Netherlands Innovation Network

HYDROGEN

"Hydrogen makes it possible to deliver cheap, green energy all over the world. And that's not just an opportunity, it's a necessity."

Ad van Wijk,
Chair of Future Energy Systems
at TU Delft

Connecting Innovation Worldwide

DEVELOPMENTS

“The Netherlands has an excellent starting position to develop the clean hydrogen market.”

It is our pleasure to present this fourth edition of the Netherlands Innovation Network magazine. This edition is about the developments in the field of hydrogen, on production, infrastructure and applications taking place across the 17 countries worldwide where the Netherlands Innovation Network is active.

The Netherlands has launched an ambitious hydrogen strategy in 2020. Hydrogen as an energy carrier is regarded as an indispensable link in our energy transition. The Netherlands has an excellent starting position to develop the clean hydrogen market : large existing industrial hydrogen market, huge potential for linking offshore energy production to hydrogen production, transportation and storage; large ports for importing hydrogen; and an extensive natural gas grid that can be repurposed for transporting large volumes of hydrogen to industrial clusters in the Netherlands and neighboring countries.

Innovation will be key to achieve the required cost reductions and scale-up of production and application. In the Netherlands we have a strong network of knowledge institutions, companies and universities that work on hydrogen and related technologies.

Innovation in hydrogen related technologies is very much an international effort. Right now there is an unprecedented momentum in worldwide hydrogen developments. In many countries hydrogen strategies have been published and the coming years we will see a strong increase in investments in hydrogen projects.

“We are keen to learn from innovations in other parts of the worlds and welcome companies and knowledge institutions from abroad to come the Netherlands to participate in our efforts.”

This is a very welcome development , considering the urgency of the energy transition and the need to work on solutions that have a global impact. The Netherlands regards international collaboration as key to strengthening and accelerating these developments. We are keen to learn from innovations in other parts of the worlds and welcome companies and knowledge institutions from abroad to come to the Netherlands to participate in our efforts.

The Netherlands Innovation Network is there for you: for companies and knowledge institutes of every sort and size, and from every sector. So I encourage anyone with ambitions in the field of international innovation, research and collaboration to contact our attachés at the Netherlands’ embassies and consulates with whatever questions or needs you may have.

Focco Vijselaar
Director General Entrepreneurship and Innovation, Ministry of Economic Affairs and Climate Policy

Sandor Gaastra
Director General Climate and Energy, Ministry of Economic Affairs and Climate Policy

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- PROVIDER OF H_2
- REQUESTER OF H_2
- REQUESTER AND PROVIDER OF H_2
- REST OF THE WORLD/ NO INFORMATION

CONVERSION

1000 KILO H_2

= 40 MW

= 40000 KWH ENERGY

STORAGE OF H_2

350 GW

OF H_2 CAN BE STORED IN THE CURRENT GASNETWORK AND FUTURE H_2 STORAGE OF THE NETHERLANDS. WHEREAS THE CAPACITY OF THE CURRENT ELECTRITY STORAGE IN THE NETHERLANDS IS ONLY 20 GW.

PRICE OF H_2 PER KWH IN EUROS

8 CENTS WHEN MADE IN THE NETHERLANDS

4 CENTS WHEN MADE IN PORTUGAL

1 CENT WHEN MADE IN THE SAHARA

Source: Interview Ad van Wijk, Tu Delft

Richard van de Sanden
Chairman of the ElectroChemical Conversion and Materials (ECCM) Advisory Committee

Hydrogen: knowledge is capital

Ecology energy solution. Power to gas concept. Source: Shutterstock.

With his background in fundamental plasma research and energy research, Richard van de Sanden has a wealth of knowledge – making him exemplary of the state of the Netherlands. He believes the Netherlands should not focus predominantly on production, but on hydrogen knowledge and expertise.

The Netherlands is a major grey hydrogen producer. That does not necessarily mean we could do the same in green hydrogen, which is a completely different industry. Grey hydrogen production stems from the large chemical industry and the supply of gas and oil. Soon, this won't be possible anymore. Van de Sanden: "To produce green hydrogen, we need green electricity. Right now, this would cost six times more than the hydrogen we make today." Electricity from wind in the Netherlands costs about 4 cents per kWh, compared to 0.5 cents per kWh in Portugal and even less in Abu Dhabi.

"I expect our (green) electricity to remain too expensive. Also, there will be too many competing applications. Electric mobility is booming and the built environment is further being electrified. I think the electricity we generate will go primarily to that end." Besides, to ensure stability of the electricity grid, hydrogen can be produced with the purpose of being both a buffer and a raw material for industry. The Netherlands will eventually import most of the hydrogen it needs.

Export commodity: knowledge

Not a bad idea, as long as the Netherlands doesn't seek its revenue model in production. "We should focus on the supply chain: the equipment and processes that need to be developed. The Netherlands is working hard on the required knowledge for system integration." Van de Sanden proposes to export that knowledge and expertise to countries where electricity is cheap and plentiful for large-scale production of hydrogen.

The largest electrolyzer currently being built in the Netherlands has a capacity of 20 megawatts. "If you compare that with the capacity in the North Sea alone, which is around 60 to 70 gigawatts, we are in the same position with hydrogen technology as we were with solar cells some 20 to 25 years ago. This also means that the development of production technology and embedding this in the system constitute a learning curve we're only just starting. In the past, every solar panel was assembled by human hands. The same is now true to a large extent for electrolyzers. The whole production chain must continue to develop."

> **"We should focus on the supply chain: the equipment and processes that need to be developed."**

And yet, the Netherlands is further ahead than many countries and there are opportunities to grow into an important player in the field of the production industry for H_2 technology. This is in part due to cooperation and exchange between the government, the business community, and knowledge institutes. "We have several knowledge hubs, such as here in Eindhoven and in the region surrounding Arnhem. This is unique in the world. Knowledge-intensive companies that are attracted by this will help accelerate the development."

Hydrogen gas

While there is a long way to go, the progress already made is equally impressive. "I recently saw a 2009 booklet from the ministry of Economic Affairs on energy. Reading it, I thought: surely this can't be just a little over ten years ago! It contains clauses about 'advanced' coal power plants", says Van de Sanden, with a laugh. "Bizarre. Ever since the climate agreement, there has been a total turnaround."

The role of hydrogen in this transition is important, he says, but not a panacea. "Smart electric heating with microwaves or RF technology, for example, is promising. Many thermochemical processes now use natural gas for heating and this can be done more sensibly with electric heating. You don't need to burn hydrogen for that." He warns against the danger of replacing gas with hydrogen. "That's not a good idea; hydrogen is too high-value and expensive."

Van de Sanden reckons there won't be a genuine business case for Dutch hydrogen until the CO_2 price rises substantially, = the price of electricity drops dramatically – to around 0.1 cents per kWh – and the use of natural gas becomes exorbitantly more expensive and therefore discouraged. "That is so unlikely that it's better not to count on it. Electrolyzers in the Netherlands are ultimately not intended for production. They're intended for learning purposes and to keep the power supply stable. And continuing to learn is exactly what the Netherlands must do."

USE AND NEED OF H_2 IN THE NETHERLANDS

20 MW ELECTROLYZER
IS CURRENTLY IN USE

200 MW ELECTROLYZER
IS CURRENTLY BEING DEVELOPED

1000 MW = 1 GW
ELECTROLYZER IS BEING RESEARCHED

60-70 GW
TOTAL NEEDED POWER AT SEA

860 TW
TOTAL ENERGY USE IN THE FUTURE

“HYDROGEN IS WHERE SOLAR CELLS WERE 20 YEARS AGO; WE NEED A CHAIN DEVELOPMENT TO ACCELERATE.”

RICHARD VAN DE SANDEN

China is kick-starting the green hydrogen economy

China is the world's largest hydrogen producer, but for now, the vast majority still concerns grey hydrogen. Green hydrogen may make up 70% of all hydrogen supplied by China by 2050, up from 15% in 2030 and 4% in 2020. The country aims to reach carbon neutrality in 2060. China, like the Netherlands, sees a major role for green hydrogen in this process.

Hydrogen hubs

China has taken major steps to kick-start the green hydrogen economy and, just as it did in the wind and solar energy sectors, aims to become a leading player. The national government sees hydrogen as part of new strategic industries. However, provincial governments are driving the hydrogen agenda. At least 16 provinces specifically mention hydrogen as a key priority. Certain regions are recognized as hydrogen hubs. Beijing, Guangdong and Shanghai have been designated as fuel cell vehicle (FCEV) application demonstration regions. Shanghai, with 1,171 FCEVs in 2020, aims to have 10,000 units by 2025. Guangdong Province is the most active applicant for government subsidies, aiming to build 300 hydrogen refueling stations with 16,000 FCEVs on the roads by 2025.

Crude Oil, Storage Tank, Fuel and Power Generation in the harbor of Hong Kong.
Source: iStock/Getty Images

A hydrogen fuel cell bus concept. Source: iStock/Getty Images

> “In China, several thousands of hydrogen buses already operate nationwide.”

Hydrogen application

The hydrogen economy is now gaining momentum, but the application of hydrogen in China is still trailing behind other components of the hydrogen supply chain, such as production. It’s still very impressive because of China’s large-scale use of several thousands of hydrogen buses that already operate nationwide.

China had over 8,000 FCEVs at the end of 2020, with around 5,000 hydrogen buses and 3,000 trucks. It trailed South Korea’s 10,000 FCEVs and the 9,000 units in the US. About 104 hydrogen refueling stations were built by the end of 2020, mostly in Guangdong and Shandong provinces.

Meanwhile, many projects focusing on other forms of transport, like trains and vessels, are underway. Most famous example is the hydrogen tram in the city of Foshan. Chemical parks are scaling up projects with hydrogen as a feedstock and the huge Chinese steel industry is looking at the use of hydrogen in steelmaking.

Opportunities

Local governments and hydrogen hubs in China are not cooperating and there is often competition between these areas. Because of this, they all want and need to build up their own local hydrogen supply chains. There are opportunities here for Dutch companies and universities to cooperate on a technological level or to sell technology-advanced products to improve the local supply chains. Within China, the Netherlands is well-known for its developed hydrogen industry and advanced hydrogen technology. For universities such as TU Delft and research institutes such as TNO, China is full of opportunities to do joint experiments where a larger scale or longer distances are required. For example, the transportation of hydrogen is an issue that many larger areas are still struggling with.

