NOK 25 million to assist county authorities in their work of promoting zero and low emission high-speed passenger ferries. The high-speed ferry initiative is part of the Klimasats subsidy scheme administered by the Norwegian Environment Agency. In the budget for 2020, this high-speed ferry initiative was boosted with a budget of NOK 80 million. Funding from this scheme allows processes including development contracts to be set up. The use of development contracts could play an important role in creating the right financial conditions to allow technology communities to compete to develop the best zero emission solutions for selected high-speed ferry routes. In order to ensure that a process of development contracts can be initiated in 2020, the government proposes increasing the grant by NOK 20 million for the Klimasats high-speed ferry scheme.

Access to hydrogen and ammonia are vital if these alternatives are to become viable zero emission solutions for transport. The government therefore, through Enova, supports the establishment of fuelling infrastructure in the early phase. Through NOBIL for road infrastructure and the Norwegian Coastal Administration for infrastructure for maritime transport, the government will ensure that there is a publicly available database of infrastructure for alternative fuels for transport by road and sea in Norway.

- The government will perform a survey of all ferry routes, high-speed ferry routes and other scheduled maritime traffic in order to establish which zero emission technologies could be suitable. This is in order to ensure that the authorities and private companies have a better overview of what could be of interest in terms of low and zero emission technologies in the maritime sector, including the use of hydrogen.

Green public procurements
The public sector spends over NOK 500 billion on procurements every year. This covers everything from major procurements such as ferry services and buildings, to office supplies. New climate-friendly and environmentally-friendly goods and services are rapidly being developed, and through its procurements, the public sector could be an important driver of innovation and transition in the Norwegian economy.

- The government will prepare an action plan in order to increase the proportion of climate-friendly and environmentally-friendly public procurements and green innovation.

Transport and low and zero emission solutions are some of the prioritised areas in which public procurements have been evaluated as a particularly suitable policy instrument towards achieving Norway's climate and environmental targets. These will be described in more detail in the action plan.

Safety and standards
The use of hydrogen and hydrogen-based systems must be safe. This is absolutely crucial if new technology and new systems are to be adopted, and if hydrogen is to become a viable solution.

- The government will continue the work of developing regulations and standards, nationally and internationally, for the use of hydrogen-based systems within new areas of application, and in line with technological and market developments.
- The government will ensure that the Norwegian Maritime Authority and Norwegian Coastal Administration has the capacity and skills to handle new green shipping solutions, including the development of regulations for the use of hydrogen in maritime industries.

National research
Norway has strong research communities in a number of hydrogen-related technology fields, and over the past 10 years has provided funding worth around NOK 500 million through the Research Council of Norway for research and development focusing on hydrogen. The most important policy instrument is the broad energy research programme ENERGIX, in which hydrogen is included as a prioritised thematic area. Norwegian research communities have also improved their hydrogen competence through other publicly funded initiatives, in fields such as social science, mathematics and material technology, and through participation in other public pilot and demonstration projects.

The contribution of the authorities to the research and development of new hydrogen solutions and technologies allows businesses to scale up the use of hydrogen more quickly, cost effectively and safely. This is particularly important in terms of adapting the technology to new areas of application, such as the maritime sector and heavy goods transport.

- The government will increase its focus on research initiatives towards the transition to a low emission society, cf. its Long-term plan for research and higher education (2019–2028). The government will also prioritise the development of technology and solutions for the green transition.

An increased focus on research initiatives and the development of green technologies and solutions also includes research into and the development of hydrogen technologies and hydrogen-based systems.

In light of the Covid-19 situation, the government proposes granting NOK 120 million to the Research Council of Norway's ENERGIX programme. This funding will go to innovation projects with a commercial focus, in order to maintain the level of research activity and stimulate Norwegian businesses' green transition projects. Hydrogen-related technologies and solutions will hold a key place in this initiative, allowing new technologies and solutions to be developed and implemented in the market, and Norwegian businesses to continue developing their skills and portfolios in this field.

International collaboration and research
Most of the technology development and future demand for hydrogen solutions will come from outside Norway. It is therefore important for the Norwegian authorities and Norwegian research and technology communities to participate internationally, both in order to benefit from what is happening outside Norway, and to participate internationally by providing knowledge and technology. By way of example, the European Commission recently announced the establishment of a Clean Hydrogen Alliance, in which Norway could participate.

International collaboration will play a crucial role in establishing a functioning market that stimulates the increased use of clean hydrogen.

- The government will continue facilitating participation in relevant international fora that contribute to promote and establish sustainable technologies and markets for hydrogen as a low emission solution.

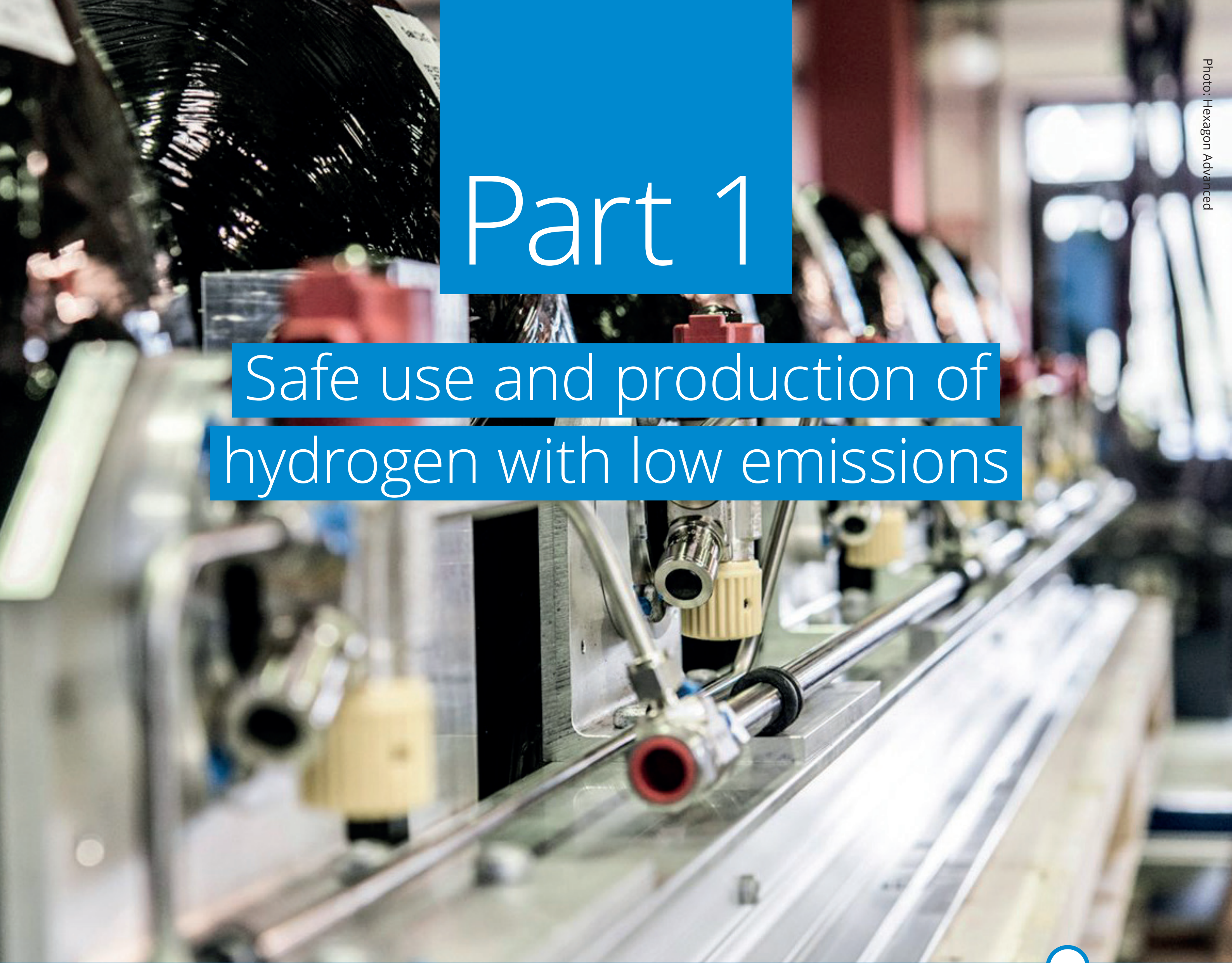


Photo: Hexagon Advanced

Part 1

Safe use and production of hydrogen with low emissions

1 Hydrogen with low emissions – from production to consumption

The production and use of hydrogen depends on factors such as cost, the design of the energy system, technology readiness level, alternative technologies, and financial and political framework conditions. These apply to all energy carriers. These factors vary between countries, and affect where and to what extent the use of hydrogen is adopted. In this section, we attempt to provide an overview of the limits and prerequisites applying to hydrogen as a technology, from production to storage, distribution and use, and of the various safety aspects of these.

1.1 Production

The most widespread methods of producing hydrogen are natural gas reforming and coal gasification. Global demand for hydrogen is today around 70 million tonnes[11]. Around 3 per cent of global energy production is used to produce this volume. The bulk of hydrogen produced globally comes from natural gas (76 per cent), followed by coal (23 per cent). Only 1 percent comes from electrolysis of water.

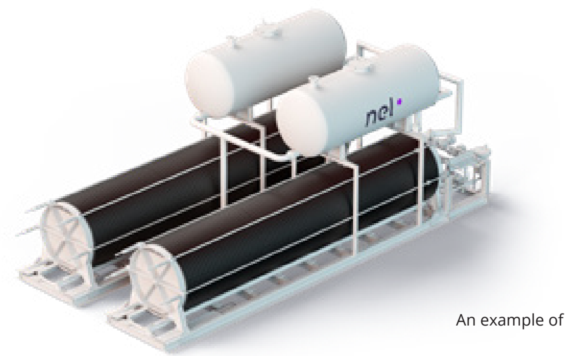
11 DNV GL (2019), Production and use of hydrogen in Norway

For hydrogen to be regarded as a low and zero emission energy carrier, it has to be produced with virtually zero emissions. Ways of achieving this include the electrolysis of water based on renewable electricity, or by integrating the capture and storage of CO_2 when reforming natural gas. Hydrogen production from fossil energy sources, natural gas and coal does not currently involve capturing and storing the CO_2. Globally, this generates emissions of around 830 million tonnes of CO_2 per year[12], which is roughly equivalent to the total greenhouse gases emitted by Germany in 2018.

In Norway, electricity used to produce hydrogen through electrolysis is currently exempt from the consumer tax on electricity. This helps to reduce the cost level at which hydrogen becomes competitive compared with other energy carriers. In 2020, the consumer tax on electricity is NOK 0.1613/kWh.

Two production methods: Electrolysis and steam reforming combined with CCS
In simple terms, electrolysis involves separating the two hydrogen atoms and the oxygen atom in a water molecule from each other using electricity. Electrolysis requires around 9 litres of water to produce 1 kilo of hydrogen. The by-products are heat and 8 kilos of oxygen, which can be collected and distributed for medical use or for use in various industries like the metal and chemical industries. Selling the oxygen and utilising the waste heat can help reduce the costs of production.

For **electrolysis**, two main technologies are currently commercially available on the market: Alkaline electrolysis and polymer electrolyte membrane (PEM) electrolysis. Both technologies are relatively mature, but there is still room for further development. Energy efficiency and lifespan are both slightly higher with alkaline electrolysis. At the moment, PEM plants are slightly more expensive, partly because they use noble metals (such as platinum and iridium), and they have a slightly shorter lifespan than alkaline plants. The advantage is that the plants are more compact, require less space and are more flexible. Alkaline electrolysis currently has an estimated energy efficiency of around 55–70 per cent compared to 55–66 per cent for PEM (i.e. an energy loss of 30–45 per cent), and an estimated lifespan of 60–90 thousand hours, compared to 30–90 thousand hours for PEM. It is estimated that by 2030, the lifespans could increase to 65–100 thousand hours for a 100 MW alkaline plant and to 30–85 thousand hours for PEM[13]. To produce one kilo of hydrogen gas (with an energy content of 33 kWh), around 50–55 kWh of electricity[14] is needed, but as mentioned above, this will depend on the energy loss from the electrolysis plant. Indirect emissions of greenhouse gases through the production of hydrogen by electrolysis depends on how the electricity itself is produced. For example, there will be significant indirect greenhouse gas emissions if the hydrogen is produced using electricity based on coal power.



An example of an alkaline unit for electrolysis.
Photo: NEL ASA.

12 IEA (2019), The Future of Hydrogen

13 DNV GL (2019), Production and use of hydrogen in Norway; IEA (2019), The Future of Hydrogen

14 Home, Hallgeir; Hole, Jarand (2019), Hydrogen in the modern energy system in Norwegian Water Resources and Energy Directorate Fact Sheet (2019:12), NVE (2019, Oslo), Taken from website on 25 May 2020 from http://publikasjoner.nve.no/faktaark/2019/faktaark2019_12.pdf

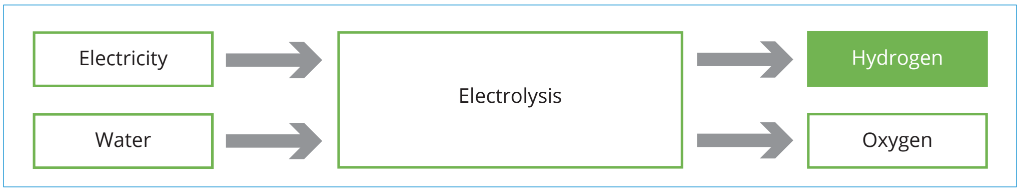


Figure 1-1 Electrolysis – using electricity to separate water into hydrogen and oxygen

In **steam reforming**, natural gas, which consists mainly of methane, reacts with steam under high pressure and at a high temperature. This process produces hydrogen and carbon dioxide. If the process is to produce clean hydrogen, the capture and storage of CO_2 must be integrated in the process. Steam reforming has an energy efficiency of around 70–85 per cent. Without CO_2 capture from steam reforming of gas, the production of 1 tonne of hydrogen will generate around 8 tonnes of CO_2[15]. Compared with electrolysis, the production plant and thereby the production volume is considerably larger. A large-scale steam reforming plant can produce around 120–240 tonnes of hydrogen per day. By comparison Nel ASA, which produces electrolysers and fuelling stations, states that one of their alkaline modules can produce up to 8 tonnes of hydrogen per day[16]. Steam reformers can also be built on a smaller scale, but the cost per produced unit is then considerably higher. Just as the price of electricity is an important cost driver for electrolysis, the price of gas represents a considerable portion of the production cost in steam reforming. If CCS is adopted, this would add significantly to the production cost.

