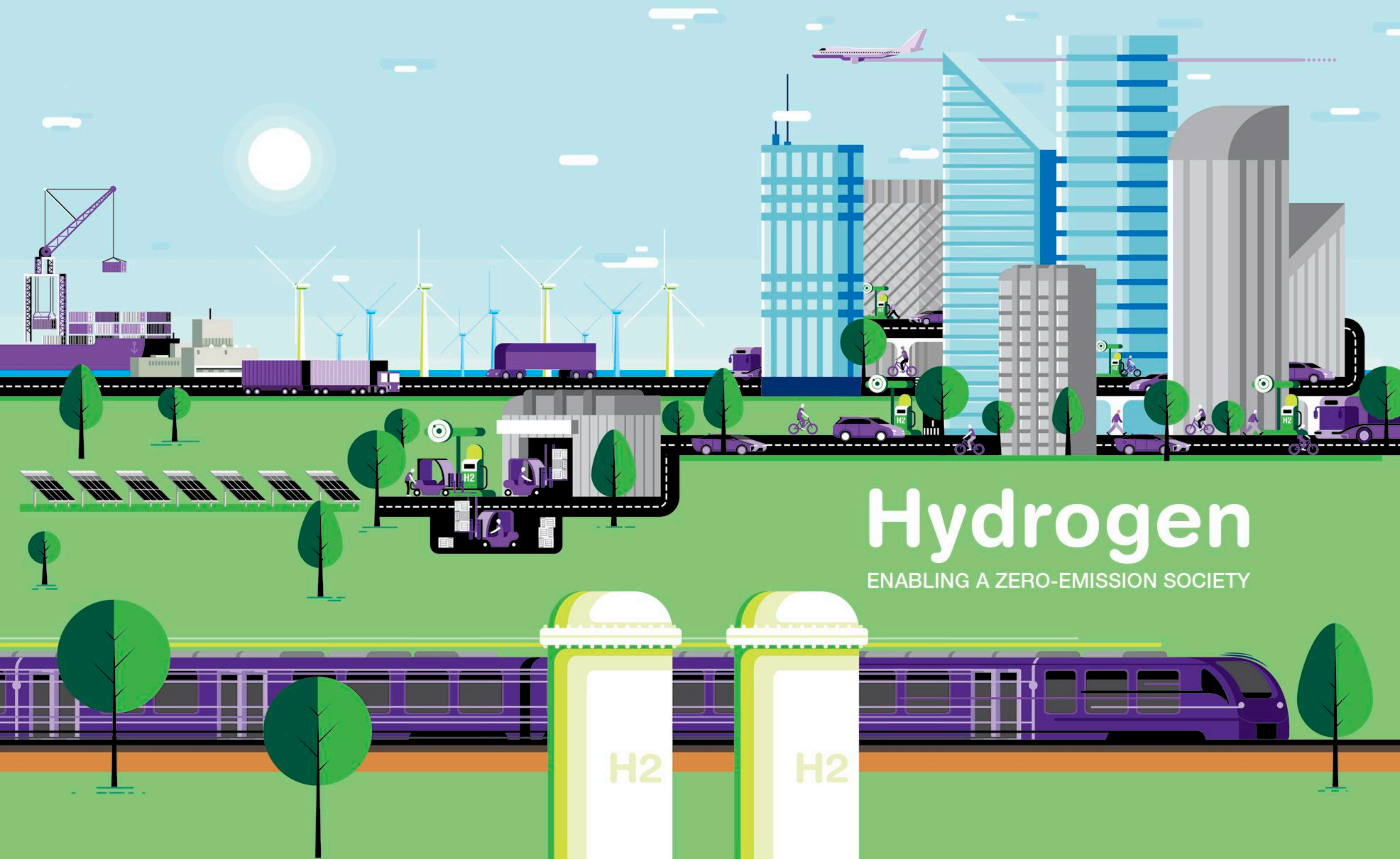
A Special Report by

REVOLVE

Hydrogen Europe

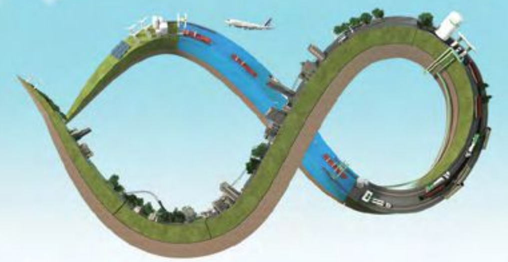


Hydrogen

ENABLING A ZERO-EMISSION SOCIETY

AIR PRODUCTS

H$_2$fM®
Hydrogen for Mobility



Unlocking the Potential of

Sustainable Hydrogen in Europe and Beyond

Climate change is one of the greatest challenges facing the world today and energy systems need to meet the commitments made at the 2015 Paris Agreement now.

Writer: Caroline Stancell, General Manager, Hydrogen for Mobility, Europe and Africa, Air Products

It is now widely accepted that hydrogen derived from renewable energy sources will be required as part of decarbonised energy systems, and there is significant momentum building in the renewable and low-carbon hydrogen energy sector around the world.

Electrification of energy demands is central to decarbonisation strategies of many countries, creating a growing need for renewable electricity. Although installed renewable generation capacity is increasing, many countries (particularly densely populated ones) are finding that the need for renewable energy for large-scale production of green hydrogen competes – and will continue to compete – with demands for electricity in other sectors. The situation is exacerbated by the intrinsic intermittency of renewable generation. Producing hydrogen and hydrogen-derived fuels in geographies with abundant, reliable renewable energy resources for export to other regions offers a solution to this challenge. Imported green hydrogen is a useful complement to domestically produced low carbon/renewable hydrogen, and several countries, including notably Germany, have started forming strategic alliances in this area.

The advantages offered by imported renewable hydrogen as part of a diversified energy strategy include:

- **Access to excellent renewable energy resources** – decoupling the location of hydrogen production facilities from demand centres provides the freedom to site production plants in areas with abundant, highly consistent, cost-effective renewable energy resources.
- **Reliable, predicable renewable hydrogen supplies** – as a result of the above, imported hydrogen offers consistent, 24/7/365 supplies which domestic production may not be able to match in the near term in the absence of the large-scale, low-cost hydrogen storage facilities required to manage the intermittency of local renewables.
- **Accelerated deployment** – project developers can select countries and sites with favourable conditions and few barriers to deployment of new renewable electricity generators linked to large-scale electrolysers. This offers the dual advantage of accelerating the roll-out of renewable generation capacity and bringing green hydrogen to market at scale rapidly.
- **Large-scale energy storage** – concepts for international shipping of green hydrogen generally involve converting the hydrogen into a form suitable for bulk storage and transport. The recipients of such products will therefore benefit from a ready-made bulk, long-term storage solution. Furthermore, having access to imported green hydrogen can reduce the costs of deploying hydrogen production and distribution systems locally due to the scale and continuity of supply offered.

To summarise, if European countries want to meet their climate, and specifically, hydrogen targets, imports of green hydrogen will be a useful complement to domestically produced renewable hydrogen, as part of the portfolio of solutions in decarbonised energy systems. The technical solutions are there and Air Products is working with partners and policy-makers to ensure that they can be realised.

Every action. Every detail. It all matters when you're generating a clean source of energy on a global scale.

Air Products is the leading green hydrogen producer in the world, actively investing in real projects such as the **NEOM Green Hydrogen Project**.

Operational in just a few year's time, this project will . . .

- include four gigawatts of renewable energy – from solar and wind sources
- produce 650 tons of green hydrogen per day
- save over 3 million tons of CO_2 emissions per year

It is, without question, the world's first large-scale green hydrogen project and will make a significant contribution to the decarbonisation of the heavy duty.

Ivo Bols
President,
Europe and Africa

"By mid-2020s, Air Products will be delivering the first commercial green hydrogen production and distribution systems at gigawatt scale."

tell me more
airproducts.com/H2fM

Contents

Air Liquide and Hydrogen:

Transitioning to Clean Energies is a Reality

Air Liquide commitments address the urgency of climate change and energy transition, targeting carbon neutrality by 2050.

As a pioneer, Air Liquide is convinced that hydrogen is a cornerstone of the energy transition. In the past 50 years, the Group has developed unique expertise enabling it to master the entire supply chain, from production and storage to distribution, contributing to the widespread use of hydrogen as a clean energy carrier for a wide range of applications such as industrial usages and clean mobility.

> Air Liquide is committed to reaching several ambitious goals, investing approximately €8 billion in the low-carbon hydrogen full value chain by 2035, and a total of 3 GW electrolysis capacity by 2030.

Air Liquide's long-term commitment to hydrogen energy and its ambition to be a major player in the **supply of renewable and low-carbon hydrogen is at the heart of its strategic investments.** Indeed, Air Liquide inaugurated the **world's largest low-carbon hydrogen membrane-based production unit** in Canada earlier this year, illustrating that **the fight against climate change is at the heart of the Air Liquide Group's strategy.** The new 20 MW proton-exchange membrane (PEM) electrolyser, equipped with Cummins technology, is the largest operating unit of its kind. Supplied with renewable energy, this unit is now producing up to 8.2 tonnes per day of low-carbon hydrogen and will help meet the growing demand in North America.

In order to meet rapidly renewable hydrogen growing demand, and to lower costs, **it is key to accelerate the production of sustainably generated hydrogen through large-scale PEM electrolysers.** In this context, Air Liquide and Siemens Energy have joined forces to create a **European ecosystem for electrolysis and hydrogen technologies.** The first worldscale PEM electrolyzer Air Liquide is planning to build in the framework of this partnership will be located in Oberhausen, Germany. This renewable hydrogen production plant, with a total capacity to reach 30MW, will support sectors such as Steel, Chemicals, Refining and Mobility in North Rhine-Westphalia by accelerating the availability of gases produced with renewable electricity for their efforts to reduce their carbon footprint.

Moreover, the Group increased to 100% its total stake in H2V Normandy in October 2021. Renamed Air Liquide Normand'Hy, this company aims to build a large-scale **electrolyzer of at least 200 MW for the production of renewable hydrogen in France to supply industry and mobility markets.** This strategic investment will support the development of a low-carbon hydrogen ecosystem in the Normandy industrial basin.

Using its extensive experience in hydrogen plants, **Air Liquide has developed a process unique in the world, the CryocapTM H2 technology, which was commissioned in 2015 in Air Liquide's largest hydrogen production unit in France, in Port-Jérôme-sur-Seine. This technology makes it possible to recover and isolate the CO_2 emitted during hydrogen production involving low temperatures to separate gases.**

In July 2021, the Group announced working with other major players in the Normandy industrial basin to implement a CO_2 capture and storage chain, from their industrial activities to final storage in the North Sea.

Air Liquide is therefore fully involved in the development of low carbon and renewable hydrogen, serving both the **decarbonization of industry and mobility.** As well as the roll-out of stations for light vehicles in Europe, Japan, South Korea and the United States, Air Liquide is also focused on the truck segment. Large-scale projects are becoming a reality: in Rotterdam in the Netherlands and Fos-sur-Mer in France for example, where the Group is part of key initiatives to develop large-capacity hydrogen stations which will be used to power long-distance trucks. Air Liquide's ambition is also to contribute to build the sustainable aviation ecosystem alongside the leading players in the sector. Our Group started at the end of the 2000s to promote **hydrogen applied to aviation, notably through studies and demonstrators in flight or on land.** In June, Air Liquide, Airbus and Groupe ADP signed a Memorandum of Understanding to prepare for the arrival of hydrogen in airports by 2035 as part of the **development of hydrogen-powered commercial aircraft.** Alongside Airbus and Vinci Airports, the Group also announced a partnership to promote the use of hydrogen at airports and build the European airport network to accommodate future hydrogen aircrafts.

A global transition towards a low-carbon society is underway. As a pioneer in hydrogen technologies, Air Liquide is fully committed to achieving this goal.

Air Liquide

Hydrogen Europe

REVOLVE

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Visit:
hydrogen.revolve.media

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revolve.media

This report is curated by Stuart Reigeluth, founder, REVOLVE

Contributors

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Bastien joined Hydrogen Europe in 2020 where he coordinates the association's Industry Working Group, the ad hoc Working Groups on PFAS (poly- and perfluoroalkyl substances) and the EU Carbon Market Reforms.

Michela Bortolotti | Manager, Communications

Michela joined Hydrogen Europe in March 2018 and is responsible for all communications matters of the association. She is also involved in the communication and dissemination packages of several European funded projects in which Hydrogen Europe is a partner.

Alexandru Floristean | Manager, Intelligence

Alexandru has deep understanding of the market and regulatory framework of clean hydrogen technologies in Europe and since 2018 is part of the Funding and Innovation team of Hydrogen Europe. He is also involved in the Clean Hydrogen Monitor, a yearly report presenting key indicators on the hydrogen sector in Europe.

Felicia Mester | Manager, Energy & Production Policy

Felicia joined Hydrogen Europe in February 2021 and she is responsible for the Energy and Production Working Groups. Previously, she worked with Eurogas where she focused on EU internal gas market regulation, taxation and hydrogen technologies.

Grzegorz Pawelec | Manager, Intelligence

Grzegorz is a Manager for the Funding and Intelligence team at Hydrogen Europe. He joined Hydrogen Europe in May 2019 and was responsible then for the coordination of the Maritime Working Group, focusing on decarbonisation of shipping as well as Finance and Funding Working Group with focus on future PPP on hydrogen under the Horizon Europe framework and the ETS Innovation Fund.

Hydrogen as an enabling fuel to achieve net zero

Industry is on the right path but has more to offer in pursuit of energy access and global decarbonisation, writes Rod Christie, Executive Vice President, Turbomachinery & Process Solutions at Baker Hughes

Hydrogen can play a significant role in decarbonisation as part of a multi-faceted approach to improving efficiencies, reducing emissions and deploying new solutions. The promise of the technology, however, can only be delivered if industry and policymakers face up to a series of hard truths.

First, major acceleration across technologies and infrastructure will be required to meet net zero. Today's solutions will help to address emissions but alone cannot meet the scale of change necessary.

Second, hydrocarbons will not disappear overnight; oil and gas will be required to help meet energy demand for the next 30 years. Any transition path must incorporate and facilitate efficiencies and decarbonisation in this sector.

And third, collaboration is central to reaching net zero. Producers, technology providers, energy buyers, and policymakers must all work together to leverage existing solutions, those at prototype stage, and those at an earlier stage of development.

Hit the accelerator

An array of technologies is required to deliver the power of hydrogen across production, storage, transportation, and utilisation.

These include compressors, gas turbines and non-metallic pipes; sensors, monitoring and diagnostics including inspection solutions for enbrittlement prevention or detection; and clean, integrated power solutions to produce power with hydrogen and blends.

Any company looking to position itself in this sector—and to maximise the speed of development—must commit to adapting its core operations to these requirements, and all that means for investment in growth and positioning to take advantage of any gaps.

There are several ways to produce, transport, and use hydrogen and opportunities will exist, and should be grasped, to improve project economics. This is particularly true as the technology matures and governments prioritise different segments of the market.

Financial incentives could further encourage deployment of production technologies and fast-track the R&D required to reduce costs going forward. Groups such as the Hydrogen Council are already helping to shape opinion in this area.

It takes a village...

No one company has all the answers when it comes to hydrogen; collaboration and partnerships will be required to deploy solutions effectively and sustainably.

On the production side, for example, our partnership with Air Products is a strategic global collaboration to develop next generation hydrogen compression to lower the cost of production and accelerate the adoption of hydrogen as a zero-carbon fuel.

As part of the collaboration, Baker Hughes will provide Air Products with advanced hydrogen compression and gas turbine technology for global projects, including NovaLT16 turbines for Air Products' net-zero hydrogen energy complex in Edmonton, Alberta, Canada and advanced compression technology for the NEOM carbon-free hydrogen project in the Kingdom of Saudi Arabia.

And we are partnering with Snam—which has one of Europe's most extensive natural transmission networks and natural gas storage capacity—to implement the adoption of hydrogen blended with natural gas in their current transmission network infrastructure through the testing and development of our NovaLT12 "hybrid" hydrogen turbine.

Hydrogen will undoubtedly be a critical component of the energy mix of the future, a key enabler to achieve net zero, which is why companies including Baker Hughes—which has served the sector since 1962—have placed technology at the centre of the efforts to make our energy safer, cleaner, and more efficient.

Financial incentives could further encourage deployment of enabling technologies and infrastructure and fast-track the R&D required to reduce costs going forward. Groups such as

the Hydrogen Council and Hydrogen Europe are doing the crucial work of helping to shape opinion in this area.

Finance will also play a central role. The Five T Hydrogen Fund, for example, has already invested €260m as part of a €1bn ambition backed by the financial, strategic, and technical expertise of investors including Baker Hughes.

Team H_2

The hydrogen supply chain has an obligation to speed the energy transition through development and deployment. We must collectively participate to take energy and industry forward with innovation, on behalf of both people and the planet.

There is already a marked willingness to achieve these shared goals, a new way of working that acknowledges the variety of technologies and skills required to develop new forms of energy including hydrogen.

The solutions developed are crucial to meeting the net-zero challenges in front of us, in areas including capital, capabilities, and infrastructure. The industry, including Baker Hughes, is committed to putting its expertise to work so we can all achieve the changes necessary.

Hydrogen Economy to Give Major Push for Fighting Climate Change

JON ANDRÉ LØKKE
PRESIDENT AT HYDROGEN EUROPE

The long-awaited 2021 United Nations Climate Change Conference – COP26 – is expected to become a watershed moment in global efforts to fight climate change. After the Paris COP21 Conference reached a breakthrough agreement to limit the global warming to 1.5 degrees, all eyes are on Glasgow now to make sure the world stays on track and keeps 1.5 degrees within reach.

With world leaders, climate negotiators, scientists, industry, and society representatives coming together to discuss how to get the climate changes under control, COP26 will be a litmus test for global policy makers to prove they can put words and ambitions into action.

COP26 must go beyond a mere goal of setting standards for emissions reductions: It must give a clear indication on how a climate-neutral future will be achieved, with what means and which methodology should be applied.

High hopes are on hydrogen.

Hydrogen is the most abundant element in the universe. It can be produced from various sources, including renewables such as solar and wind, and used as a net-zero energy carrier or fuel. Hydrogen is key and will be a solution to many of the world's climate neutrality objectives: it unleashes the potential of renewables, ensures energy system efficiency, and enables a carbon-neutral transport system, both on land and sea.

By using hydrogen technologies, we can contribute to the decarbonization of economies, notably within industry and transport, thus making renewables relevant in new areas not accessible in the past. It can also replace coal, oil, and gas by being a renewably produced energy vector, fuel, and chemical feedstock. Furthermore, it boosts the use of electricity generated from renewable power and makes the energy system of the future more efficient.

We already see the change happening: the world's first passenger train powered by a hydrogen fuel cell is already running on German railways. The world's first green steel made with hydrogen production was delivered in Sweden. These are just a few examples.

Europe is already home to the electrolyser technology, capable of producing significant amounts of green hydrogen to power industries and homes. Clean hydrogen technologies have strong potential to provide innovative solutions to decarbonise the economy and generate jobs growth in Europe and worldwide.

The business case for hydrogen is there. What is left then?

For hydrogen to become a commercial success, European and global decision-makers need to develop regulatory and policy incentives for clean hydrogen technologies to scale up and cut costs.

COP26 is a chance for Europe to demonstrate its leadership in building a clean hydrogen economy and prove its ambition to become the showcase and benchmark of a global hydrogen revolution.

Clear policy incentives for hydrogen development will give a major push to fighting climate change across all continents. In Europe, this will power the green transformation, create future European jobs and secure a clean energy future for generations ahead. ●

01 Fork lifts can also be powered by hydrogen, shown here at the Solhub, Fronius R&D site Thalheim.
Source: Fronius International GmbH

01

In a Nutshell

A Modern History of Hydrogen

1520
First recorded observation of hydrogen by Paracelsus through dissolution of metals (iron, zinc, and tin) in sulfuric acid.

1801
Humphry Davy discovers the concept of the Fuel Cell.

1875
L'Île mystérieuse (*The Mysterious Island*) by Jules Vernes is published.

1909
Count Ferdinand Adolf August von Zeppelin made the first long distance flight with the Zeppelin LZ5.

Linde–Frank–Caro process

1919
The first Atlantic crossing by airship with the Beardmore HMA R34.

1929
The hydrogen-filled LZ 127 Graf Zeppelin made a 33,234 km circumnavigation of the world. The voyage took a total of 21 days, 5 hours, and 31 minutes.

1937
6 May
Hydrogen is the scapegoat for the Hindenburg crash, operated by Zeppelin, while the causes are more complex, shattering nonetheless public confidence and delayed the advent of air travel

1939
Hans Gaffron discovered that algae can switch between producing oxygen and hydrogen.

1966
General Motors presents Electrovan, the world's first fuel cell automobile

1970

John Bockris or Lawrence W. Jones coined the term hydrogen economy

2002

The Hydrogen Economy by Jeremy Rifkin is published.

2008

Fuel Cells and Hydrogen (FCH) launched

www.fch.europa.eu

2014

6 May

FCH 2 Joint Undertaking (JU) extended by the European Commission to 2020 with €1.33 billion

2016

Toyota releases its first hydrogen fuel cell car, the Mirai

2018

Launch of **Hydrogen Valleys (H2Vs) Platform**

www.h2v.eu

2020

8 July

‘A hydrogen strategy for a climate-neutral Europe’

Kick-Start Phase 2021-2025

Ramp-Up Phase 2025-2035

Market Growth Phase Post-2035

‘A hydrogen strategy for a climate-neutral Europe’

www.ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

‘EU hydrogen policy: Hydrogen as an energy carrier for a climate-neutral economy’

www.europarl.europa.eu/RegData/etudes/BRIE/2021/689332/EPRS_BRI(2021)689332_EN.pdf

European Commission > Energy > Topics > Energy system integration > Hydrogen

www.ec.europa.eu/energy/topics/energy-system-integration/hydrogen_en

2020

8 July

Creation of the **European Clean Hydrogen Alliance**

www.ec.europa.eu/growth/industry/policy/european-clean-hydrogen-alliance_en

2020

World Hydrogen Alliance MENA

www.dii-desertenergy.org/mena-hydrogen-alliance/

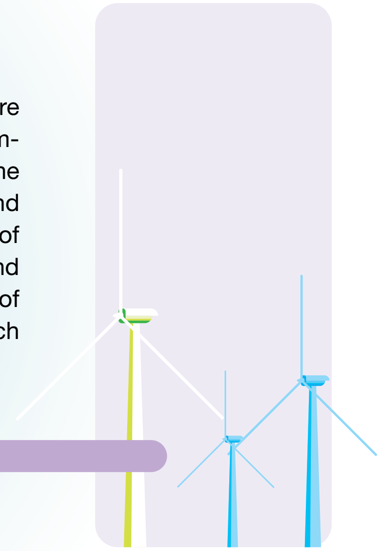
Myth Busters

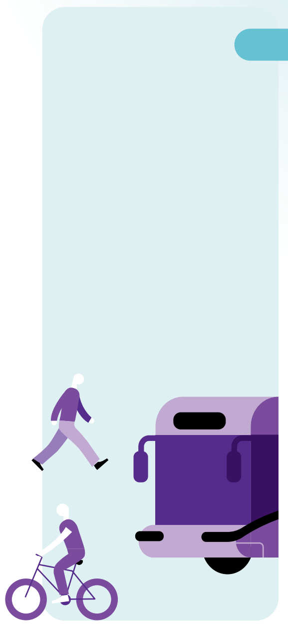
Debunking the usual cliches undermining the value of hydrogen.

Myth 1

Hydrogen energy is not all that energy efficient

While hydrogen is the most abundant element in the Universe, here on Earth, it typically needs to be extracted from water or organic compounds. This is not particularly different from the diesel and gasoline used in combustion engines which are produced from refining and cleaning crude oil (a process which actually heavily involves the use of hydrogen). While hydrogen is currently extracted from natural gas and is already a multi-billion dollar global industry used in a wide range of industrial applications, it is also produced via renewable sources such as solar, wind or biogas without the need to use fossil fuels.





