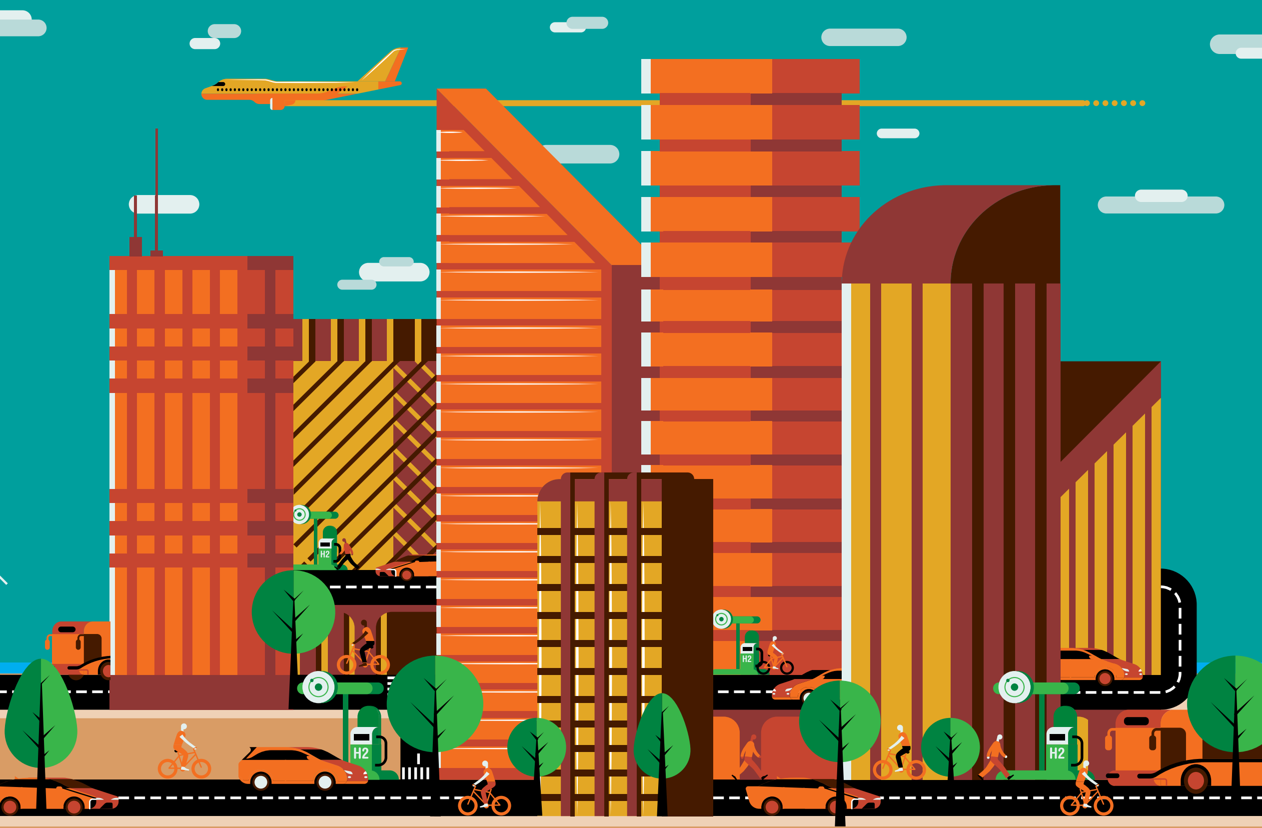
Hydrogen Europe



Hydrogen

ENABLING A ZERO-EMISSION SOCIETY

Think Hydrogen.
Think Linde.

Accelerating the energy transition.

Making our world more productive

Production

With over 150 SMR and PSAs worldwide and 80+ electrolysis plants installed, Linde is one of the leading companies in hydrogen production – from gray, through blue to green! Using processes like steam or autothermal reforming, we generate gray hydrogen from natural gas, LPG and naphtha. We are also able to offer blue hydrogen through our CCS technologies and produce green hydrogen via steam reforming using bio-based feedstock, or via electrolysis, powered with electricity generated from renewable sources.

Processing

Once produced, hydrogen requires further processing. Typical steps include the removal of impurities, the separation of carbon dioxide (CO_2), compression and/or cryogenic liquefaction. Linde has long-standing experience in separating synthesis gas through cryogenic processes. To enable storage and transportation of large quantities using less space, hydrogen is converted from its gaseous form to liquid hydrogen (LH_2) in a hydrogen liquefier. Linde is the world leader in liquid hydrogen production and has decades of experience in the construction of hydrogen liquefaction systems, with capacities ranging from 0.25 TPD to more than 34 TPD in one train.

Distribution and Storage

Once the hydrogen has been processed, it needs to be transported to the point of use. With approximately 1,000 km of hydrogen pipeline and the largest fleet of hydrogen trailers in the world, Linde offers reliable and efficient transportation of both gaseous and liquid hydrogen. For storage, we provide cryogenic tanks for liquid hydrogen with capacities ranging from 3,000 to over 100,000 liters. In addition, we have been successfully operating the first-ever commercial, high-purity hydrogen cavern for over 15 years.

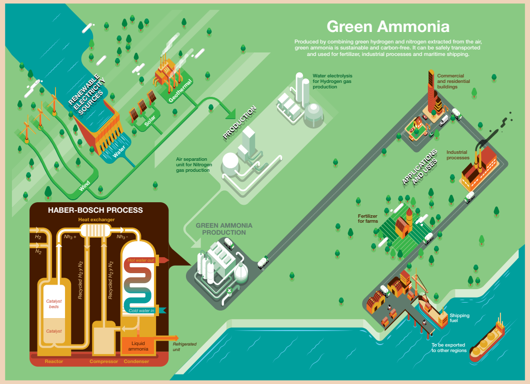
Applications

Hydrogen is used today across a wide range of industrial processes in sectors such as chemicals, refining, aerospace, electronics, metals, and glass. As the world unfolds the full potential of the lightweight gas, the scope for its application increases beyond its traditional uses to include a key role in decarbonizing transportation and hard-to-abate sectors and in enabling renewable power. We are using our expertise, extensive network and infrastructure to help accelerate the transition to clean energy.

As one of the world's leading industrial gases and engineering companies, Linde covers the full spectrum of the hydrogen value chain. We can help customers and industry stakeholders navigate through the complexities of the transition to a zero-carbon economy. Our engineers work with customers in identifying their path to zero emissions and provide support to design, build and operate that project, every step of the way.

www.lindehydrogen.com

Contents



26-27 In a Nutshell / Green Ammonia

68-69 Women in Hydrogen

70-87 VIEWS

122-131 Beyond Europe

60 Years on the Hydrogen Road

NovaLT™16 gas turbines can burn up to 30% vol H2 in DLN mode, with design enhancements moving toward 100% H2

"When internal meetings get into decarbonization," says Rod Christie, Baker Hughes EVP of Industrial & Energy Technology (IET), "through carbon capture, hydrogen, and other programs on the company's books, the energy level spikes. There's genuine excitement in the room."

For a company that built its first hydrogen compressor in 1962, and the first gas turbine in the world to run on 100% hydrogen in 2008, it's no surprise the employees are excited about the global energy industry now being on board to move forward.

There were a lot of technological hurdles overcome in those 60 years—and there are still many more spanning infrastructure and economics. But there's finally light at the end of the tunnel thanks to the commitment of countless researchers around the world, and a handful of companies that view hydrogen as a huge opportunity rather than an obstacle.

For Baker Hughes, among those companies there is Air Products.

In 2021, Air Products and Baker Hughes announced 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. Baker Hughes contributions include NovaLT™16 turbines and advanced compression technology for the net-zero hydrogen energy complex in Edmonton, Canada, and advanced compression technology for Neom's carbon-free hydrogen project in Saudi Arabia.

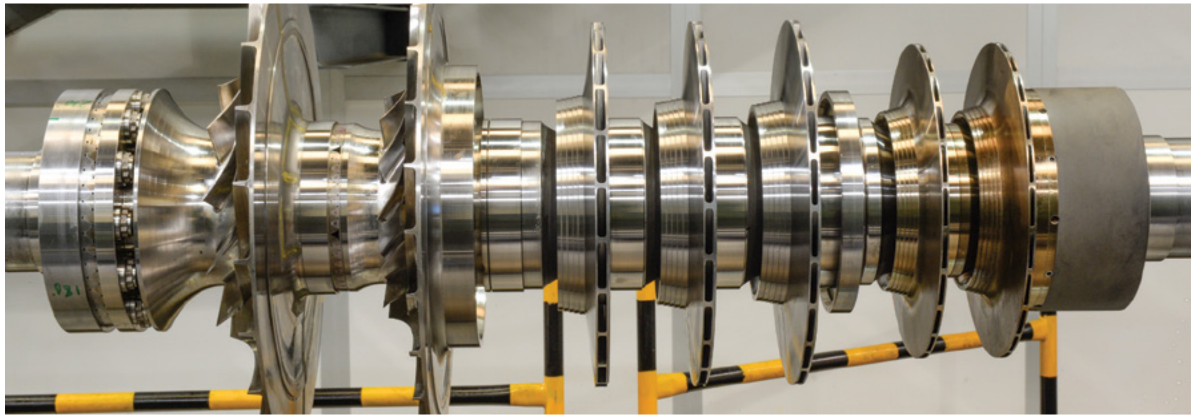
Blue H2 in Western Canada

This project in Edmonton, Alberta, expected to come on stream in 2024, will combine advanced hydrogen reforming technology, carbon capture and storage, and hydrogen-fueled electricity generation to make net-zero possible.

Edmonton's "blue, but better" hydrogen will replace diesel and natural gas in downstream sectors, providing significant GHG reductions across the region.

Baker Hughes is supplying the project with NovaLT™16 gas turbines. Off the shelf, these units can burn up to 100% vol. hydrogen in WET NOx abatement system and 30% vol. hydrogen in Dry Low NOx (DLN) mode, while design enhancements are moving toward 100% H2 capability also for DLN. NovaLTTM turbines can start with pure hydrogen, with no need of additional fuel for this phase, and can switch, if required, the secondary fuel "on the fly"—not shutting down the plant to move from one gas composition to another.

Also, hydrogen compression will be provided by Baker Hughes' High Pressure Ratio Compressor (HPRC) technology that enables a significant reduction of compressor bodies due to its unique design and power density. Well proven in natural gas compression, HPRC is now finding a perfect fit in hydrogen applications. The hydrogen recycle service is done through an



HPRC is a high-speed rotor-compressor with small footprint and high-performance stages for various applications including hydrogen

> **Air Products chose Baker Hughes for its leading-edge compression and gas turbine offerings and robust hydrogen experience.**
> –Dr. Samir J. Serhan, COO, Air Products

API618 reciprocating compressor with a single frame capable of managing three different services with different flow rates and pressures.

Since the 1960s, Baker Hughes has been designing, manufacturing, testing and installing reciprocating compressors specifically for hydrogen applications, including all related auxiliaries such as cooling consoles, crank-gear lubrication, coolers, and pulsation suppression devices. Hydrogen compression takes place in a 6HG model with six large cylinders, tailored to the required operating conditions and driven by a 9-MW fixed-speed electric motor.

Green H2 in Saudi Arabia

In Saudi Arabia, the NEOM Green Hydrogen project is on track to sell carbon-free green hydrogen by 2026 for green ammonia production, using 120 electrolyzers to split hydrogen from water. When completed, it will be the world's largest single-line ammonia and the first full-scale green ammonia plant. It will be powered by 4 GW of on-site solar and wind. The fuel will be exported to international markets as green ammonia, which is easier to transport than gaseous hydrogen, where Air Products will convert it back to green hydrogen to fuel the mobility market.

Baker Hughes is supplying advanced compression technology for the production of green ammonia. Compression is performed by a combination of centrifugal HPRC barrel compressors and no-lube reciprocating compressors manufactured. This solution ensures high flexibility in plant operability while optimizing space usage and leverages Baker Hughes' broad experience and references in supplying syngas and ammonia compressors.

As the energy landscape continues to change, we believe the opportunity to use hydrogen as a zero-emissions fuel source has significant growth potential and as Baker Hughes we can support customers with our expertise and portfolio of solutions in multiple areas along the entire hydrogen value chain.

Contributors

Foreword by

Frans Timmermans
Vice-President of the
European Commission

Hydrogen Europe

Editorial by

Jorgo Chatzimarkakis
Chief Executive Officer

Grzegorz Pawelec
Intelligence Director

Bastien Bonnet-Cantalloube
Industry Policy Officer

Joana Fonseca
Intelligence Analyst

Michela Bortolotti
Communications Director

Nicola Liverani
Junior Communications Officer

Marton Antal
Junior Industry Policy Officer

Matus Muron
Senior Intelligence Analyst

Peter Collins
Press & Media Officer

Felicia Mester
Public Affairs Director

African Hydrogen Partnership (AHP)

Bamidele Adebisi
AHP University Board Member

Innocent Uwuijaren
AHP Chairman

Toby Greenbury
AHP Ambassador

Siegfried (Siggi) Huegemann
AHP Secretary General

Hydrogen Europe

REVOLVE

Graphic Design
Filipa Rosa
Francisco Oldemar

Web Development
Raul Jimenez van Hoorn

Editors
Joshua Franklin-Mann
Danielle Kutka

Visit:
hydrogen.revolve.media

REVOLVE is a communication group fostering cultures of sustainability:
revolve.media

This report is curated by Stuart Reigeluth, founder of REVOLVE

Hydrogen Is an Essential Component of the New Climate-Neutral Economy

FRANS TIMMERMANS
VICE-PRESIDENT OF THE EUROPEAN COMMISSION

COP27 takes place against the backdrop of a truly global energy crisis sparked by Russia's brutal and unjustified invasion of Ukraine. Across Europe, millions of people struggle because of excessively high gas and coal prices, and across the world, millions more who only recently gained access to electricity, risk losing the ability to afford it at all. While this energy crisis affects us all very deeply, we know we cannot solve it at the expense of our fight against the climate crisis. It is still possible to avoid the worst repercussions of climate change if we steer the world economy in the right direction now.

Hydrogen is an essential component of the new, climate-neutral, economy. In the current circumstances, investments in renewable hydrogen can also strengthen energy security and ensure industrial competitiveness.

Over the past two decades Europe has successfully demonstrated that renewable power generation can be deployed at a large scale if it is supported by a stable and ambitious policy framework. To develop the global hydrogen sector, we want to replicate the success story of renewables, and at a much quicker pace.

Europe's strategy to become independent from Russian fossil fuels – REPowerEU – means an accelerated exit from fossil fuels. REPowerEU boosts the deployment of renewables and ensures a faster roll out of renewable hydrogen, backed by more energy efficiency, massive energy savings and diversification of gas supplies. By 2030, we want to produce 45% of our energy from renewable sources and use 20 million tonnes of renewable hydrogen, coming from both European production and overseas imports.

Across the world, the page on fossil fuels was already turning. Recent events and the consequences of Russia's war against Ukraine are only accelerating this transition.

While cheap fossil fuels will not return, we must act now to avoid getting tied down between expensive fossil fuels and the future promise of affordable green energy. We must all take this jump together to make sure that our citizens and businesses have access to affordable renewable electricity and to renewable hydrogen. This will only happen if we remain focused; facilitate investments in renewables, de-risk and support investments in electrolysers, in hydrogen infrastructure and in hydrogen-based technologies for energy-intensive industrial sectors.

This new industrial revolution can also dramatically change the geopolitics of energy. It can also bring industrialisation to regions and countries left behind by previous development. It is often here that wind and solar energy are available in abundance. And to transport the excess energy to other places in the world, you need a carrier like hydrogen.

African countries and other emerging economies around the world can reap enormous benefits from green growth and from the green industrial revolution. To unleash this potential, we must work more closely together on clean tech, sound investment frameworks and regulations and access to capital. The EU, with its thriving electrolyser manufacturing industry and an economy which is on track to become climate neutral by mid-century, is ready to work with the rest of the world to make hydrogen a new success story and an opportunity for a fair industrial revolution. ●

01 Hydrogen is zero emissions.
Source: ezps / Shutterstock

01

EDITORIAL

COP27 Special Report on Hydrogen

JORGO CHATZIMARKAKIS
CEO OF HYDROGEN EUROPE

The climate crisis affects us all. It transcends geographic boundaries and disregards economic and social differences, exposing humankind to the same fate. We must rethink the system starting from its foundations. Any commitment that does not involve the decoupling of our energy system from fossil fuels cannot be considered a serious one.

Hydrogen is a strategic enabler for the energy transition and an impulse for a new industrial revolution that will have positive returns in terms of economic growth, employment, and energy security. In its REPowerEU communication, the European Commission acknowledged the centrality of hydrogen in the green transition by striving to achieve a supply of 20 million tons of green hydrogen by 2030. During the past few months, the European institutions have been working vigorously to facilitate the ramp-up of the sector by intervening in simplifying the regulatory framework and providing new financing instruments, as the European Hydrogen Bank which was recently announced by President von der Leyen in her State of the European Union speech.

However, some ideological positions risk undermining the unlocking of hydrogen's full potential, preventing it from being a game changer in the energy transition. The war in Ukraine has awakened old fears that we had hoped to leave in the past, one of which is precarious access to energy supply. Our heavy dependence on Russian fossil fuels has revived some arguments that the EU can domestically produce the emission-free electricity it needs, with enough reserve power to electrolyze all the hydrogen by itself. Although Europe's clean hydrogen capacity has grown in recent years, the World Energy Council estimates that it will only be able to meet no more than 20% of the projected hydrogen demand in 2030 and less than 50% in

01 Flag of the United Nations Climate Change Conference COP27. **Source:** rafapress / Shutterstock

01

2050. The quest for energy partners thus turns out to be an essential condition for decarbonizing Europe.

With its abundance of natural resources, Africa can become one of the powerhouses of renewable energy, as well as a valuable energy partner for Europe. In the context of energy cooperation, we must acknowledge Europe's colonial past and strive to ensure the establishment of fair and equitable partnerships with our African partners. It is equally important to acknowledge the differences the current condition presents. The natural resources employed in renewable energy production are limitless and not transportable elsewhere, which allows African countries to control them and limit the risk of exploitative extractions. The clean hydrogen produced in Africa will be for Africa first, and then for exports.

Green hydrogen could reposition the role that Africa plays in the world economy. Let's take the mineral transformation processes as an example: if green hydrogen was used to fuel such activities, the continent would cease to exclusively be a supplier of raw materials - destined to be transformed in other parts of the world - and becomes an area of industrial transformation itself. The transition to a renewable-based economy would also allow the end of some African countries' dependence on imported petrol and use their own resources to power their economic activities.

To achieve Africa's economic independence and avert any possible future form of neo-colonialism, it is necessary to empower its countries via socially and environmentally sustainable investments designed to generate prosperity in the region, for the region, using the resources at their disposal. If those investments are used wisely, green hydrogen can be much more than a green fuel for Africa and become the means through which the continent can build a future of development and prosperity.

Quoting the poet John Donne 'no man is an island entire of itself', fighting climate change requires joint visions, free of preconceptions, to embrace solutions that can secure a future for generations to come. I hope you will enjoy reading this Special Report on Hydrogen and grasp how this molecule, the most abundant in the universe, can be a valuable ally in the global clean energy transition. ●

Hydrogen is an integral part of a complete green portfolio

After identifying hydrogen as the missing part in its renewable energy portfolio in 2019, Smartenergy has been forging new partnerships and engaging in the development of green hydrogen projects.