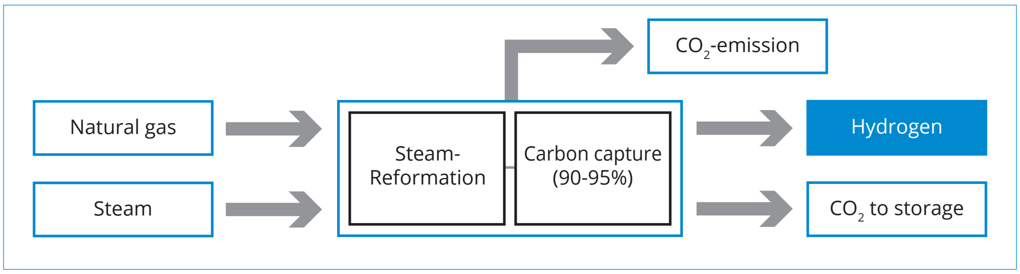


Figure 1-2 Steam reforming with capture and storage of CO_2 as a climate-friendly solution

Production costs

The various production methods have differing production costs. It is however important to differentiate between production cost and total cost, which will also include costs associated with transport, storage and conversion. The IEA estimates that hydrogen produced from fossil sources with no CO_2 capture will be competitively priced by 2030. A higher price for CO_2 emissions, applicable globally, is needed to make hydrogen produced from renewable energy or from fossil sources with CO_2 capture and storage profitable.

Given the current prices of gas and electricity, steam reforming of natural gas combined with the capture and storage of CO_2 is estimated to be cheaper per kilo of produced hydrogen than electrolysis in large-scale production, but this depends on factors such as access to natural gas infrastructure and whether CO_2 capture and storage is feasible. The prerequisites behind this estimate include restrictions on where such plants may be located, and in some cases can involve long distances between producers and consumers, which

15 Hallgeir; Hole (2019), Hydrogen in the modern energy system

16 NELhydrogen.com (2020), Atmospheric Alkaline Electrolyser, Taken from website on 25 May 2020 from https://nelhydrogen.com/product/atmospheric-alkaline-electrolyser-a-series/

can result in increased transport costs. Any large-scale hydrogen production via electrolysis requires access to large volumes of renewable energy. The cost of energy, and parameters affecting this cost (such as energy efficiency of the production method), are by far the most important cost factor in both these production methods[17]. In steam reforming, natural gas is used, and for electrolysis, electricity is used. Differing trends in the prices of gas and electricity may therefore lead to differing cost trends for the production methods in the future. Other factors such as cost trends for CCS and electrolysers could also play a role.

For smaller volumes of hydrogen distributed across multiple end users, such as its use in vehicles or vessels, electrolysis could be cheaper in a value chain perspective when the costs of transport and storage are included. Electrolysis plants also have the advantage that they are modular, which makes them relatively easy to scale up and adjust to meet demand. The average size of new electrolysis plant installations in recent years has been 1 MW[18]. According to the IEA, there are projects under development with electrolysis plants of 10 MW or more. Since large plants are made up of several units, the benefits of building a large plant are consequently limited. However, there can still be significant benefits of scale associated with the storage and conversion of hydrogen (e.g. for liquefaction plants). The unit price of electrolysers is expected to go down, both as a consequence of developments in technology and scale of production (see Figure 1-3).

An alternative to dedicated hydrogen production via electrolysis or steam reforming combined with CCS is the utilisation of by-product streams from existing industrial plants, where hydrogen is already produced as an integrated part of a process. Currently, these industrial plants do not capture and store CO_2. The utilisation of surplus heat from electrolysis plants that produce hydrogen, e.g. by connecting the production plant to the district heating network, increases the utilisation ratio and profitability of hydrogen produced from electrolysis. In other words, which production method has the lowest total costs will depend on geography, available infrastructure, estimated demand and price of input factors (mainly price of electricity and gas).

Hydrogen is an energy carrier that must be converted from electricity, natural gas or coal, which generates energy losses in production. If hydrogen is to compete with fossil energy sources globally, it is important for CO_2 emissions to be priced sufficiently high. The development of technology is also needed in order to reduce the costs of producing clean hydrogen. For electrolysis, this means reducing the costs of the actual electrolysis plant, but also developing production facilities that convert electricity to hydrogen in a more energy-efficient manner. In addition to improved efficiency, trends in the price of electricity will be important, since the price of electricity represents a significant portion of the cost of producing hydrogen through electrolysis. The IEA estimates that the cost of producing hydrogen from renewable electricity could fall by 30 per cent by 2030, as a result of the falling costs of renewable energy and scaling up of production facilities.

Research and testing of more efficient electrolysis plants is currently ongoing, funded by the Research Council of Norway, PILOT-E and Enova. For example, in 2018 Yara received funding through PILOT-E for a joint project with Nel, involving the introduction of a new generation of electrolysers, the aim of which is to reduce production costs. In 2019, Nel received funding from Enova for a project involving an improved process for electrode production. Large-scale electrolysis could also eventually help to reduce costs further. The timing of when to build large-scale production facilities should be determined by the market, and will largely depend on developments on the demand side, in vehicles, vessels and industrial processes.

17 IEA (2019), The Future of Hydrogen

18 IEA (2019), The Future of Hydrogen

	Alkaline electrolysis		PEM electrolysis	
	Today	2030	Today	2030
Electrolysis efficiency (%*)	63-70	65-70	56-60	63-68
System cost (USD/kW)**	500 - 1400	400 - 850	1100 - 1800	650 - 1500

Figure 1-3 Estimated energy efficiency and system costs for electrolysis (IEA, 2019)

**Efficiency is based on lowest calorific value. Calorific value is the energy that is released through the complete combustion of a given quantity of fuel. Lower calorific value indicates the total calorific value minus any volume that may be released through the vaporisation of water, which can often not be utilised. For example, this is the case if steam from combustion or a fuel cell is released through a chimney or exhaust pipe.*
***System cost does not reflect different system sizes and the uncertainty of future estimates.*

1.2 Conversion, storage and distribution

Since hydrogen has a low energy density per unit of volume under normal pressure compared with other energy carriers (see Figure 1-4), its energy density must be increased in order to improve the efficiency of its storage, transport and use. This can be achieved either through compressing the hydrogen gas, liquefying it, or converting it into other hydrogen-rich substances. This conversion requires energy, thereby increasing the cost for potential consumers. Which solution is most suitable depends on factors such as storage needs, distribution distance and type of application.

Compressed hydrogen gas can be suitable for short distribution distances and applications requiring moderate volumes of energy. For example, at 50 bar[19], a storage density of 4 kg of hydrogen per cubic metre can be achieved, while a pressure of 700 bar results in 40 kg of hydrogen per cubic metre. In cars, standard tanks can usually store hydrogen at a pressure of 700 bar. Pressurised hydrogen can be transported in gas tanks on trucks, trains or ships in the same way as compressed natural gas and biogas are currently transported. Like natural gas, hydrogen gas can also be distributed over long distances in pipelines. For longer distribution distances or for applications requiring large volumes of energy over long periods, such as in maritime vessels, liquid hydrogen may be more suitable.

19 1 bar is roughly the same as atmospheric pressure at sea level.

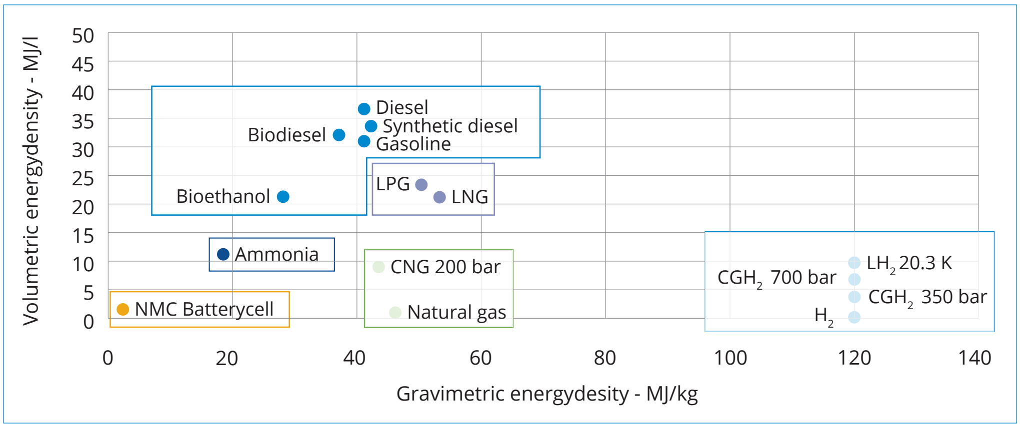


Figure 1-4 Comparison of energy density of hydrogen and other relevant fuels/energy carriers. The Y axis is volumetric energy density – how much energy the various carriers have per unit of volume (litre). The X axis is gravimetric energy density – how much energy the various carriers have per unit of weight (kilogram) Source: Shell (2017), Shell hydrogen study: Energy of the future? Sustainable mobility through fuel cells and hydrogen, figure taken from DNV GL (2019)

Hydrogen gas turns into a liquid when cooled to -253°C. Liquid hydrogen has a storage density of around 71 kg of hydrogen per cubic metre. The cooling process is energy-intensive, which adds to the cost. In Europe, there are currently only three facilities capable of liquefying hydrogen. Liquid hydrogen can be transported in tanks on ships, trucks and trains.

Hydrogen can also be converted into other energy carriers in liquid form, that are easier to transport over longer distances using existing transport systems. One alternative is to use clean hydrogen to produce ammonia. Ammonia can contain over 17 per cent hydrogen. This is equivalent to 121 kg of hydrogen per cubic metre. Another alternative is to use liquid hydrogen carriers, where hydrocarbons are enriched to a higher hydrogen content. Like other conversion processes, this involves energy losses through the value chain. The benefits of liquid hydrogen carriers are that they can be transported and stored at normal atmospheric pressure and temperatures close to zero degrees. They can also make more use of existing infrastructure.

Plants for the production, storage, tapping, fuelling and bunkering of hydrogen require relatively large areas because of the need for safety zones. What safety zones are needed depends on the volume of hydrogen, type of technology, storage type and whether large volumes of hydrogen are held in tanks above or below ground, in air or in water. These can be limiting factors or can increase the cost. It may be possible to reduce the land area needed as we acquire more experience with the new aspects of the technology.

1.3 Consumption

The energy content of hydrogen can either be utilised by converting hydrogen into electricity through fuel cells, or by producing energy or heat through combustion, in the same way as natural gas. Hydrogen can also replace fossil fuel input factors in industrial processes. Continued research and development is needed in order to improve the technology and make it cheaper. National and international research on hydrogen is described later in chapters 6 and 7.4.

Fuel cells
In a fuel cell, hydrogen and oxygen are converted into electricity, with steam as the only emission. There are several types of fuel cells with various strengths and weaknesses. The choice of fuel cell will therefore depend on which application it will serve. Factors such as temperature, output, energy efficiency, lifespan and materials used vary from type to type, and also affect cost. Costs have gone down significantly in recent years, while efficiency has improved[20]. Lifespan can vary from around 5,000 up to around 90,000 hours. However, fuel cells may not operate continuously in all applications. In a vehicle for example, drivers have to manage with fewer hours than in a stationary power and heat production plant. The efficiency of fuel cells in vehicles is around 60 per cent. By comparison, the efficiency, or how much energy goes towards propulsion, in an ordinary petrol-driven combustion engine is around 20 per cent[21]. Efficiency is expected to improve somewhat in the years ahead. According to the IEA[22], total efficiency could be less than 30 per cent, if the total energy consumption (loss) in the value chain is included, from conversion of electricity into hydrogen, transport and storage, and conversion back to electricity. This will be reflected in the total cost to the user, and to some degree also in the price of hydrogen.

Gas turbines
Gas power represents a significant proportion of electricity production in Europe and the rest of the world. Gas power stations can regulate production up and down relatively quickly, thereby helping to balance the power system according to electricity consumption. This flexibility also makes gas power stations suitable backup for variable renewable energy production during periods when there is no sun or wind and during periods when demand for electricity or heat are particularly high – such as seasonal variations. Just like for fuel cells, gas power stations also involve energy losses. The efficiency of a typical combined cycle gas power plant is just under 60 per cent[23]. If the surplus heat is also used for heating purposes, efficiency can increase to as much as 80 per cent.

Modern gas turbines can be modified to use either a mixture of natural gas and hydrogen, or hydrogen alone. This will result in power and heat production with reduced or no CO_2 emissions. It will also be possible to reduce emissions by capturing the CO_2 from the power station's exhaust gases. Gas turbines that operate exclusively with hydrogen are not currently available off the shelf. However, turbine manufacturers are in the process of modifying their products in order to be ready for a future in which hydrogen operation could be of interest. For example, all the major manufacturers that currently supply gas turbines for the European market have jointly declared that all new turbines delivered from 2020 must be capable of running on natural gas with a 20 per cent hydrogen admixture, and on 100 per cent hydrogen from 2030[24].

Hydrogen as chemical feedstock
Besides being used as an energy carrier, hydrogen is also used as chemical feedstock in industry. Its most widespread use as a chemical feedstock is currently in the production of ammonia and in refining.

20 IHS Markit (2019), Hydrogen: The missing piece of the zero-carbon puzzle. An IHS Markit study considering the potential role of hydrogen in a net-zero carbon Europe, IHS Markit (2019, London)

21 IEA (2019), The Future of Hydrogen

22 IEA (2019), The Future of Hydrogen

23 Hofstad, Knut (2019, 15 October), Combined cycle power plant, in Store Norske Leksikon, taken on 3 April 2020 from https://snl.no/kombikraftverk

24 EU Turbines (2019), The gas turbine industry's commitment to drive the transition to renewable-gas power generation, taken on 25 May 2020 from https://powertheeu.eu/wp-content/themes/euturbines/dl/EUTurbines_renewable-gas-commitments_2019.pdf

AMMONIA AS FUEL IN TRANSPORT

Ammonia can be a zero emission alternative similar to hydrogen. The use of ammonia has some advantages compared to hydrogen. Ammonia is a gas at normal temperatures and atmospheric pressure, but it turns into a liquid at a pressure of 10 bar and 25ºC, or minus 33ºC at atmospheric pressure. By comparison, hydrogen must be at minus 253ºC in order to turn into a liquid. Ammonia also has a higher energy density. Per unit of volume, liquid ammonia holds 50 per cent more energy than liquid hydrogen. It thereby requires less storage space and therefore permits longer voyages, other factors being equal.

Ammonia can be both a hydrogen carrier, and used directly as a fuel. In principle, ammonia can be used both in combustion engines and fuel cells. There are currently no marine engines on the market that can use ammonia as a fuel without technical modifications, but development work is under way that within a few years is expected to result in engines that can burn ammonia. Engine manufacturers report that engines suitable for ammonia could be on the market in as little as three years[25].

Fuel cells that can use ammonia are further off as they are currently in the research stage. Some of the challenges involved in the use of ammonia are its combustion characteristics and NOx emissions. Ammonia is toxic and can also be corrosive. As for hydrogen, there is currently no bunkering infrastructure available for ammonia as a fuel for ships.

The costs associated with the use of ammonia on board ships are estimated to be comparable with the use of LPG, i.e. the cost of the engine is slightly higher than for traditional diesel-driven engines, and there are additional costs involved in the storage tanks. However, the costs are lower than for LNG.[26]

The production costs for ammonia will be slightly higher than for hydrogen, because the hydrogen in turn has to be converted into ammonia. If storage costs are included, the costs could be lower, because it is cheaper to store than hydrogen. Determining which is the cheapest alternative will depend on factors such as production cost (including conversion/ liquefaction) storage cost and energy efficiency in use.

