Noordelijke InnovationBoard

The Green Hydrogen Economy

in the Northern Netherlands

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Preface

This vision document for a green hydrogen economy in the Northern Netherlands is the result of a collaborative process among industry, governments and organizations, initiated and led by members of the Northern Netherlands Innovation Board (NIB), in particular prof. Ad van Wijk (member of NIB for energy transition) and Denisa Kasová (director of NIB). The process began on April 1, 2016, the same day that NIB itself started. Many companies, institutions and governmental organizations were consulted early on, and based on these consultations, prof. van Wijk developed the initial ideas for a green hydrogen economy in the Northern Netherlands.

About NIB

Accelerating the economic growth of the Northern Netherlands is the greatest and most important ambition of the Northern Netherlands Innovation Board, a collaboration among the northern entrepreneurs, governments and academic institutions who created the Northern Innovation Agenda in 2014. NIB is tasked with implementing and updating this agenda with the goal of expediting economic growth in the Northern Netherlands. This includes yielding a greater return from the energy, water, food/agro, health and industry ecosystems. Entrepreneurs have been tasked with taking the lead in this endeavor by sharing their vision, initiating collaborations and stimulating development. Our board consists of entrepreneurs, representatives of the three northern Dutch provinces, the four largest northern cities and all of the vocational and secondary education institutions and universities of applied sciences and research in the north.

Accelerating economic growth and employment in the Northern Netherlands is challenging, as can be seen in the facts and figures table below, and there is a clear need for new ideas, and vision for a green, clean and innovative economy in the Northern Netherlands.

	2010	2011	2012	2013	2014	2015	2016
Population							
Groningen	576,668	579,036	580,875	581,705	582,728	583,942	583,721
Friesland	646,305	647,282	647,214	646,862	646,317	646,257	646,040
Drenthe	490,981	491,411	490,807	489,918	488,988	488,576	488,629
Jobs (x 1,000)							
Groningen	249.2	249	240.7	238.6	239.3	243.5	
Friesland	258.2	258.4	253.1	242.1	242.2	247.1	
Drenthe	193.7	196.1	193.6	190.5	194.5	193.8	
GDP (x M€)							
Groningen	28,520	29,541	31,575	33,322	29,193	26,164	
Friesland	17,315	18,100	18,051	18,041	18,278	18,178	
Drenthe	13,026	13,295	13,307	13,278	13,614	13,807	

Approach and process

The Northern Netherlands has a strong position in energy production. The Groningen/Slochteren gas field is one of the largest gas fields in Europe. The Slochteren field has been in production since the early 1960s and has contributed considerably to economic growth and employment in the Northern Netherlands. In addition to this, the Eemshaven has developed into an energy harbor, which has large coal-fired power plants as well as gas and electricity connections to Norway. However, there is a need to make changes toward a carbon-free energy system. Natural gas production will be reduced in the coming years, which means that fossil fuel-based power plants must considerably reduce their carbon footprint.

After consulting with a wide range of companies, governments and organizations in the second quarter of 2016, the idea for the development of a green hydrogen economy as a successor to the gas economy in the Northern Netherlands was born. In August 2016, prof. van Wijk outlined the initial contours of what such a green hydrogen economy would look like and defined the questions and issues that needed to be addressed along the way. It became clear that the realization of a green hydrogen economy would require an integrated approach for the development of green hydrogen production, markets, infrastructure, the regulatory framework and other societal aspects.

Two important gatherings in September and December of 2016 and a series of one-on-one meetings provided valuable input while developing a vision and roadmap for a green hydrogen economy, including production, markets, infrastructure and societal aspects. A work group composed of members representing NIB, Gasunie, NWP (H_2 Platform) and the province of Groningen actively contributed to the development of this vision and roadmap. Once the projects were defined, a roadmap and initial costs and investment estimates were provided by Rabobank, ING's Economics Department and Accenture. ING's Economics Department analyzed the effect of decreases in gas production on the economy of the Northern Netherlands. Rabobank prepared an initial financial model to assess the viability of the construction and operation of electrolysis and biomass gasification for production of green hydrogen. Accenture has analyzed how the realization of a green hydrogen economy in the Northern Netherlands should be organized.

By the end of April 2017, a summary of "The Green Hydrogen Economy in the Northern Netherlands" was published. This summary laid out the commitments made by companies, governments, institutions and organizations toward the realization of a green hydrogen economy. Many companies are committed to developing new business in the field of green hydrogen; educational institutions are committed to incorporating green hydrogen into their curricula; governments are committed to integrating green hydrogen into their policies; and energy and chemical companies are committed to realizing large-scale production and green hydrogen offtake.

This full report describes production projects, markets, infrastructure and societal issues that will contribute to the development of a green hydrogen economy in the Northern Netherlands. However, the green hydrogen economy is not a fixed and well-defined concept; therefore, this report is a living document. New projects and systems have been proposed since the publication of the summary, such as hydrogen storage in salt caverns, hydrogen production from imported natural gas from Norway and carbon dioxide storage in empty Norwegian oil/gas fields, as well as a market for green hydrogen use in heating homes and buildings, especially in rural areas, villages and older areas of cities. It is useful to consider this report as a first edition in an ongoing process toward the development and realization of a green hydrogen economy in the Northern Netherlands.

Next steps

This report shows that green hydrogen will facilitate the energy transition for chemistry, transportation, electricity and heating. It is necessary not only for the realization of the Paris climate goals, but also for making the economy of the Northern Netherlands greener and stronger.

The Northern Netherlands is uniquely positioned to develop one of the first green hydrogen economies in Europe. The main features which create these conditions are large-scale green electricity production and importation, a large-scale chemical industry, gas expertise and, above all, a gas pipeline infrastructure originating in the Norther Netherlands which can easily, quickly and cheaply be converted to transport hydrogen.

A high level roadmap has been developed in conjunction with companies, government and organizations. This roadmap will have to be implemented through a collaborative, well-coordinated and tightly directed effort by companies, governments and educational institutions. Companies must develop their business cases for large-scale green hydrogen production, hydrogen infrastructure and use cases for hydrogen in industry, especially the chemical sector, transportation, electricity balancing and heating buildings. Governments must create the right market conditions, such as the regulatory framework, financial instruments to kick-start these developments, stimulating valuing green hydrogen and facilitating societal acceptance. Educational and scientific institutions need to incorporate hydrogen and all related knowledge into their academic programs and initiate research, development and innovation.

Political institutions on the regional, national and EU level need to implement integrated green hydrogen economic development into their energy transition roadmaps, strategies, scenarios and policies for the future.

1

Why green hydrogen?

On December 12, 2015 in Paris, 195 countries signed a legally binding agreement to keep global warming well below 2°C. This is an ambitious goal that will require decarbonizing vast swaths of the world's energy system. Many studies show that a drastic reduction in greenhouse gas emissions – at least 90 percent by 2050 – is necessary. Significant amounts of renewable energy must be implemented and integrated, and securing the supply and ensuring the resilience of the system is a demanding challenge. Energy end-use sectors such as industry, transportation and buildings must be decarbonized at scale.

Transporting large-scale, cheap, renewable electricity production

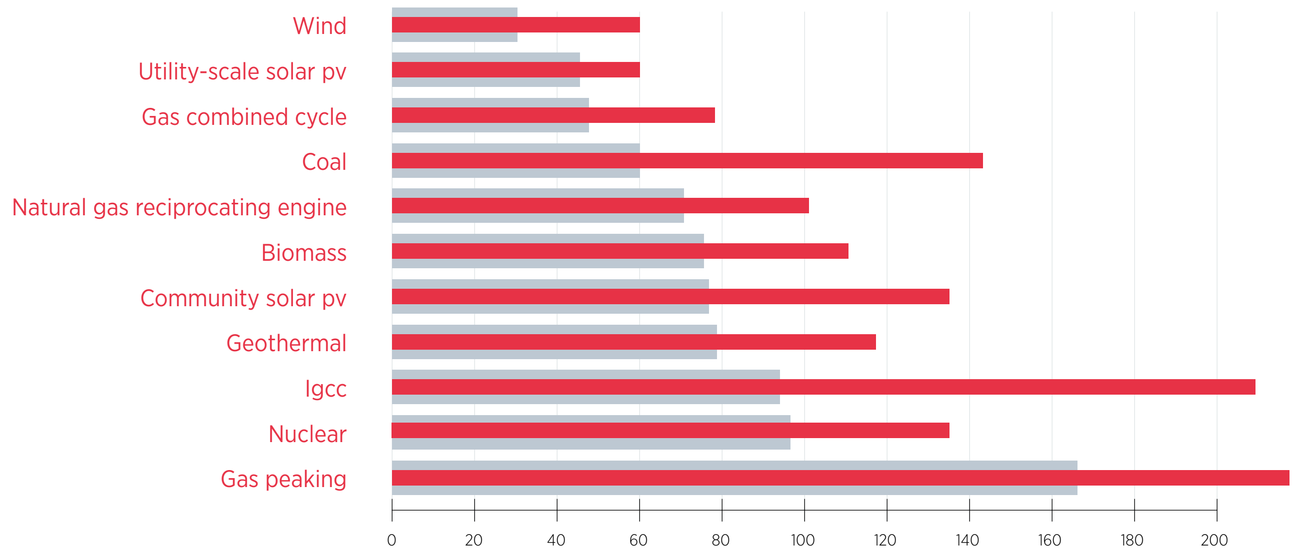
Around the world today, solar and wind electricity are among the cheapest sources to produce in areas with high solar irradiation and/or wind speeds. Currently, unsubsidized production costs for solar and wind are 2 to 4 cents (in dollars per kWh worldwide, be it in Australia, Chile, Saudi Arabia, Morocco, China or Mexico. The levelized cost of energy for the US is shown below, based on a study by Lazard: wind (3 cents per kWh) and utility-scale solar (4.5 cents per kW) are the cheapest.

Offshore wind has also experienced a dramatic reduction in price in the past few years. Recent tenders by the Netherlands and Denmark in the North Sea have included prices below 5 cents (in euros) per kWh. The first offer to build an offshore wind farm without a subsidy was submitted in April 2017 in Germany. With wholesale market prices of around 3 cents (in euros) per kWh, an offshore wind farm could be realized at a cost below 3 cents (in euros) per kWh.

Bloomberg's New Energy Outlook 2017 expects that, by 2040, the levelized costs of electricity from solar will fall by 66 percent, onshore wind will fall by 47 percent and offshore wind will fall by 71 percent. If these figures are true, the prices for renewables in 2040 will be well below 1 cent (in dollars) per kWh.

US unsubsidized levelized cost of energy (figures by Larzard)

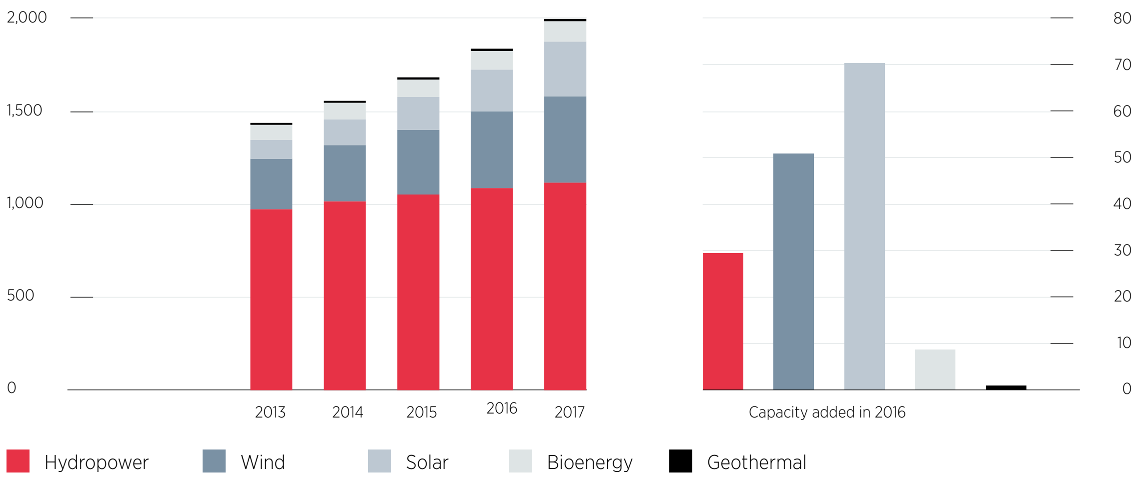
Gray = low estimate. Red = high estimate. Figure = $/MWh



Data by Lazard | Chart by CleanTechnica | Zachary Shahan, January 2017
https://cleantechnica.com/2017/01/22/renewables-now-cheapest-renewable-energy-costs-low-too-high/

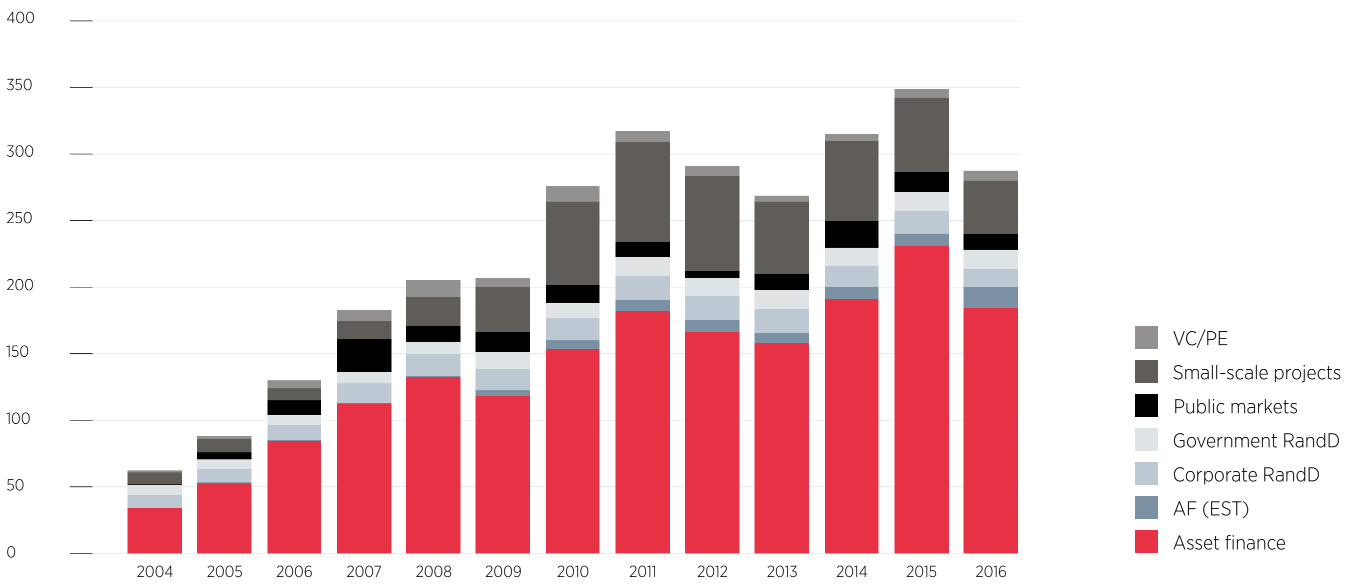
Due to these cheap production costs for renewables, there has been a massive capacity expansion in wind and solar (see the table below). In 2016, more than 161,000 MW of renewable energy production capacity was added worldwide, over 120,000 MW of which was solar and wind. That was an 8.7 percent increase in capacity over 2015. China added a renewable electricity capacity of 14.6 GW in hydropower, 19 GW in wind power and 34 GW in solar power in 2016. In that same year, the US added 9 GW in wind and 11 GW in solar.

Capacity growth



Source: Capacity growth renewable energy worldwide; IRENA, March 30, 2017
http://www.irena.org/DocumentDownloads/Publications/RE_stats_highlights_2017.pdf

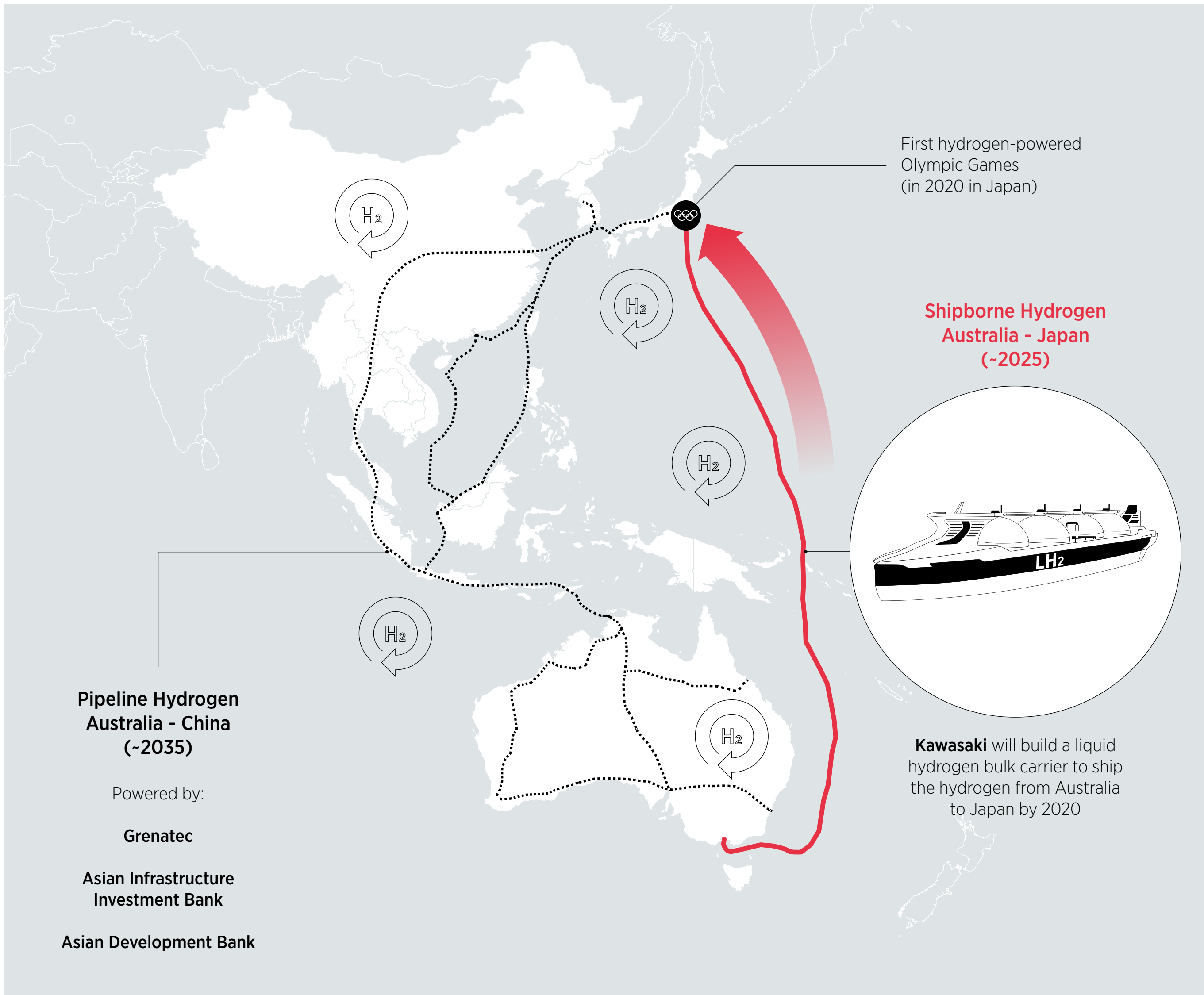
Bloomberg figures show that in 2015, investments in renewable energy were about 350 billion dollars, which was more than double the amount of investment in fossil-based energy. In 2016, investments totaled 290 billion dollars, which was less than in 2015, but that is partially because the investment costs in renewables decreased considerably in 2016. Even with a modest oil price of around 50 dollars per barrel, capacity for renewables has increased considerably because they are competitive with fossil-based energy sources.



Source: Bloomberg New Energy Finance. Note: In this chart, asset finance is adjusted for re-invested equity. AF (EST) stands for asset finance of energy smart technologies projects, including smart grid, smart meters and energy storage. VC/PE stands for venture capital and private equity.

Now that prices for large-scale renewable electricity production have come down so dramatically and will continue to decrease even further in the near future, the challenge remaining is how to transport this cheap renewable energy from the places where it is produced to the centers of demand. The renewable energy has to be transported around the world, which can only be done by electrolysis of water with electricity. This hydrogen can be compressed or even turned into liquid and then shipped. With nitrogen captured from the air, the hydrogen could also be converted into ammonia. Ammonia is liquid at around 10 bar and therefore easier to transport.

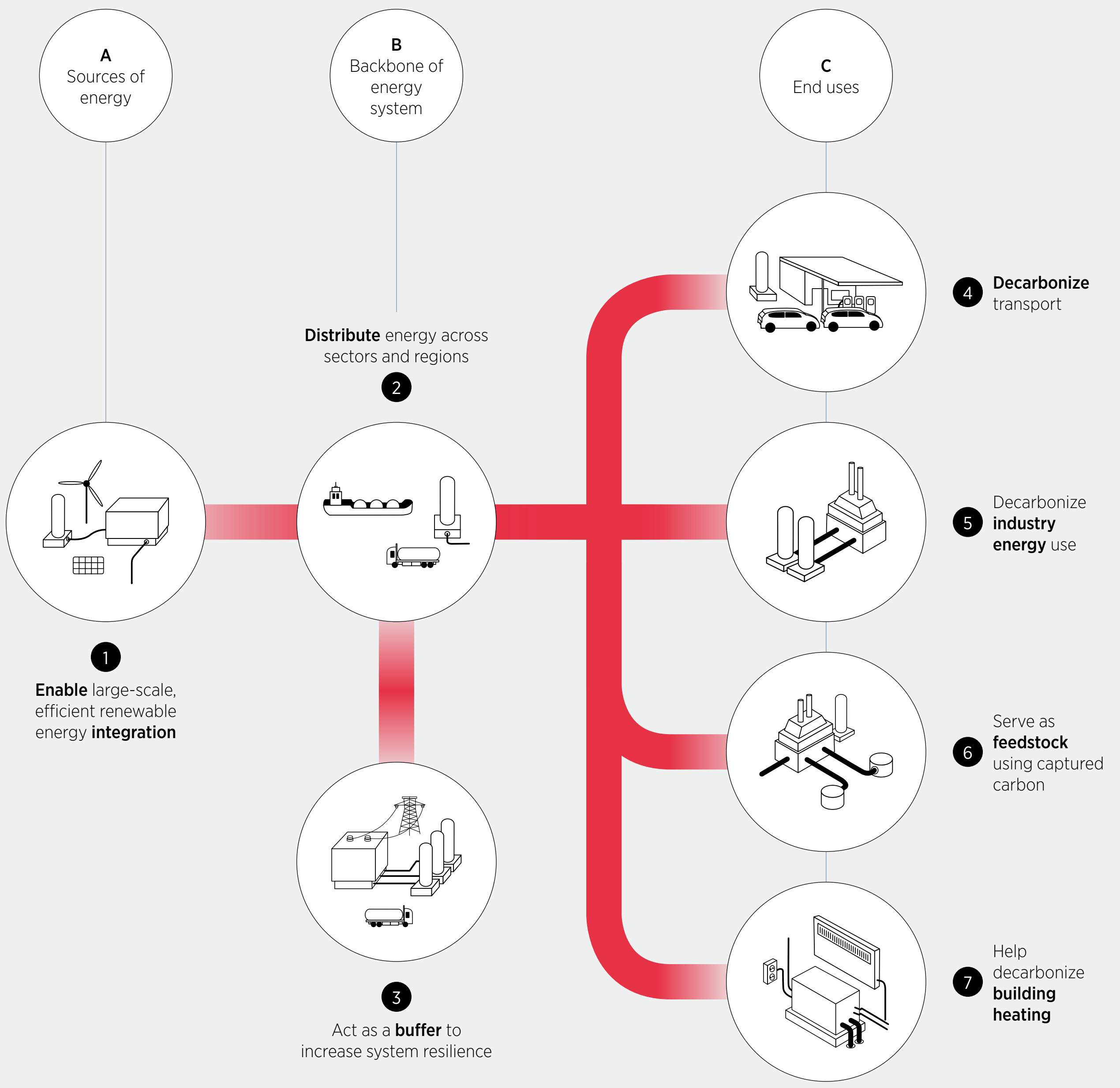
The first agreements to ship hydrogen overseas are in place. Japan and Australia entered into an agreement in January 2017 to transport hydrogen which will initially be produced through gasification with carbon capture and then later through solar by electrolysis. Kawasaki will build a liquid hydrogen bulk carrier to ship the hydrogen from Australia to Japan by 2020 (https://www.abo.net/en_IT/topics/Australia-Hydrogen-en.shtml). Norway is trying to compete with Australia and is offering to produce green hydrogen from renewables - mainly hydropower - then convert it into liquid and ship it to Japan (http://www.reuters.com/article/us-japan-hydrogen-race-idUSKBN17U1QA). Japan's commitment to developing the hydrogen economy will be demonstrated during the Olympic Games in 2020, which are meant to be the first hydrogen-powered Olympic games. There are also plans to build a hydrogen pipeline grid around East Asia (shown below).



Empowering the transition to a sustainable energy supply

In transitioning toward a sustainable energy system, green hydrogen can play many important roles. Hydrogen is a clean and safe energy carrier that can be used as a fuel in transportation and electricity production, as well as a feedstock for industry. Green hydrogen can be produced from green electricity by electrolysis, from biogas by steam reforming or from biomass through gasification. Like natural gas, hydrogen can be transported by ships and trucks or via pipelines.

Hydrogen can be compressed or liquefied and can easily be converted into a liquid chemical/fuel, such as ammonia or methanol. Large-scale hydrogen storage is possible in salt caverns under pressure or, in liquefied form, in tanks. Ammonia or methanol could also be stored in tanks, which also effectively stores hydrogen. Fuel cells and electrolysis are enabling technologies that will amplify the use of hydrogen.



Source: Hydrogen Council

Council figure

The role of hydrogen in the energy transition is depicted by the Hydrogen Council figure on the left.
There are seven major and distinctive roles for hydrogen:

1. Enabling large-scale, efficient renewable electricity integration: Due to the intermittent character of solar and wind, the electricity system needs to be balanced. Green hydrogen in fuel cells or flexible combined cycle power plants can produce electricity during times of shortage.
2. Transportation and distribution of renewable energy across sectors and regions in the world: Green electricity can be produced from solar, wind, hydro and geothermal sources. In high resource areas, solar and wind can now produce electricity for between 2 and 3 cents per kWh. However, since there is no demand in these areas, that electricity needs to be converted into hydrogen and shipped elsewhere.
3. Hydrogen storage and buffering to increase system resilience: Hydrogen has a high-energy density, can be stored for long periods and is easy to transport. It is therefore well-suited to serve as an energy buffer and for strategic reserves of energy.
4. Decarbonization of transportation: Fuel cell electric vehicles using hydrogen as a fuel will be introduced to the market in the coming years. Fuel cell technology will make zero emission transportation possible, even for heavier vehicles, trains and ships.
5. Decarbonization for industrial energy use: Industries can use a mix of green electricity and green hydrogen to produce high temperature steam which is necessary for many industrial processes.
6. Serving as a feedstock for industry: Carbon from biomass and green hydrogen are the main feedstocks for production of every bulk chemical product.
7. Helping decarbonize building heating: Building heating needs to be minimized as much as possible and, in many cases, district heating or combining heat sources with heat pump technology are the preferred solutions for sustainable building heat. However, in some specific cases, natural gas could be replaced by green hydrogen transported via retrofitted gas pipelines to produce the necessary heating for buildings.

To summarize, green hydrogen is essential in the transition to a sustainable energy system. Hydrogen is a clean and safe energy carrier that can be used as a fuel in transportation and electricity production or as an industrial feedstock. Hydrogen and electricity will be the energy carriers of the future, whereby hydrogen can be transported over long distances and stored for a long time.

2

Green hydrogen: a unique opportunity for the Northern Netherlands

The economy in the Northern Netherlands is, to a large extent, based on the agricultural sector and natural gas production, especially from the Slochteren gas field. Over the years, the related agro- and chemical industries have developed into innovative, dynamic and established economic factors in the Northern Netherlands. More recently, the Northern Netherlands has developed into an energy production and transportation region through electricity production from fossil fuels and renewable resources, like onshore and offshore wind and solar power. Biogas production is also prominent in the Northern Netherlands. Transportation of energy via a strong electrical grid, a very strong gas grid and, since 2008, an offshore electrical grid connection with Norway, facilitate this energy production.

The Northern Netherlands, as well as the rest of the Netherlands, Europe and the world at large, must transform into a renewable energy-based economy in the future. As put forward in the Paris Agreement, this change is necessary in order to mitigate greenhouse gas-induced climate change. As such, gas production in the Northern Netherlands needs to be reduced in the coming years and replaced by renewable energy sources, notwithstanding the fact that gas production is already declining because the gas fields in the Northern Netherlands are becoming depleted.

Furthermore, due to gas extraction from the Slochteren gas field, earthquakes have become more pronounced in recent years and are causing damage to homes and buildings. This has a negative impact on the general well-being of the people living in the affected area, both materially and socially. Efforts are being put into repairing damaged buildings and homes. Reducing the amount of gas extracted from the Slochteren field has already shown a reduction in the earthquake activity in the area.

Reducing gas production should result in less damage due to earthquakes, but it will have a negative effect on the economy and employment in the Northern Netherlands. Therefore, there is an urgent need to transition towards other economic activities.

In many ways, green hydrogen produced from green electricity, biogas or biomass could offer an interesting opportunity. The main reasons that the Northern Netherlands is uniquely poised to develop a green hydrogen economy are:

- Abundant availability of low-cost green electricity from offshore wind and offshore electrical cables.
- Large and very sophisticated gas infrastructure, both onshore and offshore.
- A well-established gas industry and knowledge network.
- The presence of relevant chemical and agricultural industries.
- Neighboring Germany is rapidly developing hydrogen fueling infrastructure for cars.

This mix of industrial activities, assets and infrastructure, together with the compelling need for change, presents the Northern Netherlands with a unique opportunity to develop (one of) the first green hydrogen economies in Europe.

Increasing renewable energy and electricity production

In the Northern Netherlands, renewable energy production has strongly increased in recent years. Biogas is produced from the waste products of the agricultural industry, waste water plants, dung and other organic residue. These activities already have a strong position in the Northern Netherlands: At present, 50 million m3 of biogas is produced annually. The onshore wind turbine capacity in the Northern Netherlands was about 650 MWe as of the end of 2015. The first offshore wind farm, Gemini, will be fully operational in 2017 with a capacity of 600 MW. Solar power systems are installed on many homes and buildings and, more recently, the first large-scale solar farms have been built. A biomass energy plant producing electricity and steam, Golden Raand, is also up and running in Delfzijl. In the city of Groningen, a large geothermal project will be created to heat homes and buildings. In Friesland, an innovative system to produce electricity via osmosis is being developed at the Afsluitdijk. On the island of Ameland, important projects have already been realized which can make Ameland self-sufficient by 2020. Many more projects and activities will be developed in the coming years.

One of the most interesting areas of development is in the Eemshaven, which is quickly becoming an electricity production and transportation hub. It features:

- Onshore wind turbine capacity (more than 275 MW).
- The Gemini offshore wind farm (600 MWe) which has a grid connection in the Eemshaven.
- A coal-fired power plant owned by RWE (1,560 MWe).
- The Nuon Magnum power plant (1,320 MW), which currently runs on natural gas.
- Older gas-fired power plants owned by Engie (2,450 MWe combined. Engie has already announced the planned closure of some of these gas-fired plants).
- The NorNed cable, an offshore electrical cable from Norway (700 MWe).
- The Cobra cable, an offshore cable from Denmark (700 MWe), will be operational in 2019.
- An inland grid cable from the Eemshaven with a capacity of about 4,000 MWe.

In the future, the capacity of offshore wind farms connected to the Eemshaven will increase, either from the Dutch portion of the North Sea or from the German portion: An additional 4,000 MW by the year 2030 is a realistic estimate. It is safe to say that the Eemshaven will develop into a green electricity hub where more than 6,000 MW of green electricity will be made available from offshore and onshore wind farms and offshore electrical cables.

Simultaneously, fossil fuel electricity production will be phased out, although it is not yet certain when exactly that transition will be completed. In the meantime, the Magnum power plant will remain open, but will be operating on green or carbon-free ammonia, or green or carbon-free hydrogen, instead. The inland electrical grid capacity will be expanded in installments to an eventual capacity of 5,610 MW. Although there is a lot of flexibility in electricity production and offshore bidirectional electricity transport, the inland grid capacity could present limitations to transportation of all electricity produced. If we intend to transport all the green electricity from wind farms and import low-cost green electricity from Norway and Denmark, the inland grid capacity will not be sufficient for that task. With that in mind, converting electricity into hydrogen could avoid investment costs due to electrical grid expansion.