When we started to experience negative prices in the electricity market at the end of 2010, we thought it was a good idea to add hydrogen generation to our renewable projects where suitable to mitigate the risk of electricity price volatility. Since our initial motivation in 2019, the world has changed dramatically, and the ambitions and expectations for hydrogen have exploded. We assume that up 30 % of global decarbonization can be achieved through green hydrogen. In particular, to reduce emissions from hard-to-abate sectors.

Smartenergy is a Swiss-based investment and developer company dedicated to identifying, developing, and delivering green energy assets. We have developed a substantial pipeline of green hydrogen projects for the industry and mobility sectors, including aviation.

Clean energy is our entry point into the hydrogen ecosystem. As such, our strength lies in the development of decentralized and directly connected hydrogen projects in full compliance with the additionality criteria. Electricity is the key lever for the levelized cost of hydrogen (LCOH). For this reason, we started our projects in the Iberian Peninsula, where we already have a GW-scale solar PV portfolio. We are currently expanding into further European markets such as Italy and Germany.

Investments to produce green hydrogen and derivatives require long-term partnerships. For us, it is essential to create partnerships that bring together the private and public sectors to open markets and support to create hydrogen valleys with complete ecosystems, including legacy and new hydrogen off-takers.

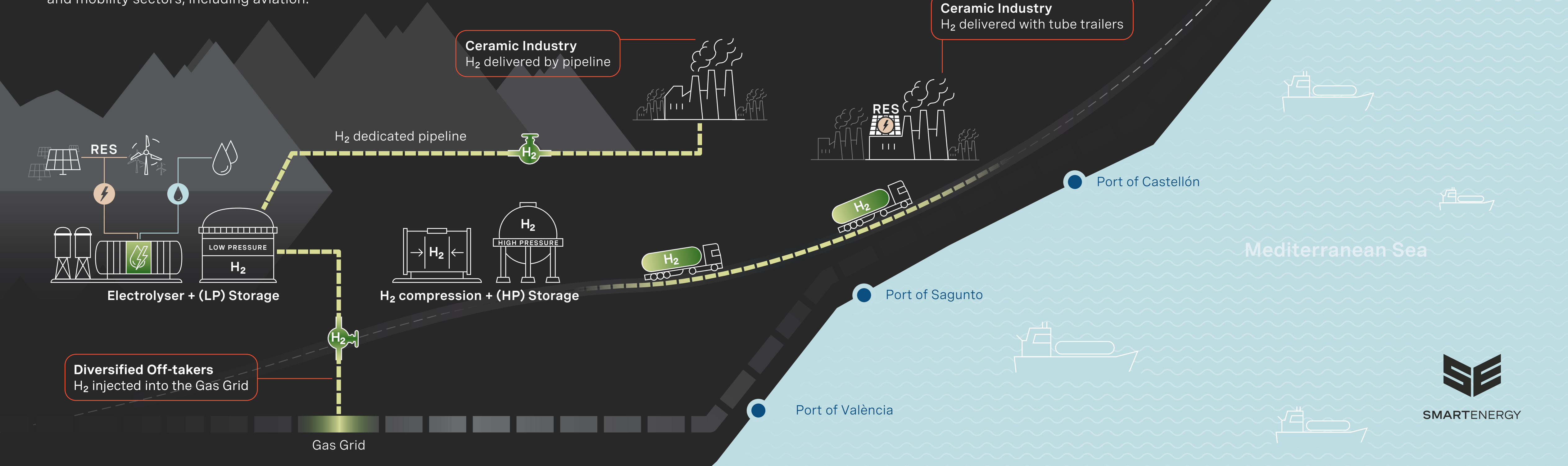
An example is our ORANGE.BAT project, sized at 100 MW, which aims to support the decarbonization of the ceramic cluster of Castellón in the Valencian Community of Spain. It is one the leading ceramic clusters in Europe, having a strategic relevance for Spain in terms of economic, social and labour impact, but contributes to over 40 % of GHG emissions in the region.

In cooperation with ETRA I+D, the national ceramic associations (ASCER and ANFFECC) and with the support of the regional government, we set up the ORANGE.BAT project with the most relevant stakeholders, including small and medium-sized ceramic companies, technology and research centers, and neighboring ports.

Such projects, along with the capability of hydrogen to be stored as energy vector and feedstock long-term to overcome the seasonal challenge, fully unleash the potential of renewables to the next level. This goes in line with our strategy of being fully committed to the energy transition.

Christian Pho Duc
Chief Technology Officer at Smartenergy

info@smartenergy.net
smartenergy.net



In a Nutshell

A Modern History of Hydrogen

Using hydrogen as a fuel for transport is now in the public eye but the foundations of the 'hydrogen economy' have been building for 500 years.

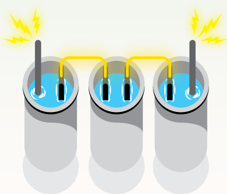
1520

First recorded observation of hydrogen

Paracelsus discovers hydrogen through the dissolution of metals (iron, zinc, and tin) in sulfuric acid.

1842

Sir William Robert Grove develops the first fuel cell



His invention produced electrical energy by combining hydrogen and oxygen.

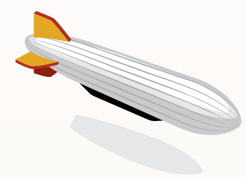
1875

The *Mysterious Island* by Jules Vernes is published

In it he wrote of how "water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used alone or simultaneously, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable."

1900

The first flight by airship



Count Ferdinand von Zeppelin makes the first flight in the LZ1. The flight lasted 20 minutes and was carried out at Lake Constance, Germany.

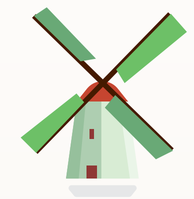
1916

The first Atlantic crossing by airship

The Beardmore HMA R34 flew across the Atlantic from east to west in March 1919, while the return flight was completed three months later in four and a half days.

1923

A hydrogen economy?



J.B.S Haldane proposes a network of hydrogen-generating windmills, foreseeing that Great Britain's coal supply would inevitably be exhausted. This is the first proposal for a 'hydrogen-based' economy.

1928

Around the world

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

1937

A hydrogen catastrophe

Hydrogen is made a scapegoat for the Hindenburg disaster. While the causes are more complex, public confidence is nonetheless shattered, severely delaying the advent of air travel.

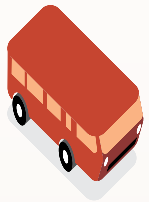
1939

Realising hydrogen production

Hans Gaffron discovers hydrogen metabolism in green algae, which allows it to switch between producing oxygen and hydrogen. This pioneering discovery opened the door to future commercial hydrogen production.

1966

The first hydrogen car



General Motors presents Electrovan, the world's first fuel cell automobile. The vehicle used almost the same technology as the Apollo spacecraft that first put men on the moon.

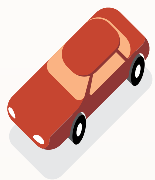
1970

A 'hydrogen economy'

John Bockris and Lawrence W. Jones begin to popularise the term 'hydrogen economy'. Bockris coined the phrase in a talk at General Motors Technical Centre.

1992

Hydrogen for the masses



Toyota starts development of Fuel Cell Vehicle (FCV) technology, aiming to create mass-produced private vehicles.

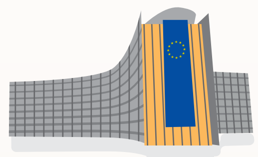
2002

A safer hydrogen world

The Hydrogen Economy by Jeremy Rifkin is published. In it he theorises how global security relies on "weaning the world off oil and turning it toward hydrogen."

2008

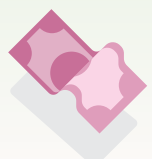
The EU takes steps



The European Commission launches the Fuel Cells and Hydrogen (FCH) Joint Undertaking, tasked with accelerating market entry of fuel cells and hydrogen technologies.

2014

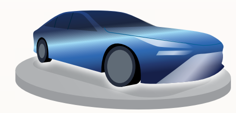
Hydrogen for the future



The European Commission extends the FCH Joint Undertaking to 2030 with more than €1.3 billion funding.

2015

The hydrogen Mirai



Toyota releases its first hydrogen fuel cell car, the Mirai. A lack of hydrogen refuelling stations is holding back widespread uptake of hydrogen personal vehicles.

2018

Hydrogen collaboration

Hydrogen Valleys (H2Vs) Platform launches, promoting global collaboration on large-scale hydrogen flagship projects.

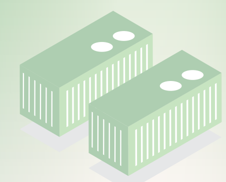
2020

A strategy for Europe

The EU Hydrogen Strategy (EUHS) launches, working for a climate-neutral Europe by 2050.

2021-24

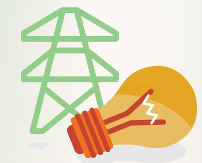
First steps



Kick-starting the hydrogen transition will see the installation of 6GW of renewable hydrogen electrolysers across Europe.

2025-30

Accelerating the hydrogen transition



The 'ramping-up' phase of the transition will see hydrogen becoming an intrinsic part of our integrated energy system, with at least 40 GW of renewable hydrogen electrolysers.

Post 2023

Market Growth

Renewable hydrogen is deployed at a large scale across all hard-to-decarbonise sectors.

Busting 5 Myths

Dispelling common misconceptions about hydrogen.

Green hydrogen is too expensive

When considering global events driving up oil prices and subsidies for its production, green hydrogen is right now cheaper than jet fuel. The three to fourfold increase in hydrogen demand predicted over the next decade will require 30% annual growth of global installed electrolyzer capacity every year until 2050. Every component in the hydrogen value chain will fall in price. The cost of electrolyzers could easily drop by 40% in a few years while some electrolyzer manufacturers projecting even faster declines. Then comes the continuously falling price of the renewable electricity needed to make green hydrogen. Costs for utility-scale solar power, for example, have fallen 85% between 2010 and 2020. Some projections for renewable power fall to 2 cents per kWh by 2025, leading to a cost of green hydrogen at $1.5 per kg.

Source: Universal HydrogenAssociation

Hydrogen is a renewable energy source

No. Hydrogen is a gas: it is the most abundant element in the universe, and here on Earth it typically needs to be extracted from water or organic compounds. We use renewable energy sources such as wind and solar power to extract hydrogen more sustainably with water vapor as a by-product and zero emissions. Today, the production of 'grey' hydrogen (from natural gas still dominates the international landscape, but 'green' hydrogen from renewables is taking off. Learn more about the different colours of hydrogen here.

Source: American Public Power Association

Mainstream hydrogen is futuristic

While some estimates pin 2050 as when green hydrogen could become cost competitive, many factors, including the relative price of renewables, supportive policies, and ramped-up technology development could make using hydrogen more attractive as early as the 2030s. A 2020 review by the Hydrogen Council asserts that 22 of 35 applications for green hydrogen would be cost competitive relative to other noncarbon options before 2030. Projects are already underway with goals to convert generating plants to 100% hydrogen in the 2040s or earlier.

Source: American Public Power Association

Hydrogen as a fuel is new

Not so new. Hydrogen was first produced by electrolysis in 1789 and first used as a fuel in 1792 when it was produced as a constituent of coal gas. The modern oil industry dating back to 1847 is youthful by comparison. Although hydrogen is a fuel in that it contains chemical energy, it is not like fossil fuels. It is artificially made, transported, then used to power something. As such, it is an energy carrier medium, more akin to electricity or steam.

Source: FuelCellsWorks

Hydrogen gas is unsafe

Hydrogen presents the same, if not fewer, hazards than other fuels due to its non-toxic and low-volatility characteristics. Since hydrogen is 14x lighter than air and 57x lighter than gasoline vapor, it will typically rise and disperse rapidly when leaked, greatly reducing the risk of ignition at ground-level.

Source: Swagelok

Facts & Figures

10 key facts to take with you anywhere about the value of hydrogen.

In 2022, **demand for hydrogen** is estimated at between **8.4 and 8.7 mt.**

Source: Hydrogen Europe

Demand for **hydrogen** has grown **more than threefold** since **1975.**

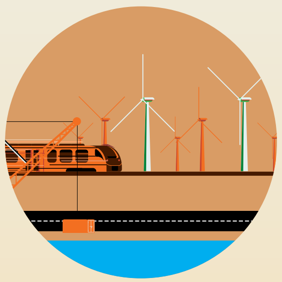
Source: International Energy Agency

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

Source: NASA

More than half of the total EU, EFTA, and UK hydrogen consumption takes place in just four countries: **Germany,** the **Netherlands, Poland,** and **Spain.**

Source: Fuel Cells and Hydrogen Observatory



To meet REPowerEU goals, investments **between €86-126 billion** will **be needed.**

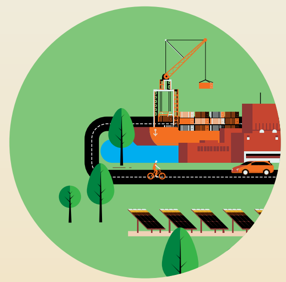
Source: European Commission

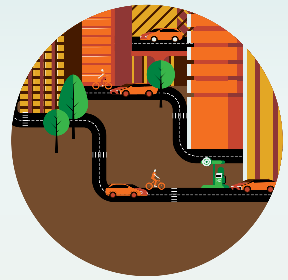
Decarbonisation with hydrogen will require **$15 trillion** between 2022 and 2050.

Source: The Energy Transitions Commission

Portugal produces **the most affordable renewable hydrogen** in the EU at **€3.50/kg.**

Source: Hydrogen Europe



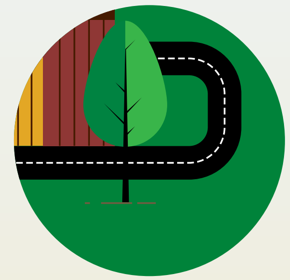


Despite increasing capacity for clean hydrogen in Europe, **99.3% of hydrogen** was produced **by conventional, polluting methods.**

Source: Clean Hydrogen Monitor

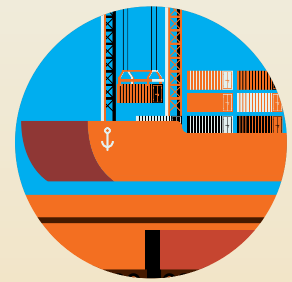
The **European Hydrogen Backbone** proposes **39,700 km of hydrogen pipelines** by 2040.

Source: Gas for Climate



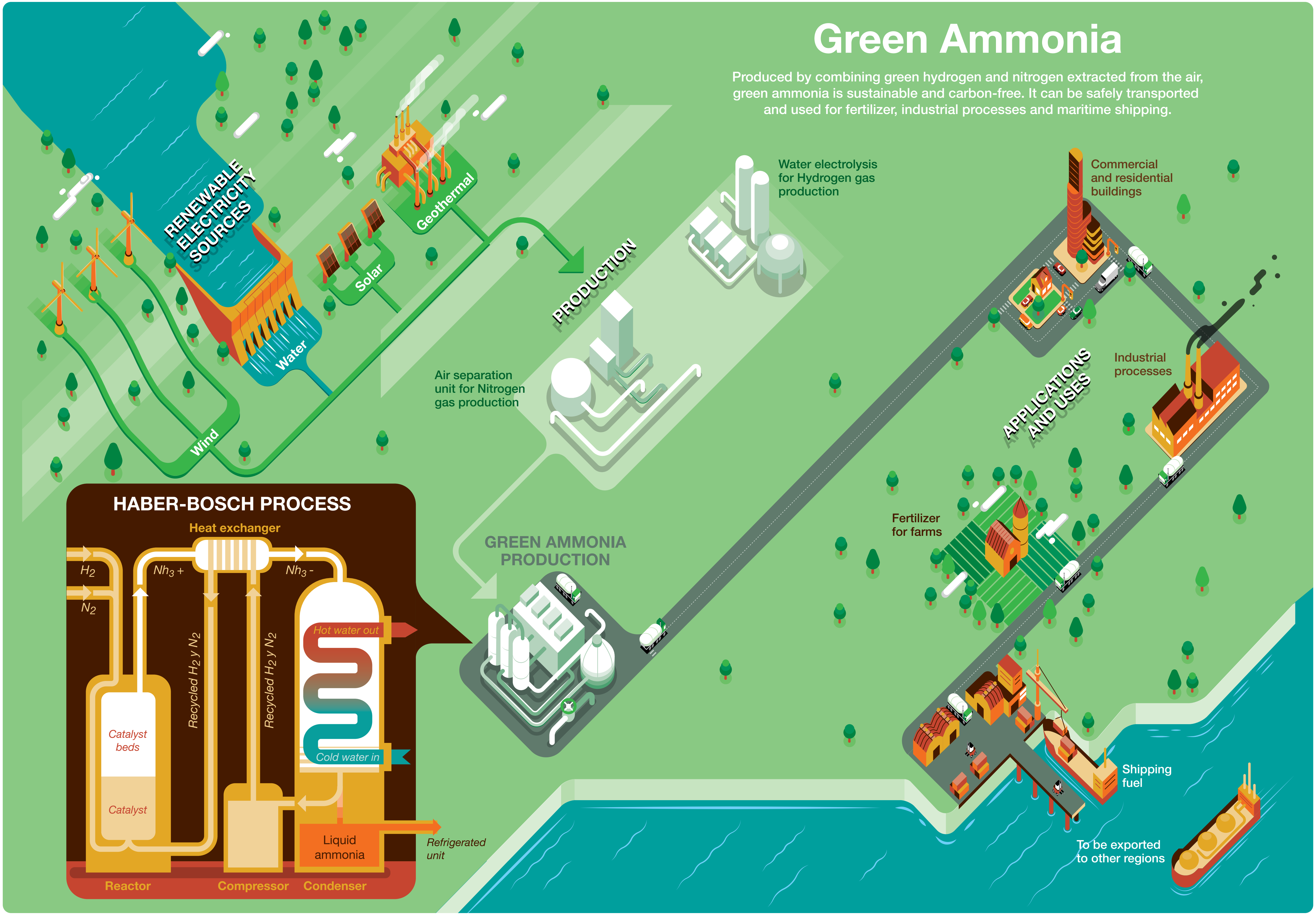
Global **hydrogen demand** is forecast to **more than double** by 2030.