Box 1-5, Ammonia as fuel in transport

25 Norwegian Environment Agency, Norwegian Public Roads Administration, Norwegian Coastal Administration, Norwegian Agriculture Agency, Norwegian Water Resources and Energy Directorate and Enova (2020), Climate Cure 2030, taken on 24 May 2020 from https://www.miljodirektoratet.no/klimakur

26 (DNV GL (2019). Reduksjon av klimagassutslipp fra innenriks skipstrafikk. Rapportnr 2019-0939)

2 Safety and regulations

The use of hydrogen and hydrogen-based systems must be safe. Safe use is critical if potential users are to adopt new technology and new solutions, and if hydrogen and hydrogen-based solutions are to become viable alternatives for users. Experience gained through hydrogen projects will be important for the Norwegian authorities' work on developing regulations for the use of hydrogen and other hydrogen-based solutions such as ammonia. There will also be a need for training and for skilled personnel throughout the hydrogen value chain. In addition to rules and regulations applying to technical solutions, regulations should also be considered for the training of personnel who will work with hydrogen or hydrogen-based solutions. This applies particularly for use in shipping, where use is in an early phase.

Hydrogen gas is colourless, odourless and non-toxic. The gas is classified as a flammable gas, and the ignition of hydrogen mixed with air can result in explosion. Hydrogen is combustible when mixed with air in concentrations ranging from 4 to 75 per cent by volume, and compared with other flammable substances, very low energy input is required to ignite the gas. For example, hydrogen gas can be ignited by static discharge from clothing and equipment and by spontaneous combustion.

Hydrogen is lighter than air – which means that a leak will rise quickly. In the outdoor use of hydrogen, this is positive in terms of safety, because a leak will quickly dissipate. However, it is still important to focus on preventing accidental discharge, in view of the fact that hydrogen is highly combustible. When handling hydrogen in enclosed spaces, any hydrogen leaks will collect on the ceiling or at the highest point, and effective ventilation and detection systems tend to be a prerequisite for safe operation.

There are also a number of challenges depending on whether the hydrogen is in the gas or liquid phase. Hydrogen in the gas phase tends to be stored at very high pressure – up to 1,000 bar in refuelling stations for cars. The hydrogen molecule is the smallest of all molecules, which means that it is difficult to prevent leaks at joints in equipment. In addition, hydrogen diffuses into steel and other metals, which can weaken the material and result in fractures (known as hydrogen embrittlement).

For liquid hydrogen, the challenges relate to the low temperature (-253°C). In addition to the obvious risk of frost damage for personnel handling liquid hydrogen, the melting point of the atmospheric gases of oxygen, nitrogen and argon are higher than the temperature of the liquid hydrogen. This means that air will freeze if it comes into contact with liquid hydrogen or equipment at the same temperature. This will in turn increase the concentration of oxygen, resulting in an increased risk of ignition.

Standard Norway's mirror committee SN/K 182 Hydrogen technology monitors the standardisation work of CEN-CLC/TC 6 "Hydrogen in energy systems" and ISO/TC 197 "Hydrogen Technology". The committee works with experts in working groups set up by the ISO and CEN, and receives drafts of new standards in order to comment and vote on them.

In Norway, the specialist authority regarding flammable, reactive, pressurised and explosive substances, including hydrogen, is the Norwegian Directorate for Civil Protection (DSB). The Directorate is also the specialist authority for the road transport of hazardous goods.
DSB is also the administrative authority responsible for electrical safety, i.e. requirements for the safe design and use of distribution networks and electrical systems. These also include hydrogen production systems, storage batteries, charging stations for electric vehicles and shore connections for ships. DSB also administers the regulations that set out requirements governing the design of electrical systems on board ships.

The Norwegian Act relating to the prevention of fire, explosion and accidents involving hazardous substances and the fire services (Fire and Explosion Act) grants the legal authority to draw up regulations for the safe handling of hazardous substances, for example for energy stations involving hydrogen. This is described in more detail in the action plan for infrastructure for alternative fuels in transport (2019)[27].

REGULATIONS AND DIRECTIVES

The handling of hydrogen is governed by the Regulations relating to the handling of hazardous substances[28]. The regulations also governs hydrogen bunkering, up to the point at which the Norwegian Maritime Authority's regulations govern bunker hose connections to ships. In the operations phase, the Regulations relating to health and safety in potentially explosive atmospheres[29] are relevant to hydrogen plants. Stationary equipment used to handle hydrogen must be in compliance with the requirements in the Regulations relating to pressure equipment[30]. Hydrogen must be transported in compliance with the requirements in the Regulations relating to the transport of dangerous goods by road[31]. Undertakings storing 5 tonnes of hydrogen or more will also be covered by the Major Accident Regulations[32]. The latter four regulations are based on directives, which means that the requirements in these regulations are the same as those in regulations in other EU/EEA countries. The Regulations relating to the handling of hazardous substances is a national regulation.

The Regulations relating to the handling of hazardous substances set out requirements which include the preparation of risk assessments for hydrogen plants and for the plants to be constructed and inspected in accordance with recognised norms. In order to achieve a sufficient safety level for third parties, it is important that hydrogen is handled at an appropriate distance from surrounding objects. The regulations set out a requirement for enterprises to document whether there is a need for land use restrictions around the facilities where hydrogen is handled. It is important to consider the safety of a location when establishing a hydrogen plant. The DSB has prepared thematic guidelines including safety distances for facilities including refuelling stations for hydrogen for cars.

Box 2-1 Regulations and directives

27 Ministries (1 July 2019), Action plan for infrastructure for alternative fuels in transport, Ministry of Transport and Ministry of Climate and Environment (2019, Oslo)

28 Regulations of 8 June 2009 no 602 relating to the handling of flammable, reactive and compressed substances, as well as equipment and facilities used in this handling

29 Regulations of 30 June 2003 no 911 relating to health and safety in potentially explosive atmospheres

30 Regulations of 10 October 2017 no 1631 relating to pressure equipment

31 Regulations of 1 April 2009 no 384 relating to the transport of hazardous goods by road

32 Regulations of 3 June 2016 no 569 relating to measures to prevent and limit the consequences of major accidents in enterprises where hazardous chemicals are present

2.1 Safe use of hydrogen in shipping

It is important for regulations to be capable of handling both new technology and new digital solutions. The development of international regulations for the future is vital if the Norwegian maritime industry is to be able to market new technology internationally, and if the maritime industry is to be able to operate internationally with new, innovative technology developed in Norway. The government wants Norway to continue being a driving force in the development of regulations and standards, in order to be able to adopt new solutions and technologies in the maritime sector.

In 2015 IMO adopted the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (the IGF Code). It was Norway that took the initiative of putting the code on the IMO's agenda. The code contains functional requirements and specific requirements regarding fuel systems, tanks and operational requirements for ships that use LNG as a fuel, but also apply to the use of other gases and fuels with a low flashpoint, such as hydrogen, by documenting compliance with functional requirements.

The Norwegian Maritime Authority administers the key regulations in the fields of maritime safety and the environment. The industry's innovative projects challenge the maritime regulations. The Norwegian Maritime Authority is an active participant in work involving new technology, and approves and certifies new fuel systems such as hydrogen, methanol and fuel cells. The Norwegian Maritime Authority is working on a partnership project with the industry, one of the aims is to identify knowledge and research in the field of hydrogen for the purpose of creating a Hydrogen Handbook. This, together with experience gained through projects studying alternative designs, will eventually be used to establish regulations relating to hydrogen. In the UN's maritime organisation, IMO, the directorate is an active participant in the work on "Interim Guidelines for Fuel Cells", which is scheduled to be approved by the UN's Maritime Safety Committee (MSC) in 2021.

There are also projects in Norway that will contribute to the further development of regulations and standards for the use of hydrogen. These will also apply to the use of ammonia as a fuel. An important component of the Norwegian Public Roads Administration's development contract for a hydrogen-electric ferry on the National Road 13 Hjelmeland – Nesvik – Skipavik route is the safe use of hydrogen. The development contract allows for close cooperation between the participants in the competition, the Norwegian Public Roads Administration as the client, in addition to DSB and the Norwegian Maritime Authority as the authorities responsible for safety aspects. The Norwegian Maritime Authority, DSB and Norwegian Public Roads Administration were able to follow the shipping companies' nine concepts from the outline stage up to detailed solutions. This has provided a broad platform for the development of regulations. The high number of contributors to each concept has helped to provide the Norwegian maritime industry with a foundation for the implementation of several hydrogen projects.

Through its connection with the development contract, the Norwegian Public Roads Administration has taken the initiative to perform tests on the safe use of hydrogen. This testing is being achieved through a partnership project, in which Norwegian teams that have been working on hydrogen safety for many years can share experiences based on hydrogen research associated with potential technical solutions for the use of hydrogen in the maritime industry.

Part 2

Hydrogen in Norway

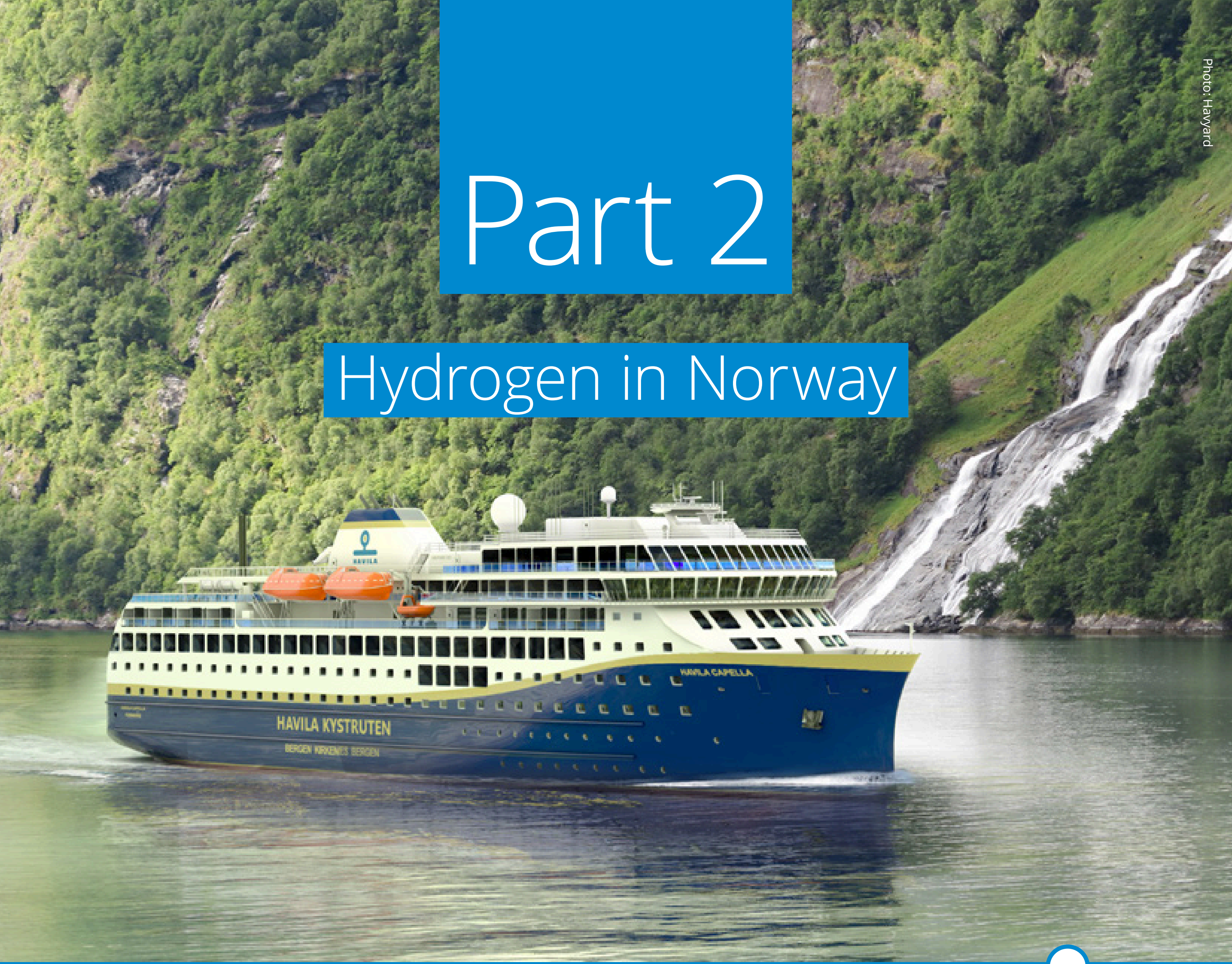


Photo: Havyard

Hydrogen has a number of applications and could be relevant in several sectors as part of the transition to a low emission society. Determining which sectors and applications in Norway will be appropriate for the use and technological development of hydrogen as a low emission solution will depend on several factors. These factors include whether it is possible to influence the development of hydrogen technology, and whether hydrogen will contribute to value creation in Norway. Ultimately, the role of hydrogen as a low or zero emission alternative will depend on its comparative strengths compared to other relevant alternatives.

This section of the strategy examines various applications that could be relevant in Norway. Currently, the most relevant applications appear to be the maritime sector, heavy goods transport and industrial processes. There is still some uncertainty regarding this, since the technology for several of these applications is at an early stage. Several of the applications being considered in other countries are of little relevance to Norway. For instance, Norway has a robust hydropower supply and virtually emission-free heating, therefore, typical applications for hydrogen such as an energy storage unit for variable renewable energy are less relevant.

Climate targets and political ambitions

Norwegian greenhouse gas emissions,
52 million tonnes of CO_2 equivalents in 2018

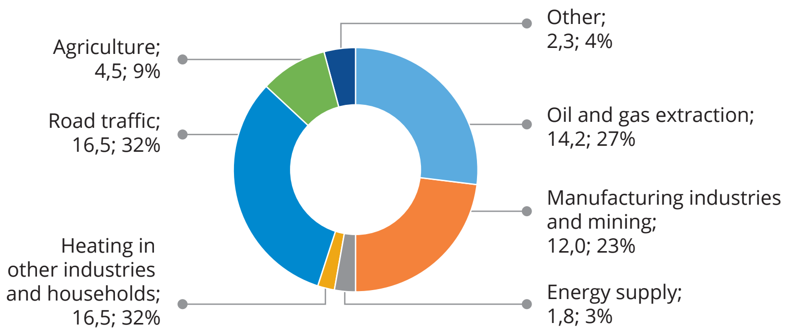


Figure 3-1 Norwegian greenhouse gas emissions in 2018, million tonnes CO_2 equivalents and % of the total emissions. Source: Statistics Norway

Norway is to become a low emission society by 2050. This is a society in which greenhouse gas emissions (based on the best scientific foundation, global emission trends and national circumstances) have been reduced in order to counteract the harmful effects of global warming as described in the Paris Agreement. The government has a target for greenhouse gas emissions in 2050 to be reduced by between 90 and 95 per cent compared to 1990 levels. As part of its follow-up work resulting from the Paris Agreement, the government has signed up to a more ambitious climate target of reducing emissions by 50 per cent and up to 55 per cent in 2030, compared with 1990. As Figure 3-1 shows, Norwegian greenhouse gas emissions in 2018 amounted to 52 million tonnes of CO_2 equivalents. The transport sector accounts for a third of the total emissions, and for around 60 per cent of the emissions which are not part of the EU's Emissions Trading System. Around 50 per cent of the emissions, mainly from industrial operations and oil and gas recovery, are part of the EU's Emissions Trading System (EU ETS).