Finally, there are already several Dutch hydrogen companies active in China, such as Teesing, Shell, SHV, and Bronkhorst; as well as a Hydrogen PiB with 5 cluster members, namely KIWA, Nedstack, HAN University, HyMove, and HyEt. This all showcases the strong interest that the Dutch hydrogen sector has in the Chinese market.

Although the pandemic has not made the situation any easier, the Netherlands Innovation Network in China will continue to strengthen scientific and economic cooperation by establishing dialogue, looking for opportunities, and bringing both parties together via webinars, online roundtables, online match-making sessions, local delegations, conferences and expo’s, etc.

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Hydrogen – future energy carrier for the German industry

The German industry is feeling the pressure to reduce CO_2 emissions. Especially the steel and chemicals sectors that mainly depend on oil and gas today see the potential of hydrogen as an energy carrier to transform their manufacturing process. In June 2020, the German government stated the ambition to become a global leader in hydrogen technology in their National Hydrogen Strategy. This strategy sets out measures of € 9 billion that will help private parties with investments in hydrogen production, infrastructure and use.

Demand vs. supply

Total hydrogen demand in Germany, mainly coming from the industrial sector and heavy transport, is expected to be 110 TWh in 2030. On the supply side, the German government has doubled the goal for the capacity of electrolyzers from 5 GW to 10 GW in 2030. Even if this goal can be met, experts state that national production will only cover 26% of the total hydrogen demand. To facilitate the ramp-up of import chains and a market for green hydrogen, the German government launched the H2Global initiative. The H2Global foundation will buy hydrogen on the international market and resell it via auctions within Germany. The government will compensate for the price difference, estimating a total cost of € 915 million. A substantial part of the hydrogen from countries like Morocco, Spain, and Chile will be imported via the Netherlands.

Research

The German government is investing in research on all aspects of hydrogen and has created numerous well-funded research clusters and new institutes all over the country. Examples are a center for synthetic fuels in aerospace and shipping in Bremen and the HC-H2 cluster for industrial transformation in Jülich. The federal ministry of Education and Research invested € 700 million in 3 large projects: H2Giga (technology for series manufacturing of electrolyzers), TransHyDE (hydrogen transport for long and short distances) and H2Mare (hydrogen production offshore).

> "Germany has explicitly stated the intention to cooperate with the Netherlands."

Regions

Several of Germany's 16 federal states have published their own hydrogen strategies. North-Rhine Westphalia has a lot of heavy industry for which electrolysis and power-to-X developments are important. Cross-border infrastructure (pipelines, rails, boat) provide opportunities for Dutch companies. The northern parts of Germany and the Netherlands are cooperating closely as they have a lot in common with the offshore wind farms in the North Sea. Saxony is an interesting region because of the high-tech and chemical industries as well as investments in sustainable transport and H_2 production. The two southern states, Bavaria and Baden-Württemberg, are known for their automotive industries and invest massively in H_2 refueling stations and fuel cell technology.

Cooperation with the Netherlands

Germany has explicitly stated its intention to cooperate with the Netherlands both on national and regional level. The Dutch diplomatic network in Germany actively supports Dutch-German cooperation in creating the next generation of electrolyzers and helps strengthen the Dutch position within the import chain of hydrogen to Germany. Together with public and private partners in the Netherlands, and several regional German clusters and research centers, we are organizing a series of knowledge exchange and matchmaking events.

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Offshore wind farm turbines at dusk in the middle of the sea. Source: iStock/Getty Images

Canada: The Silicon Valley of hydrogen fuel cell technology

The world is slowly waking up to Canada's tremendous hydrogen potential. There is a reason some call it the Silicon Valley of hydrogen fuel cell technology. The recently signed "Canada-Netherlands Hydrogen Memorandum of Understanding" shows that Ottawa and the Hague realize what is at stake and it is a clear sign that both countries want to capitalize on the opportunities quickly. With a leading innovation and industry position Canada is very well positioned to become a world-leading supplier of hydrogen and related technologies in the near future.

Hubs for hydrogen fuel cell development, electrolyzers, and SMR+CCUS technology are forming around Toronto, Edmonton, and Calgary, with Vancouver as the country's true clean-tech/hydrogen powerhouse. These hubs are supported by strong academic research universities and national labs across Canada. Universities, entrepreneurs, research institutions and VC's have created diverse and promising ecosystems throughout the country. Altogether, Canada offers over a hundred companies working with hydrogen technologies and dozens of academic and research hubs.

Canadian Hydrogen Intensity Mapping Experiment (CHIME) Radio Telescope near Penticton, British Columbia, Canada. Source: Adobe Stock

CANADA

CANADA

“Canada has strengths across the whole low carbon hydrogen value chain.”

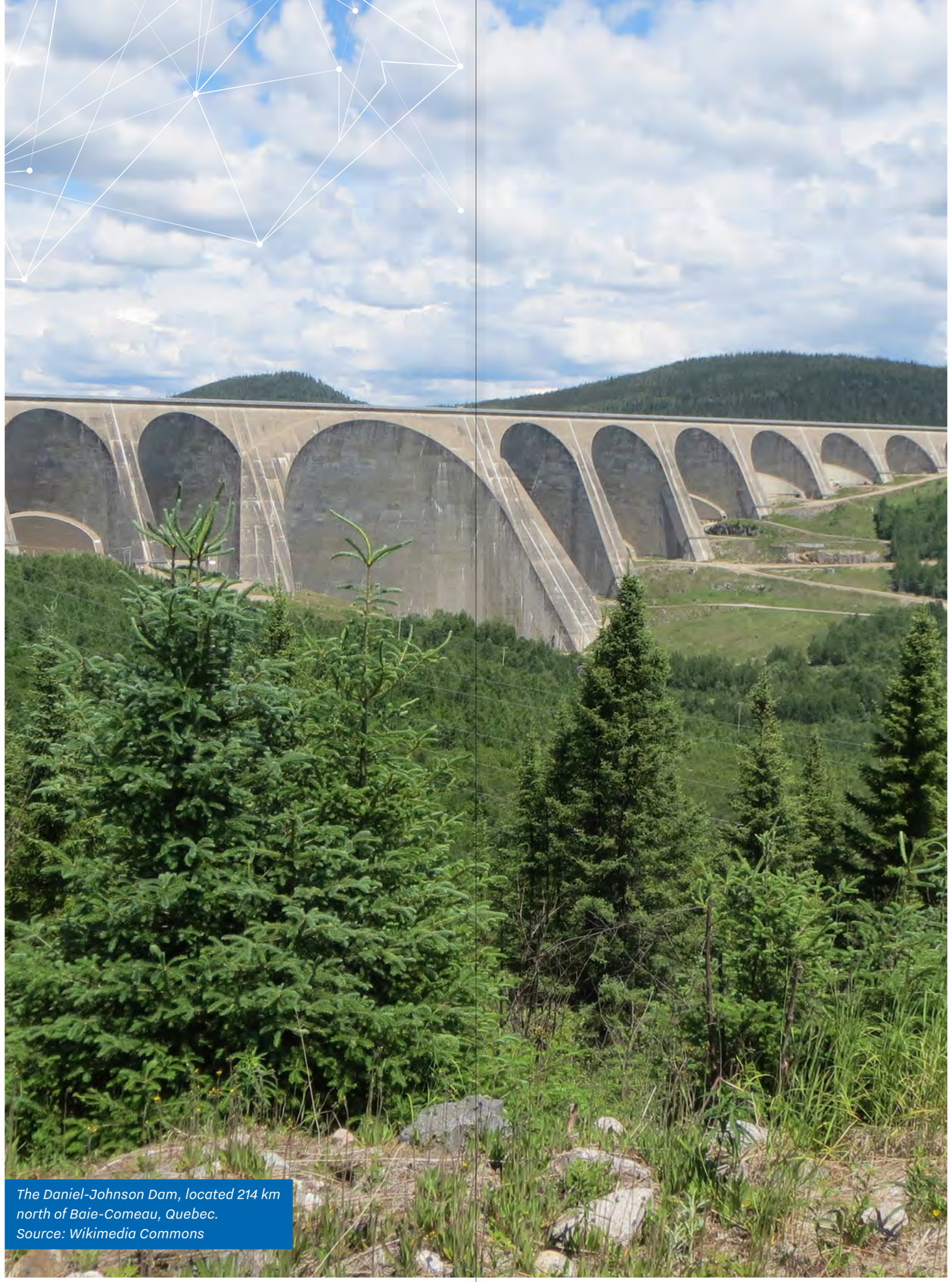
In December 2020, Canada released its national-level hydrogen strategy. The goal is ambitious: to become one of the top three global clean hydrogen producers, users and exporters of clean hydrogen and associated technologies in the world. Being blessed with abundant resources to produce green hydrogen – such as tremendous hydroelectricity capacity – this ambition could well become reality.

Canada is known to have strengths across the whole low carbon hydrogen value chain: from hydrogen production through storage and transport technology and end-use applications. Increasing demand for clean energy products and solutions domestically and worldwide is generating opportunities for investments in a broad range of applications, including passenger vehicles, buses, trucks, trains/trams, ships and planes, stationary and back-up power, and material handling.

Vancouver - British Columbia

Vancouver has quickly become known as a major cleantech hub, having exciting start-ups (many of them with unicorn potential), outstanding research at for example the University of British Columbia (UBC), a community of top international scientists and its own ambitious hydrogen strategy. Some shining examples:

- One of Canada’s hydrogen technology leaders, Ballard Power Systems, has for decades dominated the global fuel cell technology. Ballard develops and manufactures fuel cell products and is widely considered to be the leader in the global market for customized fuel cell engineering solutions and services. In total, almost 160 hydrogen buses with Ballard fuel cells are currently in operation in Europe (28 in the Netherlands), an increase of 80 per cent compared to October 2020. Worth mentioning is the number of hydrogen buses driving on Ballard’s fuel cells in China: 2800 (with an objective to put a million fuel cell vehicles on the road by 2030).
- Another inspiring startup is Svante Inc., a company that helps capture carbon from industrial cement, steel, and other manufacturing plants. Svante has raised more than $190 million since being founded in 2007, and has operating projects with a number of companies including Husky Energy, Total S.A. and LaFargeHolcim and both the Canadian and US government.
- One exciting academic example is Mérida Labs, an energy innovation hub located at UBC. It recently has secured $23 million in funding to convert a city-sized block into a smart energy district through the addition of a solar array, a hydrogen refueling station for light- and heavy-duty vehicles and charging infrastructure for electric vehicles.