Myth 2

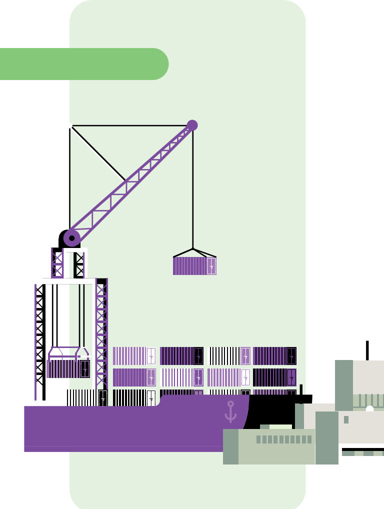
Hydrogen gas is dangerous to store and use

Arguably one of the most common concerns raised when discussing the use of hydrogen is that, as a flammable gas, it can be easily ignited and as such far too hazardous to be stored either in refuelling stations or within a pressure tank. Yet, hydrogen is no more dangerous than other flammable fuels or the batteries used in electric cars. In fact, vehicles with pressure gas storage tanks are nothing new. With millions of on-the-road miles driven over the last few years, an existing global multi-billion industry transporting and making hydrogen for many decades, the automotive industry seems to be more than sufficiently convinced that hydrogen can be stored safely, with Toyota for example having received approval from Japan's Ministry of Economy, Trade and Industry (METI) to self-inspect and manufacture hydrogen tanks for FCEVs.

Myth 3

Hydrogen is really too expensive

The price of green hydrogen has fallen in recent years and it is expected that the reduction will be even higher over the next decade, making it truly competitive against other energy solutions. António Vidigal from EDP Innovation reinforces that the cost of H2 is not so much in the technology or in the infrastructures: "The main component of the cost of green hydrogen is the renewable energy from which it is produced via electrolysis, which corresponds to 70% of the total." It is neces¬sary to have good renewable energy resources, and to optimize the solar and wind mix.

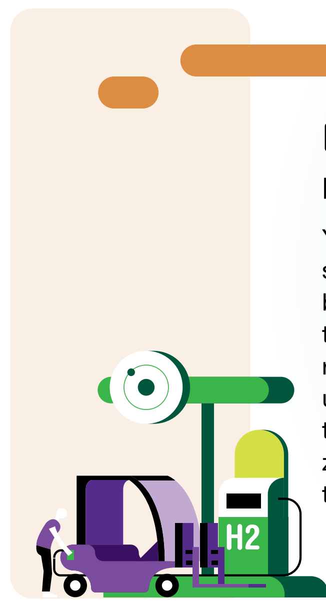


Myth 4

Hydrogen is not completely ecological

In fact, we can take on hydrogen with different colors, and you can read more here. In the production of gray hydrogen, which still dominates the international landscape, gases are released into the atmosphere. And in the case of blue hydrogen produced by the same steam reforming technique, these pollutant emissions are captured for subsequent storage, but there is a small percentage that escapes to the atmosphere in the process.

Green hydrogen however is produced 100% by renewables as shown here.



Myth 5

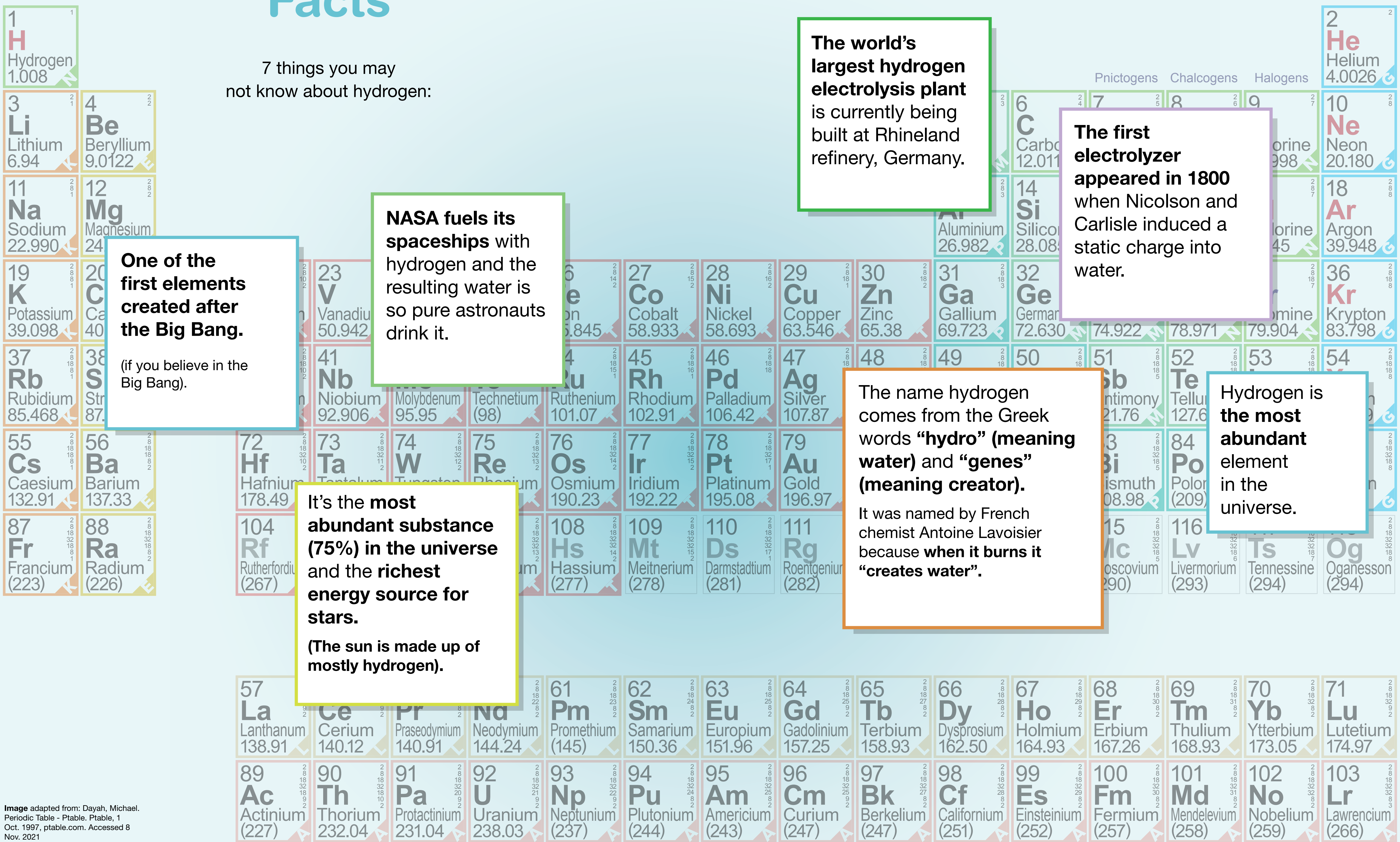
Hydrogen is too explosive!

You may think of the hydrogen bomb or atomic weapons of mass destruction when you hear hydrogen, but the process for making such bombs is the opposite to electrolysis for example which is about splitting the water molecule. Even the Hinderburg accident in 1937, often remembered for the fact that the zeppelin floated due to hydrogen, is unrelated to the gas itself. The most accepted explanation indicates that it was the flammable components on the paint that covered the zeppelin - not hydrogen, which dissipated in seconds - that caused the fire in the aircraft structure.

Sources: HIRINGA, EDP

Facts

7 things you may not know about hydrogen:



One of the first elements created after the Big Bang.

(if you believe in the Big Bang).

NASA fuels its spaceships with hydrogen and the resulting water is so pure astronauts drink it.

The world's largest hydrogen electrolysis plant is currently being built at Rhineland refinery, Germany.

The first electrolyzer appeared in 1800 when Nicolson and Carlisle induced a static charge into water.

It's the **most abundant substance (75%) in the universe** and the **richest energy source for stars.**

(The sun is made up of mostly hydrogen).

The name hydrogen comes from the Greek words **"hydro" (meaning water)** and **"genes" (meaning creator).**

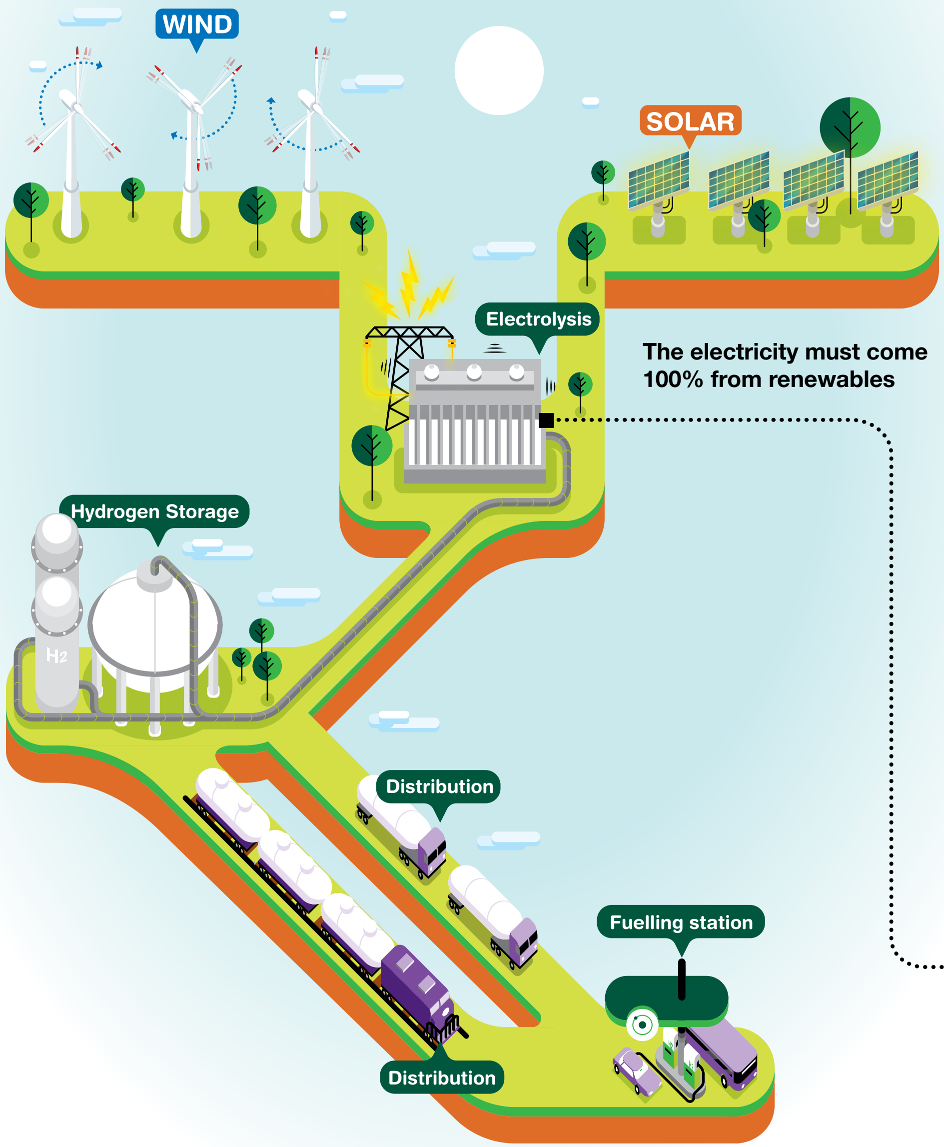
It was named by French chemist Antoine Lavoisier because **when it burns it "creates water".**

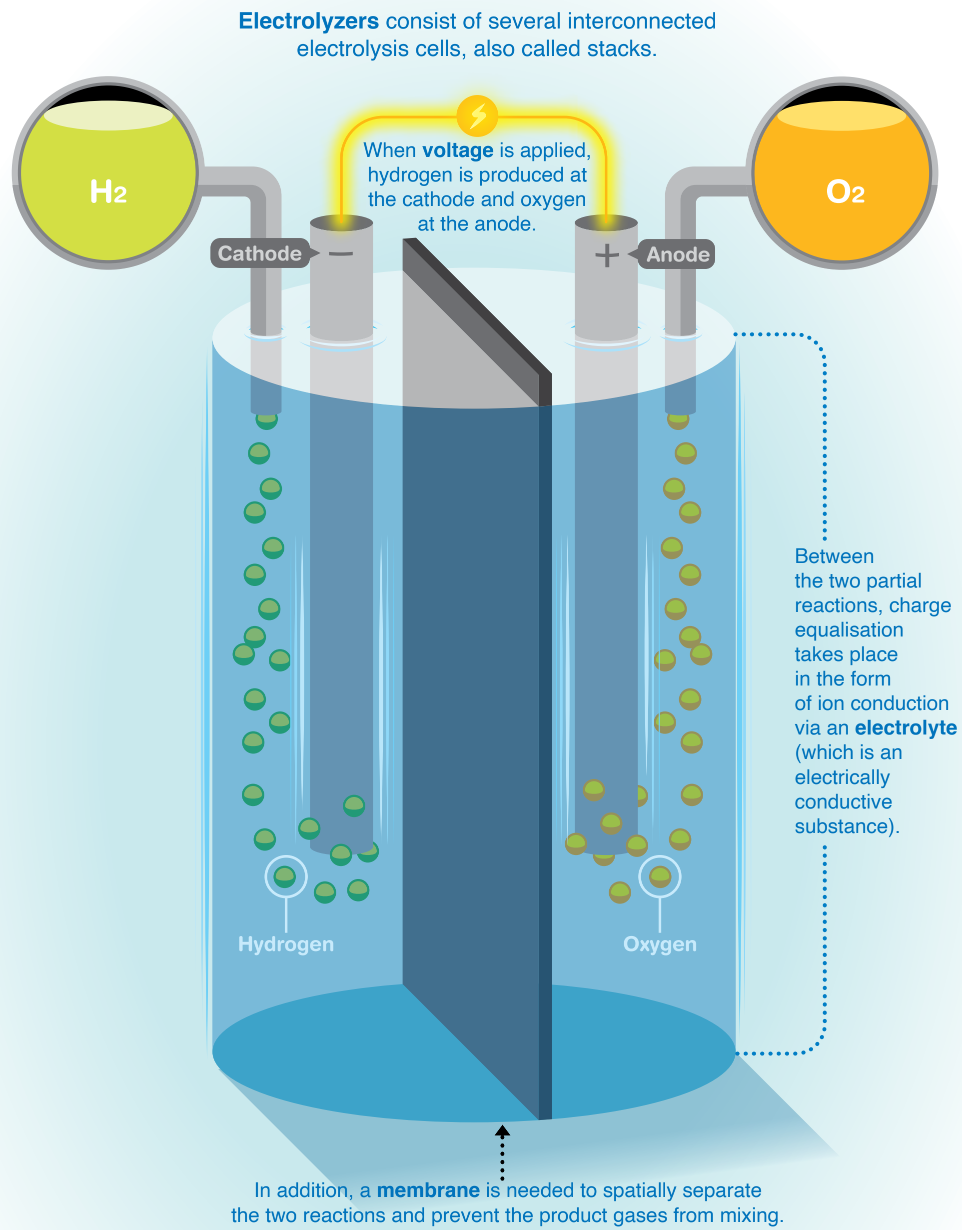
Hydrogen is **the most abundant** element in the universe.

Image adapted from: Dayah, Michael. Periodic Table - Ptable. Ptable, 1 Oct. 1997, ptable.com. Accessed 8 Nov. 2021

How Green Hydrogen is Produced

Currently, 95% of global hydrogen production is based on fossil materials, which cause significant CO_2 emissions. However, hydrogen can be produced via electrolysis without negative environmental consequences and replace fossil fuels for transport.





HOW DOES ELECTROLYSIS WORK?

The basic principle of electrolysis is to split water into oxygen and hydrogen with the help of electricity.

The Colors of Hydrogen

Discover all the different hues of the first element in the periodic table.

Green

(Renewable)

Green hydrogen is mainly produced by splitting water (i.e. water electrolysis) using electricity generated from renewable energy sources (RES).

The reason it is called green is that there is no CO_2 emission associated with the hydrogen production nor with its usage. When used in a fuel cell, the only by-product of its use is the pure water that was originally used in its production. Renewable hydrogen is generally more expensive than blue hydrogen, though prices are becoming more competitive.

Although “green” hydrogen often refers to electrolytic hydrogen produced using electricity generated from renewable energy sources, it can also refer to hydrogen produced via different methods using other renewable sources such as biogas, biomethane, bio-waste and other renewable sources, these methods are less common than water electrolysis but also result in either very low or zero emissions.

Turquoise

Extracted by using the thermal splitting of methane via methane pyrolysis, this process (though at the experimental stage) removes carbon in a solid form instead of CO_2 gas.

Grey

Grey hydrogen is produced from fossil fuel and commonly uses steam methane reforming (SMR) method. During this process, CO_2 is produced and eventually released to the atmosphere.

White

White hydrogen refers to naturally occurring hydrogen in its most natural state.

Pink

Pink hydrogen is generated through electrolysis of water by using electricity from a nuclear power plant.

Purple

Purple hydrogen is made though using nuclear power and heat through combined chemo-thermal electrolysis splitting of water.

Black / Brown

Produced from coal, the black and brown colours refer to the type of bituminous (black) and lignite (brown) coal. The gasification of coal is a method used to produce hydrogen. However, it is a very polluting process, and CO_2 and carbon monoxide are produced as by-products and released into the atmosphere.

Red

Red hydrogen is produced through the high-temperature catalytic splitting of water using nuclear power thermal as an energy source.

Blue

Blue hydrogen refers to hydrogen derived from natural gas, which is a fossil fuel, however, most (albeit not all) the CO_2 emitted during the process would be captured and stored underground (carbon sequestration) or bound in a solid product (such as bricks) and utilized. This is called carbon capture, storage and utilisation (CCSU).

One process for achieving this is called steam methane reforming (SMR). This mixes natural gas with very hot steam, in the presence of a catalyst, where a chemical reaction creates hydrogen and carbon dioxide and carbon monoxide. An improvement of this process, auto-thermal reforming (ATR) combines the steam reforming reaction and fuel oxidation into a single unit. This process is more efficient and is able to capture more of the CO_2 emitted in course of production. When considering the CO_2 emission reduction potential of “blue” hydrogen, it is important to acknowledge the importance of tackling methane leakage upstream of the hydrogen production plant. This should be done by applying a strict life-cycle assessment when determining the CO_2 emissions associated with its production.

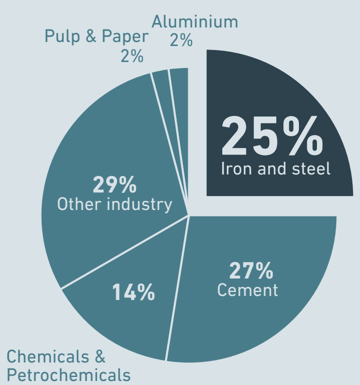
Due to the differences in CO_2 emissions that can occur in the production of “blue” hydrogen (depending on upstream methane emissions and the production technology used), the term itself can be considered too broad. Instead, when referring to hydrogen produced from natural gas, it is more accurate to refer to it using the actual GHG footprint associated to its production.

DECARBONISING STEEL WITH HYDROGEN

The iron and steel industry is responsible for up to 10% of global greenhouse-gas emissions. Switching from carbon to hydrogen as a feedstock will replace CO_2 emissions with steam emissions. The task is technologically feasible, but momentous in scale.

CO_2 EMISSIONS FROM THE STEEL INDUSTRY

TOTAL INDUSTRY CO_2 EMISSIONS



GLOBAL ANNUAL STEEL PRODUCTION **1,869 Mt**

CO_2 EMISSIONS **3.7 Gt**

APPLYING HYDROGEN

- **DIRECT REDUCTION** replacing natural gas
- **H_2 INJECTION** replacing coal
- **H_2 BURNERS** replacing natural gas
- **HYDROGEN PLASMA SMELTING REDUCTION** replacing coal

HYDROGEN STEELMAKING

70% of total steel production is suitable for hydrogen route

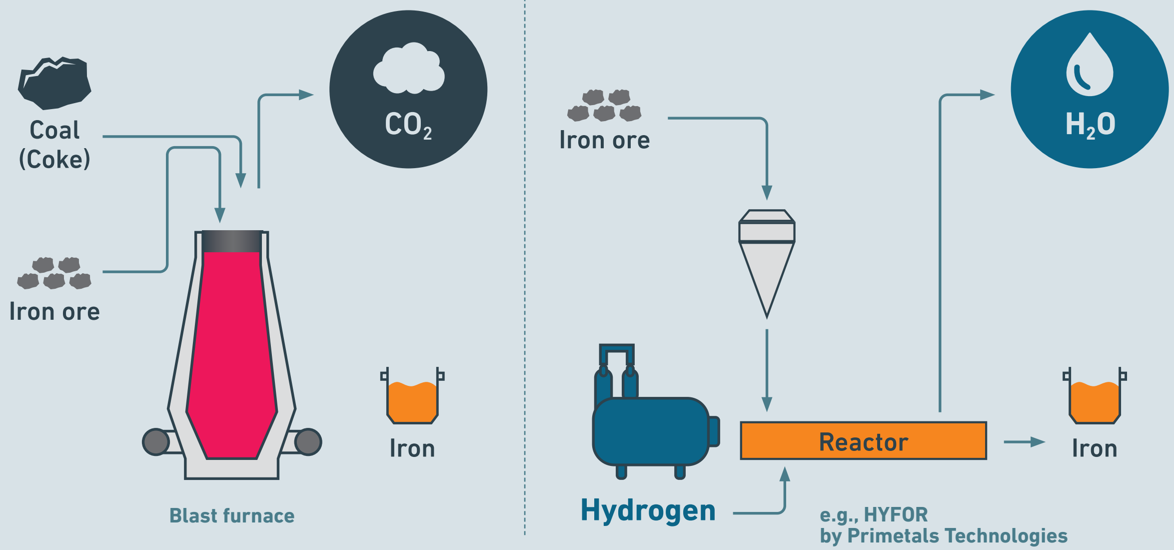
1,308 Mt of production capacity to convert

26 Fe Iron 55.845 — 1 H Hydrogen 1.008

1t steel requires approx. **55 kg** H_2

TRADITIONAL ROUTE

HYDROGEN-BASED



WHAT WILL IT TAKE?

- **72,000,000 t** tonnes of hydrogen per year
- **500 GW** of electrolyser capacity
- **4,000 TWh** of green electricity per year

Policy Developments

Policy Developments

WRITERS:
BASTIEN BONNET-CANTALLOUBE & FELICIA MESTER

Introduction

New policies and initiatives deeply affect the energy sector, and hydrogen is no exception. As a carbon-free energy carrier, hydrogen has been increasingly the focus of policy-makers, not least under the EU's Recovery Plan, the European Commission's 2020 Hydrogen Strategy, and in 2021 with the advent of the Fit-for-55 Package. **Hydrogen will become a crucial energy vector and the other leg of the energy transition – alongside renewable electricity – to replace coal, oil, and gas across different segments of the economy.**

The climate crisis and its rising political prominence has led to the EU Green Deal - the key driver for the energy transition and the EU's decarbonisation agenda. In late 2019, the European Commission presented it as Europe's "new growth strategy". It entails a more ambitious target for EU greenhouse gas (GHG) emission reduction (-55%, up from -40%) and the enshrinement of the carbon

Hydrogen will become a crucial energy vector and the other leg of the energy transition – alongside renewable electricity – to replace coal, oil, and gas across different segments of the economy.

neutrality objective for 2050 in an EU Climate Law. To achieve this, the EU Green Deal also implies a broad review of EU legislations and policies, as well as new proposals.