Value chains

If hydrogen is to become a viable zero emission alternative, it must be an available, safe and economically sustainable alternative. With regard to competitiveness between various energy carriers, it is important to look at the entire value chain, including the total costs of production and transport to the consumer. For hydrogen, in addition to the price of input factors such as electricity or gas, factors such as distance from producer to consumer, the need for storage, demand, and the costs and energy losses associated with chemical conversion matter. For hydrogen used in vehicles/vessels, it is important to emphasise that the combined weight of fuel, tanker, propulsion system and space required will also be significant.

In support of the value chain approach, the national funding scheme PILOT-E requested comprehensive solutions for a competitive and energy-efficient supply chain for hydrogen in its 2019 call for proposals (cf. Box 3-2). Experiences from incoming proposals to relevant calls from schemes like PILOT-E accentuate the current limitations for hydrogen initiatives with regards to a lack of demonstrated technologies. In particular, there are few projects operating with end-user experience in the use of hydrogen. The government has therefore a goal to increase the number of pilot and demonstration projects in Norway, funded by schemes such as PILOT-E.

Large scale hydrogen production is possible with existing technology. However, the cost of hydrogen from electrolysis is high, and not competitive compared with other energy carriers. More energy-efficient and cost-effective production is therefore needed if large-scale produ-ction is to be achieved.

Furthermore, as pointed out in chapter 2, the large-scale construction of publicly accessible infrastructure will only be relevant when the technology on the consumer side has been demonstrated and tested.

PILOT-E

PILOT-E is a collaboration between the Research Council of Norway, Innovation Norway and Enova, designed to achieve the green transition by accelerating energy technology projects throughout the development pathway from concept to market. In 2019, PILOT-E announced that it would be funding projects that would help achieve complete supply chains for hydrogen. Two consortia were awarded funding totalling NOK 71 million:

In the first consortium, led by BKK AS in Bergen, the project aims to develop large-scale supply of liquid hydrogen, intended to be a first step towards a national hydrogen infrastructure.

The second project is led by Flakkgruppen AS, which through the Hellesylt Hydrogen Hub project will establish a functional and commercially sustainable value chain for hydrogen in the north of Western Norway. The aim of the project is to develop and demonstrate a complete supply chain for green hydrogen in Geiranger.

In 2016, 2017 and 2018, funding was also awarded to hydrogen projects to be used in the shipping, road transport and industrial sectors.

Box 3-2, PILOT-E

Synergies

Synergies across applications, in addition to efficient value chains, can be an important contributor to better profitability in hydrogen projects. One of the current challenges is that the production of hydrogen requires a certain scale and sufficient sales if it is to be profitable. This also applies to profitability in the refuelling infrastructure. Strengthening collaboration across sectors and users, thereby pooling demand, could help raise profita-bility. The land areas required in order to have suitable safety zones around production, storage and refuelling facilities can also indicate a benefit of co-locating multiple consumers. It is important for companies planning to adopt hydrogen systems to look at how their projects can be connected to other projects, sectors and applications. These connections can reduce costs, create synergies and contribute to more profitable production.

3 Transport

Hydrogen and other hydrogen-based systems have the potential to reduce emissions in the transport sector. In addition to price, hydrogen's potential will depend on its fit compared with other low and zero emission alternatives such as batteries, biogas and biofuel. Since batteries with the current technology can be too heavy if they are used to store a lot of energy, and biofuel is a limited resource, hydrogen could be suitable for transport involving longer distances, or when weight and refuelling time matters. Heavy goods transport and the maritime sector stand out as potential segments in this perspective. These are applications that will require large volumes of hydrogen, thereby increasing demand in alignment with profitability criteria for hydrogen production. However, it is difficult to say where hydrogen will obtain a competitive advantage in the long run, as hydrogen technologies and other related technologies are developing at a rapid pace.

The transport sector accounts for a third of Norwegian emissions, and for around 60 per cent of the emissions which are not part of the EU's Emissions Trading System. In addition to its general climate targets, the government has an ambition to halve emission levels from the transport sector by 2030, compared to its 2005 levels. The ambition to halve these emissions is based on improvements in the technology readiness level in various parts of the transport sector. There is therefore a pressing need to introduce and continue to develop zero emission technologies in the transport sector.

The use of hydrogen in most transport segments is currently at an early stage, and research, technology development and testing are all required before hydrogen can become a commercially available alternative. The cost estimates for the use of hydrogen and ammonia in the Norwegian government's report Climate Cure 2030[33] (in Norwegian) are at the upper end of the cost spectrum (costing more than 1,500 NOK/tonne of CO_2). These are uncertain estimates, but they illustrate that the widespread use of hydrogen in many applications very much depends on cost reductions through technology developments outside of Norway. This applies particularly to new road transport solutions.

The need for technology development is also clearly illustrated in the figure from a study conducted by Shell, in which they evaluated the readiness level of fuel cells for mobile applications. Figure 3-3 shows the technology readiness level (TRL)[34] for the use of hydrogen for various mobile purposes. The technologies towards the top of the scale are commercially available and have been in operation for some time under commercial conditions and in all expected operational situations. Technologies further down the scale require more testing, pilot schemes and development in order to be ready. The Institute of Transport Economics (TØI) also concludes in a report on zero emission heavy goods transport that the introduction of fuel cell vehicles is some way off in the future[35].

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33 The Norwegian Environment Agency, Norwegian Public Roads Administration, Norwegian Coastal Administration, Norwegian Agriculture Agency, Norwegian Water Resources and Energy Directorate and Enova (2020), Climate Cure 2030, taken on 24 May 2020 from https://www.miljodirektoratet.no/klimakur

34 Technology readiness level tends to be measured on the TRL scale. This scale indicates how far the development process has come, and what documentation is available regarding the technology's performance, and at what scale. Laboratory-scale testing is performed on system solutions under relevant operating conditions. Taken on 26 May 2020 from https://www.enova.no/bedrift/industri-og-anlegg/tema/technology-readiness-levels-trl/

35 Jordbakka, Guri Natalie; Amundsen, Astrid Helene; Sundvor, Ingrid; Figenbaum, Erik; Hovi, Inger Beate (2018), Technological maturity level and market introduction timeline of zero-emission heavy vehicles, TØI report 1655/2018, Institute of Transport Economics (Oslo)

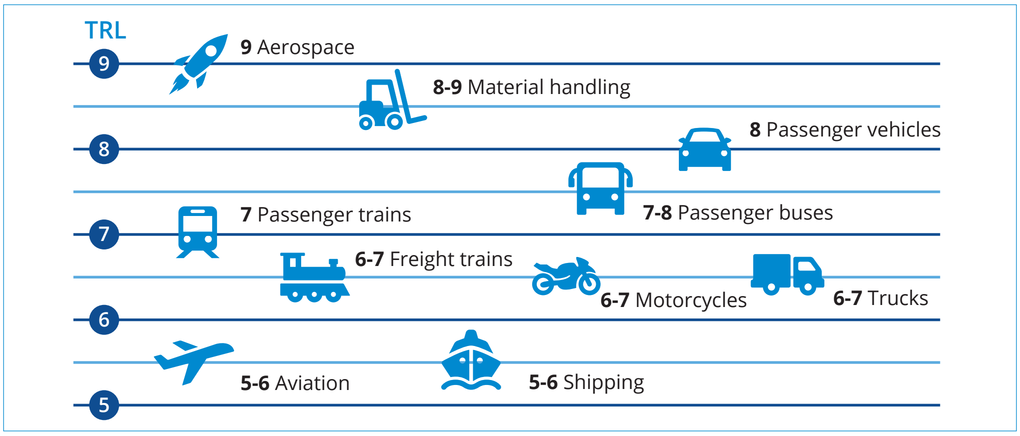

Figure 3-3 Technology readiness level (TRL) of fuel cells. Source: Shell (2017) Shell hydrogen study: Energy of the future? Sustainable mobility through fuel cells and hydrogen), figure taken from DNV GL (2019), Production and use of hydrogen in Norway

Funding for research and technology development is therefore still important. In Energi21, Norway's national strategy for research, development and commercialisation of climate-friendly energy technology, hydrogen is a recommended area for investment, and through the Research Council of Norway, Innovation Norway and Enova, the authorities are contributing to the research, development and demonstration of zero emission technologies for transport, including hydrogen. Through MoZEES (Mobility Zero Emission Energy Systems), a Centre for Environment-friendly Research (FME), the Research Council of Norway is helping to improve knowledge about battery and hydrogen technologies in the transport sector, through research measures such as helping to design and develop safe, reliable and cost-effective zero emission solutions and propulsion systems for heavy goods transport. Several research programmes that are relevant to hydrogen are described in more detail in chapter 3.5.

The Research Council of Norway, Innovation Norway and Enova have funded several pilot scheme and demonstration projects for hydrogen, and support the government's objective to increase the number of pilot projects and demonstration projects in Norway. Through the Zero Emissions Fund that was established in 2019, Enova will also provide funding for vehicles and vessels when the technology matures sufficiently.

Public procurements

The government considers there to be areas in which public procurement is a particularly suitable instrument through which to achieve Norway's climate and environmental targets. Procurers should particularly look at climate and environmental aspects when they review their procurement practice and evaluate how they can achieve the best possible climate benefits. Transport, low and zero emission solutions are areas that could be suitable for public procurement.

Through public procurements, the authorities can both facilitate innovation and actively seek it out. Clients can provide opportunities for innovative solutions by using open requirement specifications that present the client's needs rather than specifying a particular solution. This type of procurement is often described as innovation-friendly procurement. Public sector clients can also actively seek out innovative solutions. This is often described as procurement for innovation, and can be suitable in cases when the needs of the public sector cannot be addressed by the solutions that are already available on the market. In this context, it is important for the procurements to be designed so as to provide enough flexibility for technology to be developed where necessary, allowing the solutions delivered to satisfy needs and functional requirements. In other words, good procurement skills are needed for good, innovative procurements.

If the development and implementation of new technology is to achieve its potential through public procurements, real competition in the relevant markets is vital. The purchaser must therefore have a proactive approach to the market and must evaluate both their own risk and that of the bidders. As announced in Report no 22 to Parliament (2018–2019) Smarter procurements – effective and professional public sector procurement, the government is working on an action plan that will help to increase the proportion of climate friendly and environmentally friendly public procurements and green innovation.

COMPETITIVE DIALOGUE

The "competitive dialogue" procurement process can be a good way of contributing to technology development through close cooperation between the public and private sectors. The Norwegian Public Roads Administration has used this procedure to introduce battery-electric (Ampere) and hydrogen-electric ferries. The hydrogen-electric ferry on the National Road 13 Hjelmeland – Nesvik – Skipavik route is scheduled to start operating in October 2021. This procedure allows for close cooperation between the participants in the competition, with the Norwegian Public Roads Administration as the client, and DSB and the Norwegian Maritime Authority as the authorities responsible for safety aspects. All the parties have been able to follow nine concepts from the outline stage to detailed solutions. This has provided a broad platform for the development of regulations. The high number of contributors to each concept has also helped to provide the Norwegian maritime industry with a foundation for the implementation of several hydrogen projects.

Box 3-4 Competitive dialogue

There are several bodies which, in various ways, are working on innovative public procurements. Innovation Norway has funding schemes that support innovation in public procurement, through its innovation contracts scheme. The national programme for supplier development ("Leverandørutviklingsprogrammet") is a partnership between parties including the Confederation of Norwegian Enterprise, Norwegian Association of Local and Regional Authorities, Norwegian Digitalisation Agency, Innovation Norway and Research Council of Norway, and its objective is to increase the innovation effect of public procurements. The Klimasats subsidy scheme has also provided funding to make good procurements possible. Authorities including Trøndelag county authority have received funding for an innovative procurement process that has involved five consortia and led to the development of several high-speed ferry concepts, including hydrogen-powered ferries.

HYDROGEN IN THE ARMED FORCES

The Armed Forces sector is working to further the development of future-oriented power supply systems for operative units such as vessels, vehicles and land-based stations. New power supply systems with hydrogen as the energy carrier can reduce the probability of unwanted detection of their own military units, and also reduce fuel expenses and the negative environmental impact of the Armed Forces' activities. For example, the Armed Forces is in the process of acquiring new submarines with fuel cell technology. The Armed Forces may also make use of hydrogen as an energy carrier for other categories of vessels and vehicles, and to generate electricity in the field, where other power sources are less practical or available. The Armed Forces is likely to be a small player in comparison with the potential use of hydrogen by the civil sector.

Box 3-5 Hydrogen in the Armed Forces

3.1 Maritime transport

With activity across the entire value chain, the Norwegian maritime industry has a unique opportunity to contribute to both reduced emissions and increased economic value. Ammonia and hydrogen systems are currently not commercially available, but several pilot and demonstration projects are ongoing in Norway. The main barrier today is the immaturity of the technology. In order to break down the barriers, the government will continue funding the development and implementation of new technologies and solutions through Enova, Innovation Norway and the Research Council of Norway.

Domestic shipping and fishing account for around 8.6 per cent of Norwegian emissions. The government has an ambition to halve these emissions by 2030.

In its action plan for green shipping[36], the government highlighted the maritime industry's opportunity to reduce emissions and increase value by developing and commercialising zero and low emission solutions. The government will assist the Norwegian maritime industry in acquiring the skills and experience that will allow it to become a major supplier in the transition that is coming to global shipping. Several of the government's objectives and action points in the action plan are also relevant to hydrogen; see Figure 3-7.

The Norwegian maritime industry is an international leader, and includes shipping companies, maritime services, shipyards and equipment suppliers. In 2018, the maritime industry contributed to 8 per cent of the value creation in Norway, and 17 per cent of Norwegian exports. The industry has a strong focus on developing and testing technology for environmentally friendly shipping, zero and low emission technology. The development of electric ferries has provided new opportunities for Norwegian maritime equipment suppliers. High-technology solutions in autonomy and green shipping are the industry's most important competitive advantages internationally. An increasing proportion of ships now use zero and low emission technology.

In the five years since Ampere, the first battery-powered ferry, came into operation on the Larvik – Opedal route, developments in zero emission technology on ships have been formidable. In 2021, there are expected to be up to 80 ferries with batteries installed operating on Norwegian fjords. In total there are around 200 ferries operating in Norway. Batteries have also been installed in other shipping segments, and Menon[37] estimates that as of June 2019, around NOK 4.5 billion had been invested in the maritime sector in Norway, roughly half of which involved ferries. DNV GL[38] estimates that in March 2020, there were over 200 battery-equipped vessels in operation, more than half of which were operating outside Norway.

Other than the use of liquefied natural gas (LNG) with the admixture of biogas and use of battery hybrids, there are currently few commercially available low emission technologies for long-distance or high-speed vessels with their consequent high energy needs. In terms of zero emission solutions, there are currently no commercially available technologies for the long-distance or high-energy vessel categories. Liquid biogas (LBG) could be a suitable solution, but biogas is not produced in sufficient volumes, and the production of biodiesel and biogas will both be limited by access to sustainable raw materials. Batteries become too heavy and their charging needs too burdensome. Although hydrogen storage and hydrogen-based systems such as ammonia require larger land areas than conventional fuels, these stand out as potential alternatives.

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36 Ministries (2019), Action plan for green shipping, Ministry of Climate and Environment (Oslo).