The Daniel-Johnson Dam, located 214 km north of Baie-Comeau, Quebec. Source: Wikimedia Commons

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Turkish challenges in the energy transition

Turkey has always imported around three-quarters of all its needed energy. Last year, the costs of this import skyrocketed. Moreover, the EU Green Deal and its "Fit for 55" program force Turkish companies to switch to carbon neutral energy resources. Turkey finally ratified the Paris agreement during COP26 and was one of the 12 signatories of a Memorandum of Understanding initiated by the Dutch Ministry of Water & Infrastructure about Zero Emission Heavy Duty Vehicles by 2030.

To alleviate the dependence on energy imports and to meet international standards, Turkey has invested in local energy resources. Building a hydrogen industry has become an important energy strategy. Recently, the gas distribution association of Turkey – Gazbir – launched a

Turkish Petroleum Refineries Corporation in Izmit, Kocaeli, Turkey. Source: iStock/Getty Images.

Yellow gas pipeline with additional equipment, pipes and a valve to shut off the gas supply. In the background an gas compressor station.
Source: Shutterstock.

“A clean hydrogen center was recently launched.”

clean hydrogen center which focuses on hydrogen as well as biogas. Gazbir successfully tested various levels of hydrogen blending into the natural gas grid. Turkey is expected to decide on a hydrogen strategy later in 2022. The Turkish Ministry of Transport has already indicated the intention to develop R&D programs for use of green hydrogen in key ports and the national fleet, as well as for developing hydrogen fuel cell production.

Turkey’s green hydrogen production potential in 2050

Currently, 42% of the electricity that Turkey generates comes from renewable sources, mainly hydropower installations. The total installed renewable energy capacity is expected to grow to 174GW by 2050, or 84% of the net total electricity demand (546 TWh). By 2050 green hydrogen production can reach 3,4 Mt/year. The export potential ranges from 1,5 to 1,9 Mt/year by 2050.

Potential use of hydrogen in Turkey

Turkey’s energy consumption in the heavy industry at 645 TWh is 38 per cent of the overall energy demand. Heavy industry accounts for half of Turkey’s total net electricity output and the share of electricity in this energy consumption is over 25 per cent. Hydrogen has been widely used in oil refining and chemical and petro-chemical production. This experience of production, transportation, and industrial use of hydrogen may help the introduction of cleaner hydrogen in Turkey.

Ministry of Energy Resources of Turkey,
https://enerji.gov.tr/info-bank-energy-diplomacy-detail

Use of boron in hydrogen storage

Since Turkey possesses 72,8% of the world’s boron reserves, there is a strong focus on developing uses for boron. Eti Maden, the Turkish mining company, is developing sodium borohydride technologies for hydrogen storage, as is the National Boron Research Institute.

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2021–2025	Initial pilots, including innovation and demonstration projects, finalize testing of domestic appliances, and start working on a regulatory regime.
2025–2030	10 per cent hydrogen blending (i.e. 3-4 per cent by energy content) into parts of the natural gas grid, development of the renewable and low-carbon gas market, increasing incentives for the production of hydrogen-ready appliances, and development of regulations for transport, storage, distribution and consumption of hydrogen.
2030–2040	Up to 20 per cent regional hydrogen blending, an increase in hydrogen production, and connecting industrial clusters to hydrogen storage and production facilities by dedicated hydrogen pipelines.
2040–2050	Widespread use of hydrogen in heavy industry and residential buildings, distribution lines to be 100 per cent hydrogen compatible, start of hydrogen export, sufficient hydrogen production and storage capacity.

Sunset of Rotterdam Harbor. Source: iStock/Getty Images.

Port Authority is the driving force behind the hydrogen transition

Monica Swanson
Business manager international hydrogen projects for the Port of Rotterdam

Monica Swanson had been working for the Port Authority for several years when she was asked for this role. Swanson assesses potential opportunities: for the port, for countries that can produce hydrogen and for companies and countries that want to use it as a sustainable alternative to fossil energy.

At the time Swanson started, in late 2019, hydrogen was a new subject for her. “I literally read a chemistry book to become familiar with the subject. I can recommend that to anyone. Hydrogen was new to a lot of people at that time, so we were all starting at the same level, so to speak.”

Assignment

The Port Authority is strongly committed to the energy transition. It wants to facilitate industry in reducing CO_2 emissions and at the same time ensure that Rotterdam remains the most important energy port in Europe. At the moment, a lot of oil is still imported. In the future, this must be sustainable energy. In this context, the Port Authority was asked by the government to look for sources of hydrogen for the future energy supply of the Netherlands. “We were in effect given a task by and for the country,” says Swanson. Together with her colleague Martijn Coopman, she started making an inventory. “We first made an analysis with the whole team. We scanned the entire world, so to speak, for good conditions for generating green electricity, because that is what you need to make green hydrogen.”

These conditions are plentiful in many different parts of the world. The Middle East, for example, has perfect conditions for generating solar energy, but Canada is also ideally suited because of its abundance of hydropower. Iceland has wind and geothermal power. And there are numerous other examples worldwide. Proximity to seaports is also a relevant factor, as otherwise the hydrogen cannot be exported. Swanson sees enormous opportunities, both for importing, using, and transporting hydrogen, and for the development of countries. “Northwestern Europe is densely populated, we all consume a lot of energy and we have too little space to generate it sustainably. Some other parts of the world are much more sparsely populated, while the conditions for generating green electricity there are much more favourable than here. The export of green hydrogen could be a welcome source of income for many countries.”

Taking the lead

The port of Rotterdam plays a key role in the European energy system. It transports three times as much energy, mainly in the form of oil, as the whole of the Netherlands consumes. “We have done an analysis and along the way have made many contacts, helped set up projects and created coalitions to set up import chains for hydrogen. We assume that in 2050 we will be importing eighteen million tonnes of hydrogen via Rotterdam. From 2030 onwards, demand will rise very quickly from two to eighteen million tonnes,” says Swanson. The port authority is helping to kick-start that market. The company now has dozens of cooperation projects running with the aim of setting up imports via Rotterdam. “That means we are now also developing infrastructure for hydrogen in the port and towards industry in Chemelot and Germany.” Because hydrogen is gaseous, efforts are being made to find the best way to transport it by ship. The most likely way seems to be to ‘pack’ the hydrogen molecule in other substances such as ammonia and methanol.

“We assume that in 2050 we will be importing eighteen million tonnes of hydrogen via Rotterdam.”

Swanson sees a world full of opportunities. “Let’s hope governments see these opportunities and move along with them. We need governments, big companies with capital, small companies with interesting technology, and, above all, cooperation.”

Not only the Netherlands and Europe, but also other countries with a large energy demand are working on the hydrogen transition. Japan and Korea no longer want to use nuclear energy and, in fact, no coal either. Swanson: “There is a lot of interaction between those countries and Australia, which of course is close by. We are looking all over the world to see where the opportunities lie and what we can get going most quickly. Distance is not a major factor in cost. Once it’s in a ship, it doesn’t really matter how far you sail with it. It is also expected that those distances will be covered by ships with increasingly cleaner and ultimately emission-free fuels - and then we will have come full circle.”

EXPORT OF H_2
IMPORT OF OFFSHORE WIND
IMPORT OF H_2

Source: Interview Monica Swanson, Port of Rotterdam

“WE SCANNED THE ENTIRE WORLD, SO TO SPEAK, FOR GOOD CONDITIONS TO GENERATE GREEN ELECTRICITY.”