The EU's climate ambitions propel all aspects of EU policy with a view to shift our economies away from carbon emitting energy sources and carriers. This stretches from the energy and mobility sectors to taxation, industrial policy, climate and environmental protection. **Hydrogen is the crossroads between climate policies and the deep decarbonisation of our economy.**

Legislative acts and policies adopted or presented in 2020 and 2021

The adoption of the European Hydrogen Strategy marked a first step towards the development of an EU-wide clean hydrogen market. Its 2030 targets set the ambition for the subsequent adoption of the EU Climate Law, the Fit-for-55 package and the imminent publication of the hydrogen and gas decarbonisation package. This is the third economic revolution which will be marked by the establishment a proper functioning and liquid

Policy mentioned in the article

EU Green Deal
EU's Recovery Plan
European Commission's 2020 Hydrogen Strategy
EU Green Deal
Hydrogen Strategy
Energy System Integration Strategy
Offshore Renewable Strategy
Sustainable and Smart Mobility Strategy
EU Climate Law
Fit-for-55
Renewable Energy Directive (RED)
EU Emissions Trading System (ETS)
Carbon Border Adjustment Mechanism (CBAM)
CORSIA scheme
Energy Taxation Directive (ETD)
Alternative Fuels Infrastructure Regulation (AFIR - formerly AFID)
CO_2 Emission Standards Regulation for cars and vans
FuelEU Maritime
RefuelEU Aviation
Trans-European Network – Energy (TEN-E)
Third Gas Package
Delegated Act of the Renewable Energy Directive
TEN-T regulation

EU Green Deal
Climate neutrality by 2050

- Halving emissions from cars and vans (55% and 50%)
- Zero emissions from new cars by 2035
- 35 million renovated buildings by 2030
- 160,000 additional green jobs in construction sector
- 40% new renewable energy target
- 36-39% energy efficiency targets for final and primary energy consumption
- New target of -310 Mt of carbon removals

Source: ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en#making-transport-sustainable-for-all

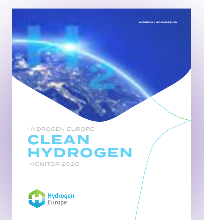
Fit-for-55
Cutting 55% of emissions by 2030

- Strengthen EU Emission Trading Scheme (ETS)
- Extend ETS to maritime sector, reduce airline allowances
- New ETS for road transport and buildings by 2025
- ReFuelEU Aviation initiative to oblige sustainable aviation fuel blends
- FuelEU Maritime initiative to stimulate sustainable maritime fuels and zero emission technologies

Source: ec.europa.eu/clima/policies/transport

Clean Energy Monitor

See Clean Hydrogen Monitor 2020 for a full analysis of the European Hydrogen Strategy



The Clean Hydrogen Monitor 2021 is a comprehensive source of data, facts and analysis surrounding the hydrogen market in Europe to support fact-based policy and business decisions, monitor development of the hydrogen market and assess the progress of clean hydrogen at replacing the consumption of fossil fuels.

Content of this year's report:

Current hydrogen demand and production capacity

Levelized cost of hydrogen analysis

Planned projects (production and consumption of hydrogen in industry)

Policies and incentives

Funding opportunities

market for clean hydrogen as a new commodity in Europe, building up the backbone of a global clean hydrogen market.

Non-binding policies and strategies

In the EU legislative process, non-binding policy documents, strategies, communications, white papers and other soft law examples play an important role in setting a long-term vision for the direction that will be taken by EU law. The most fundamental ones for hydrogen are the EU Hydrogen Strategy and the Energy System Integration Strategy, both published on 8 July 2020.

The **Hydrogen Strategy** adopts the 2030 target of 2x40 GW of electrolysis capacity (40 GW in the EU and 40 GW in neighbouring partner countries) as a guiding vision. An intermediary target of at least 6 GW by 2024 is set too. The priority for the Commission is to develop renewable hydrogen, produced from renewable electricity. At the same time, the Strategy recognises the role of low-carbon hydrogen in the short- and

> **Hydrogen is the crossroads between climate policies and the deep decarbonisation of our economy.**

medium-term to rapidly reduce emissions from existing hydrogen production and drive the development of the hydrogen backbone.

The **Energy System Integration Strategy** aims to foster circularity and flexibility in the energy system by taking increasing advantage of synergies across sectors. Decarbonisation, energy efficiency, and security of supply are the main end goals. In this roadmap, hydrogen is seen as a technology to link the components of the energy systems, to store energy for long-term periods, and to decarbonise hard-to-abate sectors (especially trucks, industry, maritime, and aviation).

The European Commission published numerous supporting strategies in 2020 that include the **Offshore Renewable Strategy** which considers offshore hydrogen production and hydrogen pipelines as the most promising means of delivering offshore energy to consumption centres onshore; the **Sustainable and Smart Mobility Strategy** is also very relevant, as it provides the EU's first clear targets for hydrogen refuelling stations: 500 in 2025 and 1,000 in 2030, up from 144 in 2021.

While the foundations for the legislative environment affecting hydrogen were already in place, the developments which took place following the adoption of the Hydrogen Strategy have the potential to be truly transformational for the clean hydrogen sector. Figure 15, below presents just a few of such developments which are likely to have a major impact.

EU Climate Law – A binding legal act

The (revised) EU Climate Law (Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality) was formally adopted on 30 June 2021 and effectivley sets a new EU target of reducing GHG emissions by at least 55% by 2030 compared to 1990 levels (up from 40% previously) and the binding objective of climate neutrality (net zero emissions) in the EU by 2050. This set the stage for the "Fit-for-55" legislative proposal package. fuel (If produced from renewable or low-carbon sources), hydrogen is indispensable to any scenario for reaching net-carbon neutrality

The Fit for-55 package and legislative proposals

Proposed by the European Commission on 14 July 2021, the **Fit-for-55** package represents perhaps the most fundamental change to the EU legislative acquis since the completion of the EU single market. The package touches upon almost all aspects of the EU economy, especially in the area of energy, industry and mobility. For the purposes of this report, we will limit ourselves to a short presentation of the legislative proposals within the Fit-for-55 package with the highest potential impact on the hydrogen market and highlight provisions which are most relevant.

The **Renewable Energy Directive (RED)** sets rules for the development of renewable energy across all sectors of the EU's economy. The revised proposal raises the renewable energy target from 32 to 40% in total energy consumption, but also sets minimum binding targets for the use of renewable fuels of non-biological origin (RFNBOs) by 2030, which means some 50% of hydrogen consumption in industry and at least 2.6% of the total energy consumption in the transport sector (including renewable hydrogen consumed in refineries).

Specific provisions are also proposed to mainstream renewable energy in heating and cooling, such as 1.1% annual increase in heating and cooling becomes a binding baseline, and an indicative target of at least 49% renewables in the buildings sector; as well as to extend the scope of the Union Database to cover the tracing of liquid and gaseous renewable fuels and recycled carbon fuels and their life-cycle greenhouse gas (GHG) emissions. In its current form, the revised RED generates a demand for renewable-only hydrogen of at least 4.9 Mt and, as such, represents one of the main drivers for the widespread adoption of renewable hydrogen in the EU.

The **EU Emissions Trading System (ETS)** is a 'cap-and-trade' mechanism aiming to decrease GHG emissions by setting a maximum amount of emission allowances (the 'cap') per set periods. This cap decreases over time, following a linear reduction factor. Most allowances are auctioned, and the rest is allocated for free to some sectors deemed to be at risk of carbon leakage (an index that is based carbon intensity in the sector's processes and the intensity of the sector's trade flows).

The ETS is slated to undergo a major revision, the main change being that covered emissions should be cut by 61% by 2030 (up from 43%). The higher target will be achieved through a combination of a higher LRF and a one-off reduction of the cap. This increased ambition of the carbon market will likely trigger the clean switch across multiple applications driven by higher CO_2 prices (e.g., in ammonia, steel and cement production).

On top of increased ambition, the proposal suggests an extension of the EU ETS to most maritime transport, with a phasing-in period until 2026, road transport and buildings under a new separate ETS without free allowances, with the aim to cut emissions by 43% in these sectors by 2030 compared to 2005.

01 Building site. Milano, Italy.
Source: Michele Bitetto /Unsplash

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Revenues stemming from the ETS auctions are set to increase and be channelled towards the Innovation and Modernisation Funds and target climate-related purposes. In addition, a new Social Climate Fund could mobilise €72.2 billion for 2025-2032 to help most vulnerable households and transport consumers.

Furthermore, free allocation is proposed to become conditional on installation decarbonisation efforts. Furthermore, the revision proposal includes the production of all hydrogen production methods (i.e., electrolytic) under the scope of the EU ETS, making renewable and low-carbon facilities eligible for free allowances.

Some sectors covered by the current ETS – steel, aluminium, cement, fertilisers, and electricity – could also fall under the scope of a new legislation, called the **Carbon Border Adjustment Mechanism (CBAM)** that aims at protecting those industries against carbon leakage while gradually phasing out (over a 10-year period from 2026 to 2035) free allowances that those sectors receive. This may work by imposing on importers to the EU that they purchase CBAM certificates whose price will reflect the CO_2 price level under the ETS for the corresponding goods, minus the free allocations still being received by those sectors. Free allowances will also be phased out for the aviation sector by 2026 (for intra-EU flights); external-European flights are to be subject to offsetting under the international CORSIA scheme.

Phases of Corsia implementation

The proposed revision of the **Energy Taxation Directive (ETD)** heavily incentivises a switch to renewable and low-carbon hydrogen. The revision aims to tax the energy content of energy products rather than their volume and places them in tax categories based on their environmental performance when setting minimum excise rates. This ranking must be maintained when Member States set actual rates.

Fossil fuel tax exemptions delivered for certain products would be phased out, ensuring that those are no longer taxed below minimum rates. After a 10-year transition period, this would also apply to fossil fuels used for intra-EU air transport, maritime transport and fishing – a crucial measure given the role of these sectors in energy consumption and GHG emissions.

The proposal foresees a preferential minimum tax rate of €0.15/GJ for renewable and low carbon hydrogen (during a 10-year transition period for

It is imperative that hydrogen moves from an afterthought to a central pillar of the energy system.

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02 Self service hydrogen filling station.
Source: Scharfsinn

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03 A Toyota Mirai fuel cell vehicle parked in a street in Shinjuku, Japan, 2019.
Source: Ned Snowman

the latter), incentivising the use of clean hydrogen in multiple applications, not least in maritime and aviation. In contrast, non-renewable fuels of non-biological origin (i.e., fossil hydrogen) are taxed at a minimum rate of €7.17/GJ. The lowest minimum rate of €0.15/GJ applies to electricity – regardless of its use and of the primary energy source used for its production.

The **Alternative Fuels Infrastructure Regulation (AFIR - formerly AFID)** proposal, as a directly applicable Regulation, proposes binding targets for the development of Hydrogen Refuelling infrastructure along the main transport axes. It promotes the rolling out of hydrogen refuelling stations at a maximum distance of 150km between stations. In order to consider the specificities for heavy-duty vehicles, as well as cars and light-duty transport, it requires a minimum daily capacity of 2 tonnes of H2/day and a 700-bar dispenser.

The proposal to revise the **CO_2 Emission Standards Regulation for cars and vans** maintains its 2025 target and sets an increased emission GHG reduction target by 2030 on vehicle manufacturers, this time differentiating between cars (55% reduction) and vans (50% reduction). This is a strong policy incentive for the adoption of zero emission vehicles. In addition, the proposal includes a new target for 100% emission reductions in 2035 effectively signalling the phase-out of internal combustion engines under the current accounting scheme (tank-to-wheel) in favour of zero tailpipe emission vehicles.

The **FuelEU Maritime** and **RefuelEU Aviation** are regulation proposals to promote the use of clean fuels in the maritime and air transport to decarbonise those sectors. Targets are set based on the fleet average GHG intensity of the energy used onboard by large ships (above 5,000 gross tonnage) for maritime. Emission level is reduced by 2% from 2025 to 75% from 2050 for all intra-EU voyages and stays in within a port of call covered, and half of voyages between EU and non-EU ports of call will also be included (aligned with the scope of the EU ETS extension).

04 Concept of hydrogen fuel cell ferry ship.
Source: Scharfsinn

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For aviation, an obligation is set on fuel suppliers, as from 2023, to provide sustainable aviation fuels (SAF) to airlines at all EU airports. This obligation only considers SAF such as biofuels, advanced biofuels and RFNBOs which are chemically identical to the fossil fuels they are replacing. After 2030, it introduces a minimum share of e-fuels (RFNBOs). By 2050, the objective is a minimum of 63% SAF, of which at least 28% of synthetic fuels.

Although not part of the Fit-for-55 package, the proposal for the **Trans-European Network – Energy (TEN-E)** Regulation revision (2020) represents another key legislative milestone. Formerly, the legislation considered four energy infrastructure categories: electricity, gas, oil, and carbon dioxide. The 2020 proposal proposes the following five categories: electricity, smart gas grid, hydrogen, electrolysers, and carbon dioxide. The hydrogen sector is now fully represented with natural gas and oil infrastructure projects not being able to get priority status for accelerated permit-granting processes and improved regulatory treatment (PCI list). The Regulation foresees the planning for the conversion of natural gas infrastructure to hydrogen and the emergence of a 'hydrogen backbone'.

Expectations for the future period (Q3 and Q4 2021 and 2022)

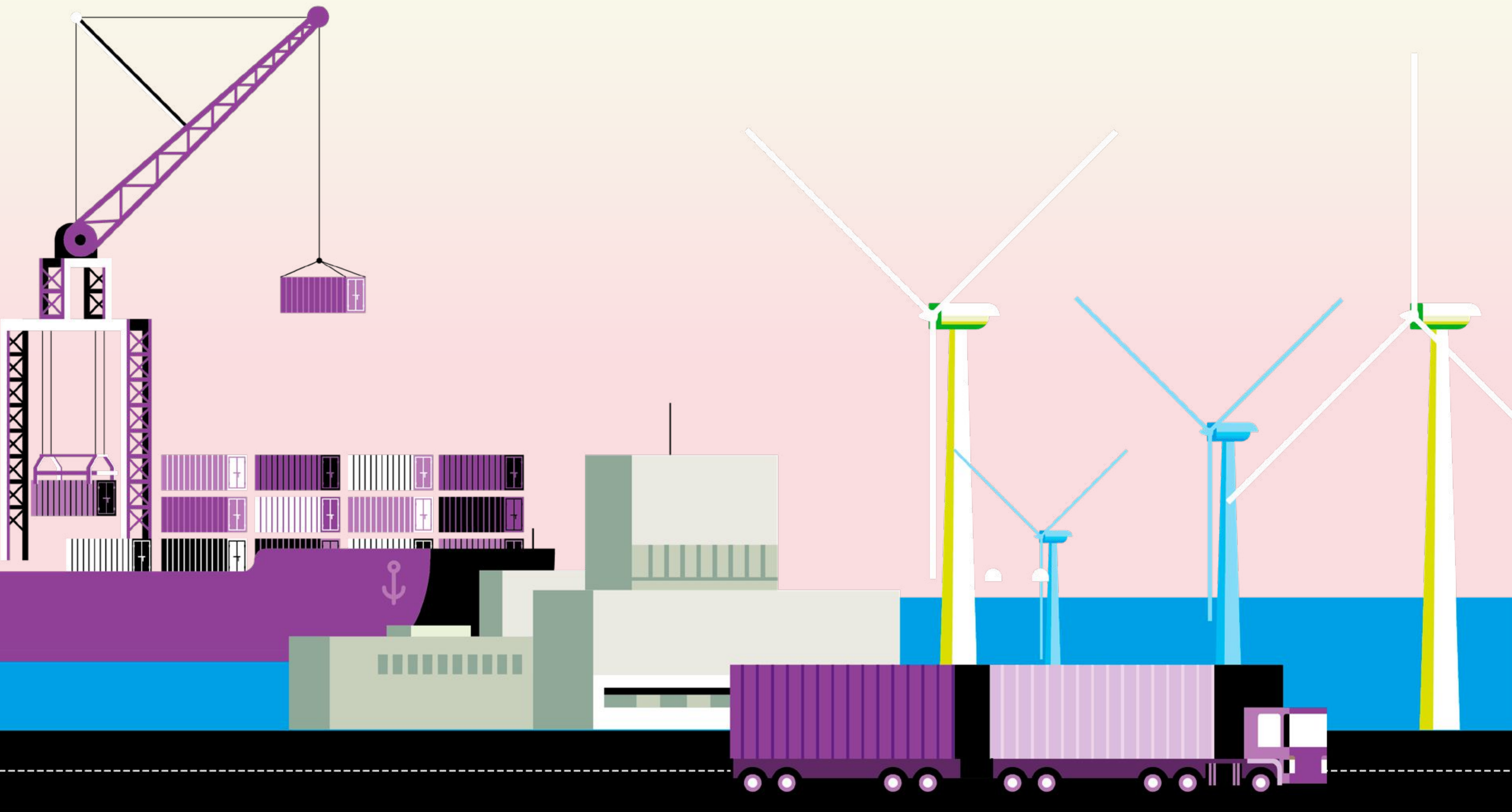
The imminent release of the hydrogen and gas decarbonisation package on 14 December 2021 will mark a key development in EU energy, climate, and transport policies. It is imperative that hydrogen moves from an afterthought to a central pillar of the energy system. Continuing to regulate hydrogen across different legislation and patchwork will delay the necessary energy transition and can lead to fragmentation, overlapping and sometimes contradictory legislation, and uncertainty for investors.

For the hydrogen sector, the revision of the **Third Gas Package** must remove barriers to hydrogen investment, create a level playing field with other net-zero technologies and promote a harmonised approach to hydrogen via the development of a dedicated regulatory approach where infrastructure, demand and production related issues come together.

December 2021 will also be marked by the publication of **the Delegated Act of the Renewable Energy Directive on additionality, geographic and temporal correlation**, currently precluding investors from financing projects aiming to replace carbon-emitting energy carriers with renewable hydrogen. It is time to recognise that renewable hydrogen creates demand exclusively for renewable energy not for fossil-based power.

Finally, the revision of the **TEN-T regulation** will be an opportunity for the Commission to align guidelines on transport infrastructure funding with the objectives of the EU Green Deal. It should provide further opportunities for the uptake of clean transportation modes, including for hydrogen technologies and refuelling stations, consistent with both the AFIR, as well as the revised TEN-E. ●

Market Developments



Market Developments

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Expected Market Development Overview

The European Hydrogen Strategy identifies three main phases of development for hydrogen: the kick-start phase, the ramp-up phase, and the market-growth phase.

The kick-start phase will largely occur from 2021 to 2025 with some countries being ahead of the curve and some catching up to the others. During these years, the foundations of the European hydrogen economy will be developed. At the end of the kick-start phase, 1 million ton of clean hydrogen will be produced per year and at least 6 GW of electrolyser capacity will be installed (according to the EU Hydrogen Strategy). Given the absence of a clear and harmonised EU framework for hydrogen and the initial lack of competitiveness in key applications, **a fast-track approach to both removing regulatory hurdles and providing financial support measures will have to be adopted** to achieve these goals with a focus on mature and scalable projects.

A fast-track approach to removing regulatory hurdles and providing financial support measures for hydrogen is primordial.

During the ramp-up phase from 2025 to 2035, there will have to be a solid supporting framework to develop a European hydrogen economy and achieve its commercial competitiveness. Hydrogen will shift from local to regional and national applications as large-scale storage, hydrogen 'backbones', and hydrogen valleys will be realised with support from the appropriate measures to stimulate supply and demand. Throughout this period and for many applications, hydrogen will also require regulatory support, including for example through tariffs, auctions/tenders, quotas, investment support, tax relief, and supported by **Guarantees of Origin (GO)**. Most hydrogen production and applications will have achieved commercial competitiveness at the end of the ramp-up phase.

After hydrogen has achieved commercial competitiveness, the next phase, post 2035, will focus on market growth without any support frameworks. Hydrogen will continue to replace unabated fossil fuels by converting natural gas pipelines and further development of the European hydrogen system. The hydrogen market will be transparent, liquid, and governed by mechanisms of supply and demand. As network integration deepens, the market will require regulation to ensure interoperability and market rules to avoid monopolistic behaviour.

Clean hydrogen consumption in industry

Although new emerging technologies, such as fuel-cell vehicles in the transportation sector, have highlighted the value of hydrogen to our societies, this most-abundant element in the universe known as hydrogen has been used for many years already as a source of energy in many industrial processes. In 2019, total demand for hydrogen was estimated at 8.4 Mt with the biggest share of demand coming from refineries and ammonia production. Together, these two sectors consumed almost 80% of total hydrogen consumption in EU, EFTA, and UK. About 13% is consumed by the chemical industry. Emerging hydrogen applications for clean hydrogen, like the transportation sector, comprised in 2019 only a minuscule portion of the market (<0.1%).

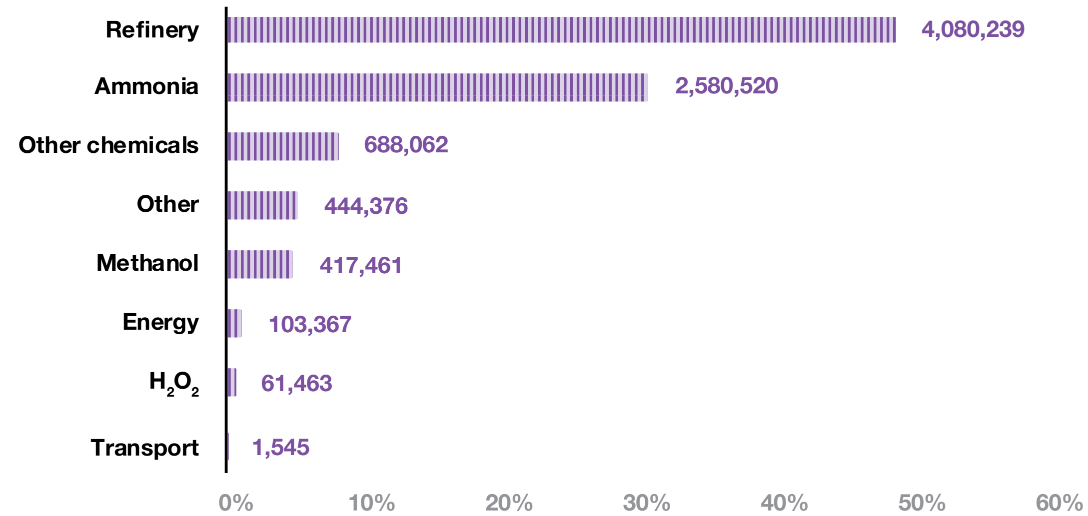
With constant pressure to reduce CO_2 emissions in industry and ambitious targets being put in place, **many hydrogen-consuming sectors are transitioning from fossil-based hydrogen to clean hydrogen**, as the emissions involved in the production of the former add-up to their own direct carbon emissions. This is the case for **refineries**, which already typically use hydrogen for the reduction of sulphur content in diesel fuel. The transition into clean hydrogen represents a way of reducing the emissions in this sector.

01 Night View of a Chemical Plant.
Source: Albert Pego

02 Power plant, Sines, Portugal.
Source: Pedro Farto /Unsplash

03 Large-capacity workshop for the production of ammonia of a petrochemical plant. Exterior of tube furnace, Shaft converter, CO2 adsorber with copy space.
Source: yarm_sasha/Shutterstock

Total demand for hydrogen in 2019 by application
Source: Fuel Cells and Hydrogen Observatory



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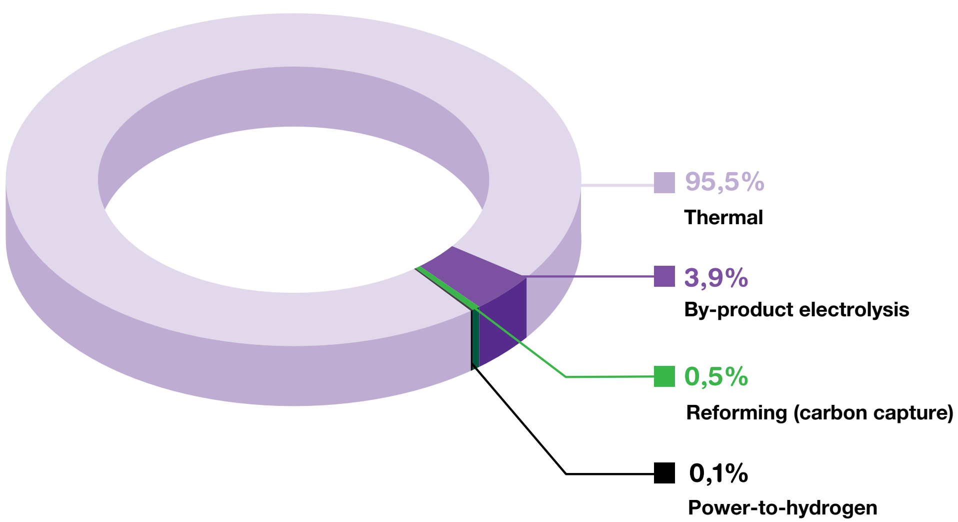
Clean hydrogen capacity in Europe has grown significantly from 90 MW in 2019 to 135 MW.