37 Menon (2019), Green maritime – status of sales, exports, jobs and investments, Publication 66/2019

38 DNV GL (2020), Alternative Fuels Insights Platform, taken on 26 May 2020 from https://afi.dnvgl.com/

LOW AND ZERO EMISSION SHIPS

In the background reports for the government's action plan for green shipping, DNV GL defined low emission ships as vessels that have reduced their greenhouse gas emissions by at least 40 per cent compared with conventional technology. This can be achieved by using hybrid propulsion systems, such as partial electrification, or using LNG with an admixture of biogas. It can also be achieved through a combination of technical and operational measures (such as optimisation of hull, propeller and propulsion machinery, lower speeds or more automated control systems).

Zero emission ships are defined as vessels that have reduced their greenhouse gas emissions by around at least 95 per cent compared to conventional technology. This cannot be achieved using fossil fuels. Examples are the use of batteries and hydrogen in fuel cells.

Box 3-6, Low and zero emission ships

Hydrogen and ammonia can be suitable for various vessel types, but the choice of energy carrier must be adapted and optimised to suit the energy needs and operating profiles of each vessel. In Norway, it has been calculated that just over two thirds of the energy needs in the ferry sector could come from electricity[39]. Hybrid systems using hydrogen and batteries could be suitable for the remaining routes. High-speed ferries have higher energy and lower weight requirements, which indicates that hydrogen could be more suitable for a higher percentage of these routes. It can also be achieved through a combination of technical and operational measures (such as optimisation of hull, propeller and propulsion machinery, lower speeds or more automated control systems).

39 Norwegian Public Roads Administration (2019), A quiet revolution in Norwegian fjords, taken on 24 May 2020 from https://www.vegvesen.no/_attachment/2796219/binary/1341772?fast_title=En+stille+revolusjon+i+norske+fjorder.+Innovasjon+-+utviklingskontrakt.pdf

RELEVANT POINTS FROM THE GOVERNMENT'S ACTION PLAN FOR GREEN SHIPPING[40]

The government will:

- Stimulate further green growth and competitiveness in the Norwegian maritime industry, and facilitate higher exports of low and zero emission technology in the maritime sector.
- Stimulate zero and low emission solutions in all vessel categories.
- In future reviews of the standard spending assessments in the revenue system for the county authorities take into consideration the spending increases arising as a result of the requirements set by the county authorities for low and zero emission systems on ferry and high-speed ferry routes.
- Follow up the resolution to introduce a zero emission requirement for cruise ships and ferries in the world heritage fjords as soon as this is technically feasible, and no later than 2026, and come back to Parliament when the time is right.
- Extend to other Norwegian fjords the environmental requirements stipulated for ships in the world heritage fjords.
- Evaluate an environmental benefit scheme for zero and low emission ships in the NIS and NOR ship registers.
- Ensure that the Norwegian Maritime Authority and Norwegian Coastal Administration have the capacity and skills to handle new systems in green shipping, including the development of regulations for the use of hydrogen in maritime industries.
- Consider stipulating requirements for low and zero emission systems in public ferry and high-speed ferry services, wherever practical.
- Evaluate requirements for the introduction of zero and low emission systems for service vessels in the aquaculture industry.
- Consider introducing requirements for zero and low emission systems for new operations vessels involved in petroleum production.

Box 3-7, Relevant points from the government's action plan for green shipping

In Climate Cure 2030[41], the technology readiness level was considered to be a significant barrier to the use of hydrogen and ammonia. The use of hydrogen-electric propulsion in vessels is still at the development stage, and a number of pilot and demonstration projects are under way; see Box 3-8. As previously mentioned, hydrogen will be tested on the Hjelmeland – Nesvik – Skipavik ferry route from 2021, and in its battery laboratory, SINTEF is working with ABB to test hydrogen technology in combination with batteries and diesel engines. Several of these projects, including Havyard's Havila Kystruten and several of the high-speed ferry concepts, focus on reducing energy needs. This is important to enable the use of hydrogen and batteries, since both have a lower energy density than fossil fuels. One high-speed ferry on the Haugesund – Røvær route and one in Lysfjorden are currently being converted to battery-electric power. The projects are funded by Klimasats and Enova respectively. At the same time, more projects, particularly for routes over longer distances, are looking at concepts involving the use of hydrogen.

To make it easier for companies and the authorities to see where the use of low and zero emission technologies could be appropriate, the government will survey all ferry routes, high-speed ferry routes and scheduled maritime traffic in order to show which zero emission technologies could be appropriate. Information about characteristics such as voyage length, tonnage, frequency and current energy consumption are useful in terms of evaluating suitable solutions.

40 Norwegian Government (2019), Action plan for green shipping, Norwegian Ministry of Climate and Environment (Oslo)

41 Norwegian Environment Agency et al. (2020), Climate Cure 2030

A SELECTION OF HYDROGEN PROJECTS IN THE MARITIME SECTOR

As mentioned in the text above, the Norwegian Public Roads Administration has signed a contract with the Norled AS shipping company, which will develop, build and operate a hydrogen-electric ferry for the Hjelmeland – Nesvik – Skipavik route from 2021 onward. No less than 50 per cent of the ferry's energy needs will be met by hydrogen. Norled is also involved in an EU-funded development project in which it is looking at using hydrogen on one of the ferries on the Finnøy route just outside Stavanger.

Havyard Group ASA is heading a project with the ambition to achieve zero emission operation in the world heritage fjords and on parts of the new Kystruten's scheduled service, by combining batteries and hydrogen.

Samskip AS, with funding from PILOT-E, will develop and build profitable maritime container transport using hydrogen and fuel cells, which will achieve zero emission propulsion and make it possible to transfer goods by sea instead of by road. Autonomous cargo handling is key to achieving cost efficiency in a zero emission system.

Several companies are working to develop hydrogen-powered high-speed ferries, including three out of five consortia in the Klimasats "High-speed ferry of the future" project, run by Trøndelag county authority. Two of the companies in these consortia, Selfa Arctic AS and Flying Foil AS, with funding from PILOT-E, are each running their own partnership projects for zero emission high-speed ferries. They will develop solutions that improve energy efficiency and thereby make it possible to have new electric propulsion systems based on batteries or fuel cells.

In early 2020, a consortium made up of 14 European companies, including Eidesvik, Equinor, Prototech AS, Wärtsilä and NCE Maritime CleanTech received funding from the EU's Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU) programme for the ShipFC project, in which they will test the use of ammonia in fuel cells on the Viking Energy[42]. The plan is for the modified ship to sail on ammonia produced through electrolysis for a test period of one year from 2024. The ship is currently being powered by LNG. Ammonia must be able to meet 60–70 per cent of the on-board energy needs during the test period, while the ship will still be able to use LNG and top up with batteries. The five-year project has a budget of NOK 230 million.

Box 3-8, A selection of hydrogen projects in the maritime sector

Regarding infrastructure, there is also a potential to draw on knowledge from related industries on such matters as the use and development of liquefied natural gas (LNG). Infrastructure for maritime applications is described in more detail in Section 3.2.5. The LNG companies' knowledge of stationary bunkering facilities in combination with flexible bunkering from tankers will be important for maritime hydrogen applications over long distances, since hydrogen has a lower energy density than fossil fuels and biofuels.

42 NCE Maritime CleanTech (2020), Major project to convert offshore vessel to run on ammonia-powered fuel cell, taken on 25 May 2020 from https://maritimecleantech.no/2020/01/23/major-project-to-convert-offshore-vessel-to-run-on-ammonia-powered-fuel-cell/

3.2 Road transport

The government is supporting a broad array of zero emission solutions in the transport sector, including hydrogen. However, the technology must be developed if hydrogen is to become a competitive zero and low emission alternative for road transport. Since Norway has no vehicle production, our primary contribution must be through pilot and demonstration projects. As the technology gradually matures, we can also help to speed up its introduction and growth on the market, something that the government supports through its Zero Emissions Fund for commercial transport.

Road transport, which consists of both road-going and non-road-going vehicles and machinery (such as excavators) accounts for around 23 per cent of Norwegian emissions. Road-going vehicles are the biggest source of emissions in the transport sector, accounting for around 17 per cent of national emissions. The government has an ambition to halve emissions from the transport sector by 2030, compared to 2005. This ambition is based on improvements in the technology readiness level in various parts of the transport sector. The National Transport Plan (NTP) for 2018–2019 also set target figures for zero emission vehicles; see Box 3-9.

TARGET FIGURES FOR ZERO EMISSION VEHICLES

- Target figures for zero emission vehicles in 2025:
  - New cars and light vans must be zero emission vehicles by 2025.
  - New urban buses must be zero emission vehicles or use biogas by 2025.
- By 2030, new large vans, 75 per cent of new long-distance buses and 50 per cent of new trucks must be zero emission vehicles.
- By 2030, goods distribution in the biggest urban centres must be virtually zero emission.
- Public agencies must use biofuel, low and zero emission technology as much as possible in their own and leased vehicles and vessels.
- By 2050, transport must be virtually zero emission or climate neutral.

The target figures assume that there will be improvements in the technology readiness level in the vehicle segments, allowing zero emission vehicles to compete with conventional systems.

Box 3-9, Target figures for zero emission vehicles in the road traffic sector, National Transport Plan for 2018–2019.

Heavy goods transport by road is an area in which hydrogen could potentially play a role in reducing emissions. This is thanks to its lower weight-to-range ratio compared to batteries, and to the fact that there could be limited access to sustainable bio-based fuel. A hydrogen tank can also be refilled as quickly as a tank of diesel, which is significantly faster than the time needed to charge an equivalent battery vehicle. This can be advantageous if time is an important factor, unless charging with a very high charging output is available, or if a vehicle can be charged during the goods delivery process or during statutory rest breaks.

However, while alternative technologies to hydrogen are also developing rapidly, it is difficult to say where hydrogen will obtain a competitive advantage, particularly in the long-term. For example, if autonomy becomes more widespread in the future, the cost driver in terms of charging time, in the form of staffing costs, will be reduced. The advantage of hydrogen's shorter refuelling time would then be reduced. On selected main roads, which carry high volumes of freight traffic, high-speed charging could become a reality, thereby increasing the range of battery-electric vehicles while reducing charging time/needs. However, hydrogen currently represents a potentially good solution, particularly for heavy vehicles.

By the end of 2019, 149 hydrogen cars, 1 light van, 5 hydrogen buses and 1 hydrogen truck had been registered in Norway. By comparison 260,581 electric cars, 7,331 electric vans, 199 electric buses and 21 electric trucks had been registered by the end of 2019. The development of battery-electrical systems has made the most progress in the car segment, although also in the light van and urban bus segments. In the heavy vehicle segments, electric and hydrogen-powered vehicles are produced by converting fossil-based vehicles, albeit in very limited production series. For example, ASKO in Trondheim is testing trucks converted to hydrogen power. However, several companies have plans to manufacture more extensive series, and Norwegian companies have pre-ordered around 70 hydrogen trucks from the American company Nikola Motor. These are not yet in production, and the company has announced that the expected delivery will not be before 2023[43].

For heavy vehicles, continued development and testing is still needed before the technology will be mature enough to use. In order to help achieve this, the government will continue funding the development and implementation of new technologies and solutions through Enova, Innovation Norway and the Research Council of Norway. Demonstration and pilot projects that provide end-user experience in the use of hydrogen in operational conditions will be particularly important for further technology development. Enova has funded several hydrogen projects, including the ASKO project, in order to test vehicles and related infrastructure (see Box 3-10) and will be an important instrument in supporting the government's target to increase the number of pilot and demonstration projects in Norway.

ASKO

In January 2020, ASKO started using the world's first hydrogen-powered trucks. The trucks have a range of 500 kilometres with a gross weight of 26 tonnes, and will deliver groceries to stores including those of NorgesGruppen, and will initially operate in Trondheim. ASKO has ordered a total of four trucks, all manufactured by Scania, with funding from agencies including ENOVA.

ASKO starts driving Scania trucks powered by hydrogen fuel cells. Photo of ASKO truck

The hydrogen will be produced locally, using energy from 9,000 square metres of photovoltaic panels on the roofs of ASKO Midt-Norge's buildings. The refuelling station, which is also on ASKO's premises, has been funded by Enova as an integral part of the truck project. The hydrogen produced will not only be used by the new trucks, but also by ASKO's cars and fork-lift trucks.

Box 3-10, ASKO

Heavy vehicles are generally manufactured in much smaller series than cars, which provides a somewhat better opportunity to influence manufacturing decisions through smaller orders. In an early phase, fleet orders or 'group buys' from several parties can make it more attractive for vehicle manufacturers to start the manufacturing process and help to reduce the price of procurements. With the establishment of the Zero Emissions Fund for commercial transport, the government has strengthened Enova's ability to speed up the

43 CNH Industrial N.V. (2020), CNH Industrial brands IVECO and FPT together with Nikola Motor Company announce future Nikola TRE production in Ulm, Germany, Link obtained on 24 May 2020 from https://www.globenewswire.com/news-release/2020/02/06/1981067/0/en/CNH-Industrial-brands-IVECO-and-FPT-together-with-Nikola-Motor-Company-announce-future-Nikola-TRE-production-in-Ulm-Germany.html

introduction and growth on the market of zero emission technology in the commercial transport sector. Through the fund, Enova will subsidise the procurement of heavy hydrogen vehicles when the technology has become sufficiently mature.

In Norway, hydrogen-powered vehicles get the same purchasing and user benefits as electric vehicles; see Box 3-11. As we have seen for electric vehicles, these benefits can create very rapid developments in sales when an adequate range of models becomes available on the market at a reasonable price.

PURCHASE AND USER INCENTIVES FOR HYDROGEN VEHICLES

Purchase and user incentives for hydrogen-powered vehicles (fuel cell vehicles) are the same as for battery-powered vehicles. In the national budget for 2017, the Conservative, Progress, Liberal and Christian Democrat parties adopted a resolution to extend the benefits applying to electric vehicles to fuel cell vehicles until 2025 or 50,000 vehicles. ESA has been notified of and has approved the VAT exemption for fuel cell vehicles until 2023.

Taxes
- Electric vehicles are exempt from vehicle registration tax and VAT. The Granavold political platform stated that the government would continue the exemptions from vehicle registration tax and VAT throughout the parliamentary term.
- From 1 January 2018, they have been exempt from road traffic insurance tax (formerly a low rate in the annual motor vehicle tax) and registration transfer fee.
- In 2020, 40 per cent discount on the list price compared with the normal rules, when calculating the benefit for the use of a company car.

User incentives
- In the past, zero emission vehicles have been exempt from road toll fees and ferry charges, with free parking and access to bus lanes. Now it is up to local authorities to decide whether to exempt electric vehicles from road toll fees and parking charges. A national rule has been established to ensure that zero emission vehicles do not pay more than half the normal rate when passing through toll stations and on ferries. A similar rule is being drawn up for parking, but this has not yet been introduced, pending final clarification on area of jurisdiction.

Box 3-11, Purchase and user incentives for hydrogen vehicles

3.3 Other transport (aviation and railways)

Aviation

The current alternatives to fossil fuel (jet fuel and aviation gasoline) in aviation appear to be sustainable jet biofuel, synthetic fuel (e-fuels) (see Box 3-12) and electrification. Other than for small planes on which systems are already being tested, according to Avinor's and the Civil Aviation Authority Norway's 2020 "Proposal for programme for the introduction of electric planes in commercial aviation", it is assumed that it will be possible to certify electrified planes carrying up to 19 passengers and operate them on normal civil schedules from 2025–2030, subsequently increasing to larger planes.