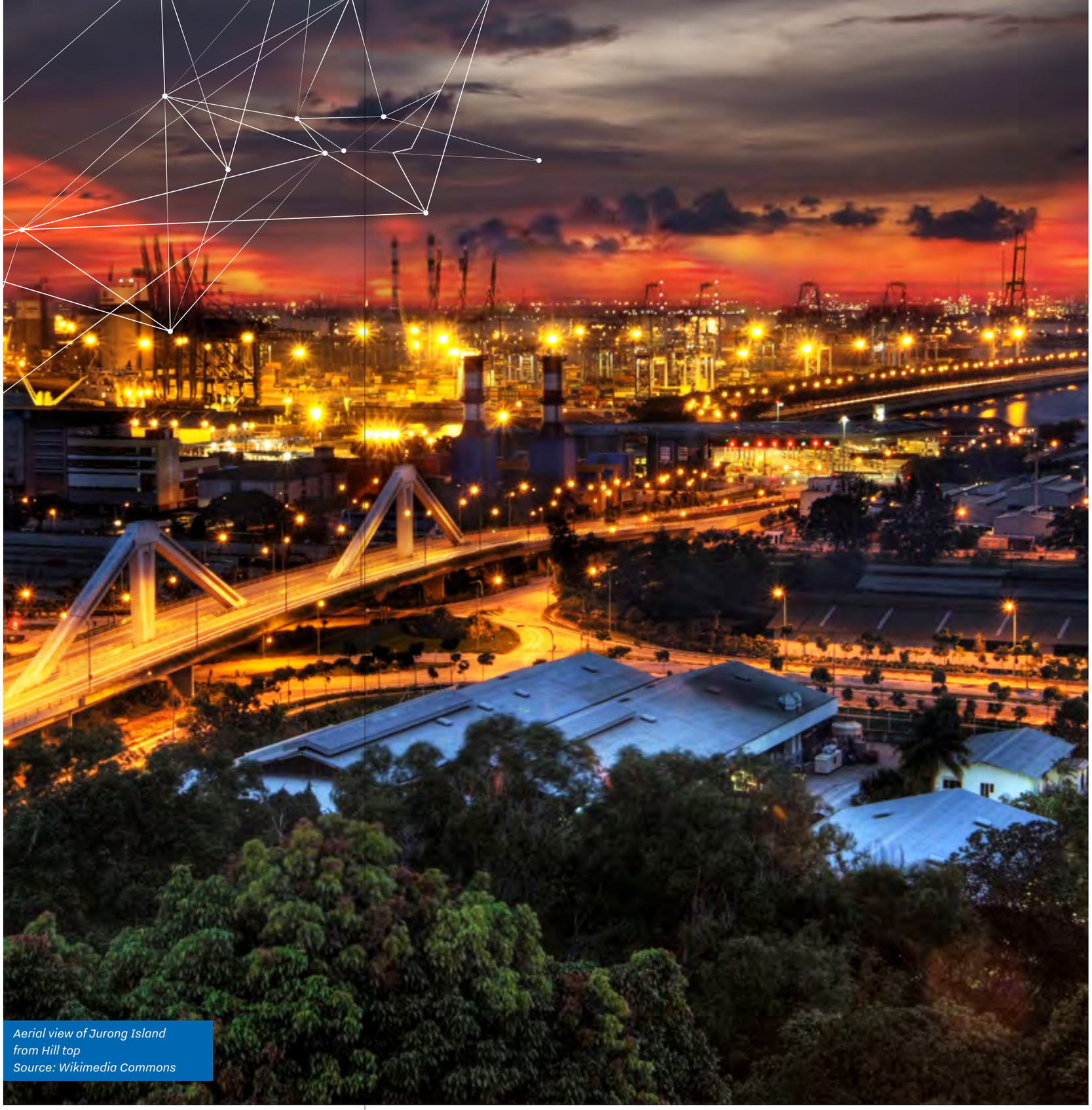
MONICA SWANSON

Singapore: using and transporting energy by the gigawatts

Singapore is a relatively small and densely populated city-state. Over 95% of the energy mix consists of imported natural gas; the remaining 5% is mainly generated from the sun, waste and biomass. According to the country's "Green Plan 2030", the use of low-carbon hydrogen is essential to make sure that Singapore achieves its vision of a cleaner, more reliable and affordable energy future. Low-carbon hydrogen can either be produced domestically or imported via ships and pipes.

Application areas of hydrogen: industry and maritime

The country wants to exploit its existing grey hydrogen and natural gas infrastructure to pilot the use of



Aerial view of Jurong Island from Hill top
Source: Wikimedia Commons

SINGAPORE

Singapore Port viewed from The Pinnacle. Source: Wikimedia Commons.

hydrogen in suitable downstream applications, with a clear pathway towards the eventual use of low-carbon hydrogen. A lot of the energy is consumed by the maritime sector and port. Therefore, Singapore aims to use low-carbon hydrogen as fuel in the maritime sector, as well as in the operation of their port.

The Port of Singapore is one of the busiest in the world and it is also the world's most important bunkering hub with 130,000 vessels making port calls annually. For port operations, hydrogen is expected to become an important fuel as it should power port equipment such as tugboats, passenger boats, and bunker tanks, as well as heavy transport vehicles operating on land. Singapore has been running a pilot program for liquefied natural gas (LNG) as a maritime fuel since 2017. To decarbonise the shipping industry, Singapore wants to play an important role as a hydrogen hub within the Asia-Pacific region and export knowledge and developed technologies to neighbouring countries. To this end, the Maritime and Port Authority of Singapore is in the process of establishing a research centre which will focus its efforts on maritime decarbonisation. This centre will bring together industry partners and focus on translating technologies into viable solutions for ocean-going vessels.

Singapore plans to use blue or green hydrogen as a replacement for the use of grey hydrogen in the industrial cluster on Jurong Island. Hydrogen is an important feedstock in the oil refining and petrochemical industry and can be used as a substitute for natural gas to produce heat and electricity. Singapore wants to transform the island as a model for solutions in the field of Carbon Capture, Utilization, and Storage (CCUS), low-carbon hydrogen, and circular economy.

Other areas of application

Research is being done on the needed infrastructure to support the deployment of hydrogen. In the aviation sector, R&D efforts go to ensuring the safe and economic use of hydrogen for future aircrafts. Changi Airport is looking to setup a hydrogen aviation hub in collaboration with governmental and industry partners to explore demand and production supply of hydrogen. The authorities are also looking into the applications in the mobility and transport sector within Singapore. Singapore is stepping up R&D expenditure and announced in July 2022 the set up of a hydrogen R&D center focusing on hydrogen carriers and global hydrogen supply chain.

"Singapore wants to transform the island as a model for solutions."

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India’s aim to produce the cheapest hydrogen in the world

Producing 500GW of renewable energy by 2030 and to become a net-zero emitter by 2070: India is aiming high. CEEW, a think tank based in Delhi, projects that investing in green hydrogen and CCS is crucial to achieve these targets, and the government has slowly but surely been pushing for policies to adapt to these technologies. The strategic reasoning is not only to mitigate climate impacts, but also to reduce international energy dependence for India, which currently imports 85% of its oil, 50% of its natural gas, and 30% of its coal.

> “India can become a global leader because it has the advantage of a large domestic market and low labor cost.”

In August 2021, Prime Minister Narendra Modi launched the National Hydrogen Mission. This mission comes with a budget of € 88 million and sets the goal to reduce petroleum use and greenhouse gas emissions. It is India’s ambition to get the price of green hydrogen below € 1.8/kg in the next decade and make India the largest and cheapest (green) hydrogen producer in the world.

These are high ambitions in a global market where many strong players are emerging, notably from the EU, China, and Japan. Moreover, on a national and international level, hydrogen will have to compete with fossil fuels and low-carbon alternatives such as electric batteries. Policy think tank TERI does see a window of opportunity for India to become a global leader as it has the advantage of a very large domestic market combined with low labor cost.

Enabling mass production of green hydrogen

India’s green hydrogen sector is currently at a nascent stage, as a result of which the cost of production is high. The state-run Indian Oil Corporation announced India’s first green hydrogen plant using electricity from wind energy projects. It expressed interest in international cooperation on green hydrogen plants and initiated talks with prospective bidders.

The private sector also shows a lot of interest in green hydrogen. Adani, an Indian conglomerate, pledged to invest € 62 billion over the next decade to produce the cheapest hydrogen in the world. Asia’s richest man, Mukesh Ambani, has a € 8.8 billion plan to invest in (green) hydrogen solutions through his multinational company Reliance.

To further enable the hydrogen market, the ministry of New and Renewable Energy (MNRE) proposed to include green hydrogen in Renewable Purchase Obligations. The ministry also established Research, Development and Demonstration programs that welcome (inter) national collaboration on the production of hydrogen through renewable routes. Projects to develop regulatory frameworks, hydrogen-based public transport, and hydrogen refueling stations are ongoing.

Opportunities for Indo–Dutch cooperation

In July 2022 the Netherlands Innovation Network in India and thinktank TERI launched the report ‘Towards a Clean Hydrogen Ecosystem: Opportunities for Indo–Dutch cooperation’. The report is the result of a project that explored bilateral collaboration and connected Indian and Dutch hydrogen stakeholders from both industries, governments, and academic institutions. The report shows that bilateral cooperation can be fruitful for both India and the Netherlands as the countries can benefit from each other’s expertise on developing and scaling up a green hydrogen sector, particularly in the field of technology transfer, transportation and storage.

Want to know more?

Please contact the Netherlands Innovation Network India at *nde-ia@minbuza.nl*

Hydrogen tanks. Source: Shutterstock.

Facing the challenges

On November 29, 2021, Ms. Karin Elharrar, the Israeli minister of Energy, Hans Docter, NL ambassador, and Marieke Monroy, deputy NL ambassador to Israel, discussed ways in which the Netherlands can play a role in Israel's attempts to develop its green hydrogen economy. Israel aims to produce, store, and use green hydrogen, following a transition from grey hydrogen production to blue hydrogen, including the application of Carbon Capture, Utilization, and Storage (CCUS) from its natural deep-sea gas fields.

This will be achieved by i) transitioning from natural gas to renewables, mainly solar energy (aiming at 30% renewable energy by 2030); ii) the construction of small-scale green hydrogen production facilities; iii) the application of hydrogen in the mobility sector (Israel is building its first hydrogen refueling station and is considering importing hydrogen fuel cell buses); iv) the development of national hydrogen policy, including legislation and regulation. These actions are aligned with Israel's commitment in Glasgow to reach net-zero CO_2 emissions in 2050, by, among others, phasing out coal by 2025 and electrifying the mobility sector.

Ashalim Power Station, Israel, on its completion the tallest solar tower in the world. Source: iStock/Getty Images.

Challenges

Green hydrogen production from renewable solar energy poses several challenges, such as land use for solar panels and technological matters, both of which offer opportunities for the Netherlands. Following the Abraham Accords, the United Arab Emirates-funded Jordan-Israel agreement, signed November 22, 2021, demonstrates that energy and water are tradeable: Israeli desalinated seawater will be exchanged for Jordanian solar energy which can be used to produce green hydrogen.

Other regional green hydrogen sources are the huge production initiatives in the Gulf Countries. Israel can transport imported green hydrogen to the Netherlands/Europe through pipelines and/or its seaports. Thus, Israel can serve as a gateway of green hydrogen from the Middle East region to the Netherlands/Europe and contribute to the Netherlands' need to import green hydrogen.

Startup ecosystem

Dutch electrolyzer technology and know-how can address Israel's ambition to produce green hydrogen. Currently, Israeli hydrogen generation initiatives, such as the ICL Group hydrogen hub in the Dead Sea area for industrial usage, and a small-scale hydrogen pilot project by Energy Infrastructure Ltd. in the North, are at early discussions with companies from the Netherlands.

Israel is known for its vibrant startup ecosystem, which led to the development of Israeli Climatech startups, such as H2Pro and GenCell. The former won Shell's 2020 New Energy Challenge prize and the latter produces hydrogen from ammonia. These technologies could also be scaled up in the Netherlands.