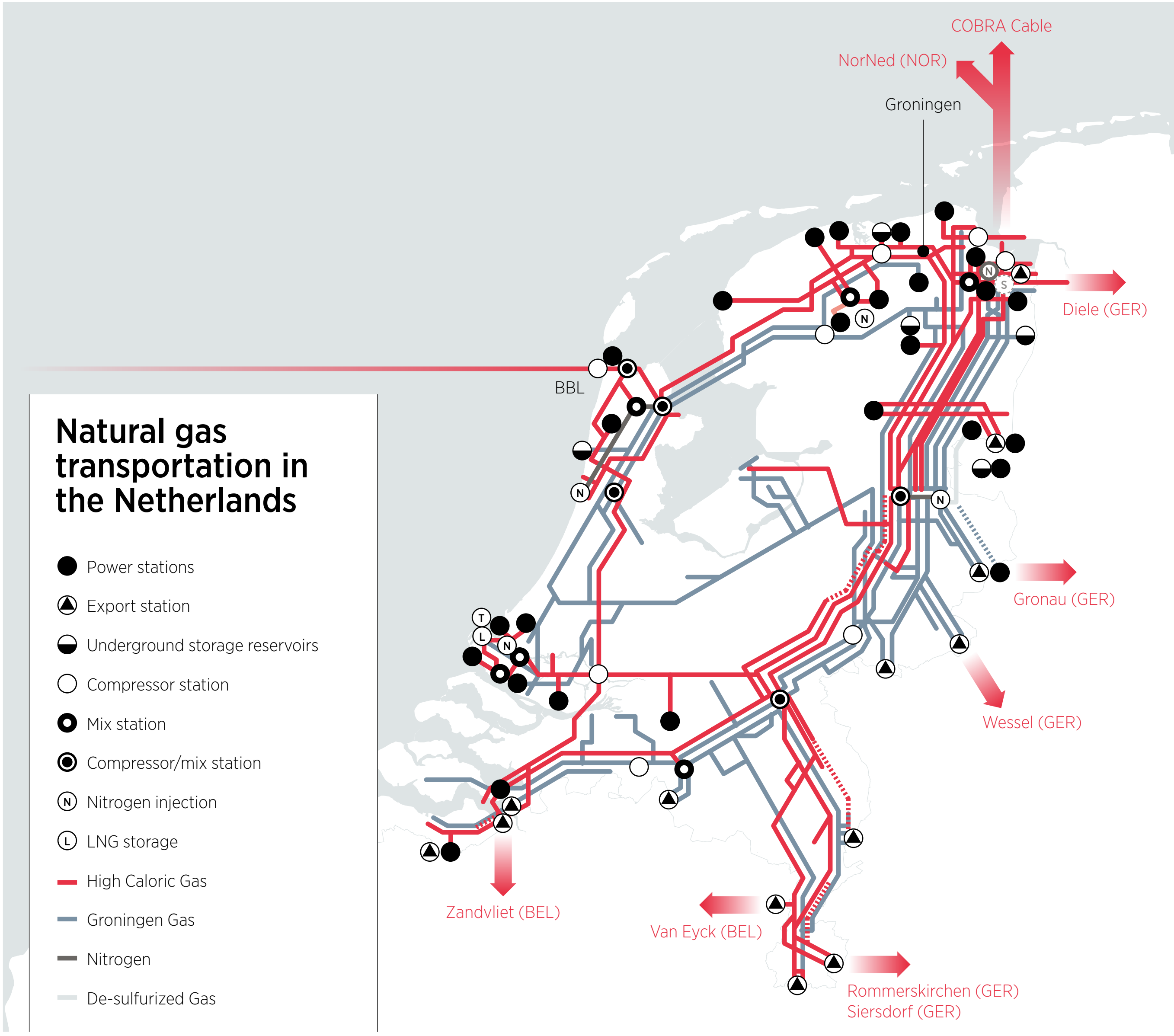
Avoiding electrical grid investment costs is not the only reason to pursue green hydrogen production in the Eemshaven, however. The fact that a large amount of low-cost green electricity is available as the base load in the Eemshaven makes it possible in turn to produce green hydrogen at a low cost. The offshore cable connections with Norway and Denmark combined with the offshore wind farms will make it possible to run an electrolyzer plant for more than 8,000 hours a year and could offer low-cost electricity from hydropower and excess wind power.

Another unique feature in the Eemshaven is the gas infrastructure, both offshore and onshore. The onshore gas infrastructure could initially be used to blend hydrogen into the existing natural gas stream. Once a sufficient volume of hydrogen is available, one of the existing gas pipelines could be converted so that it can transport hydrogen onwards, for instance to Delfzijl, Zuidwending, Rotterdam, Limburg and Germany. Gas pipelines can transport large quantities of hydrogen, so the extant gas infrastructure can be used to transport the renewable energy in the form of hydrogen from offshore wind, thereby avoiding the need for paying for new electricity transportation cables.

The same cost-cutting effect applies to using the offshore gas pipeline to transport the hydrogen from far offshore wind farms to the Eemshaven in the future. These far offshore wind farms will deliver their electricity to a nearby offshore gas platform. Electrolyzers placed at these offshore platforms will convert the electricity into hydrogen.

Using the existing gas infrastructure for hydrogen transportation could also save money. The gas pipelines will be transporting a decreasing amount of natural gas in the future. Transporting hydrogen through converted gas pipelines will give this infrastructure a second life, which means that demolition and its associated costs will not be necessary.

This unique situation in Eemshaven offers a great competitive advantage for large-scale green hydrogen production, consumption and transportation at competitive prices. The Eemshaven is well positioned to become a pioneering green hydrogen hub in Europe.



Established gas industry and infrastructure

Because of the Slochteren gas field, a network of companies, institutions, researchers and innovation and education centers have been established in the Northern Netherlands. Gas was discovered in Slochteren in 1959, and the NAM began drilling. In the 1960s, het Gasgebouw was established, which eventually split into NAM for exploration and production and Gasunie for transportation and sales. In 2005, GasTerra was established and took over the gas sales and trading activities from Gasunie. Over more than 50 years, the NAM (which is 50 percent owned by Exxon and 50 percent owned by Shell), Gasunie and GasTerra have overseen considerable growth. Many companies supply their products and services to the gas industry. The chemical industry was able to develop in this region because of the inexpensive supply of gas, both as a fuel and as a feedstock. The methanol plant in Delfzijl started methanol production from natural gas in 1978 because of gas prices were cheap at the time. Additionally, the knowledge infrastructure, education and innovation focused on gas - conducted by the University of Groningen, the Hanze University of Applied Sciences, Energy Academy Europe, Energy Delta Institute, EnTranCe, Energy Valley and many other educational institutions - is internationally recognized and therefore has a strong position in the field.

Hydrogen is a gas, too. Although the chemical and physical characteristics differ, the handling, transportation, distribution, infrastructure, storage and markets for hydrogen are similar to natural gas. The groups active in natural gas have the right people, expertise and skills to handle hydrogen instead of natural gas, which means that these companies could easily expand their activities into hydrogen.

- The NAM and/or Shell could become active in hydrogen production. Hydrogen can be produced from gas by steam reforming or by electrolysis of water using electricity. If biogas is used instead of natural gas in this process, and if the electricity used is generated from renewable resources, then the hydrogen which is produced is green. Shell has already begun investing in offshore wind farms as a partner in the consortium that will build Borssele 3 and 4 in the North Sea, so it would be logical next step to become partners in green hydrogen production.
- Gasunie owns and operates the gas transportation infrastructure, so they could also install and operate hydrogen pipelines. An interesting opportunity would be to convert part of the existing gas infrastructure into hydrogen infrastructure. Gasunie could also be a partner in hydrogen production as an infrastructure provider.
- GasTerra is the trading and sales company for natural gas, and they could have a similar position when it comes to trading and sales of hydrogen. Gasunie and GasTerra have established the TTF trading platform for gas, which is the leading platform for gas in Europe. When the time comes, a similar platform for hydrogen could be developed.
- Energy Academy Europe, now a part of the New Energy Coalition, could play an important role in the realization of a green hydrogen economy, first and foremost through their research, innovation and education, but also through helping companies, organizations and institutions to further develop their knowledge and skills on hydrogen and other related areas.

These gas companies cannot go it alone, but they could serve as the leading partners located in the Northern Netherlands in building this green hydrogen economy. In doing so, they could create an environment that attracts other industries, such as:

- Industrial gasses companies specialized in hydrogen. production and distribution (i.e. Air Liquide, Linde, Air Products).
- Technology engineering and contracting companies (i.e. Technip, Lurgi, Fluor Daniels, Engie, etc.).
- Equipment suppliers of electrolyzers and compressors (i.e. Siemens, ITM, NEL or Hydrogenics, etc.).
- Offshore industry (i.e. Van Oord, Boskalis, Mammoet or Heerema); cable companies (i.e. ABB or Pirelli); and wind turbine manufacturers (i.e. Siemens, GE, Mitsubishi, Vestas, etc.).
- Chemical industries using hydrogen and syngas (i.e. AKZO, OCI, Evonik, Dupont, Yara, Mitsubishi, BP, etc.).
- Energy companies (i.e. Total, Statoil, BP, Engie, Nuon/ Vattenfall, RWE, Eon, Eneco, etc.).
- Many others - not only large companies, but innovative small and medium-sized companies and startups in particular - could develop new and innovative products, systems or services in a green hydrogen economy.

Relevant chemical and agricultural sectors

At the Delfzijl chemical site, there is an integrated chain of companies that use and process one another's products and services, and the availability of salt and natural gas serves as common ground. These feedstocks are processed into chlorine, hydrogen, caustic soda and methanol. In turn, these become the feedstock for other chemical products. Examples of the companies already active on this site are AkzoNobel, BioMCN-OCI, Evonik, Teijin and Delamine. Delesto delivers steam and electricity produced from gas on site. Since December 2016, the Eneco Bio Golden Raand biomass plant has been delivering green steam to this chemical site.

The Emmtec Industry and Business Park in Emmen is the preeminent polymer competence network of the Netherlands: renowned companies like DSM, Teijin and Bonar chose to locate here, and a pilot plant site and a research and competence center are also on site. Emmtec utilities deliver electricity and steam produced by gas to this site as well. The chemical cluster in Emmen is an innovative group with an emphasis on changing from fossil-based to bio-based feedstock. One example of that is BioBTX, a small company that wants to use wood to process BTX (Benzene, Toluene, Xylene).

AkzoNobel uses electricity and electrolysis from brine (saltwater) to produce chlorine at their site in Delfzijl. The byproduct of this process is hydrogen. About 3,000 tons of hydrogen is produced annually. Currently, this hydrogen is primarily used as a fuel to produce electricity and steam. Together with AkzoNobel, PitPoint is creating a hydrogen fueling station at this chemical site and using the hydrogen for transportation. In an initial phase, two buses with routes between Groningen and Drenthe should be running on hydrogen by the end of 2017. This project is an effort by the provinces of Groningen and Drenthe, Qbuzz and AkzoNobel.

The same electrolysis technology is used to produce green hydrogen from green electricity and pure water. It is not a new technology and the chemical sector already has plenty of experience using it. Another component is the production of pure water via reverse osmosis. Pure water production already exists in the area: pure water plants are operational at the chemical site in Delfzijl (North Water, a joint venture of Waterbedrijf Groningen and Evides Industrial Water) and in Emmen. As such, all relevant knowledge and operational experience to start an electrolysis plant for the production of green hydrogen is already available in the Northern Netherlands.

Agriculture in the Northern Netherlands is a strong and innovative sector with leading companies in the dairy sector (FrieslandCampina), the sugar beet sector (Cosun) and the potato sector (Avebe). All of these companies use their waste products to produce biogas, bring new, high-value products to the market, and work together with the chemical industry to supply bio feedstocks. The agricultural sector in the Northern Netherlands is truly innovative and is at the forefront of developing into a bio-based economy. Bringing together bio-based practices and the green hydrogen economy will be a real driver of a sustainable future.

Green hydrogen can also be produced through biomass gasification of solid biomass, such as straw or wood. In Groningen, a company named Torrgas has installed an experimental biomass gasification plant that uses torrefied biomass. This biomass gasification plant produces a syngas consisting of hydrogen, carbon monoxide and carbon dioxide. Almost every bulk chemical can be made from a combination of hydrogen and a syngas. Together with the more specialized bio feedstocks from the agricultural sector in the Northern Netherlands, every chemical product could be made and would ergo be a green chemical.

Green hydrogen and green syngas production, together with the existing agricultural and chemical sectors in the Northern Netherlands, will create a strong and unique environment for growth in the region. It will also attract new chemical, energy, agricultural, equipment and service companies to the region.

Rapid development towards clean mobility

The transportation sector will shift towards electric driving, both with batteries and with fuel cells fueled by hydrogen, to supply the electricity to an electric engine. The hydrogen-fueled fuel cell presents an attractive solution for heavier vehicles that drive long distances in particular. The public transportation sector - buses, taxis and non-electrified trains - will be one of the first markets for hydrogen, followed by trucks, boats and eventually cars. Nearly all major car manufacturers are already developing fuel cell electric cars and will bring them to the market in the coming years.

However, in order to develop the market for fuel cell hydrogen mobility, a fueling station infrastructure must be present. Together with the German government, a consortium of energy companies and car manufacturers - Shell, Total, Linde, BMW and Mercedes, among others - has agreed to develop 400 hydrogen fueling stations in Germany by 2023. This initiative will mean that a hydrogen fueling station is within reach no matter where you travel in Germany. The Northern Netherlands could do the same and, together with industry players, develop a full-coverage hydrogen fueling infrastructure in the Northern Netherlands. There is already a lot of serious interest and commitment from companies in the Northern Netherlands for installing hydrogen fueling stations: Together with Resato and

GreenPlanet, Holthausen has announced the opening of up to eight hydrogen fueling stations in the coming years, and the first hydrogen fueling station from PitPoint is already under construction near AkzoNobel in Delfzijl.

An interesting feature of the Northern Netherlands is the presence of 50 diesel trains for public transportation. Alstom has developed a fuel cell hydrogen train to offer a zero-emission solution for non-electrified trains, i.e. diesel. Across the border of the Northern Netherlands, a first test will take place in Germany in early 2018 which also presents an opportunity to easily extend it into the Northern Netherlands as well. When a new budget is tendered for public train transportation, it should call for a zero-emission solution.

The use of electricity and hydrogen in mobility can boost companies in a variety of industries, such as logistics suppliers, transportation companies, garages, agricultural contractors, ship builders, automobile leasing companies, sail boats and city distribution, among many others. New and innovative products, services and concepts could be developed, such as parcel delivery by fuel cell hydrogen drones, self-driving city logistics and waste resources collection, to name a few. Electricity and hydrogen will be the energy sources in all of these mobility systems. There is a need for development of new storage systems for hydrogen and electricity, electro engines, fuel cells, electrolyzers and compressors, in tandem with enabling technologies, such as membranes, sensors and new materials, and new IT and app services. Together, these innovations will boost startups and SMEs (Small and Medium Enterprises) in the region.

Local green energy production and balancing offers opportunities for everybody

Future smart areas, villages, farms, data centers, islands, industrial sites and everything in between need to become fully sustainable in many ways, including energy provision. Reducing the energy demand for heating and cooling, appliances and lighting by generating all of the electricity through solar is one achievable system concept for a zero-energy smart area. However, not every moment is zero energy: In the summer months, more electricity is produced than consumed, and in the winter, more electricity is consumed than produced by solar, to say nothing of energy consumed in transportation.
In a fully sustainable, smart energy system, a balanced electricity system can be achieved with batteries for day/night balancing and hydrogen for seasonal balancing. During the summer, excess electricity can be converted into hydrogen by installing an electrolyzer. In the winter, a fuel cell (either stationary or in a car) could supply electricity by converting hydrogen into electricity. There is a need for extra renewable energy for driving and balancing, and that energy could be supplied to the smart areas as hydrogen produced from wind, biomass, biogas or large-scale solar.
An all-electric green energy system of this nature will use hydrogen to balance the energy and electricity systems. On islands or in villages and city areas, this could be achieved via small-scale energy systems owned by the inhabitants themselves. People can add solar cells to roofs, install small-scale electrolyzers to produce hydrogen and buy fuel cell electric cars, which can be used both for driving and for producing electricity in times of shortage. They can also either trade in or exchange energy with their neighbors by creating co-operatives: They could buy a large-scale offshore wind turbine that produces hydrogen for driving and covers that shortage. In doing so, consumers become "prosumers" (both a consumer and at the same time a producer), and together, they could have full control and ownership of their sustainable energy system for all of their needs. These new energy systems will generate many new products, services and economic activity, especially in combination with the construction, energy and transportation sectors, and as such boost innovation in the Northern Netherlands.

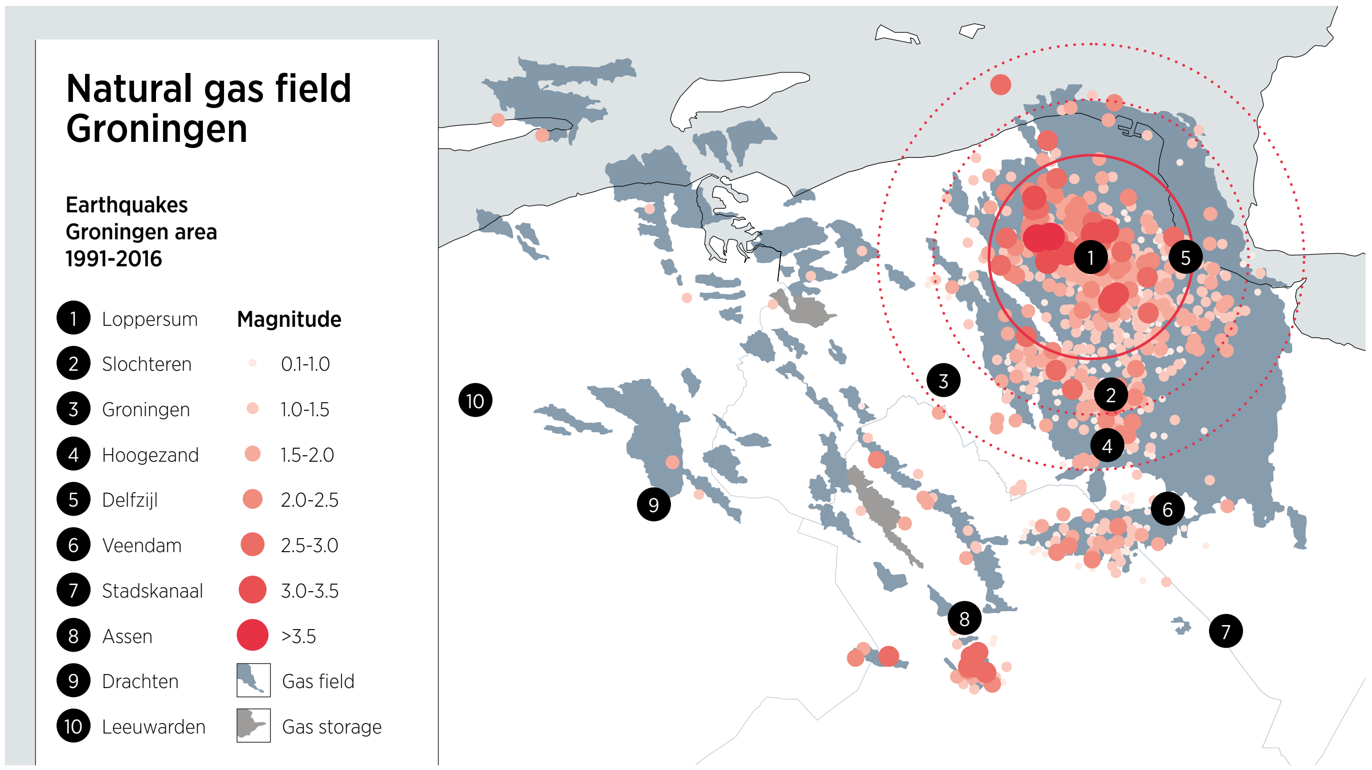
Green hydrogen for heating buildings

Homes and buildings need to become zero emission structures in the coming decades. The energy demand must be considerably reduced for heating and cooling by insulating floors, roofs and walls and by double or triple glazing windows. But it is very expensive and difficult to bring the energy demand for heating to zero in buildings and homes which are already standing. As such, there is a need for additional green energy sources that can be supplied to these buildings and homes. In city areas with a high density of homes and buildings, a heat grid could supply this additional heat. In other areas, homes could be better insulated, and a low-temperature heating system with an electric heat pump - together with heating and cooling storage underground - could solve the problem. But in small villages and older sections of cities, it is very difficult and expensive to install a heating grid or heat pumps with their own wells in the ground. But the natural gas grid is available in these areas; therefore, it is worth examining whether green hydrogen or biogas could be delivered to homes and buildings in these areas through retrofitting the existing gas infrastructure. If green hydrogen is supplied via such a retrofitted gas pipeline to homes, the burners in the boiler and stove will have to be changed, which is a relatively easy and cheap operation. A similar change was made in the 1960s when the system shifted from town gas, which was more than 50 percent hydrogen, to natural gas.

Urgency for change in the Northern Netherlands

Since 1963, gas has been extracted from the Slochteren gas field, which is one of the largest gas fields in the world. The Slochteren gas field has contributed considerably to Dutch economic welfare. Since the 1960s, the Dutch state has received 265 billion euros from gas revenues. As of the end of 2012, it was predicted that the Slochteren gas field still contained one-third - about 780 billion m3 - of its original gas contents. Slochteren gas production was predicted to naturally begin declining in 2020, so the Netherlands had already been preparing for a change in the national energy supply moving forward.
Gas production also has disadvantages: In Groningen, it has caused subsidence for years, which influences the groundwater levels and has direct consequences for regional water management and indirect consequences for agriculture and nature. This influence is predictable and monitored, and those who are impacted by it are financially compensated.
Another consequence of gas production is earthquakes, which have been occurring since 1986. The majority of the earthquakes are below magnitude 2.0 on the Richter scale, but there are about five heavier earthquakes per year on average. These earthquakes can cause damage to homes and buildings. The earthquakes themselves and the threat of earthquakes affect the quality of life of the residents of the region. It has become clear that measures must be taken to repair the damage and to reduce the earthquakes. On June 1, 2015, the Dutch government appointed Hans Alders as the National Coordinator for Groningen, a position responsible for the repairs to and earthquake resistance of homes, buildings and infrastructure in the area. To reduce the amount and strength of the earthquakes, the Dutch government has decided to decrease gas production from the Slochteren gas field. From 2012 to 2017, the production level was nearly halved to an agreed upon maximum production of 24 billion m3 (between October 1, 2016 and September 30, 2017). The Dutch parliament has recently decided that gas production needs to be reduced further still in the future.

The Netherlands was already facing the challenge of addressing the expected decline in the production of the Slochteren gas field, but the earthquakes and the Paris Agreement have accelerated and increased the sense of urgency for the Netherlands to change from the fossil-based energy system of today into a sustainable and green energy system of tomorrow. These major challenges have made it even more imperative to make significant changes in the Northern Netherlands.



Source: NAM, TNO, KNMI

3

Green hydrogen production, markets, infrastructure and society

A green hydrogen economy can only exist if green hydrogen production, infrastructure, markets and societal aspects are developed interdependently. Through consultation with multiple companies, organizations, governments and institutions, a selection of relevant projects and activities for the Northern Netherlands has been set forth in each of these four categories (see graphic on next page). These projects and activities are the first phase in the development of a green hydrogen economy in the Northern Netherlands up to the year 2030. Once this first phase is a success, further growth in green hydrogen production, infrastructure and market development will occur following 2030.

Large-scale hydrogen production must be achieved in order to reach competitive hydrogen prices of 2 to 3 euros per kg. A sufficient amount of hydrogen must be produced to economically justify retrofitting an existing gas pipeline into a dedicated hydrogen pipeline and infrastructure system. The first market for green hydrogen, therefore, must be the chemical industry, where hydrogen is used as a feedstock to make chemical products like ammonia and methanol. This chemical feedstock market can absorb the volume of hydrogen being produced. With green hydrogen, the chemical industry can decarbonize their chemical products and thereby contribute to the greenhouse gas emission reduction which was agreed upon in Paris. As one of the first large-scale users, the Nuon Magnum power plant could absorb large volumes of green or carbon-free hydrogen.

Once green hydrogen can be produced for 2 to 3 euros per kg, the market for hydrogen fuel cell buses, trucks, trains, boats and cars can be developed. Car manufacturers are introducing the first hydrogen fuel cell vehicles to the market, but scaling up production and sales of these cars will only be possible if infrastructure for hydrogen fueling stations exists. In the coming years, pilot projects should open up the market in combination with the well-coordinated installation of hydrogen fueling stations. The hydrogen fuel cell transport market will develop most prominently in the public transportation sector, namely in buses, trains and specialized trucks. Such development could easily be directed by the provinces and municipalities, since they are the ones who oversee the budget for public transportation.

The third market for green hydrogen is the electricity balancing market. Green hydrogen could be used to produce electricity with fuel cells, gas turbines or flexible combined-cycle power plants for periods when there is insufficient electricity from wind and solar power, for example at data centers that want to run entirely on green electricity. They can buy electricity from a wind farm, but for periods when there is insufficient wind electricity, electricity can be supplied by green hydrogen fuel cells, gas turbines or flexible combined cycle power plants. The balancing could also be done the other way around: If a neighborhood with many solar panels on the roofs of buildings and homes produces excess electricity in the summer, it could be converted into green hydrogen by a small electrolyzer.

A fourth market for green hydrogen could be heating homes and buildings. Green hydrogen could be distributed via retrofitted gas distribution pipelines. By simply changing the burners in the boilers and stoves, it will be possible to burn hydrogen instead of natural gas. This is an option to realize a fully carbon-free heating system and low costs in rural areas, small villages and older sections of cities.

Production: 4,000 MW of offshore wind energy

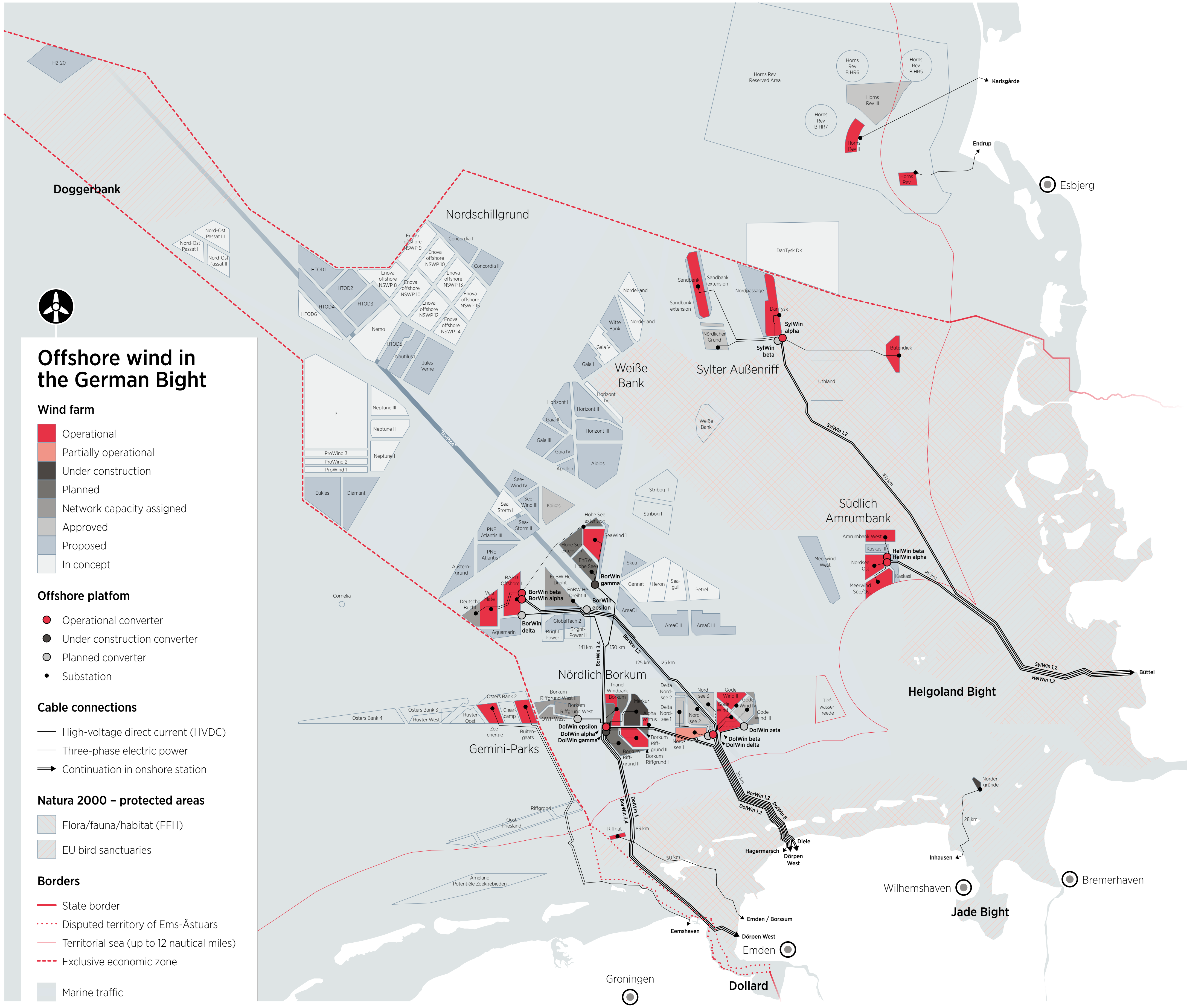
In the German portion of the North Sea, a huge amount of offshore wind is either planned or already under construction (the German projects are shown below). Approximately 6,500 MWe capacity from offshore wind is projected to be installed by 2020. Altogether, there are plans for more than 25,000 MWe from offshore wind energy.

A green hydrogen economy can only be realized when green hydrogen production, markets, infrastructure and societal aspects are developed interdependently.

The 600 MW Gemini wind farm with a grid connection to Eemshaven has already been built in the Dutch portion of the North Sea above the Wadden islands. An additional 800 MWe can be developed in the Dutch portion of the North Sea on top of the amount produced by the Gemini wind farm. Other areas north of the Wadden islands are currently excluded from offshore wind development because they are military zones, but even a small portion of the area north of the Eemshaven would be enough space to install offshore wind with a production capacity of 4,000 MWe.

Even if there is no offshore wind north of the Dutch portion of the North Sea, the electrical grid cable from multiple German offshore wind farms would still be useful to connect to the Eemshaven. When it comes to pending offshore wind farms, Harlingen could also be an interesting place to connect to an onshore grid. Tennet is a transport grid company which is currently active in both the German and Dutch portions, and it needs to connect the offshore wind farms to the grid. Connecting a minimum capacity of at least 4,000 to 6,000 MWe to the Eemshaven would likely be the most cost-effective solution.

It is realistic to estimate that 4,000 MW of offshore wind capacity connected to the Eemshaven onshore grid will come online in the next 10 years. Currently, investment costs for offshore wind are around 3 to 3.5 million euros for 1 MW, including the grid cable and connection. Recent requests for tender for offshore wind in the Netherlands and Denmark illustrate that electricity prices have come down to 7.3 euro cents per kWh in the Netherlands for Borssele 1 and 2 (Dong) and 5.45 euro cents per kWh for Borssele 3 and 4 (Eneco/Shell). In November 2016, it was announced that a new offshore wind farm in Denmark, to be built by Vattenfall, would deliver electricity for 4.99 euro cents per kWh. In the tendering round in Germany in June 2017, an offer was made to build the first offshore wind farm without any subsidies, which implies a price for electricity of about 3 euro cents per kWh.



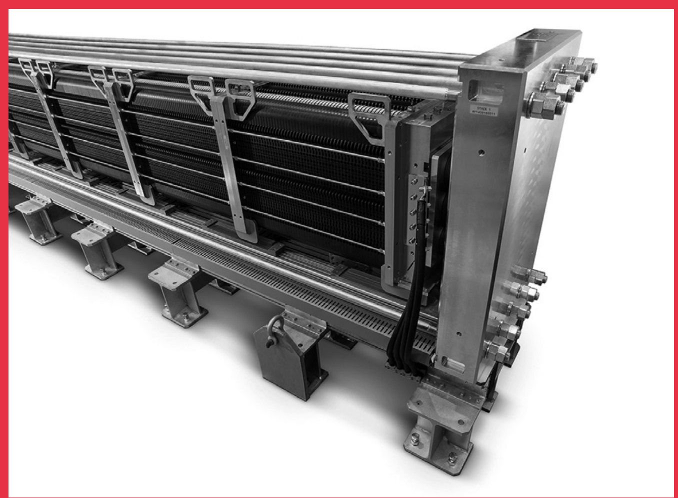
Production: 1,000 MW electrolysis hydrogen production

The NorNed cable, an offshore electrical cable from Norway with a capacity of 700 MWe, comes on land in the Eemshaven. The Cobra cable from Denmark, which has a capacity of 700 MWe, is also planned to connect to the onshore grid at the Eemshaven. The Gemini wind farm is connected to the grid in the Eemshaven with a capacity of 600 MWe. Within 10 years, an additional 4,000 MWe from offshore wind is projected to connect to the Eemshaven via electrical cables. There is already a significant amount of onshore wind turbine capacity in the Eemshaven (more than 275 MWe), and there is a capacity of more than 5,000 MWe from fossil fuel-fired power plants: a new coal-fired power plant owned by RWE (1,560 MWe); the new Nuon Magnum power plant (1,320 MWe), which should eventually be fueled by green hydrogen cracked from green ammonia; and the older gas-fired power plants owned by Engie (2,450 MWe altogether). Engie has already announced that some of the older gas-fired power plants will close, but a substantial amount of power plant capacity (eventually fired by biomass and green ammonia/hydrogen) will remain operational in the coming years.