Because of the energy content per unit of weight, it is evident that hydrogen could be relevant as an energy carrier on long flights, but it is far too early to say for certain.
On a general basis, very stringent safety requirements apply to aviation, and these will also apply to the use and storage of hydrogen and other alternative solutions.

SYNTHETIC FUEL (E-FUELS)

Several companies are working on the production of synthetic fuel or e-fuel from electricity, water and captured CO_2. The technology is immature and the costs are currently very high. Hydrogen is produced from electrolysis, which then reacts with the captured CO_2 and is then further refined into synthetic methanol or diesel. The process requires a great deal of carbon-free electricity. Norway is often mentioned in discussions about e-fuels, because of the high renewable percentage in the country's electricity production. Synthetic diesel can replace fossil products and reduce CO_2 emissions from other processes, while CO_2 will be released again when the product/fuel is combusted. Along with the carbon footprint of the electricity, the CO_2 source will affect the climate properties of the synthetic fuel. Synthetic fuel can also be produced from plastic.

Box 3-12, Synthetic fuel (e-fuels)

Railways
At present, around 80 per cent of rail traffic in Norway runs on electricity. The remaining 20 per cent of trains run on diesel:

- Trønder and Meråker line (200 km)
- Solør line (93.6 km)
- Røros line: Hamar-Støren (382 km)
- Nordland Railway: Steinkjer-Bodø (602 km)
- Rauma line (115 km).

Annual greenhouse gas emissions are around 50,000 tonnes of CO_2 equivalents.

Parliament has asked the government to look into starting trials of hydrogen trains on a small scale, to test whether the technology can be scaled up and used on the long sections which currently operate on diesel. To provide a basis for this evaluation, the Ministry of Transport asked the Norwegian Railway Directorate to prepare a report that assesses the costs and feasibility of such a trial project. The report has been part of a more extensive Norwegian Railway Directorate ongoing project, "ZERO emission solutions for non-electrified rail lines" also known as NULLFIB[44]. The project has studied battery trains and battery operation with partial electrification, as well as future solutions using either biodiesel, biogas or hydrogen for non-electrified sections of line.

Preliminary cost estimates for a small scale hydrogen trial range from NOK 545 to 1,900 million. There are challenges associated with safety due to the use of potentially explosive gases (like hydrogen) on railways. This is particularly applicable in tunnels, where gas can collect, because the tunnels are not designed to direct gases out. The railway companies are responsible for safe operation, and they cannot be overridden if their own safety evaluations conclude that an activity is not justifiable from a safety aspect.

Based on the study, the Norwegian Railway Directorate recommends that pilot projects aimed at operations using hydrogen do not go ahead for the moment, but that we should actively stay up-to-date with relevant research and development and experiences with hydrogen as an energy carrier for trains. The Norwegian Railway Directorate's assessment

44 CNH Industrial N.V. (2020), CNH Industrial brands IVECO and FPT together with Nikola Motor Company announce future Nikola TRE production in Ulm, Germany, Retrieved 24 May 2020 from https:// www.globenewswire.com/news-release/2020/02/06/1981067/0/en/CNH-Industrial-brands-IVECO-and-FPT-together-with-Nikola-Motor-Company-announce-future-Nikola-TRE-production-in-Ulm-Germany.html

is that battery-based technology is the most suitable for providing a permanent and robust solution to replace the use of fossil-based diesel on railways. This concept is also compatible with current technology, which means that it can be used on the entire existing rail network, provided that it is combined with infrastructure upgrades on non-electrified sections[45].

3.4 Fuel infrastructure

In July 2019, the Minister of Transport and Minister of Climate and the Environment presented the action plan for infrastructure for alternative fuels in transport. In this plan, they presented general guidelines regarding the government's policy in this field. An important prerequisite is that the development of infrastructure for alternative fuels should be driven by the market, and at the earliest possible stage should be viable without government funding. The authorities will use their policy instruments to support market developments in an early phase. Infrastructure for charging and refuelling with alternative fuels must be seen in context with developments in vehicles and vessels.

Access to hydrogen is a prerequisite for its use, as is access to vehicles and vessels. This means that the development of refuelling infrastructure will depend on which segments adopt hydrogen and how quickly the vehicle and vessel fleets grow. If the need for hydrogen proves to be greater for heavy vehicles or ships, the need for infrastructure will be different than if its use in private cars becomes the main focus. Notwithstanding, needs in an early phase will not be the same as those in a fully developed market.

In its action plan for infrastructure for alternative fuels in transport, the government stated that a vital prerequisite for a well-functioning market is good user information. Measures such as providing information about available refuelling and charging stations for alternative fuels, and comparable price information will lower the barriers against adopting alternative fuels. Through NOBIL for road infrastructure and the Norwegian Coastal Administration for infrastructure for maritime transport, the government will ensure that there is a publicly available list of infrastructure for alternative fuels for maritime and road transport in Norway.

The maritime sector is made up of several different segments with varying sailing patterns, which are likely to need different solutions. For example, ammonia could be appropriate for cargo ships and bulk carriers, while hydrogen (liquid or compressed) could be appropriate for ferries and high-speed ferries. It is however not yet clear which technologies and solutions will gain acceptance in the various vessel categories. It will require a great deal of resources to establish infrastructure for all the technologies with national coverage. Development of infrastructure must therefore take place as new solutions become relevant or as they are being tested. This applies particularly in an early phase. Developments on the ship side and infrastructure side must therefore be coordinated.

In the long-term, if hydrogen, ammonia and biogas (LBG) are to become viable alternatives, charging and refuelling infrastructure must be in place so that the fuel is available where the ships require it. Projects that are currently in the planning stage and that are being discussed in the maritime sector tend to involve fixed ports of call, and in these cases it is relatively easy to plan where bunkering is needed and what volumes of hydrogen must be available.

Bunkering from ships is also an alternative that is being studied. This could reduce the need for onshore facilities, and could be more flexible and adaptable around usage and sailing

45 Norwegian Railway Directorate (2019), Provide input for ZERO emission solutions for non-electrified rail lines (NULLFIB), taken on 24 May 2020 from https://www.jernbanedirektoratet.no/no/strategier-og-utredninger/utredninger/vurderer-flere-nullutslippslosninger/gi-innspill-til-nullutslippslosninger-for-ikke-elektrifiserte-baner-nullfib/

patterns. A consortium made up of Equinor, Wilhelmsen, Moss Maritime and DNV GL have joined forces to develop a complete ship design for a hydrogen bunkering ship.

In the same way as for maritime applications there will in the early phase probably not be need for a nationwide network of refuelling stations for land based transport either. Most fleets of vehicles such as regional buses or trucks used for regular goods distribution (e.g. food wholesalers) will be able to manage with a small number of refuelling stations within their area of operation. For long-distance buses and other goods transport, it is possible to start with the most heavily trafficked corridors for such vehicles, and then gradually expand the network.

In the early phase of hydrogen development refuelling infrastructure must be planned at an early stage as part of the project, as has been the case in ASKO's truck project and the Norwegian Public Roads Administration's ferry project. As the vehicle and vessel technology is gradually demonstrated and matures, bigger projects could become of interest. It will still be sensible to develop infrastructure in tandem with the projects as they go ahead and with developments in the use of these, rather than developing large-scale, publicly accessible infrastructure. It is important for companies planning to adopt hydrogen systems to look at how their projects can be connected to other projects, sectors and applications. These connections can reduce costs, create synergies and contribute to more profitable production.

Enova will fund the development of infrastructure for alternative fuels in the early phase, wherever public funding is needed. So far, Enova has funded nine hydrogen refuelling stations, as well as infrastructure in ASKO's hydrogen project. In total, Enova has promised funding of around NOK 82 million for the establishment of publicly accessible hydrogen stations.

4 Industry

Norway has excellent conditions for research, development and implementation of new technology in industrial processes. The Research Council of Norway, Innovation Norway and Enova together fund projects across the whole technology development cycle, from basic research to full-scale testing. Norway is and will continue to be an attractive country for future oriented industry to invest in. That is why it is important to facilitate an efficient and competitive industry which will continue to provide value creation also in a low emission society.

The use of hydrogen in industrial processes falls into three categories: use as chemical feedstock in production, as an energy carrier, or in the process itself. There are also some industrial processes that currently produce hydrogen as a by-product. This hydrogen can be used in other applications.

Almost all the hydrogen currently used in Norway is used as chemical feedstock in the chemical industry and in refining petroleum products. In these applications the hydrogen becomes part of the end product. In fertiliser production, hydrogen is used to produce ammonia, which is then used to produce synthetic fertiliser. The hydrogen currently being used is almost exclusively produced through natural gas reforming without CO_2 capture and storage (CCS). This generates large emissions. If CCS is used, or the hydrogen is produced through electrolysis, the emissions would be reduced considerably.

Use as an energy carrier involves converting the hydrogen to electricity and/or heat through combustion or in a fuel cell. Other than the sectors which have already been electrified, the manufacturing industry's energy needs are currently largely addressed through fossil energy products such as oil, natural gas and LPG. In theory, hydrogen could replace these fossil energy carriers and reduce emissions, provided that the hydrogen is produced with zero emissions. For example, hydrogen could be combusted instead of oil or gas where heat is needed, or gas turbines could be upgraded to allow them to run on hydrogen or ammonia instead of natural gas.

The extent to which hydrogen could be used as an energy carrier or chemical feedstock largely depends on what is profitable for each company, and which alternatives are available. This depends on the price of the fossil products, taxes and the cost of zero emission hydrogen or use of other low emission systems. For facilities that are part of the Emissions Trading System, the emission allowance price plays a part in determining what is profitable, but for facilities that are not part of this system, it is mainly the carbon tax and in some cases requirements in emissions permits that determine what is profitable. In principle, the Emissions Trading System is designed to ensure that the cheapest measures in the system are implemented first.

The final category in which hydrogen could be used is in industrial processes in which energy carriers are currently used for their chemical properties, such as reducing agents. At the moment, coal is mainly used for this. In some processes, it is theoretically possible to replace the coal with hydrogen as a reducing agent. Processes in which it is possible to use hydrogen as a reducing agent include steel production, reduction of titanium oxide and in manganese production. Norway does not produce steel from iron ore, but countries such as Sweden and Germany are looking into and testing the use of hydrogen as a reducing agent in steel production. In Norway, TiZir in Tyssedal has a project in which they are working on the development and testing of technology needed to use hydrogen as a reducing agent in titanium oxide production; see Box 4-1. The first phase has received funding from Enova.

TIZIR TYSSEDAL – HYDROGEN REDUCTION OF ILMENITE

TiZir Titanium and Iron AS is working on a project in which they will replace coal with hydrogen as a reducing agent in the production of titanium slag and high purity pig iron. Enova has given TiZir funding amounting to NOK 127 million, which has been spent on the pre-engineering of a demonstration plant and verification of new furnace technology, which is a first step on the road to turning the hydrogen project into reality.

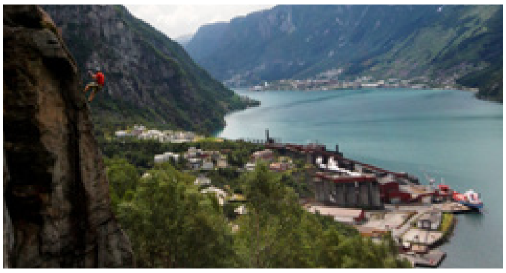


Photo: TiZir v/Haavard Elstad

The current production process involves cold feeding into the smelter, which causes a loss of energy. The planned process using hydrogen will enable hot feeding into the smelter. If hydrogen is used instead of coal, it is estimated that certain emissions will reduce by 90 per cent, with energy consumption estimated to reduce by 40 per cent.

As part of this project, new purification systems will be installed, which will reduce diffuse dust emissions and reduce the dust concentration in the purified exhaust gases. Hydrogen will be produced from water using water electrolysis based on electricity. It will be possible to transfer the technology being developed to other types of production and other industries.

Box 4-1, TiZir Tyssedal – hydrogen reduction of ilmenite

The reduction process is an integral part of the core industrial processes, the use of hydrogen as a reducing agent therefore entails a conversion of major elements of the production process itself. This is expensive and presents an increased financial risk. The technology needed to use hydrogen as a reducing agent is in the research and development stage. It will require major research and development activity before hydrogen can be used on a large scale, and not least before it can become a profitable investment. Technology development cycles like this tend to take a long time. It is important that development continues on new technologies and solutions, if hydrogen is to be capable of taking over from parts of current process technology in the future.

The manufacturing industry and petroleum sectors in Norway are part of the European Emissions Trading System (EU ETS) (see Box 4-2). Annual reductions in available allowances mean that the Emissions Trading System will contribute to significant reductions in emissions. After 2020, the annual cuts in allowances will represent almost 50 million tonnes of CO_2 equivalents on the EU-level. If the reduction in the volume of allowances continues at the same rate after 2030, the number of allowances available to companies will have fallen from 2 billion in 2013, to 365 million in 2050. That would mean that the emissions would be approximately 86 per cent lower than the emissions in 1990. This means that companies subject to the Emissions Trading System will have to cut their emissions dramatically by 2050. If the EU sets a target to become climate neutral by 2050, this will also result in a need to make further cuts in emissions that are not subject to the trading system.

Developing technology is expensive and risky, and its implementation relies to a large extent on public funding. The tools available through the Research Council of Norway, Innovation Norway and Enova are important and will continue to fund this work.

THE EU'S EMISSIONS TRADING SYSTEM

The EU's Emissions Trading System (ETS) is aimed at reducing greenhouse gas emissions. The emissions in the ETS cannot exceed the number of available emission allowances in the system. The ETS therefore sets a cap on emissions. This is reduced by a certain number of allowances every year. The ETS covers around 45 per cent of the total greenhouse gas emissions in the EU, from over 11,000 companies, and around 50 per cent of the emissions in Norway, from approximately 120 companies.

Box 4-2, EU Emissions Trading System

5 The energy sector

Norway's renewable energy resources and well-functioning energy sector is a competitive advantage. The Norwegian power supply is renewable, flexible, secure and has competitive prices that make it possible to produce hydrogen more cheaply in Norway. However, the value of hydrogen is less in the Norwegian energy system than in Europe, because of the low prices and flexibility of Norway's hydropower. For some specific applications that do not have access to the grid, hydrogen systems are already competitive.

The Norwegian energy supply has the highest share of renewables and the lowest emissions in Europe. The energy supply in Norway is essentially provided by hydropower, wind power and thermal power, with hydropower being by far the most dominant. The 1,600 or so hydropower plants in Norway have a combined installed capacity of just over 32,000 MW, and represent around 95 per cent of the Norwegian production capacity.

One of the features of Norwegian hydropower is the ability to store energy in water reservoirs. Half of Europe's reservoir capacity is in Norway. Gravity dam power stations are very flexible, production can be adjusted up and down as required, and the costs are low. This means that about 75 per cent of the Norwegian production capacity can be regulated.