Source: IEA

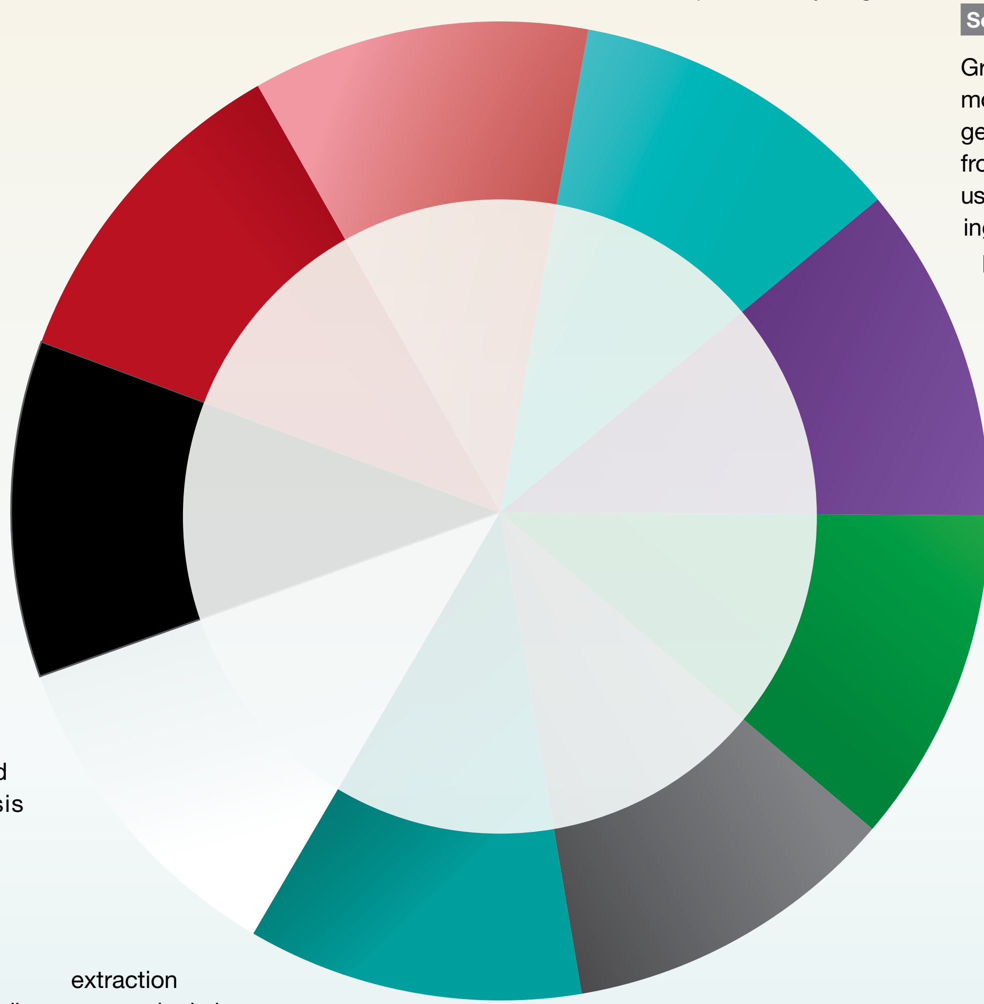


Green Ammonia

Produced by combining green hydrogen and nitrogen extracted from the air, green ammonia is sustainable and carbon-free. It can be safely transported and used for fertilizer, industrial processes and maritime shipping.



The Colors of Hydrogen



Blue

Source: Natural Gas

Blue hydrogen is derived from natural gas, however, most of the CO_2 emitted during the process is captured and stored underground (carbon sequestration) or is extracted as a solid and is able to be reused. When considering the CO_2 emissions of 'blue' hydrogen, it is important to acknowledge the potential methane leakage upstream of the hydrogen production plant. With this in mind, the term 'blue hydrogen' 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 carbon footprint associated to its production.

Pink / Red / Purple

Source: Nuclear

Pink, red, and purple hydrogen are all generated by splitting water using electricity generated from nuclear power plants. Pink hydrogen is generated through the electrolysis of water, decomposing water into oxygen and hydrogen. Alternatively, red hydrogen is produced through the high-temperature catalytic splitting of water, with the chemicals used in the process reused in a closed-loop production cycle.Finally, purple hydrogen is made though using nuclear power and heat through combined chemo-thermal electrolysis splitting of water.

White

Source: Natural

White hydrogen refers to naturally occurring hydrogen in its most natural state. It is generated by a natural process inside the Earth's crust, with projects already being set up to produce white hydrogen in industrial quantities.Its extraction process is similar to natural gas, requiring drilling deep underground to tap into naturally occurring hydrogen wells. It is considered by some to be a cheaper alternative to green hydrogen.

Black / Brown

Source: Coal

Black and brown hydrogen is produced from coal, with the colours referring to the type of bituminous (black) and lignite (brown) coal used in the production process. Hydrogen is produced through the gasification of coal. This is an extremely polluting process, with CO_2 and carbon monoxide produced as by-products and released into the atmosphere.

Grey

Source: Fossil Fuels

Grey hydrogen is currently the most common method of hydrogen production. It is produced from fossil fuel and commonly uses the steam methane reforming (SMR) method. During this process, CO_2 is produced and released to the atmosphere. While not as environmentally damaging as black or brown hydrogen, this process produces far more emissions than green hydrogen.

Turquoise

Source: Methane

Turquoise hydrogen is extracted by using thermal splitting of methane via methane pyrolysis. This process is a relatively new method of hydrogen production and is still at the experimental stage. This form of production results in the removal of solid carbon, rather than CO_2 emissions. This solid carbon can be used in the production of car tires, plastics and batteries, and is considered a critical raw material. The process uses natural gas as a feedstock, and if the energy for splitting the methane comes from renewable sources, the process is close to carbon neutral.

Green

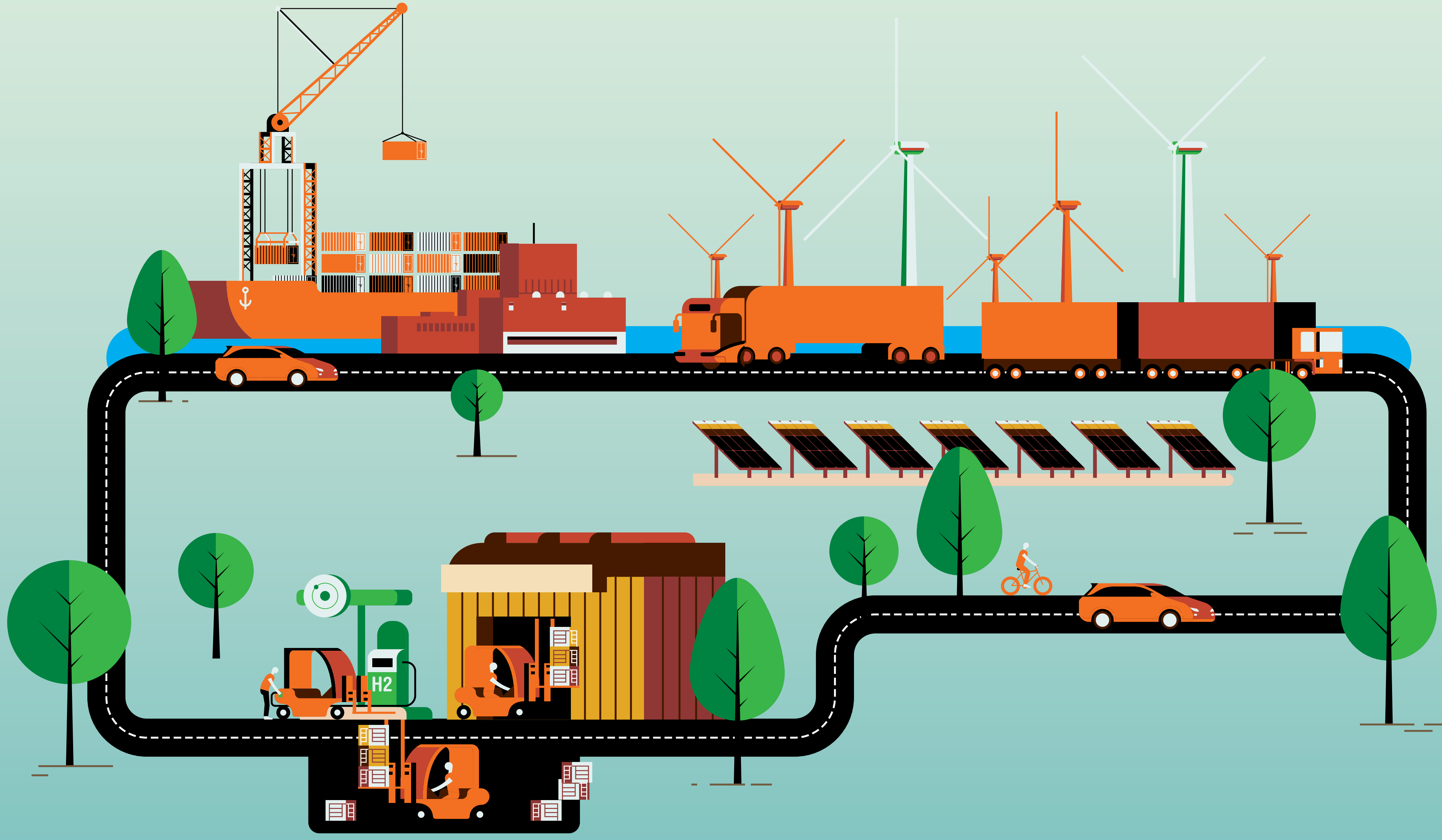
Source: Renewables

Green hydrogen is mainly produced by splitting water – also know as water electrolysis – using electricity generated from renewable energy sources.

There are no CO_2 emissions associated with this type of 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.

Although 'green' hydrogen often refers to 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, or bio-waste. These methods are less common than water electrolysis but also result in either very low or zero emissions.

Case Studies



SPERA Hydrogen™

Application:
End-to-End Global Hydrogen Value Chain

Dimensioning:
100ktpa-H2 by 2026
300ktpa-H2 by 2030

SPERA Hydrogen™ Ready for Commercialization

Preliminary feasibility study on importing hydrogen at the Port of Rotterdam successfully completed in March 2022.

Mitsubishi Corporation, Chiyoda Corporation and Koole Terminals have studied the technical and commercial feasibility of an end-to-end global hydrogen value chain utilizing SPERA Hydrogen™ technology[1] to conclude that methylcyclohexane (MCH)/toluene pathway for commercial-scale hydrogen import at Rotterdam could be viable.

In May 2022, the European Commission released the REPowerEU Plan including the target of 10 million tons of local hydrogen production and import of 10 million tons of hydrogen by 2030. Considering the double urgency to transform Europe's energy system to lessen the dependence on fossil fuels and reduce GHG emissions to combat climate change, the immediate introduction of hydrogen into society is crucial.

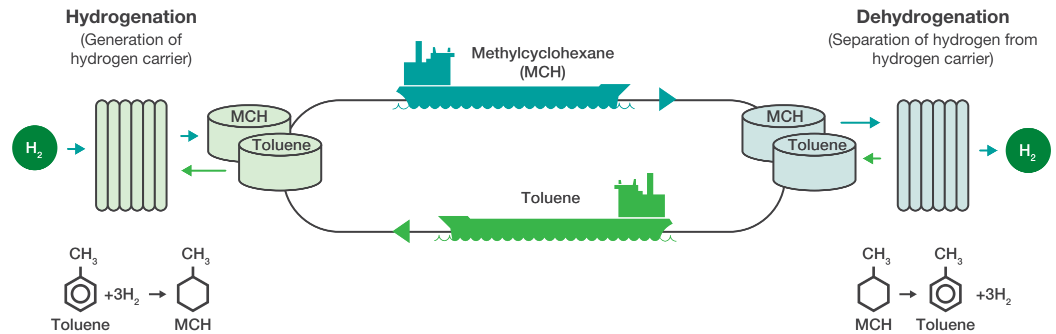
In 2020, Mitsubishi Corporation and Chiyoda Corporation, with its partners in Japan, demonstrated the first international hydrogen supply chain utilizing SPERA Hydrogen™ between the Nation of Brunei and Japan. Based on this track record, technical feasibility of SPERA Hydrogen™ was duly proved, thus has a Technology Readiness Level of 7. SPERA Hydrogen™ is expected to play an important role in the realization of commercial-scale hydrogen supply chains around the world.

Mitsubishi Corporation CHIYODA CORPORATION koole TERMINALS

01

01 Dehydrogenation plant reaction area.
Source: Advanced Hydrogen Energy Chain Association for Technology Development

Liquid Organic Hydrogen Carrier (LOHC) with MCH



(Based on data provided by Chiyoda Corporation.)

Koole Terminals, whose extensive experience with handling special liquid products, will play a key role to materialize the hydrogen import project at Port of Rotterdam by providing land and existing port facilities. Since SPERA Hydrogen™ utilizes common chemical materials, existing oil and gas infrastructures could be repurposed without significant modifications, thus initial investment could be optimized.

The parties intend to move forward to the next phase – a detailed feasibility study and pre-FEED – during 2022 under the collaboration with potential hydrogen offtakers in the Netherlands and/or Germany. Commercial operation is expected to be achieved in 2026-2027. We will be ready to deliver. If you want to discuss further, contact: ryo.kogure@mitsubishicorp.com ●

[1] **SPERA Hydrogen™** is a technology to transport and store hydrogen utilizing Methylcyclohexane (MCH), which is Liquid Organic Hydrogen Carrier (LOHCs.) LOHC technologies allow hydrogen to be safely transported in chemical tankers at ambient temperature and pressure.

GASCADE's Offshore Hydrogen Transport Infrastructure

INSIGHTS WITH DR. CHRISTOPH VON DEM BUSSCHE
MANAGING DIRECTOR OF GASCADE

"GASCADE will be one of the first companies to implement offshore hydrogen transport infrastructure."

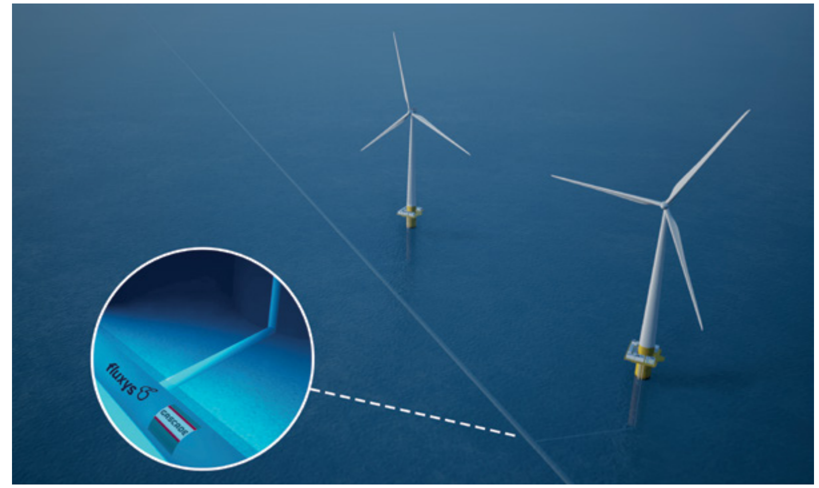
For many years, GASCADE provided transport capacities for fossil fuels. Why is GASCADE now also strongly committed to hydrogen?

The energy industry is undergoing a radical change. In addition to diversification from fossil energy sources, German and European energy policy is focusing on a rapid switch to climate-friendly energy sources. This energy must be transported to industry and consumers.

A well-connected hydrogen infrastructure plays therefore a central role in the ramp-up of a national and European hydrogen market.

We have been transporting energy at the highest technical level for years. That's why the development and realization of hydrogen-related infrastructure projects is a logical, important, and a necessary step for us to make our contribution to the energy market of tomorrow.

01 Aquaventus.
Source: GASCADE



01

What expertise does GASCADE bring to the table?

Energy must be taken to where it is needed. It is therefore obvious that the transmission system operators with their interconnected pipeline networks can and must make a decisive contribution. GASCADE has many years of expertise in the construction and operation of large-scale gas transport infrastructure. We also see an opportunity to increasingly expand our know-how as a competent partner for energy infrastructure in a decarbonizing economy, so that we can then bring it back into projects.

You are involved in AquaDuctus hydrogen infrastructure project. What exactly is happening there?

GASCADE is pursuing the goal of gearing its transmission network to the transport of hydrogen in the medium term - whether it is imports, hydrogen produced onshore or offshore. The offshore pipeline project for green hydrogen "AquaDuctus" in the North Sea represents one of the most promising and forward-looking projects (for more information visit www.gascade.de/en/hydrogen).

What are the chances of success for the implementation?

We are very optimistic. The project has the prospect of government funding and is characterized by its enormous scalability and potential to promote conversions of existing GASCADE natural gas pipelines. If everything goes according to plan, GASCADE will be one of the first companies to implement hydrogen infrastructure projects in Germany in three years, thus occupying a strategically important position in the future energy market.

About GASCADE

GASCADE Gastransport GmbH independently operates a gas pipeline network throughout Germany. Based in Kassel, the company offers its customers state-of-the-art and competitive transport services for hydrogen and other gases in the heart of Europe via the company's own high-pressure pipeline network, which is around 3,200 kilometres long. GASCADE is pursuing the goal of converting its transmission network to the transport of hydrogen and is therefore active in several specific onshore and offshore hydrogen projects.

Green Transport

Rail's fundamental role in the green mobility transition.

Governments can act to decarbonise mobility by pushing a modal shift towards rail. Yet they must also support the replacement of diesel train fleets with zero-emission solutions.

The three main options for this are track electrification, batteries and hydrogen fuel cells.

Rail uniquely suited for hydrogen

With large, predictable, localised and enduring demand, rail mission profiles are uniquely suited for the use of hydrogen technology. Hydrogen fuel cells bring high performance in terms of range, with an Alstom Coradia iLint owned by LNVG recently setting a distance record by travelling 1,175 km on a single tank of hydrogen. The competitiveness of hydrogen in rail will only increase as there are more large-scale deployments of hydrogen ecosystems.

Alstom is also a pioneer in the use of hydrogen in rail designing, developing and manufacturing the first 100% hydrogen train, the Coradia iLint regional train, which entered commercial service in Germany in 2018. Alstom is now extending hydrogen technology to other types of passenger trains and to freight locomotives, both through new build and refurbishment, and promoting synergies with other applications such as maritime and stationary.

Developing a hydrogen ecosystem

The rail sector is leading the transition to sustainable mobility, successfully implementing innovations in digitalization, safety, reliability and carbon reduction. Rail investments in hydrogen will stimulate further innovations that can spur the development of a viable and shared hydrogen ecosystem.

A recent positive advance is the European Commission's approval of funding support for 41 integrated hydrogen projects in 15 member states (IPCEI Hy2Tech), including Alstom as the only major rail participant. Progress is not limited to Europe, with Alstom recently signing an MoU with Saudi Railway Company to develop hydrogen train solutions adapted for Saudi Arabia.

Further support from public authorities, by accelerating the implementation of regulatory frameworks compatible with carbon neutrality and introducing more supportive policies for rail players and green hydrogen production will ensure hydrogen in rail is a strong contributor to achieving carbon neutrality by 2050. ●

ALSTOM
• mobility by nature •

01

01 Alstom Coradia iLint hydrogen train in Germany. **Source:** Alstom/Sabrina Adeline Nagel

700 t CO_2 avoided **per year** for **each train** with green hydrogen

Equivalent to the emissions of **400 cars**

An Alternative Hydrogen Production for the Future

INSIGHTS WITH PHILIPPE HAFFNER
CO-FOUNDER AND CEO OF HAFFNER ENERGY

Can biomass thermolysis be the future of sustainable hydrogen production?

Thanks to its unique 'carbon negative' hydrogen production process Hynoca®, Haffner Energy's technology produces renewable hydrogen by thermolysis of sustainable biomass. A viable, competitive and flexible alternative, which could prove to be a key asset for combining Energy Independence and Carbon Neutrality for Europe.

How can production of hydrogen from biomass be competitive?

The unfortunate events in Ukraine highlighted what distinguishes our process from other hydrogen production technologies. First, its stable cost. Since February, energy prices soared, but we have seen almost no increase in our costs because our process is unrelated to the cost of fossil fuels and electricity. Biomass allows the production of hydrogen at very competitive cost, between €1.5/kg and €3/kg. Our process gives value to sustainable biomass, producing 'green' hydrogen on demand, without intermittency, and provides a complementary solution for decarbonization thanks to biochar co-production.

Does your process achieve a negative carbon footprint?