As such, it is reasonable to conclude that the Eemshaven will develop into a green electricity hub where between 6,000 and 8,000 MWe of green electricity will be available. However, the inland grid cable from the Eemshaven only has a capacity of about 4,000 MWe as of now. Expansion of the grid capacity to 5,610 MW is scheduled to occur in phases. Even if the capacity increases, green electricity production will still exceed it in periods of full wind power availability. A small portion can be absorbed by data centers, but there is potential for at least 1,000 MWe in green electricity available for green hydrogen production via electrolysis. The need for (green) hydrogen in the chemical industry and the current limited nature of the grid are equally important arguments for building additional electrolysis capacity.

A 1,000 MWe electrolyzer plant that runs 8,000 hours a year uses 8 billion kWh and 1.5 million m3 of pure water to produce 160,000 tons of hydrogen. A reverse osmosis plant using sea water or surface water as input would produce the necessary amount of pure water. Assuming an electricity price of 2 to 3 cents per kWh and a total investment of between 500 million and 1 billion euros with ten years' depreciation time, the resulting production costs of green hydrogen will be 2 to 3 euros per kg. This is competitive with current prices for hydrogen produced from natural gas by steam reforming, which also costs somewhere in the range of 2 to 3 euros per kg. Once the green nature of the hydrogen is valued properly, a market for green hydrogen as a feedstock in industry and (eventually) for mobility could certainly be developed.

SILYZER 200 basic system	Technical data
Electrolysis type/principle	PEM (Proton Exchange Membrane)
Rated stack capacity	1.25 MW
Skid dimensions	6.30 m x 3.10 m x 3.00 m
Startup time	< 10 sec
Output pressure	Up to 35 Bar
Hydrogen purity (dep. on operating point)	99.5% - 99.9%
Hydrogen quality 5.0	Optional DeOxo dryer
Hydrogen production under nominal load	225 Nm^3/h
Life cycle design	> 80.000 h
Weight	17 t
CE conformity	Yes
Fresh water demand	1.5 l / Nm^3 H_2



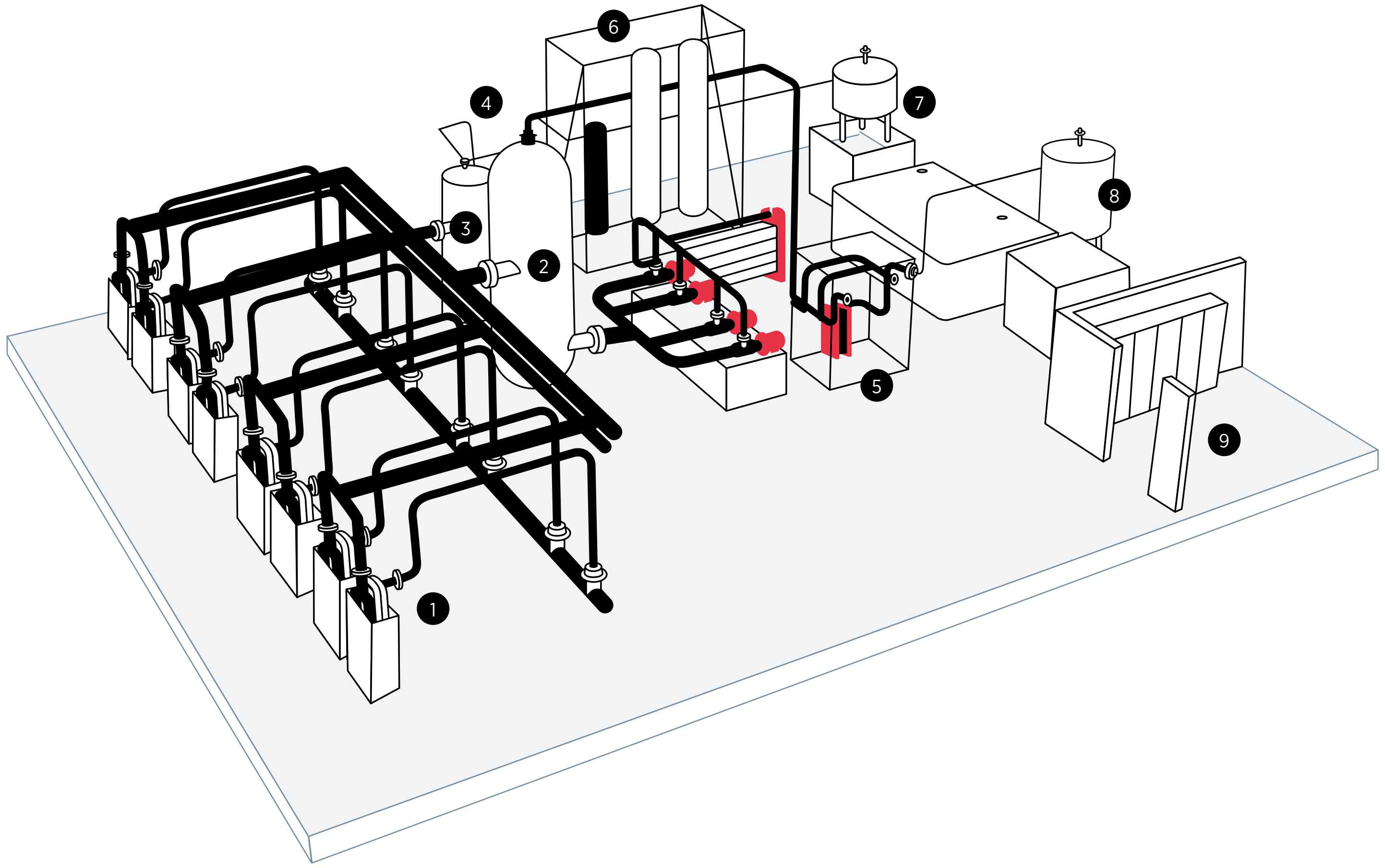
Siemens PEM Electrolyzer; Silyzer 200

Several companies - Siemens, ITM, NEL and Hydrogenics - are developing large-scale electrolyzer systems. Siemens is working on the Silyzer 300, a 10 MWe PEM electrolyzer stack. Hydrogenics is developing integrated large-scale electrolysis systems. The lay out and footprint of a 20 MWe PEM electrolyzer system is shown below. These companies are confident that they can deliver a large-scale 1,000 MWe electrolysis plant for an investment cost of 600 euros per kWe with a lifetime of 15 years.

Hydrogenics

20 MW PEM electrolysis plant lay out and foot print

1. PEM stacks
2. Oxygen gas seperator
3. Hydrogen gas seperator
4. Hydrogen valve assembly
5. Oxygen valve assembly
6. Hydrogen purification system
7. Denim catchment tank H_2
8. Denim catchment tank O_2
9. Control room



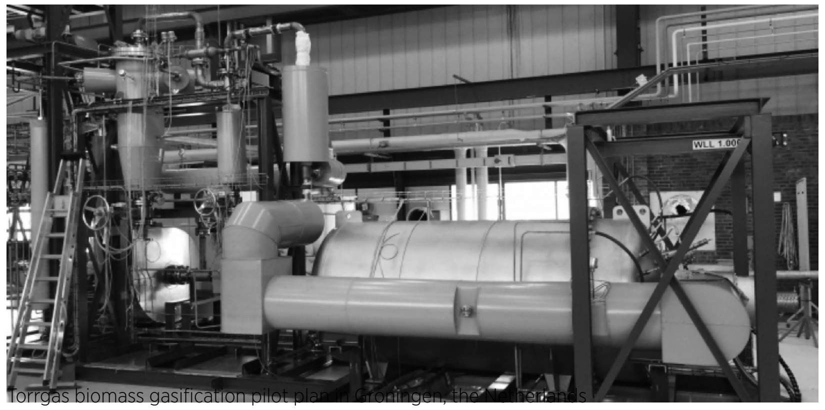
Production: 1,000 MW biomass gasification

Green hydrogen can be produced through electrolysis using green electricity, but it can also be produced from biomass via gasification. Biomass gasifiers use solid biomass as an input and deliver a green syngas - a mixture of hydrogen, carbon monoxide (CO) and carbon dioxide (CO_2) and char - as an output. Together with water (H_2O), the CO could be used to produce additional hydrogen. Therefore, the resulting products from biomass gasification are green hydrogen (H_2) and green CO_2. Every chemical product could be produced from CO_2 and H_2 and, as such, the combination of green hydrogen and CO_2 or green syngas represents an opportunity for a fully green chemical industry in the Northern Netherlands.

Biomass gasification technology is still in a developmental phase. In Groningen, the company Torrgas has developed a biomass gasifier using torrefied biomass as an input. Torrefaction is a process to create a unified biomass product from all kinds of solid biomass residues, such as wood, straw and coconut shells, among others. Torrefaction is the same process as roasting coffee beans: It makes the biomass water resistant and inert, and it breaks the fibers. Gasifying torrefied biomass is a lot easier than gasifying virgin biomass, which means that this process is both technologically and economically promising. Within two to five years, this technology and other gasification technologies are expected to be available on the market.

The idea is to install a 1,000 MW biomass gasification plant next to the electrolysis plant. This will make it possible to use the oxygen which is released at the electrolysis plant in the biomass gasifier, which saves on costs. A 1,000 MW biomass gasification plant consumes 166 tons of torrefied pellets per hour. With over 8,000 hours of full load operation time per year, 1.3 million tons of torrefied biomass pellets will be needed. About 3 to 3.5 million tons of wood or agricultural residues is needed to produce this amount. This yearly output is 300,000 tons of char (with a carbon content of 85 percent), 1.3 million tons of green CO_2 and about 100,000 tons of green hydrogen.

The necessary investment for a torrefaction plant is between 1 and 2.5 million per ton of annual torrefied biomass output, which includes a total investment of 200 to 400 million euros. The investment in a 1,000 MW gasification plant will be between 300 and 600 million euros. The total investment will therefore be between 500 million and 1 billion euros. Char is a valuable product on the market as a soil enhancer, a feedstock for activated carbon or as a replacement for petcoke. The company ESD SIC in Delfzijl could use char to replace low sulfur petcoke (60,000 to 80,000 tons), for example. If char is sold to the world market but the CO_2 is not valued, then the resulting hydrogen price, based on a delivered biomass price of 8 euros per gigajoule (approximately 180 euros per ton), will be around 1.50 to 2.50 euros per kg.

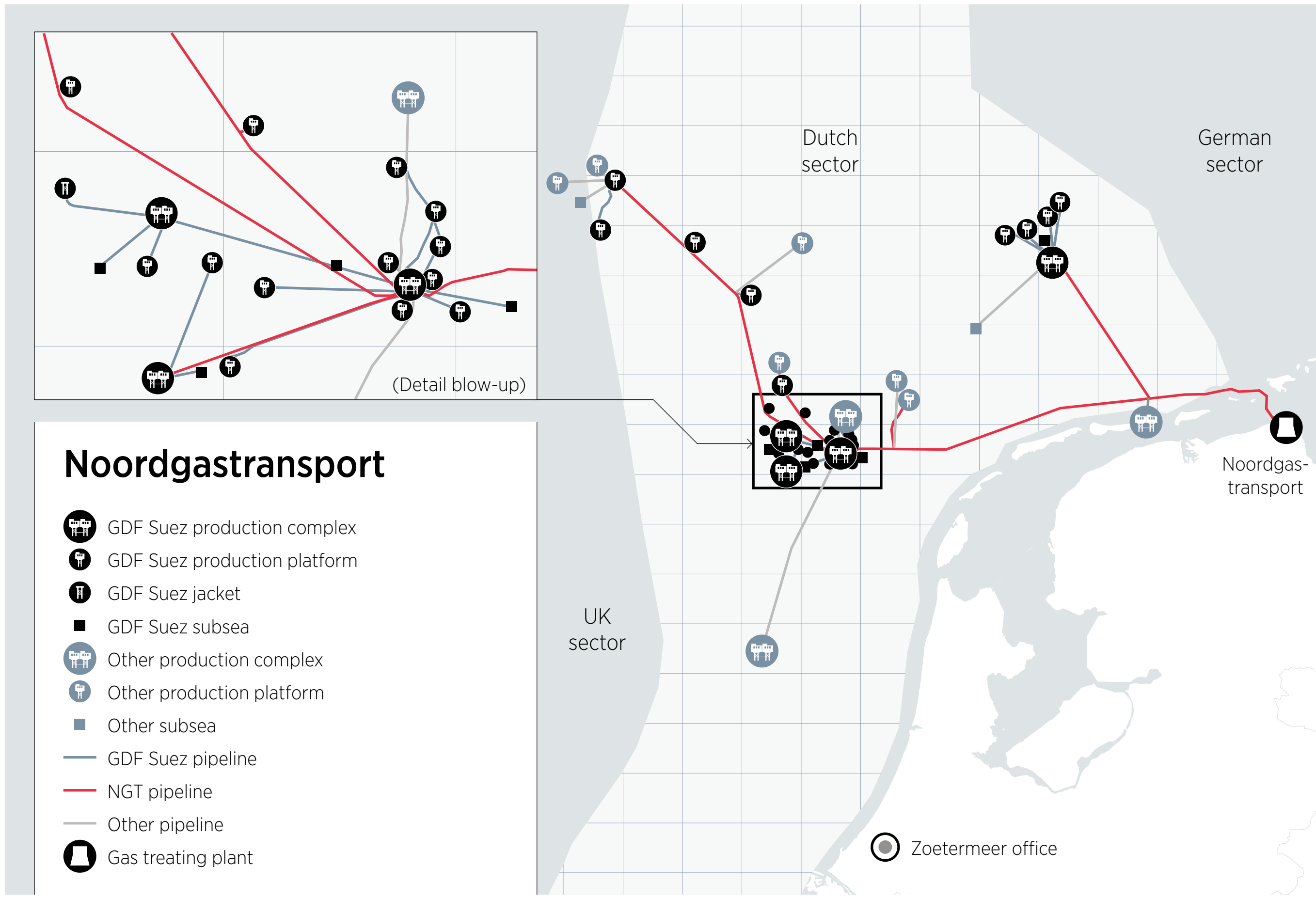

Torrgas biomass gasification pilot plan in Groningen, the Netherlands

Future production: Far offshore wind farm hydrogen production

Offshore wind farms produce electricity can be brought onshore via an electrical cable, which is expensive. The farther offshore the wind farm is, the more expensive the cable. In the North Sea, an alternative solution for these wind farms would be converting the electricity into hydrogen at an existing oil/gas platform and, after mixing it with gas via an existing gas pipeline, transporting it. Once onshore, the hydrogen can be separated from the natural gas and cleaned for transportation via pipeline, ship or truck to the markets. In 2016, the North Sea Energy Challenge initiative was launched to explore the possibilities for far offshore wind to hydrogen production, among other things (see https://www.gasmeetswind.eu/).

Noordgastransport, a subsidiary of Engie, operates a grid of 740 km of offshore gas pipelines in the Dutch portion of the North Sea. The transportation capacity of these pipelines is 42 million Nm3 of natural gas per day. This pipeline comes on land in the Emmapolder, which is near Eemshaven. Engie operates several of these gas fields and offshore platforms.

A detailed feasibility study was conducted in 2016 by the Energy Delta Institute (EDI) and ECN into offshore green hydrogen production on existing platforms using either extant gas infrastructure or new, dedicated hydrogen pipelines for hydrogen transport. The study explores all of the economic aspects related to the energy conversion with the help of electrolyzers, transporting energy to and from the platforms, and externalities including the benefits of postponing platform decommissioning and avoiding power grid investments. Taking all of these economic factors into account, under favorable conditions (specifically with electrolyzer costs of 300 euros per kW and an electricity price of two cents per kWh), by 2025 or 2030, the calculated economic costs of producing green hydrogen - including transporting it to shore - are predicted to range between 2.20 and 2.90 euros per kg, which would be competitive with current fossil-based hydrogen prices (2 to 3 euros per kg). However, if future economic conditions for offshore production and transportation of green hydrogen remain similar to those at present, production costs will range between 3.40 and 4.20 euros per kg.



Production: 100 solar-hydrogen smart areas (cities, villages, islands)

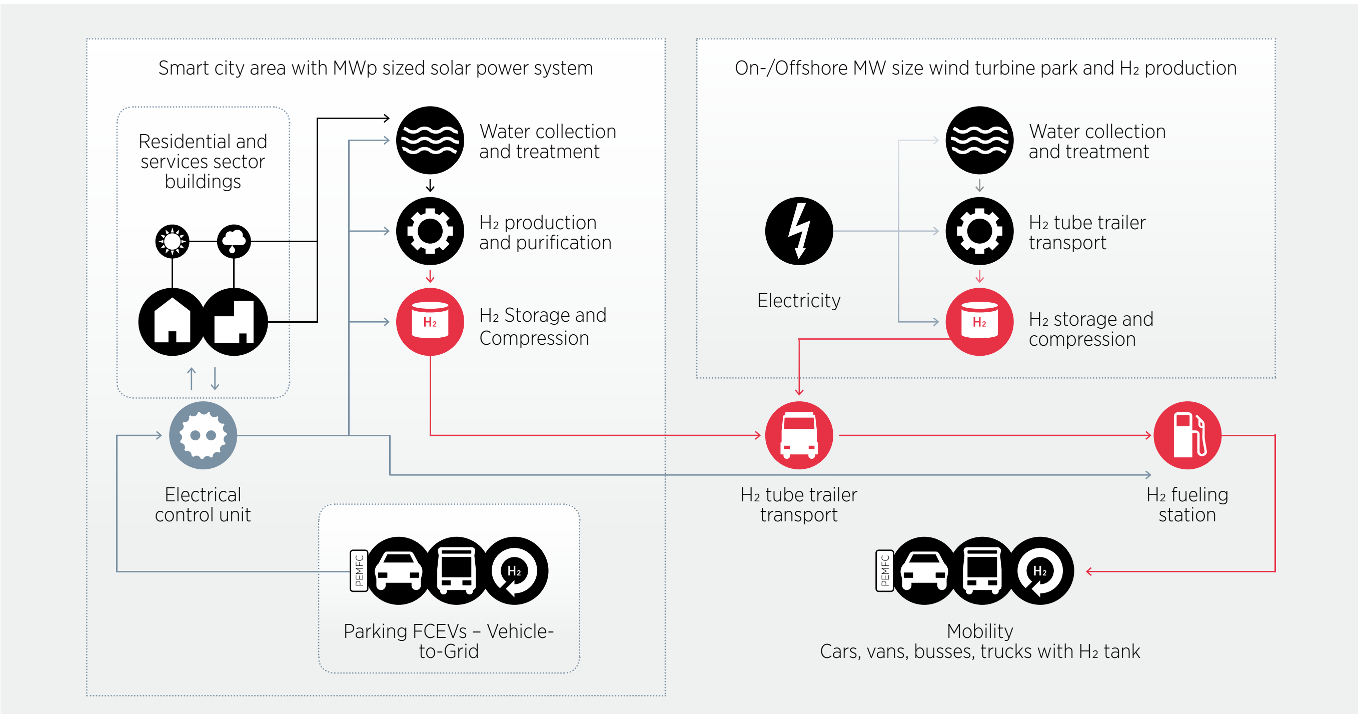
Future smart areas, villages, farms, data centers, islands, industrial sites and everything in between need to become fully sustainable in many ways, including energy provision. Reducing energy demand for heating and cooling, appliances and lighting by generating all of the electricity through solar is one achievable system concept for a zero-energy smart area. However, not every moment is zero energy: In the summer months, more electricity is produced than consumed, and in the winter, more electricity is consumed than produced by solar, to say nothing of energy consumed in transportation.

In a fully sustainable, smart energy system, a balanced electrical system can be achieved with batteries for day/night balancing and hydrogen for seasonal balancing. During the summer, excess electricity can be converted into hydrogen by installing an electrolyzer. In the winter, a fuel cell (either stationary or in a car) could supply electricity by converting hydrogen into electricity. There is a need for extra renewable energy for driving and balancing, and that energy could be supplied to the smart areas as hydrogen produced from wind, biomass, biogas or large-scale solar.

The average city area or village in Europe with a population of 4,500 people contains 2,000 homes, one shopping center, one gas station, schools, offices, 2,300 cars and several buses and trucks. In such an area, about 20 MWp of solar can be installed on roofs. A 5 MW electrolyzer is needed to convert the excess electricity into hydrogen. The investments in solar and electrolyzer capacity, hydrogen compression and storage is estimated to be 25 million euros for each smart area.

The installed electrolyzers convert the excess solar electricity into hydrogen, and hydrogen-fueled fuel cells can produce enough energy to compensate for the deficit in the winter, therefore saving on electrical grid capacity expansion. As such, once electrolyzers and fuel cells are installed, electricity distribution companies can avoid having to make additional investments into grid capacity expansion. Studies still need to be conducted into whether these distribution companies can offer a financial incentive for local energy cooperatives or companies to avoid grid capacity expansion, for example by installing electrolyzers and fuel cells in these smart areas with high solar energy penetration. Such an incentive will certainly stimulate local hydrogen production.

Local energy cooperatives or local energy companies can realize and operate fully renewable energy systems for heating and cooling, electricity and transport. They can produce, distribute, sell and buy electricity in the smart area, as well as use it for transportation and balancing the electricity system. In other words, the smart area community is fully in control of its own sustainable energy system.



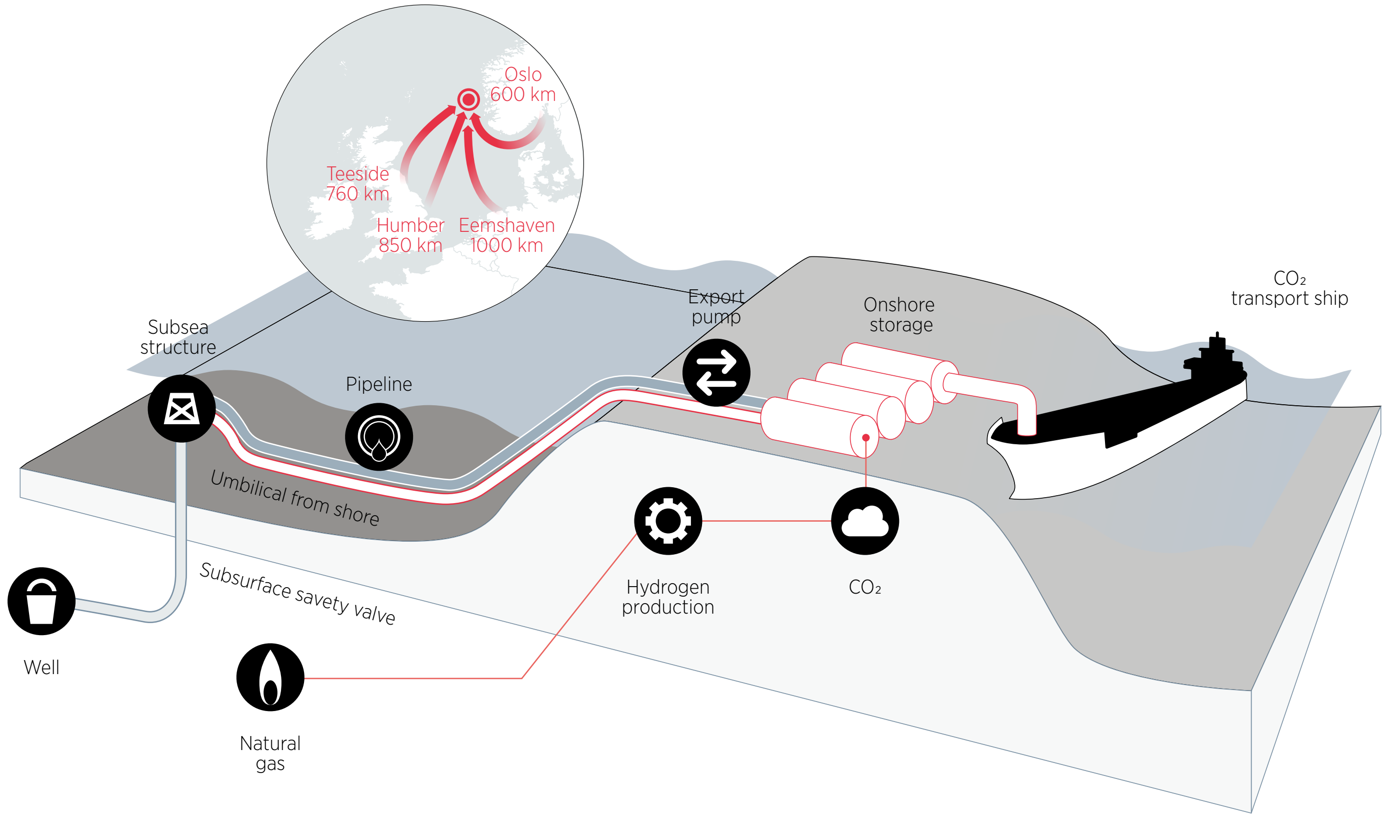
Production: Hydrogen from natural gas with CCS in Norway

Presently, hydrogen is mostly produced from methane through Steam Methane Reforming (SMR). This hydrogen is widely used in the chemical and petro-chemical industries, but it is neither carbon-free nor green hydrogen, because the resulting CO_2 is emitted either directly or indirectly into the air. One way to produce low-carbon hydrogen from methane is to capture and store the CO_2 in an offshore receptacle, for instance an empty oil or gas field. The natural gas production from the Slochteren field cannot be used to this end because production must be reduced and storing carbon dioxide somewhere underground in the Netherlands is not a viable option. This is why producing carbon-free hydrogen from natural gas and storing the CO_2 underground was not initially considered as a possibility.

However, Statoil has recently approached us with the following option. Statoil is exploring the potential to deliver low carbon fuels. In their view, this starts by developing a CO_2 value chain which is planned for capturing CO_2 from industrial sites in Norway (cement and ammonia) and transporting it by ship to an onshore terminal located on the west coast of Norway. Once there, CO_2 will be injected into an offshore receptacle for permanent storage. Statoil is planning to utilize this infrastructure to deposit the CO_2 byproduct resulting from hydrogen produced from reforming of natural gas. Statoil has been operating facilities to store CO_2 in empty reservoirs under the sea at the Sleipner and Snøhvit gas fields for 20 years already. The offshore area where they plan to store CO_2 is the Smeaheia field, which is about 1,000 km from the Netherlands.

Statoil, Nuon and Gasunie have joined forces and are evaluating the conversion of Nuon's 1,320 MW Magnum plant to run on hydrogen. As part of this project, Statoil is exploring the realization of a hydrogen production plant (Auto-Thermal Reformer) either in the Eemshaven or at a location in Norway which will convert methane into hydrogen and CO_2. If this plant were to be built in the Eemshaven, the natural gas from Norway would be transported via pipeline to the Eemshaven. The CO_2 will be liquefied in the Eemshaven and transported via ship to the planned CCS (carbon capture and storage) hub in Norway. If the hydrogen plant is built in Norway, then there are two options: either an existing gas pipeline could be converted to hydrogen, or a dedicated hydrogen pipeline could be built connecting to Eemshaven.

Low-carbon hydrogen can be produced in large quantities. Together with electrolysis and biomass gasification, it could kick-start the realization of dedicated hydrogen pipeline infrastructure in a first phase up to 2030.



Markets: 300,000 tons of green methanol and 300,000 tons of green ammonia

Hydrogen (H_2) and carbon dioxide (CO_2) can be used in chemical processes to produce a wide variety of chemical products. Two of the main building blocks in chemistry are methanol and ammonia. Methanol can be produced from H_2 and CO_2. Ammonia is produced from H_2 and nitrogen (N_2) captured from the air.

Methanol is primarily used to produce other chemicals, such as formaldehyde for plastics and paints, DME, olefins (ethylene, propylene) and acetic acid, among others. There is already a methanol production plant at the chemical industry site in Delfzijl. In the past, natural gas was used to produce methanol, but today, there is a bio-methanol production plant: BioMCN, which is owned by OCI. Green methanol production could be easily expanded on this chemical site, and there is already an existing chemical industry situated in the Northern Netherlands that uses methanol as a feedstock (e.g. ChemCom, AkzoNobel). But methanol is also a fuel that can be used in gasoline combustion engines – either directly or blended – and because it is a liquid, it can be easily shipped worldwide.

Ammonia is primarily used to produce fertilizers, but it is also used in a variety of other pharmaceutical and chemical products. At Delamine in Delfzijl, ammonia is used to produce ethylene amines. At present, the ammonia is imported by train, but it can be produced from green hydrogen and nitrogen on site. The other product necessary for producing ethylene amines is ethylene dichloride, which is also imported. But this product could be produced through an entirely green process on the Delfzijl site based on green hydrogen and carbon dioxide.

It could also be based on ethanol, which could be produced from sugar beets. Sugar beets are one of the agricultural products produced on a large scale in the Northern Netherlands by Cosun. The applications of ethylene and polyethylene are numerous, including use by companies on the Emmtec industrial site in Emmen.

Nuon-Vattenfall is also studying the import of carbon-free ammonia, cracking it in hydrogen and nitrogen and using that hydrogen in the Magnum power plant in the Eemshaven to produce electricity. Because ammonia is a liquid with a high energy density, it is ideal for large-scale energy storage and could also easily be transported overseas, effectively facilitating imports of large volumes of renewable energy.

Based on competitive green hydrogen prices and cheap carbon dioxide, it is realistic to expect green methanol production expansion of 300,000 tons. This amount consumes about 60,000 tons of hydrogen and 360,000 tons of carbon dioxide. A green ammonia plant with a capacity of 300,000 tons can also be realized in the Northern Netherlands by using an additional 60,000 tons of green hydrogen. Both a 300,000 ton capacity methanol plant and a 300,000 ton capacity ammonia plant would require an investment of 50 to 60 million euros. Methanol and ammonia production will generate follow-up investments in plants that use methanol or ammonia as a feedstock. Assuming an investment multiplication factor of four, a total methanol and ammonia production-related and spin-off investment between 500 and 600 million euros can be expected.

Chemical site, Delfzijl, the Netherlands

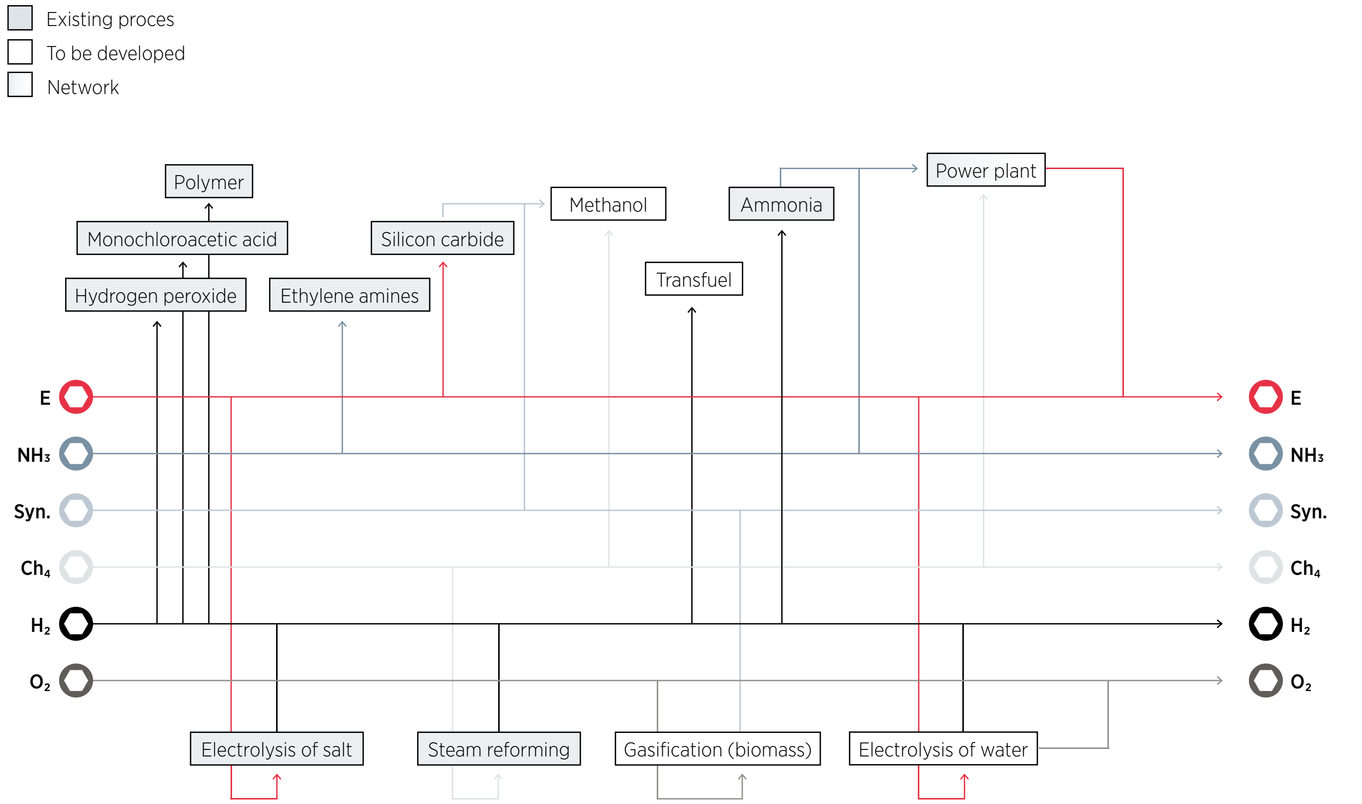
Markets: Delfzijl chemical industrial site

At the chemical site in Delfzijl, AkzoNobel already produces about 3,000 tons of hydrogen per year as a by-product of the chlorine industry. The hydrogen is already used as a feedstock in several processes and as a fuel to produce high-temperature steam. A hydrogen fueling station for buses should be operational by the end of 2017 near the site. The local use of hydrogen as a feedstock and a fuel for transportation in existing and new processes is a good starting point for the development of a hydrogen economy.