Similarly, the **ammonia** production process is a big hydrogen consumer that can benefit from the adoption of clean hydrogen. Although it is usually used as a feedstock for fertilizer production, ammonia has also been seen as a potential energy carrier and/or fuel, already considered a suitable e-fuel for maritime applications. The same reasoning can be applied to the production of **methanol**, used both in chemical processes and, as of recently, as an e-fuel.

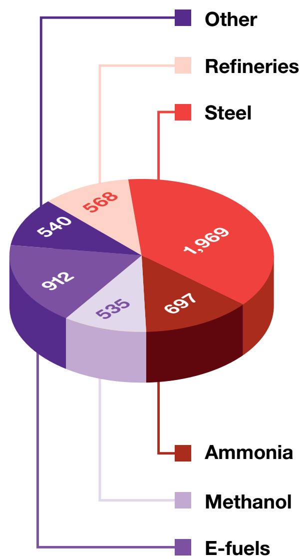
E-fuels are synthetic hydrogen-based fuels that can be burned in combustion engines and help decarbonize hard-to-electrify vehicles (e.g., in the aviation and maritime sectors). Provided that carbon is captured from the atmosphere, renewable electricity is used during the synthesis and the hydrogen source is low-carbon, e-fuels such as e-methanol, e-ammonia, e-diesel, e-L(N)G and e-kerosene are great alternatives to reduce emissions in mobility. Carbon dioxide is still emitted during the combustion of e-fuels, but provided the conditions expressed above are met, the CO_2 emissions should correspond to the amounts of carbon dioxide taken out of the atmosphere and used in the production process as a feedstock.

Clean hydrogen can also be used to help decarbonize the **steel** industry, a highly energy-intensive process that is responsible for 4% of the total GHG emissions in Europe. The steel production process can take different routes. In Europe, 60% of the production involves a blast furnace (BF) and a basic oxygen furnace (BOF), where coal is used as a reductant to transform iron ore into steel. The second route makes use of an electric furnace arc (EAF), powered by electricity, to produce steel from steel scrap and direct reduced iron (DRI) in different proportions. While the EAF route is already less carbon intensive than the BF/BOF method, emissions still occur when natural gas is used as a reductant to produce the DRI pellets. Replacing the natural gas by low-carbon hydrogen, combined with the supply of renewable electricity to power the EAF, will help decarbonize the entire steel production process. The steel industry is, in fact, the sector that is currently planning the biggest consumption of clean hydrogen by 2030, according to the Clean Hydrogen Monitor.

Hydrogen generation capacity by technology
Source: Clean Hydrogen Monitor 2021, Hydrogen Europe



Planned clean hydrogen annual consumption in 2030 by sector
Source: Hydrogen Europe



04 Blast furnace smelting liquid steel in steel mills. **Source:** ABCDstock / Shutterstock

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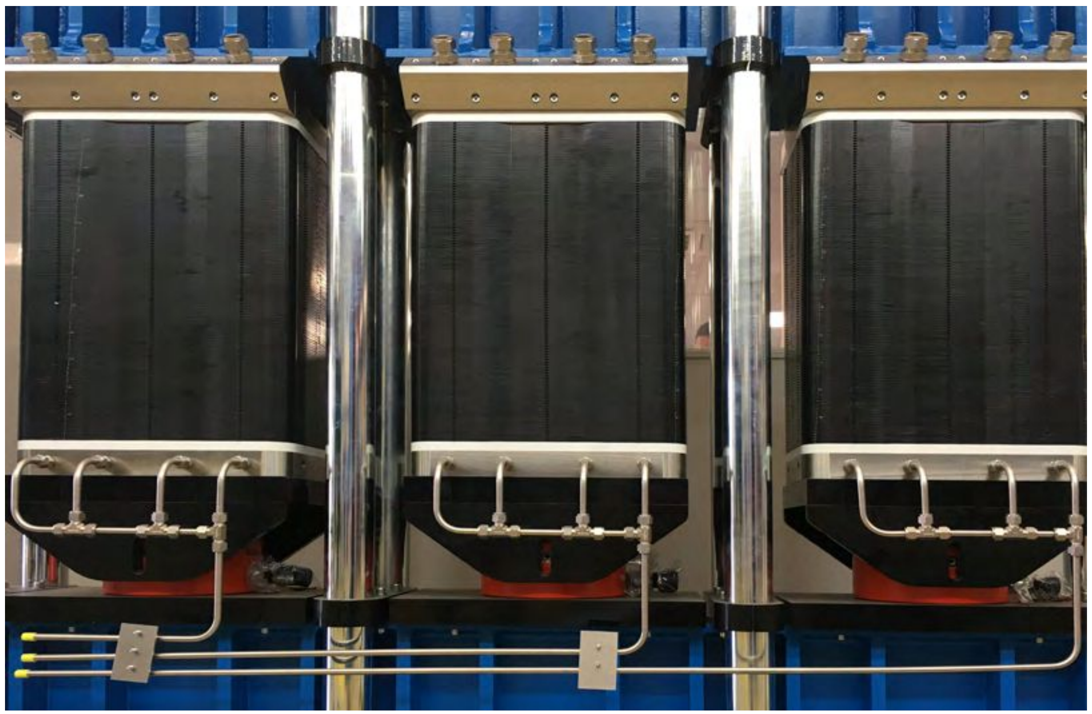
The total planned consumption of low-carbon hydrogen in the industrial projects tracked by Hydrogen Europe amounts to 5.2 Mt H2/year by 2030. In current industry ambitions, emerging technologies such as new ways to produce steel and the e-fuels industry will be the biggest consumers of clean hydrogen.

The clean hydrogen production market

The vast majority of current hydrogen production is from fossil fuels. According to Hydrogen Europe's Clean Hydrogen Monitor, there are 504 hydrogen production points in EU, EFTA, and the UK with production capacity of 10.5 Mt of hydrogen per year as of 2019. The **"thermal"** production methods (reforming, partial oxidation, by-product production from refining operations, and by-product production from ethylene and styrene) constitute **95.5%** of the total hydrogen production capacity. **By-product electrolysis** (i.e., capacity from chlor-alkali and sodium chlorate processes) accounts for **3.9%**. **Reforming with carbon capture** provides **0.5%** of total hydrogen production capacity. **Power-to-hydrogen** accounted for only **0.1%** of total hydrogen production capacity as of 2019.

For reference, the **EU Hydrogen Strategy has defined a renewable hydrogen production target for 2030 at 10 million tonnes.** This is almost equivalent to total current hydrogen production capacity of 10.5 Mt that has been developed over several decades**.**

Countries with the largest hydrogen production capacity are **Germany, Netherlands, Poland, and Spain**. These four countries account for **50% of the total EU, EFTA, and the UK** hydrogen production capacity. Figure 1(4) below provides an overview of total hydrogen production capacity by country and by production type.



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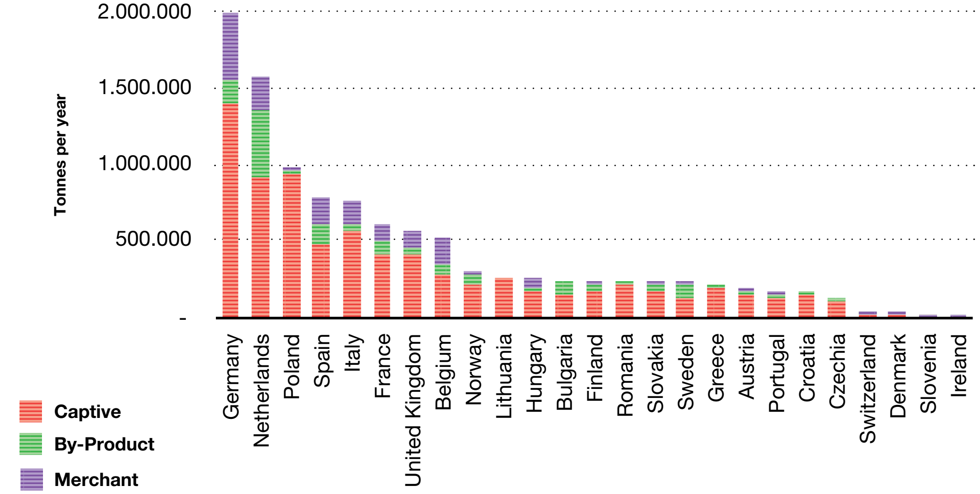
Total hydrogen production capacity by country
Source: Fuel Cells and Hydrogen Observatory



Clean hydrogen capacity

While power-to-hydrogen technology has been available and used for decades, it is only now expanding from installations measured in KW to installations measured in tens of MW. There is about **135 MW of operational electrolysis capacity in Europe** right now according to the Clean Hydrogen Monitor 2021 compared to approximately 300 MW deployed globally as according to the International Energy Agency.

This capacity in Europe has grown significantly in the last few years **from 90 MW in 2019 to 135 MW** as of the time of writing in 2021. The average project size gradually increased from 0.9 MW in 2019 to 1.02 MW in 2021. Another sign of a gradual development of this market is the largest operating electrolyser. While in 2019, the largest operating electrolysers in Europe were around 7 MW, a 10 MW electrolyser was installed in 2021. There are multiple electrolysers of 20 MW and one of 30 MW under construction in 2021 that are scheduled to become operational in 2022. According to current industry ambitions, there are several projects in a 100 MW scale planning to be operational in Europe by 2023.

The largest operating and planned power-to-hydrogen projects are driven by project partners from the industry who serve as off-takers of the produced electrolytic hydrogen. In most cases, these off-takers are already using fossil fuel-based hydrogen and these projects serve as initial pilot phases for their more ambitious future decarbonization plans. One example is decarbonization of an ammonia plant or a refinery where the owner begins with a small electrolyser to pilot replacing their current fossil hydrogen supply with renewable hydrogen production before further committing and increasing the installed electrolyser capacity.

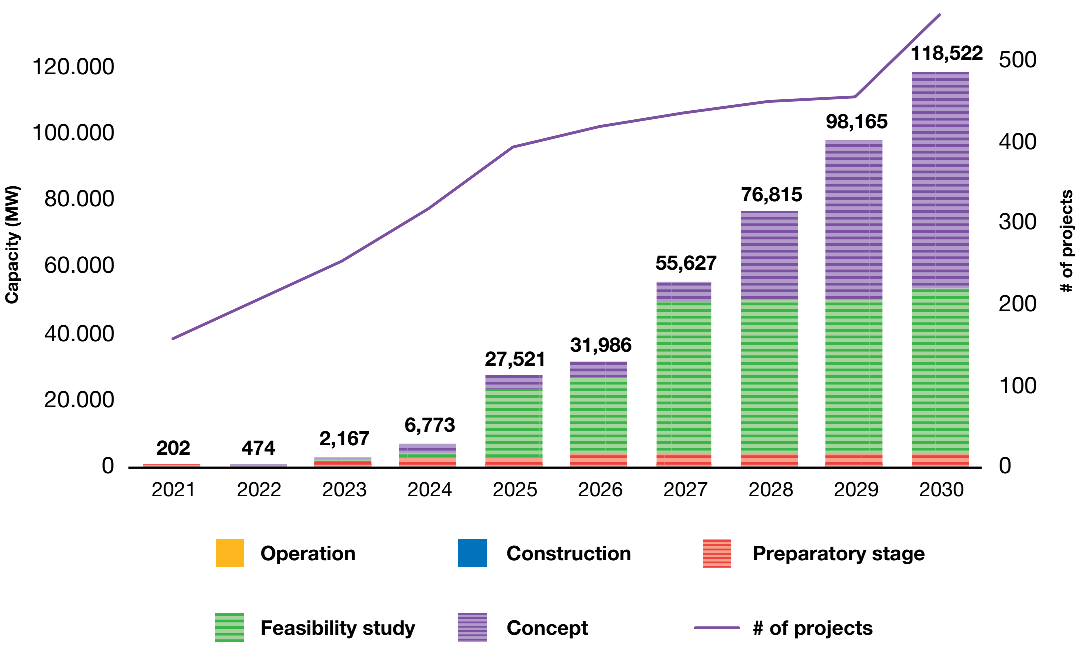
05 Electrolyser stacks. **Source:** ITM Powers

The EU Hydrogen Strategy = a renewable hydrogen production target = 10 million tonnes by 2030.

Some of the smaller, but common projects in late stages of development are focused on producing hydrogen for new mobility applications such as fuel cell electric passenger cars, buses, or smaller maritime vessels. These production sources are usually distributed and produced onsite at a refuelling depot/station. These are significantly smaller compared to the hydrogen production planned for industrial applications.

The EU Hydrogen Strategy's projected goal is to reach 40 GW of water electrolysis capacity in Europe to produce renewable hydrogen by 2030. However, according to the Clean Hydrogen Monitor 2021, industry ambitions based on announced projects amount to 119 GW already. The graph below outlines the operational and planned projects as according to industry ambitions by 2030.

Cumulative planned and operational PtH projects by year 2021-2030 in MW and # of projects
Source: Clean Hydrogen Monitor 2021, Hydrogen Europe



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In addition to renewable hydrogen, companies are planning to continue producing fossil fuel-based hydrogen while adding carbon capture technologies to reduce or sequester carbon emissions. This is what the public calls blue hydrogen. According to the Clean Hydrogen Monitor, there are only three operating plants producing hydrogen with carbon capture. However, companies have announced plans for numerous large-scale plants around Europe planning to use this technology with the largest capacities being developed in the United Kingdom and the Netherlands.

While the business case outcomes vary depending on the location, industry, and carbon price, the large scale emergence on the production side of the hydrogen market will continue to depend on either supply- or demand-side market stimulation that will help bridged the gap between fossil-based hydrogen and renewable hydrogen. ●

06 Hydrogen filling station, Hamburg, Germany. **Source:** FrankHH / Shutterstock

07 Hydrogen renewable energy production (3D rendering). **Source:** Audio und werbung / Shutterstock

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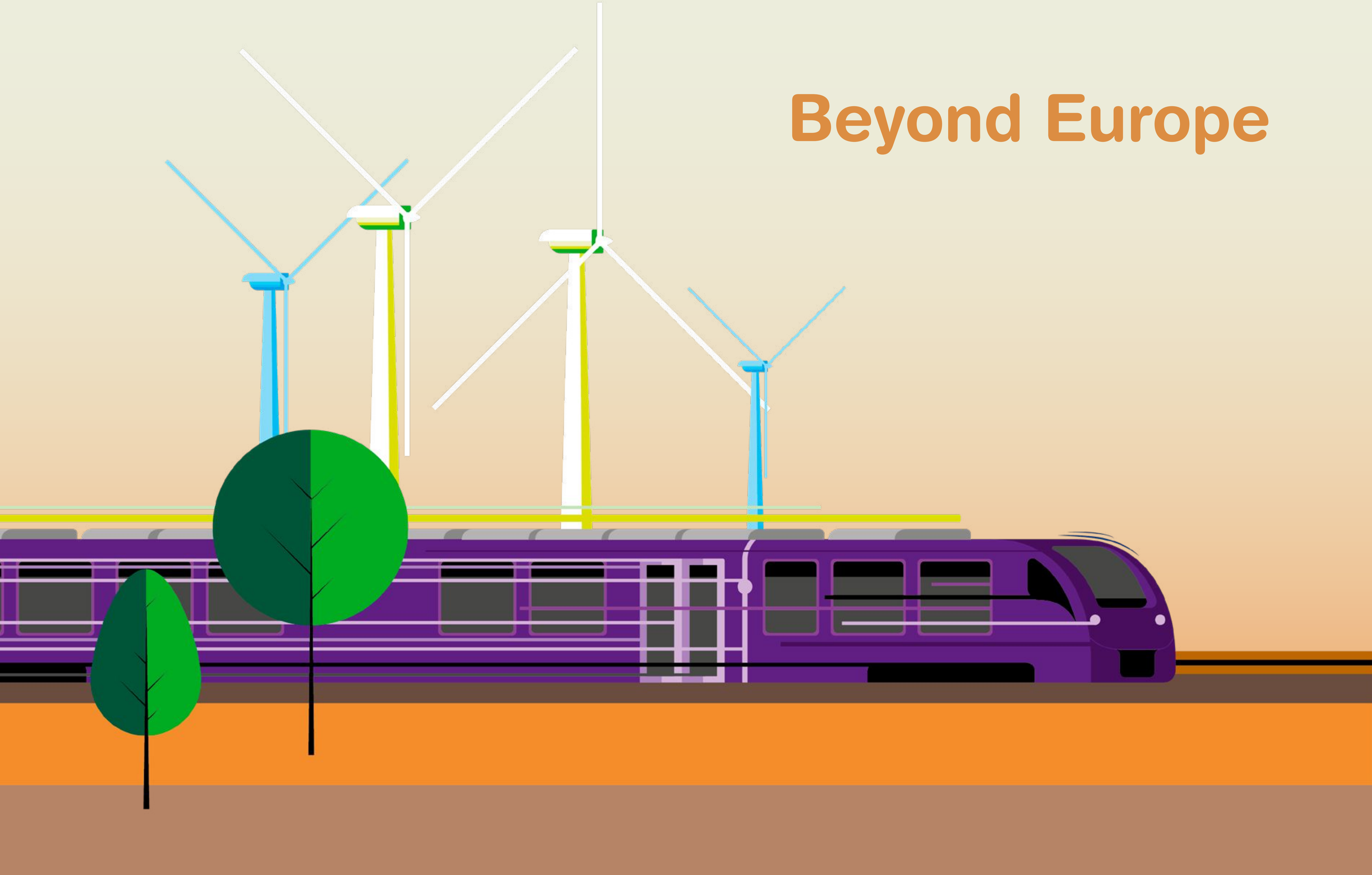
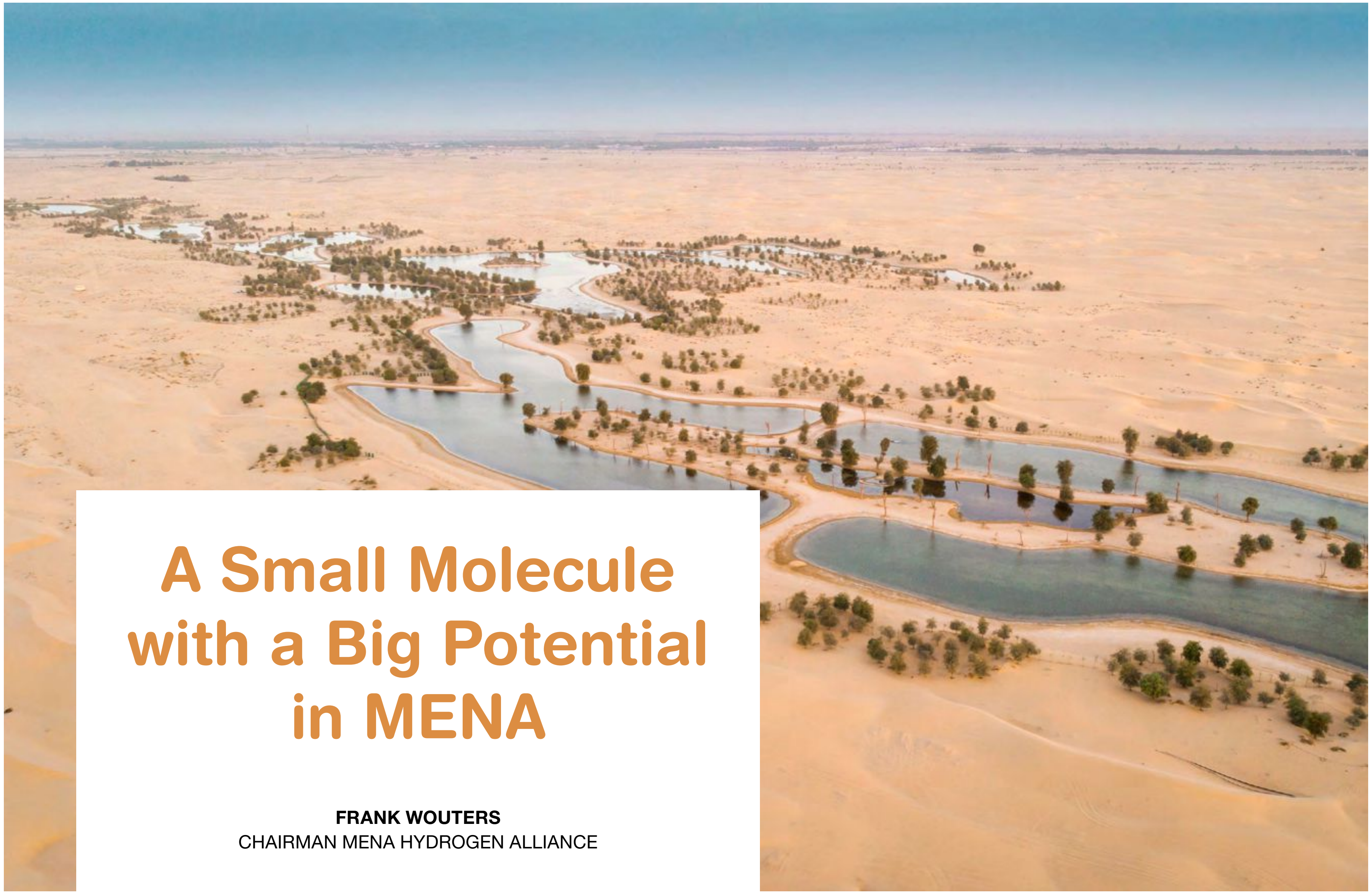
Beyond Europe



A Small Molecule with a Big Potential in MENA

FRANK WOUTERS
CHAIRMAN MENA HYDROGEN ALLIANCE



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Climate change is finally receiving the attention it deserves. According to IPSOS, two thirds of the global population is concerned about the consequences of global warming and expects more action from public and private leadership. The Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC), released in August 2021, was a wake-up call: the window of opportunity to avoid climate chaos is closing fast.

The energy sector – one of the largest sectors of the global economy – has traditionally been a major source of greenhouse gas emissions. However, in recent years, clean energy solutions have been developed that are now quickly becoming the bedrock of positive climate action.

The energy sector is integral to development and our modern way of life. Low carbon energy technologies include renewable energies, storage solutions, carbon capture and storage (CCS) and hydrogen, and have proven to be cost-effective alternatives to unabated combustion of fossil fuels.

With increasing deployment, economies of scale and ever higher efficiencies, modern renewable electricity is now on average cheaper than conventional fossil power and quickly replacing coal, natural gas, and oil power stations all over the world.

Hydrogen

Low carbon hydrogen will play a crucial role in our decarbonized future economy, as shown in many recent scenarios. In a system soon dominated by variable renewables such as solar and wind, hydrogen links electricity with industrial heat, materials such as steel and fertilizer, space heating, and transport fuels. Furthermore, hydrogen can be seasonally stored and transported cost-effectively over long distances, to a large extent using existing natural gas infrastructure.

Green hydrogen in combination with green electricity has the potential to entirely replace hydrocarbons, although blue hydrogen, made from natural gas with CCS, will help meet hydrogen demand in the short to medium term. More than half of all hydrogen initiatives are in Europe and predictions for hydrogen's share in the EU's final energy demand by 2050 range from 24% to 50%. An estimated 50% of that will be imported.