Biochar, a co-product containing carbon generated during the biomass thermolysis, is the foundation of our 'carbon negative' technology. For every kg of hydrogen produced in a Hynoca® station, 5.5 kg biochar is co-produced, allowing the sequestration of 12 kg of net CO_2. A perennial and stable carbon sink, biochar is a quality fertilizer, especially for acidic soils and draining soils. COP 26, the IPCC and the European Union described biochar as the most mature method for capturing CO_2.

01

01 Our first industrial demonstrator in Strasbourg for the R-HYNOCA project. The unit is sized to produce 700 kg of renewable hydrogen per day.
Source: Haffner Energy

> **A vehicle powered by hydrogen produced by Hynoca® is not only carbon neutral, but it also offsets the emissions equivalent to 1.5 equivalent diesel vehicles.**

How does your process fit into a local and circular dynamic?

Biochar allows the recovery of local biomass. By offering an economic outlet to a resource derived from agricultural or forestry waste, unexploited and free from competition of use, our process stimulates the circular economy by creating jobs and value; energy production is relocated to its place of consumption.

Does our project provide a complementary decarbonization solution for industry and mobility players?

Hydrogen is the flagship of the Energy Transition, and must be surrounded by a fleet of solutions to ensure complementary functions such as the five-in-one solution.

We are committed to becoming major players of the decarbonization and energy transition, by providing massive and immediate solutions to produce competitive decarbonized hydrogen. ●

Biomatch,
Ethical and Sustainable Biomass

As part of its IPO, Haffner Energy created Biomatch, a service that makes it possible to source, recommend and/or provide certified sustainable biomass to its customers to support them throughout the biomass and biochar supply chain.

Speeding Up Clean Ammonia in Shipping

For a speedy transition, partnerships are key.

The energy transition in shipping is driven by the climate crisis. The shipping industry is a core part of global supply chains but the market for refuelling ships is still dominated by fossil fuels, making emissions from this sector a challenge for decarbonisation.

The transition towards clean fuels in the shipping industry needs to increase for it to play a role in meeting global climate targets and to act as a catalyst for decarbonisation in other sectors, for example in the realm of technology development and hydrogen and renewable energy markets. The demand for clean fuels such as clean ammonia will support the investment required to increase their scale of production, which will also encourage investment in the mid- and down-stream legs of the supply chain - which is fundamental to achieve the transition.

Today, Yara Clean Ammonia (YCA), a company capitalising on the existing global network of assets and customers of Yara International, is working to decarbonise its ammonia production plants as well as grow and build midstream and downstream operations to deliver clean ammonia to ships.

Yara Clean Ammonia

01

02

01 Ammonia Barge Design.
Source: Azane Fuel Solutions

02 Yara Kara, ammonia tanker.
Source: Yara Clean Ammonia

Value chain partnerships:

The energy transition involves partnerships on the supply and the demand side. Producers and distributors like YCA will be involved in both.

On the supply side, the current shipping industry's global refuelling business is fragmented. The transition will involve partnerships to reduce the large risk profile of these investments and seek efficiencies in the supply chain driven by cost considerations and factors such as safety, technology, and business strategy considerations. An example is the Azane Bunkering Solution recently launched in Norway.

On the demand side, joint studies and collaborations with charterers and ship owners are fundamental to increase knowledge and the understanding of ammonia, its characteristics and risks, what it involves from a handling perspective to increase confidence that the fuel can be made available when and where it is needed. This can be achieved via joint initiatives but must also be the objective of ongoing business discussions. YCA is doing this by sharing information with stakeholders on activities related to its trade and shipping operations, for example.

Creating an enabling environment:

Partnerships between private sector players pursuing investments in the clean ammonia space are fundamental, yet these entities are faced with the same core challenge of uncertainties in demand. This barrier will be reduced to a great extent when the price of clean fuel and costs of operating ammonia-propelled ships compete with the price of fossil fuels.

As argued by the 2021 Green Ammonia Volumes analysis report published by Maritime Clean Tech and DNV, scenarios where this can be mitigated and reduced include policies and incentives. For example, blue ammonia with high capture rates (90%+) is considered a good alternative since it is expected to be cost competitive with grey ammonia with CO_2-taxation between 2030-2035. Green ammonia, which has high capex costs as well as technology efficiency issues and faces competition for renewable electricity in grid-connected locations, will require support in the first years. However, this will change in the longer term as total plant capex comes down and efficiencies and load factors increase as the industry develops but will take time to become cost competitive without subsidies.

YCA and others are pushing to develop the market for ammonia as a clean fuel for the shipping industry by combining lessons-learned with forward-looking initiatives and partnerships to develop new solutions for the sector. ●

Renewable Hydrogen at the Heart of ENGIE's Strategy

INSIGHTS WITH VALÉRIE RUIZ DOMINGO
GROUP HYDROGEN VICE PRESIDENT

Hydrogen is a decarbonization accelerator and a growth driver for ENGIE.

To achieve a carbon-neutral future, the Group relies on a diversified energy mix and has clear objectives for the development of hydrogen production, transport and storage capacities. One of the most ambitious roadmaps, announced by CEO Catherine MacGregor in May 2021, is in line with ENGIE's front-runner position on renewable hydrogen.

What is the Group's hydrogen strategy?

The hydrogen we are talking about at ENGIE is renewable hydrogen, knowing that low-carbon hydrogen will – with no doubt – be necessary temporarily, to accelerate the market. It fits naturally and consistently into ENGIE's overall strategy, with concrete projects across the entire hydrogen value chain, from design to operation of facilities. Our conviction is that hydrogen is a major energy vector to move towards a carbon-neutral economy, in addition to renewable energies. At ENGIE, we are very present in electricity, particularly renewable, and historically in gas – which will become green. It is a link between infrastructure, renewable energies and the decarbonization of our customers. Our ambition is to support industrial players and heavy mobility such as road, rail, sea and air transport to achieve their carbon neutrality objectives. By 2030, we plan to develop a green hydrogen production capacity of 4 GW, have 700 km of dedicated hydrogen networks and 1 TWh of storage capacity, and manage more than 100 refueling stations.

01

02

01 HyNetherlands Project H_2 and methanol. **Source:** Engie x OCI x EEW

02 Hygo Infrastructure Brittany. **Source:** Engie x Michelin

Where does ENGIE stand today?

Five years ago, we were pioneers and we naturally focused on pilot projects and their scaling up. We are now targeting large-scale projects, focusing on industrial areas where ENGIE is already present. I am thinking, for example, of the HyNetherlands project, in Holland, which is a good illustration of our ambition to decarbonize industry in a complex port ecosystem. The project aims to develop, build and operate one of the first large-scale industrial value chains in Europe for the production of e-methanol, combining renewable hydrogen and biogenic CO_2. I am also thinking of many mobility projects at French regional level, such as HYGO in Brittany, with Michelin, or Hyport in Toulouse.

As for infrastructure, we are on pilot projects, for hydrogen transport and storage using existing gas infrastructure. The Storengy HyPSTER demonstrator will, from 2023, allow to test the production and storage of hydrogen in a salt cavern, on the Etrez site, also in France. The MosaHyc project, a French-German-Luxembourg transborder project, led by GRTGaz, targets the conversion of 70km of existing network and the construction of 30km of new transport hydrogen pipes.

Internationally, we are present in both industry and heavy mobility, as we produce hydrogen to fuel Anglo-American's giant trucks in the world's largest platinum mine, in Mogalakwena in South Africa. This solution to decarbonize the mining industry is replicable in other geographies and with other customers and that is what we are looking at in Chile in particular.

What do you need to accelerate and scale up in Europe?

At European level, more than 20 billion euros are planned to develop the hydrogen sector. The French government's 2030 Recovery Plan provides for an envelope of around 10 billion euros, which does not yet include infrastructure. Storage, in particular, will provide flexibility to compensate for the intermittency of renewables.

We are on the right track; however, the market requires a stable European regulatory system as well as a simplification of the processes which will accelerate the effective allocation of subsidies (Innovation Fund, IPCEI). This will support the market acceleration needed to achieve industrial scale and therefore reduce production costs.

Green hydrogen will need to be competitive in order to replace grey hydrogen. This requires having renewable energy available and at low cost. Customer engagement will also be key to project development and investment decisions. ENGIE is fully mobilized to create future hydrogen ecosystems with its public and private stakeholders. ●

France Is Ready to Lead the Battle Against Climate Change

INSIGHTS WITH PHILIPPE BOUCLY
PRESIDENT, FRANCE HYDROGÈNE

Hydrogen is a key pillar for France and Europe to meet decarbonisation targets and enhance energy security.

Like other countries worldwide, France has published an ambitious national strategy for the development of renewable and low-carbon hydrogen. The aim is to reduce greenhouse gas emissions by 6 million tons of CO_2 annually in 2030.

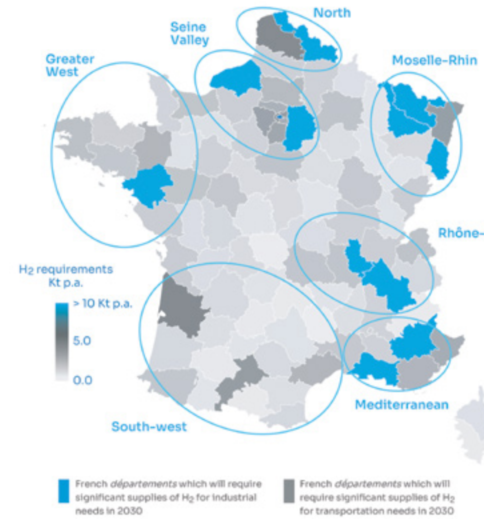
Backed by €9 billion from the French government[1] one of the strategy's main aims is to create a competitive hydrogen production sector based on electrolysis. With a goal of 6.5 GW of installed electrolyzer capacity by 2030, this will enable France to produce clean hydrogen on a large scale.

Producing clean hydrogen in France

The annual consumption of renewable or low-carbon hydrogen in France is set to reach between 680,000 and 1,090,000 tons by 2030 in two different scenarios[2] to strongly decarbonize industry and heavy-duty transportation sectors and to a lesser degree, the energy sector.

But to achieve ambitious decarbonization targets at the French and European level by 2050, it is vital to apply technological neutrality and to recognize the necessary role of low-carbon hydrogen, especially that produced using nuclear power, alongside renewable hydrogen (issued from solar or wind power and biomass).

France Hydrogène
Engagée pour la transition écologique



With a strong industrial hydrogen sector

An industry is being structured at national scale. As a result, France Hydrogène brings together more than 450 stakeholders active in the field of hydrogen covering the entire value chain, from manufacturing of equipment, production of hydrogen or derivatives, to the main use areas for hydrogen.

French industrial stakeholders with an international dimension and a skilled workforce, as well as companies and start-ups working closely with research centers to develop innovative products and services, demonstrate a strong industrial dynamism.

French companies with the support of the French government invest in the construction of gigafactories to manufacture electrolysers, fuel cells, tanks and vehicles with a twofold objective: both to drive down costs and to make France and the European Union self-sufficient in manufacturing key equipment.

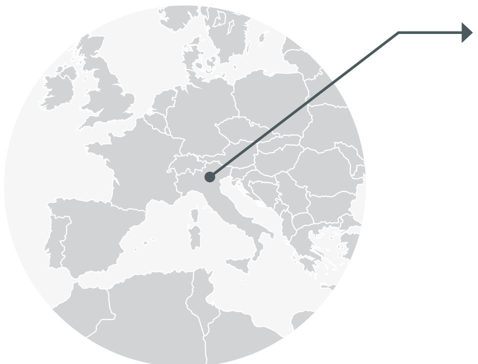
The first ten industrial projects have been launched in France and approved by the European Commission involving public and private investment of €2.1 billion and €3.2 billion respectively – representing the creation of 5,200 direct jobs.

France is ready to be a leader in hydrogen and must strive to take advantage of its full potential. However, the French strategy, as ambitious as it is, will not succeed without cooperation at all levels involving countries across Europe and the rest of the world, between governmental authorities and the private sector, and manufacturers and research centers.

France and Europe must move away from the reliance on fossil fuels faster. The scale and the speed at which this challenge must be met – in a time-frame of less than thirty years – demands a collective response. In particular, hydrogen interconnections between European countries will help drive cooperation in pursuit of our collective decarbonization goals: the French hydrogen industry would support such an initiative as long as it will be used to transport hydrogen, not hydrocarbons. We need to pull all levers and focus all our efforts on a single goal and start viewing varied national strategies as complementing each other in the drive to reach net zero emissions by 2050. All forces must come together to decarbonize European economy by developing all uses of hydrogen, and to make the energy transition an ecological and industrial success. France is ready! ●

1 The National Hydrogen Strategy received 7.2 billion euros in funding, along with an additional 1.9 billion euros as part of the France 2030 investment plan.

2 France Hydrogène conducted a study on the deployment of renewable or low-carbon hydrogen in France by 2030. Given the current and potential hydrogen demand as well as the planned projects, it appears that hydrogen will develop within seven major hydrogen clusters including the main ports, the valleys as well as the transborder areas with Spain and with Germany. These major consumption areas will concentrate nearly 85% of hydrogen demand by 2030. Deployment of hydrogen refueling stations along the main motorways and in urban nodes (TEN-T) will cover the rest of territory.



Headquarter:
Milan, Italy

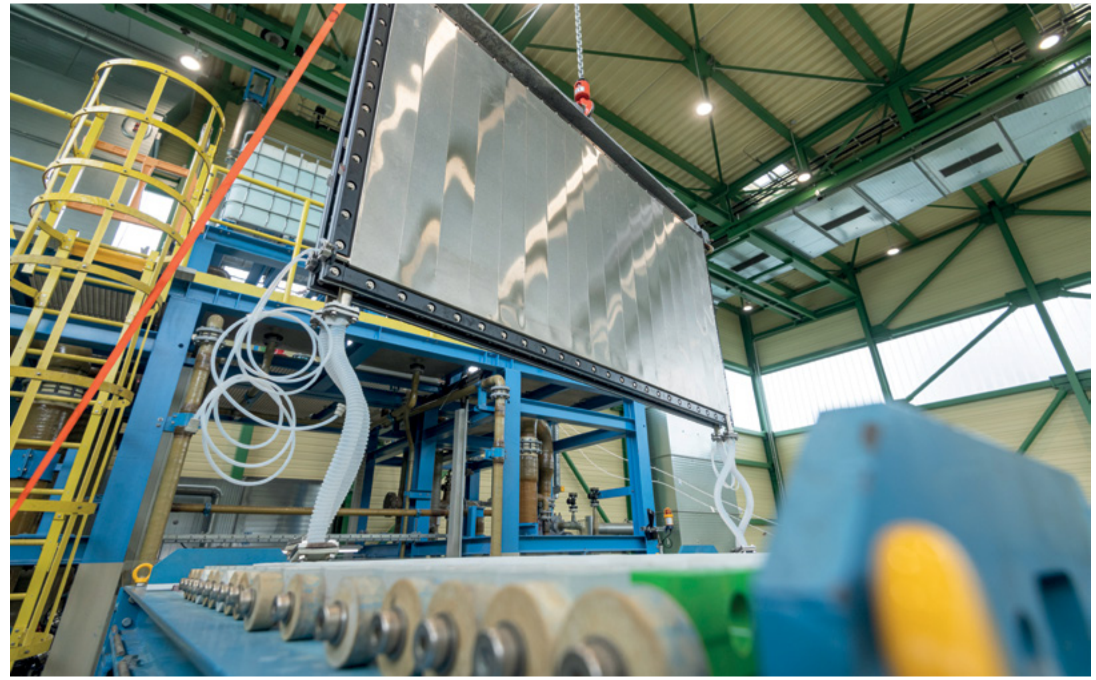
Sustainable Electrochemical Solutions for the Energy Transition

Industrie De Nora is an Italian multinational specialized in electrochemistry and sustainable technologies, playing a key role in the industrial green hydrogen production chain.

Leveraging 100 years of experience with electrodes and cells with global players on large scale projects worldwide, the company has a portfolio of products and systems to optimize the energy efficiency of key industrial electrochemical processes and a range of products and solutions for water treatment.

Globally, Industrie De Nora is the world's largest supplier of activated electrodes – serving a broad portfolio of customers operating in the fields of chlorine and caustic soda production, components for electronics, and non-ferrous metal refining. Thanks to its well-established electrochemical knowledge, proven manufacturing capability, and well-established supply chain, the company has developed and qualified a portfolio of electrodes, components, and systems for the production of green hydrogen, a critical element for the energy transition. For De Nora, the energy transition via green hydrogen is a natural evolution of its core electrode technology business.

De Nora already has a manufacturing capacity for green hydrogen coatings of approximately 2 GW per year, which will be further increased in the coming years. The company holds a stake of about 34% in the thyssenkrupp Nucera joint venture, a world-leading engineering company in chlor-alkali, hydrochloric acid and water electrolysis plants. Within the framework of Important Projects of Common European Interest (IPCEI), De Nora has been selected to build up a Gigafactory for production of components and systems for water electrolysis and fuel cells. ●



01

02

01 Alkaline water electrolsysis cells manufacturing for Thyssenkrupp Nucera joint venture. **Source:** De Nora

02 Coating processes tailored to meet customer needs while always keeping health and safety first. **Source:** De Nora

Snam at the Forefront of Mediterranean Hydrogen

INSIGHTS WITH PIERO ERCOLI
SENIOR VICE PRESIDENT OF THE DECARBONIZATION PROJECTS UNIT AT SNAM

Snam's decarbonization plans targeting a net-zero economy.

Snam's Decarbonization Projects business unit was set up to support the company in achieving these targets and with the aim of defining the energy transition strategy towards a decarbonized and sustainable economy.

What will be the main focus of the new Decarbonisation Projects unit going forward? How do you see the role of hydrogen in the EU energy system?

We are convinced that hydrogen and its applications will play a central role in the EU energy system, as well as CCS&U (Carbon Capture, Storage and Utilization) solutions that will support the energy transition in the short/mid-term. Our main objective and challenge in focusing on hydrogen stands in the design of the hydrogen market also by leveraging on our infrastructure, in a way to support its development at lowest cost, thereby guaranteeing the efficiency of the system as well as the European security of supply.

Key projects are now under development, with the aim of demonstrating the feasibility of Hydrogen Valleys as a building block of a wider and more integrated hydrogen ecosystem in Italy, from a technical and economic point of view. Moreover, hydrogen asset readiness and the R&D activities carried out by our unit will also play a crucial role in achieving these objectives.

What are the main opportunities and challenges regarding the hydrogen economy?

Snam is actively contributing to modelling and designing the Italian and European hydrogen framework. Hydrogen's key role in achieving decarbonization targets has been clearly defined and shared by the international energy community, nevertheless there is still an important set of opportunities to be explored and challenges to be addressed.

As infrastructure operators, we are working to ensure we are ready for playing our central role in hydrogen transport across Italy and Europe, from production hubs to consumers. This can be done by using existing infrastructure, through repurposing projects, and by building new dedicated pipelines. One of the main challenges is to guarantee the accessibility of low-cost green hydrogen along the whole national and international framework: the optimization of the production in strategic hubs will be a crucial focus for the development of the entire hydrogen supply chain.

In its REPowerEU plan, the EU Commission envisages the creation of a hydrogen corridor across the Mediterranean. How will this project unfold and what role can Snam play?