To facilitate the use of hydrogen at the Delfzijl chemical and industrial site, Groningen Seaports and other industrial partners should develop a hydrogen pipeline network. This pipeline could connect current producers and users of hydrogen to create more value, backup production and new business opportunities for the industry. A schematic overview of the use and production of these industrial gasses and electricity network, both existing and under development, is shown below.

Green hydrogen, oxygen and syngas will be produced in large quantities at competitive prices on the Eemshaven site, which is about 25 km from the Delfzijl site. A to-be-built pipeline street with multiple pipelines between the Eemshaven and Delfzijl will transport green hydrogen, syngas and oxygen from the Eemshaven to Delfzijl, creating even more opportunities to produce all kinds of green chemical products at competitive prices. Delfzijl will develop into an important green chemical site and green hydrogen hub.

One such opportunity is the production of green ammonia in Delfzijl. Ammonia is already used there to produce ammine, but it is currently imported by train. Another opportunity would be the production of green methanol from green hydrogen and green syngas. Currently, BioMCN produces green methanol from biogas, but they could expand production considerably. Another interesting possibility would be the storage of hydrogen in salt caverns.



Schematic overview of the use and production of industrial gasses and electricity network

Markets: Emmtec chemical industrial site

The Emmtec Industry and Business Park is the preeminent polymer competence network in the Netherlands, housing renowned companies like Teijin, DSM and Bonar. Emmtec utilities delivers electricity and steam produced from natural gas to the companies on this site, among others. High-temperature and high-pressure industrial steam is required for the continuous production processes in the chemical and food processing industry on the Emmtec site. A steam distribution network is already present, as well as a district heating network which is fed with waste heat from industrial companies and steam from the Emmtec utilities network. The gas turbines that produce the high temperature steam and electricity could be fed by green hydrogen as well. Once hydrogen can be supplied via pipelines for competitive prices, taking into account the green character of this hydrogen, Emmtec will be at the forefront of making use of this green hydrogen for green high temperature steam and electricity production, as well as supplying green heat to the local district heating network. Under those conditions, the waste heat from the companies is also green waste heat.

Near the Emmtec site, across the German border, there are many wind farms already up and running, and several large-scale solar farms are being developed. A demineralized water plant owned by NAM is also operational in the area. This provides an opportunity to produce green hydrogen via electrolysis by using the demi water and local green electricity on the Emmtec site.

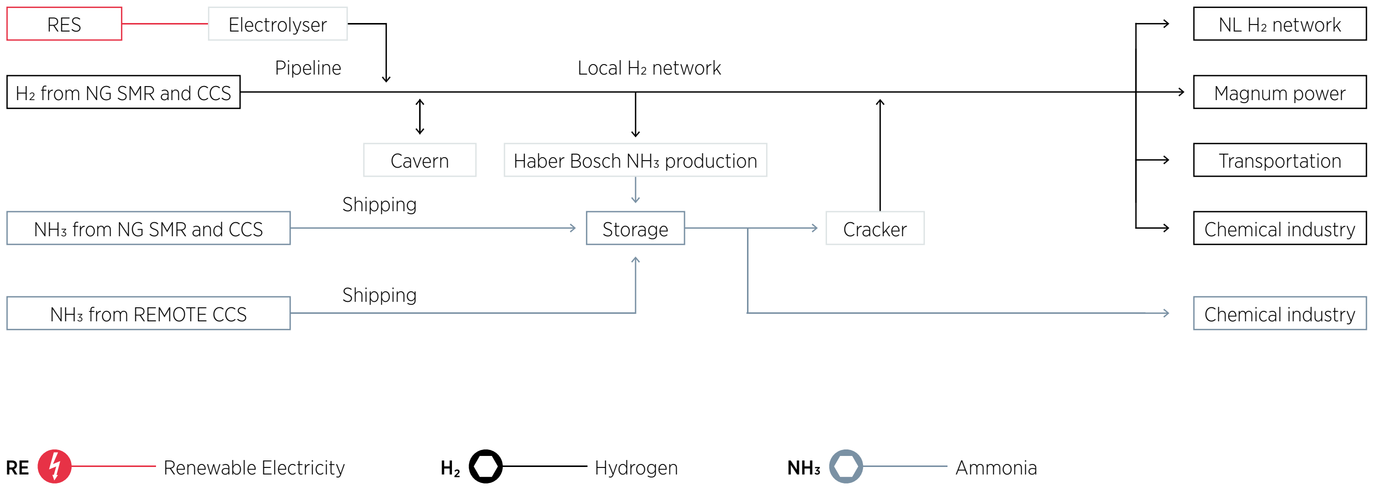
Once a hydrogen pipeline to the Emmtec site is present, it will be a good location for hydrogen distribution and local green hydrogen production. At a hydrogen distribution station, the hydrogen will be compressed and put into hydrogen tubes. These hydrogen tubes will be placed in a container rack which can subsequently be placed on a truck. Such a container truck can supply hydrogen fueling stations, harbor hydrogen fueling stations and other hydrogen distribution points. A large hydrogen fueling station could also be built on the Emmtec site to provide hydrogen to buses, trucks, vans and cars.

The Emmtec Industry and Business Park is well positioned to enable the development of a green hydrogen system. Green hydrogen could be used in several production locations as a green feedstock, albeit in small quantities. The main applications for green hydrogen on this site are green high-temperature steam, green heat for local heating, distribution of green hydrogen and hydrogen fueling. The site offers several opportunities to facilitate the development of green hydrogen, such as an engineering and innovation center and a pilot site to test the application of hydrogen as a feedstock, for steam and for heat production.

Emmtec Industry and Business Park Emmen, the Netherlands

Markets: Nuon Magnum power plant fueled by green ammonia-hydrogen

Nuon wants to convert the new Magnum Combined-Cycle Gas Turbine power plant (3 CCGT units of about 440 MWe each) to use CO_2-neutral fuel in the form of ammonia (NH_3) or H_2 switching from natural gas in the Eemshaven. The CO_2-neutral fuel will be produced from renewable or largely CO_2-neutral sources (see figure below).



The CO_2-free fuel can be produced from (remote) renewable electricity sources such as wind, solar, geothermal or hydro power using electrolysis, or from natural gas in combination with offshore CCS (carbon capture and storage). The produced hydrogen (H_2) can subsequently be converted with nitrogen (N_2) from cryogenic air separation into NH_3. This process will enable transportation and storage of the energy by ship over long distances. The NH_3 will be transported to the Eemshaven and stored for use in the power plant.

Before combusting the fuel in the gas turbine, NH_3 will be cracked into H_2 and N_2. The hydrogen will be fueled into the gas turbines. This ammonia cracking provides opportunities to deliver H_2 to other H_2 consumers via the hydrogen pipelines during periods when Magnum is not operating at full capacity. One benefit of this is that the cracker can operate continuously, which has a positive impact on the ability to operate the Magnum power plant flexibly.

Using CO_2-neutral fuel, the Magnum power plant will produce flexible and dispatchable (a source which can be turned on or off) CO_2-free electricity. With increasing amounts of variable renewable electricity fed into the electrical grid, the need for energy storage, and the ability to deliver electricity when there is insufficient supply from renewable electricity sources, increase in tandem. By means of NH_3 and H_2, excess electricity can be stored and re-converted back into electricity when necessary, which will transform Magnum into a super battery (https://www.nuon.com/nieuws/nieuws/2016/nuon-en-tu-delft-onderzoeken-opslag-windenergie-in-nieuwe-superbatterij/).

Once sufficient volumes of H_2 are being produced in the Eemshaven, be it by electrolysis or biomass gasification or from being imported by an offshore hydrogen pipeline or ship in the future, the Magnum power plant could use this green H_2 to directly fuel the power plant. Excess hydrogen could be stored either by converting it into ammonia or storing it in its current form in salt caverns.

Nuon's plan is to begin firing CO_2-neutral fuel at Magnum in 2023. By 2026, one of the three CCGTs should be operating exclusively on CO_2-neutral fuel. After that, the other two CCGTs will be converted. When they are operating at baseload, one CCGT will consume approximately 1.3 million tons of NH_3 (cracked to about 200,000 tons of H_2) on an annual basis, producing 3.6 TWh of electricity (3 percent of the demand in the Netherlands) with direct annual CO_2 savings of 1.3 million tons.

Markets: 100 hydrogen fueling stations in the Northern Netherlands

Refueling vehicles in the Northern Netherlands will require the installation of hydrogen fueling stations (HRS). These fueling stations will be able to fuel passenger cars, light and heavy duty commercial vehicles with pressurized hydrogen at 700 bar and, in some cases, buses at 350 bar. Buses will continue to be primarily fueled at the bus depot, so there should be dedicated hydrogen fueling stations at the depots.

In the short term, fueling stations will mostly be supplied with hydrogen by truck. In some cases, local hydrogen production will be present near the hydrogen fueling station. It is assumed that in 10 percent of cases, there will be local production by means of electrolysis through green power. In the future, fueling stations may be connected to a hydrogen pipeline (similar to Rhoon/Rotterdam). From a cost perspective, this is the most attractive supply method; however, from a (financial) planning perspective, this will be an exception in the early years of infrastructure development. Once demand matures and the hydrogen grid becomes denser, this supply method may begin to offer more opportunities.

The Netherlands currently has around 4,000 regular fueling stations, but this number is expected to eventually decline toward closer to 3,000 (http://www.tankpro.nl/specials/2014/09/17/aantal-tankstations-in-nederland-licht-gedaald/). Users consider 10 percent of all public stations offering hydrogen to be a reasonable amount of station coverage, according to a study conducted by THRIVE (https://www.ecn.nl/docs/library/report/2011/e11005.pdf). The Northern Netherlands will need at least 100 hydrogen fueling stations to ensure that there is a station either within 20 minutes driving distance or every 30 km (maximum).

Hydrogen dispensers will be integrated into existing or recently built fueling stations featuring other fuels, electric charging, shops and carwashes, among others. In principle, hydrogen can be integrated into existing sites and business models. The minimum hydrogen supply is about 200 kg per day (40 to 60 cars), but should grow to about 1,000 kg per day (200 to 300 cars). Hydrogen fueling stations need to be SAE 2601 and PGS-35 compliant.

Hydrogen fueling stations (HRS) investment costs

Type	Capex (x M€)	Number of HRS	Investment (x M€)
HRS; hydrogen supplied by truck	1.5-2	90	135-180
HRS; local hydrogen production by electrolysis	3-5	10	30-50
Total investment			165-230

A Toyota Mirai, a hydrogen fuel cell vehicle, at a hydrogen fueling station

How to get started with hydrogen fueling stations

During the initial phases of establishing a hydrogen fueling network, building large-scale stations throughout the region with a low degree of market saturation of hydrogen fuel cell cars is not economical. At the same time, car owners do not want to drive too far to refuel. In order to break free of this chicken and egg situation, we should envision a concept with medium-scale HRS containers. These containerized units can quickly enlarge the network filling points at a fraction of the cost. Once a local area (Emmen, Sneek, Veendam, etc.) has enough cars, buses and trucks to justify a large-scale station, the medium container unit can be moved to another location and, in this way, extend the network. Once the entire network has been developed, the medium scale units can be moved to a final destination elsewhere. In this way, initial Capex (capital expenditures) is limited and start-up of the hydrogen fueling network is faster. The medium scale containers are developed locally by Resato (Assen) and will be installed and operated by Holthausen (Hoogezand).

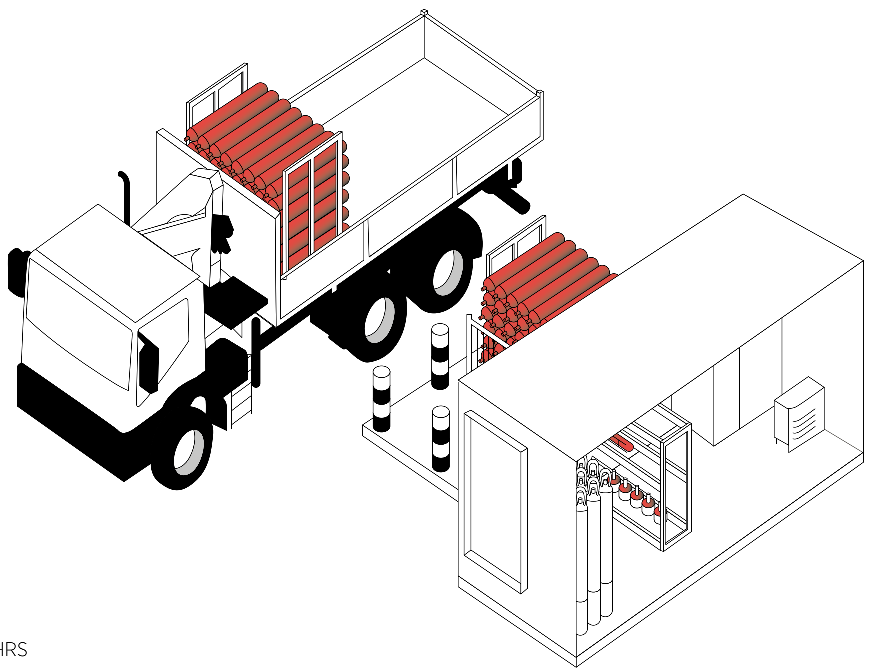
Holthausen presented their initiatives for the realization of a green hydrogen economy in January 2017. Holthausen wants to help create hydrogen fueling stations, a showcase hydrogen fueling station in Groningen and several other hydrogen fueling stations at existing fueling stations. In addition to the realization of hydrogen fueling stations, Holthausen also has the knowledge and expertise to retrofit existing electric or hybrid vehicles into fuel cell electric vehicles (FCEV).

Furthermore, Resato has developed a small-scale fleet owner version at a fraction of the cost compared to a large scale HRS. This will enable smaller fleet owners to get started quickly. Filling the units at a slow rate eliminates the requirements for deep cooling and high power compression, thus lowering the total investment costs. With this technology, (small) fleet owners can start providing the necessary showcases today in the early development phases of the green hydrogen economy in the Northern Netherlands.

There are several initiatives to help create hydrogen fueling stations in the Northern Netherlands. A new hydrogen fueling station will be established in Delfzijl next to the Delfzijl chemical site. PitPoint will create this hydrogen fueling station using the relatively cheap hydrogen produced as a by-product from the chlorine production at AKZO. The fueling station must be operational at the end of 2017, initially fueling 2 hydrogen fuel cell public buses.

Other fueling station owners in the Northern Netherlands have shown interest in helping to realize hydrogen fueling stations at their existing fueling stations, such as GreenPlanet (Pesse) and AVIA (throughout the Northern Netherlands)

All of these initiatives from local companies are proof of the interest in green hydrogen as a transportation fuel. This development could provide a positive stimulus for the Northern Netherlands economy and employment.



Medium scale HRS

Markets: 5 green hydrogen fuel cell balanced data centers

Google has built a very large data center in the Eemshaven (see picture below). The reasons for Google to choose the Eemshaven are the existence of an offshore data cable, sufficient space and green electricity. Google and other companies that build and operate data centers want them to run on green electricity. That is why Google has signed a power purchase agreement with Eneco to buy green electricity for 10 years, and in turn, that is why Eneco is building an onshore wind farm nearby. Annually, this wind farm will produce enough electricity on average to meet the data center's demands. However, supply and demand are not always in balance. At moments that there is no wind, other power plants must provide for the electricity supply.

Currently, these power plants are fossil-fired. In the future, these power plants will be closed, and supply and demand must be balanced by other means – and those means need to be renewable electricity sources. This can be achieved with fuel cells, gas turbines or flexible, combined-cycle power plants fueled with green hydrogen. Fuel cells can follow supply and demand variations very quickly and efficiently. Fuel cells are quiet and have no emissions, except for very clean (demineralized) water.

These fuel cells could be placed at data centers for balancing, but they could also be used for the electrical grid. Assuming the opening of five data centers in the Northern Netherlands, 500 MWe of fuel cell systems would need to be set up for grid balancing. With investment costs of between 400,000 and 800,000 euros per MW, this implies a total investment of 200 to 400 million euros.

Emmtec Industry and Business Park Emmen, the Netherlands

Markets: Hydrogen innovation/ startup centers

Innovation in technology, systems and products will be crucial to the development of the green hydrogen economy. New and better conversion, storage, transportation and distribution technologies will be necessary for green hydrogen. The application of green hydrogen in chemical processes, materials, products, and mobility by land, water and air, must be developed further. New products and systems such as drones, robots, wireless appliances, electrical grid balancing and remote electricity production must also evolve. All kinds of related technologies and systems - sensor technology, demi-water production technology, safety control, fueling systems, compression technology, smart IT systems, smart city/village design, Internet of Things - must also progress. Innovation is not only technological: business models, safety procedures, social acceptance, regulatory framework and procedures and institutional organization are equally important, and will also have to keep up with all of these other fronts of development.

There is already a well-established infrastructure for research, education, innovation and startups in the Northern Netherlands, which will enable the region to play a leading role in the crucial innovations for the green hydrogen economy. There is strong knowledge and education infrastructure in the Northern Netherlands in the field of natural gas, and this can easily be extended to hydrogen. The academic institutions in the region include Energy Academy Europe, the University of Groningen, several universities of applied sciences (Van Hall Larenstein in Leeuwarden and the Hanze University of Applied Sciences in Groningen) and secondary education centers. Energy Academy Europe and three research and innovation centers could play a crucial role in green hydrogen innovation, startup and new business development in particular:

- EnTranCe (http://en-tran-ce.org/) in Groningen is the hotspot for the applied sciences for businesses and innovations in energy. Innovation in green hydrogen production, conversion, storage, transportation and distribution can and will be one of EnTranCe's strongest contributions.
- Wetsus (https://www.wetsus.nl/) in Leeuwarden is a European center of excellence for sustainable water technology. Pure water production by reverse osmosis with membranes is crucial for electrolysis of water to hydrogen. Membrane technology in particular is crucial, not only in reverse osmosis but also in electrolysis, fuel cells, hydrogen gas cleaning and gas compression. Wetsus could take the lead in membrane technology application.
- Senbis Polymer Innovations (http://senbis.com/en) in Emmen is a leading institution and facilitator for the chemical industry to develop new and bio-based chemical products, as well as biomass syngas and bio-based chemicals. Senbis, together with the Emmtec pilot plant facilities, can contribute to developing new and better chemical processes and applications for green hydrogen.

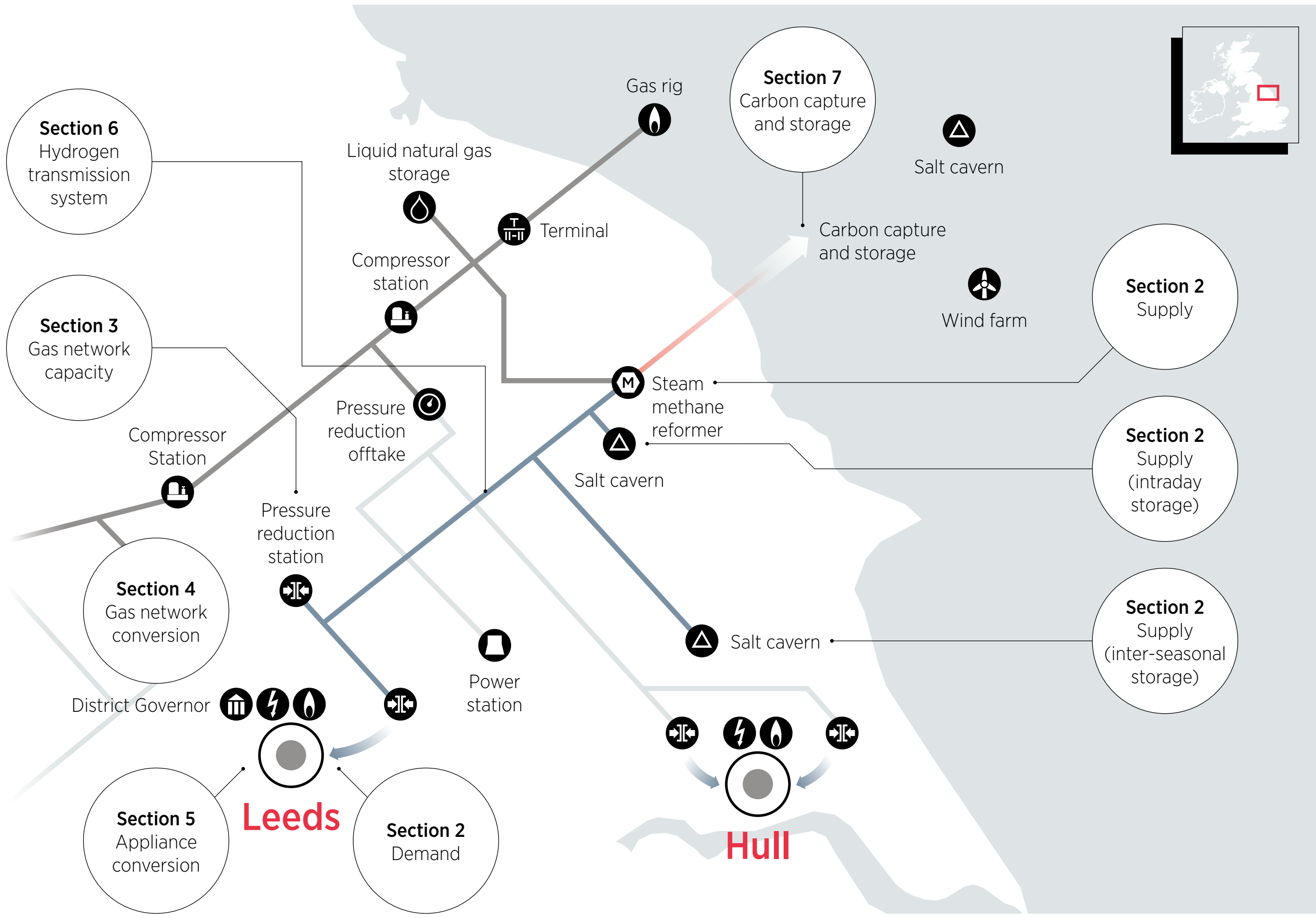
In addition to these institutions, there are many developments and innovative industries that could integrate green hydrogen into their products, systems or activities, such as:

- Groningen Airport Eelde, which will be redeveloped into a drone airport: Drone Hub GAE. Hydrogen with fuel cell technology will be crucial for longer drone flights.
- A maritime industry cluster (http://www.maritiemclusterfriesland.nl) in Friesland, which can integrate fuel cell and hydrogen technology for propulsion in the maritime sector, sailing, yachts, ferries, ships, etc.
- A manufacturing industry cluster - High-Tech Systems and Materials - that can manufacture sensors, products and materials for the hydrogen industry, as well as use fuel cells and hydrogen technology in products such as buses, drones, robots and planes.

Markets: 10 villages heated by green hydrogen

Homes and buildings need to become zero emission structures in the coming decades. Energy demand needs to be considerably reduced for heating and cooling through insulating floors, roofs and walls and by double or triple glazing windows. But it is very expensive, and it is more difficult to bring the energy demand for heating down to zero in buildings and homes which are already standing. As such, there is a need for additional green energy sources that can be supplied to the built environment. In city areas with a higher density of homes and buildings, a heat grid could supply this additional heat. In other areas, homes could be well insulated, and a low-temperature heating system with an electric heat pump - together with heat and cold storage in the ground - could solve the problem. But in small villages and older sections of cities, it is very difficult and expensive to install a heat grid or heat pumps with their own wells in the ground. But the natural gas grid is available in these areas; therefore, it is worth examining whether green hydrogen or biogas could be delivered to homes and buildings in these areas through retrofitting the existing gas infrastructure. If green hydrogen is supplied via such a retrofitted gas pipeline to homes, the burners in the boiler and stove will have to be changed, which is a relatively easy and cheap procedure. A similar change was made in the 1960s when the system shifted from town gas, which was more than 50 percent hydrogen, to natural gas.

In the UK, Northern Gas Networks has conducted an extensive study into converting the gas distribution network in the city of Leeds (500,000 inhabitants) from natural gas to hydrogen, called the Leeds City Gate 21 project. They have looked into many aspects of how such a conversion could be realized, with little impact economically and socially on the people involved (see their full report here: http://www.northerngasnetworks.co.uk/wp-content/uploads/2016/07/H21-Report-Interactive-PDF-July-2016.pdf).



The conclusions have been summarized as follows:

- The gas network has the correct capacity for conversion to 100 percent hydrogen.
- The network can be converted incrementally with minimal disruption to customers.
- A conversion could be undertaken with minimal impact on gas customers' bills.
- Minimal new energy infrastructure will be required when compared to alternatives.
- The existing heat energy demand can be provided by hydrogen generated via steam methane reforming.
- Inter-seasonal energy storage can be managed by using salt cavern storage.
- All of the technology in the proposal already exists.

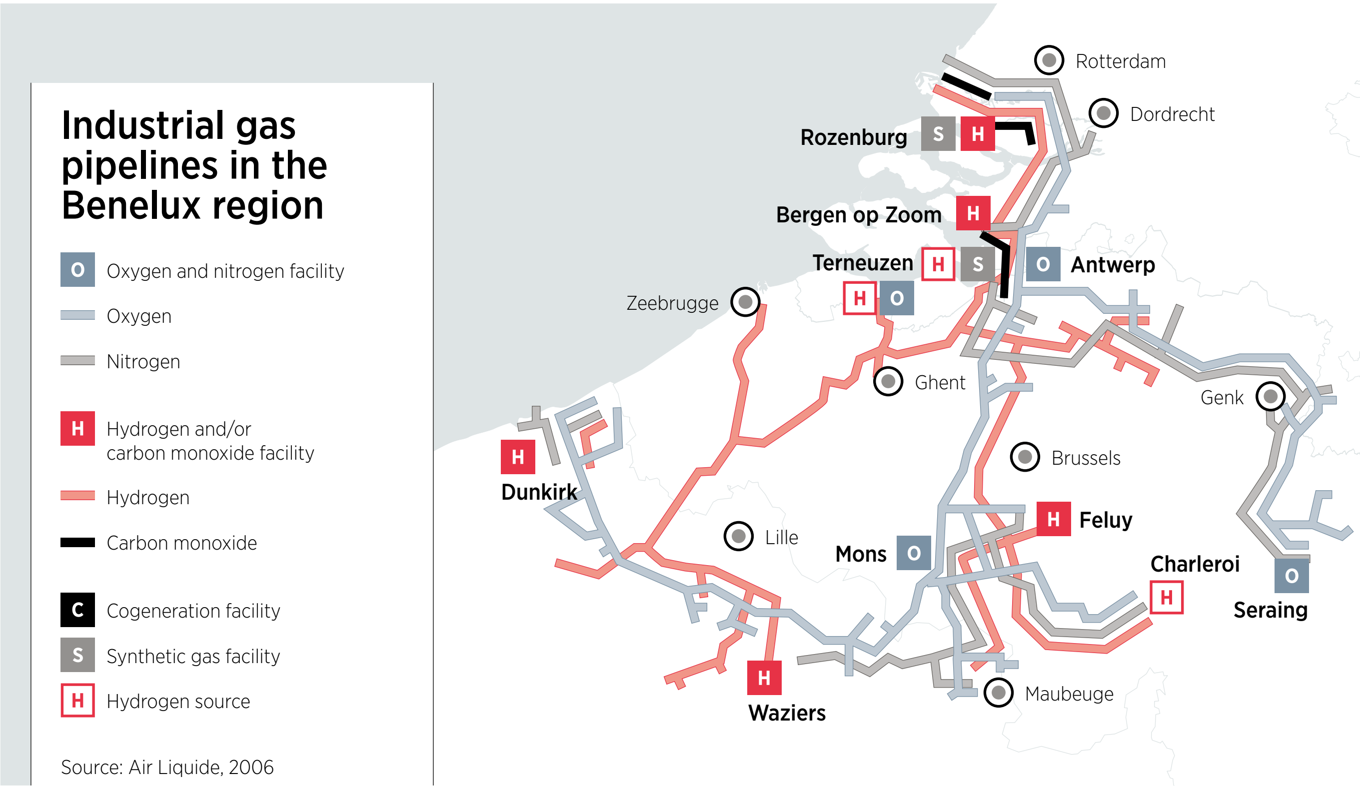
On the island of Ameland, important projects have already been realized toward making Ameland energy self-sufficient by 2020. Since 2007, the municipality of Ameland has been working together with Eneco, GasTerra, NAM, Philips, EnTranCe, TNO and Alliander to implement new energy innovations and projects on the island. Energy-saving projects, LED lighting for a large solar farm, hybrid heat pumps and solar panels on roofs have already been achieved. An electrolyzer has also been installed that converts excess electricity into hydrogen. This hydrogen has been fed into the gas grid. This experiment has shown that a mix with up to 20 percent hydrogen can be fed into the gas distribution grid without posing any problems. The idea is to install 45 high temperature SOFC (Solid Oxide Fuel Cells) that can generate electricity at moments that there is not enough solar electricity or heat. It is worth studying the options on this island for converting the gas grid fully to green hydrogen for heating, hot water and cooking in homes and buildings. Green hydrogen could be supplied to the island via the gas pipeline from Harlingen.

Converting from natural gas to green hydrogen could also occur in other villages and rural areas. Emmen and its rural areas have already shown interest in such a transition, and there are many areas in the Northern Netherlands that would be potentially interesting to study for converting to green hydrogen.