R&D efforts

Green hydrogen production requires international R&D efforts which could be financed by Horizon Europe and FCH-JU projects at which Dutch and Israeli partners cooperate as member state and associate country, respectively.

In 2021, Innovation Attaché (IA) Israel transferred knowledge on hydrogen through bilateral mini-symposia with Dutch and Israeli speakers from industry, academia, and governmental organizations. IA Israel will co-organize a mission from Israel to the Netherlands in May 2022 in cooperation with EZK and Dutch partners, such as New Energy Coalition and TU Eindhoven, which is expected to lead to R&D cooperation and economic opportunities in the field of hydrogen production and storage. Additionally, we expect the bilateral forum to reconvene in 2022 during which Dutch-Israeli green hydrogen cooperation can be discussed.

> "Israel is blessed with solar renewable energy, revolutionary green hydrogen production and storage technology"

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A world-leading hydrogen economy

The United States (US) is singularly positioned to build a world-leading hydrogen economy, being blessed with abundant, low-cost primary energy sources needed to produce low-carbon hydrogen, such as wind, solar, hydropower, and nuclear. Owing to its large refining and chemical sector, the US is already one of the largest producers and consumers of hydrogen, yet ambitions continue to be raised. The Department of Energy (DOE) recently launched the Hydrogen Shot, bringing together stakeholders with the aim of slashing the cost of clean hydrogen by 80% (to USD 1.00/kg H2) by 2030. Studies show scenarios for expanding the hydrogen market to 41 Mt per year – doubling or even more than tripling current demand. Today's major hydrogen-producing states – California, Texas, and Louisiana – are expected to play a key role.

> "California, Texas and Louisiana will play a key role."

Fuel-cell electric vehicles: it's a California thing

California is the center of demand for clean hydrogen, driven by the demand for gas to power fuel-cell electric vehicles (FECVs). With fifty different regulations and incentives, California has been actively encouraging the growth of this market. Of the 100 hydrogen fueling stations in the US, 60 are located in California and another 118 are currently in development in this state. Around 11.000 FCEV's call the California roads their home, out of the total of 14.000 having been sold in the US thus far. Also, a number of international truck manufacturing companies, such as Hyundai, have announced plans to introduce the world's first mass-produced, heavy-duty trucks powered by hydrogen fuel-cell technology in California.

Texas, a leader in the energy transition?

With a production of 3.6 million metric tonnes of hydrogen per year, Texas is currently the largest hydrogen producer in the US. About 95% of this production is "gray" hydrogen – produced from natural gas – and this is being used in the petrochemical sector. However, with tremendous opportunities for CCUS (Carbon Capture, Utilization and Storage), this gray hydrogen could easily become blue. And with limitless availability of cheap renewable energy (particularly wind energy), eventually, Texas could become the country's major hub for producing green hydrogen. DOE is funding a demonstration of the design, build, and operation of the country's first dedicated renewable hydrogen network, starting in Texas. Over a three-year period, H2@Scale in Texas and Beyond aims to scale up clean hydrogen technology, working together with the University of Texas and private companies like Shell, Mitsubishi Heavy Industries, and Air Liquide.

Blue hydrogen in the US Gulf Coast

Louisiana is the third major producer of hydrogen in the US. Currently, most of the hydrogen produced in Louisiana is used for industrial purposes, but the state is poised to produce hydrogen for FCEVs as well. Air Products recently announced an investment of $4.5bn to produce blue hydrogen in Louisiana, providing low-carbon fuel to oil refiners along its US Gulf coast pipeline. Oil refiners along the pipeline will for example use hydrogen to remove impurities such as sulphur from fuels. The project will capture and sequester 95 percent of CO_2 emissions from the production process, making it the world's largest carbon capture and storage project.

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Hydrogen gas station in Southern California. Source: iStock/Getty Images

Ad van Wijk
Chair of Future Energy Systems at TU Delft

Hydrogen, an all-round energy carrier

Liquid Natural Gas globe containers in Europoort industrial area location Botlek in Port of Rotterdam Source: Shutterstock.

Ad van Wijk is concerned with the future of energy, and hydrogen is a very important, if not central, element in this. This is because hydrogen can make use of a lot of existing infrastructure, both for transport by pipeline and ship, as well as for storage. However, hydrogen does require the conversion of natural gas installations for use.
The Netherlands can play a major role in this conversion and reuse of infrastructure.

He often hears people wondering if energy won't be wasted if electricity is turned into hydrogen. But it is not about energy efficiency. It is about avoiding greenhouse gas emissions, reliable energy supply and, ultimately, costs. "With hydrogen, you make it possible for cheap sun and wind to be brought to the market at the right time and the right place. That is why it is interesting and indeed the future of the world's energy supply."

Transport and storage

The Sahara is more than twice the size of all EU countries plus Great Britain. The opportunities there for generating electricity and converting it into hydrogen are thus immense. The sun shines more abundantly in the Sahara so the same solar panel produces 2-3 times as much electricity as here, there is plenty of land, labour is cheaper and electrolyzers can be built in cooperation with and with subsidies from countries that are keen to import hydrogen. Van Wijk speaks passionately about it. "Electricity generated in the Sahara is almost impossible to transport in that form. Moreover, we do not have good storage facilities; that would require gigantic batteries. Hydrogen has ten times lower transport costs. Storage, for example in empty gas fields or salt domes, is a hundred times cheaper."

Electricity that has been converted to hydrogen in the Sahara can, in some cases, be converted back to electricity here. In fact, that is what happens to a car that runs on hydrogen. Inside the car the hydrogen is converted into electricity that drives an electric motor.

Thus, hydrogen as a carrier of electricity is an excellent solution. Electricity accounts for only 15-20 percent of the total energy demand in the Netherlands. Mobility is a bigger energy consumer, at around 30 per cent. In addition, industry and the agricultural sector are major consumers.

> "In principle hydrogen is the answer to and the replacement for fossil energy."

Infrastructure

Hydrogen is also perfectly suited for these other forms of energy use. Grey hydrogen is now used to make fertiliser, for example. But hydrogen can also be used to power new factories that produce steel. And hydrogen can be transported via the existing natural gas infrastructure, including to heavy industry. "The electricity grid in our country has a capacity of about 20 gigawatts," says Van Wijk. "The gas grid has 350 gigawatts. And the electricity connection in a house is 3 kilowatts, while the gas pipe has a capacity of 30 kilowatts. You need that to get warm. The electricity system can never supply enough." And what about factories that use gas to heat boilers to 600, 700, sometimes even 1000 degrees Celsius. They have natural gas pipelines through which hydrogen can eventually flow. It's not as simple as it sounds, of course, but in principle hydrogen is the answer to and the replacement for fossil energy.

Van Wijk advocates a smart combination of green electricity and green hydrogen. It requires only minor adjustments to the gas grid and the use to make the Netherlands hydrogen-ready. He foresees a role for our country in this because we have a lot of experience in designing applications. Today it is for gas, but soon it will be for hydrogen. "Many companies that are now in natural gas can reposition themselves with hydrogen. The principles are the same and the knowledge is already there." He cites the example of reforming the 'blast furnaces' to a new, hydrogen-powered process. But also, of central heating boilers and of fuel cells in households that turn hydrogen into part electricity and part heat. Hydrogen is the future for almost all conceivable applications.

In conclusion, is it high time to invest heavily in hydrogen, the way for example Germany is doing? That country is subsidising hydrogen production in Morocco to be transported to Germany via pipelines. "Yes, definitely," says Van Wijk. "A solar farm that yields a million tonnes of hydrogen takes up about 500 square kilometres." For comparison, the Sahara is 9.2 million square kilometres. "The size of the electrolyzer that goes with it is already completely negligible. Hydrogen makes it possible to deliver cheap, green energy all over the world." And that's not just an opportunity, it's a necessity. But above all, it is a wonderful opportunity.

CURRENT DUTCH DEVELOPMENTS AND INITIATIVES IN THE FIELD OF

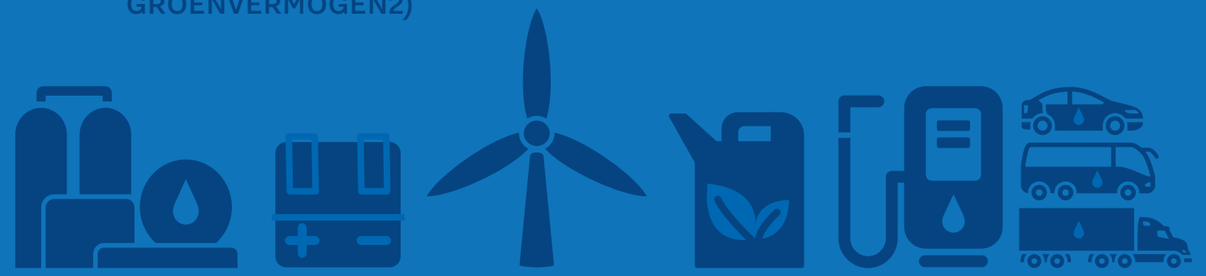
HYDROGEN

- NUMEROUS **PUBLIC-PRIVATE PROJECTS** IN THE AREAS OF H_2 PRODUCTION/ELECTROLYSIS:
  - E.G. A LARGE NUMBER OF **PILOT PRODUCTION FACILITIES** 100MW – 2GW IN THE HARBOURS OF ROTTERDAM, EEMSHAVEN, TERNEUZEN, DELFZIJL, AMSTERDAM
  - **ALTERNATIVE CONVERSIONS**, E.G. WASTE-TO-CHEMICALS AND BIOMASS TORRIFICATION FACILITIES IN CHEMELOT, BIOMASS GASIFICATION IN ‘THE GREEN HEART’
  - DEVELOPING PROJECTS THAT CAPTURE AND STORE CO_2 FROM EXISTING NATURAL GAS BASED HYDROGEN PLANTS, RESULTING IN **LOW-CARBON HYDROGEN PRODUCTION**
  - DEVELOPING PROJECTS THAT AIM TO **CONVERT RESIDUAL OFF GASES TO LOW-CARBON HYDROGE**N, WHILE CAPTURING CO_2 DURING THE PROCESS, IN THE PETRO-CHEMICAL SECTOR
  - INTEGRATION OF **ELECTROLYSIS WITH ON/OFFSHORE WIND**, E.G. IN THE WIERINGERMEER AND ON THE NORTHSEA (NORTH2, POSHYDON), H2-ON-SEA GROWTH FUND PROPOSAL,
  - **H_2 STORAGE** , E.G. STORAGE OF H_2 IN SALT CAVERNS EEMSHAVEN (H2M), STORAGE IN POWER (H2FUEL)
  - **INFRASTRUCTURE/TRANSPORTATION & DISTRIBUTION**, E.G. H2-BACKBONE NL, HYWAY27, DELTA-CORRIDOR ROTTERDAM, CHEMELOT/RUHR
  - **H_2 DEPLOYMENT**, FOCUSING ON THE TRANSFORMATION OF INDUSTRY, ENERGY SUPPLIERS OR MOBILITY PROVIDERS AWAY FROM FOSSIL FUELS TOWARDS H_2 (E.G. H2SHIPS, HYTRUCKS, SKYNRG