Green hydrogen made from renewable electricity and water is currently still more expensive than conventional hydrogen but is expected to become cost-competitive within a decade. The 2020s are described as the "hydrogen's decade" by the likes of HSBC and Wood Mackenzie, building on the IEA's landmark 2019 report "The Future of Hydrogen" calling for international action to tap into hydrogen's vast potential.

With all its promise, hydrogen still faces many barriers before it can become a globally accepted

With all its promise, hydrogen still faces many barriers before it can become a globally accepted energy commodity.

energy commodity. Many aspects of the hydrogen ecosystem require R&D effort, there is a lack of internationally recognized standards, and it is still unclear what financial mechanisms are most suitable to cover the short to medium term cost gap.

Hydrogen in the Middle East and North Africa (MENA)

Many countries and regions that will have a high hydrogen demand, such as the EU and Japan, do not have sufficient solar and wind potential to produce the green hydrogen they need. This gives a competitive advantage to countries with abundant resources such as the MENA region, which is situated in the world's sun belt. In addition to the solar and wind resources, Gulf countries can also build on the hydrocarbon infrastructure and expertise and tap into low-cost capital. These endowments can become a crucial basis to compete as future hydrogen exporters. Gulf Cooperation Council (GCC) countries can hence retain the basic business model of the oil era, cheap production of a universally used fuel. Also, the ability to start blue hydrogen production immediately using abundant low-cost hydrocarbons gives the GCC countries an additional competitive edge. But equally, countries that are currently net energy importers such as Morocco and Jordan, green hydrogen made from indigenous renewable energy promises a more secure and affordable energy future.

Contrary to now, Gulf countries will have to learn to compete with a broader set of countries and regions, including North Africa, Sub-Saharan Africa, Australia, Chile and India. But many of these countries, especially in Africa, are lacking the investment capital and business environment to rapidly engage in hydrogen production and export, providing a competitive edge for Gulf countries with low cost of capital.

A recent study carried out by Dii Desert Energy and Roland Berger found that a GCC hydrogen economy could create 1 million new jobs and generate $200bn in annual revenue by 2050.

Hydrogen in the GCC

Three of the six Gulf Cooperation Council (GCC) countries have embarked on ambitious hydrogen journeys: Oman, Saudi Arabia and the UAE.

Oman

In 2021, Oman established a national hydrogen alliance, known as Hy-Fly, led by the Ministry of Energy and Minerals, will initially have 13 members, which includes government agencies, oil and gas operators, educational and research institutions and ports that will work together to support and facilitate the production, transport, domestic use and export of clean hydrogen.

Oman has access to the Arabian Sea and is blessed with strong winds and abundant sunshine, a combination that ensures high load factors for water electrolyzers. Several initiatives have been launched, including:

- **Duqm.** The Indian company ACME is developing a large-scale facility to produce green hydrogen and green ammonia at the Duqm Free Zone. The plant with an investment of $3.5 billion will be an integrated facility using 3 GWp of solar and 0.5 GW of wind energy to produce 2,400 tonnes per day of green ammonia with an annual production of about 0.9 million tonnes. The green ammonia will be exported to demand centres like Europe and Asia.
- **Green Energy Oman.** A consortium consisting of the state-owned oil and gas company OQ, the Hong Kong-based renewable hydrogen developer InterContinental Energy and the Kuwait-based energy investor Enertech is planning to build one of the largest green hydrogen plants in the world in a move to make the oil-producing nation a leader in renewable energy technology. Construction of the $30bn project is scheduled to start in Al Wusta governorate on the Arabian Sea in 2028. It will be built in stages, with the aim to be at full capacity by 2038, powered by 25 GW of wind and solar energy. The project will produce 1.8 million tons per annum of green hydrogen and up to 10 million tons per annum of green ammonia to make Oman a world leader in truly zero carbon fuels.

01 Aerial view of al Qudra desert and lakes near Dubai. **Source:** Katiekk / Shutterstock

02 Jeddah, Saudi Arabia. **Source:** Backer Sha / Unsplash

02

Saudi Arabia

The Kingdom of Saudi Arabia is driving a dual track with Saudi Aramco as the champion of blue hydrogen, and NEOM, a new city in the north-west of the kingdom championing green hydrogen.

- NEOM (the word is an original mix of 'new' in English and 'yawm' ('day' in Arabic) means a 'new day'. It is rare when countries build big cities from scratch. Often, such projects are politically motivated, as was the case in Kazakhstan, Brazil and Nigeria. Astana – renamed to Nur-Sultan and Kazakhstan's capital – was meant to be further away from the Chinese border; Abuja, Nigeria's capital, was in the center of the country to be closer to the Northern Nigerian States; and Brasilia, Oscar Niemeyer's vision of a future city with stunning architecture, was also located in the center of Brazil to be closer to a larger part of Brazil's population. Abuja, Nur-Sultan and Brasilia are all located in a much more central location than the capital cities they succeeded.

  NEOM is part of Saudi's Vision 2030 and a planned city in the Tabuk Province of north-western Saudi Arabia. NEOM is different in several ways. Firstly, it is not centrally-located nor intended to replace Riyadh as Saudi Arabia's capital. Secondly, NEOM's sheer size, at 26,000 square kilometers (the size of Belgium), and its unique constitution-like legal framework, make it a hybrid between a city and a country. NEOM is pursuing a zero-carbon philosophy for its energy system, based on solar and wind. NEOM's location is an important factor in that respect. Not only are the solar and wind resources of very high quality, but they are also very complementary. The wind is predominantly of thermal origin over the Red Sea and picks up every afternoon. So, when the sun sets, the wind starts picking up and a combination of the two provides for an exceptionally high annual load factor of more than 70%.

- In July 2020, a consortium of NEOM, Air Products and ACWA Power announced the launch of the HELIOS project. HELIOS will be equally owned by the three partners, will integrate 4GW of renewable power from solar, wind and storage, the production of 650 ton per day of hydrogen by electrolysis, the production of nitrogen by air separation and the production of 1.2 million ton annually of green ammonia. The project is scheduled to be onstream in 2025. Air Products will guarantee the offtake of ammonia and distribute it to global markets, aiming to dissociate ammonia at hydrogen refueling stations (Figure 1).

Thyssenkrupp has been selected as provider of the electrolysers, Air Products will supply the air separation unit and Haldor Topsoe will supply the ammonia synthesis unit. ACWA Power is responsible for the development of the renewable energy projects. Air Products is responsible for the overall engineering, procurement and construction of the project.

A 1.2 million ton/a ammonia project is large, but not unusual, with most modern ammonia projects in the million-ton range. The Gulf Coast Ammonia project in Texas, under construction as of 2021, has a similar capacity of 1.3 million ton anhydrous ammonia per year. It is not a coincidence that Air Products is involved in that project, supplying hydrogen from a steam methane reforming unit and nitrogen from an air separation unit. It is fair to assume that a large part of the knowledge gained in the Gulf Coast Ammonia project informed the HELIOS project. But the HELIOS project itself will significantly contribute to the development of the global hydrogen economy. The size of the investment that Air Products is making, both in NEOM and in its sales and distribution network to deliver the NEOM product, is impressive. Beyond the $5 billion plant cost, AP will invest an additional $2 billion in "distribution to end customers." Building

Carbon-free Hydrogen
Produced and delivered with proven, world-class technology

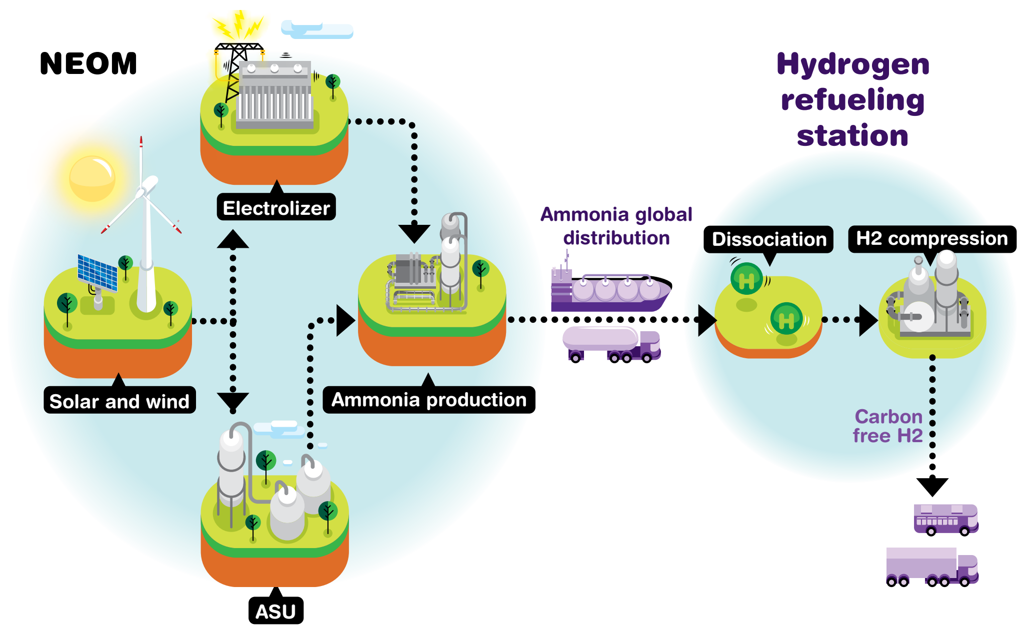


Figure 1. The Helios Project

Carbon-free Hydrogen
Produced with proven, world-class technology in NEOM, Saudi Arabia

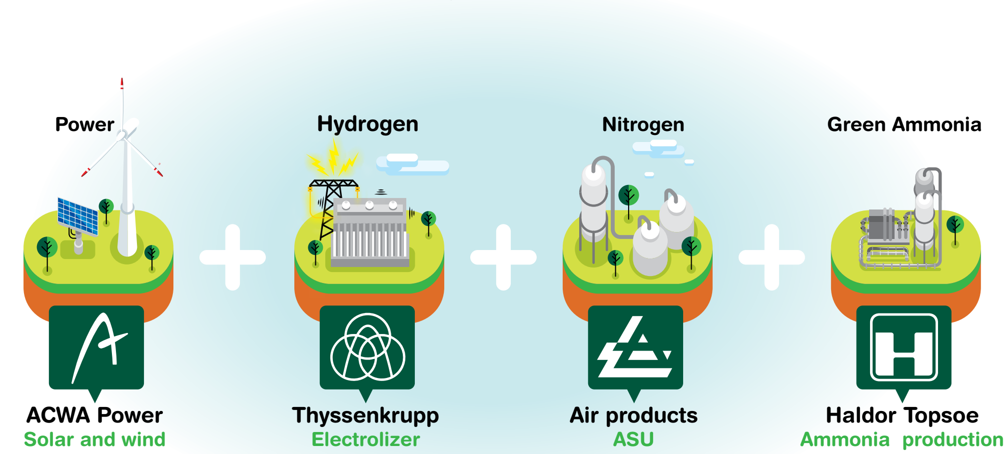


Figure 2. Technology providers of the Helios project

this plant will have a significant impact on the cost of electrolyzers and on the cost of ammonia crackers. The cost of initial infrastructure to deliver this volume of ammonia might be significant, but those volumes can later be expanded at far lower incremental delivery cost. Going further, the second and third big green ammonia plants will be cheaper; the second and third hundredth plants will have economics that we've yet to quantify.

UAE

Grey hydrogen from fossil fuels is already widely used in the UAE but is currently not a widely traded commodity. however, the UAE is developing ambitious plans to deploy hydrogen not only as a key pillar of decarbonization but also creating new export markets. In 2020, Abu Dhabi's Supreme Petroleum Council instructed the Abu Dhabi National Oil Company (ADNOC) to become a "hydrogen leader". The formation this year of the Abu Dhabi Hydrogen Alliance between ADNOC, Mubadala, ADQ, and the Ministry of Energy and Infrastructure was a further important step towards building a UAE hydrogen ecosystem. Several initiatives are currently being developed:

- **HELIOS.** Khalifa Industrial Zone Abu Dhabi (KIZAD) will develop a green ammonia plant, with up to $1 billion invested over the coming years. Helios Industry, a private special projects company, will develop the plant in two phases alongside local and international partners. The project, which will be powered by an 800 MWp solar power plant within KIZAD, is expected to produce 200,000 tonnes of green ammonia from 40,000 tonnes of green hydrogen.

- **ADNOC.** Abu Dhabi National Oil Company announced the development of a large blue ammonia project at its downstream centre in Ruwais as it looks to expand the UAE's hydrogen economy. It will have a capacity of 1,000 kilotonnes a year. The blue ammonia facility is currently in the design phase and will be built within the Ta'ziz industrial complex at Ruwais. Ta'ziz is a $5bn joint venture between ADNOC and ADQ.

- **TAQA.** TAQA, one of the largest listed integrated utilities in the region, and Abu Dhabi Ports are developing an industrial scale green hydrogen to ammonia export project in Abu Dhabi. The companies will work together on a green ammonia export facility to be based in Khalifa Industrial Zone Abu Dhabi (KIZAD). The new plant would be fuelled by hydrogen produced by an electrolyzer facility paired with a 2 GWp solar photovoltaic (PV) power plant. The green hydrogen would be turned into liquid ammonia to supply ships converted to use ammonia as a bunker fuel and for export from Abu Dhabi Ports via specialized gas carriers. The project will also feature a storage facility at Khalifa Port, opening the opportunity for it to become a hub for exporting green ammonia to international markets including Europe and the East Asia.

03

Hydrogen in North Africa

A number of non-GCC MENA countries have also started exploring green hydrogen opportunities, including Morocco, Egypt and Jordan.

Morocco

The Southern Mediterranean countries can currently be divided in net energy importing and net energy exporting countries. Libya and Algeria have built their economies on the back of their substantial oil and gas reserves, whilst Morocco has always had to import fossil fuels.

Morocco has embarked on an ambitious renewable energy program with a target of 52% of renewable electricity by 2030. The state-owned entity MASEN plays a pivotal role. MASEN pre-develops renewable energy sites, carries through the procurement process, acts as the government entity borrowing concessional finance from development finance institutions and commercial lenders, and co-invests on behalf of the government. In Ouarzazate, a beautiful city south of Morocco's High Atlas Mountains, known as a gateway to the Sahara Desert and known from "Game of Thrones", Morocco built the Noor solar complex, consisting of CSP and PV projects, totaling 582 MW at peak. The scale of these projects and Morocco's clever financial engineering, have brought down the cost of CSP, which is now competitive with conventional power.

The energy ties between Europe and North Africa are very strong today; 13% of the gas and 10% of the oil consumed in Europe comes from North Africa, and over 60% of North Africa's oil and gas exports are sent to Europe.

The electricity grid infrastructure in North Africa is not well developed, requiring major reinforcements and expansion in the coming decades, especially to transport electricity from the good solar and wind resource areas to the demand centers in the cities and rural areas.

Today, there is only one electricity grid connection between Europe and North Africa, the 700 MW grid interconnector between Spain and Morocco. However, there is a gas transport infrastructure available between North Africa and Europe, transporting gas from Algeria and Libya to Europe via Italy and Spain. The gas transport volume through these pipelines is over 63.5 bcm per year, which equals a capacity of more than 60 GW.

In a first phase, between 2030-2035, the natural gas infrastructure could be used to transport hydrogen from North Africa to Europe. Initially, a substantial hydrogen volume can be produced by converting natural gas to hydrogen, whereby the CO_2 is stored (blue hydrogen). Over the years however, with declining cost of renewable electricity and electrolyzers, more and more green hydrogen from solar and wind electricity can be fed into these pipelines. Eventually, purpose-built hydrogen pipelines would connect Moroccan production sites with the European hydrogen backbone.

- **OCP.** One of the largest phosphate mining companies in the world is Morocco's OCP. The phosphate mined in Morocco is combined with imported ammonia to produce fertilizer. OCP currently import 1-2 million tons of grey ammonia but has been studying local production of green ammonia. Given Morocco's excellent solar and wind resource, ability to attract concessional finance and execute well-managed projects, should enable them to produce green ammonia cost competitively if one factors in a price on carbon (currently there is no carbon market in Morocco, but that is not likely to remain so).

- **HEVO.** In July 2021, trading firm Vitol signed a memorandum of understanding (MOU) to manage offtake from the Hevo Ammonia Morocco project, which is being developed by Ireland-based green hydrogen technology company Fusion Fuel and Middle East construction company Consolidated Contractors. The location of the facility has not yet been finalised, but it is expected to be in the vicinity of Jorf Lasfar, Essaouira or Agadir. The project would be Morocco's largest green ammonia and green hydrogen project, with an estimated total investment value of around $850 million. Development of the first phase is expected to begin in 2022 following the completion of a feasibility study. When fully commissioned, the project is expected to produce 183,000 t/yr of green ammonia. Fusion Fuel expects to supply the technology to produce the 31,000 t/yr of green hydrogen that the project will need.

04

Egypt

The production of hydrogen by water electrolysis using hydropower has a long tradition in Egypt. The KIMA Company in Aswan started producing green hydrogen in 1960, and only changed to natural gas recently. In addition to hydropower, Egypt is also blessed with excellent solar and wind, making it a good location for green hydrogen production.

- **German projects.** The Egyptian government this year signed two MoU's with Germany's Siemens and ThyssenKrupp. In January 2021, the Egyptian Minister of Electricity and Renewable Energy, Mohamed Shaker, signed an MoU with Siemens CEO Joe Käser to study the implementation of a pilot project for the production of green hydrogen in Egypt, as a first step towards potential export. In May 2021, Egyptian Prime Minister Mustafa Madbouli held a meeting with Oliver Tietze, the CEO of Thyssenkrupp Industrial Solutions, to discuss establishing a factory for green ammonia and green hydrogen production in Egypt, with the aim to to export the green ammonia from Egypt to Germany.

03 Master plan for the KIZAD Industrial Zone where the Helios project will be located. **Source:** KIZAD

04 Ouarzazate Solar Power Station. **Source:** Richard Allaway / Flickr

The energy ties between Europe and North Africa are very strong today; 13% of the gas and 10% of the oil consumed in Europe comes from North Africa, and over 60% of North Africa's oil and gas exports are sent to Europe.

Jordan

Jordan is a net energy importer and has been receiving natural gas from Egypt through the Arab Gas Pipeline, which has a capacity of 10bcm/a. However, from 2011 onwards, the supply of gas has been seriously reduced due to a shortage of gas in Egypt, and at least 26 attacks on the pipeline in the period between 2011 and 2014. This made Jordan pivot towards indigenous solar and wind power, through a smart system of consecutive auctions, leading to competitive power rates. Like Egypt and Morocco, Jordan has ample land and an excellent solar and wind resource. The share of electricity from renewables in Jordan grew from 0.7% in 2014 to over 13% in 2019, making Jordan a regional front-runner in renewable energy.

Dii Desert Energy carried out a study assessing the potential for exporting green hydrogen from MENA to Europe, and assessed the potential in Jordan. It should come as no surprise that the potential is vast, given the strategic location, including suitable infrastructures, such as an existing gas pipeline to Egypt, a natural gas link to Israel, an LNG terminal in Aqaba and of course excellent solar and wind resources, also in the south of the country where desalinated seawater would be close. In addition, Jordan has a sizable chemical business, largely focused on potassium and bromine industries. They could act as local off-taker for green molecules, and create value added downstream industries. With the high prices for energy, trucks and buses might also be powered by green hydrogen in the future, and a large refinery south of Amman could use green hydrogen. The ambitious NEOM project, just 200 km south of Aqaba, could be a partner, rather than a competitor for production of green hydrogen or Ammonia, to create synergies locally and for export. Undoubtedly, Jordan would have all ingredients to produce low-cost green hydrogen, with the possibility to export internationally via the Aqaba port. Many jobs have been created in the solar and wind sector, and Jordan could build on this to develop a green hydrogen economy.

- **FMG.** A delegation from Andrew Forrest's Fortescue Metals Group met with the Jordanian government in April 2021. They discussed potential opportunities of exploring green hydrogen and ammonia with the Jordanian Minister of Planning and International Cooperation Nasser Al-Sharida, potentially for export purposes.

Hydrogen Action

We can see growing momentum in countries of the Middle East and North Africa towards green hydrogen developments. Many such initiatives are still in the earlier stages, but their number is growing. At the 2021 United Nations Climate Change Conference (COP26) in Glasgow (November 2021), governments, including in MENA, must achieve consensus on decisive climate action. Clean energy and hydrogen will be part of the solution to the climate crisis. Immediately after COP26, ADIPEC, the largest annual global gathering of energy executives will take place in Abu Dhabi. ADIPEC will have a full sub-section of sessions dedicated to hydrogen, in which the energy sector can discuss the climate conference's key recommendations.

If the 2020s are indeed to be hydrogen's decade, several elements appear critical to its success:

1. **Integration in economies' post-COVID recovery programs.** The momentum unleashed by governments in the wake of the pandemic must be channeled in the right direction, as expressed in the often-used phrase "build back better". The global tragedy could be used to start a transformation towards a cleaner, just, and more inclusive societal fabric. Although much of the recovery money has been channeled to putting the status quo back on its feet, there is still some opportunity left to build back better.
2. **A conducive policy framework to incentivize the necessary investments.** The private sector is capable to innovate and provide the capital for the energy transformation. Governments should provide the policy frameworks for the private sector to do so at the required speed and in the right direction, for example by setting standards, providing carrots (subsidies) and sticks (quotas), devise international treaties and regulate markets.
3. **Rapid scaling-up of technologies to reduce the cost gap.** Support for innovation and research, development and demonstration will lead to accelerated deployment of low-carbon hydrogen.

There is great momentum for green hydrogen all over the world including in the Middle East and North Africa. It's time for the energy sector to come together around this clean fuel's immense potential. ●

DEMYSTIFYING HYDROGEN REFUELLING

How it works and why it holds the key to helping unlock the world's zero-carbon ambitions

Haskel
An Ingersoll Rand Business

Whilst hydrogen has a long history, having powered the first internal combustion engines over 200 years ago, and in more recent times fired up NASA rockets, today its true potential for helping the world reach net zero is yet to be unlocked.

It is light, storable, energy-dense and produces no direct emissions of greenhouse gases. And crucially – its wider adoption presents a unique chance to propel the global fight against climate change.

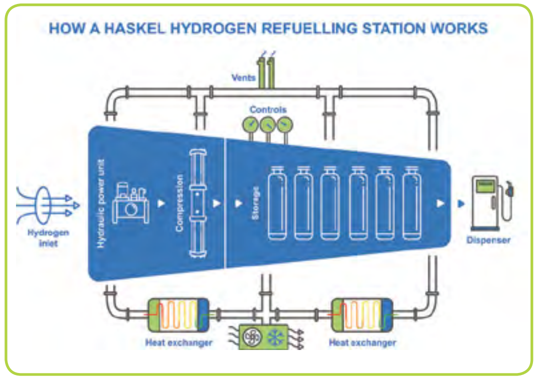
However, there is one major piece of infrastructure missing from the 'hydrogen puzzle' which effectively holds the key to widespread adoption - a network of hydrogen refuelling stations.

In order to scale adoption, we need to scale refuelling infrastructure.

How a hydrogen refuelling station works

Hydrogen fuel cell vehicles can be refuelled quickly at a refuelling station – *just like a petrol or diesel vehicle*.

But its backend operations are entirely different, and these are supported by a number of key components that are critical for the safe and effective functioning of a refuelling station.



The key components of a refuelling station

Hydrogen inlet

Refuelling stations are configured for optimum performance based the hydrogen inlet pressure. The hydrogen can be produced on site most commonly via electrolysis, delivered to site and filled directly from a tube trailer or via on site storage.

Compression

The hydrogen is then compressed to increase the pressure, and reduce the volume, to enable a greater amount of hydrogen to be stored in the system and an efficient flow of gas for dispensing.