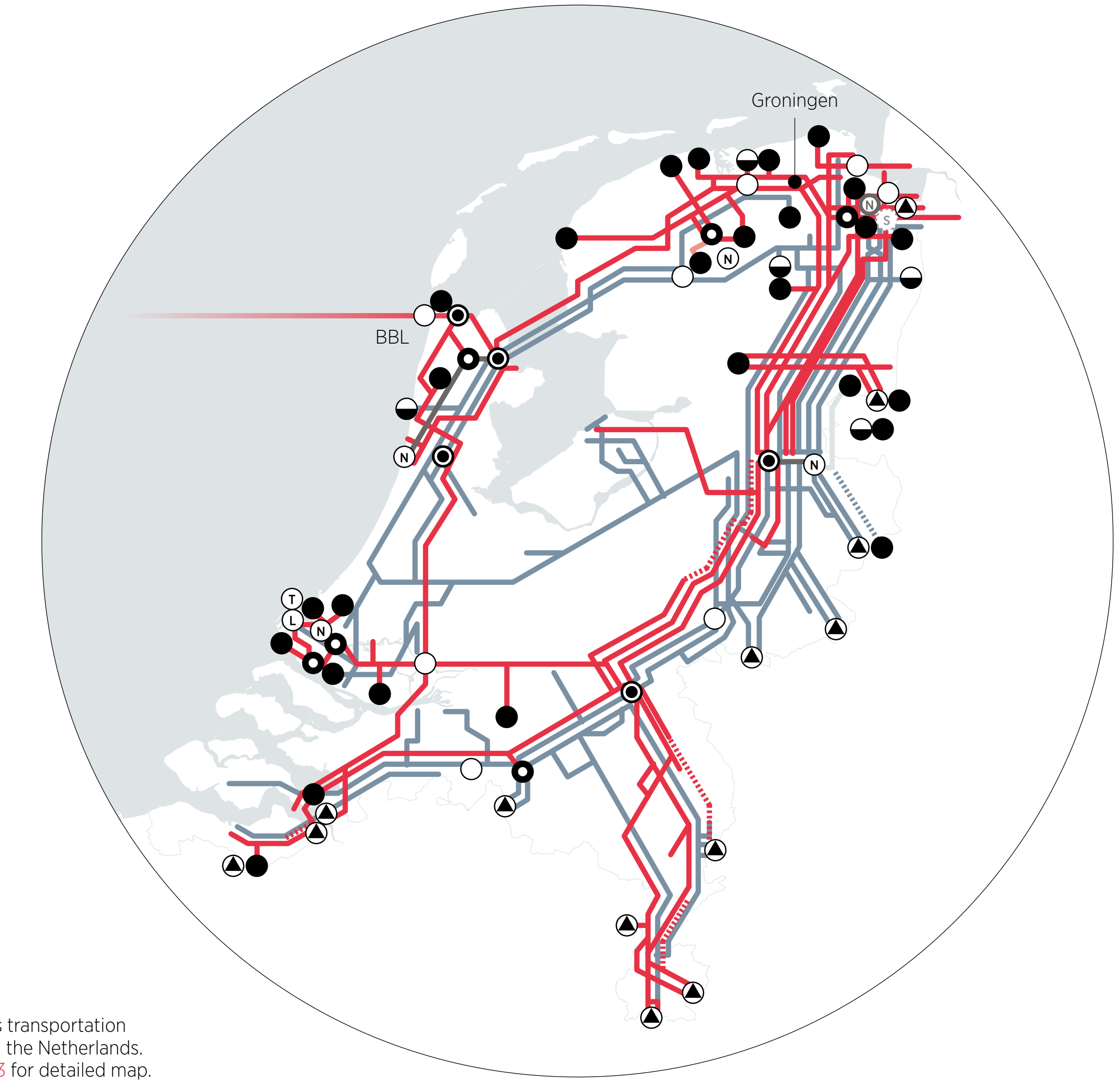
Ameland solar farm

Infrastructure: Hydrogen pipeline to Rotterdam, Limburg and Germany

The market for hydrogen is not limited to the Northern Netherlands. In Rotterdam, large volumes of hydrogen are consumed by the chemical and petrochemical industries. Hydrogen pipeline infrastructure already exists, connecting the Rotterdam area to Antwerp and other parts of Belgium to Terneuzen in the Netherlands and the northern part of France (operated by Air Liquide). In the Ruhr area and near Bremen and Hamburg in Germany, the chemical industry also uses large volumes of hydrogen.



A hydrogen pipeline is a cost-effective solution for transporting large quantities of hydrogen over longer distances by land. A hydrogen pipeline at 120 bar, with an input pressure of 35 bar, will cost between 0.04 and 0.16 cents per 100km for each kilogram of H_2. For a very large hydrogen pipeline with a maximum capacity of 1.5 million tons of hydrogen per year from the Eemshaven to Rotterdam (275 km), the projected investment cost is between 300 and 400 million euros (not including the costs of compression, which would be between 50 and 100 million euros). A similar amount needs to be invested for the pipelines to Germany. In total, these new pipelines will cost about 1 billion euros.



Natural gas transportation pipelines in the Netherlands. See page 13 for detailed map.

Another more practical, cheaper and faster option would be to use one of the existing gas transportation pipelines and adapt it for hydrogen use. This could be done either by refurbishing the existing natural gas pipelines or by putting a new hydrogen pipeline into the existing gas pipeline, the costs of which would be at least a factor of 10 less expensive than for new pipelines. The permit procedure would also be much shorter. This will ultimately be the preferred option since existing natural gas infrastructure will be used less in the future and this approach would mean that the gas infrastructure will not need to be removed and demolished, but will rather be given a second life

A retrofitted pipeline could bring green hydrogen to Rotterdam where a hydrogen pipeline owned by AirLiquide already exists. This hydrogen pipeline transports hydrogen (produced at several sites by steam methane reforming from natural gas) to Antwerp, Terneuzen and all the way to the north of France. If the green hydrogen produced in the Eemshaven can be transported by a pipeline to Rotterdam, it could be fed into this pipeline and thus deliver green hydrogen to different clients who are connected to it.

But other gas transport pipelines could also be retrofitted into a hydrogen pipeline. One pipeline to Zuidwending could be transporting hydrogen to store it in salt caverns at that site. A pipeline to the Emmtec area could be retrofitted into a hydrogen pipeline to fuel gas turbines at that site with hydrogen. Another option is that a retrofitted pipeline could bring green hydrogen to the chemical site in Limburg, where several chemical companies could use green hydrogen. For example, OCI could use the green hydrogen to produce green ammonia at this site.

Before large quantities of hydrogen are available, an interim solution may be blending hydrogen into the existing gas stream, thus greening the energy supply to domestic and industry end users via the existing gas infrastructure. A small-scale controlled test on Ameland has shown that a mix of up to 20 percent hydrogen could be added to the domestic gas supply. The extent to which larger quantities of hydrogen can be safely blended into the larger scale gas system is unknown and needs to be studied with the specific aim of identifying and mitigating technical obstacles. This solution may provide a means to moving closer to the realization of a large-scale, dedicated hydrogen infrastructure system.

Infrastructure: Hydrogen trading platform

Over the years, Gasunie and GasTerra have developed the international gas trading platform TTF, which has become the biggest in Europe. TTF's success is based on three pillars:

- Transportation is secured for all natural gas available in the Dutch gas network via a standardized entry and exit system.
- Electronic trading platforms at trading exchanges and brokers where standard contracts are traded.
- Sufficient market parties that want to trade via the TTF and therefore create liquidity in the market.

The production of hydrogen differs from the production of natural gas. In principle, hydrogen can be produced everywhere by using another energy source as an input (gas, coal, biomass or electricity) on a large, medium or small scale. Natural gas is extracted from large underground reservoirs and put into a pipeline for distribution. Nowadays, natural gas is also liquefied (LNG) and transported by ship and truck.

Currently, the market for hydrogen is based on specialized contracts between hydrogen suppliers and hydrogen consumers. In the chemical and petrochemical industries, large volumes of hydrogen are produced on site or supplied via a privately-owned pipeline. On the other hand, there is a market for very small volumes of hydrogen that are supplied via hydrogen bottles to specific customers.

In the future, the markets for hydrogen will be diversified, not only as a feedstock for industry but also as a fuel for transportation and electricity system balancing. There will be many producers and customers demanding small, medium and large volumes of hydrogen. Transportation and distribution will initially be by pipeline and/or by ship/truck, but the goal is to have hybrid transportation and distribution systems as options in the future. In such a market, a trading platform for hydrogen, green hydrogen certificates and perhaps other related products (such as methanol or ammonia) could enable growth for the green hydrogen markets.

The following elements need to be in place in order to realize a hydrogen trading platform:

1. A group of transporters and distributors who can collect the hydrogen from the producers and deliver it to consumers. There is no direct relationship between the producer and the client. All hydrogen will fulfill predefined quality criteria, and producers will pay an entry fee to the transporter/distributor. All customers will pay an exit fee to the transporter/distributor. Both pipeline transporters/distributors and ship/truck transporters/distributors could be partners in this group.
2. Independent parties that will organize the trading. These parties should develop software for these trading systems and standard contracts with standard products for trading. A clearing organization to finalize all financial transactions should also exist. In the gas industry, these organizations are ICE, Trayport and APX. The standard contracts in gas are EFET (European Federation of Energy Traders) contracts.
3. Trading companies that want to take part in an up-and-coming hydrogen trading platform. At first, a large hydrogen producer or consumer must be prepared to make the initial move on this platform and take the lead as a market maker.

Infrastructure: Hydrogen harbor facilities in Eemshaven

The Eemshaven harbor will play a crucial role in the development of a green hydrogen economy. It is the site where a 1,000 MWe electrolysis plant and a 1,000 MW biomass gasification plant are scheduled to be built during the first phase. The output of these two plants will be hydrogen, syngas and/or carbon dioxide, oxygen and byproducts such as char. The input for the electrolysis plant will be green electricity from offshore wind provided through the NorNed and Cobra cables. This electricity could be supplied for electrolysis by a DC cable from the sea cables, which would prevent the need for DC-AC and AC-DC conversions. Input for the biomass gasification plant is 3 to 3.5 million tons of wood chips or other solid biomass residues. A torrefaction plant at the Eemshaven needs to torrefy this biomass, which will result in 1.3 million tons of pellets which will be fed into the biomass gasifier. This biomass or the torrefied biomass will primarily be imported by ship.

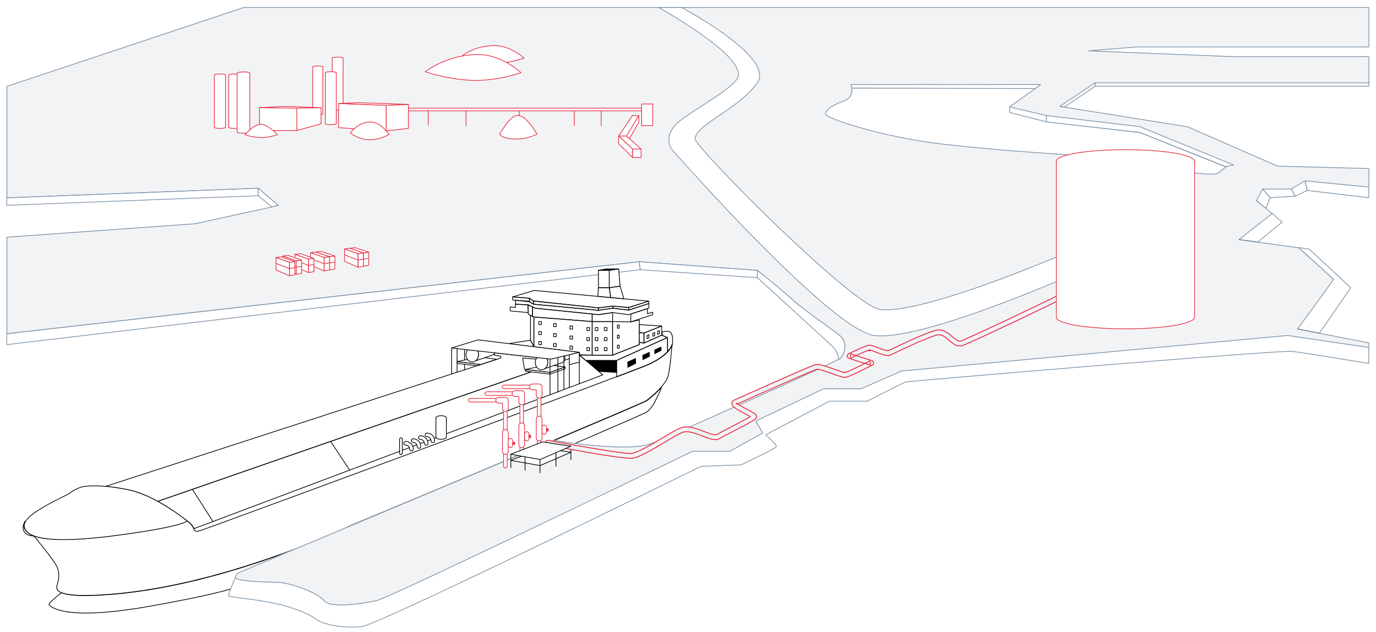
The Eemshaven is a deep-sea harbor where ships with a water depth of up to 11 meters can enter one of four basins. Quays for transshipment with storage facilities for biomass and pellets could easily be created for biomass import in the Eemshaven. These types of quays would cost about 50,000 euros per meter, and a quay of about 500 meters would be necessary to accommodate the largest ships, which means a total investment of about 25 million euros. A similar investment is needed for biomass storage.

The Eemshaven , the Netherlands

The hydrogen produced at the Eemshaven must be transported to the hydrogen markets by pipeline, ship or truck. The following steps must be taken in order to facilitate these different modes of transportation:

- The Delfzijl industrial site, which is 25 km away from the Eemshaven, houses several large chemical companies, such as AKZO (new production of ammonia), OCI (methanol) and Evonik (hydrogen peroxide). Hydrogen, oxygen, syngas and CO_2 must be transported from the Eemshaven to Delfzijl by pipelines. Research has already been conducted into developing a pipeline street, and it could be built relatively quickly.
- The hydrogen must be transported to sites where green hydrogen is needed as a feedstock or fuel, like Rotterdam and Limburg in the Netherlands, Antwerp in Belgium, and the Ruhr area, Bremen and Hamburg in Germany. A transportation pipeline from Eemshaven to these locations should exist, preferably in the form of the existing natural gas pipelines.
- A hydrogen filling station for pressurized bottles and tubes should exist, as well as a logistics center for (un)loading container racks with hydrogen tubes and trucks to transport hydrogen to fueling stations.
- A dedicated hydrogen harbor basin must be built to facilitate importing/exporting (liquefied) hydrogen. A hydrogen harbor basin would be similar to a LNG harbor facility, which costs between 40 and 60 million euros. Additionally, a large-scale hydrogen liquefaction plant with 50 to 100-ton daily capacity should be created, as well as a facility to feed imported (liquefied) hydrogen into the hydrogen transportation pipeline.
- Alternatively, ammonia could also be imported by ship, which would mean harbor facilities and storage tanks for ammonia in the Eemshaven.
- Hydrogen, either liquefied or compressed, can be transported from offshore electrolysis platforms via an existing offshore gas pipeline to the Eemshaven for further distribution. A facility needs to either ship this or place it in a pipeline or truck for further inland transportation.

All of these facilities combined will form the main hub for hydrogen transportation by ships, pipelines and trucks. An initial rough estimate is that they will need a combined investment of 400 to 800 million euros.



Main impex terminal LNG (Wärtsila)

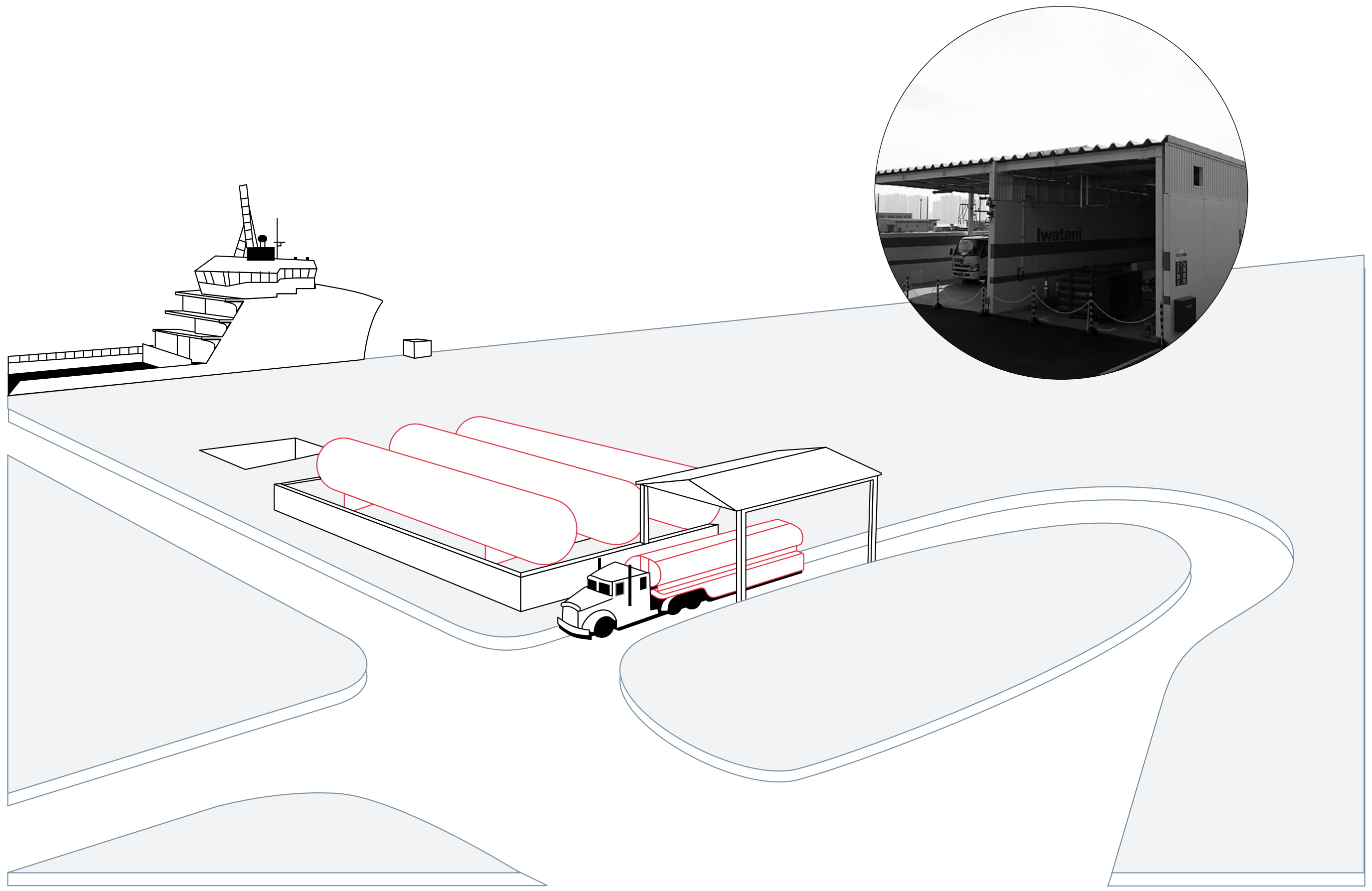
Infrastructure: 5 hydrogen distribution centers

The Northern Netherlands is a wide geographical area that needs distribution hubs for intermediate storage of hydrogen when is it not being distributed through pipelines. This is comparable to the small-scale infrastructure already in place for liquid natural gas (LNG). Liquid natural gas and liquid hydrogen are quite similar in terms of how they are handled: Both are cryogenic gases which are liquefied at low temperatures and are kept in thermally insulated storage.

Larger quantities of hydrogen can be shipped to these hubs either by inland vessels or trucks or, alternatively, by pipeline and thereafter in tube trailers. It could also be liquefied for transportation by liquid hydrogen trucks to individual demand centers, such as public fueling stations, bus depots, train depots and forklift fleets, among others. The hubs will therefore feature truck loading bays. The inlet will feature a high pressure (50 to 120 bar) hydrogen pipeline or inland vessel offloading facility.

The proposed locations of the small-scale hubs are Harlingen, Leeuwarden, Groningen, Emmen and Hoogeveen, locations which are fairly equidistant across the region and are close to larger demand areas.

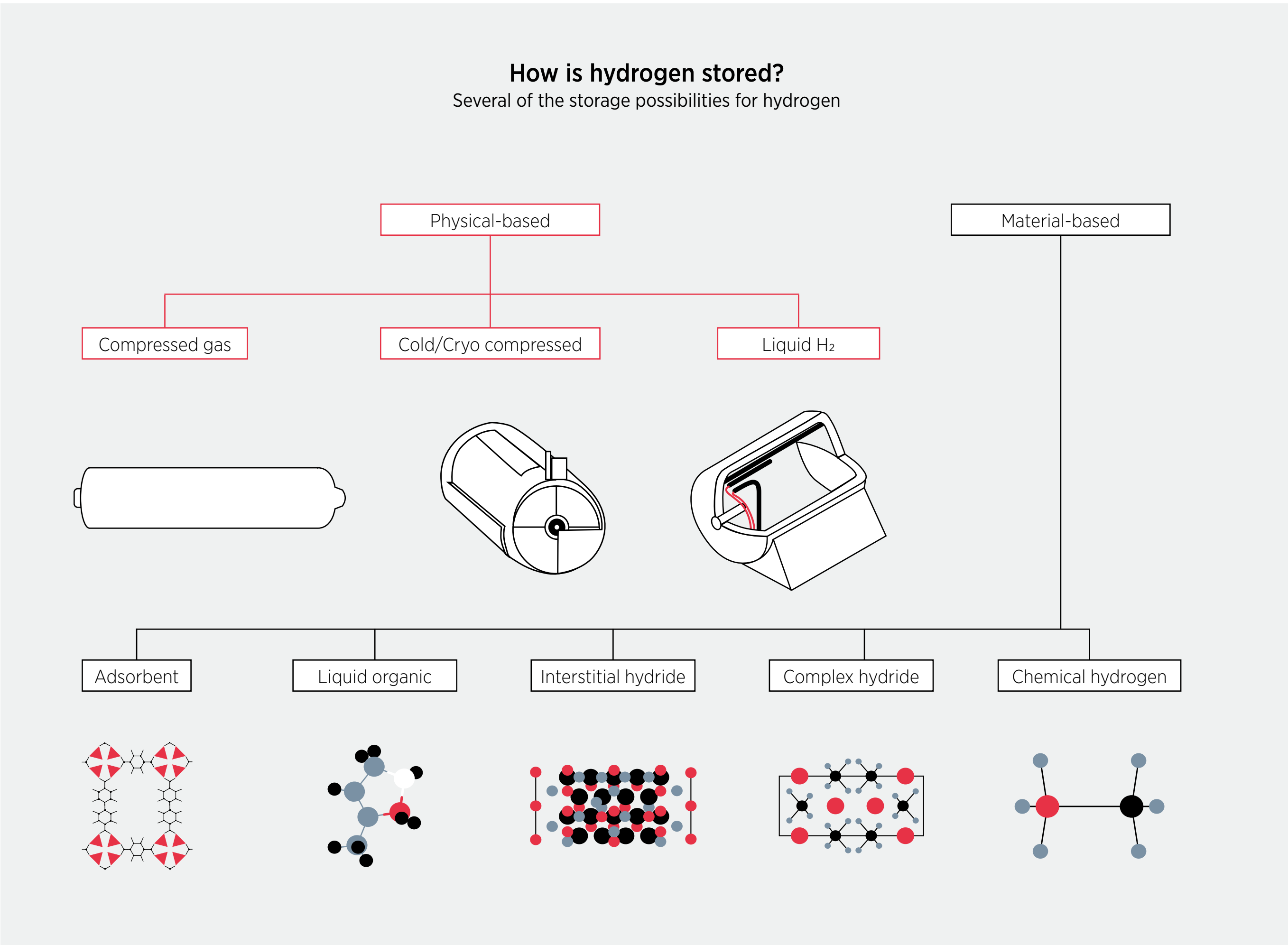
The investment for a small-scale hydrogen hub, including truck loading bays, is estimated to be between 10 and 20 million euros each. As such, 50 to 100 million euros would need to be spent for five small-scale distribution hubs.



Liquid hydrogen truck loading bay (Iwatani)

Infrastructure: Hydrogen storage in salt caverns

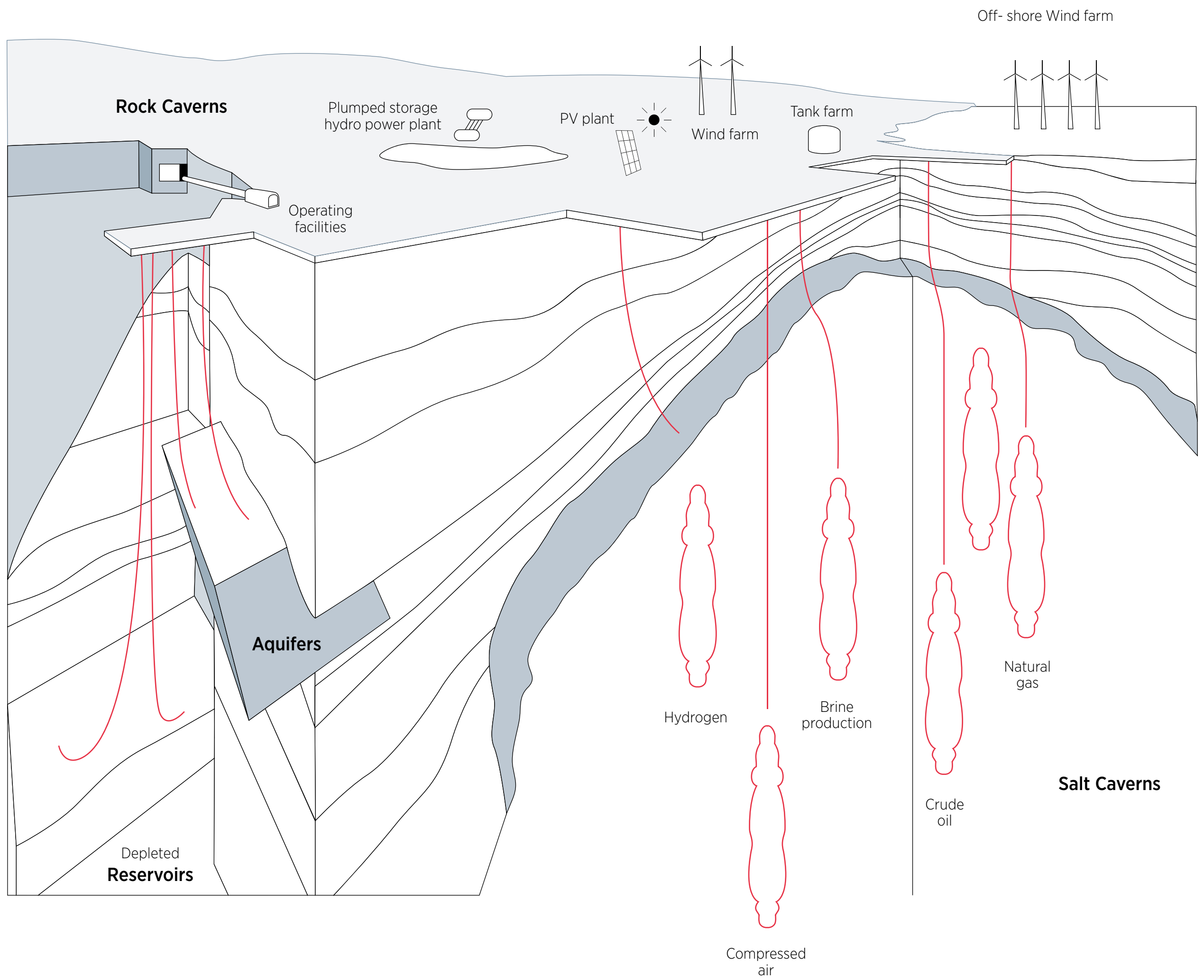
Converting electricity into hydrogen makes it possible to store renewable energy for a longer period without notable losses and at a reasonable cost. Electricity can only be stored in batteries or capacitors, but the energy density per kilo in a battery is low compared to the energy density per kilo of hydrogen or any other fuel. Hydrogen storage therefore offers a cheap solution for storing renewable energy over a longer period and in large quantities. There are many ways to store hydrogen: It can be compressed or liquefied and stored in a bottle or tank, or it can be stored in metal hydride or nanotubes. Another option is to adsorb hydrogen to another molecule or to convert hydrogen into another chemical. Conversion to ammonia is an especially interesting possibility, because ammonia is a liquid at a pressure of about 10 bar. The diagram below shows several of the storage possibilities for hydrogen.



Source: energy.gov

In the Northern Netherlands, however, there is a unique feature for storing hydrogen in large quantities. In Zuidwending, near Veendam, the company Energystock, a subsidiary of Gasunie, operates salt caverns for fast cycle natural gas storage. But these salt caverns can be adapted for hydrogen storage, too. There are ten salt caverns, at least three of which can be made available for hydrogen storage. Such a cavern is 300 meters tall with a diameter of about 70 meters. One cavern like this can store about 6,000 tons of hydrogen, of which about half is cushion gas.

At this site, a European Synergy subsidy project will start to produce hydrogen by electrolysis on a small-scale by using electricity from a solar farm. This hydrogen will be stored in tubes and used at hydrogen fueling stations or blended into the gas pipelines. The project is intended to help learn how to handle hydrogen. In a later stage, green hydrogen will be transported from the Eemshaven/Delfzijl to this site via a converted gas pipeline and stored in these caverns for later use. https://www.agbzw.nl/waterstofproject



Salt caverns can be adapted for hydrogen storage

Society: Zero emission public transportation

Governments are responsible for public transportation by buses, taxis, trains and ferries. They issue public tenders on the basis of companies making an offer. In these tenders, they can make zero emission transportation an obligation. The expectation is that this will lead to the use of fuel cell hydrogen buses and trains.

In the Northern Netherlands, approximately 1,300 city buses operate daily (city bus refers to both city and rural use). The main operators are Arriva and QBuzz. Based on current bus prices, an investment of about 715 million euros will be necessary to replace all of these buses with fuel cell hydrogen buses. Total hydrogen consumption will be about 10,000 tons per year.

Fuel cell buses

- All buses in the Northern Netherlands (approximately 1,300 units).
- Hydrogen consumption of 9 to 10 kg of H_2 per 100 km in city/countryside mix.
- Two-thirds of the buses will operate in city areas (200 km per day) and one-third of the buses will operate in rural/mixed areas (300 km per day); 225 km per day on average.
- Buses are in operation 6 days a week on average and 330 days a year, which equals 74,250 km per year.

Capex (capital expenditure) per bus today is approximately 550,000 euros (1,300 units › 715 million euros)

#	Daily km	Yearly km	Yearly H_2 consumption (tons)
1	225	74,250	7.4
1,300	292,500	96,525,000	9,600

In the Northern Netherlands, 50 diesel trains are operated on non-electric lines on a daily basis. These trains, operated by Arriva, have two or three carriages and 450 to 600 KW of power supplied by diesel electric engines. Fuel cell electric hydrogen trains could replace the diesel trains. Alstom is a company that builds these fuel cell hydrogen trains and will perform a test next year in Germany and, hopefully, in the Northern Netherlands. Because the depreciation time for trains is 25 years, not all trains will be bought new. Some trains may need to be retrofitted with a fuel cell electric power supply, which is technically achievable. Replacing all 50 of these diesel trains with new or retrofitted trains will require an investment of roughly 300 million euros. Total annual hydrogen consumption of these trains will be about 5,000 tons.

Fuel cell trains

- Total number of (diesel) trains in the Northern Netherlands: 50 units.
- Hydrogen consumption: approximately 25 kg of H_2 per 100km.
- Trains operate 6 days a week on average. A train covers approximately 1,200 km a day, based on covering a distance of 50 km two times each hour.
- Trains operate 330 days per year.

Capex per train is approximately 6 million euros (50 Units (50 units › 300 million euros)

#	Daily km	Yearly km	Yearly H_2 consumption (tons)
1	1,200	396,000	100
50	60,000	19,800,000	5,000

Green hydrogen bus, driving between Delfzijl and Groningen


Alstom, electric fuel cell hydrogen train

Society: Hydrogen trade fair and exhibition

An international green hydrogen trade fair and exhibition for businesses, professionals and an interested public should be held in the Northern Netherlands. A trade fair and exhibition would serve several goals:

- It would put the Northern Netherlands on the map as the center for green hydrogen.
- It would create a platform for businesses, information exchange and what is happening in the world.
- It would inform stakeholders about ongoing research, development and innovation.
- It would inform all interested parties (companies, organizations, politicians, civil servants and the public) about new products, systems and services in the green hydrogen economy.
- It would encourage society to further embrace and get involved in green hydrogen.

The integrated green hydrogen chain would need to be presented at such a green hydrogen trade fair and exhibition. The chain consists of the following aspects:

- Renewable energy production and conversion to hydrogen.
- Hydrogen storage, transportation and distribution via pipelines, ships and trucks.
- Hydrogen utilization in the chemical industry and industry in general.
- Hydrogen use in transportation (cars, buses, trucks, trains, boats, planes).
- Hydrogen for balancing the electricity system.
- Hydrogen for new applications (drones, robots, 3D printers, computers, mobile devices).
- Hydrogen safety and environmental impact.
- Hydrogen economics and financing.
- Hydrogen policies and societal aspects.
- Hydrogen training and education.

A trade fair and exhibition of this nature is imperative for generating business attention, international reach and societal awareness in the Northern Netherlands for developing a green hydrogen economy. Every year, a large trade fair and exhibition should be organized in a city in the Northern Netherlands. In the interim between these events, a mobile green hydrogen exhibition could travel around the Northern Netherlands to inform the public. A budget to cover the startup costs and losses in the first years will be necessary in order to develop these activities.