- **DUTCH ELECTROLYSER MAKERS PLATFORM** UNITING SOME 50 COMPANIES AND KNOWLEDGE INSTITUTES IN THE FIELD OF ELECTROLYSIS

- TOPSECTOR ENERGY, PART OF THE MISSION ORIENTED INNOVATION IN HET NL, PROVIDING THE **QUADRUPLE HELIX FRAMEWORK** (BUSINESS, KNOWLEDGE INSTITUTES, GOVERNMENT AND SOCIAL INSTITUTIONS) SUPPORT TO COLLABORATION TOWARDS THE ENERGY SYSTEM OF THE FUTURE. SPECIFIC ORIENTATION TOWARDS HYDROGEN IN TOPCONSORTIUM FOR KNOWLEDGE AND INNOVATION ‘NEW GAS’

- **LARGE-SCALE INVESTMENT PROGRAMMES** UNDER THE UMBRELLA OF THE DUTCH NATIONAL GROWTH FUND CONTRIBUTING TO R&D&I AND SCALE-UP IN THE FIELD OF H_2 (GROENVERMOGEN, H2OPZEE, GROENVERMOGEN2)



“MANY COMPANIES THAT ARE NOW IN NATURAL GAS CAN REPOSITION THEMSELVES WITH HYDROGEN. THE PRINCIPLES ARE THE SAME AND THE KNOWLEDGE IS ALREADY THERE.”

AD VAN WIJK

Japan commits to 1% hydrogen in its power energy mix by 2030

Japan invests strategically in hydrogen to maintain a secure, affordable and green energy system. The new five-year Basic Energy Plan of October 2021 contains a concrete target to supply 1% of the power energy mix of 2030 by hydrogen and ammonia. Japan and the Netherlands recognize each other as important players and partners in the hydrogen supply chain.

The Japanese attention for hydrogen grew substantially after 2011 when the Fukushima incident shook the foundations of the energy mix of the world's third economy. Nuclear energy suddenly had to be compensated by natural gas, challenging the country's efforts to reduce emissions as well as its position to secure supply amidst increased energy demands on the international market. From 2012 onwards, the government started focusing on renewables with a Feed-in-Tariff scheme. To further diversify the energy supply system, the country was the first to formulate a proactive hydrogen Roadmap in 2014.

The world's first liquified hydrogen carrier 'Suiso Frontier' arrived in Kobe on February 25th 2022 from Australia. Source: Hystra

Fuel cell bus SORA in front of Tokyo Teleport Station (Koto-ku, Tokyo). Source: iStock/Getty Images.

"Large-scale demonstration and feasibility projects are interesting opportunities for the Netherlands."

The government takes a leading role by organizing, since 2018, a yearly Hydrogen Energy Ministerial Meeting (HEMM) to promote international collaboration. In 2020, then Prime Minister Suga announced the ambition to become a climate-neutral country by 2050.

"To achieve the new 1% target, we are investing 25 billion euros out of the new Green Innovation Fund to develop hydrogen supply chains towards Japan," says Mr. Eiji Ohira, General Manager at the Fuel Cell & Hydrogen Office of government agency NEDO. Large-scale demonstration and feasibility projects like Hystra (shipment of liquid hydrogen) and Spera (shipment of hydrogen in a chemical bond) are interesting opportunities for the Netherlands, considering its ambition to play a leading role in the future logistics and shipment of hydrogen.

In the Hystra project, Shell and Kawasaki Heavy jointly developed a special 8,000 tonne class vessel and the landing point in the Japanese Port of Kobe for liquid hydrogen from Australia. Last October, the Port of Kobe visited the Netherlands for an international hydrogen program for port authorities. Both governments joined an IMO committee to set up a provisional Code for shipping liquified hydrogen in bulk.

The Spera project led to interesting other ways to ship hydrogen using conventional chemical carriers and vessels. In July 2021, the Port of Rotterdam and Chiyoda Corp. started a feasibility study on the shipment and storage of hydrogen using such carriers (LOHC).

Power Energy Mix	Fossil	Nuclear	Renewables	Hydrogen	Hydrogen supply	
					Supply	Price
2010 (*)	65%	25%	10%	0%	-	-
2020 real	76%	4%	20%	0%	2 Mt/y	0.80 euro/Nm3
2030 plan	41%	21%	37%	1%	3 Mt/y	0.24 euro/Nm3

(*) Before the Fukushima accident of 11 March 2011. Source METI

In addition, the country will invest 5 billion euros over the coming decade in domestic hydrogen production with Power-to-X and water electrolysis, and an annual sum of 100 million euros into regional projects comparable to the European Hydrogen Valleys.

On the demand side, Toyota, Panasonic, Mitsubishi, and other companies develop high-value hydrogen solutions and products for the international market for mobility, residential areas, and industry. They collaborate in the Japan Hydrogen Association.

Relations with the Netherlands

IA-Tokyo proactively develops relations with Japan: multiple delegations resulted in a government Memorandum of Cooperation in 2019. In January 2021, RVO and 14 Dutch organizations started a three-year hydrogen programme towards commercial collaboration with Japan.

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Brazil is full of green hydrogen potential

With over 40% of renewable energy, and over 80% of renewable electricity (mainly hydropower), Brazil already has a low carbon energy matrix when compared to other large economies. And there is much more renewable electricity potential still to be explored, mainly solar and wind.

Recognizing this wealth of green energy, several projects are looking at Brazil as a potential exporter of green hydrogen. For example, very recently the Dutch Transhydrogen Alliance signed a US$ 2 billion agreement with the Brazilian state of Ceará for the production of 500 ktonnes of green hydrogen per year. The tropical northeast of Brazil, of which Ceará is a part, is a huge territory with unique conditions for combining solar and wind energy, producing green electricity with a very low intermittency. The Port of Pecém, which is co-owned by the Port of Rotterdam, has installed a hub of green hydrogen and will host a pilot project consisting of a 3 MW solar plant and an electrolyzer from the Brazilian energy company Hytron.

“Brazil’s potential goes beyond the export of green hydrogen”

Brazil’s potential goes beyond the export of green hydrogen. The country has a large chemical sector, steel sector and aviation sector. This industry, active internationally, provides a strong technology base for future domestic use of hydrogen, as an energy carrier or as feedstock. For example, the Brazilian airplane manufacturer Embraer, in collaboration with Delft University of Technology, is developing hydrogen-based aircraft concepts. This involves technology development of novel materials, engines and chemical processes. Furthermore, Brazil is the world’s 2nd largest producer of (bio)ethanol, which could be used as a liquid carrier for hydrogen transport and storage. Additionally, research is being done to generate hydrogen from waste streams of sugar-cane-based ethanol production.

For about two decades now, Brazilian researchers and companies have been developing hydrogen technology. For example, the Federal University of Rio de Janeiro developed a hydrogen bus which was launched during the 2012 United Nations Conference of Sustainable Development (Rio+20). Hytron, a spin-off from the University of Campinas, is pioneering in fuel reformers to produce hydrogen from ethanol, which is readily available in fuel stations throughout the country. And Shell Brasil, together with the São Paulo Science Foundation, is investing in several hydrogen related research projects through the joint Research Center for Greenhouse Gas Innovation and the Center for Innovation on New Energies. These centers involve the University of Campinas, the University of São Paulo, and the Nuclear & Energy Research Institute (IPEN). And as fourth and final example, Brazil’s largest hydropower plant, Itaipu, has been experimenting with hydrogen production using so-called spilled turbinable energy, i.e., energy from flood water that is released via a spillway.

The Brazilian ministry for Mines & Energy is developing a national strategy for hydrogen, in line with Brazil’s commitments at the 2021 UN High-level Dialogue on Energy. And the National Council for Energy Policy (CNPE), chaired by the minister of Mines & Energy, adopted a resolution to prioritize hydrogen in the allocation of R&D funds in the electricity sector and oil & gas sector, through the regulating agencies (resp. ANEEL and ANP). Just like the Netherlands, Brazil participates in the International Partnership for Hydrogen and Fuel Cells in the Economy, represented by the ministry of Science, Technology and Innovation, and in the Clean Energy Ministerial Hydrogen Initiative coordinated by IEA.

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Hytron’s ethanol reforming technology. Courtesy of Hytron.

Hydrogen: the next step for Taiwan

With 98% of the energy imported and 82% of the electricity generated by fossil fuel, Taiwan is undergoing a significant energy transition focusing on phasing out nuclear energy and increasing the supply of renewable energy to 20% by 2025. The production of solar and wind energy is a key focus, while hydrogen is considered a next step. So far, Taiwan mainly targeted the development of fuel cells through national R&D subsidy schemes. In other uses of hydrogen, Taiwan is still at its infacy stage, although it is currently in the process of formulating a national hydrogen development strategy.

> "Taiwan will gradually increase the production of green hydrogen."

Fuel Cell Technology

The government began providing R&D funds for fuel cell development in the late 90s. To further stimulate market-driven R&D activities and explore business opportunities, various national programs and policies related to hydrogen were announced since.