In Norway, hydrogen production and storage as a source of flexibility in the power system will have to compete directly with adjustable hydropower or other flexible storage solutions. Hydropower has a much lower cost and is significantly more efficient than electrolysis. Since gas is not used to any significant degree for heating, using hydrogen for this purpose instead is not an option. In a study performed by Thema Consulting in May 2019[46], hydrogen's potential role in the Norwegian energy supply was examined through a number of specific case studies looking at energy production, grid and security of supply. They found that generally, the value of hydrogen as backup flexibility is less in Norway than in Europe because of the flexibility of hydropower.

Hydrogen production from small power stations and from wind power not connected to the grid can be worthwhile if several applications are involved to cover the fixed costs of hydrogen production, for example the sale of oxygen for aquaculture. The costs of transport and storage are also highlighted as an important financial barrier, and profitability will depend entirely on an unbroken value chain for hydrogen. The wind farm at Raggovidda is an example of this type of application, with energy that is not connected to the grid being used for hydrogen production.

Hydrogen has also been studied as a possible solution for back-up in the Norwegian electricity grid through two case studies from Thema: The first study looked into the profitability of a 'power to power' hydrogen chain as an alternative to upgrading a transformer station which suffers overloads for several hours each year. In this example, Thema found that the transformer upgrade is currently cheaper than either batteries or hydrogen. The competitiveness of hydrogen as a provider of grid balancing services in Europe has also been examined in a perspective looking ahead to 2025. Thema has assessed that hydrogen systems will encounter strong competition from battery systems and will probably only be of interest in areas where hydropower cannot deliver adequate volumes.

46 Thema (2019), Effects on the system and industry perspectives of hydrogen, taken on 24 May 2020 from https://www.thema.no/wp-content/uploads/2019/05/THEMA-rapport-2019-07-System-virkninger-og-n prosent pst.C3 prosent pst.A6ringsperspektiver-ved-hydrogen.pdf

HAEOULUS AND RAGGOVIDDA

Wind turbines at Raggovidda. Credit: Varanger KraftVind. Photo: Bjarne Riesto

The wind farm on Raggovidda in Berlevåg municipality has very high operating efficiency because of constant and stable winds. NVE granted Raggovidda a license for up to 200 megawatts (MW) in 2010, but required the available capacity in the grid to be documented for the development of more than 30 MW. Varanger Kraft has built 15 turbines with a total capacity of 45 MW on Raggovidda, but the grid conditions in the area limit how much wind power can be connected to the grid. Varanger Kraft has studied alternative ways of using its potential surplus, and hydrogen production using electrolysis stood out as an option. On the basis of this, Berlevåg municipality had a feasibility study performed on hydrogen production based on electrolysis using surplus energy from the wind farm. After a preliminary project run by Varanger Kraft and SINTEF, they applied jointly with several European universities and research institutions for development funding from the EU. The result was an award of NOK 50 million from the Hydrogen 2020 research programme to build a hydrogen plant. The plant is under construction and will be completed in 2020.

Box 5-1 HAEOULUS and Raggovidda

An important input in the electrolysis process is electricity. The profitability of hydrogen produced in this way will therefore be affected by the price of electricity, grid costs and electricity taxation. The consumer tax on electricity is largely imposed for fiscal reasons, and there is a difference between the standard rate for ordinary consumers and the reduced rate for e.g. energy-intensive industry. Electricity supplied for use in chemical reduction or electrolysis, metallurgical and mineralogical processes is among the groups of specified purposes that are exempt from the consumer tax on electricity. This is also governed by the EU's Energy Taxation Directive.

Wherever possible, the power grid companies must design their tariffs to ensure that they help to ensure that the grid is designed and utilised effectively. The grid companies currently have the option to offer reduced tariffs for disconnectable consumption, or disconnectable tariffs, which is consumption that can be disconnected when there are problems with capacity in the power grid. This can be of interest to various types of consumer loads that can be disconnected at short notice and that can cope with being disconnected for given periods of time, often up to several days, such as a production facility for hydrogen. In this way, security of supply in the power grid can be maintained, while also avoiding unnecessary and expensive investments in the grid.

If a power grid company is to be able to offer certain customers a disconnectable tariff, this must have a positive impact on the power grid in the grid company's area. It is a fundamental principle that the tariffs must be non-discriminatory. For example, if a hydrogen production facility receives a disconnectable tariff, other customers must also be given the same option. This applies within the entire area of the power grid company's license, and cannot be limited to those areas which may have problems with capacity.

6 National research and development (R&D)

The main objectives of the government's focus on energy and petroleum research is to improve long-term value creation and ensure that Norwegian energy resources are used safely, cost-effectively and sustainably. With a power supply almost exclusively based on renewable energy, a well-functioning energy market and good access to even more renewable energy resources, we have a good starting point. Norwegian research and education institutions and Norwegian businesses also have extensive expertise in a range of climate and energy technologies, including hydrogen.

Over the last 10 years, considerable R&D expertise has been built up in Norway in the field of hydrogen. A deliberate and long-term focus on research and development has given Norway strong research and technology communities specialising in a range of hydrogen fields. For example, Norwegian research communities are experts in high-temperature fuel cells and electrolysers, with a particular focus on proton-conducting ceramics. Within this field, we have world-class, fundamental expertise in materials. Norwegian research communities are also experts in low-temperature fuel cells and electrolysers, including alkaline electrolysis, and in the combustion of hydrogen and hydrogen storage in metal hybrids. Norway is also in front internationally when it comes to modelling and analysing hydrogen systems and value chains for hydrogen, as well as in associated hydrogen fields such as refuelling station technology and hydrogen tanks. Norwegian companies are also pioneers in the development of hydrogen technologies for maritime purposes.

Through the Research Council of Norway, the authorities have funded research and development relating to hydrogen, fuel cells and water electrolysis worth around NOK 550 million between 2009 and 2019. In this respect, the most fundamental research programme is the thematically broad ENERGIX energy research programme. The programme aims to help achieve energy and business policy objectives, and is an important instrument in the implementation of the Energi21 R&D strategy. The focus on hydrogen is safeguarded through ENERGIX, through research and development of new materials, conversion processes and solutions for the production and use of hydrogen and hydrogen technologies. Based on the research and technology communities' interests, expertise, assessments and guidelines, and on recommendations from the Energi21 strategy, the Research Council of Norway advertises funds in the field of hydrogen every year. ENERGIX also supports participation in international R&D projects.

The CLIMIT research and demonstration programme also funds research and development into the production of hydrogen from natural gas combined with CCS. Projects that they have funded include the demonstration of Hydrogen Mem-Tech's membrane technology at Tjeldbergodden.

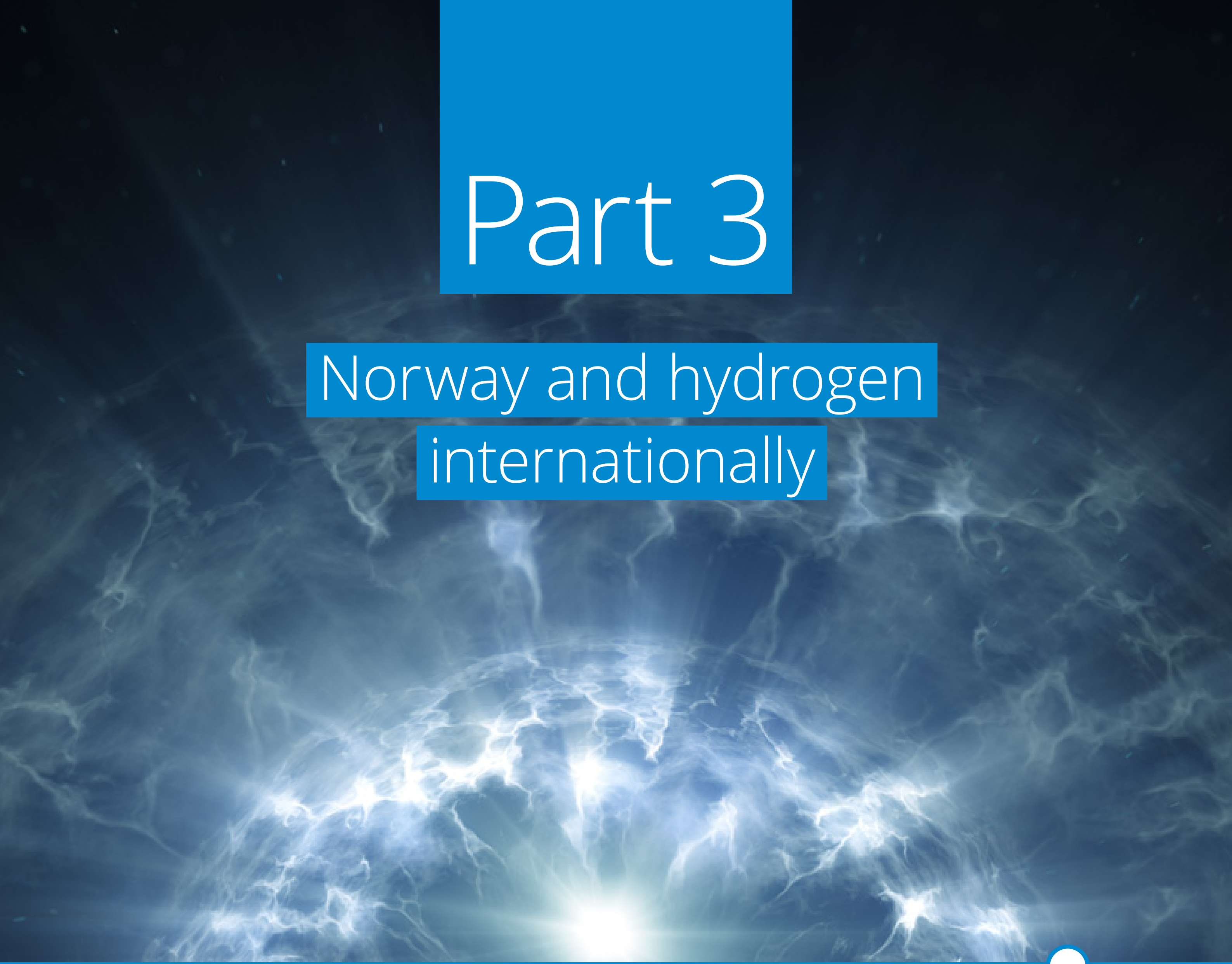
Energi21, the national strategy for research, development, demonstration and commercialisation of new climate-friendly energy technology, highlights two focus areas in particular that are relevant to hydrogen: climate-friendly energy technologies for maritime transport, and climate-friendly and energy-efficient industry including carbon capture and storage (CCS). In maritime transport, hydrogen is being evaluated as one of three important solutions. In the field of industry, the increased use and transition to emission-free hydrogen represents an important focus for the future.

As for Energi21, the OG21 strategy for petroleum research has moved hydrogen up the agenda and performed a project involving hydrogen from natural gas combined with CCS. The study emphasises the importance of R&D in terms of decarbonising natural gas and CCS, and the need to see offshore and onshore energy systems in the same context, in order to achieve climate-friendly and cost-effective solutions.

In addition to the technology-oriented research, it is important to perform more research on the social aspects associated with hydrogen. Examples of research themes could be: Contribute to research-based knowledge based on technological maturity and potential cost-efficiencies of the various applications for hydrogen; research into social acceptance of the use of hydrogen on a large scale and in new applications; and the role of the public authorities in the development of hydrogen in a low emission society.

Part 3

Norway and hydrogen internationally



7 European ambitions

Europe has high ambitions for the energy transition, and both the EU and individual companies are demonstrating a growing interest in hydrogen systems. This interest is particularly focused on applications that are difficult and expensive to electrify, such as long-distance transport, heating and some industrial processes. It is therefore expected that the consumption of hydrogen in Europe will gradually increase. In the EU's low emission strategy towards 2050[47] hydrogen is involved in a number of scenarios, and several European countries have recently developed strategies, roadmaps and funding schemes to increase the use of hydrogen. The European Commission is about to publish its own strategy on hydrogen, and recently (March 2020) submitted a strategy for European industry mentioning its key role in achieving the targets in the European Green Deal concerning climate neutrality and the circular economy. The European Commission mentioned that hydrogen technology could help to reduce greenhouse gas emissions in sectors such as aviation, transport and heavy industry. Various parties will join forces to develop hydrogen technology in 2020, with enterprises from a number of EU countries participating (European Clean Hydrogen Alliance).

47 European Commission, Directorate-General for Climate Action (2018), A clean planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, COM (2018) 773, Brussels)

EU'S LONG-TERM BUDGET AND CRISIS PACKAGE

The Covid-19 crisis has reinforced the European Green Deal's message about the importance of investing in sectors and infrastructure that have a positive impact on human health and the environment, and ensuring that we have a robust supply of environmental goods and services.

On 27th May 2020, the European Commission submitted a proposal for a new long-term budget for the EU for the period 2021–2027 period[48]. The proposed budget also includes an extra package of measures (crisis package) to help rebuild Europe from the consequences of Covid-19. The measures were presented in the announcement "Europe's moment: Repair and Prepare for the Next Generation"[49].

The European Commission is proposing two new funding streams to save vulnerable companies and invest in strategic value chains. The second of these, the "Strategic Investment Facility" under InvestEU, is intended to improve Europe's resilience by building strategic independence into important supply chains at a European level. This could include investment in technologies that are essential for the transition to clean energy, including renewable energy, technology for energy storage, clean hydrogen, batteries, carbon capture and storage, and infrastructure for sustainable energy.

Box 7-1, The EU's long-term budget and crisis package

In a European context, studies will examine how renewable energy production without connection to the grid could be converted to hydrogen and make use of existing pipeline infrastructure in order to avoid expensive and unpopular investments in new power grid capacity.

Several European countries are now preparing their own hydrogen strategies. For example, Germany is in the process of preparing a hydrogen strategy, the United Kingdom is carrying out several studies and projects relating to the development of a hydrogen economy, and the Netherlands is working on specific hydrogen projects.

Both in the EU and in several of its member countries, there is a discussion on the regulation of various types of clean hydrogen. One of the topics of discussion is whether there will be any regulatory consequences if hydrogen is produced by electrolysis based on renewable energy production (often called "green hydrogen") or through natural gas reforming, combined with carbon capture and storage (often called "blue hydrogen"). Around 90 per cent of the hydrogen produced in Europe is currently based on natural gas reforming without CCS. In large-scale production, it is estimated that natural gas reforming combined with CCS will have lower costs than hydrogen produced from water electrolysis. Natural gas could therefore become an important source of clean hydrogen.

Several parties involved in CO_2 capture and storage projects in Europe and Norway, including through the EU's PCI scheme (Projects of Common Interest)[50], are looking at the opportunity to switch from hydrogen based on coal or natural gas to hydrogen produced

48 "The EU budget powering the recovery plan for Europe", (COM (2020) 442 final).

49 "Europe's moment: Repair and Prepare for the Next Generation" (COM (2020) 456 final).