Heat exchanger

The compressed hydrogen is then passed through a heat exchanger to remove the excess heat from the gas that was generated during the compression process. Specially designed hydrogen resistant valves and fittings are used to control the highly pressurized hydrogen, these components utilize specific materials that are resistant to hydrogen embrittlement to prevent any cracking.

System control

The process is powered, monitored and controlled via the electronic control panel in the non hazardous zone.

Dispensing chiller system

The hydrogen is then cooled to sub zero temperatures for fast and efficient filing to ensure the hydrogen can be dispensed safely and to comply with filling protocols i.e. J2601.

Vent stacks

A safety feature to vent any escaped hydrogen safely. Hydrogen is lighter than air so dissipates quickly and safely should an incident occur.

Storage

The high pressure gas is then stored in the system until required for dispense at the point of use. The storage is controlled by specially designed valves, fittings and electrical controls designed to regulate pressure and interact with the dispenser and vehicle as needed.

Dispenser

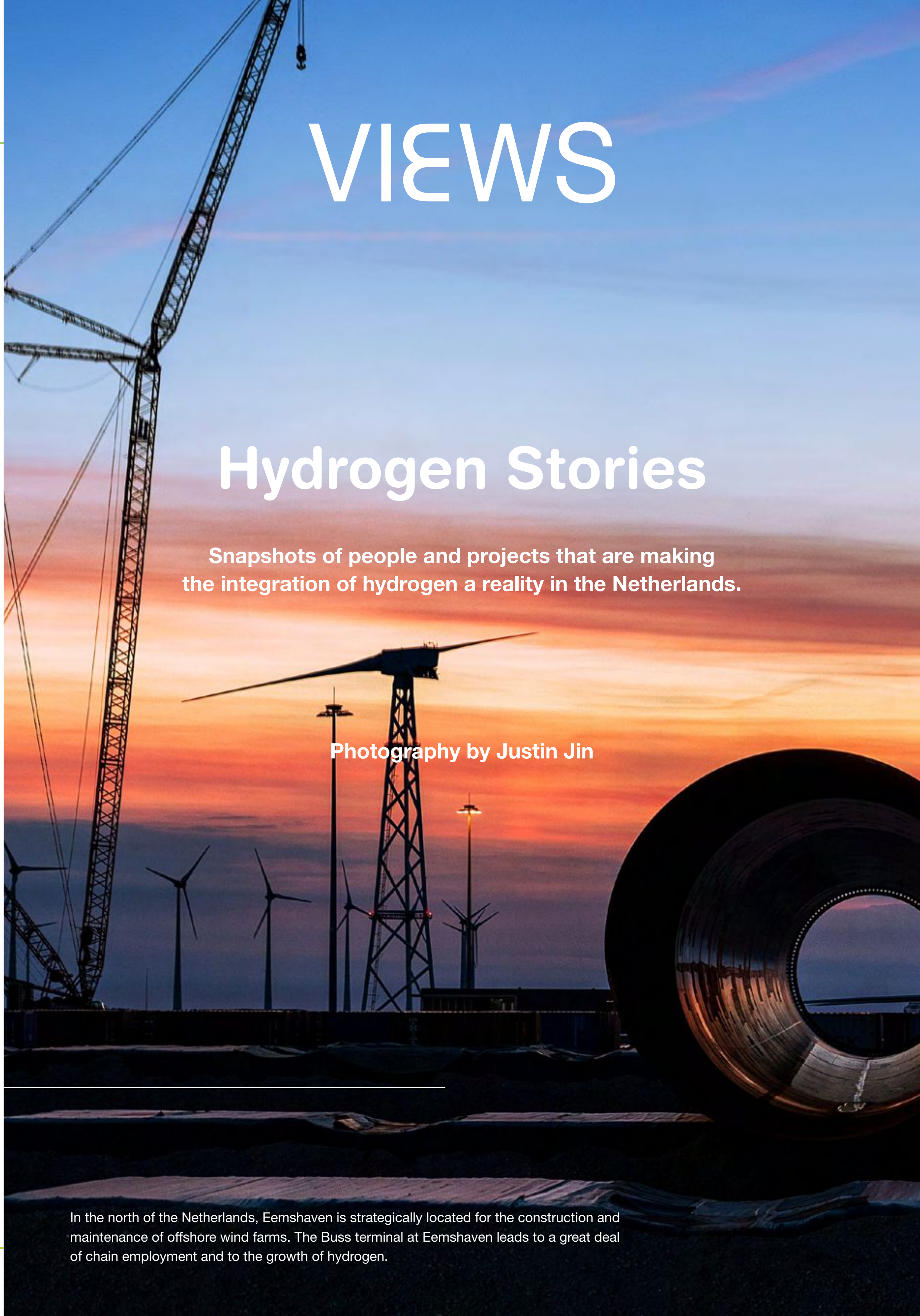
Designed to emulate traditional fuelling methods, the hydrogen is dispensed via a nozzle controlled by a smart valve which regulates the flow rate of the gas to fill the vehicle to the required pressure in accordance with the fuelling protocol.

Haskel is a global expert in hydrogen compression and refuelling. Headquartered in Sunderland, UK, Haskel is a tried and trusted hydrogen refuelling expert. It offers end-to-end refuelling solutions - from designing and manufacturing a station, to installing and maintaining it - with a legacy of having worked with compressed gases in mission critical industries for 75 years.

Ultimately, to reap the decarbonisation benefits that hydrogen has to offer, in particular eliminating carbon emissions produced by heavy goods vehicles and buses, regional authorities and policymakers must invest in developing a robust refuelling infrastructure network at a regional and national level.

There has never been a more pressing time to seize this opportunity.

For more information on Haskel please visit www.haskel.com.



VIEWS

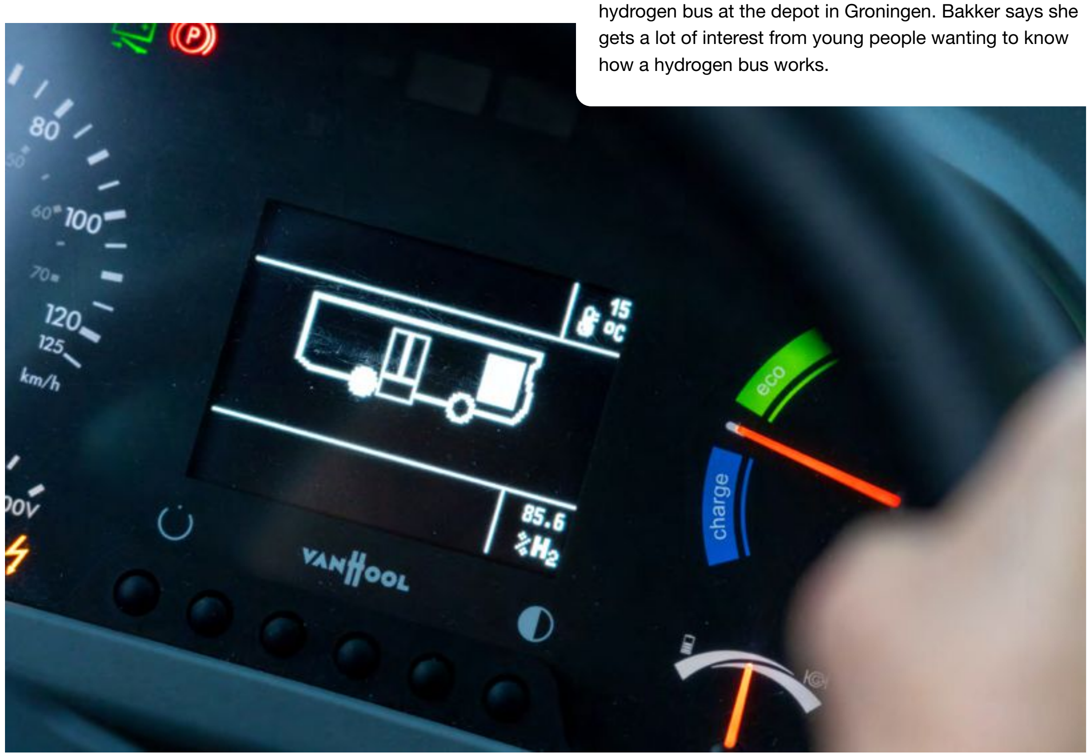
Hydrogen Stories

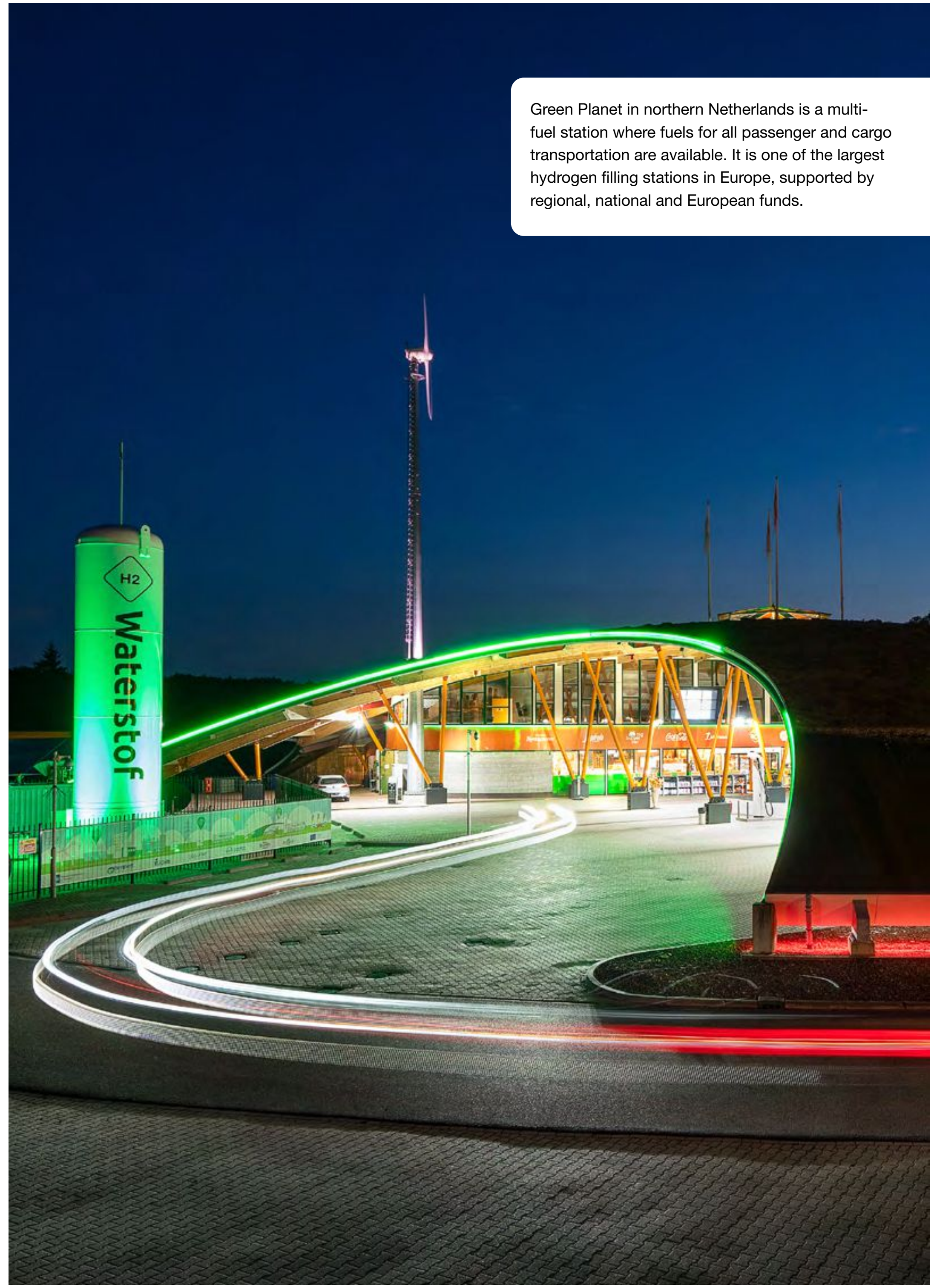
Snapshots of people and projects that are making the integration of hydrogen a reality in the Netherlands.

Photography by Justin Jin

In the north of the Netherlands, Eemshaven is strategically located for the construction and maintenance of offshore wind farms. The Buss terminal at Eemshaven leads to a great deal of chain employment and to the growth of hydrogen.

Employed by Qbuzz (a Dutch bus company owned by an Italian conglomerate), Gea Bakker, 60, starts up a hydrogen bus at the depot in Groningen. Bakker says she gets a lot of interest from young people wanting to know how a hydrogen bus works.





Green Planet in northern Netherlands is a multi-fuel station where fuels for all passenger and cargo transportation are available. It is one of the largest hydrogen filling stations in Europe, supported by regional, national and European funds.

Wind turbines stand behind solar panels in Eemshaven in the Groningen Seaport.

Continuum of past and present: The 1897 "Goliath" windmill (right) stands amongst the larger wind farm in Eemshaven in the province of Groningen.

Technicians prepare a gas-sealing test above an underground cavern at a hydrogen energy project inside Gasunie's HyStock site in Veendam. >>

>> The underground cavern, formerly used to store natural gas, will now be used to house hydrogen. Each cavern is around 300-400 metres high and 50-80 metres wide: big enough to contain the Eiffel Tower.

Workers prepare to refill the Green Planet fuelling station with hydrogen. Green Planet is a state-of-the-art multi-fuel station where fuels for all passenger and cargo transportation are available.

A trailer carrying hydrogen arrives at the Green Planet fueling station in northern Netherlands to refuel the station. The green hydrogen that is tanked here comes from electrolyzers.

A quai operator lifts a wind turbine blade to prepare for installation at a windfarm at the Eemshaven.

10 minutes to refuel a hydrogen bus at the depot in Groningen, a northern city in the Netherlands. The provinces Groningen and Drenthe currently operate one of the largest zero-emission bus fleets in Europe with 20 hydrogen buses now and a total of 30 buses by the end of 2021.

A ship carrying wind turbine blades from China arrives at the Groningen sea port in northern Netherlands.

A supply ship in Eemshaven lifts the monopile of a wind turbine onboard, ready to be transported to offshore.

The Buss group opened the terminal in the Groningen Sea Port in 2012 to service growing demand for the offshore wind energy industry. Reachable by rail, road and sea, the terminal in Eemshaven soon became the launching point for the construction of offshore wind parks in the North Sea. Today, thanks to the growing demand of wind energy to produce green hydrogen energy, the Buss terminal's business is booming, making it one of the world's important players.

Inside the tower of a wind turbine being built by a "climbing crane" in Groningen near the sea port in the northern Netherlands. Invented by the Dutch company Lagerwey, the "climbing crane" saves space and transport of large machinery parts. When it reaches the top, it lifts the turbine, adds the rotor blades, then climbs down.

Engie gas powered plant in Eemshaven - the energy port of the Netherlands - producing around 30% of the country's electricity. The power plant will produce hydrogen energy. In addition to the RWE coal-fired power station pictured here, two inter-connectors from Denmark and Norway are coming in and several offshore wind farms above the Wadden Islands will be connected. Here, offshore sustainable energy can be converted into green hydrogen on a large scale.

Thierry Trouvé
CEO of GRTgaz

Hydrogen & the Energy Transition

The 3rd Gas Revolution: Back to the Future

In line with the 2015 Paris Agreement, the gases consumed in France and Europe will be renewable or carbon-neutral, and hydrogen has a special role to play. Renewable gases and the energy transition together form the third gas revolution that more than a transition, it's a real transformation.

The first gas revolution was town gas in Europe from coal. Natural gas was the second gas revolution, which took place in the middle of the 20th century with gas becoming a raw material from oil. The third gas revolution is the renewable gases revolution: hydrogen and biomethane.

In a way, we are going *back to the future* because local town gas in the 20th century consisted of methane and large quantities of hydrogen. So, the return to hydrogen and to green gases made in Europe is a recent adaptation of the gas industry to new challenges – now the fight against climate change.

The Hydrogen Ecosystem: From Valley to Continent

There is now a broad consensus in Europe that hydrogen will first be developed on a local basis in what are called "clusters" or "valleys" – with production and consumption being relatively close. As more players produce and consume hydrogen, it will be necessary to manage situations in which production and consumption sites are potentially more distant; and it will also be necessary to manage the need for access to hydrogen storage, since one of the major interests of hydrogen is precisely the storage of large quantities of energy. These clusters and valleys will become increasingly connected: going from a 'leopard-spots' network to integrate progressively until they form the hydrogen backbone of Europe.

Our Commitment: Innovation and Network Design

Decarbonizing the gas network simply means replacing natural gas, representing 99% of the volumes we transport today, with renewable or low-carbon gas. This is the challenge of our work for the years to come: transporting hydrogen and biomethane and designing the new European gas system.

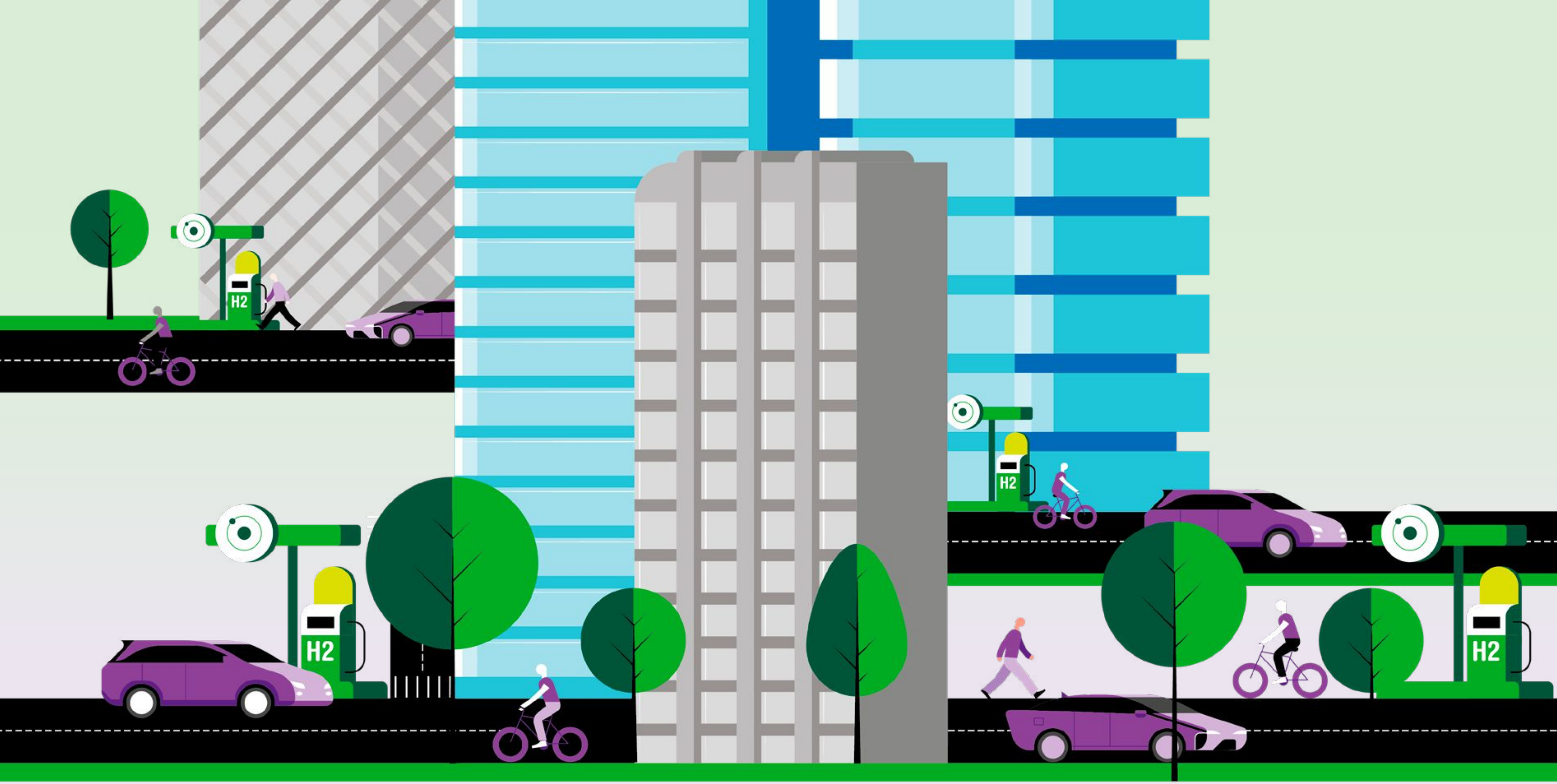
The key areas we work on are to assess the capability of our network to receive hydrogen and pure hydrogen. This is what we are doing with our MosaHYc project aiming at leveraging the existing natural gas network already connecting France, Germany and the border of Luxembourg to transport pure hydrogen. In 2021, we organized a nation-wide consultation to listen to the expectations and needs of all stakeholders in the French low-carbon and renewable hydrogen market to conceive and plan the hydrogen transmission network of tomorrow. We are also working with European authorities to design the regulation of the future hydrogen market, highlighting the logistics issues, because **if we don't get logistics right, we will hinder the development of the hydrogen economy**.

In the energy transition, R&D is essential, and that is why in 2017 we set up a research department named RICE to enable us to focus on these energy transition issues: in particular on gas quality, on hydrogen and on smart gas grids. This is a key element and today GRTgaz is one of the network operators with the highest rate of research and development in its category, and we intend to maintain this effort because it is absolutely vital.

Dealing with hydrogen shows our desire and our ability to provide innovative solutions and work with all the players across the hydrogen value chain. Our commitment is to enable an energy transition towards a carbon-neutral world that is safe, in the sense of energy security, and affordable, in the sense we will all be able to pay for it – a transition to an ideal world that we can't afford is not a real transition.

Watch Video: *Le monde de l'hydrogène avec GRTgaz : présentation des atouts par Thierry Trouvé*

Research & Innovation Center for Energy, RICE. Source: Azmoun Hamid / GRTgaz.



Case Studies

FRONIUS / SOLHUB
CUMMINS
GREEN CITY FERRIES
TÜV-SÜD
EH GROUP
LINDE
ALSTOM
NEL HYDROGEN
BOSCH
REPSOL
VIESSMAN / SMARTQUART PROJECT
UNIPER

Biotech Park,
Lower Austria

Application:
700bar refuelling infrstructure
Emergency power supply by fuel cell
1.5 MWp PV plant for PV optimised operation

Dimensioning:
Daily output of 96 kg green hydrogen

Solhub: a Solution for Deploying Green Hydrogen

Fronius has been researching and developing hydrogen solutions for 20 years, becoming an innovation leader in the use of green hydrogen from solar energy. We talk with Thomas Rührlinger (Hydrogen Solution Manager) and Mathieu Delpierre (Hydrogen Sustainability Expert) about the societal benefits of green hydrogen.

What is green hydrogen and what can be realized with hydrogen in general?

Mathieu DELPIERRE - Currently, there is no uniform definition (yet). There have been political debates about the definitions of the different types of hydrogen. At present, hydrogen production methods are divided via color-coded scheme. Green hydrogen therefore stands for renewable hydrogen. The most established technology options for producing green hydrogen is water electrolysis powered by renewable electricity.

Thomas RÜHRLINGER - Together with the fuel cell, hydrogen has the potential to revolutionize the entire energy supply. Whether as a fuel in transportation or as an energy supplier for electricity and heat generation: Hydrogen enables the use of renewable energy sources in all these areas.

Fronius offers a sustainable solution for green hydrogen from renewable energy with its Solhub. What are the benefits for customers?

TR - The Fronius Solhub is our system solution for generating, storing, distributing and converting green hydrogen from solar, wind and water energy back into electricity. It uses electrolysis to convert ecologically generated on-site electricity (and renewable electricity via the public grid) into green hydrogen, which can be stored over the long term. This opens up various possibilities: On the one hand, the solar power yield of the summer can be brought into the winter, and thanks to reconversion, green electricity is available all year round. On the other hand, the hydrogen can be used to fuel hydrogen vehicles. More and more vehicle manufacturers are already offering models or prototypes with fuel cells. In-house logistics, work vehicles, bus fleets, trucks, special vehicles or snow groomers are good examples. The task now is to build up the necessary ecosystems consisting of decentralized refueling infrastructure combined with the use of available vehicles.