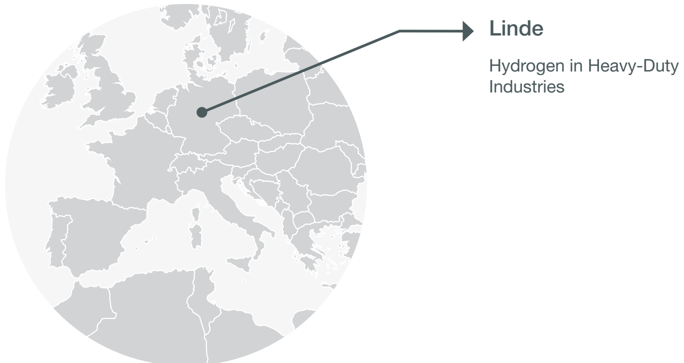
North Africa is well placed to become a key area for large scale green hydrogen production thanks to its huge natural potential for low-cost renewable electricity. Moreover, its geographical position on the Mediterranean allows it to project itself as a potential supplier for the countries in Central and Northern Europe, characterized by growing demand going forward.

The EU Commission is a strong supporter of hydrogen role as a "game changer for Europe" – as stressed by the President of the EU Commission, Ursula von der Leyen in her speech at the EU State of the Union Address last September – and is willing to create a clean hydrogen market by bridging the two shores of the Mediterranean. The REPowerEU Plan envisages 10 million tonnes of domestic renewable hydrogen production as well as 10 million tonnes of renewable hydrogen imports by 2030.

Gas infrastructure can play a crucial role in facilitating this development. Leveraging on the existing gas transmission network North Africa and Southern Europe, with relatively low investment requirements for repurposing, it will be possible to bring green hydrogen to other countries. Snam's pipeline network, extending for about 33,000 km throughout Italy, is already able to export gas to other markets thanks to Snam's investment in the reverse flow technology.

We have completed a thorough assessment of our assets' readiness to carry hydrogen and we are among the pioneers in the 'European Hydrogen Backbone' initiative, which aims at fostering the development of a hydrogen-ready grid connecting 28 European countries by 2040. ●

> Snam is Italy's Transmission System Operator and the biggest natural gas infrastructure player in Europe by km of pipelines and storage capacity.
>
> We are firmly committed to the energy transition with a net-zero target by 2040, and we aim at supporting the energy, industry and mobility sectors to reach the ambitious decarbonization targets set out by the EU.



Hydrogen Hope in the Hard-To-Abate Industries

How hydrogen expertise can support customers in heavy industry sectors along their decarbonization journey.

Deep decarbonization in sectors such as steel, maritime, aviation, and ammonia is easier said than done. Such sectors are known as "hard-to-abate" due to either a lack of technology to date or prohibitive costs – or both. But while these challenges cannot be solved overnight, there are strategies that can be applied today to get the decarbonization journey started.

A pioneering past and future in hydrogen

"Linde has been in the hydrogen business for many decades," explains David Burns, VP Linde Clean Energy, "Our expertise throughout the value chain is unrivalled and we can draw on it to help accelerate the energy transition. We're hydrogen-ready now!"

Given that hydrogen has the potential to avoid 80 gigatons (GT) of cumulative CO_2 emissions from now through 2050, fuel switching – swapping out high carbon containing fuels for low carbon or green hydrogen in industrial processes – is clearly the end goal. But it's not necessarily the starting point. Unfortunately, it's not as simple as "green means go".

01

Steelmaking: Where hope hangs on hydrogen

Coupling hydrogen know-how with industry-specific knowledge based on years of "traditional" business with industrial players is paramount for success – as David Burns explains: "For Linde, steel is already a very important business. We're very familiar with it and we're well connected with the major players. So as customers look to decarbonize, we're in a good position to step in and support."

When steel is produced using the conventional blast furnace-based route, it emits about two tons of CO_2 for every ton of steel, making it one of the worst offenders when it comes to emissions: 8% of global annual emissions to be precise. For an industry in which fossil fuels are baked into the production processes, all hope for decarbonization hangs on hydrogen.

"The viability of green hydrogen is largely dependent on having a continuous and viable supply of green power. That's what will determine the pace of uptake," explains Joachim von Scheele, Director Metals & Glass at Linde. But in many areas, there are near-term decarbonizing steps that can be taken today to prepare for a switch to hydrogen in the future. "Maximizing the energy efficiency of the existing processes is where we always start with our customers," explains von Scheele. The more energy efficient a production process, the less fuel is required. That brings an immediate benefit of reduced CO_2 emissions from the current fuel, but also the future benefit of reduced spend on hydrogen. When it makes sense, customers might switch to hydrogen one process at a time. "It's about growing over time and adapting to customers' needs," says von Scheele.

In the world's first full-scale trial conducted with steelmaker Ovako in March 2020, Linde used green hydrogen together with Flameless Oxyfuel to heat steel before rolling. Executed in a full production environment, it proved that hydrogen works as a viable replacement to propane as burner fuel,

02

01 Linde has a long history of hydrogen production, processing, distribution and storage. It is the largest producer of liquid hydrogen in the world. **Source:** Linde

02 Linde is collaborating with industry partners to explore the feasibility of airport hydrogen HUBs, where H2 will be used for powering aircraft ground services, operational equipment and refueling systems. **Source:** Linde

03 Every year, ammonia production generates 500 million tons of carbon dioxide, accounting for roughly 2% of overall carbon emissions. Using low-carbon hydrogen in its production will dramatically reduce emissions. **Source:** Linde

03

with no loss of performance. “The problem when it comes to scaling this is simply cost,” explains von Scheele. In the meantime, a range of proven technologies can already reduce emissions – again, through improved efficiency. “When applied to steel, Hot Oxygen Technology and Flameless Oxyfuel solutions like OXYGON® and REBOX® HLL could cut carbon emissions from some processes by up to 60%,” von Scheele explains.

Sustainable Aviation: How hydrogen is taking off

A promising pathway to decarbonizing aviation is to fuel today’s planes with synthetically produced, cleaner alternatives to kerosene – which is refined from fossil fuel feedstock such as crude oil. One production method of a more sustainable aviation fuel (SAF) employs a Power to Liquid (PTL) process, which relies on the supply of a sustainable carbon feedstock and the production of green hydrogen through electrolysis using renewable energy. The carbon and hydrogen are converted to synthesis gas, a mixture of carbon monoxide and hydrogen, which in turn is converted to longer chain hydrocarbons for the production of jet fuel or SAF via the Fischer-Tropsch Process.

“The majority of SAF fueling today’s planes comes from cooking oils and animal fats, or biomass, such as sugarcane and corn grain. However, such feedstocks are grown on arable land, which could potentially be used to grow food, so feedstock limitation becomes a challenge,” says Kate Macfarlane, Sr. Business Development Manager, Clean Energy at Linde. “With the EU and its member states establishing increasingly tightening quotas for SAF blending, PtL kerosene is acknowledged to be an important piece of the decarbonizing strategy going forward.”

Efforts to decarbonize the aviation industry are not limited to reducing emissions from flights. Planes take off and land from the complex supportive ecosystems we know as airports. The facilities themselves need heating and lighting, passenger buses and other airport vehicles need fueled, and energy is needed for all of this. These hubs of activity could become hydrogen hubs – offering a way to achieve climate-neutral operations across the entire value chain.

Ammonia: Kick-starting decarbonization with hydrogen

Ammonia production is a heavy contributor to harmful emissions. Every year, roughly 190 million tons of ammonia are produced globally – mostly for agricultural fertilizers. Using green hydrogen to produce ammonia is therefore a promising path toward a more sustainable future.

As with other sectors, scalability of green ammonia production will prove to be a challenge in the coming years. Blue hydrogen – generated when carbon capture technologies are applied to conventional hydrogen production methods – is an important steppingstone on the path to zero emissions. This already effective solution allows for the necessary frameworks and infrastructures to be developed while green hydrogen production reaches the necessary scale.

“Clean hydrogen is the key ingredient when it comes to green steel, sustainable aviation fuel, alternative drop-in fuels for shipping and of course, green ammonia – which itself can be used as a zero-carbon fuel or as an energy vector for clean power,” says Burns. “As a global leader, we can offer our expertise in production, distribution and storage when exploring these opportunities,” he adds.

Ammonia is set to play a fundamental role in the development of the hydrogen economy as the market benefits from well-established global trade routes and infrastructures, as well as fully commercial technology already in place, at scale. New use cases for ammonia, such as marine fuel, hydrogen carrier and power generation, show significant growth potential in the next 10-15 years.

So far, when it comes to hydrogen, the good news is that viable decarbonization solutions exist. It works. And while these sectors may be hard to abate, at least it’s easy to see where the solution lies. ●

Unlocking Hydrogen's Full Potential

INSIGHTS WITH ANDREA BOMBARDI
EXECUTIVE VICE PRESIDENT CARBON REDUCTION EXCELLENCE

Advancing Europe's deployment of hydrogen with cross-border corridors.

Hydrogen will no doubt play a key role in the net zero scenario. How can it be financially supported during the current economic crisis?

The hydrogen economy is being launched and sustained at European level – we can find dedicated measures issued recently, in the case of the European Hydrogen Bank and in RePower EU plan, but also consistent financial support for hydrogen technologies and applications through the first and second wave of IPCEI: €10.6 billion and more than 70 projects financed to steadily advance the deployment of scalable and applicable solutions – among them a RINA project to decarbonize the steel industry utilizing hydrogen.

Transporting hydrogen is often noted as a challenge due to its flammable and low-density characteristics. In what way will RINA assist this process?

In terms of transport, the EU is active with the development of five cross-border corridors within the "Backbone" project: one of them is also paving the road for hydrogen imports from north Africa, where local low energy consumption is combined with an abundance of renewable sources. Indeed, hydrogen – in all its colors – will be traded at international level.

The amount of hydrogen needed to decarbonize hard-to-abate industries, mobility, those industries using it as a feedstock and potential domestic use will be significantly higher than the amount produced in most European countries. South America, Middle East and Africa, instead, could cover the role of exporters of green hydrogen, especially in case of technology breakthroughs related to the availability of water for electrolyzing. At the same time, other countries' reach of natural gas could export blue hydrogen. From a technical standpoint, RINA is supporting Italian and international transmission system operators (TSOs) and distribution network operators (DSOs) in repurposing or retrofitting pipelines to hydrogen. We have to first advance on a European regulatory framework first, and international later, with the guarantee of origin in preparation for the future market.

From a logistics perspective, what can countries do to ensure hydrogen is used to its full potential?

To ensure hydrogen's contribution to decarbonization targets, it must be available at a convenient cost and exploited alongside all the other solutions: technologies and infrastructure must reach the necessary maturity to let this new vector have a broad and safe adoption. In this scenario, south Mediterranean countries, and Italy in particular, are in a key position to stock up energy vectors from abroad for their own use or to serve northern countries: the evolution of port infrastructure, with the opportunity to develop or become hydrogen hubs, and gas transport networks are essential in securing the quantities of hydrogen needed by the end users who are called on today to make new investments in the technology of the future. ●

01

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

Hitachi's Innovations for a Carbon Neutral World

Hitachi is combining advanced energy and digital technologies to power the hydrogen economy. It aspires to be a driving force in the sustainability transition.

Hitachi's hydrogen innovations

Hitachi is developing a wide range of innovative technologies to help accelerate sustainability transitions. As hydrogen becomes a key element to society's energy system of the future, Hitachi is exploring ways to connect across the value chain through advanced digital solutions. This includes hydrogen production, transmission and distribution, hydrogen-based power production, and applications such as process plants and mobility.

Hitachi has also combined high-voltage power systems with water-electrolysis control to achieve low-cost green hydrogen production.

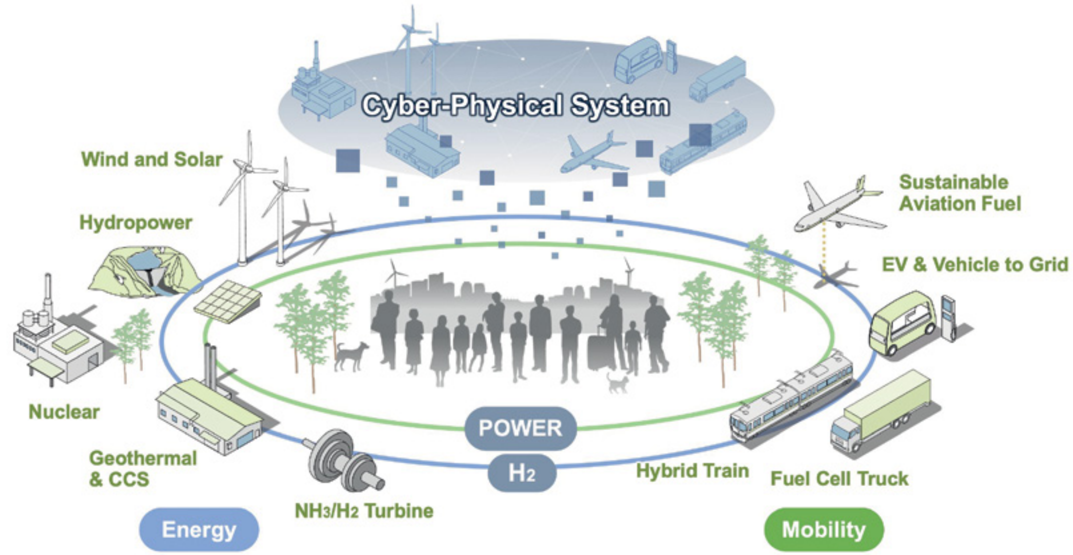
Hitachi's multi-grid management system will allow for the integrated control of renewable sourced vectors such as electricity, hydrogen, and gases. Connecting hydrogen supply systems to power and gas grids, this system will become a necessary infrastructure for the hydrogen economy to emerge. The system being studied by Hitachi could even be connected to a carbon grid to circulate carbon dioxide for solar chemical synthesis for example.

Talking about a carbon neutral world

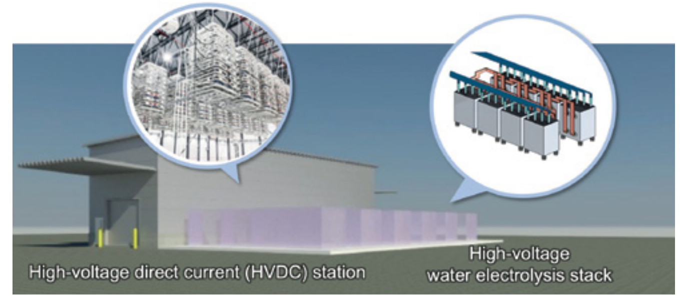
Such innovations can only power the sustainability transitions when they are rightly embedded in the existing societal and natural environments. With the understanding of an organic multi-sectorial collaboration Hitachi is in dialogue with a wide range of actors. At the Hitachi-UTokyo Lab (a joint research platform between Hitachi and the University of Tokyo) researchers are developing a "transition scenario" for Japan's carbon neutrality in 2050.

Based on its unique research, simulations, and expert interviews, Lab researchers have constructed detailed descriptions for transition pathways to

HITACHI
Inspire the Next



01



02

01 Hitachi's vision for a hydrogen-powered life in 2050. **Source:** Hitachi

02 Hitachi High-Voltage Direct Current (HVDC) and high-voltage water electrolyzer. **Source:** Hitachi

be expected in dozens of domains, including energy, industry, and societal behavior. The Lab convenes various public forums to invite leading experts in government, business, and local communities to discuss the challenges of their specific domains.

Envisioning prosperity within the Planetary Boundaries

In the 21st century age of socio-ecological crisis, we must envision a world in harmony with nature and to define concrete pathways to achieve this vision. The objective is to enable our society to prosper within the planetary boundaries.

Hitachi aspires to be a driving force in constructing a sustainable future. We will continue to seek for the most advanced knowledge and technologies of our time and to engage in dialogue with people around the world. ●

For more on Hitachi's visions on sustainability transitions, visit: sustainability-transitions.com and www.threetransitions.earth

#turningmetalsgreen and beyond

Policies to curb climate change are forcing the steel industry – which accounts for more than 7% of global CO_2 emissions – to fundamentally transform and decarbonize.

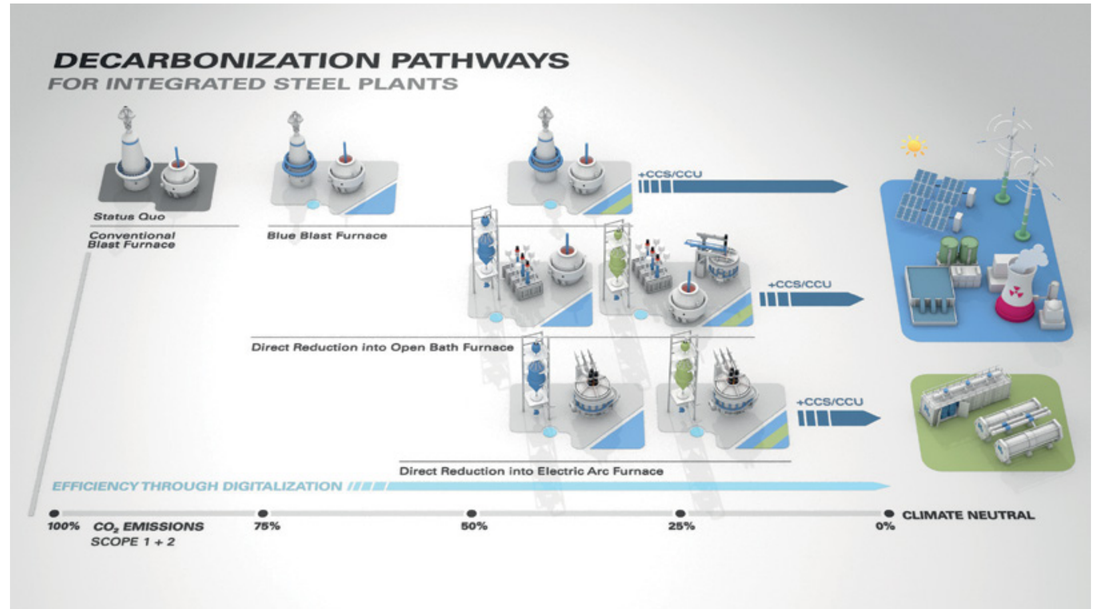
01

Plant engineering plays a key role in the transformation of the steel industry, since all the necessary processes, technologies and designs are developed by or in cooperation with plant manufacturers. With 150 years of experience in plant engineering, SMS group and Paul Wurth are paving the way for a carbon-neutral metals industry, providing different routes towards green steel production. A hydrogen excellence center, located at Paul Wurth in Luxembourg, is supporting the whole portfolio of SMS group including hydrogen generation and Power-to-X.

When available at a fair cost and on a large scale, green hydrogen plays a pivotal role in cutting emissions in the steel industry as it is a perfect reducing agent for substituting the fossil fuel-based iron ore reduction.

In the medium and long term, most steel producers' roadmaps to climate neutrality foresee replacing the conventional carbon-based blast furnace route with a hydrogen-based route using a direct reduction process. As an alternative to the direct reduction route, which requires substantial investment,

PAUL WURTH SMS group · SMS group



02

01 SMS group hydrogen-related activities.
Source: SMS group

02 SMS group provides three major routes to decarbonize integrated steel plants.
Source: SMS group

existing steel mills can also be gradually converted to achieve rapid reductions in greenhouse gases. For example, injecting synthesis gas and/or hydrogen into the blast furnace reduces the carbon input and can achieve CO_2 savings of up to 70%.