50 PCI (Projects of Common Interest) – a category of projects that the EU has identified as a main priority in order to connect Europe's energy system infrastructure. These projects are qualified to receive common European funding. The PCI list is reviewed every two years.

from natural gas combined with CCS. Equinor is involved in several studies in a number of European countries looking at how blue hydrogen could be used by European industry instead of natural gas and coal, thereby significantly reducing greenhouse gas emissions. Various options of supplying blue hydrogen are being evaluated, including producing hydrogen close to the end user and transporting CO_2 to a store in the North Sea. In the long term, companies including Equinor are also looking at the option of producing hydrogen in Norway from gas, with a short distance to CO_2 storage, and transporting hydrogen through pipelines or possibly by ship in the form of ammonia. The long-term aim of this projection is to outline for Europe the supply of emission-free gas, i.e. hydrogen, if there were limited demand for natural gas without CCS. Since exporting hydrogen from Norway to Europe will need to be on a major scale in order to justify such an investment in new infrastructure (pipelines), the option of setting up hydrogen production close to customers, with the CO_2 being transported back to Norway, is considered to be more practical in an early phase while the market is being developed to use hydrogen instead of natural gas or coal. If this conversion of the energy system succeeds, production in Norway could be considered. Ultimately, it is up to the market actors to assess whether it will become commercially attractive to export blue hydrogen from Norway in the future.

Norway currently meets around 3 per cent of the global demand for natural gas. Export to Europe is mainly through pipelines. Norwegian natural gas exports represent around a quarter of European gas consumption. That alone is equivalent to a volume of energy between three and four times Europe's total current hydrogen consumption.

The government will facilitate the long-term production of oil and gas on the Norwegian shelf. Gas produced efficiently and with low emissions on the Norwegian shelf could help to meet future energy needs for gas for the production of clean hydrogen in Europe.

Large scale, natural gas-based hydrogen export from Norway is not currently regarded as a realistic option. However, this may be possible in the longer term, if factors such as more stringent requirements regarding greenhouse gas emissions, combined with demand and the willingness to pay for blue hydrogen are present. Currently, the possibility that Norwegian natural gas could play an important role in a European hydrogen strategy is more realistic.

The Norwegian authorities will work to ensure that natural gas reforming combined with CCS can compete on equal terms with hydrogen from water electrolysis in the European energy market.

TECHNICAL FEASIBILITY OF EXPORTING HYDROGEN FROM NORWAY

From a technical point of view, it will be possible to export hydrogen produced in Norway – through natural gas reforming or water electrolysis – to the rest of Europe through existing gas pipelines, assuming that there is available capacity, or by using ships. Hydrogen production based on gas in the consumer countries on the continent will also allow them to produce hydrogen from gas bought from producers other than those on the Norwegian shelf. Because of the higher transport costs per delivered energy unit for hydrogen than for natural gas, it will currently be more effective to produce hydrogen close to the end users rather than in Norway.

If existing pipelines are to be used to transport clean hydrogen gas, these must be adapted and re-qualified, since the properties of hydrogen gas are different from those of natural gas. Alternatively, using the gas infrastructure requires a market that includes an adapted distribution network for hydrogen.

Another option could be to mix hydrogen in with the natural gas that is sent through the pipeline system to Europe – and gradually thereby build up a market. Mixing hydrogen in the gas pipeline network and establishing production close to users in Europe is currently the more rational approach.

For hydrogen exports on a *small scale* – produced using electrolysis or gas reforming – transport by ship could be a possible alternative. Liquid hydrogen can be exported by specially constructed ships using the same principles as for LNG. The world's first ship for the transport of liquid hydrogen was launched in 2019. Another alternative is to convert hydrogen to other hydrogen-rich substances that are easier to transport on existing ships, for example ammonia or organic hydrogen carriers in liquid form. Solutions like this assume that there is demand and also reception terminals for liquid hydrogen in the export market. For ammonia, there is currently a global market involving its transport by ship.

Box 7-2, Technical feasibility of exporting hydrogen from Norway

8 International collaboration on hydrogen

International collaboration on the development and use of hydrogen and hydrogen technologies will be very important in the coming years, in terms of establishing a global market for hydrogen. This includes the exchange of experience, participation on large joint projects, the design of common standards and facilitation of global trade.

An example of an international arena for the authorities is the Hydrogen Energy Ministerial Meeting organised by Japan, in which the authorities from those countries (including Norway) that have made the biggest advances in the field of hydrogen meet to discuss various hydrogen systems. The objective of the initiative is to speed up a broad commercial breakthrough for hydrogen. The harmonisation of standards and regulations, as well as information-sharing regarding value chains, research partnerships and safety have been identified as important measures. These are now being followed up in existing platforms for energy collaboration, such as the Clean Energy Ministerial (CEM), Mission Innovation (MI) and International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), where Norway also participates. Japan also used its presidency of the G20 to put hydrogen on the agenda of the G20 Summit in 2019.

There are also ongoing initiatives to improve coordination at a European level. In 2018, the European Commission set up an expert group to identify the strategically important value chains in which Europe should be investing, in order to maintain the industry's competitiveness in the years ahead[51]. Six value chains, including hydrogen technology, were highlighted as particularly important in the mobilisation of investments and political dynamism in the future. Through a recently presented industry strategy, the European Commission also announced the establishment of a special Clean Hydrogen Alliance. Several EU strategies will also be developed, in which hydrogen is expected to play a key role, including the "Strategy for Smart Sector Integration" and "EU Strategy for Clean Steel".

8.1 Nordic collaboration

In several of Norway's neighbouring countries, there is increasing interest in hydrogen as an energy carrier. This could provide favourable conditions for Nordic collaboration in this field. The Nordic countries (Norway, Sweden, Denmark, Finland and Iceland) all have ambitious climate targets, and using hydrogen and hydrogen-based systems could help to achieve these. The fact that the countries are geographically close to each other and good collaboration has already been established in several important platforms like the Nordic Council of Ministers, means that there are opportunities to establish shared systems and infrastructure beneficial for an environment in which hydrogen can be used across borders.

In the summer of 2019 in Helsinki, the Nordic prime ministers adopted a vision of the Nordic region as the world's most sustainable and integrated. In the Helsinki Declaration, the Nordic prime ministers decided to work together in removing barriers to low emission systems and decarbonising the transport sector as part of making the Nordic region carbon neutral. Against this background, the Nordic Council of Ministers decided to develop their collaboration on green transport. Each of the five Nordic countries has signalled their interest in investing in hydrogen based on renewable energy. Three of the countries (Denmark, Finland and Norway) have also been looking into hydrogen as an alternative fuel in the maritime sector.

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51 Strategic Forum for Important Projects of Common European Interest (IPCEI) (E03583) (2018), taken on 26 May 2020 from http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=3583&NewSearch=1&NewSearch=1

NORDIC COLLABORATION

In September 2019 and at the urging of Norway, a hydrogen conference organised by Nordic Energy Research was held at the Nordic Council in Copenhagen. The conference brought together relevant parties from various Nordic countries and helped to highlight the opportunities, joint initiatives and projects in the field of hydrogen. As a follow-up to the conference, the project *"Nordic P2X for sustainable road transport"* was started. Nordic Energy Research was tasked with leading the project. The project will look at the opportunities for converting green electricity (particularly surplus electricity) to hydrogen (via electrolysis) and possibly converting again to green fuels such as ammonia or synthetic fuel (Power-to-X). The project will end with a report that identifies and analyses the potential for Power-to-X in the Nordic region, and that will form the basis for future policies in this field. The project is provisionally scheduled to be completed by the end of 2020.

Nordic Energy Research also has plans to call for proposals for projects within the theme of *"Nordic Sustainable Maritime Fuels and Efficiency"* (working title). Alternative fuels and propulsion systems with a low carbon footprint will have a central place in the research programme. Nordic Innovation currently has *"Nordic Smart Mobility and Connectivity"* as one of its main focus areas. Business clusters have been established and project funding granted for innovative solutions for the smart mobility of people and goods in a number of fields, including hydrogen.

Through the Nordic collaboration (Committee of Senior Officials for climate and environment in the Nordic Council of Ministers), in October 2019 the decision was taken to develop Nordic collaboration on green transport, including green aviation, green maritime transport, road transport and rail transport in the Nordic region. In view of this, there is a proposal for a Nordic focus on the introduction of carbon neutral fuels in shipping. The proposal is partly based on an existing hydrogen initiative, the objective of which is a full-scale infrastructure plan for hydrogen in Norway, aimed at the maritime sector, but also looking at synergies with other applications, such as hydrogen for trucks/heavy goods transport from refuelling stations in ports. The hydrogen initiative is in a start-up phase, with broad participation from public and private parties.

Box 8-1, Nordic collaboration

8.2 Norwegian participation in international research partnerships

Most of the technology development in the field of hydrogen is taking place outside of Norway. If Norway is to succeed with its focus on hydrogen, Norwegian communities must be active participants in the most relevant international research arenas. The most important of these is collaborative work on research and innovation within the EU.

The EU arena

The **SET Plan** (European Strategic Energy Technology Plan) is the EU's framework for strategy development in research and innovation in low carbon energy. The collaboration has materialised in 14 implementation plans in selected technology fields. None of these has hydrogen as its main focus, but hydrogen, electrolysis, fuel cells and hydrogen production from natural gas combined with CCS represent important energy technologies in several of the thematic strategies. This shows how important hydrogen is in terms of connecting different sectors, and that the focus should be on phasing in transport throughout the energy system, not just in transport.

The **Fuel Cells and Hydrogen Joint Undertaking** (programme no 2) **(EUs FCH 2 JU)** is the EU's public-private partnership for funding for research and innovation of hydrogen and fuel cell technologies in Europe. The strategic purpose of the programme is, by the end of 2020, to demonstrate hydrogen and fuel cell technologies as one of the pillars in the future European energy and transport system, which includes contributing to the transition to a low emission society by 2050. The Research Council of Norway is the Norwegian representative in the steering group, and technology communities have been active participants in the programme's calls for proposals, with good results being achieved.

ACT (Accelerating CCS technologies) is an ERA NET Cofund established under the EU's framework programme for research and innovation, Horizon 2020, in which the research-funding authorities in the participating countries, including the European Commission and some non-European countries, join forces on calls for proposals and knowledge sharing relating to CCS technologies. The Research Council of Norway is the coordinator for the ACT collaboration. The calls for proposals are open to projects including the production of hydrogen from natural gas involving CCS.

ZEP (Zero Emission Platform) is a technology platform for CCS. Participants include parties from academia, industry, the authorities and the environmental movement, and the objective is to make recommendations on how CCS can be developed and commercialised in Europe. The production of hydrogen from natural gas combined with CCS is one of many topics included in ZEP's recommendations.

Horizon Europe (2021-2027) is the EU's new framework programme for research and innovation, and is succeeding the Horizon 2020 framework programme (2014-2020). The programme has put hydrogen high on the agenda. The content of the working programmes and potential partnerships on selected themes are under development. Among the proposals of the European Commission is a partnership on "Clean Hydrogen".

Other important research arenas for hydrogen

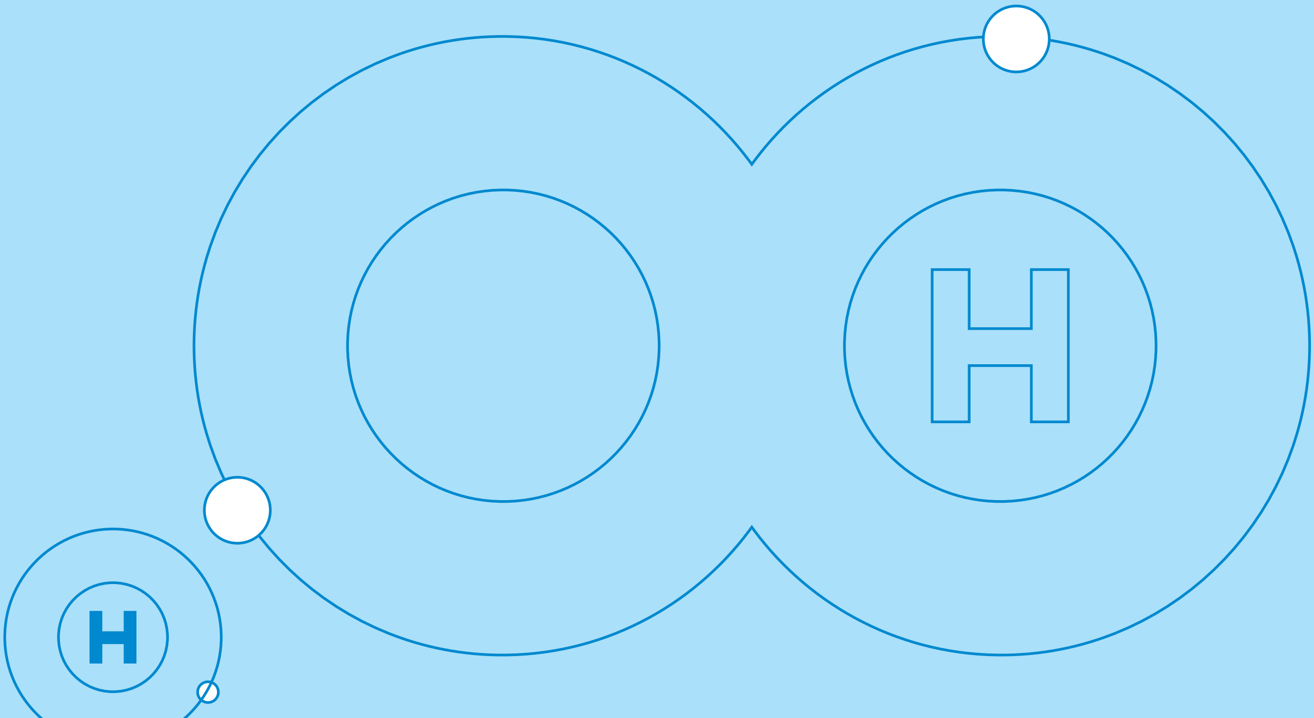
The **International Energy Agency (IEA)** has set up a number of partnership programmes researching a range of different thematic areas. The partnership agreements are signed by the authorities and are under their control, while the research and technology communities participate in the various work packages within the programmes. Norway is currently involved in 21 of these programmes, 2 of which are relevant for hydrogen.

IEA Hydrogen TCP aims to accelerate the global implementation and utilisation of technologies for the production, storage and distribution of hydrogen in relation to power, heating, mobility and industry. The main working areas are coordinated research, development and demonstration activities in order to promote knowledge and technologies for the production, storage and integration of hydrogen in the energy system, hydrogen analyses, including technical studies and market assessments, and the dissemination of information in order to improve understanding, awareness and social acceptance of hydrogen, including the safety aspects of using hydrogen.

IEA Greenhouse Gas R&D (GHG TCP) addresses opportunities for, and the development of, CCS technologies and other technologies that could reduce greenhouse gas emissions. Among other things, the programme addresses the production of hydrogen from natural gas combined with CCS and the use of hydrogen in industry.

International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), whose aim is to facilitate and accelerate the transition to clean and efficient energy and transport systems through the use of hydrogen and fuel cell technologies in a range of applications and sectors. The IPHE informs broad groups of interested parties, including decision-makers and the public sector, about the benefits and challenges associated with the establishment of commercial hydrogen and fuel cell technologies in the economy. There are currently 20 partners involved, who organise, coordinate, promote and initiate partnerships in the research, development and dissemination of these technologies on a global basis.

Carbon Sequestration Leadership Forum (CSLF) is an international initiative at ministerial level with a focus on climate change through the development and implementation of cost-effective technologies for carbon capture and storage. A total of 25 countries plus the European Commission are participating. The forum includes a working group on CCS and hydrogen, run by the Research Council of Norway. The CSLF collaborates with programmes such as the IEA's partnership programmes on hydrogen as part of its follow-up work on hydrogen.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