By 2019, there were 37 fuel cell demonstration projects. Most of them concern stationary electricity supply for telecommunication base stations, factories and exhibition, but also non-stationary electricity supply for motorcycles. At the same time, Taiwan developed a mature and complete fuel cell industry chain, providing international manufacturers with affordable high-quality fuel cell products and related key components, such as: (full list of companies available upon request)

- Raw materials: bipolar plates
- Battery components: battery packs
- System applications: stationery and transportation
- Peripheral products: hydrogen storage tank, system peripheral components, crude hydrogen

Hydrogen as Energy Carrier

In 2021, the government announced its ambition to achieve net-zero emissions by 2050 and an inter-ministerial coordination group has been established to formulate a roadmap to reach that goal. Hydrogen has been listed under the Decarbonized Energy Working Group and includes:

Application: initial focus on power generation (hydrogen co-firing in gas turbines) and the industrial sector (blast furnace ironmaking and co-production of steel and chemistry). Only to be introduced to other domains in mid to long-term.

Supply: short to mid-term focus on imported blue/green hydrogen and gradually increase the production of green hydrogen from local renewable energy (long-term).

Infrastructure: assessing for the development of hydrogen facilities and hydrogen demonstration sites in the short-term, followed by the construction of hydrogen infrastructures based on its application and supply (mid to long-term).

In addition, the Ministry of Economic Affairs established a "Hydrogen Promotion Taskforce" to work out the "National Hydrogen Development Strategy and Applications" towards low-carbon economic and industrial developments.

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3D rendering of hydrogen gas production for clean electricity solar and windturbine facility. Source: Shutterstock.

Policy/ Program	Date	Hydrogen related content
National green energy development program	1993-2015	Provide funds for the development of fuel cell
Taiwan Fuel Cell Partnership	2001.07	Inter-ministerial support for the development of Fuel Cell
National Energy Conference, Executive yuan	2009.04	Included "manufacturing & storage of hydrogen, hydrogen transportation strategy, fuel cell and hydrogen internal combustion engine" under new energy technology development
Fuel cell demonstration promotion program	2009.09	Stimulate integration of the fuel cell value chain through demonstration project and product verification scheme
National Green Energy development strategy	2009.10	Developing Taiwan as the global fuel cell system assembly center
New energy policy	2016.05	2025 fuel cell installed capacity of 60MW
2050 net zero emissions roadmap	2021 (draft)	National goal of net zero emissions by 2050 with the national hydrogen development strategy on hydrogen applications, supply and infrastructure.

Great ambitions for a small country

South Korea is actively implementing its Hydrogen Economy Roadmap since 2019, with the most recent update in November 2021. The government has successfully set up regulatory and subsidy frameworks and the private sector has jumped on the new opportunity. Under the roadmap (themes are hydrogen production, distribution and applications), the government sets ambitious targets for 2030 and 2050.

The expectation is that the public and private sectors will continue their strong push in hydrogen with an increased focus on production/import and infrastructure. This projection is supported by investment trends and the forging of strategic international partnerships in 2021.

Hydrogen handling equipment for storage and mobility, such as compressors, storage tanks and dispensers, is still predominantly imported; mainly from Japan. However, hydrogen compressors of Thomassen Compressors (part of Howden) can be found in 200 hydrogen projects in Korea. Like in other high-tech fields, Korea is diversifying its supply chain away from Japan.

In terms of transportation, hydrogen is mainly carried through tube trailers at 200~300bar. However, the port cities Ulsan (with many chemical plants) and Yeosu already have combined 200 kilometres of dedicated hydrogen pipelines. Korea wants to retrofit existing pipelines for natural gas so they can carry hydrogen; it is asking the Netherlands to share its expertise to make this happen. As for new pipes, Korea will likely go for flexible pipes that operate with relatively low pressure (<40bar).

The country lacks space and resources to produce all the hydrogen it will need for its ambitious plans, so it needs to import the majority of the hydrogen it will use. For transportation, KOGAS is reviewing a liquid hydrogen carrier ship. Korea is also looking at the option to import ammonia and transform it locally into hydrogen. Ammonia as a feedstock and maritime fuel are also areas of interest for Korea. To facilitate these developments, Korea has formed a task force known as the 'Hydrogen and Ammonia Power Generation Demonstration Promotion Group', which will be looking for foreign partners.

The Netherlands has had many meaningful exchanges with Korea to date and should continue this effort to benefit from the many opportunities that Korea represents. Prime minister Mark Rutte and president Moon Jae-in discussed hydrogen during their virtual summit on July 7th. The Joint Innovation Committee (JIC) had the subject of cooperation on the agenda last June. It will also be discussed by the Joint Economic Committee (JEC) likely in the second half 2022. On a business level, the embassy organized a hybrid presence at two Korean exhibitions with Dutch Pavillions, matchmaking sessions, webinars, and forum participation. Furthermore, it is connecting with Ulsan, Ansan, and other hydrogen pilot cities.

In the upcoming years, the embassy in Seoul will continue its efforts to connect Dutch businesses and knowledge with the Korean hydrogen economy.

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Hydrogen station of National Assembly in Seoul with Hyundai Nexo cars filling in South Korea. Source: iStock/Getty Images

	2030	2050
Hydrogen Supply	3.9mn tonnes (34% blue & green H2)	27.9mn tonnes (60% blue & green H2)
Electrolyzer Commercialization	10MW-scale electrolyzers	GW-scale electrolyzers
Hydrogen Charging Stations	660	2,000+
Annual FCEV Production	880,000	5.2mn
Green Hydrogen Target Price	KRW 3,500/kg (EUR 2.62/kg)	KRW 2,500/kg (EUR 1.87/kg)

"Korea lacks space and resources, so it needs to import the majority of the hydrogen it will use."

Nicole Vermeulen
Supply chain manager green hydrogen & integrated projects at Shell

Cooperation in the chain is imperative

IL is blessed with solar renewable energy, revolutionary green hydrogen production and storage technology
Source: Shell

Shell wants to play an active role in the energy transition and is involved in several projects, including the major NortH2 project.

The energy transition is called a transition for a reason, says Nicole Vermeulen. “This is not simply a switch that you can turn on or off. It takes time to make the transition.” Gas and oil are still very much needed worldwide. At the same time, Shell wants to use the proceeds from fossil operations to build new transition fuels and clean resources such as hydrogen and electricity. The company’s Powering Progress strategy aims to achieve net-zero emissions by 2050. “It is impossible to say at the moment exactly how that will play out,” Vermeulen says. “Will the use of hydrogen suddenly take off? Will electricity suddenly slow down? Although we don’t yet have the answers, that dot on the horizon has been set and we know what we are working towards.”

In concrete terms, Shell wants the hydrogen transition to take place in four steps. Step one is replacing grey hydrogen by clean hydrogen at Shell’s own facilities. Steps two and three are aimed towards hundres of megawatts and eventually gigawatts of production and the use of hydrogen outside of Shell’s own facilities, so cooperation plays a big part in this. The last step is import and export, whereby production and purchase will no longer take place at the same location. Steps two and three are aimed at slowly going public with hydrogen from the company’s own facilities and slowly expanding partnerships and production. “All in all, we are talking about investments worth billions. For example, we are involved in the Holland Hydrogen 1 project in Rotterdam and NortH2 in Groningen.”

In the latter project, Shell is working with Gasunie, Groningen Seaports, Equinor, RWE, and the province of Groningen to conduct a feasibility study into the large-scale production, storage, and transport of green hydrogen. “The supply chain of the hydrogen economy is quite a complex story in which you have to look at the whole chain from the production of electricity and all the suppliers around it to the customer. It is therefore extremely important for us to work together with all the parties in a chain, right down to the customer.” NortH2 helps all players to better understand the complex supply chain. The study starts with offshore wind and then looks at how that energy is brought ashore, how it is stored and transported to the end client throughout the Netherlands and Western Europe, what and who plays a role in this, and how it all fits together.

In pace with society

Customer demand is central to Shell’s energy transition. The company was already producing hydrogen twenty years ago, but found it hard to find clients for it. The environmental activism and awareness that is now prevalent in society has a positive influence on this customer demand. “We will stay in pace with society. There can only be a sustainable business case once consumers have embraced something and there is no need for any more government incentives.”

However, this is not yet completely the case. Governments are playing an important role in the transition. “IAN and RVO are providing plenty of support and that is important, because right now the production capacity already needs to be scaled up a lot to meet the demand. The market for electrolyzer manufacturers is relatively small and we are in the initial phase. This is not the time to leave everything to supply and demand, but there is a noticeable shift taking place. Let’s say it’s a combination of social awareness and governments driving the transition, such as a consistent government policy for renewable hydrogen in refinery processes.”

> “The supply chain of the hydrogen economy is quite a complex story in which you have to look at the whole chain from the production of electricity and all the suppliers around it to the customer.”

The time is now

At the moment the supply of clean hydrogen is limited, something Shell also acknowledges. Within Shell, eyes are on the Dutch branch. The Netherlands and Europe are slightly ahead in the hydrogen transition, but the worldwide market is dynamic. The Netherlands has a good starting point. The North Sea is shallow and often windy, Gasunie’s pipelines can be used for hydrogen and the government is aware of the urgency of the energy transition. “Change can also be achieved by simply making a start, especially now. If you do nothing, you will never get anywhere.”

Shell has faith in the momentum and the cooperation between public and private parties, which shows in its plans with the largest green-hydrogen factory in Europe and the research in NortH2. Vermeulen’s role as supply chain manager puts her right in the middle of it. She enjoys the challenge of connecting all the necessary pieces of the puzzle in time. “In the supply chain, every part matters. The urgency that comes with it is there today. To us, in a sense, 2030 is tomorrow.”

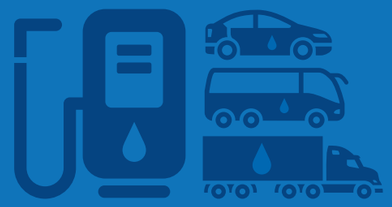
47%

OF ALL ENERGY IS USED
IN INDUSTRY APPLICATIONS

29%

OF ALL ENERGY IS USED
IN RESIDENTIAL APPLICATIONS

17%



OF ALL ENERGY IS USED
IN FUEL CELL VEHICLES

6%

OF ALL ENERGY IS USED
IN AGRICULTURE

Source: PBL

80% still oil and gas

“WE EXPECT HYDROGEN TO REPLACE GAS AND OIL. OUR FOCUS IS CURRENTLY ON HYDROGEN USE IN INDUSTRIES.”