Apart from accelerating the use of hydrogen in the steelmaking processes, SMS is also actively shaping the production of renewable hydrogen. In 2019, Paul Wurth became a strategic investor and technology partner of Sunfire, a leading electrolysis provider, which has developed a highly efficient process for high-temperature electrolysis; the Solid Oxidizer Electrolyzer Cell (SOEC) uses steam instead of liquid water. Since the steam can be generated from waste heat from industrial plants, this technology is the perfect fit for the integration into steel mills, non-ferrous and other industries.

One best practice example is the Green Industrial Hydrogen (GrInHy) project in Salzgitter. The project consists of a SOEC system producing renewable hydrogen, which is directly fed into Salzgitter's hydrogen grid. Another showcase is the MultiPLHY project, set at Neste's renewable products refinery in Rotterdam, which relies as well on SOEC technology and Paul Wurth's engineering and system integration.

SMS group is also involved in the development of projects for producing synthetic fuels. Replacing fossil fuels with hydrogen-based synthetic fuels is particularly interesting for hard-to-electrify sectors such as the aviation industry and other heavy goods transportation. In 2020, Paul Wurth and partners founded the company Norsk e-Fuel – a consortium focusing on the production of sustainable aviation fuels. Furthermore, SMS is an investor and strategic partner of Swiss company Synhelion, pioneering in the field of sustainable solar fuels. ●

Hydrogen - SMS group GmbH (sms-group.com)

Hydrogen EV Charging: A Carbon-Zero Energy Bridge Across Middle East and North Africa (MENA)

GenCell deploys new green, grid-independent hydrogen-based EV charging solution that can run 24/7 – anywhere.

GenCell is deploying first of their kind autonomous EV charging stations at some 8 sites across Israel that can fill the gap when grid power is insufficient. The rapid recent rise in EV sales in Israel is driving a demand for more EV charging stations to quell EV drivers' range anxiety; more charging is dependent on more power. This new zero-emission solution, available now and rapid to deploy, facilitates the expansion of EVs in any location regardless of grid conditions, enabling green transportation across MENA and around the world.

Beyond Israel and around the world the rise of EV sales is faster than the charging infrastructure can support, causing a power gap. To meet the electricity demand from EV charging in Europe, Ernst Young estimated the need for an additional 200TWh by the end of this decade.[1] In response to Joe Biden's EV policies, some 48 million electric vehicles are expected on U.S. roads by 2030 , requiring twenty times the quantity of chargers available today.[2] Development of EV charging infrastructure in response to these trends is slow and uneven; off-grid stations can fill this gap anywhere the grid is insufficient; including across MENA where hydrogen will act as a bridge to regional cooperation.

MENA's sustainability focus

Traditional energy powers in the Middle East are being supplemented by clean energy hubs incorporating technologies that enable power for humanity in remote locations that to date have suffered from insufficient electricity. Private and public policy makers, investors and entrepreneurs are gathering at COP27 to accelerate investments in renewable power generation and hydrogen storage in the countries where sun and wind are plentiful, developing these economies via profitable export of hydrogen to Europe to replace fossil fuels.

Leveraging innovative technologies to accelerate renewable power generation and hydrogen storage in the Middle East and Africa drives regional cooperation and expands the local adoption of clean energy; note that this example of zero-emission EV charging in Israel can propel similar deployments in off and weak grid locations across MENA as well as in Europe, the U.S. and elsewhere.

01 GenCell EVOX EV Charging Station.
Source: GenCell

Hydrogen fueled solutions

Only a few hundred kilometers from Sharm el Sheikh – in conjunction with the COP27 Climate Conference – EV Pure Energy is deploying the first revolutionary hydrogen-fueled EV charging solutions powered by GenCell hydrogen-to-power at sites across Israel. Combining hybrid renewable energy sources with storage and hydrogen fuel cells, the solution optimizes power performance while ensuring power for 24/7 fast charging anywhere, in any grid conditions.

The hydrogen-to-power technologies adapted for the EVOX EV charging solution also deliver long-duration backup and off-grid power for continuous telecom connectivity. They aim to displace pollutant diesel generators powering telecom towers that emit almost 7 million metric tons of CO_2 per year – equal to some 3% of the industry's annual emissions.

Looking to reduce hydrogen fueling cost and complexity, GenCell has also developed ammonia-to-power technologies, launching in 2022 the FOX™ off-grid power solution now being tested by Deutsche Telekom, Vodafone and several other telecom operators and tower managers. As the availability of hydrogen and ammonia increases, MNOs in remote locations in MENA will be able to leverage these weather-resistant, low-maintenance and theft-adverse solutions.

Managing the climate crisis by meeting decarbonization goals while at the same time meeting the increasing global demand for power will be a challenge, but continued investment in hydrogen technologies - enabling resilient, zero-emission, extended runtime power solutions - plays a key role in meeting these objectives. ●

1 "As eMobility accelerates, can utilities move EVs into the fast lane?", Ernst Young Dec 2020.

2 Building the electric-vehicle charging infrastructure America needs – McKinsey 2022 – Philipp Kampshoff, Adi Kumar, Shannon Peloquin, Shivika Sahdev.

GenCell at a Glance

- Develops innovative fuel cell & green ammonia technology; products deployed in 22 countries
- Traded on the Tel Aviv Stock Exchange (GNCL)
- 9 Patents
- 150 Employees
- 1,250 accumulated R&D man-years

Driving the Hydrogen Economy in South Africa

INSIGHTS WITH NATASCHA VILJOEN
CEO, ANGLO AMERICAN PLATINUM

Bringing the South African hydrogen valley concept to reality, Anglo American and partners have successfully launched the world's largest hydrogen-powered vehicle.

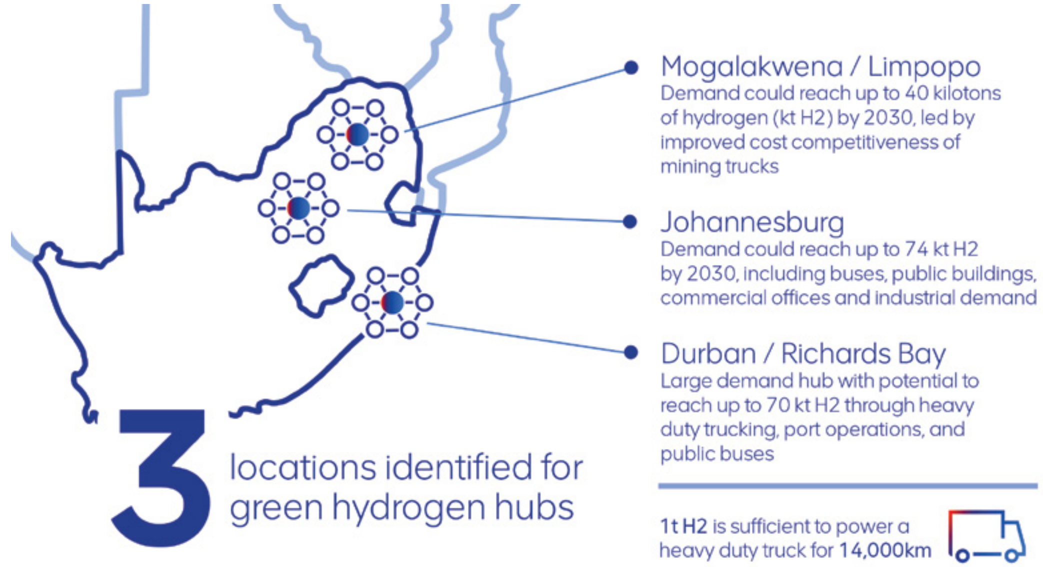
At Anglo American, we're transforming our business to deliver on our purpose of reimagining mining to improve people's lives. Underpinning this is our Sustainable Mining Plan, which guides how we mine and process our products to shape a more sustainable business across our entire value chain.

Our Sustainable Mining Plan is built around three key pillars, aligned to the UN's Sustainable Development Goals. One of these, alongside how we view our role as a trusted corporate leader and the support we provide to thriving communities, is our commitment to maintaining a healthy environment, and our corporate response to climate change, one of the defining challenges of our time.

To address this, we're taking action to make a meaningful contribution to the decarbonisation of our industry, and working to achieve a greener, cleaner, and more sustainable world. Developing the hydrogen economy, a sector with the potential to play a significant role in the sustainable energy transition, is firmly at the heart of our framework.

Courtesy of its world-leading solar and wind resources, and access to the platinum group metals (PGM) used in polymer electrolyte membrane (PEM) electrolysers needed to produce green hydrogen as a fuel, and in fuel cells to generate electricity from hydrogen, South Africa is among

AngloAmerican



the countries primed to capitalise; both in terms of hydrogen generation and consumption.

As a leading producer of PGM, and a business operating in South Africa for more than a hundred years, we have been working towards establishing the right ecosystem to successfully develop, scale-up and deploy hydrogen-fuelled solutions. As part of this, we are exploring the potential for a hydrogen valley in South Africa, intended to cluster several industrial and research initiatives, and to carry out a series of pilot projects across the complete hydrogen value chain.

Feasibility study has identified three key hydrogen valley hubs

In collaboration with South Africa's Department of Science and Innovation (DSI), the South African National Development Institute (SANEDI), ENGIE, and Bambili Energy, we completed a hydrogen valley feasibility study in October 2021.

The study identified three hubs – Johannesburg, extending to Rustenburg and Pretoria; Durban, encompassing the city itself and Richards Bay; and Limpopo province, centred around our Mogalakwena PGM mine. These hubs will have a fundamental role to play in integrating hydrogen into the country's economy, and in establishing South Africa and its abundant renewable energy resources as a strategically important centre for green hydrogen production.

Hydrogen valley presents substantial economic and employment potential

The results of the independently conducted feasibility study show that the hydrogen valley could add between $4-9 billion to South African GDP (direct and indirect contributions) by 2050, while also creating between 14,000 - 30,000 direct and indirect jobs per year. These jobs will span the entire hydrogen value chain, from research and development, engineering and maintenance, to training and outreach – across sourcing, production, transportation and storage.

Nine individual pilot projects have also been identified across these hubs, recommended to be prioritised by developers, and spanning the transport, industrial, and construction sectors. Since the publication of the feasibility study results, we have worked with South Africa's DSI and other partners on the implementation of relevant projects, including the Rhynbow Project. This initiative, which we are progressing together with partners Bambili Energy, ENGIE, Sasol and TotalEnergies, will look to aggregate demand for fuel cell heavy duty vehicles, including buses and articulated trucks, to scale a viable operational ecosystem.

We also continue to advance independent efforts to introduce hydrogen powered solutions to our mines; part of our aim to achieve carbon neutrality across our operations by 2040. The investment in renewable hydrogen production technology and the development and introduction of hydrogen-powered fuel cell mine haul trucks at our Mogalakwena PGM mine, is a prime example of this approach.

nuGen™ – Anglo American's Zero Emissions Haulage Solution

nuGen™ represents a different way of thinking about mining; one that, aligned with our FutureSmart Mining™ programme, brings together technology, digitalisation and sustainability, with step-change innovation intended to transform the very nature of mining.

This broader objective is behind the nuGen™ Zero Emission Haulage Solution (ZEHS) project, an end-to-end integrated green hydrogen production, fuelling, and haulage system for mine sites.

01 nuGen™ hydrogen-powered ultra-class mine haul truck, Mogalakwena, South Africa. **Source:** Anglo American

The world's lightest 510t truck

The pilot for nuGen™ is a hydrogen-powered ultra-class mine haul truck. It's an ambitious project that marks the first time a truck of this size and load capacity (a 220t truck with a load capacity of 290t = a total laden weight of 510t) has been converted to run on hydrogen that will be produced on-site in hybrid combination with a battery.

Retrofitted from a diesel-powered vehicle, the nuGen™ truck uses a hybrid hydrogen fuel cell to provide roughly half of the power and a battery pack the other half, enabling energy recovery from braking. Hydrogen enters the fuel cell from the tank and mixes with oxygen to create water in a chemical reaction catalysed by platinum. This generates electricity which is then used to power the motors that drive the wheels. The only emission from the vehicle is water vapour.

The 2-megawatt hybrid battery/hydrogen fuel cell powerplant, which replaces the diesel engine installed, has been designed by Anglo American and its partner First Mode in Seattle, USA. The power management and battery systems in the truck have been developed to improve overall efficiency by recovering energy when the haul trucks travel downhill, through regenerative braking.

This energy stored in the battery extends the truck's range and reduces the out of cycle time for the trucks, since hydrogen refuelling is significantly faster than recharging batteries. It also reduces our dependance on external energy sources.

As part of the integrated nuGen™ solution, we have built a zero emission hydrogen production, storage, and refuelling complex for vehicles at Mogalakwena, which incorporates the largest electrolyser in Africa and a solar PV field to support the operation of the haul truck. ENGIE is the hydrogen producer and supplier in this proof-of-concept project.

We're taking action to make a meaningful contribution to the decarbonisation of our industry, and working to achieve a greener, cleaner, and more sustainable world.

Looking to the future

We plan to retrofit 40 diesel powered ultra-class haul trucks at Mogalakwena to hydrogen, before rolling out the technology across our global fleet of around 400 trucks. The launch of nuGen™ provides a real-world case for the wider adoption and use of hydrogen across the heaviest duty forms of transport.

With haul trucks representing up to 80% of diesel emissions at our mine sites, this technology will make a major contribution towards our operational carbon neutrality target. The truck is a tangible example of the technology advances that are needed to enable the global shift towards more sustainable, affordable hydrogen power, and of the way investment in infrastructure and innovation can deliver a clear vision for the future.

Rolls-Royce's *mtu* Hydrogen

Rolls-Royce's *mtu* aims to produce affordable, large-sale hydrogen and on a large scale using green electricity.

Rolls-Royce's business unit Power Systems, with its product and solution brand, *mtu*, has the whole hydrogen ecosystem in mind – from production of green hydrogen to use. The "Sustainable Power Solutions" unit founded for this purpose takes care of products and solutions that do not emit carbon dioxide. A first fuel cell project is already in sight for 2023.

Green hydrogen with *mtu* electrolyzers

High-performance electrolyzers produce green hydrogen, which can be used as fuel both for fuel cells and combustion engines and further processed into synthetic fuels. *mtu* electrolyzers will be equipped with polymer electrolyte membrane (PEM) stacks from Hoeller Electrolyzer.

Rolls-Royce is developing *mtu* electrolyzers with inputs of up to 2 MW and more that can be scaled up to over 100 MW and has acquired a 54% stake in Hoeller Electrolyzer, a specialist company that develops and manufactures the cell stack. The shared aim of Rolls-Royce and Hoeller Electrolyzer is to develop a solution to produce hydrogen cheaply and on a large scale using green electricity. The electrolyzer will be an ideal add-on for a *mtu* microgrid. It creates the possibility to store and use solar and wind power, thus making an important contribution to the energy transition.

"Hydrogen contains no carbon and cannot produce carbon dioxide when powering fuel cells or hydrogen engines. The trick, though, is to ensure that no CO_2 is produced during production of the hydrogen – as is the case when hydrogen is obtained from natural gas," explained Armin Fürderer, who heads up net zero solutions at Rolls-Royce's Power Systems business.

This calls for 'green' hydrogen produced in ways that give off no carbon emissions, and that's where solar parks and wind turbines come in – supplying the electrolyzers with electricity generated with zero CO_2 emissions. The collected hydrogen can be used in fuel cells or to power hydrogen engines. Either way, electricity can be fed into the grid or used to power vehicles or ships.

Combustion engines run climate-neutral

Another possibility is to produce methanol from hydrogen and CO_2 in the air. If this methanol is used in a future *mtu* methanol engine, CO_2 is released again, but in quantities equivalent to those extracted from the air during the methanol production – meaning the whole process is 'net zero carbon'. Rolls-Royce already cooperates with shipbuilders like Sanlorenzo and Lürssen for *mtu* methanol engines for the propulsion of big yachts.

01

02

01 Fuel cell demonstrator for a hydrogen based power supply: The first pilot installation is planned for Duisburg's future climate neutral container terminal. **Source:** Rolls-Royce

02 High efficient electrolyzer stack: Rolls-Royce acquired a 54% share in Hoeller electrolyzer. The Hoeller stack is the core component for future mtu Electrolyzers. **Source:** Rolls-Royce

According to Stefan Höller, Managing Director and the resourceful mind behind Hoeller Elektrolyzer, "With our stack, you're going to be able to produce hydrogen in a way that's so inexpensive it's so far been thought impossible." Over 25 years of expertise and pioneering work by company founder Stefan Höller have gone into the Hoeller stack, which uses significantly less platinum and iridium than usual, and a higher output pressure makes it even more powerful.

The first *mtu* electrolyzer using a Hoeller stack is set to go into operation in 2023, showing the part an electrolyzer can play in the overall architecture of a microgrid. An initial customer project is already planned for 2024.

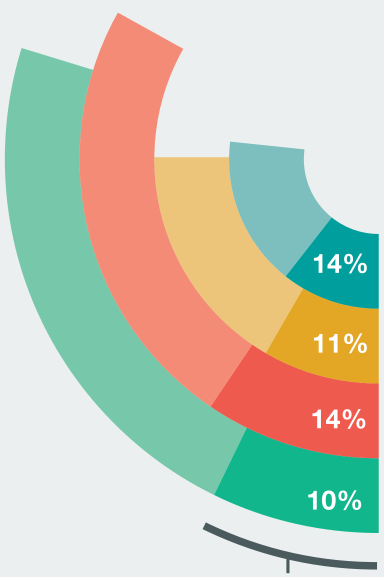
Another climate-friendly hydrogen project will come to fruition even sooner: In 2023, Rolls-Royce will equip the port's future climate-neutral container terminal in Duisburg (Germany) with three *mtu* fuel cell units with a total output of 1,500 MW and two *mtu* Series 4000 hydrogen engines with 2 MW output. ●

Women Shaping the Future of Green Hydrogen

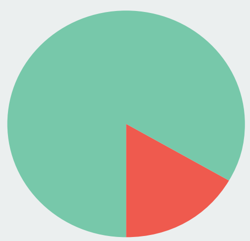
Women in Green Hydrogen is on a quest to make energy transition more inclusive and diverse.

The Women in Green Hydrogen (WiGH) network was founded in 2020 to address the lack of equal representation in most hydrogen industry events and to support the work and contribution of the talented women working in the sector.

Data from IRENA and IEA studies show the prevalence of under-representation of women in green hydrogen related-industries, confirming the real need for women to be more engaged and visible.



Women constitute just 20% of speakers at Green Hydrogen conferences.



"It has been widely proven that diversity unlocks innovation and drives market growth, and our sector is in great need of it," states Afkenel Schipstra, Senior Vice President Business Development Hydrogen at ENGIE. Working towards its mission to "connect, empower and change," WiGH thus seeks to drive up gender equality and increase visibility of women in the sector.

Through partnering with over 20 like-minded organisations and companies, WiGH aims to have at least 30% representation of women in industry event panels. In addition, over 35 in-person and virtual events have been hosted by WiGH globally to promote diversity in the Green Hydrogen sector by creating a safe space for women to network and discuss the developments in the sector, as well as showcasing female experts.

WiGH works to provide women with opportunities to connect, grow, and rise to executive roles, ultimately to bring about a positive change in the hydrogen sector and the world. Today, in addition to organising women-oriented networking events, WiGH offers an Expert Database with over 700 profiles from 55 countries that enables event organisers to put together more diverse and inclusive speaker panels, broadening the conversation while curbing the gender gap.