What role will green hydrogen play in the European energy mix of the future? What hurdles are there to overcome?

MD - As shown in many scenarios, hydrogen will play a vital role in Europe's climate neutral economy as a crucial energy vector and could supply a substantial part of the European energy mix by 2050.

The production of green hydrogen via electrolysis enables synergies from sector coupling to be exploited, reducing technology costs and increasing the flexibility of the power system. Low various renewable energy (VRE) costs and technological improvement are decreasing production costs of green hydrogen. For these reasons, green hydrogen from water electrolysis has been gaining interest.

However a supportive policy framework will be required to cover the cost gap with alternatives. ●

01 Solhub, Fronius R&D site Thalheim
Source: Fronius International GmbH

02 Source: Fronius International GmbH, DI Thomas Rührlinger

03 Solhubs are already in realization, such as the first green hydrogen customer plant in Lower Austria. **Source:** Visualisation: Janusch - the visual collective | SAN Group

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HyLYZER – The World's Largest PEM Electrolyzer

Global technology and power solutions leader Cummins Inc. has installed a 20-megawatt proton exchange membrane (PEM) electrolyzer system to generate green hydrogen. Commissioned in January 2021, the Cummins electrolyzer system – called the HyLYZER – is the largest of its kind in operation in the world and is located at the Air Liquide hydrogen production facility in Bécancour, Quebec.

The Cummins HyLYZER® PEM electrolyzer technology is the result of over 20 years of development by Hydrogenics – a Canadian company acquired by Cummins (September 2019). This installation features four compact pressurized electrolyzer skids that were fitted inside an existing building. This is a modular and scalable electrolyzer platform designed to address utility-scale hydrogen production.

The Bécancour facility can produce over 3,000 tons of hydrogen annually, increasing hydrogen production capacity by 50% and allowing Air Liquide to meet the growing demand for low-carbon hydrogen. The decision to locate the PEM electrolyzer system in Bécancour was based on two location attributes: its access to the abundant renewable power from Hydro-Québec and its proximity to

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01 HyLYZER 1000-Becancour.
Source: Cummins

the hydrogen mobility market in the north-east region of the continent.

The electrolyzer system is powered by the region's electrical grid, which is largely supplied by hydro-electric power, meaning that the hydrogen generated will be almost green. Compared to the traditional hydrogen production process, this new production unit avoids around 27,000 tonnes of CO_2 per year, equivalent to the emissions of 10,000 cars per year. It is a great illustration of Air Liquide's and Cummins' commitment to generalize the use of hydrogen as a clean energy vector. This is a key milestone on the path towards a low-carbon society.

"Creating hydrogen technologies at scale is paramount to growing low-carbon solutions," said Amy Davis, Cummins Vice President and President of New Power, the company's alternative power business. "We have successfully developed our technology from 1MW to 5MW, and now have the largest PEM electrolyzer in operation in the world. It will continue to take enterprises, governments, forward-thinking customers and utilities all working together to make alternative power a reality. Here we are seeing how green hydrogen can improve sustainability for industrial manufacturing and how the demand for decarbonized hydrogen solutions will grow."

Susan Ellerbusch, CEO, Air Liquide North America and Group Executive Committee Member, says: "The fight against climate change is at the heart of the Air Liquide Group's strategy. With this world's first and biggest, Air Liquide confirms its commitment to the production of low-carbon hydrogen on an industrial scale and its ability to effectively deploy the related technological solutions. Hydrogen will play a key role in the energy transition and the emergence of a low-carbon society."

Prior to Bécancour, Air Liquide and Cummins installed a 1.2-megawatt PEM electrolyzer called they HyBalance in 2018. Located in Denmark, the site supplies clean hydrogen to customers and supports Denmark's carbon reduction goals. In partnership with Air Liquide, this electrolyzer provided proof-of-concept and became the predecessor that led to the Bécancour project.

Electrolyzers provide a means to address one of the largest dilemmas in the renewable energy industry – how to store the renewable energy when it is not in demand. Electrolyzers enable the storage of excess energy that would otherwise be sold off to the market at a financial loss (or not harnessed at all) and instead stores that energy to sell into the green hydrogen market. They can also be used to decarbonize multiple sectors including zero emission transportation, industrial processes, and the green chemicals sector.

Continuing to scale and advance their electrolyzer capabilities, Cummins announced in May 2021 that they are locating one of the world's largest electrolyzer manufacturing plants in Spain. The 22,000-square meter facility will produce electrolyzer systems with an initial production capacity of 500 megawatt per year and are scalable to more than one gigawatt per year. This manufacturing facility is expected to open in 2023. Additionally, a 230-megawatt green hydrogen production project is planned in Spain and is poised to set the next benchmark for large electrolysis projects globally. ●

Case Study: Becancour (YouTube Video)

Zero-emission Ferries for Zero-emission Cities

Approximately 2.1 billion people use ferries every year, putting the industry on a par with commercial airlines in terms of annual users worldwide. To many cities and their citizens, travelling the waterways lies at the heart of everyday life. While some cities have mandated the switch to 'fossil-free' biodiesel, these vessels are still omitting harmful particles that cause numerous health issues to citizens. Despite a widespread push to reduce emissions, ferries have long been neglected in the drive to create cleaner, greener public transport in cities.

The European Commission has set out its vision to establish 100 climate-neutral smart cities by 2030, but this cannot be achieved without investing in new emission-free waterborne transport solutions. With air pollution continuing to kill 400,000 people annually in the EU, zero-emission ferry systems must be implemented across the EU. The technology to do is here. The time to act is now.

Green ferry technology

As a systems integrator, **Green City Ferries** (GCF) offers a holistic solution for cities. We bring together state-of-the-art zero-emission (ZE) fast passenger ferries and shoreside and hydrogen infrastructure. The company has unveiled the **Beluga24** – the world's first hydrogen high-speed catamaran ferry.

The **Beluga24** comes with two emission-free options – electric for short journeys and hydrogen for long – and has been designed as a multi-purpose solution for public transportation with space for 150 passengers and 28 bikes. The high-speed ferries have low-wake signatures, a long range, and are extremely well-suited for usage on waterways in and around cities by enabling attractive timetables and comfortable commutes.

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01 Beluga24 – the world's first hydrogen high-speed catamaran ferry. **Source:** GCF

The biggest challenge with these vessels is their weight compared to a conventional diesel ferries. To mitigate this, the **Beluga24** uses a hydrofoil system and lightweight carbon fiber hulls. The lifting force created by the hydrofoil when the vessel is operating at cruise speed effectively reduces the displacement of the vessel, lifts the hull partly out of the water, and thereby reduces the resistance, alleviating the impact of the additional weight of the electrical propulsion system.

The solutions are here

GCF's first commercial application starts in 2023 in the Stockholm archipelago with a high-speed hydrogen ferry taking on longer routes within the area, with support from the European Union funded project, TECOW. With many other cities already showing interest in the technology it won't be long before hydrogen ferries are taking mobility into cleaner waters across the EU and beyond. Except for the vessels itself and the infrastructure GCF also offers financing for authorities for an efficient transition.

GCF stands ready to contribute to the 1.5°C target by introducing its zero-emission ferry on a global scale. ●

www.greencityferries.com

Project TECOW (Transition to Emission-free Commuting on Waterways) will introduce the fuel-cell powered Beluga24-FC in Stockholm – Sweden.

With the contribution of the European Maritime and Fisheries Fund of the European Union. Grant agreement: 101038671

Hydrogen - Safety and Sustainability in the Energy Revolution

REINER BLOCK
CEO INDUSTRY SERVICE DIVISION, TÜV SÜD

The costs of generating electricity from wind and solar power have fallen significantly below other energy sources. The more widespread the use of renewable energies in energy systems and decarbonisation processes, the greater the importance of hydrogen as storage medium and essential element of green fuels, gases and chemicals.

Green electricity generated in regions with favourable climatic conditions has to be transmitted over long distances in order to reach major cities and industrialised regions, and must be storable as required in order to compensate for daily and seasonal fluctuations in generation. Power lines and battery storage systems are only suitable for use in locations of close and medium proximity or for short-term storage.

01 As Europe's first steel producer, Salzgitter AG has obtained two conformity statements in line with TÜV SÜD's VERIsteel procedure. **Source:** Salzgitter AG

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Hydrogen, on the other hand, can be produced from renewable sources and stored and transported, all in large quantities – and all using existing gas infrastructures. Reputable studies are forecasting cost parity between green and conventional hydrogen in favourable regions by 2030

Holistic approach, transparent baseline

In addition, it has been extensively used in industry (ammonia and fertiliser production) and in refineries for over a century, and is thus tried and tested. The production of steel can be rendered virtually carbon-free when hydrogen is used to directly reduce the iron ore. With its ground-breaking VERIsteel procedure, TÜV SÜD can provide proof of product-specific CO_2 emissions in steel products.

The first VERIsteel conformity statements were handed over to Salzgitter AG in February 2021. But the procedure can also be applied to other energy-intensive industries to flank the process of decarbonisation. It is the method of choice to help industries and companies to validate their success in reducing CO_2 emissions, as part of the global fight against climate change.

Safety in use, credibility in trade

As a fuel, hydrogen can power railways, trucks, ships and aircraft, in either direct-combustion or fuel-cell systems. All elements of those systems and, naturally, the vehicles themselves must be in line with the state of the art and as safe as is humanly possible.

While comprehensive regulations are already in place governing the quality of materials used for tanks, pipelines and industrial installations and addressing explosion protection, they must now be aligned to these new areas of application to ensure that hydrogen can be safely used in achieving widespread decarbonisation of all systems.

As energy consumers do not distinguish between hydrogen molecules generated using different methods, European and global markets need to introduce guarantees of origin for hydrogen which supply reliable, impartial assessment and measure and verify the carbon reduction in its production. A first step in this direction is the Europe-wide CertifHy scheme. ●

www.tuvsud.com/hydrogen

The Road to Decarbonizing Transport

Why Fuel Cells are no longer the Wallflowers

As the electrification of transportation continues to accelerate with battery solutions leading the way, are the right technological and strategic decisions being made? It is now increasingly recognized that fuel-cell (FC) systems are best applied to commercial vehicles where range, payload and extensive usage are key. They offer range and refueling times that compete or often exceed that of fossil fuel vehicles. With the rapid industrialization of the key building blocks of the hydrogen ecosystem, are we fast approaching a tipping point where hybrid solutions combining FCs with battery technology become the true norm, and with far wider coverage of transport applications?

Tackling Cost & Complexity

Aside from hydrogen infrastructure, cost remains arguably the most significant obstacle to the more widespread adoption of FC technology in mobility. To meet this challenge, the industry is ramping up its production capacity with significant investments by the likes of major automotive suppliers (such as Bosch), existing players (such as Ballard, Toyota and Hyundai), and nimble start-ups (such as EH Group Engineering of Switzerland). The objective is simple: prepare to scale-up production and reduce cost. We believe that a fully integrated assembly process is the best path to radically reduce costs. In parallel, fuel-cell systems remain complex, with often expensive balance of plant components. Pathways to simplifying these are also being rapidly developed, leading to higher efficiencies and lower costs.

Low Hanging Fruit

While for many years much of the attention on fuel-cell mobility was focused on cars as an alternative to battery solutions, the real battle was being waged elsewhere – on the floors of large e-commerce fulfillment centers. The forklift model, perfected by the likes of Plug Power, has demonstrated that where intensive commercial vehicle use is required, with low downtimes, fuel cells are already economically competitive. We are witnessing a similar development in the heavy goods vehicle market where the right combination of CO_2 incentives and forward-thinking logistics companies have created the right environment for FC trucks to enter the market. This mirrors developments in the municipal bus market across much of Europe where FC buses continue to gain traction and are set to match diesel buses on a total cost of ownership (TCO) basis within a few years. Finally, we believe the opportunity for fuel-cell systems to replace diesel trains remains under-appreciated for new locomotives and retrofits. With nearly half of train lines in Europe unelectrified, the prohibitive cost of adding cantilevered lines at over 1 million EUR/km makes the TCO of FC locomotives a compelling story.

Next Challenges

The next significant areas where FCs with high-power densities will yield a significant advantage over battery technologies will play out in the maritime and aerospace sectors, both of which offer tremendous long-term opportunities, although with some near-term challenges to be overcome. To meet the growing potential in these applications, EH Group has developed a high-power density 250kW FC solution that sets new market standards. Across all mobility sectors, a new generation of skilled jobs is being created to accelerate these deployment opportunities.

we are entering a new era that is characterized less by competition and more by the wisdom of complementarity, circularity, and hyper-efficiency

The rapid scale-up of fuel-cell technology in parallel to the battery means that we are entering a new era that is characterized less by competition and more by the wisdom of complementarity, circularity, and hyper-efficiency. For decades now, the opportunity of the fuel cell must not be underestimated if we wish to come closer to the SDG and other climate targets set for 2030 and beyond. As the old adage goes: a mistake repeated more than once is a decision. The energy sector and investors have made the error before in thinking of the fuel cell as the unattractive wallflower; FCs still remain unequivocally the most sustainable, ecological and carbon-zero technological energy options of our age. ●

EH GROUP Engineering AG

01 EH TRACE Fuel Cell System. **Source:** EH Group
02 EH-81 Fuel Cell Stack. **Source:** EH Group

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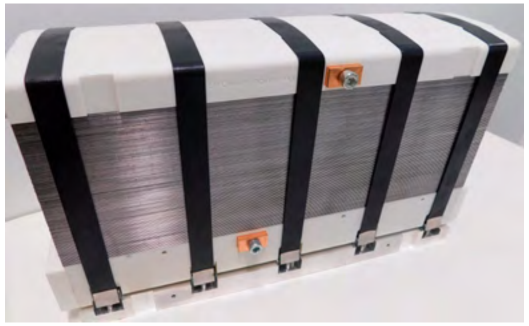

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Partnerships are Key

ANDREAS OPFERMANN
EXECUTIVE VICE PRESIDENT CLEAN ENERGY AT LINDE

With its extensive hydrogen portfolio and large installed base, Linde is a driving force in the transition to a hydrogen economy. Yet success will also depend on striking new partnerships.

Societies are focusing on decarbonization, and that has moved the topic of hydrogen front and center. What does this mean for Linde?

This is an important opportunity for us to contribute to the development of a hydrogen economy. Our experience with hydrogen stretches back over 100 years, initially with Carl von Linde co-developing a method for producing hydrogen in the early 20th century. Today, we cover every aspect of the hydrogen value chain: production using steam methane reforming (SMR), more recently including CO_2 capture, and expanding use of electrolysis; storage in cryogenic tanks and in the world's first commercial high-purity hydrogen cavern; distribution via pipeline, trailers and tankers; and, finally, hydrogen applications across many different sectors – including mobility, industry and export/power. Linde is also a pioneer in the use of hydrogen as a carbon-free fuel, with the first studies dating back to the mid-1970s.

There seems to be a lot of momentum being generated around hydrogen for heavy-duty transport, instead of batteries. What's your take here?

Hydrogen packs more energy per weight and volume than batteries, which means that you can travel longer distances and propel heavier vehicles. To achieve the same with batteries, the system would have to be very large, becoming sub-optimal in terms of weight, space and cost. Furthermore, it is much faster to refuel hydrogen than to charge

To ensure that we lead the way with environmentally friendly solutions, we have earmarked a third of our annual R&D budget for decarbonization.

01 Originally opened for refueling single-decker buses, today this station in Aberdeen, Scotland, has been upgraded to also refuel double-decker buses, cars, vans, refuse collection vehicles and road sweepers. **Source:** Linde

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an electric battery. For these reasons, hydrogen is becoming a solution of choice for buses, heavy trucks, forklifts, trains, ferries and planes.

To support the emerging public mobility sector, a good network of refueling stations is needed. Any particular developments that are worth highlighting?

We supply a large portfolio of fueling stations to serve a diverse set of needs. We are building the first hydrogen refueling station for trains with Alstom in northern Germany that will be able to fuel 14 hydrogen-powered passenger trains, with regular passenger service scheduled to start next year. Another good example is a bus fueling station in Aberdeen, Scotland. It was first installed in 2015 to refuel single-decker buses. In the years since, the station has been upgraded to also refuel double-decker buses, cars, vans, refuse collection vehicles and road sweepers. Once the infrastructure is in place, it can be used for different types of vehicles. But the investment needed to create the necessary infrastructure and to define industry standards is too large for a single company to achieve on its own. To really get hydrogen mobility going, partnerships with players from different industries are key. This was the thinking behind us joining H2Accelerate, where vehicle manufacturers and infrastructure players come together based on their shared commitment to create a commercially viable hydrogen trucking system in Europe. Collaborations like this are essential to make hydrogen mobility a success at scale, something the world needs to achieve society's ambitious climate goals.

02 Hydrogen can help hard-to-abate sectors, such as steel, meet their decarbonization targets.
Source: Linde

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Of course, mobility is just one aspect of decarbonization in the hydrogen discussion…

That is correct. Mobility is a first mover, but the applications for clean hydrogen go far beyond. Take industries where a direct electrification of processes is difficult. In these cases, hydrogen but also carbon capture and storage (CCS) are essential for decarbonization. For instance, in cement the large-scale deployment of CCS will contribute to a significant decrease of heavy-industry emissions. Another case in point is steel production. Integrated steel mills that use blast furnaces to process iron ore rely heavily on coal and natural gas. There are concrete steps that can be taken in a phased approach to decarbonization, such as the increased adoption of natural gas, oxyfuel and eventually the full conversion to hydrogen as a fuel.

Or take refineries and jet fuels. While hydrogen may eventually be directly used as an aviation fuel, in the meantime we have to reduce the carbon footprint of jet fuels. Linde is part of a consortium to produce sustainable aviation fuels. In this project, carbon feedstock from biomass and green hydrogen is converted to synthesis gas, which is then transformed into kerosene. This project is in the exploration phase, but initial results are very promising.

There are many colors of hydrogen, with the end-goal being green hydrogen – any developments worth noting?

Linde is agnostic to the color of hydrogen, as all have a role to play in the energy transition, but we see more geographies where the production of hydrogen from renewable power, so green hydrogen, becomes competitive. A great example is a new project development in Oman, a location blessed with excellent wind and solar conditions. We've just announced the signing of a joint development agreement (JDA) with Japan's Marubeni, UAE's Dutco Group and Oman's state energy company OQ to conduct technical and commercial feasibility studies on developing a green hydrogen and green ammonia production facility in Oman's Salalah Free Zone. This project entails all the ingredients for success: strong partners, excellent geographic conditions and the ability to reuse existing infrastructure, creating a leading clean hydrogen export opportunity.

Do you think projects like those you've mentioned – of which many have yet to be commercialized – will make an impact on decarbonization?

I do. All of these early projects demonstrate progress and underline the need to work with the right partners who, like Linde, want to make a real difference. Decarbonization is not a new industry but a new value chain spanning various industries, from utilities and oil and gas to all the different end-user segments, like steel, cement and logistics. Linde as a company is committed to doing its part to establish these new value chains: Firstly, we are investing more than €1 billion in decarbonization projects by 2028, many of which will naturally include partners from other industries; secondly, to ensure that we lead the way with environmentally friendly solutions, we have earmarked a third of our annual R&D budget for decarbonization.

What role do you see hydrogen playing in 2050?

Hydrogen will be ubiquitous and used across many applications and use cases; it will have moved away from its "niche" as a chemical to become THE new energy vector; and fuel cells will be commonplace, owing in large part to wide availability of low- or no-carbon hydrogen that is also cost competitive. Enablers here include green electricity production for powering hydrogen electrolysis, and highly energy efficient SMRs (and other technologies like ATR and pyrolysis) featuring carbon capture. As a society, we will be so much closer to CO_2-free industrial processes and mobility by 2050. The work we are doing today is invaluable for accomplishing this vision. ●

World's First Hydrogen Passenger Train is Already a Reality

Alstom is convinced that decarbonising mobility is an essential part of fighting global climate change and that hydrogen trains are a key technology to enable zero emission mobility.

Alstom is the world's largest international rail technology player, we have made furthering the development of smart, green technologies like green traction a key focus of our 2025 strategy. The aim is to provide zero-emission alternatives on non-electrified rail tracks. The potential is substantial: in Europe as the world's largest rail region, almost half of all tracks are not electrified and currently rely on diesel-powered trains.

Transportation accounts for around a quarter of global CO_2 emissions. Unlike other sectors, these emissions have continued to grow, even as efforts to fight climate change have increased. Rail is already by far the greenest way to provide mobility for people and freight on land. Bringing hydrogen and battery as viable alternatives to using diesel power on non-electrified lines will unlock further reductions in the environmental impact of rail transport. On longer routes, hydrogen is the technology of choice, while non-electrified short distance rail routes are best served by battery trains.

ALSTOM
• mobility by nature •

Our Coradia iLint train, the world's first hydrogen passenger train, has proven the viability of hydrogen rail. The train provides a whisper-smooth ride with the only emissions being water vapour. Its reliability, economics, and range of up to 1,000 kilometres make it a true alternative to diesel for regional non-electrified lines, and has led to orders in multiple countries as customers, the public and policy-makers realize the massive potential of the technology.

Strong public and private support for hydrogen industry

We are convinced that hydrogen and batteries will bring about change in rail transport – towards a cleaner and ultimately emission-free energy system. For hydrogen rail, a key driver is the rapid development of a hydrogen economy in transport supported by a strong public and private alliance. Hydrogen also has an important role to play in decarbonising other industries beyond transport, that's why Alstom is a member of Hydrogen Europe and the Hydrogen Council.

The fuel cell is the core of a hydrogen train: it is where hydrogen is combined with oxygen from the atmosphere to generate electricity, with the only exhaust being steam and water. The electricity produced is used to directly power the train or stored in a high-performance battery. This battery is also used to capture energy when the train is braking, increasing its fuel efficiency. By acquiring Helion Hydrogen Power, Alstom now has access to in-house fuel cell competence, providing us with the unique ability to develop and integrate the entire on-board hydrogen technology for trains.

01 Coradia iLint in Sweden in August, 2021.
Source: Alstom / Tommy Hvitfeldt

02 A hydrogen powered train takes about the same amount of time to refuel as a diesel one. The train will then run up to 1,000 kilometers after one filling
Source: Alstom / Christoph Busse

The world's first hydrogen train in passenger service is a success

With a little less than half of Germany's rail network not electrified, the country's operators need to rely on a large fleet of diesel passenger trains for rail transport. In 2014, Alstom started work on developing cleaner alternatives to these trains with the strong support of the German and regional governments. There was a substantiated political commitment to finding sustainable alternatives for passenger transport, and to contribute to developing long-term green mobility solutions. Alstom's clear vision and technical know-how created the necessary test bed, and four years later, the world's first pre-serial hydrogen regional train was ready for passenger service.

The Coradia iLint has been certified for regular use in Germany and Austria. This followed extensive testing carried out in Lower Saxony, Germany

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© Alstom / R. Frampe

where starting in September 2018, two pre-serial trains operated in regular commercial service for 18 months, travelling over 200,000 kilometres. Passenger feedback was very positive, with many comments on the smooth ride and lack of vibration compared to regular diesel trains.

The Coradia iLint proved that hydrogen trains are more reliable and require less maintenance than diesel trains, lowering service costs for train operators, which offsets the higher initial purchase cost of the train versus a diesel train. Hydrogen has the benefit of offering a similar range to diesel while providing the same operational conditions for availability and re-fuelling. Another important decarbonizing technology is that diesel train platforms can be retrofitted for hydrogen power. Alstom is convinced that with the total costs of ownership in mind, hydrogen trains are not only greener, but are also already an economically viable alternative to diesel trains.