NICOLE VERMEULEN

France wants to produce its own hydrogen

Currently under development on the French site of Etrez, HyPSTER is the first green hydrogen storage demonstrator in a salt cavern. Source: hypster-project.eu

France, like many other countries, has been under the spell of hydrogen for some time now. This is related to the urgent energy transition. On 8 September 2020, the French government presented its national hydrogen strategy: € 7 billion between now and 2030 to develop a low-carbon hydrogen industry of international scale. The plan, which includes the development of production capacity in France, the promotion of the development of hydrogen for heavy transport, and support for research and innovation in this area, will save 6 million tons of CO_2 per year from 2030, which is equivalent to the annual emissions of the city of Paris, and create 50.000 to 150.000 jobs.

In November 2021, president Macron added an additional € 1.9 billion of support under the 'France 2030 programme' through which France aims to build "at least two huge electrolysis plants" by 2030, using different technologies. In the longer term, France wants to build five of these mega-factories. "For the energy independence of France, it is important to take the lead in hydrogen production," said Emmanuel Macron.

France wants to decarbonize industrial processes by producing hydrogen in France and not by importing hydrogen because it has the resources to develop this technology of the future, with the support of France's nuclear power plants.

For example, French energy giant, Engie, recently announced its strategy for accelerating the development of low-carbon hydrogen to develop a production capacity of 4 GW of renewable hydrogen by 2030. In the field of mobility, Engie wants to install more than 100 filling stations, 700 km of pipelines, and 1 TWh of storage capacity in France by 2030.

Genvia and McPhy for IPCEI

Of the projects supported at the European level, France has chosen to work together with –amongst others – Genvia. This start-up, a young joint venture between the French oilfield services company Schlumberger and the knowledge institute CEA, is one of the French winners of the IPCEI[1] call. Genvia will receive € 200 million in French state aid. Genvia specializes in the manufacturing of high-temperature solid oxide electrolyzers that provide "significantly higher" efficiency than current technologies and would have the advantage of being able to both produce and store hydrogen.

> "France has the resources to develop the technology of the future."

McPhy, a young French company specialized in electrolyzers and filling stations, will build a mega plant for the production of alkaline electrolyzers too, in Belfort, and also with financial support from the IPCEI call. The plant will be able to produce 1 gigawatt of electrolyzers a year, costing as much as 40 million euros, and creating around 400 jobs in France. Production is expected to start in early 2024.

Elogen for hydrogen storage

Another IPCEI candidate is Elogen, selected by Storengy for the HyPSTER project to supply a 1 MW PEM electrolyzer for the Etrez site (Ain). HyPSTER is a large-scale green hydrogen storage demonstrator coordinated by Storengy, the European leader in natural gas storage. It is the first underground green hydrogen storage project in a saline cavity supported by the European Union.

For more information, please contact your Innovation Attaché in France via par-ia@minbuza.nl

1 IPCEI: Important Projects of Common European Interest

British government's big bet on hydrogen

The United Kingdom (UK) government has "put a big bet on hydrogen" and launched its first Hydrogen Strategy in August 2021. In this strategy, the UK committed to both blue hydrogen (capturing the CO_2 that is emitted during production) and green hydrogen (produced from renewable electricity) and to a production capacity of 5GW low-carbon hydrogen by 2030. Due to recent geopolitical developments, the UK released its Energy Security Strategy in April 2022 to ensure it is less dependent on oil and gas import by increasing its production of "home-grown" energy sources. The strategy states: "we're going to produce vastly more hydrogen, which is easy to store, ready to go whenever we need it, and is a low carbon super fuel of the future" and doubled the production ambition to 10GW of low carbon hydrogen by 2030. The UK government is investing £240 million through the Net Zero Hydrogen Fund, and is developing new business models and revenue schemes to further bring down the costs for clean hydrogen producers and consumers.

> "The UK is deploying multiple hydrogen-for-heating pilots across the country."

Industry landscape

The UK has a rapidly developing hydrogen industry which is predicted to be worth £18bn by 2035 and will create 75.000 jobs. Although most hydrogen produced in the UK is still high-carbon (produced from fossil fuels with no carbon capture), the UK is home to one of the largest green hydrogen production facilities in the world: ITM Power in Sheffield. Other British companies such as Johnson Matthey and CPH2 are also developing innovative methods for producing low-carbon hydrogen. Besides, the UK is a frontrunners in carbon capture and storage for producing blue hydrogen, given the large potential of carbon storage fields around its coast.

Hydrogen for heating

The UK is a global frontrunner in the application of hydrogen for heating. The UK is deploying multiple hydrogen-for-heating pilots across the country and will soon be trialing heating over 650 homes in the North-East of England with up to 20% hydrogen blended into the natural gas supply. By 2025, the UK aims to have a full hydrogen-heated village and is also developing innovative 'hydrogen-ready' boilers and hobs. A snapshot of some innovative projects: HyDeploy (the first ever live demonstration of hydrogen in homes that aims to prove that blending up to 20% volume of hydrogen with natural gas is a safe and greener alternative), Hy4Heat (funded by the UK government to explore the safety and feasibility of H_2 heating in residential and commercial buildings) and H100Fife (green hydrogen project on the Scottish coast that delivers green H_2 straight to the Scottish pilot homes).

How can the Netherlands Innovation Network UK help you?

Please contact Lara Neervoort (Innovation Advisor) for tailored advice on navigating the UK hydrogen sector and finding the right partners.

We have commissioned a detailed market study of the UK hydrogen sector, please contact us via *lara.neervoort@minbuza.nl* to receive your copy of the report.

In 2021 we have organised both a fact-finding mission as well as a virtual trade mission on hydrogen in the UK. Please visit *this matchmaking platform* to view the UK hydrogen players that are keen to connect as well as the opportunities in the digital marketplace.

Hydrogen renewable energy production for clean electricity at private real estate home. Source: iStock/Getty Images.

Reduce CO_2 emissions and create a new industry: the Swedish way

The north of Sweden is vast and quaint. In this part of Europe, one can drive for hours without seeing a single human being. Here, the Swedes have mined for iron and produced steel for decades. But when visiting this region, one can feel a change in the air; there is a certain buzz, as huge developments and big investments are around the corner.

The steel industry has been extremely profitable for Sweden, but it has a huge downside: it makes for 8% of the total Swedish CO_2 emissions. As Sweden has ambitious climate goals (climate neutral in 2045), a strong engineering tradition, and a partly state-owned steel industry, the country decided to stop using coal to produce steel and switch to Direct Reduced Iron (DRI) with the use of green hydrogen.

SWEDEN

SWEDEN

“Sweden is not only producing green hydrogen, but green steel too.”

HYBRIT (Hydrogen Breakthrough Ironmaking Technology) involves replacing the blast furnace process with a direct induction process using green hydrogen produced from hydropower plants. Instead of CO_2, water vapor is formed.

HYBRIT started in 2016. The experimental factory is now up and running and the first ‘fossil-free steel’ has been produced and delivered to Volvo AB, which used it to manufacture an autonomous electric vehicle for the mining industry.

H_2 Green Steel

The HYBRIT project is proof that the DRI green hydrogen technology is working and that it is commercially viable. The price of green steel is higher (an estimated 25-30% higher), but the car industry and the consumer are willing to pay that price. It soon became apparent that there was interest, knowledge, and money, and so H_2 Green Steel – the second fossil-free steel factory – was founded in the autumn of 2020: ‘the Tesla of the steel factories’, as they call themselves.
‘H_2 Green Steel is on a mission to undertake the global steel industry’s greatest ever technological shift. [..] We are committed to accelerating change by eliminating almost all CO_2 emissions from the steel production process.’ (Quote from their website)
The total investment is $ 2.5 billion and the factory will start to operate in 2024. In 2030 it will produce 5 million tonnes of steel. It will have its own electrolyzer to produce green hydrogen. The steel will then be transported via the port town of Luleå, which is planning to build an electrolyzer as well to produce green hydrogen for the ships.

This proves that using green hydrogen is not only helping Sweden meet climate goals, but that it is also an economic accelerator: H2GS realized that car and truck manufacturers need to decarbonize their supply chain, for which they need ‘green steel’. By securing the revenue, H2GS can scale up and expand immediately.

The first expansion has already been announced. Together with Spanish energy provider Iberdrola, H2GS will build a 1GW electrolyzer and a steel plant (2.5 million tonnes) in 2025. The investment will be 2.3 billion dollar and it will be partly funded by the EU.

The Swedish market is small and the climate challenge is global. Therefore, ‘green steel’ initiatives have an international perspective and agenda, and there will be opportunities for the Netherlands to cooperate on a technological and commercial level. The Netherlands Innovation Network in Sweden will continue to identify opportunities and connect with the relevant Dutch parties wherever possible.

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COLOFON

Government of the Netherlands

Netherlands Innovation Network

The Netherlands Innovation Network stimulates international cooperation between companies, research institutes and public authorities in the fields of innovation, technology and science. The network's activities help implement the international knowledge and innovation agenda of the Dutch government. We address national and global challenges, aiming to further develop key enabling technologies through international cooperation and a worldwide network of offices in: France, Germany (including Switzerland), Israel, United Kingdom, Sweden, Russia, USA (including Canada), Brazil, China, India, Japan, Taiwan, Singapore and Korea.
We develop international cooperation by:

- providing knowledge and information on the latest innovation, technology and science developments around the world;
- connecting to potential partners abroad;
- organizing innovation missions, seminars, workshops and matchmaking events abroad;
- identifying funding mechanisms for bi- and multilateral cooperation.

We look forward to the opportunity to help you become involved in sustainable innovation partnerships, so we can together advance our common innovation, technology and science ambitions.

Netherlands Innovation Network

A network of
the Ministry of Economic Affairs
and Climate Policy

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