Lastly, WiGH offers its Mentoring Program that matches women at junior and mid-management levels to improve connections and networking to change the hydrogen sector. This program is a great tool for capacity training and further empowerment of the future hydrogen leaders.

Through these tools and its network channels, WiGH connects and empowers women fostering innovation while contributing to increasing the diversity and inclusiveness in the energy sector. "The energy transition is not going to be easy," states WiGH Co-Founder Brittany Westlake. "WiGH brings together a group of such talented, diverse women and I find it incredibly inspiring to be reminded that we do have the people and skills to tackle these really tough energy challenges."

WiGH Outreach:

- **3,250** members
- **1,350** newsletter subscribers
- **1,250** followers

Image: Panel discussion at the World Hydrogen Congress 2021, organized by Women in Green Hydrogen. **Source:** World Hydrogen

VIEWS

Heroes of Hydrogen

PHOTOGRAPHY BY **JUSTIN JIN**

The fuel of the future is here, and energy pioneers are hard at work bringing in the dawn of a new era. Hydrogen is the world's most abundant element and has the potential to power economies, leaving only water as waste. Daring entrepreneurs in Europe are racing to make clean hydrogen affordable.

But is the universe's oldest element really sparking a revolution? In the "Heroes of Hydrogen" photobook, Hydrogen Europe engages award-winning photographer and writer Justin Jin to see for himself. From the crisp cold of the Arctic to the dry expanses of the Sahara, this exploration shows how hydrogen is already underway to decarbonize our most polluting industries. From the frigid waters of the North Sea to the bejewelled Adriatic Coast, these spectacular images portray the people risking everything on the hydrogen bet.

Their rewards are for all humanity to enjoy should they ultimately heroically succeed.

01 Solar panels outside Nouakchott, Mauritania that could be used to produce green hydrogen for export.

01

02

SWEDEN

A Green Steel Revolution

The first stop of our journey discovering the growing hydrogen economy is in Sweden to visit the HYBRIT plant. This project yearns to revolutionize Swedish iron and steel production by delivering the first fossil-free steel. The technology employed has the capacity to reduce Swedish total carbon dioxide emissions by at least 10%.

03

04

05

02 Overview of LKAB's iron ore mine in Kiruna city in Sweden's Arctic territory.

03 HYBRIT's pilot facility for fossil-free hydrogen gas storage at Svartöberget in Luleå, Sweden.

04 The electrolyser powering the HYBRIT Fossil-Free Green Steel Pilot Plant - the site that produced the world's first batch of fossil-free sponge iron.

05 Workers using remote controls inject hot iron with carbon-enriched gas at SSAB's blast furnace in Luleå.

06

NETHERLANDS

‘Heavenn’ on Earth, Lessons from Europe’s first Hydrogen Valley

Our tour heads to the Netherlands, homeland of the first European Hydrogen Valley, to visit the HEAVENN project, an ecosystem where one can fully grasp what the future of the hydrogen industry is about. The goal is the deployment of green hydrogen across the entire value chain.

07

08

06 A boat carrying wind turbine blades cruises into Eemshaven.

07 Workers test the feasibility of converting an underground “salt-dome” used for storing natural gas to hold hydrogen at Gasunie’s Zuidwending site.

08 Gasunie’s Zuidwending natural gas site also houses a green hydrogen pilot.

09 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 refuelling stations in Europe, supported by regional, national, and European funds.

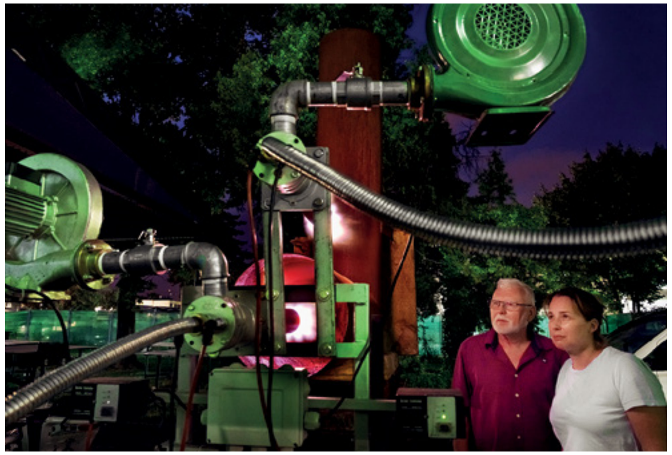
09

10

CROATIA

Extracting Every Joule

We leave Northern Europe to dive into the crystal-clear waters of the Adriatic Sea and visit Indeloop, where a Croatian team developed a machine that turns faeces and other wastes into hydrogen-rich gas.



11

12

10 Workers clean a polluted beach in Croatia. Each year, currents in the sea brings plastic waste from other countries to Croatia's Adriatic Coast.

11 Scientists Vjekoslav Majetić and Danica Maljković test a machine that turns waste into energy-rich syngas at their factory in Zagreb, Croatia.

12 Inventor Vjekoslav Majetić (in purple) discusses with his team the machine that turns waste into energy-rich syngas at their factory in Zagreb, Croatia.

13 Divers clean a polluted beach on the island of Miljet in Croatia. The waste gathered could be turned into hydrogen-rich gas.

13

14

SPAIN & MAURITANIA

Building a Solar System

Our journey ends with HyDeal España, an innovative industrial and financial project that will provide competitive renewable hydrogen to an industrial area in Asturias. To make this ambition a reality, Europe cannot do this alone. Africa needs to become a European energy partner. The two continents need to work hand in hand to connect suppliers in North Africa with off-takers in Europe.

14 ArcelorMittal plant in Gijón. Green hydrogen falls in the company's strategy in its roadmap towards the decarbonisation of steel production.

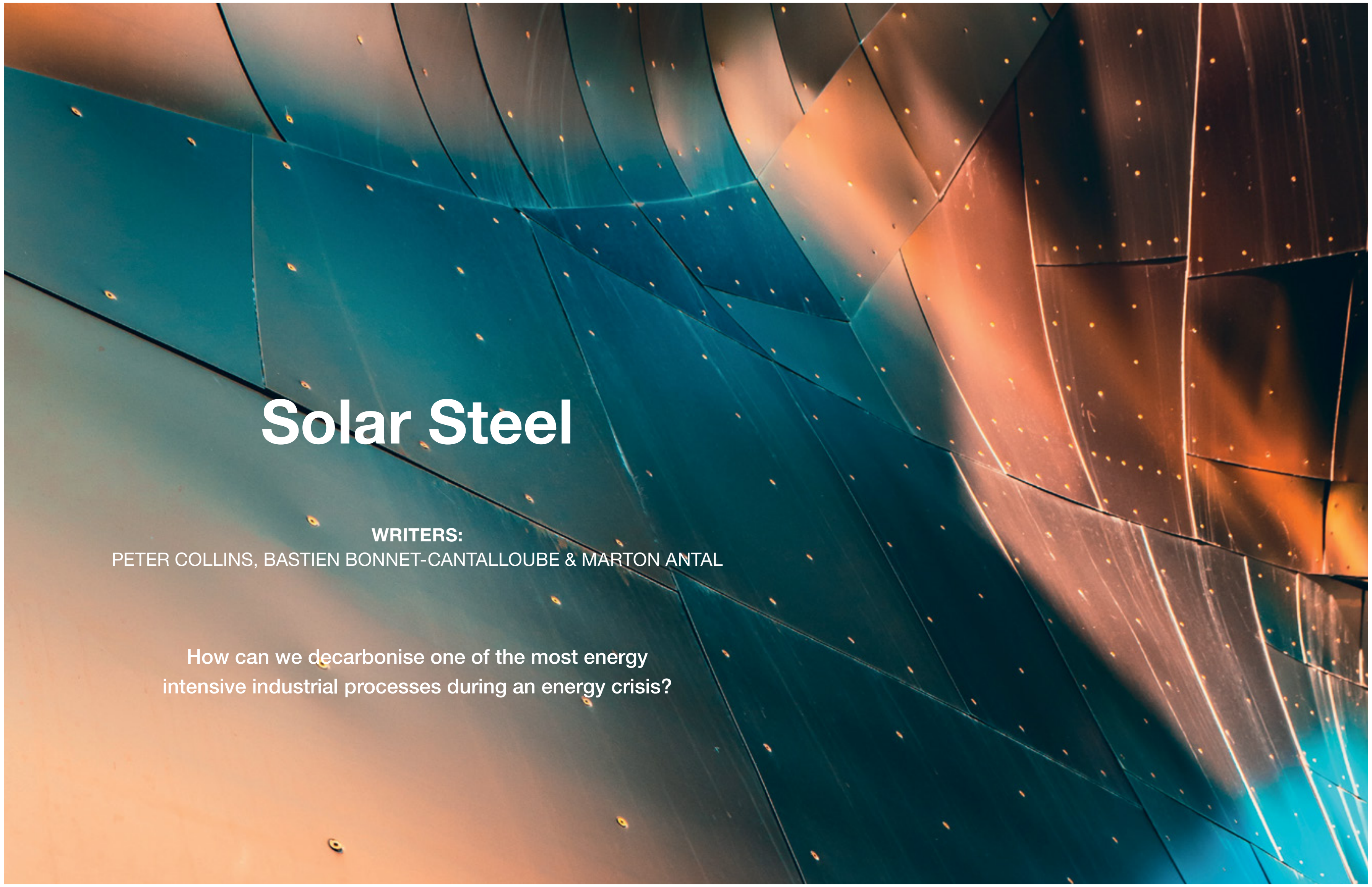
15 Fertilizer lab at Fertiberia in Avilés. The company is investing in a green ammonia plant able to cover the energy demand of the Avilés fertilizer site.

16 An experimental furnace using a mix of hydrogen gas to reduce iron ore at ArcelorMittal's R&D department.

15

16

Industry Update



Solar Steel

WRITERS:
PETER COLLINS, BASTIEN BONNET-CANTALLOUBE & MARTON ANTAL

How can we decarbonise one of the most energy intensive industrial processes during an energy crisis?

01

According to the World Steel Association, every ton of steel produced in 2018 was responsible for average emissions of 1.85 tons of CO_2 ; approximately 8% of global CO_2 emissions. But how can we decarbonise one of the more energy intensive industrial processes during an energy crisis? Serious thought must be given towards how exactly we can reduce the sector's significant emissions while protecting the approximately 2.6 million jobs it provides in the EU economy. Hydrogen Europe's May 2022 report, 'Steel from solar energy: a techno-economic assessment of green steel manufacturing', assessed the viability and economic feasibility of using hydrogen from solar power (and other renewables) as a pathway to decarbonising steel.

In 2018 steel production was responsible for 8% of global CO_2 emissions.

Analysing steel production

In 2020, total EU steel production was close to 183Mt , with Germany the bloc's biggest producer, followed by Italy, France, and Spain. The multi-billion-euro industry is an important contributor to the union's construction and infrastructure sector as well as its general economic well-being. Eurofer, the European steel association, calculated that steel creates around €134.5 billion of Gross Value Added (GVA) for Europe.

Hydrogen Europe's analysis specifically focused on hydrogen-based direct reduction of iron ore coupled with an electric arc furnace (H2-DRI-EAF), by comparing the levelized cost of steel with the Blast Furnace-Basic Oxygen Furnace (BF-BOF) benchmark. Depending on the system's energy efficiency, the BF-BOF route usually has a carbon footprint of between 1.6 and 2.0 tonnes of CO_2 per tonne of crude steel produced.

Steel companies at risk

To achieve what is needed is no small task, and it will require a massive uptake in new renewable energy capacity. Switching all primary steel production plants blast furnaces in the EU and United Kingdom to the H2-based Direct Reduction Process would require up to 5.3 Mt of renewable hydrogen and up to 370 TWh of additional renewable generation. But in the upcoming years, the steel sector – like all sectors - will face increasing pressure to decarbonise. Studies cited in a recent McKinsey report claim that the global steel industry may find approximately 14 % of steel companies' potential value is at risk if they are unable to keep up with the energy transition and successfully decarbonise.

Policy incentives will play a driving role in the energy transition, so it is worth taking a brief look at what is already in place at the EU level and how they may evolve. In particular, we will see how these will put added pressure on the steel sector's decarbonisation timeline.

Steel companies' value could fall by 14% if they are unable to keep up with the energy transition.

Currently, the following policy incentives are in place at the EU level:

EU Emissions Trading System

Now into its 4th phase (2021-2030), ETS allowances are trading at around €60-70 on the market, down from record highs of almost €100 in past months. The revision process currently underway will most likely go further, beyond 60% GHG emission reduction by 2030, implying further cap reduction, and the introduction of new industrial sectors. Free allowances – from which the steel industry benefits to cover part of its emissions – are expected to be gradually phased out too by benchmarks revision and the CBAM.

Carbon Border Adjustment Mechanism

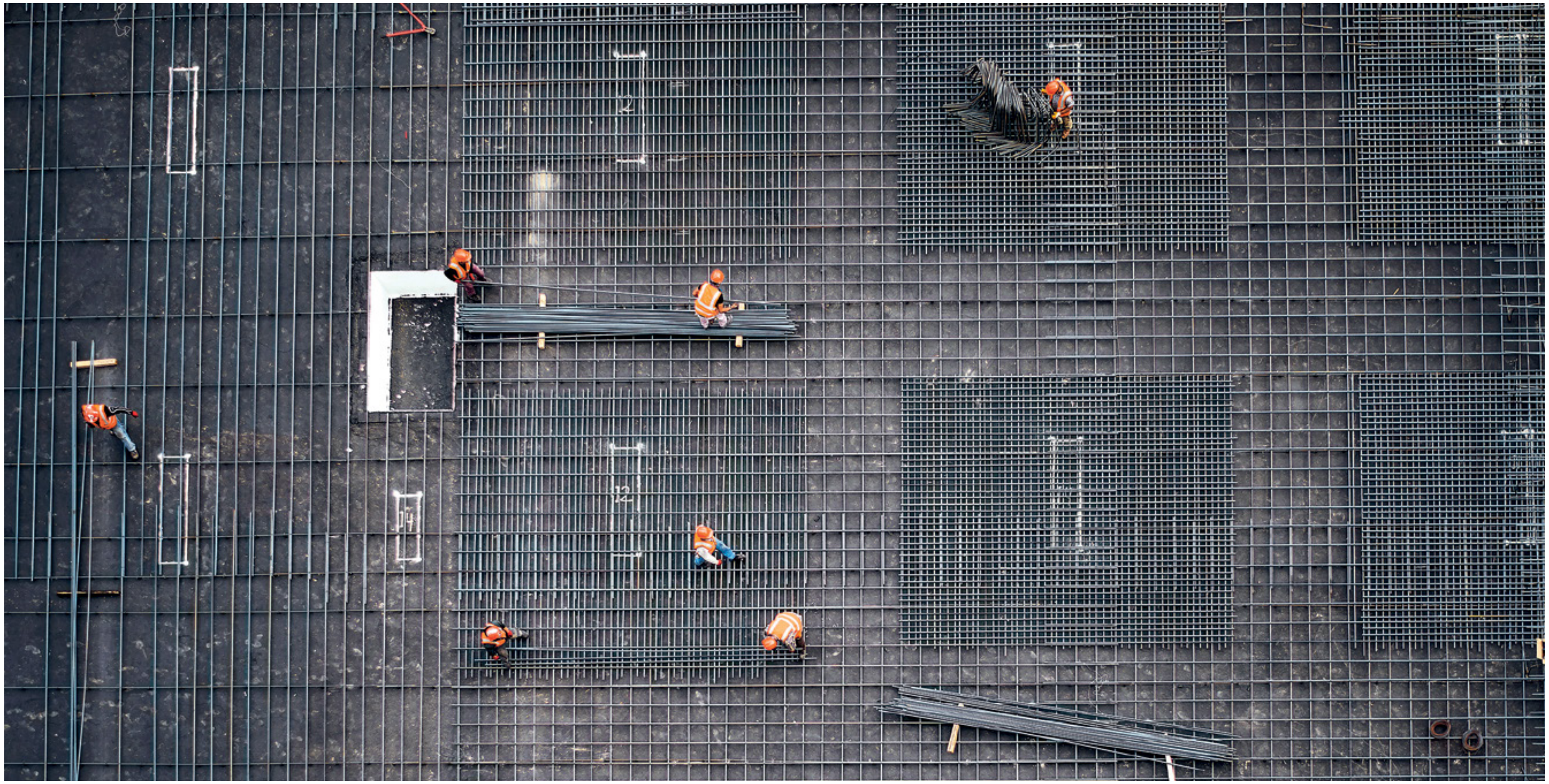
With the goal of phasing out free allowances from the ETS, lawmakers are planning to introduce the CBAM – in a first instance for a few sectors, including steel – to act as an alternative protection against the risk of carbon leakage, while aiming at evening the playing field and pushing third country companies towards deep decarbonisation. The CBAM will have a significant effect on emissions trading and decarbonisation strategy in highly emitting industrial goods, like steel.

Industrial Emissions Directive

Already a key tool to measure and regulate the industrial pollution of industrial plants, the planned revision will widen the scope of the Directive and introduce rigorous monitoring obligations to industrial companies. Industrial stakeholders such as steel producers will have to invest into manpower

01 Frank Gehry's architectural detail.
Source: Meriç Dagli / Unsplash

02 Construction site.
Source: Saad Salim / Unsplash



02

and software measures to comply with the rigorous criteria and switch to more efficient and less polluting solutions.

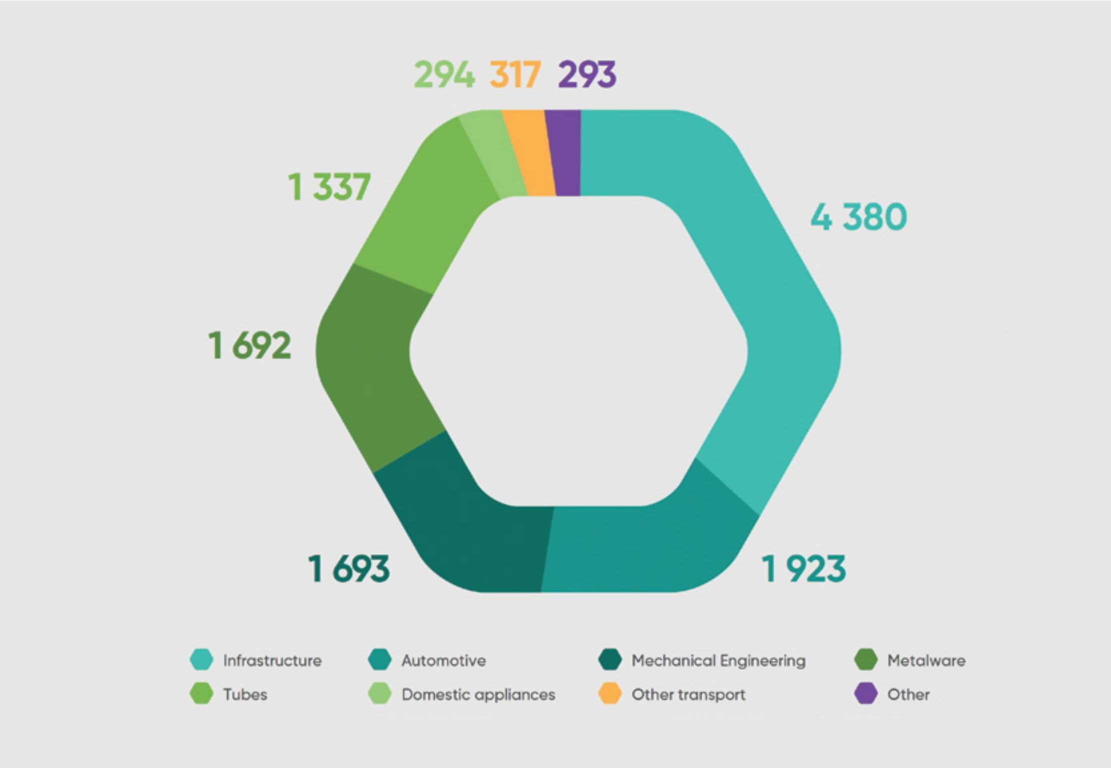
EU Taxonomy

A more recent idea within the EU legislature, the EU Taxonomy will be crucial in securing funding and financing in the historically polluting industrial sectors like steel. The ambition is to create a system where manufacturers will have to move away from polluting feedstocks – like natural gas and coal – onto green hydrogen and similar products. This means that industrial stakeholders will have to start investing heavily in alternative solutions, like green steel, to stay viable in a post-taxonomy world.