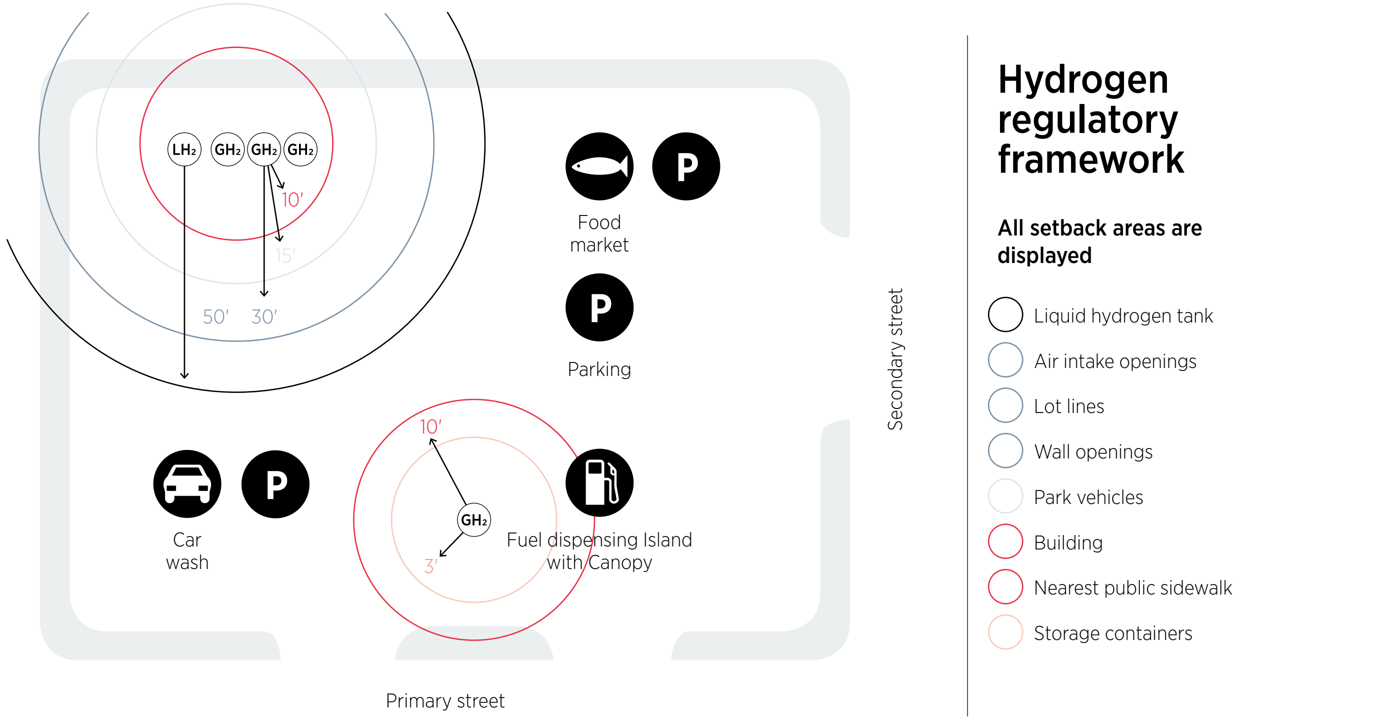
Emmtec Industry and Business Park Emmen, the Netherlands

Society: Hydrogen regulatory framework

Hydrogen is not included in the current regulatory framework (standards, regulations, permitting procedures, safety, environmental regulations and spatial planning) aside from its use in large-scale industrial production. The regulatory framework for hydrogen needs to include:

- Large-scale hydrogen and syngas production via steam reforming, electrolysis and biomass gasification.
- Hydrogen use at a large scale to produce chemicals, materials, steam, etc.
- Small-scale hydrogen production via electrolysis and steam reforming in city areas, near fueling stations, farms, waste water treatment plants, hospitals, etc.
- Hydrogen storage: large scale in harbors and small scale in city areas and near farms, among others.
- Hydrogen transportation and distribution via pipelines, ships and trucks.
- Hydrogen fueling stations, distribution stations and hydrogen bottle/tube exchanging stations.
- Hydrogen bus depots, train depots, parking lots and other transportation parking areas.
- Hydrogen use in vehicles, vessels, trains and other applications (i.e. drones or robots).

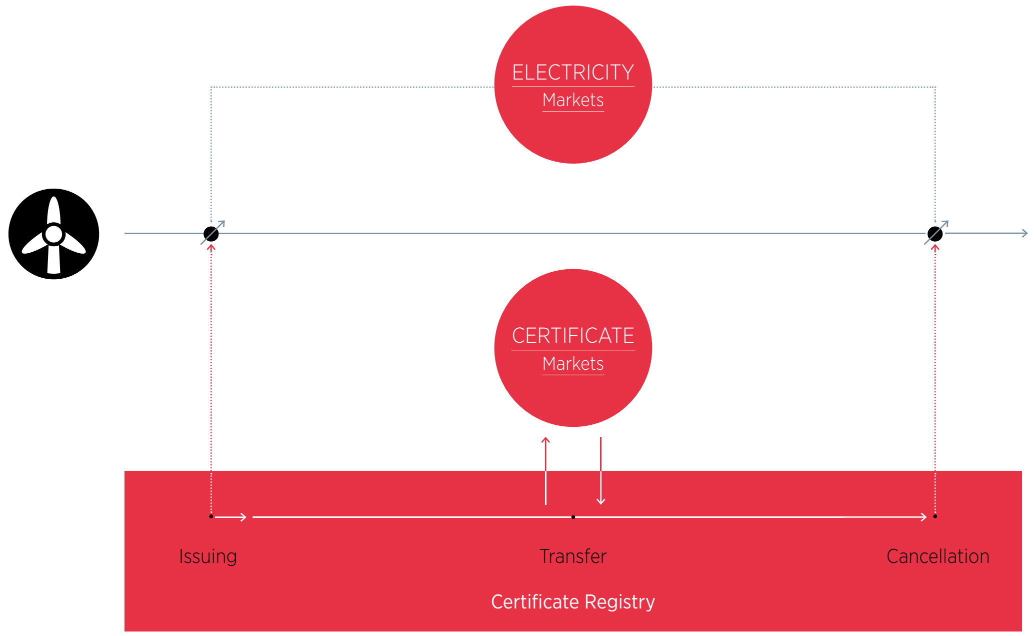
Developing and implementing such a regulatory framework for hydrogen via regular procedures will take decades and could very well be fragmented and inconsistent from one city or province to the next. It is therefore important to develop this regulatory framework in a non-traditional way, for example with a task force representing all relevant public bodies to develop a procedure for expediting the permitting process in the first years and a road map for the formal regulatory framework for hydrogen. Learning and copying regulatory frameworks and procedures from other countries, namely Germany and the US, could be a good way to expedite development.



Society: Green hydrogen certificates

Different kinds of emissions pricing and/or value for clean and green production systems are in place. Monetarily valuing the green character of these sources can lend extra financial incentive for choosing to produce clean and green energy over fossil fuels. In Europe, the Emission Trading System (ETS) has been established to reduce carbon dioxide emissions. The EU ETS operates on the cap and trade principle: A cap is set on the total amount of certain greenhouse gases in the system which can be emitted during installation. The cap will be reduced over time, as will emissions in turn. Companies will receive and buy emission allowances which they can trade with each other as needed, so long as they remain below this cap. This emission trading system will work if the cap is low enough to bring the carbon emission allowance price to such a level that companies will invest in clean and green energy production. This carbon emission allowance price is currently around six euros per ton of CO_2. Many companies and organizations argue that a price of about 50 euros per ton of CO_2 is necessary to accelerate investment into clean and green energy.

This Emission Trading System and the related carbon prices create a basis to monetarily value the green character of the production of electricity and fuels. But how can it be guaranteed that the energy being produced is from renewable sources, and how can trading green energy be made possible? In the European Union, this is achieved by issuing GOs (Guarantees of Origin) for electricity production. In short, a GO is a green label or green certificate which ensures that a certain amount of electricity has been produced from renewable energy sources. These green certificates make it possible to separate the green character of the source of the electricity which is physically produced. Both the green certificate and the electricity can be traded and sold separately, making it possible to buy green electricity everywhere by buying physical electricity and green certificates.



This green certificate system exists in the European Union for electricity, but it can be expanded to all other fuels. In the Netherlands, Vertogas (https://www.vertogas.nl/), a daughter company of Gasunie, is mandated by the Dutch government to issue Guarantees of Origin or green gas certificates based on the production of green gas. It would be relatively easy for Vertogas to develop a similar system for green hydrogen and for the Dutch government to adopt it. However, such a system for green hydrogen certificates needs to be established for the European Union, not just the Netherlands.

Society: Hydrogen safety issues and standards

Hydrogen is an energy carrier. Among other traits, hydrogen is flammable and lighter than air. Like every other energy carrier and fuel, there are rules and regulations for safe usage. Electricity, natural gas and fuel are all a part of our daily lives: We are familiar with them, and they are considered a part of the public domain.

Hydrogen has already been used for industrial purposes for more than a century, which means that handling this substance is a familiar process in this domain. There are many rules and standards for industrial applications. Hydrogen is also transported in large quantities through pipelines and via trucks. This process is well documented and familiar to those using it professionally. Hydrogen transportation via highways is overseen by the ADR (Accord européen relatief au transport international de marchandises Dangereuses par Route - http://www.evo.nl/site/wegvervoer-adr).

In addition to electricity and natural gas, hydrogen will play a major role in our energy system. It can also be used as a fuel for hydrogen vehicles and can replace natural gas in heating homes. Local generation systems can also play a role in this process.

Clear rules must be established for users, licensing authorities, emergency services and other relevant parties in these new situations and environments, which we refer to as the public domain.

A number of international standards and guidelines have been developed and implemented for hydrogen gas stations and road vehicles. The PGS-35 “delivery installations for hydrogen for use by road vehicles” has been made available in order to establish hydrogen fueling stations in the Netherlands (https://www.nen.nl/NEN-Shop/PGS-Publicatiereeks-Gevaarlijke-Stoffen/PGS-35-Waterstof-afleverinstallaties-van-waterstof-voor-wegvoertuigen.htm).

On the European level, the EN 17127 [3] is being developed. Similar documents provide a framework for licensing authorities (https://www.nen.nl/NEN-Shop/Nieuwsberichten-Energie-Distributie/Europese-norm-voor-Waterstoftankstations-ter-commentaar-gepubliceerd.htm).

The National Hydrogen Platform (formerly NWP, now H2-platform) and the Dutch Normalization Institute (NEN) have created the hydrogen safety innovation program. This program describes other matters whose realization need to be prioritized in order to support the implementation of hydrogen in the public domain. The goal of the program is to ensure a uniform approach on the national level for licensing authorities, accident response and management.
Hydrogen is suited for being broadly introduced as an energy carrier. Any risks of use are manageable, even in the public domain. Hydrogen could eventually entirely replace natural gas.

4

Roadmap for the green hydrogen economy and investments

The realization of a green hydrogen economy in the Northern Netherlands through the year 2030 will undeniably be a complicated process. This process must be carefully coordinated and planned. A high level roadmap in which green hydrogen production, infrastructure, markets and societal projects and activities has been developed with a timeline starting in 2017, including the relevant investments. The investments have to come from the business community, but local and national governments need to create the right market conditions and regulatory framework to facilitate this. In the startup phase, governments need to overcome the barriers, be it through financial measures or other incentives.

The development of a green hydrogen economy is not only about green hydrogen. Many other green energy sources and green chemicals are also produced through this process. Making the green hydrogen economy a reality in the Northern Netherlands will therefore also be a major step toward realizing a green energy system. Green hydrogen, together with other green products, can be supplied to the chemical industry as feedstocks. Green hydrogen can also be used in fuel cells for vehicles, boats and planes, and balance a fully renewable electricity system.

More than green hydrogen: A green energy system

This integral plan for a green hydrogen economy in the Northern Netherlands is not only about production and consumption of green hydrogen: It is also about the development of a green energy system. In doing so, many other green energy products are also produced, namely green electricity, green syngas, green oxygen, green carbon dioxide, green char (85 percent carbon), biopellets, pure water and green heat.

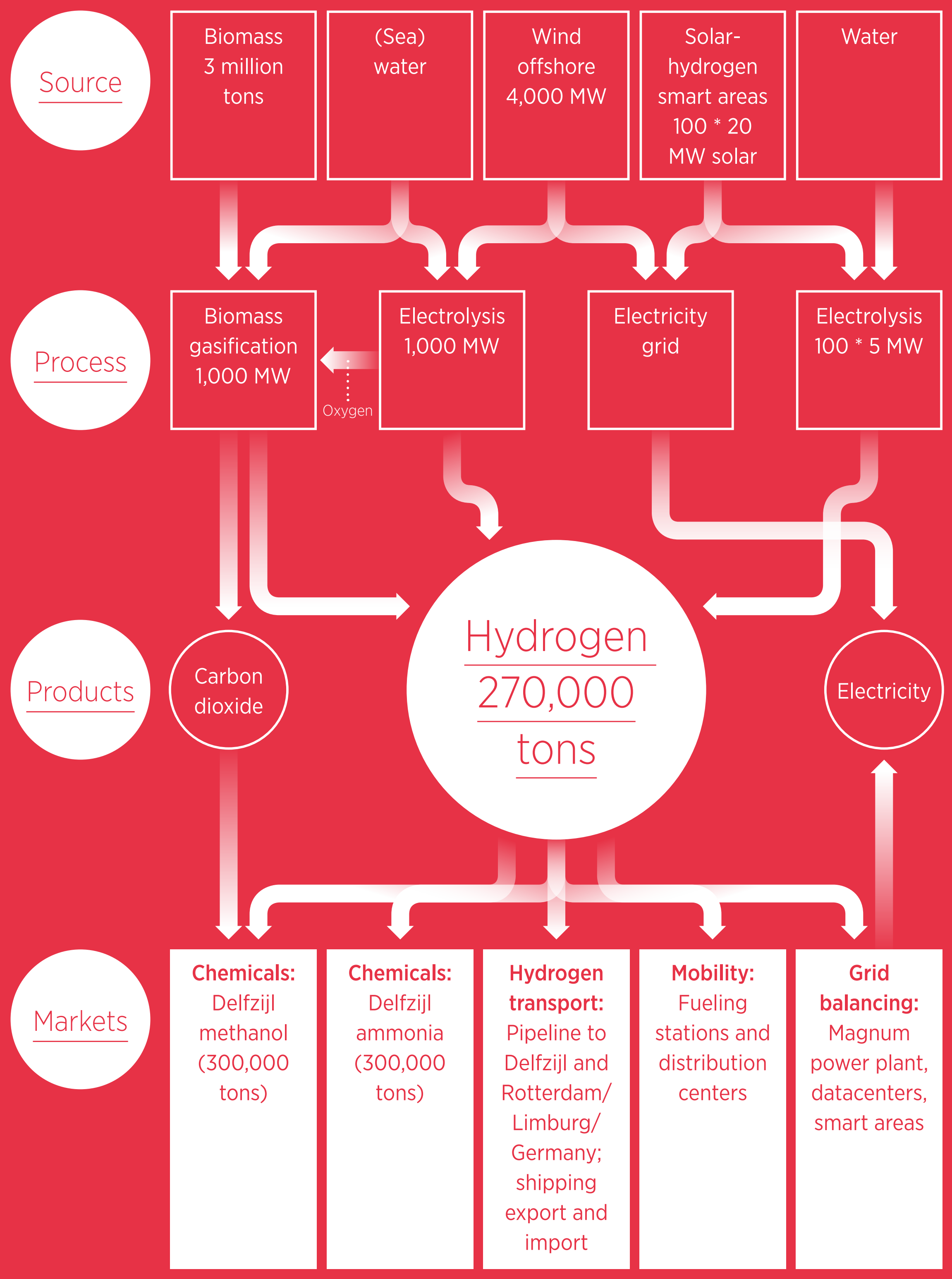
The 4,000 MWe from new offshore wind farms and the 600 MWe Gemini offshore wind farm will produce about 18 billion kWh per year. The NorNed cable and the Cobra cable can import 5 to 10 billion kWh of green electricity from hydro and wind. With a capacity of 2,000 MWe, locally installed solar panels on roofs and solar farms will produce 2 billion kWh. A 1,000 MWe capacity onshore wind facility in the Northern Netherlands will produce about 2.7 billion kWh. In its first phase, the Nuon Magnum plant will produce 1.3 to 3.6 billion kWh from CO_2-neutral hydrogen. Altogether, about 24 billion kWh of green electricity will be produced in the Northern Netherlands, and 5 to 10 billion kWh of green electricity could be imported by around the year 2030. This is about 25 to 30 percent of the total electricity consumption in the Netherlands. About 8 billion kWh will be used to produce green hydrogen, which means that an amount of between 21 and 26 billion kWh will still be available for electricity consumption. This amount far exceeds the electricity consumption in the Northern Netherlands, which means that the region will become a net exporter of green electricity.

The 1,000 MWe capacity electrolysis plant will use electricity and pure water as an input. Pure water will be produced from sea water or surface water by reverse osmosis. However, this pure water could also be used for purposes other than for hydrogen production. Pure water can be used in power plants and in chemical processes, and drinking water can also be produced from pure water. One byproduct of electrolysis is oxygen, which is a product that can be used in the biomass gasification plant and in all kinds of other chemical processes. Another byproduct of electrolysis is heat, which could be used to heat green homes in the neighborhood, for example.

The 1,000 MW biomass gasification power plant will use about 3 million tons of wood residues, straw or another woody biomass. This biomass will be torrefied before it is put into the gasification plant. The torrefied biomass could also be pelletized and sold on the pellet market to fuel biomass boilers that produce heat for homes, buildings or swimming pools. The output of a biomass gasification plant is syngas (a mixture of hydrogen, carbon monoxide and carbon dioxide) and biochar or green char, a product that contains 85 percent carbon. Biochar is a high value product which could replace petcoke in the chemical industry and be used as a soil fertilizer in the agricultural industry. The syngas could either be used directly in the chemical industry or fully shifted to hydrogen and carbon dioxide. Carbon dioxide is also a feedstock in the chemical industry and could be used in greenhouses. About 1.3 million tons of green carbon dioxide will be produced.

When green hydrogen, green oxygen, green syngas and green carbon dioxide are available, almost all basic bulk chemicals can be produced. In developing the green hydrogen economy, fossil-based feedstocks in the chemical industry can be replaced by green feedstocks, thereby producing green chemicals. >

Green hydrogen economy in the Northern Netherlands



Green hydrogen production and consumption up to 2030

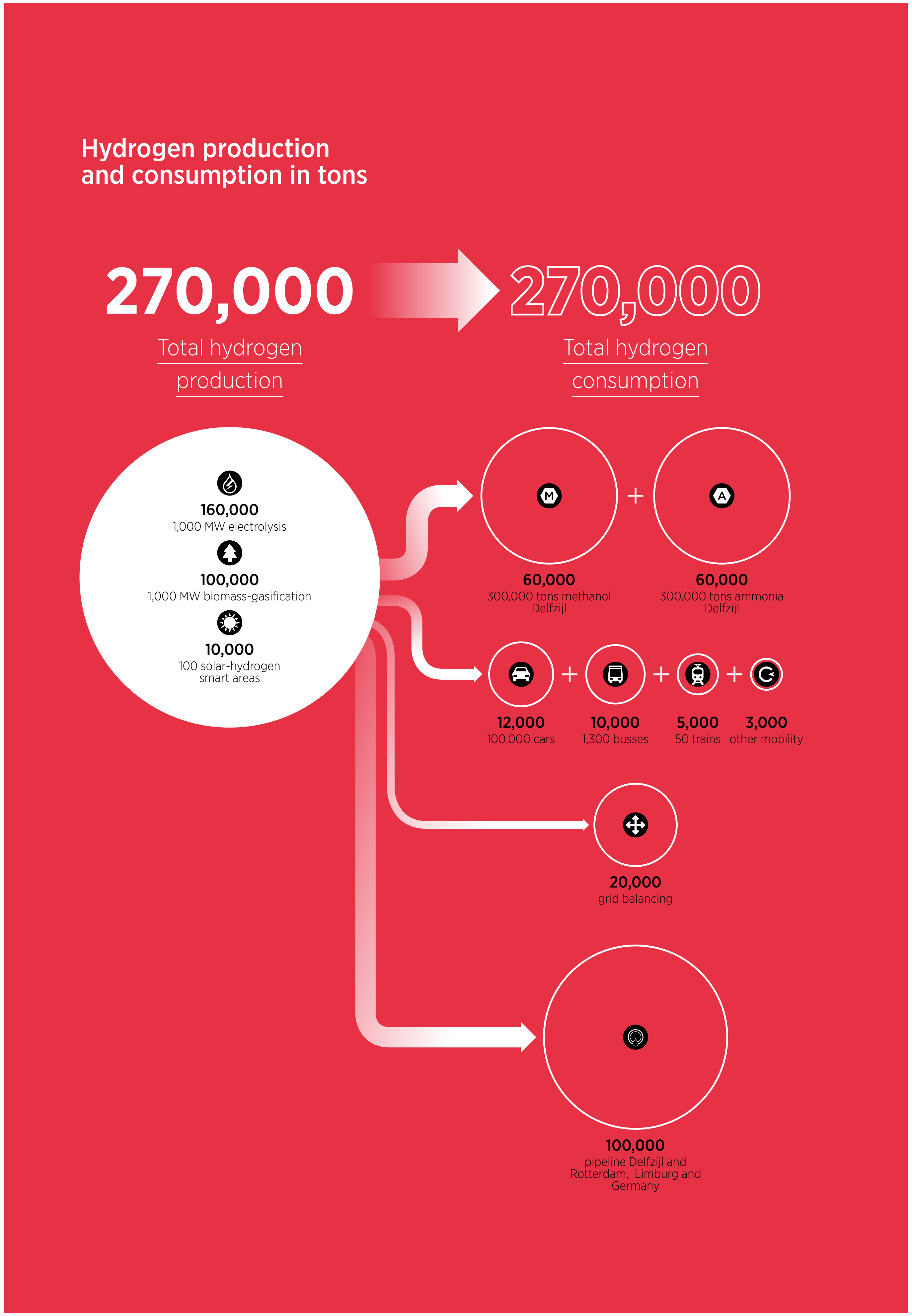
As a result of the projected developments in hydrogen production, about 270,000 tons of hydrogen (38 petajoules) will be produced in the Northern Netherlands as of the year 2030. An estimated 1 million tons of hydrogen will be produced in the Netherlands in total. The first project that will be realized is the large-scale 1,000 MW hydrogen electrolysis plant over a period of five years. A couple of years after that, the large-scale 1,000 MW biomass gasification plant will come online over the course of five years. Large-scale hydrogen production is necessary in order to realize low hydrogen production costs of 2 to 3 euros per kg, which is competitive with current fossil-based hydrogen prices. The market for this large-scale hydrogen production will initially be the feedstock market for the chemical and petrochemical industries in Rotterdam, Antwerp, Geleen, Terneuzen and the Ruhr area. The chemical industry in Delfzijl can also use the hydrogen to produce ammonia and methanol. The chemical site in Emmen can use green hydrogen as a feedstock, especially for producing green, high-temperature steam. Emerging markets for hydrogen as a fuel in mobility and grid balancing will develop at a later stage.

Ultimately, the main markets for hydrogen will be the chemical and petrochemical industries, because emerging transportation and grid-balancing markets cannot absorb the produced hydrogen volume in the period up to 2030. It will therefore be necessary to further develop hydrogen markets for feedstock (which will require hydrogen infrastructure). Hydrogen pipelines to Rotterdam, Limburg and Germany first need to be realized in order to supply the chemical and petrochemical industries. More or less simultaneously, a pipeline street with pipelines for hydrogen, oxygen, syngas and (eventually) ammonia and nitrogen needs to exist between the Eemshaven and Delfzijl. The chemical site in Emmen could be supplied via a pipeline to Germany.

Five hydrogen distribution centers in Harlingen, Leeuwarden, Groningen, Hoogeveen and Emmen are planned in order to develop the hydrogen market for transportation. The hydrogen from a pipeline will be transhipped in hydrogen tubes at these distribution centers. These hydrogen tubes will be loaded onto trucks to be transported to hydrogen fueling stations. Hydrogen fueling stations will be built at bus and train depots. In order to get the market for fuel cell electric cars and trucks going, a sufficient number of hydrogen fueling stations for cars and trucks need to be available on the highway.

The market for electrical grid balancing is central, regional and local. The Nuon Magnum power plant is located at the Eemshaven and will run on CO_2-neutral hydrogen or on imported green ammonia, which will be cracked into hydrogen to fuel the power plant that can deliver flexible green electricity to the grid. Excess green/CO_2-neutral hydrogen could also be fed into the pipeline. Any hydrogen deficit for the Magnum plant could be covered through green hydrogen production in the Eemshaven. At a regional level, hydrogen will be consumed by fuel cells that produce green electricity at moments of shortage from renewable electricity production. At a local level, hydrogen will be produced by small-scale electrolysis from excess solar electricity in the summertime and fuel cells can produce electricity from hydrogen from other sources during shortages in the winter. Studies should be conducted into the local gas distribution grid and how it could be used for hydrogen distribution. The hydrogen will also need to be transported by trucks/boats to and from city areas, farms, villages or islands.

From 2030 onward, green hydrogen can be produced at platforms in the North Sea through far offshore wind farms. This hydrogen will be transported to shore via the existing offshore gas pipelines. Hydrogen production capacity could certainly be expanded after 2030, and importing pressurized or liquid hydrogen will also be an option. The estimated hydrogen production volume of 270,000 tons is the first phase in the development of a green hydrogen economy in the Northern Netherlands. >



Roadmap for the green hydrogen economy in the Northern Netherlands up to 2030

A high level roadmap has been developed where the realization of all these projects, infrastructure, systems and activities is projected over time (see page 60).

There are two projects indicated in the roadmap that are already being developed, but they are also relevant for the development of green hydrogen production in the Northern Netherlands. The 600 MWe Gemini offshore wind farm is under construction and will be fully operational in 2017. This wind farm will deliver its electricity via an offshore cable to the Eemshaven. It is the first offshore wind farm in the Northern Netherlands. In addition to the Gemini wind farm, the Dutch government has designated another area at sea where approximately 800 MWe of offshore wind could be built by 2023. The other project that is already under construction is the Cobra cable, a 700 MWe offshore electrical cable that connects Denmark with the Eemshaven. This cable is scheduled for completion in 2019. The investments in these two projects are already secured and are therefore not included in the investments for the green hydrogen economy.

The first project that needs to be realized is a 1,000 MW electrolysis plant which can produce over 160,000 tons of green hydrogen. A pilot project of 20 MW should be completed in 2019, followed first by a large-scale 480 MWe electrolysis plant in 2021 and then second by a 500 MW capacity electrolysis plant in 2023. This large-scale electrolysis plant will be necessary for achieving green hydrogen prices of between 2 and 3 euros per kg, which is competitive with current fossil-based hydrogen prices. This large-scale hydrogen production is also necessary for developing the necessary hydrogen pipeline infrastructure. If there is insufficient volume, then there is no economic value in retrofitting an existing gas pipeline into a hydrogen pipeline. The first hydrogen pipeline will most likely be from the Eemshaven to Rotterdam, where it can connect to existing hydrogen pipeline infrastructure and fulfill part of the demand for hydrogen in the chemical and petrochemical industries.

But the market for hydrogen as a feedstock in the chemical industry first needs to be developed, particularly in Delfzijl – including construction of a pipeline street for supplying the chemical industry in Delfzijl. Once that is available, a green ammonia and green methanol production plant can be built, and a large-scale biogas gasification plant would also need to be created in the Eemshaven in order to supply syngas and carbon dioxide.

The second market segment for hydrogen in transport is public transportation, specifically buses and trains, and the green hydrogen transportation market can be enhanced and accelerated once green hydrogen is available at competitive prices. Large-scale green hydrogen production must be a reality before that can happen – until then, pilot projects can help to increase familiarity with hydrogen fueling and fuel cell electric vehicles.

Electricity balancing is the third potential market for green hydrogen. Nuon has already developed a plan to convert the gas-fueled Magnum power plant into a flexible power plant for balancing through CO_2-neutral hydrogen produced by cracking green ammonia or direct use of carbon free hydrogen. But the electricity balancing market is very local, too. Excess solar electricity is converted into hydrogen and green electricity, which is produced by hydrogen-fueled fuel cells during shortages. These solar-hydrogen energy systems can be developed at every level: in villages, farm houses, on the Dutch islands and in city areas. One of the Dutch islands, Ameland, is already planning to create a balanced green electricity system with a large solar power system and hydrogen-fueled fuel cells. Realizing several additional showcase areas like this will be necessary before these solar-hydrogen systems can be implemented on a larger scale.

The fourth market for green hydrogen could be heating homes and buildings through green hydrogen distributed via retrofitted gas distribution pipelines – people can burn hydrogen instead of natural gas by simply changing the burners and stoves in their homes. This could lead to a fully carbon-free heating system and low costs in rural areas, small villages and older sections of cities.

Many other activities need to be developed in order to create the green hydrogen economy. One vital aspect is the development of a regulatory framework for hydrogen. This will be necessary for issuing permits for electrolysis plants, biomass gasification plants, hydrogen infrastructure and hydrogen fueling stations, among others. Education and training in the production and use of hydrogen is necessary at all levels. Educational and training programs that deal with natural gas need to extend to hydrogen as well. Several research and innovation centers need to extend their research and innovation to hydrogen production, infrastructure, storage, use and new applications.

High level roadmap for the green hydrogen economy in the Northern Netherlands up to 2030

Under construction *A* | A Priority to realize
Included in investments A A | (A) Not included in investments

	2017	2018	2019	2020	2021	2022
Wind offshore	*600 MW Gemini*				1,000 MW	
Electrolysis			20 MW		480 MW	
Biomass gasification					20 MW	
Solar-hydro areas		Ameland	1 icon area	1 icon area		5 areas
Offshore cable	*600 MW Gemini*		*700 MW Cobra*		1,000 MW wind	
Ammonia					(Magnum Nuon First import)	Delfzijl 150,000 tons production
Methanol						
Pipeline					Delfzijl, Rotterdam, Limburg	
Fueling stations	Delfzijl	2	4	6	8	10
Distribution centers					Harlingen i.e. trains	Groningen i.e. trains
Fuel cell balancing						
Harbor facilities			Truck loading		Ammonia import	
Busses	2	6	20	20	20	20
Trains			Groningen-Leeuwarden		10	20
Trucks	2	6	10	20	30	50
Cars		20	100	500	1,000	3,000
Boats			Ecolution	Sail boats	Sail boats	First ferry
Others		Forklifts	Drones	Robots	Mobile	
Research, innovation centers	Energy Academy Europe, research universities, universities of applied sciences, EnTranCe (Groningen), Wetsus (Leeuwarden), Emmtec (Emmen)					
Trading platform						
Trade fair		Shows	Shows	First time	1	1
Green certificates					Established NL	Established Germany
Regulations		Provisionally established			Fully implemented	
Education	MBO, HBO, universities, high schools, primary schools, etc.					
Training	Automotive, fire department, police, installation technicians, builders, technicians, regulators, etc.					

Last but not least, an internationally renowned hydrogen trade fair in the Northern Netherlands will help to establish the reputation of the Northern Netherlands as the preeminent green hydrogen region of Europe, which can attract innovative companies and talented people.

This high level roadmap shows that there is interdependence among the realization of projects and infrastructure, the development of the markets and the regulatory framework. The green hydrogen economy in the Northern Netherlands can therefore only become a reality if it is approached in a coherent, well-directed and closed monitored manner

	2023	2024	2025	2026	2027	2028	2029
Wind offshore	1,000 MW		1,000 MW		1,000 MW		(Far offshore wind)
Electrolysis	500 MW			(1,000 MW)			(1,000 MW)
Biomass gasification	480 MW		500 MW				
Solar-hydro areas	5 areas	10 areas	10 areas	15 areas	15 areas	15 areas	20 areas
Offshore cable	1,000 MW wind		1,000 MW wind		1,000 MW wind		(1,000 MW NorNed 2)
Ammonia		Delfzijl 150,000 tons production		(Magnum Nuon 1.3 million tons Import)			
Methanol		Delfzijl 150,000 tons		Delfzijl 150,000 tons			
Pipeline	Ruhr area, Harlingen, Emmen				Bremen-Hamburg		(Offshore gas/hydrogen pipeline)
Fueling stations	10	10	10	10	10	10	10
Distribution centers	Emmen	Leeuwarden		Hoogeveen		Harlingen electrolysis	Emmen electrolysis
Fuel cell balancing			100 MW	100 MW	100 MW	100 MW	100 MW
Harbor facilities	Biomass import						(Hydrogen shipping)
Busses	50	50	50	50	50	50	50
Trains	20						
Trucks	50	50	50	100	100	100	100
Cars	6,000	10,000	10,000	15,000	15,000	20,000	20,000
Boats	First yacht	First fishing boat	First freight ship				
Others							
Research, innovation centers	Energy Academy Europe, research universities, universities of applied sciences, EnTranCe (Groningen), Wetsus (Leeuwarden), Emmtec (Emmen)						
Trading platform							Established
Trade fair	1	1	1	1	1	1	1
Green certificates			Established Europe				
Regulations							
Education	MBO, HBO, universities, high schools, primary schools, etc.						
Training	Automotive, fire department, police, installation technicians, builders, technicians, regulators, etc.						