First fleet of hydrogen trains to enter service in 2022

After successfully completing trials, 14 Coradia iLint trains will become the world's first fleet of hydrogen trains to enter service when they begin operating on Germany's Lower Saxony network in the summer of 2022. When fueled with zero-emission green hydrogen, each of these trains will ultimately reduce yearly CO_2 emissions by 700 tonnes. They will be refueled from one of the world's largest hydrogen refueling stations for passenger trains, located in Bremervoerde with the station being constructed with an eye on the future on-site production of hydrogen through electrolysis.

The first passenger operations with two pre-serial Coradia iLint trains were carried out in Lower Saxony very successfully and the hydrogen train has since operated in passenger service in Austria, been tested in the Netherlands, as well as demonstrated in Poland, France and Sweden. Alstom has also sold other hydrogen technology solutions to Italy and France.

First two orders in Germany, range of hydrogen trains increased

The successful hydrogen technology developed in the Coradia iLint has led to further orders and an extension to a broader range of hydrogen trains. Alstom has taken orders for a total of 59 hydrogen trains and now offers the technology for its Coradia Stream trains in Italy, and the Coradia Polyvalent trains for France. The Polyvalent trains will be dual mode electric and hydrogen, enabling them to efficiently operate on the electric network, and on non-electrified track, powered by hydrogen. These orders are important first steps towards decarbonizing rail transport by bringing hydrogen-powered trains to multiple European countries.

Rail transportation is already the most energy-efficient transport mode and will only improve as hydrogen trains come into regular service. Alstom is proud to pioneer the trains that hold the promise to become the backbone of mobility in a sustainable world. ●

Did you know?

- Coradia iLint will run up to 1,000 km with one filling
- Coradia iLint has run over 200,000 km in passenger service
- The Coradia iLint first entered commercial service in 2018
- Alstom hydrogen traction solutions have been sold in 3 European countries

Empowering Generations with Clean Energy Forever

FILIP SMEETS, SVP ELECTROLYSER DIVISION AND **ROBERT BORIN,** SVP FUELING DIVISION

Nel Hydrogen is a global hydrogen technology company that delivers optimal solutions to produce, store, and distribute hydrogen from renewable energy sources. Our manufacturing facilities are in Norway, Denmark, and the United States, and are supported by a world-wide sales and service network. We are publicly traded on the Oslo Stock Exchange (NEL.OSE). Nel Hydrogen is considered a "pure play" company for investors, meaning we solely focus on one line of business. In our case: hydrogen. We continuously strive to improve our product offering to maintain our earned leadership position and remain at the forefront of hydrogen technology development. **Our vision is to empower generations with clean energy forever.** That is a lofty goal; however, the momentum is building across public and private enterprises on a global scale to dramatically reduce our carbon footprint on the planet, and hydrogen is becoming a viable, clean alternative to fossil fuels in many impactful applications for industry, mobility, and energy.

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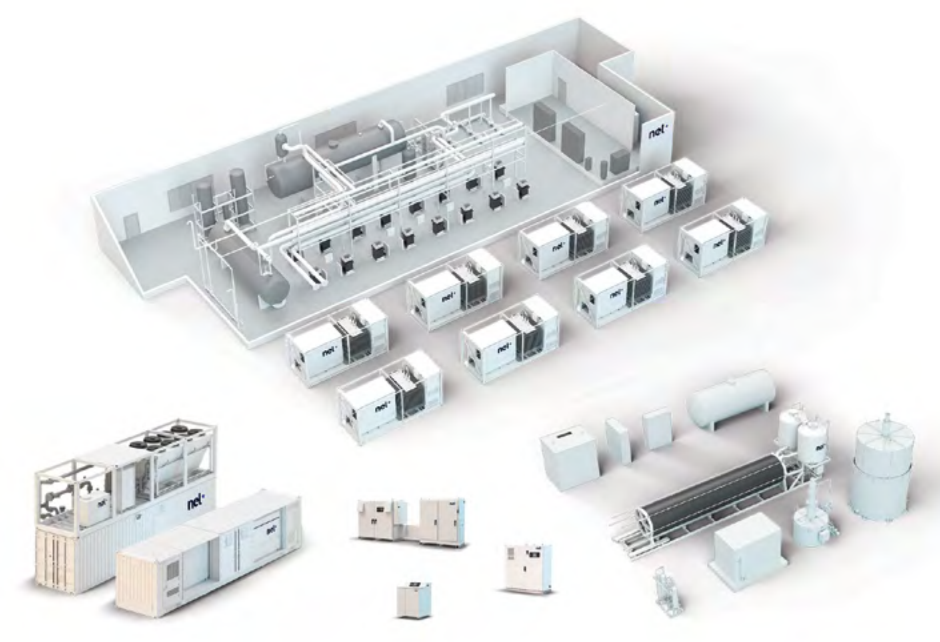
01 With more than 3,500 reliable, cost efficient electrolysers installed around the globe, Nel is the recognized industry leader of Alkaline and PEM water electrolysis. **Source:** Nel

02 Nel offers a full range of Alkaline and PEM electrolysers to cover the hydrogen output requirements of any application. **Source:** Nel

Frontrunner in Hydrogen Electrolysers and Fueling Stations

We currently serve a range of diverse customers with leading hydrogen technologies. For example, Nel is the world's largest hydrogen electrolyser manufacturer with more than 3,500 units delivered in 80+ countries since 1927. For readers new to the hydrogen topic, to put it simply, an electrolyser is a system the uses electricity to break water into hydrogen and oxygen in a process called electrolysis. Through electrolysis, the electrolyzer creates hydrogen gas. Nel offers two types of electrolysers, alkaline and PEM (proton exchange membrane). We've been making alkaline electrolysers for 90 years in Norway and PEM electrolysers for 23 years in the U.S. In Norway, Nel is dramatically increasing its production capacity. Currently, it's at 40 megawatts per year (input electrical power to electrolysis) and will increase shortly to 500 megawatts per year with the completion of a new plant, and then to 2,000 megawatts per year with subsequent expansions. In the U.S., the company is increasing its production for PEM systems to 50 megawatts per year, with additional expansion planned as demand increases. Alkaline electrolysis is admittedly a more mature technology with most of the technological innovations already absorbed. Although some technological innovation may still contribute, the cost reductions available for alkaline electrolysis are primarily around volume purchasing and equipment simplification. By comparison, PEM technology is a newer technology with room for significant technological innovation.

In the hydrogen fueling segment, we're also the leading manufacturer of hydrogen fueling stations, with over 110 H2Station™ systems in 13 countries. We have been manufacturing our renowned compact hydrogen fueling stations at our Denmark facility for 16 years at a capacity of 300 per year.



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Hydrogen Growth

Nel is bullish on the opportunities for hydrogen electrolysis within the hydrogen market. For instance, right now, only 1% of hydrogen is generated with electrolysis and that is forecasted to grow to greater than $20 billion/year within the existing market alone. **The overall hydrogen market is set to grow by 8 times, and the electrolyser market potential is forecasted to grow more than 800 times over the next 20 to 30 years.** All of this is driven by the regulations to lower surplus demand for fuel; decreased crude quality which requires more hydrogen for processing; electrification of the transport sector; and the move from coal to hydrogen in various industries. The steadily-growing industrial applications are many such as the food, glass, chemical, laboratories, thermal processing, steel, and power industries. Newer markets experimenting with hydrogen now include, ammonia, refineries, methanol/synthetic fuels, cement, remote power, gas pipelines, energy export and believe it or not, fish farming!

We have been manufacturing our renowned compact hydrogen fueling stations at our Denmark facility for 16 years at a capacity of 300 per year.

There are vast opportunities in power generation alone, and many readers may be familiar with HYBRIT, a northern European hydrogen steel plant in its pilot stage now. Transportation and mobility are another fast-growing market both for hydrogen production and fueling. Hydrogen is now accepted as a relevant form of fuel for all methods of transport.

Reaching Cost Parity

There is encouraging news on the cost front also. With falling LCOE (levelized cost of energy) of wind and solar prices, renewable hydrogen follows the same path, as electrical power constitutes 70 to 80% of hydrogen's total cost. These prices are expected to drop even further with solar down 71% and onshore wind 58%. Renewable hydrogen becomes competitive with fossil fuels in most markets at $30/MWh. Nel is establishing a new manufacturing plant targeting more than 40% cost reduction and even further CAPEX (capital expenditure) reduction is expected with the increased volume we are anticipating. In fact, we project the CAPEX will drop below steam methane reforming over time. Electrolysis is expected to be the preferred production method if the OPEX (operating expense) is low enough or at parity with alternative production methods. Nel's green hydrogen cost target is 1.5 $/kg by 2025.

Meeting Global Demand

To maintain Nel's leadership position in the hydrogen market and keep reducing costs, we have embraced and nurtured a world-class culture of continuous improvement. We are preparing for the increased hydrogen demand on a global scale. One example is our capacity expansion at our electrode manufacturing facility in Herøya, Norway. Coming online soon are fully automated production lines applying the latest Industry 4.0 techniques in staging, equipment, assemblies, software, and factory connectivity. There are fewer process steps to reduce our factory footprint and energy and chemical consumption. The more efficient processes have led to better product performance for our customers. We have tripled our staff, concentrated on core competencies, and expanded our applications knowledge base. Further, we are vastly increasing the size and capacity of our electrolyser cell stacks by a factor of 20, boosting the energy capability of a single stack to generate hydrogen reliably and efficiently. The company is also reducing the CAPEX of its PEM electrolysis equipment by transitioning from largely handmade membrane electrode assemblies containing platinum group metals to volume production roll to roll manufacturing of membrane electrode assemblies.

Hydrogen fueling station sales are expected to grow greater than 30% each year between now and 2030. Hydrogen is becoming increasingly relevant in all forms of mobility including forklifts, busses, delivery trucks, long-haul trucks, construction equipment, passenger cars and trucks, trains, fast ferries, and car ferries. The challenge is to get to a cost parity with diesel fuel prices, which would be less than $5/kg. We at Nel anticipate this will happen soon, by 2025. Nel is also addressing other key challenges such as fast fueling dispensing and the space required to accommodate the new hydrogen infrastructure products including supply cabinets, supply and fueling storage tanks, station modules, and dispenser stations. Nel is in the unique position to ramp up its capacity to meet the demand with our already proven in-house developed technologies, our full value-chain services, our operations and maintenance organization in key markets, our standardized and certified products, along with our known world's largest manufacturing capacity in this very specialized market. The goal: evolve to 10x capacity and decrease CAPEX by 90% by 2030.


03

03 Nel fueling equipment solutions are ideal for both light-duty and heavy-duty vehicles. **Source:** Nel

In sum, Nel Hydrogen is well-positioned for the growing hydrogen market. We possess the deep technology knowledge stemming from our almost 100-year history in hydrogen production technologies. This fundamental knowledge-base serves as the springboard for our leadership position for current and future developmental platforms. The company is scaling-up capacity with expertise and robust development to meet the projected demand for hydrogen solutions in the coming decade to take full advantage of these opportunities. ●

Solid Oxide Fuel Cell (SOFC) Systems

DR. WILFRIED KÖLSCHEID (LEFT) **& MARCUS SPICKERMANN** (RIGHT)
PROJECT LEADERS FOR THE SOLID OXIDE FUEL CELL AT ROBERT BOSCH GMBH

"Fuel cell systems play an essential role in the energy mix of the future."

Stationary solid oxide fuel cell systems (SOFC) are a key component in the energy mix of the future. The small, decentralized power stations generate electricity and heat from natural gas, hydrogen, or a blend of both. A promising market, in which Bosch places great hopes. The two people in charge of the project, Dr. Wilfried Kölscheid (WK), Senior Vice President Engineering & Manufacturing, and Marcus Spickermann (MS), Senior Vice President Sales & Market development, talk about fuel cell systems for power generation and their advantages.

When you think about the stationary fuel cell systems, do you get fired up?

WK: The subject electrifies us all, because we are able to offer an efficient, cleaner, decentralized energy supply. We consider stationary fuel cells to be an essential component of the energy transition, and a promising market to boot. Bosch believes that the whole market for decentralized energy production using stationary fuel cells will reach a volume of around 20 billion euros by 2030.

BOSCH
Invented for life

What is your optimism based on?

MS: With the stationary fuel cell system, we can generate electricity and heat with very high levels of efficiency from natural gas and, in the future, from 100% hydrogen. But that is not all – the production of electricity is extremely climate-friendly.

What does that mean specifically?

MS: By level of efficiency, we mean an electrical efficiency of more than 60%. If we are also using the waste heat, then the levels of efficiency can be 85% or more. This makes the solid oxide fuel cells far superior than other energy converters. A coal-fired power station, for example, has an efficiency level of 40%.

And what about the emissions?

WK: The operation of fuel cells is nearly emission-free; it produces hardly any nitrogen oxides or particulates. When run purely on hydrogen, the emission level falls almost to zero. In addition, fuel cells fed with natural gas provide a significant CO_2 emission benefit compared to electricity from coal power plants and they pave the way to zero carbon emission when green hydrogen is used.

What roles do stationary fuel cell systems play in the energy mix of the future?

WK: Without doubt, they play a relevant role, for example in markets such as Germany, where a huge natural gas network is in place. In the future, this can be converted towards green hydrogen transport. With the networked SOFC, electricity and heat can be generated efficiently in exactly the places where they are needed. In doing so, we are safely and sensibly adding to the power grid that is already limited or overstretched in some cities.

Do you already have some stationary SOFC units installed?

MS: Yes, several. For example, we have put a stationary fuel cell into operation at the main bus station in Bamberg. The system is two meters high and generates some ten kilowatts of electricity, which is enough to power more than 20 four-person households in the part of the city surrounding the bus station. We want to use it to show how a decentralized, climate-friendly energy supply of the future can look.

What other areas of application are there?

MS: A wide range. Our appliances can be used in the urban context to supply buildings, provide electricity to data centers, and to supply energy in industrial and commercial segments.

What is Bosch's position in the market for stationary fuel cell systems?

MS: With our devices, we occupy the 10-kilowatt performance class of the energy market. That is a new segment that we plan to help set up. But we can also see that many manufacturers of fuel cell systems, even those in higher performance classes, are trying to access the new market. Our aim is to become a leading provider in this segment. ●

01

01 Central bus station in Bamberg: A system there generates around 10 kW of electricity - enough to meet the annual requirements of more than 20 four-person households in an urban quarter. **Source:** Robert Bosch GmbH.

Betting on Renewable Hydrogen to Achieve Net Zero Emissions

TOMAS MALANGO
HYDROGEN DIRECTOR OF REPSOL

Why does Repsol bet on renewable hydrogen?

Repsol has been an early mover in sustainability and the first company in its sector to commit to become a net-zero emissions company by 2050. Renewable electrification is not the solution for a complete decarbonization of our economy, and we see renewable hydrogen as the leading solution for hard to abate sectors, applied both directly and transformed into hydrogen carriers like low-carbon fuels, as well as for the transformation of our industrial sites into multi-energy hubs.

Our business plan is aligned with the EU and the Spanish national hydrogen roadmaps. Repsol is the main producer and consumer of hydrogen in Spain: we have the expertise and the industrial capabilities to be at the forefront of the growing market in Spain and to play a leading role in renewable hydrogen in Europe. Our target is to develop an equivalent capacity of 552 MW in 2025 and reach 1.9 GW in 2030. Hydrogen also integrates well with other low-carbon businesses, and Repsol is taking positions throughout the renewable hydrogen value chain, from renewable power generation and energy storage to hydrogen production and transformation and commercialization of hydrogen carriers.

How do you mitigate technological uncertainties related to renewable hydrogen production?

Repsol considers different technologies for renewable hydrogen production: electrolysis, biogas reforming, and a state-of-the-art proprietary technology based on photo-electrocatalysis, that we are developing together with Enagas. This technology will use solar energy to turn water directly into hydrogen without the intermediate step of electricity, and a demo plant is planned to be launched at our Puertollano industrial site by 2025. We believe in being open-minded to new technological developments, continuous innovation, and close collaboration to speed up this process.

What is the base to foster early developments of renewable hydrogen?

Repsol's industrial sites are located strategically in the heart of the hydrogen valleys and hubs that are developing in Spain. These early developments will boost the switching of renewable hydrogen to other uses and facilitate offtakes located close to the hydrogen hubs. We have already announced the first electrolysis project to come into operation next year in Bilbao (2,5 MW), as part of the Basque Hydrogen Corridor. At a later stage, we will add capacities there of 10 MW and 100 MW to produce both hydrogen and e-fuels, not only in Basque country but also in Catalonia and Region of Murcia.

This business is strategic for Repsol and, benefitting from our integrated model, with renewable generation and commercial businesses already in place, our industrial approach, and our expertise, we are working to maximize it. Decarbonization must be efficient both in terms of emissions and economically. Detailed regulatory mechanisms, both for demand and supply, will be crucial to scale up developing technologies and achieve commercial viability.

Hydrogen is strategic for Repsol. Taking advantage of our integrated business model and our expertise, we are creating a unique value proposition for our customers.

How renewable hydrogen developments will impact Spanish economy?

Spain has the potential to become a European leader in renewable hydrogen generation due to the availability of renewable resources, industrial capabilities adaptable to new value chains, and an ambitious national hydrogen roadmap. Repsol aims to be the backbone of the national hydrogen market, developing strong alliances and public-private collaborations. The hydrogen projects led by Repsol include investments worth 2.5 billion, which will have an important impact on the national economy and lead to the creation of thousands of jobs. In terms of environmental impact, hydrogen-related projects promoted by Repsol will avoid the emission of more than a million tons of CO_2. ●

How Hydrogen Can Help Decarbonize Buildings

Kaisersesch, a small town located in the state of Rhineland-Palatinate in the quaint south-west of Germany, will soon be a frontrunner in heating innovation: by 2023, the SmartQuart project will set up a complete hydrogen infrastructure – from renewable electricity generation to hydrogen-powered transport and Viessmann hydrogen heating.

How can hydrogen help us to decarbonise heating and generate benefits for people, the environment and the economy? Heating and cooling make up 75% of the carbon footprint of every citizen in Germany, and buildings account for 36% of total EU CO_2 emissions. The majority of space heaters installed in European homes are old and inefficient (64% to be exact). And yet, yearly replacement rates for heat generators are stalling at below 4%.

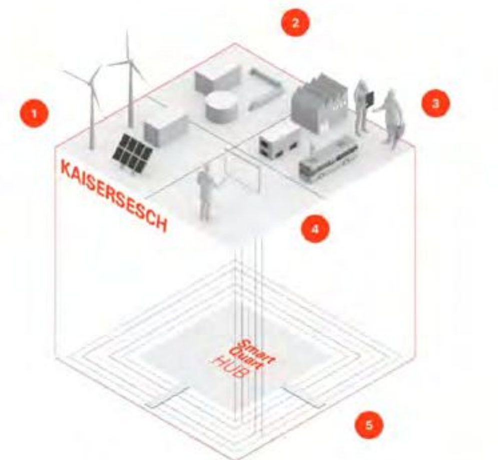
Hydrogen opens additional options – in tandem with large-scale electrification via heat pumps – to accelerate heating decarbonisation where 71% of installed space heaters in the EU are gas-based. The gas infrastructure is tailor-made for high seasonal variations in heating while peak demand in winter often coincides with low electricity generation from renewables. Using both green gases and electricity thus optimises infrastructure use and efficient planning of back-up energy generation.

Hydrogen reduces energy system costs. In addition, we can optimise the investment path for our future energy needs, reduce the risks of relying on a single source of energy as well as provide a choice of energy sources to consumers. Energy system studies conclude that a balanced energy mix is more cost-effective and in Germany alone, savings could amount to €11 billion euros every year up until 2050.

Hydrogen-readiness of heating systems is feasible at marginal costs. When hydrogen is blended directly into the gas distribution grids, connected households can automatically use the (bio)methane-hydrogen mix. In fact, today's heating installations can already run on 100% biomethane. For hydrogen blends: the existing, installed, heating equipment can already process hydrogen admixtures up to 10% right away, and new appliances can process up to 20%. For regions and localities that decide to switch to 100% hydrogen, heating systems can be upgraded at marginal costs – just like in the SmartQuart pilot in Kaisersesch.

Hydrogen increases options for home-owners to take an active part in the climate transition and lower their personal CO_2 footprint. When combined with gradual renovations, it offers optimal investment pathways for individualized building decarbonisation. This flexibility is instrumental to ensure viable options for everyone – as buildings are as heterogeneous as the preferences and financial capabilities of their owners.

From today's perspective, the supply of gaseous fuels will probably be a mixture of (bio)methane, methane-hydrogen blends and pure hydrogen by 2050 – depending on the region, the available infrastructure and gas supply. Hydrogen-ready features of today's appliances offer flexibility and peace of mind for home-owners at low cost and without the risk of fossil fuel lock-in. ●



01

01 The SmartQuart project value chain in Kaisersesch: **1 Production:** Wind turbine, photovoltaic systems, electrolyzer **| 2 Storage:** Hydrogen-based microgrids **| 3 Consuming:** Excess energy LOHC hydrogen storage plant, H2-user industrial building, heat use, hydrogen mobility, H2-cogeneration plant **| 4 Control:** Intelligent neighborhood control **| 5 Source:** "Reallabor SmartQuart".

02

02 Hydrogen-ready boilers are an affordable future-proof retrofit solution: initially they process methane or methane-hydrogen blends. If the gas supplier switches to pure hydrogen, they can be adapted with minor changes on-site. **Source:** Viessmann

Everybody TALKS Hydrogen...

but what turns words into a large-scale market ramp-up?

DR. AXEL WIETFELD
UNIPER SENIOR VICE PRESIDENT HYDROGEN

Protecting our climate and achieving a decarbonized energy future requires the efforts of business, policy and the public. We have already embarked on the path and set ourselves ambitious targets: Uniper has committed to a net zero carbon target for European generation by 2035. In addition, we will have largely phased-out coal-based power generation in Europe by 2029. For the sustainable development of a climate-friendly economy, we have made hydrogen the focus of our business activities.

We see hydrogen as a key element of the energy transition. But how can green and low-carbon hydrogen really become the driver of the decarbonized energy future?

Various studies state significant cost decreases in green and low-carbon hydrogen production and even break even with fossil-based hydrogen in the late 2020s already. This cost decrease is essential to make green and low-carbon hydrogen a key factor of success especially in hard to abate industries such as steel, aviation and shipping that face strong global competition. However, such a cost decrease will only materialize if sufficient green and low-carbon hydrogen demand triggers:

- the ramp-up of renewables in high-yield sites around the globe
- the upscaling of green and low-carbon hydrogen production capacity
- the establishment of green and low-carbon storage and transport infrastructure on- and offshore

This mutual dependency now puts the whole market into a mode of waiting for investment decisions. It can only be resolved if a clear, reliable and supportive political framework sets rules and incentives that stimulate large-scale long-term demand for green and low-carbon hydrogen. Together, with all the key players, we want to build the necessary infrastructure for the future hydrogen economy as quickly and efficiently as possible and would like to see further suitable funding instruments as part of the European hydrogen strategy.

Only if this foundation takes hold, then the industries that can use and consume green and low-carbon hydrogen will schedule and execute their conversion activities, then the signal will be sent to grow the hydrogen market. These signals of demand for green and low-carbon hydrogen will then trigger the development of hydrogen production, transport and storage infrastructure in parallel with the upscaling of renewables.

With green and low-carbon hydrogen as one important pillar to reach the ambitious and increasingly urgent climate targets of the EU Green Deal, it is time to act now.

> **we want to build the future hydrogen economy as quickly and efficiently as possible**

Uniper spends millions each year to develop projects up to financial decision with a team of more than 50 people. With our cross-functional team of experts and hydrogen specialists, we are among the pioneers in the field of green and low-carbon hydrogen and will use this expertise to actively shape the international hydrogen market. Our project portfolio aims at more than 1 GW Hydrogen Production Capacity by 2030 and a significant market share in trading and global sourcing for imports. We are also in a constructive dialogue with our customers to overcome one of the major remaining obstacles – demand uncertainty.

01 Dr. Axel Wietfeld Uniper Senior, Vice President Hydrogen. **Source:** UNIPER

02

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