Investments for the green hydrogen economy in the Netherlands up to 2030

The total investment for the development of a green hydrogen economy in the Northern Netherlands up to 2025 is estimated to be 17.5 to 25 billion euros. However, 12 to 15 billion euros of that will be invested in 4,000 MW of offshore wind farm capacity, including the offshore electrical cable and the grid connection onshore. Over the past few years, the development, construction and operation of offshore wind farms has become standardized, which means that the risks are well known and financing will not be a problem. The SDE+ (*Stimulering Duurzame Energie*; translation: Stimulation of Renewable Energy) government program is applicable in this process. In the future, these offshore wind farms will be achievable without subsidies. In order to create an additional 4,000 MW of offshore wind farm capacity in the Dutch portion of the North Sea north of the Northern Netherlands, the Dutch national government must designate areas where these wind farms can be built. At the moment, only a small section where about 800 MW can be realized, in addition to the 600 MW Gemini wind farm, is allocated to offshore wind farms at sea.

The total investment for the development of a green hydrogen economy in the Northern Netherlands up to 2025 is estimated to be 17.5 to 25 billion euros

The total investment needed for hydrogen-related projects, infrastructure, systems and activities is 5.5 to 10 billion euros, 1 to 2 billion euros of which will be for large-scale hydrogen production by electrolysis and biomass gasification. An estimated investment of between 0.7 and 2 billion euros will be necessary for large-scale hydrogen infrastructure facilities such as hydrogen pipelines, a trading platform, harbor facilities and five hydrogen distribution centers. Although the technology is ready and pilot projects are running, these projects have never been realized on such a large scale, which means that the execution of these hydrogen projects is not yet standard procedure. The national government, together with the EU, must establish a support framework for the startup phase of this green hydrogen economy. The first phase of these projects can be subsidized with a SDE+ scheme for the production and use of green hydrogen. This should be accompanied by developing the regulatory framework for hydrogen production facilities and infrastructure.

Other primary investments of between 0.6 and 1 billion euros will be made for green ammonia, green methanol production and related chemical production. These are standard chemical plants, and investments can be stimulated by the national government - together with the EU - encouraging the use of green ammonia, green methanol and other green chemicals. There are different mechanisms for doing so, for example mandating using a certain percentage of green chemicals in products or valuing the green chemicals via a green hydrogen certificate or a green chemicals certificate.

Investments into a hydrogen fueling infrastructure with 100 hydrogen fueling stations in the Northern Netherlands would cost an estimated 100 to 200 million euros. In Germany, 400 fueling stations are being built across the country to facilitate hydrogen fueling anywhere. Partners in the industry consortium are Shell, Total, Linde, BMW, Mercedes, Toyota and Hyundal, among others. This consortium and the German government (who will cover 50 percent of these investments) will realize these 400 hydrogen fueling stations for about 350 million euros. Similar cooperation between the government and industry should exist in the Netherlands in order to realize the necessary initial batch of hydrogen fueling stations.

The market for hydrogen in transportation can be initiated and stimulated by local and regional governments. Regional governments are the ones who issue the budget for public transportation (i.e. trains and buses). If these governments call for zero emission electric transportation, then fuel cell buses and trains would be the preferred options. Local governments can also stimulate the market for green hydrogen by ordering and buying zero-emissions electric vehicles for their services, such as garbage collection, parks departments and transportation for disabled people. The investment amount mentioned is the total investment in new buses, trains and municipality vehicles combined. This is not an additional investment: It would be invested regardless of these plans. Initially, these vehicles will be costlier than normal fossil fuel combustion engine vehicles. As such, local, regional, national and EU governments will need to support and subsidize this first phase of zero-emissions public vehicles and trains.

The hydrogen market for electricity balancing exists on a large, medium and small scale. In all cases, government stimulus will be necessary to realize these projects in the first phase. It could be a system similar to the existing SDE+ for green hydrogen production and/or use.

- On a large scale, the Nuon Magnum power plant aims to transition into becoming a flexible power plant. Nuon wants to import CO_2-neutral ammonia which will be cracked, thereby producing green hydrogen or CO_2-neutral hydrogen that will serve as fuel in the Magnum plant. These investments are not included. Recently, Statoil, Gasunie and Nuon-Vattenfall announced plans to study the production of carbon-free hydrogen from gas and storing the CO_2 in a depleted oil or gas field. This hydrogen could be used in the Magnum power plant.
- On a medium scale, data centers want to have a constant supply of green electricity. This can be done by using wind electricity together with a hydrogen-fueled fuel cell that produces electricity at moments that there is insufficient wind. The investment into fuel cells is estimated to be 200 to 400 million euros.
- On a small scale in city areas, on islands, in villages and farmhouses, solar power systems will generate electricity. During the summer, these solar power systems will produce excess electricity which can be converted into hydrogen by small electrolyzers. In the winter, fuel cells can produce electricity at moments when there is a shortage. An estimated 2 to 3 billion euros needs to be invested into 2,000 MW of solar power systems and 500 MW capacity small electrolyzers. An investment of 1.5 to 2 billion euros into solar power systems would have been made regardless and is therefore not directly related to hydrogen.

The use of green hydrogen for heating homes and buildings is also not included in the investments. Further research is necessary to identify which areas have favorable conditions for green hydrogen heating.

The conditions in the Northern Netherlands are uniquely suited for green hydrogen and syngas production at globally competitive prices. The chemical industry in the Northern Netherlands could yield green chemicals, materials and products for competitive prices using green hydrogen. Local communities will become clean and prosperous by generating their own green electricity, using green hydrogen for clean transportation and balancing the electricity system. Above all, green hydrogen is produced on land, at sea or imported, and no longer pumped out of the ground in the Northern Netherlands.

5

Green hydrogen production cost calculations

Summary

Rabobank has prepared an initial model to assess the financial viability of the construction and operation of two electrolysis plants and two biomass gasification units (500 MW each). Model assumptions have been provided by stakeholders involved in the Green Hydrogen Economy plan and have neither been tested nor externally validated. Additional due diligence is recommended once detailed information becomes available about contracts and cash flows.

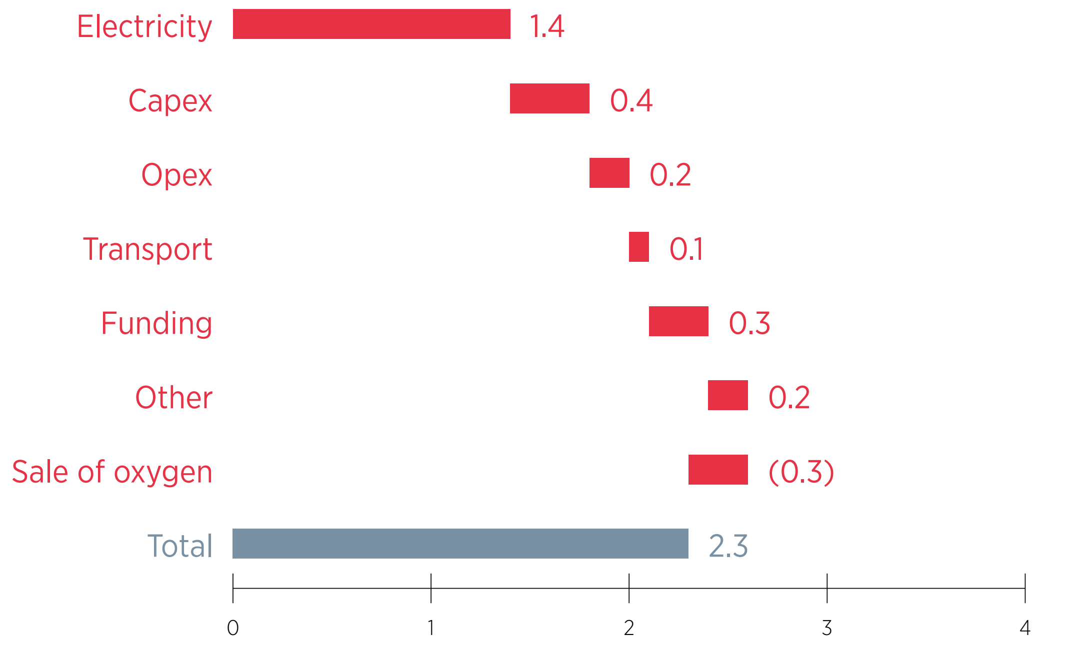
The model assumes limited recourse financing with a long debt maturity (up to 20 years) and relatively high leverage (60 percent). To accommodate such a structure, first of all, cash flows must be contracted with experienced, credit-worthy and reliable counterparties. Risks related to construction, production, offtake (price and amount of hydrogen) and feedstock supply (price, quality and amount of electricity and torrefied biomass) need to be allocated to those that are best positioned to assess and manage risk. Secondly, large-scale electrolysis and biomass gasification hydrogen production is not yet considered proven technology. A sufficient track record will need to be built to allow each project to operate as a baseload production unit (efficiency, availability and economies of scale). Third, parties like Gasunie and Groningen Seaports are presumed to incur certain capital expenditures, e.g. for modifying gas infrastructure and upgrading harbor facilities. It is considered fair to assume at this stage that these investments will become operational expenses, which reflects the situation in many other types of (renewable) energy production.

Profitability and cash flows depend on a strong correlation between hydrogen sales and input costs (electricity and biomass). Such correlation will therefore need to be embedded into a project and its financing structure, and is seen as a prerequisite for assessing financial viability. When assuming such correlation in combination with a cost of debt of 4 percent, a Debt Service Cover ratio of 1.5x and leverage of 60[1] percent , the calculations demonstrate that in most scenarios, debt can be repaid within an assumed economic lifetime of about 20 years. As illustrated below, the model supports the initial assessment that an electricity price of roughly 20 to 30 euros per MWh and a torrefied biomass feedstock price of eight euros per gigajoule could be sufficient to sell hydrogen for 2 to 3 euros per kg. Rabobank understands that such a hydrogen price could potentially be contracted with external parties on a long-term basis and could also be competitive with current hydrogen production derived from gas. >

[1] A Debt Service Cover (debt service over cash flow, "DSCR") and Leverage (debt to equity) ratio are typical constraining ratios in project finance. Rabobank considers a Leverage of 60percent and a minimum DSCR of 1.5x reasonable at this stage.

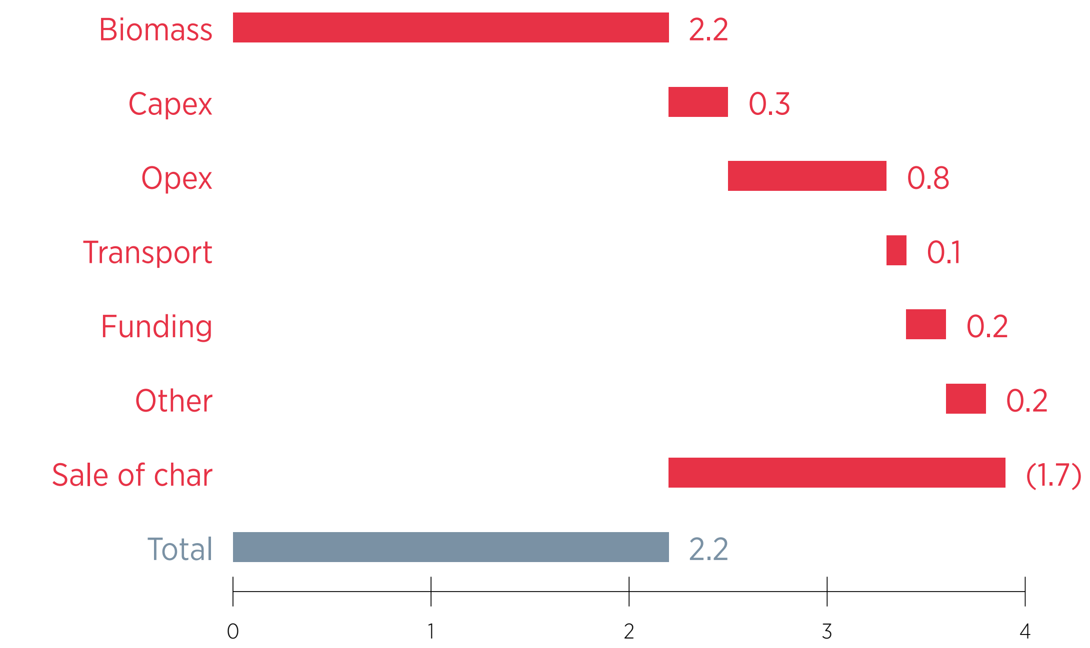
Electrolysis

Exemplary cost build-up of hydrogen
(electricity: 25 EUR/MWh, EUR per kg)



Biomass gasification

Exemplary cost build-up of hydrogen
(torrefied biomass: 8.3 EUR/GJ, EUR per kg)



Report

Assessment prepared by Rabobank on May 5, 2017 of the financial viability of large-scale green hydrogen production in the Northern Netherlands

Rabobank has prepared a financial model to assess the financial viability for the construction and operation of two electrolysis plants and two biomass gasification units (500 MW each). Model assumptions have been provided by stakeholders involved in the Green Hydrogen Economy project (such as Ekinetix, TorrGas, Gasunie and prof. van Wijk) and have neither been tested nor externally validated. Additional due diligence is recommended once detailed information becomes available about contracts and cash flows.

Financial business case seems supported by underlying trends

There are several drivers to provide further substance to the financial viability of development of a green hydrogen economy in the Northern Netherlands and the construction of large-scale electrolysis and biomass gasification:

• ***Electrolysis***: hydrogen is currently primarily produced by converting conventional gas into hydrogen. Electrolysis (power-to-gas) is an alternative to diversify the Dutch energy mix and to facilitate a desired gradual reduction of Dutch dependence on conventional gas. Thanks to an accelerated development of (i) offshore wind in the North Sea area (4000+ MW) and (ii) interconnection capacity with neighboring countries (e.g. Denmark, Norway and Germany), an increasing amount of intermittent electricity is expected to come on shore near the Eemshaven. The inland high voltage capacity to distribute this electricity to areas with the highest demand (e.g. industrial energy consumers in the Randstad and Botlek area) is limited. Converting electricity into hydrogen means a more balanced energy source which can be stored and used at times of shortage. Investments in the high voltage grid can also be replaced by converting existing gas infrastructure. As such, there is a clear economic rationale for considering large-scale hydrogen production as an alternative energy source.

• ***Biomass gasification***: the gasification of biomass produces syngas, a fuel gas containing hydrogen. In the Northern Netherlands and Germany, there is substantial demand for both hydrogen and syngas, most notably in the chemical industry to produce green ammonia and methanol. Although biomass gasification and electrolysis are separate production streams based on different inputs, the combination of both energy sources will help to (i) validate the large external infrastructure investments, (ii) create synergies by using oxygen produced by electrolysis in the gasification process, and (iii) unlock the potential demand from the methanol industry that requires both hydrogen and syngas[2].

[2] Please note that, for the sake of comparison, the model assumes the hydrogen price as output (instead of the price of syngas) based on the hydrogen component in syngas.

Initial financing considerations

A project finance structure is considered for the assessment of financial viability of the assumed investments in electrolysis and biomass gasification. Such a structure is a common solution to finance investments in tangible fixed assets with predictable, stable and contracted cash flows and a long-term repayment period.

The financial model assumes a project finance structure with a long debt maturity (up to 15 to 20 years) and a leverage of up to 60 percent. To accommodate such a structure, first of all, cash flows must be contracted with experienced, credit-worthy and reliable counterparties. Risks related to construction, production, offtake (price and amount of hydrogen) and feedstock supply (price, quality and amount of electricity and torrefied biomass) will need to be allocated to those that are best positioned to assess and manage risk. Thirdly, large-scale electrolysis and biomass gasification hydrogen production is not yet proven at this stage. A sufficient track record will therefore need to be built up so as to allow each project to operate as a baseload production unit (efficiency, availability and economies of scale). Parties like Gasunie and Groningen Seaports are furthermore presumed to incur certain capital expenditures, e.g. for modifying gas infrastructure and upgrading the harbor facilities. It is considered fair to assume at this stage that these investments will become operational expenses, which reflects the legislation that applies to many other types of (renewable) energy production units. Finally, in terms of cash flow, the main driver for financial viability will be the future correlation between hydrogen sales and input costs (electricity and biomass). Such correlation will need to be embedded in a structure and is a prerequisite for attracting sufficient enthusiasm from investors (debt and equity).

Large-scale green hydrogen production could create competitive hydrogen prices (2-3 euros/kg)

The development of all units in parallel is attractive for realizing economies of scale, for enabling the development of large-scale hydrogen production and for substantiating the investments needed to modify existing gas infrastructure. However, financiers typically prefer to finance each plant on a stand-alone basis with separate supply and offtake contracts. Breaking up the development into separate projects could also lower the overall costs of finance and allow for gradually scaling up. Depending on the development of the underlying technologies, it may be necessary to build ten 50MW units rather than a single large-scale 500MW unit. Such a modular approach would ensure that the technology is mature enough for a certain scale, mitigate the impact of potential unexpected issues (technological, operational or otherwise) and optimize each asset for certain input and output contracts.

Finally, governmental support will be an important success factor and will help to raise sufficient leverage at competitive terms. Support will initially be provided by subsidizing the development of a master plan while some support may be needed to mitigate commercial risks or to secure the assumed correlation between input costs of hydrogen sales during operations. In addition to some governmental support, co-investments from various stakeholders (suppliers, offtakers, and construction companies) could also be considered to align interests.

[3] DSCR (Debt Service Coverage Ratio) is a typical ratio for project finance that sets a minimum for the cash flow that needs to be generated to repay instalments and interest (e.g. a minimum of 1.5 times those amounts).

[4] IRR is the discount rate that makes the net present value of the cash flows equal to zero, and hence denotes the profitability of a project.

Financial model output and conclusions

As illustrated on page 68, the financial model supports the assessment of the Northern Netherlands Innovation Board that hydrogen can be produced for around 2 to 3 euros per kg when assuming an electricity price of roughly 20 to 30 euros per MWh and a torrefied biomass feedstock price of roughly 8 euros per GJ. As such, when inputs and outputs can be contracted with external parties on a long-term basis, green hydrogen production from electrolysis is already competitive with the traditional production of hydrogen from gas.

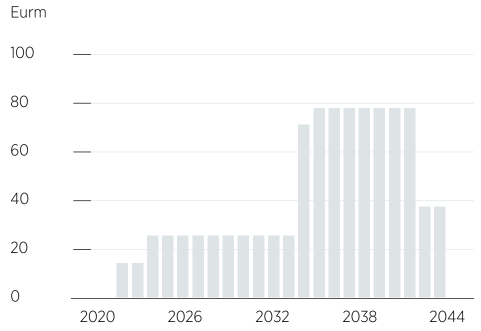
To test the debt servicing capacity of the electrolysis and biomass gasification units, the financial model assumes a funding structure with (i) 40 percent equity and 60 percent debt and (ii) a DSCR debt sizing of 1.5x[3]. Based on the assumptions provided for in Appendix A, the graphs below show that the two electrolysis and two gasification production units can be repaid within around 15 years, which is well within the assumed technical and economic lifetime of around 20 years. When assuming that excess cash flows are distributed annually in dividends, the shareholder return can also be substantial with an effective IRR[4] of around 9 to 10 percent.

While noting that the chosen scenarios are illustrative and based on many untested assumptions, the financial viability of large-scale hydrogen production is provided for and makes the planned financing attractive for both debt and equity providers. Sufficient potential is therefore predicted for the development of a master plan for the realization of the electrolysis and the biomass gasification production units.

Electrolysis: Debt development

Electrolysis: Divident payout

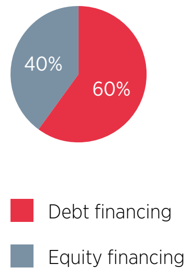
Based on DCSR of 1.5x IRR 9.7%



Electrolysis plants:

EUR 788m required

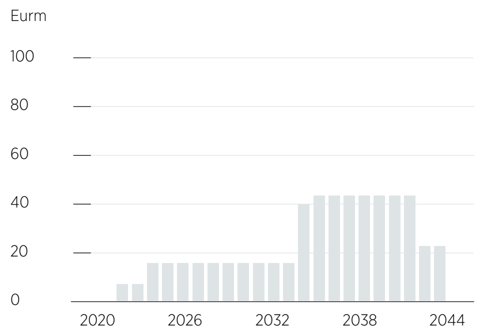
This includes Capex plants I + II and financing costs during construction



Gasification: Debt development

Gasification: Divident payout

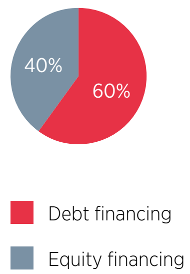
Based on DCSR of 1.5x IRR 9.7%



Gasification plants:

EUR 473M required

This includes Capex plants I + II and financing costs during construction



Appendix: Assumptions used in the financial model

Electrolysis	Plants	Plant I	Plant II	
	# years of construction	2	2	Years
	Year plant starts operating	2022	2024	Year
	Power	500	500	MV
	Capex (excl. financing costs)	375	375	Eurm
	Years of depreciation	20	20	Years
	Maintainance of capex	3.5%	20	% of total capex
	Input			
	Electricity price	25		EUR/MWh
	Utilisation ratio	94%		%
	Running time hours	8,500		hours/year
	Operating expenses	4		EUR/MWh
	Other expenses	1		EUR/MWh
	Demi waterprice	0.90		EUR/M^3
	Demi water consumption	0.009		M^3/kg H_2
	Costs electricity transport to plant	0.7		EUR/MWh
	% of electrolysis H_2 to Rotterdam offtakers	50%		
	% of electrolysis H_2 to German offtakers	50%		
	Output			
	Hydrogen production	18.2		kg/MWh
	Hydrogen price	2.29		EUR/kg
	Oxygen price	0.04		EUR/kg
	Oxygen output	133		kg/MWh
Gasification	**Plants**	**Plant I**	**Plant II**	
	# years of construction	2	2	Years
	Year plant starts operating	2022	2024	Year
	Power	500	500	MV
	Capex (excl. financing costs)	225	225	Eurm
	Years of depreciation	20	20	Years
	Maintainance of capex	2.0%	2.0%	% of total capex
	Input			
	Price torrefied biomass	8.3		EUR/GJ
	1 ton torrefied biomass	21.6		GJ
	Utilization ratio	100%		%
	Running time hours	8,000		hours/year
	Operating expenses	8		EUR/MWh
	Other expenses	2		EUR/MWh
	Oxygen price	40		EUR/Ton
	Oxygen requirement	42%		% of ton biomass
	Costs harbour facilities	3.0		EUR/Ton
	Pipeline to Rotterdam	30		EUR/Ton
	Pipeline to Germany	30		EUR/Ton

Gasification	Output	Plant I	Plant II	
	Hydrogen production per ton biomass	8%		
	Bio char production per ton biomass	33%		
	CO_2 production per ton biomass	60%		
	Bio char price	400		EUR/Ton Char
	Hydrogen price	2,198		EUR/Ton Hydrogen
	CO_2 price	0		EUR/Ton CO_2
	Pipeline to Delfzijl	20		EUR/Ton
Financing structure		**Electrolysis**	**Gasification**	
	Debt funding	60%	0%	
	Equity funding	40%	100%	
	DSCR	1,5x	1,5x	
	Interest margin	4%	4%	
	Commitment fee	2%	2%	
	Upfront fee	2%	2%	
	Tax	25%	25%	
	For this specific case: Repayment time (incl. construction period)	25	15	Years
	For this specific case: IRR on equity	10%	10%	

Source: Ekinetix, Torrgas, Gasunie, Mr. van Wijk

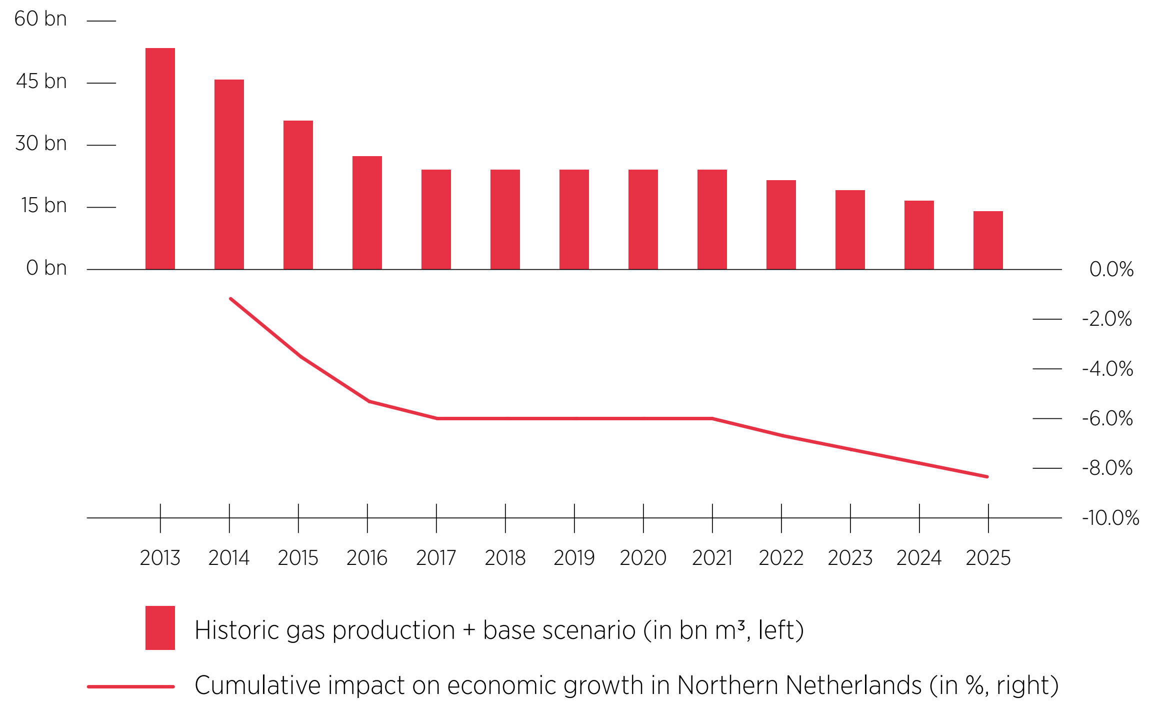
6

Impact of gas production reduction on the economy

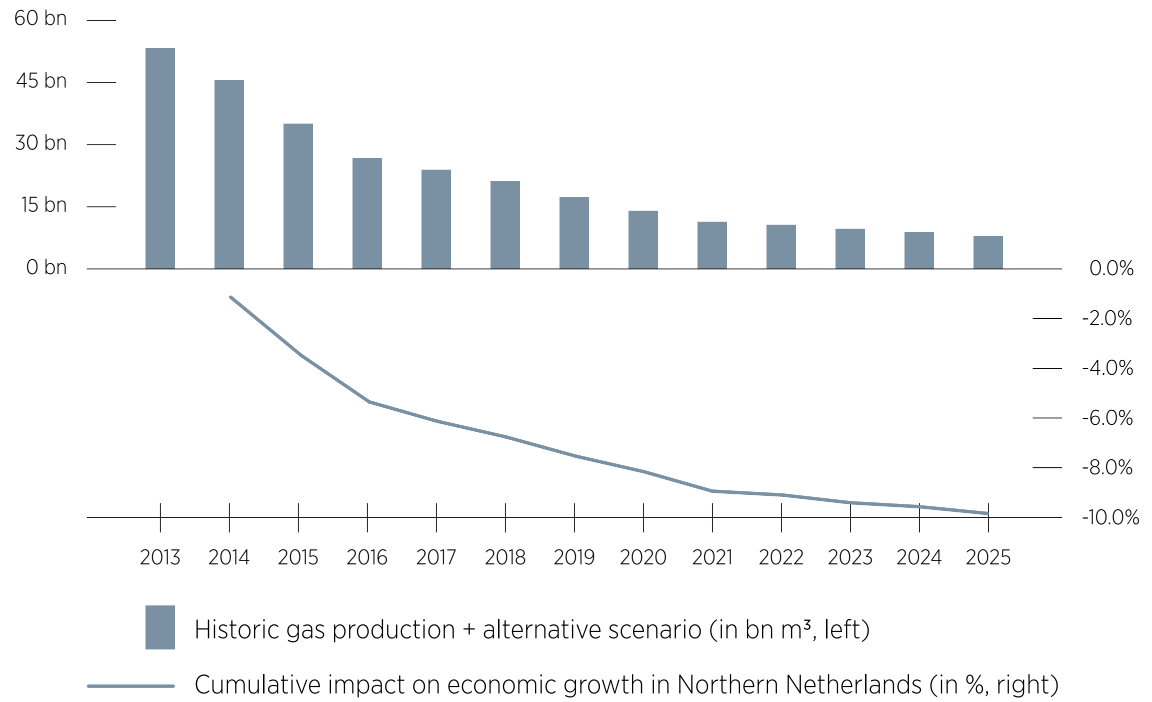
Summary

The ING Economics Department analyzed the effect of decreasing gas production on the Northern Netherlands economy. In 2014, gas, oil and minerals production contributed about 11.7 billion euros to the Northern Netherlands economy, which is roughly 20 percent of the total Northern Netherlands economy. However, due to the earthquakes caused by gas production, operations have already been reduced in recent years and will be further reduced in the future. The Economics Department's rule of thumb is that a decrease in gas production of 5 billion m^3 gas will cause the northern economy to contract by one percent. Gas production is capped at 24 billion m^3 gas in 2017, which is down from a production level of 53 billion m^3 gas in 2013. The official government policy is that the gas production can be kept at the same level up to 2021 and will be reduced further in the years thereafter. However, the Dutch parliament decided in February 2017 that gas production must already begin reducing as of 2017 and reduce further from that point forward. The chart below shows the cumulative impact on the economy if gas production is further reduced in the future, both according to the official government policy (baseline) and the Dutch Parliament's decision (alternative). As the charts reveal, it will severely affect the economy of the Northern Netherlands. A contraction of the Northern Netherlands economy in the period from 2014 to 2025 of more than 8 percent is expected in the baseline, and around 10 percent is expected in the alternative, either of which would negatively affect employment.

Gas production and cumulative economic impact - **baseline**



Gas production and cumulative economic impact - **alternative**



In the period from 2014 to 2025, gas production reduction is projected to cause economic contraction of 8 to 10 percent in the Northern Netherlands

7

How to organize the next steps

Summary

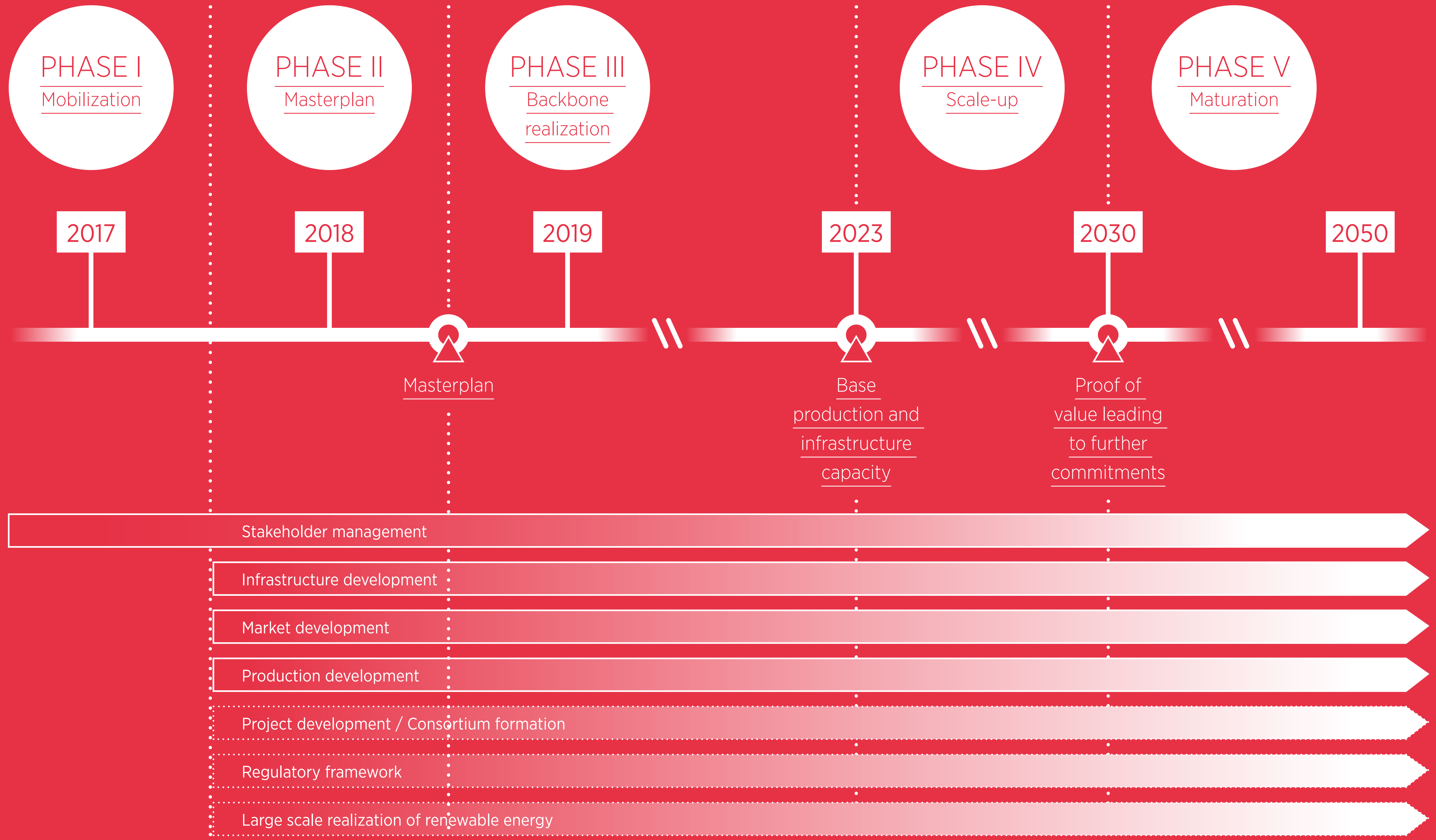
Accenture has analyzed how the realization of a green hydrogen economy in the Northern Netherlands should be organized. Although the vision to realize a green hydrogen economy could develop in the Northern Netherlands as one of the first in Europe is realistic, it will not happen on its own. In this vision, the rationale for why a green hydrogen economy could develop in the Northern Netherlands is explained. This vision also includes a high-level roadmap for the development of production, infrastructure, markets and societal activities in order to realize a first phase of the green hydrogen economy up to 2030, together with a rough estimate of the necessary investments. Accenture concluded that a green hydrogen economy can only be realized by a well-coordinated and tightly directed approach by companies and governments working together. Companies need to make the investments, but governments need to create the right conditions. To realize this large-scale green hydrogen economy, Accenture proposes the following phased approach, consisting of: I) the current phase, which is focused on ideation and mobilization; II) masterplan phase; III) backbone realization; IV) scale-up phase; and V) maturation phase.

To realize the shift to the green hydrogen economy, a range of initiatives need to be agreed upon and executed in tandem. Accenture therefore proposes developing a master plan within a strong governance structure and in alignment with multiple stakeholders. This master plan needs to be developed from mid-2017 to mid-2018 and should be led by a Green Hydrogen Ambassador in combination with strong program coordination.

The main elements of this master plan are as follows (in order):

- A plan with business cases for the realization of initial projects: the creation of large-scale production facilities, hydrogen transport infrastructure and the development of industrial offtake markets for hydrogen feedstock
- The plan and the projects need to be developed in the context of a wider green hydrogen economy. Many aspects, such as a regulatory framework, research, education and training about hydrogen also needs to be developed. Other initiatives, projects and developments should be considered that focus on the transition to a sustainable energy system and a green economy
- A covenant signed by stakeholders from industry, politics, civil society and knowledge centers.

Development phases for the green hydrogen economy realization in the Northern Netherlands



Introduction

Report prepared by Accenture on February 24, 2017

Business rationale

- The Netherlands aims for a (carbon) emission free economy in 2050[5]. This fits into the broader international endeavor to mitigate greenhouse gas-induced climate change as put forward in the Paris Agreement[6].
- The Northern Netherlands Innovation Board (NIB) thinks that it requires a mentality shift towards embracing the need for radical transformations in the energy system to establish a carbon emission free economy by 2050. Incremental changes alone are considered insufficient.
- In order to establish an emission free economy, the Netherlands needs emission free alternatives to various fossil fuel-based processes, namely electricity production, heating and cooling of industrial processes and the built environment, transportation, and production of chemicals and industrial feedstock.
- In addition to the search for substitutes, the transition will also pose challenges for balancing the energy system. There is a growing need for balancing through flexible production and/or storage as the share of intermittent renewable energy production increases.
- A one-size-fits-all solution for these transition challenges seems unlikely. We expect myriad alternatives to play a role in eliminating carbon emissions.
- Large-scale hydrogen production and transmission from the Northern Netherlands to an industrial hydrogen offtake cluster (Rotterdam, Limburg or Germany) are potential cornerstone technologies of an alternative – emission free – energy economy.

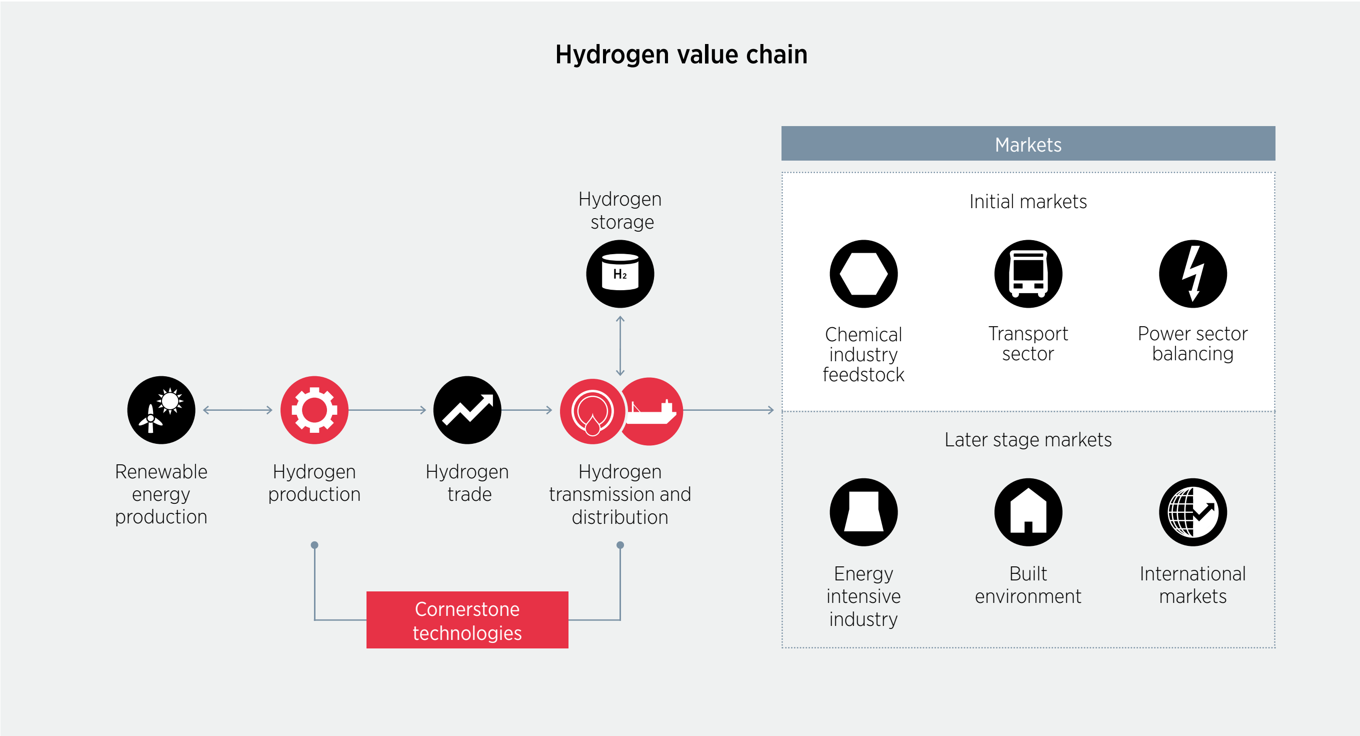


Figure 1. Overview of the hydrogen value chain

- NIB believes that the backbone of a green energy economy in the Netherlands will consist of three parts: a large-scale green hydrogen production facility producing hydrogen from renewable electricity competitively; the creation of offtake markets for hydrogen feedstock in the (petro)chemical industry; and hydrogen transmission capacity to connect green hydrogen production to an industrial offtake cluster (Rotterdam, Limburg or Germany). A set of related projects will be developed in order to quickly scale the initial market, including the Delfzijl-Eemshaven pipeline and the ammonia production facility, among others.
- In the next stage, the hydrogen backbone can be extended by developing markets and infrastructure for hydrogen in transport (through fuel cell vehicles, at first primarily trucks, buses and trains) as well as for power balancing through fuel cells.
- Later stage markets to be researched and developed are hydrogen for heating and cooling in the built environment, hydrogen as a fuel for power generation in energy-intensive industries and international hydrogen trading.

Case for the Northern Netherlands

- The NIB regards the creation of a hydrogen economy in the Northern Netherlands as a significant opportunity.
- Unique regional features of the Northern Netherlands represent exceptional conditions for large-scale and renewable energy-based hydrogen production, including but not limited to: the existing natural gas infrastructure which connects the Northern Netherlands to demand centers throughout the Netherlands and beyond; proximity to the deep-water harbor facilities of Eemshaven; and connections to international transmission cables from Nordic countries, both providing renewable energy and linking to offshore wind plots.
- The creation of a hydrogen economy can mean economic growth potential for the Northern Netherlands. This will be related to the development of various activities in the hydrogen value chain: hydrogen production, storage and trade, industrial feedstock processing and distribution, transportation fuel distribution, etc.

Moving forward

- On January 27, 2017, Accenture was invited by the Northern Netherlands Innovation Board to facilitate a workshop on the organization and governance of this green hydrogen initiative going forward. This paper was written on the basis of this workshop.
- In this paper, we propose an approach to the organization and governance of this initiative consisting of the creation of a masterplan and the mobilization of stakeholders critical to this effort.
- For the purposes of this paper, we describe a high level roadmap, critical success factors, the phases and work streams of the masterplan and which steps to take next in order to move the initiative into the next phase.

[5] The aims of the Dutch government are described in the 'Energieagenda', https://www.rijksoverheid.nl/documenten/rapporten/2016/12/07/ea

[6] The Paris Agreement, http://unfccc.int/paris_agreement/items/9485.php

High level roadmap

In order to realize this large-scale green hydrogen economy, we propose a phased approach, which will consist of I) a current phase focused on ideation and mobilization; II) masterplan phase; III) backbone realization phase; IV) scale-up phase; and V) maturation phase.

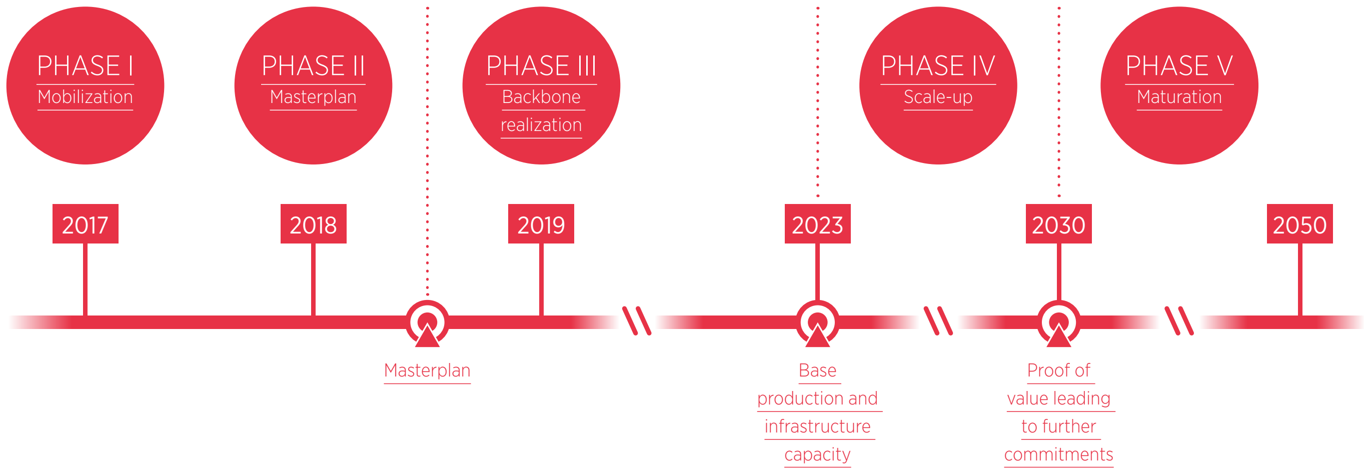


Figure 2. Roadmap for the overall project. See page 80 and 81 for the full plan.

Phase I: Ideation, formation and mobilization – (through mid-2017)

- Completion of vision document describing the initiative and its different facets, as well as the planning and governance for realizing this vision.
- Key stakeholder engagement aimed at informing and activating key stakeholders.
- Formation and mobilization of masterplan organization.
- Secure funding.

Phase II: Master plan phase – 2017-2018 (12-18 months)

- Production development, creation of the plan for the backbone hydrogen production facility and related facilities (the ammonia production facility in Delfzijl, among others).
- Infrastructure development, creation of the plan for the backbone hydrogen transmission pipeline to an industrial cluster, as well as further planning of related infrastructure (e.g. the Delfzijl-Eemshaven pipeline).
- Market development and research into and planning of the development of a market for green hydrogen as chemical feedstock, as well as research and planning for the development of the markets for hydrogen in mobility and electricity balancing. Research will also be conducted into the potential and prerequisites for the use of hydrogen in cooling/heating and electricity production and the international trade of hydrogen.
- Stakeholder management, which will ensure greater alignment between the initiative and different interest groups.
- Alignment with initiatives connected to large-scale RES realization and regulatory framework development for hydrogen, and the development of (pilot) hydrogen projects and consortia.

Phase III: Backbone realization – 2018-2023 (approximately 5 years)

- Production development: realization of the large-scale electrolyzer (1GW), biomass gasification facility (500MW) and ammonia production facility (150 Kilotons).
- Infrastructure development: realization of the transmission pipeline to an industrial cluster (Rotterdam, Limburg, or Germany), the Eemshaven-Delfzijl pipeline and initial fueling infrastructure.
- Market development: realization of markets for green hydrogen feedstock in the chemical industry and for hydrogen in mobility markets (primarily trucks and public transportation).
- Ongoing stakeholder management and alignment with related initiatives (RES, hydrogen and hydrogen regulation).

Phase IV: Scaling up – 2023-2030

- Production development: scaling up the electrolyzer, realization of offshore hydrogen production and fuel cell balancing facilities.
- Infrastructure development: realization of transmission pipelines to other industrial clusters, a hydrogen terminal (harbor facility) and offshore hydrogen pipelines.
- Market development: further scaling of mobility and feedstock markets, development of a market for hydrogen in electricity balancing, hydrogen storage and a hydrogen trading platform.
- Ongoing stakeholder management and alignment with related initiatives (RES, hydrogen and hydrogen regulation).

Phase V: Maturation – post-2030

- Production development: further scaling and maintenance of existing facilities.
- Infrastructure development: further scaling and maintenance of existing facilities.
- Market development: further scaling of balancing markets and the development of markets for hydrogen in cooling/heating of the built environment, hydrogen in energy production and international hydrogen trade.
- Ongoing stakeholder management and alignment with related initiatives (RES, hydrogen and hydrogen regulation).

	PHASE III (2018-2023)	PHASE IV (2023-2030)	PHASE V (2030-2050)
Production development	• Electrolyzer (1GW) • Biomass gasification (500MW) • Ammonia production (150 K. tons) • Offshore wind (1GW)	• Scale-up electrolyzer • Offshore hydrogen production • Fuel cell balancing • Further scaling offshore wind	• Further scaling and maintenance of existing facilities
Infrastructure development	• Transmission pipeline to industrial cluster (Rotterdam, Limburg, or Germany) • Eemshaven-Delfzijl pipeline • Fueling infrastructure	• Scale-up fueling infrastructure • Transmission pipelines to other industrial clusters • Hydrogen terminal (harbor facility)	• Further scaling and maintenance of existing infrastructure
Market development	• Green hydrogen feedstock offtake by chemical industry • First projects, hydrogen for mobility markets (trucks, public transport, trains and cars)	• Further scaling of mobility and feedstock markets • Electricity market balancing • Hydrogen storage • Trading platform	• Further scaling of balancing markets • Hydrogen use for cooling / heating of built environment • Hydrogen as fuel for energy intensive industrial areas

Table 1. Phasing of production, infrastructure and market development

Success factors and dependencies

A mentality shift towards embracing radical transformation in the energy system is necessary

- NIB believes that large-scale infrastructural changes are needed to enable a paradigm shift which will radically change the make-up of the economy (e.g. the development of the post-Slochteren gas infrastructure or the Maasvlaktes). In order to ensure competitiveness, economies of scale are needed.
- This will require a change in perspective from society, policy makers and industry alike. The three key ingredients will be: conveying a sense of urgency; demonstration of viable alternatives; and a feasible plan for staging ramp-up to large scale.

Scalability and cost of technology require validation

- Technical feasibility and economic viability of hydrogen at scale.
- Validation of technical feasibility through cooperation with industry partners (electrolysis technology contractors).
- Economic viability and scalability assessment through cooperation with corporate, societal and knowledge partners in pilot projects.

Safety of technology and projects requires validation

- Demonstrating safety and security of the technology at various points on the value chain, i.e. production, transportation, consumption, etc.
- Will require independent validation of technical safety.

The initiative requires a solid business case and investment commitments

- Investment commitments from corporate stakeholders (given the large scale).
- Will require a solid business case and sufficient engagement from investors.

The initiative needs to be embedded in stable energy policy and regulatory framework

- Long-term policy support and stability, as well as integration of the hydrogen economy in the broader policy strategy towards a carbon emission free economy.
- Will require commitment from policy makers and politicians at regional, national and European levels to provide policy support and stimulus.

Societal acceptance of the initiative and the underlying projects is essential

- Commitment and support from civic actors aimed at securing community and social support and addressing potential issues.
- Will require engagement with key actors from civil society – not only addressing issues, also conveying advantages (creation of jobs, realization of emission free public transportation, etc.).

Education and research on hydrogen production, transportation and utilization needs to be institutionalized

- The development of a large-scale green hydrogen economy requires skilled employees across the board, from technicians to researchers and chemists to policymakers.
- Will require the development of hydrogen economy related curricula at vocational and research-based educational institutions. Cooperation with universities and schools (e.g. Noorderpoort, Hanze University of Applied Sciences, University of Groningen, etc.) is essential.
- Cooperation with knowledge partners (e.g. Energy Academy Europe, University of Groningen, TNO/ECN and TU Delft) will be necessary for alignment with fundamental research.

Strong coordination between deployment initiatives is imperative

- Strong alignment is needed for the coordination of work streams and the overall portfolio of activities in order to guarantee that plans are concrete, aims are clear, work streams are aligned and involved parties are committed.
- Will require a strong ‘realization engine’ in collaboration with industry. We propose a powerful coalition governed by a board in which the (financially) involved organizations are represented and supported by program management.

Fit and alignment with other initiatives for a carbon-free economy (national and international) is necessary

- Fit with other solutions (technologies and initiatives) aimed at establishing a carbon-free economy by 2050 – i.e. electrification of transport, decentralization of RES production, bio-based economy, etc.
- Alignment with international initiatives aimed at establishing a hydrogen economy (e.g. the development of hydrogen fueling infrastructure in Germany) and a broader carbon emission free economy.
- Will require cooperation with knowledge partners and interaction with parties involved with other initiatives.

Masterplan phase (2017-2018)

We propose that the masterplan should consist of three sub-phases: a vision phase, a commitment and planning phase and a sub-phase where both the covenant and masterplan are finalized.

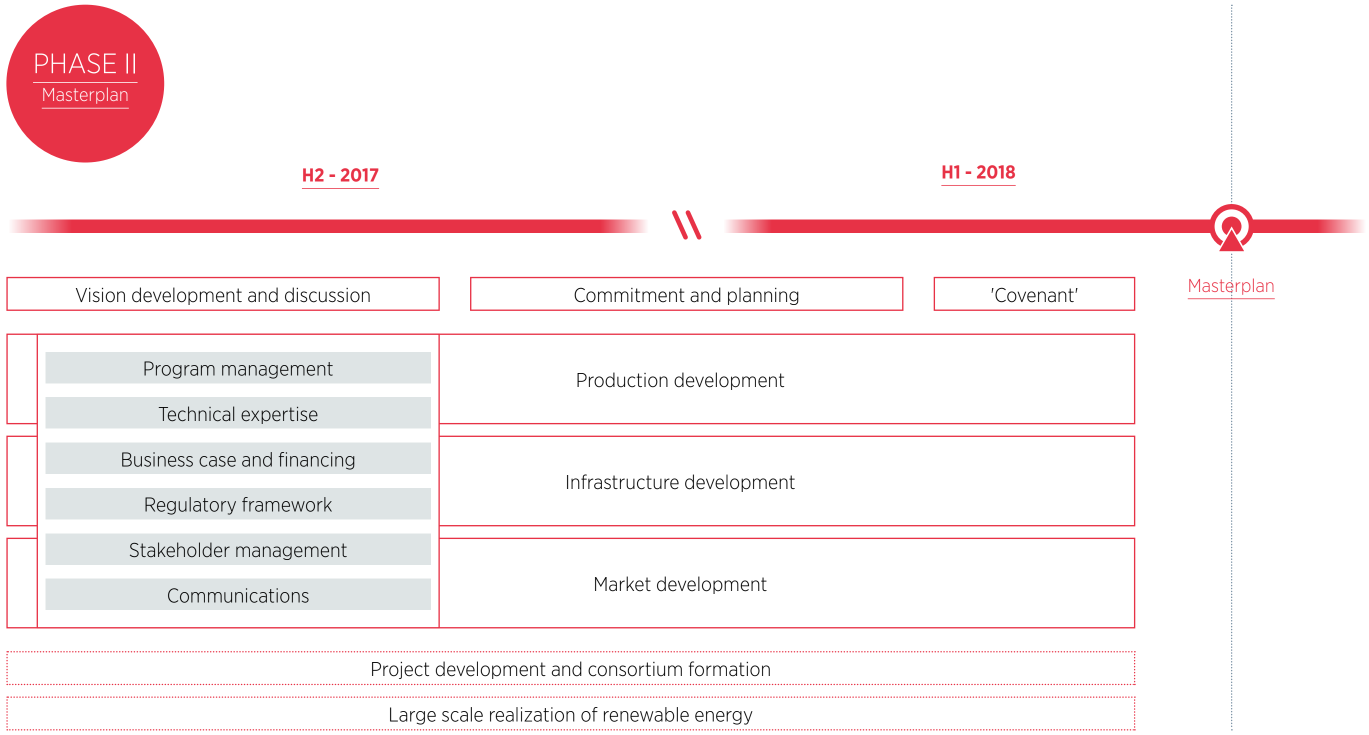


Figure 3. Roadmap for masterplan phase (Phase II)

Phase II: Masterplan

The main activity in this phase will be the creation of a master plan for the development of a green hydrogen economy in the North Netherlands. This includes three key aspects:

- A plan for the realization of initial projects: the creation of a large-scale production facility; transmission infrastructure; and the development of industrial offtake markets for hydrogen feedstock.
- This plan must take into consideration contribution to the development of a wider hydrogen economy and other initiatives/technologies aimed at establishing an emission-free economy.
- A covenant signed by stakeholders from industry, politics, civil society and knowledge centers.

Phase II involves three types of work streams: value chain work streams (horizontals); coordinating work streams (verticals); and a parallel work stream focused on alignment with project development/consortium formation activities and large-scale realization of renewable energy.

1. Value chain work streams (horizontals)
Each work stream is comprised of various topical tables:

- Production, which is primarily focused on developing the cornerstone 1GW electrolyzer. There will also be a focus on secondary production facilities (e.g. ammonia, biomass gasification) and development of offshore wind farms.
- Infrastructure, which is primarily focused on developing the cornerstone transmission pipeline to an industrial offtake cluster for hydrogen feedstock and a pipeline to Delfzijl. There will also be a focus on fueling infrastructure, distribution infrastructure, storage facilities, additional transmission spurs, port facilities, etc.
- Markets, which is primarily focused on developing a market for green hydrogen feedstock in the (petro)chemical industry. There will also be a focus on development of markets for hydrogen as a fuel for transport and for balancing. This will require research into the markets for hydrogen in cooling/heating in the built environment and for hydrogen as a fuel for electricity generation (in energy-intensive industries).

2. Coordinating work streams (verticals):

- Management of the overall project and coordination of the various work streams.
- Technical expertise and providing the necessary knowledge and technology for the development of the initiative, as well as technical feasibility and safety.
- Business cases and financing, focused on the development of a business case for the cornerstone projects needed to secure financing.
- Regulatory framework focused on research into, and the formulation and framing of, regulatory requirements for a viable green hydrogen economy and underlying projects.
- Stakeholder management to ensure public and political support for the initiative.
- Communications, specifically centrally-coordinated outreach to media and social media outlets about the overall project and work streams.

3. Alignment work stream:

- Alignment of the green hydrogen initiative with related and relevant projects: projects (consortia) resulting from this initiative and projects that are a part of the large-scale realization of renewable energy.

A clear governance structure and robust program management will be needed in order to take this multi-work stream, multi-phase, multi-stakeholder project to the next level. This entails safeguarding timelines and deadlines, ensuring that plans have clear, concrete aims, and aligning the various work streams and outputs.

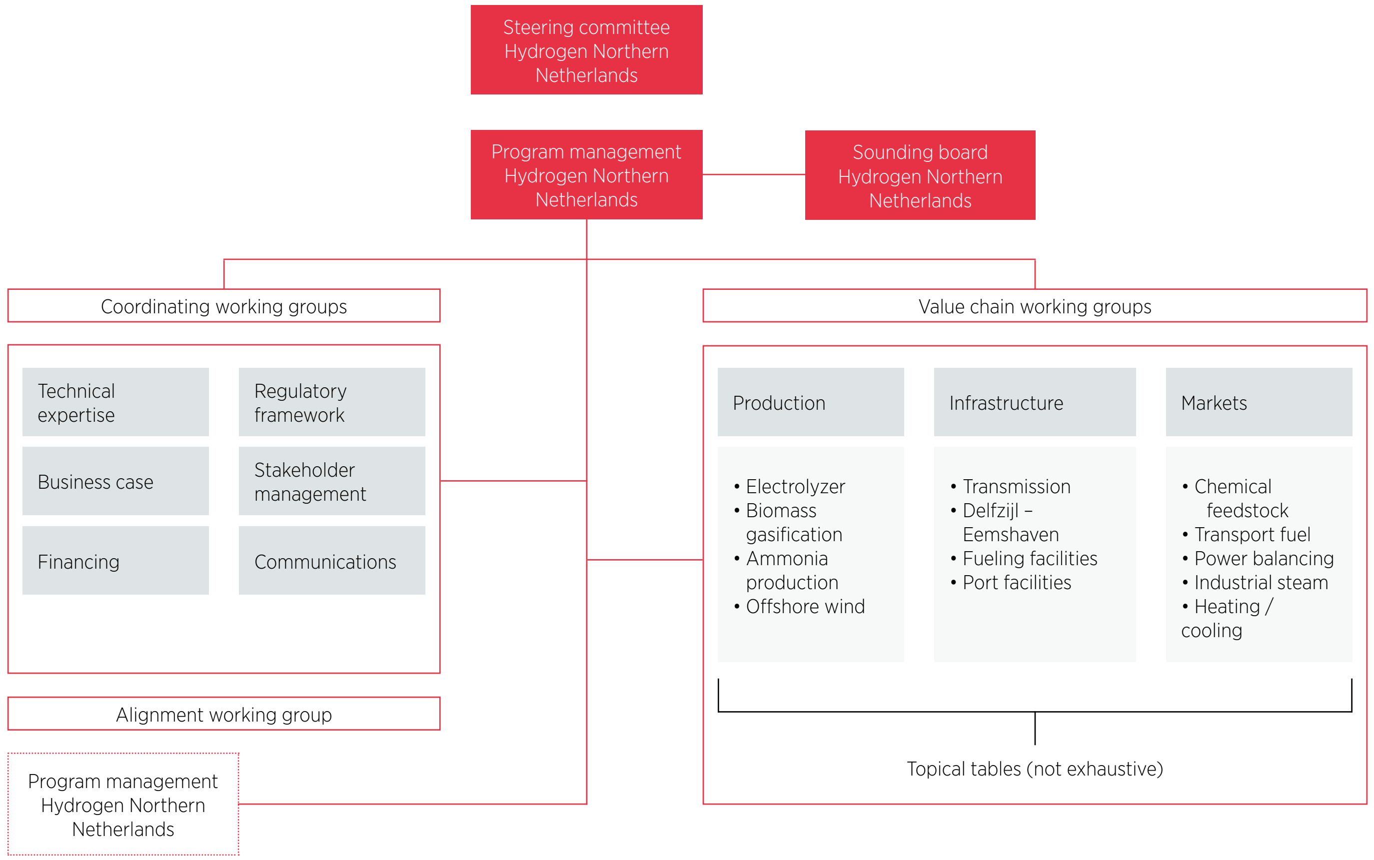


Figure 4. Project governance for the Green Hydrogen Economy in the Northern Netherlands plan

• We propose the following governance structure:

- A steering committee which will be led (on a part-time basis) by the ambassador for the initiative. The steering committee will be responsible for developing a vision, decision-making and securing commitments from investors. The committee should consist of board level decision makers from industry (e.g. chemicals, transportation and energy), politics and civil society. This team of 10 to 15 people should convene once per quarter.
- Program management which will be led (on a fulltime basis) by the program director and will receive assistance from support staff. The support staff will be in charge of the day-to-day activities, including organization, documentation, monitoring alignment among working groups, managing planning and reporting out. Program management will ultimately be in charge of governing the overall project and the work streams, as well as safeguarding coherency and overall progress.
- A sounding board with representatives from all of the stakeholder groupings. This board will be an advisory committee which provides input to program management and will meet on a monthly basis.
- The working groups will consist of a chairperson (from the industry) and other participants (from industry, academia, civil society and government) who will provide content and support. Each working group will be subdivided into topical tables to cover a range of topics relevant to each working group. Working groups will be responsible for coming up with answers and insights pertaining to their respective topics.
- Planning: three sub-phases (see figure 3). A vision phase, a commitment and planning phase and a final sub-phase where both the covenant and masterplan are produced.
- Deliverables: covenant and masterplan.
- Team: a program director (1 FTE), a support team (5-7 FTE), an expert team and a communications team.
- Budget: 3 million euros per year.

Ideation, formation and mobilization (ends mid-2017)

This initiative first started in April 2016. In this first phase, the emphasis has been on creating a vision document and a plan for the realization of this vision. The next phase will emphasize mobilizing stakeholders and securing funding.

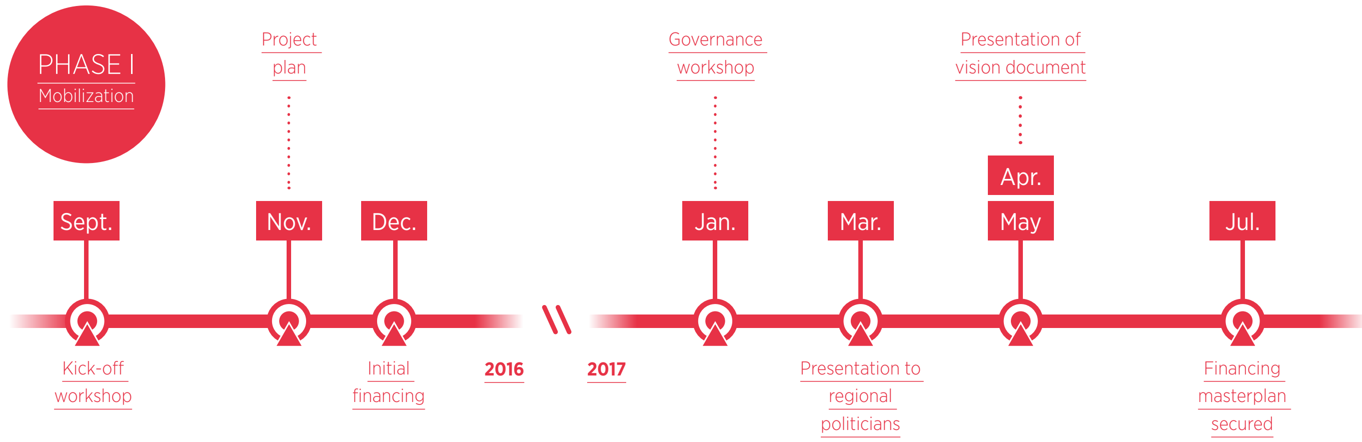


Figure 5. Project governance for the Green Hydrogen Economy in the Northern Netherlands plan

For the remained of the mobilization phase, the main activities will be to identify, engage with and mobilize stakeholders. We propose achieving this through a roadshow of workshops and meetings aimed at creating support and commitment for the masterplan phase.

Activities in the mobilization phase:

- Finish vision document.
- Interview stakeholders.
- Create a 'coalition of the willing'.
- Organization of kick-off and media events.
- Operationalization of works streams (developing project charters and establishing project teams).
- Development of the project plan.
- Coordination of media.

Two events central to mobilization:

- An event where the vision document is presented and the overall initiative is introduced to all relevant stakeholders. The event should focus on discussion and familiarization with the hydrogen initiative.
- Media event to reveal the overall plan and project leaders can present project outcomes.

Deliverables: project plan for Phase II.

Governance and team: this phase will be governed by a program management team consisting of one director (fulltime) and 2 supporting consultants (fulltime). The program management team will report to the steering committee which will be led by an ambassador for the initiative. Support from academia and communications will round out the team.

COLOPHON

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The Northern Netherlands is determined to realize a Green Hydrogen Economy