03 Train tracks. **Source:** Andre Frueh / Unsplash

04 Art work made of steel.
Source: Christophe Dion / Unsplash

Figure 1: Steel consumption in the EU by application.
Source: Steel from Solar Energy Report, Hydrogen Europe



03

Innovative projects decarbonising steel

Some early pioneer projects are in the works that will set the tone and precedent for the mass decarbonisation of the sector. One of seven innovative projects awarded under the first call for large-scale projects under the Innovation Fund, (the only steel-related project to secure funding) the HYBRIT project will demonstrate a complete industrial value chain for fossil-free hydrogen-based iron and steelmaking. Vattenfall, Swedish steel group SSAB, and fellow Swede mining company LKAB, are targeting 1.35Mt of hydrogen-reduced iron per year through HYBRIT to meet 25% of Sweden's crude steel production needs and potentially reduce the country's emissions by up to 10%.

What makes the project unique among the EU based green steel projects is that Sweden already has an almost zero-emission electricity grid. As a result, the electricity for hydrogen generation can be sourced from the grid on an almost continuous basis, thus enabling a high electrolyser capacity factor without the need for expensive hydrogen storage solutions.

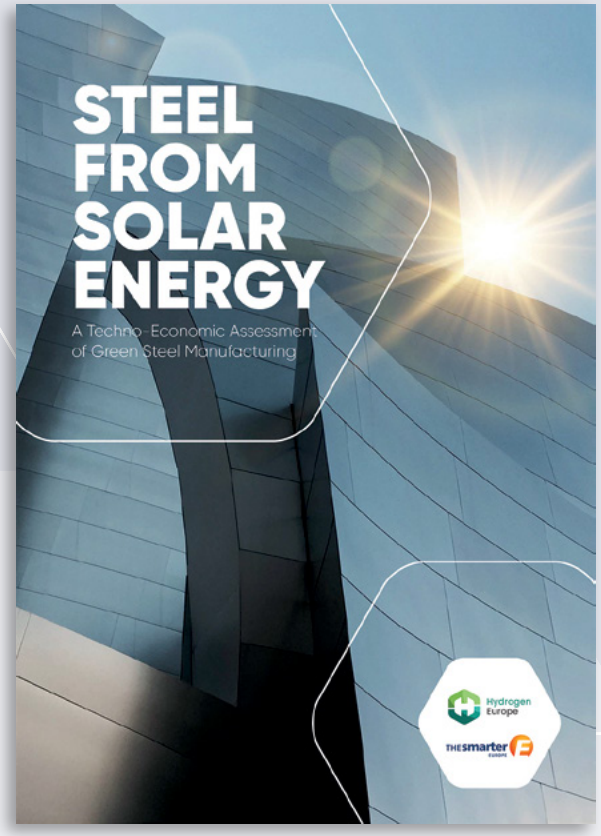
These projects are at the vanguard of a new, cleaner steel sector.

04

Another major project for green steel is the SALCOS project (SAlzgitter Low CO_2 Steelmaking), developed by the German steelmaker Salzgitter, which aims to produce enough green hydrogen to be then used in a direct reduction plant, replacing the coal currently used in the conventional blast furnace process. SALCOS faces almost the opposite problem of HYBRIT, with the German steel plants located in a heavily industrialized area, with next to no local access to low-cost renewables. In Germany, unlike Sweden, the average carbon intensity of the electricity grid cannot be considered low carbon.

Faced with these issues, SALCOS' Direct Reduction Process (DRP) will utilise any ratio of hydrogen and natural gas as the reducing agent, something which has never been achieved at an industrial scale to date. This process offers a flexible decarbonisation solution that could be implemented immediately, gradually increasing the share of renewable hydrogen as it grows in availability, and gradually replacing further BF-BOF with new DRI-EAF units. In the first stage of its development, CO_2 emissions should fall by up to 26% by the year 2025, Salzgitter says.

These projects are, among others, the vanguard of a new, cleaner steel sector, and face many challenges to demonstrate a level of cost effectiveness that will make market actors take note. In this Hydrogen Europe report, we have analysed these ground-breaking schemes as well as the main challenges that the industry will encounter. But developers alone will not drive this initiative forward. To preserve competitiveness, a sound policy framework and relevant funding activities will be paramount to accompany and support projects and investors. Revisions to the ETS, CBAM and other policies will drive demand alongside the recent commitments to hydrogen announced by European Commission president Ursula von der Leyen.

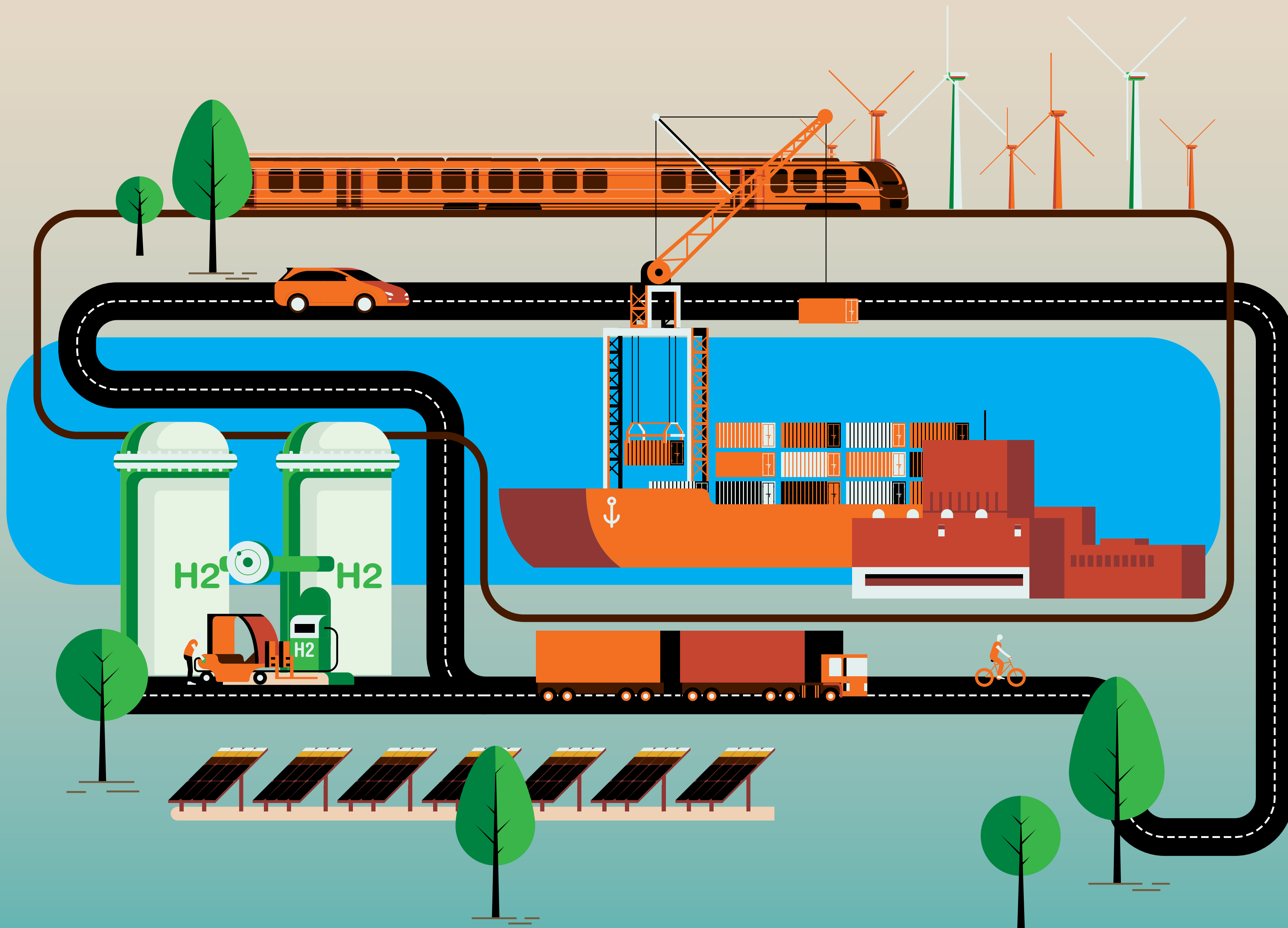


WANT TO KNOW MORE?

Read Hydrogen Europe's report:

'Steel From Solar Energy – A Techno-Economic Assessment of Green Steel Manufacturing'

Policy Update



Policy Developments

WRITERS:
FELICIA MESTER AND
BASTIEN BONNET CANTALLOUBE

Hydrogen placed at the heart of future EU energy policy.

01

A common definition of renewable hydrogen will serve as a springboard for a nascent sector and avoid market fragmentation.

The REPowerEU plan was a direct reaction to the Russian invasion of Ukraine, and as a result hydrogen has been placed front and centre in the energy transition strategy with clear targets for the replacement of fossil gas and other fuels by 2030. It is, however, becoming abundantly clear that even after maximising energy efficiency and renewable energy deployment, the EU will need energy imports. The European Commission reinforced this message with an ambitious proposal to import 10 million tonnes of renewable hydrogen and derivatives from third countries, in addition to producing 10 million tonnes locally.

New opportunities for hydrogen

Such large volumes open up new opportunities for hydrogen – beyond the existing use of unabated fossil hydrogen – to replace other uses of fossil fuels and feedstocks. Hydrogen and hydrogen carriers will support the decarbonisation of the power sector by providing an excellent form of flexibility to variable renewables. Hydrogen and carriers will store renewable energy for long periods and secure supply during times of low renewable production. It will help replace natural gas in buildings alongside other clean technologies such as heat pumps. Hydrogen will likewise play an essential role in reducing air pollution in cities and in ports,ensuring European goods and European commuters are transported more sustainably. To deliver on our common European climate ambitions, all clean technologies will be needed. Hydrogen technologies are not a silver bullet but, as regards their role in the transition, the argument has been won – they must play a significant part.

Whereas trade of hydrogen between the EU and abroad is quasi-inexistent today, the mentioned targets would require a radical change of landscape. By 2050, the potential total demand for hydrogen and its derivatives could reach 60 million tonnes. The World Energy Council indicates that domestic production of clean hydrogen would be able to meet not more than 20% of projected hydrogen demand in 2030 and less than 50% in 2050. As such, developing strategic partnerships with potential exporting players and a clear regulatory framework to enable such trade is imperative. To achieve this 20 million tonne target, some main elements of market design require urgent attention and coordination at international level: namely, a common legal definition for hydrogen and an international system of hydrogen certification with robust environmental criteria.

International standards are global market enablers, hydrogen certification is no exception.

Removing barriers to investment

Investor certainty is key for a nascent hydrogen sector. This is true both within and outside the EU. Whilst hydrogen project developers are racing to deploy large scale facilities to kick-start much needed renewable hydrogen production, their eyes are on the European Commission which promised to publish the Delegated Act (DA) defining renewable hydrogen and derivatives (for example renewable fuels of non-biological origin, RFNBO) by the end of 2021. The European Commission came under harsh scrutiny for its intention to impose a heavy administrative burden and strict criteria of additionality, temporal and geographic correlation on renewable hydrogen production. Compliance against these criteria would allow fuels to count towards the sub targets for RFNBO consumption for transport and industry proposed in the Renewable Energy Directive.

Whilst it is indisputable that we need a massive amount of additional renewable energy capacity if we want to decarbonise and achieve energy independence, it is unclear why such criteria are only imposed on renewable hydrogen producers. Having overly complex rules would strain hydrogen production and put at risk the future availability of renewable hydrogen because of potential high production costs and limited availability of renewable electricity. Indeed, excessively short time correlation and the exclusion of subsidised renewable power to be used for RFNBO production – just to name a few – would increase production costs, limit volume and risk the EU's competitive edge in a global race for scaling clean hydrogen technologies, vis-à-vis the US or the UK. Hydrogen imports would also have to comply with these criteria to count towards EU renewable energy targets, thereby severely limiting our ability to import the amount of hydrogen needed.

Developing a harmonised, bullet proof system of hydrogen certification is essential in creating a market-based estimation of relevant sustainability attributes and fostering the development of a global hydrogen market. A standard methodology for determining such attributes, such as a carbon footprint, will build consumer trust, incentivise cross-border trade and match supply with demand in a swifter manner which will increase market liquidity. Although the importance of accurate and harmonised certification has been clearly recognised by industry stakeholders and policymakers alike, most of existing hydrogen certification schemes are voluntary and limited in terms of full climate accounting. The Hydrogen and Decarbonised Gas Package proposal lacks a clear vision for hydrogen certification and fails to factor in the differences between natural gas and hydrogen in its book and claim system. This leaves the system incredibly vulnerable to greenwashing.

The Green Hydrogen Standard

There are a few voluntary initiatives that aim to build the basis of a harmonised hydrogen certification scheme. One example is the Green Hydrogen Standard launched in May 2022 which sets a maximum threshold for greenhouse gas emissions of 1kg CO_2e per kg H_2. Green hydrogen producers are invited to submit their projects for accreditation and certification by the Green Hydrogen Organisation (GH2) and are then able to obtain and trade GH2 certificates of origin. Certifhy is another important certification initiative – albeit limited to European markets – initiated

01 State of the Union address delivered by the President of the European Commission Ursula von der Leyen on 14 September 2022 in Strasbourg, France. **Source:** European Parliament / Flickr

02 European Commission headquarters, Brussels, Belgium. **Source:** Christian Lue / Unsplash

02

03

03 Industrial site. **Source:** Patrick Hendry / Unsplash

04 The giant Euro sign in front of the European Central Bank in Frankfurt am Main, Germany. **Source:** Mika Baumeister / Unsplash

05 European Parliament in Brussels, Belgium. **Source:** Paolo Margari / Unsplash

at the request of the European Commission. It works together with competent authorities and existing EU issuing bodies to provide a tradable certificate that assigns a clear value to renewable and low-carbon environmental attributes.

Hydrogen and hydrogen derivatives, whether produced in the EU or in third countries, will have to respect a GHG emission saving threshold of at least 70%. This comes on top of the rules set in the DA mentioned above addressing RFNBO production rules. To calculate these emissions savings, a fossil fuel comparator at 94 gCO_2e/MJ would be used, in line with the value set for biofuels and bioliquids. This means that, with a 70% required reduction, the GHG footprint threshold for hydrogen is 3.38 $tCO_2/tH2$.

Many types of RFNBO will contain carbon in their chemical composition, such as e-diesel, e-kerosene, e-methanol, or e-methane. The rules aim to tackle the source of the captured carbon and of upstream emissions accounting. Captured CO_2 could be deducted from the carbon footprint of the RFNBO if it is captured from air, biomass and biofuels, or a geological source. Captured CO_2 may also be deducted if captured in industries covered by the EU Emissions Trading System (EU ETS). As an example, this is possible in cases where the emissions have been taken into account upstream in an effective carbon pricing (the EU ETS or an alternative CO_2 pricing system in the case of imported CO_2 or RFNBO).

All in all, these rules will require third country RFNBO producers to rigorously verify emissions from all the fuel's inputs, processing, transport and distribution, and combustion at end use. Regarding the use of carbon, the burden of proof will be on non-EU manufacturers to demonstrate that the emissions that allowed the carbon capture have been subjected to carbon pricing in the EU or in third countries.

Does EU carbon pricing go far enough?

As such, there are ongoing discussions whether applying carbon pricing outside of the EU is enough. While emissions and sector scopes usually differ, carbon prices are also very disparate across geographies. For example 2021 average price of the EU ETS was above €50/tCO_2 while it was below €10/tCO_2 on the Chinese ETS. Mandating that a carbon price equal to that of the EU ETS should be paid could provide for a fairer level playing field. In this regard, the European Parliament would like to develop a methodology to account for all emissions of RFNBO under the EU ETS. Any secondary legislation should ensure that carbon pricing is non-discriminatory between EU production and imports of hydrogen and derivatives.

The Carbon Border Adjustment Mechanism (CBAM) may also be considered as part of the solutions to account for inputs' emissions. If covered by the CBAM, imported RFNBOs and other e-fuels would be considered 'complex goods'. Such goods would be subject to carbon pricing for their total emissions. The CBAM is an environmental policy aiming to encourage decarbonisation in the EU and abroad, by preventing carbon leakage risk. It would 'mirror the EU ETS' for imports of non-EU products, first gradually

Emissions criteria to produce RFNBO and carbon pricing policies should consistently strive for a high level of environmental performance and fairness for EU producers and international partners.

04

05

applying to 5 selected products at high risk of carbon leakage (including fertilisers and ammonia). While the European Parliament proposes to add hydrogen and some hydrogen derivatives on the list, neither the Commission nor the Council supports this initiative.

Considering the Commission's plan to start with a few sectors only, if hydrogen is not covered right from the start, it might as well be in a second stage. However, the coverage of hydrogen and derivatives by the CBAM should come in due time only after an impact assessment has been performed. In this sense, it is key to reduce the administrative burden on importers and put hydrogen and all hydrogen carriers on an equal footing in terms of carbon leakage protection. Indeed, this last condition is crucial to ensure a fair level playing field when it comes to carbon pricing policy, also on inputs such as carbon contained in an e-fuel, between the EU and third countries.

In a nutshell, both the GHG DA and the CBAM could complement each other in regulating emissions from imported fuels and could help ensure the lowest-carbon fuels are incentivised to be consumed in the EU, whether they are produced domestically or imported.

Whatever shape the final rules take, the upcoming DAs on RFNBO production and GHG savings, the CBAM and the potential EU ETS DA will be key determinants for the business cases of RFNBO producers and traders. They will have to be workable and rigorously consistent, providing for legal clarity, environmental trustworthiness, and a fair international level playing field. Ahead of COP 27 in Cairo in November 2022, it will be crucial that policymakers around the globe coordinate on the policies aimed both at *qualifying* and *carbon-pricing* hydrogen and derivatives, to allow the swift emergence of a liquid international market of such fuels and the establishment of hydrogen as an international commodity. ●

REPowerEU

In response to the hardships and global energy market disruption caused by Russia's invasion of Ukraine, the European Commission presented the REPowerEU Plan. It is a plan for:

- Saving energy
- Producing clean energy
- Diversifying our energy supplies

Short-Term Plans

- Common purchases of gas, LNG and hydrogen via the EU Energy Platform for all Member States who want to participate as well as Ukraine, Moldova, Georgia and the Western Balkans
- New energy partnerships with reliable suppliers, including future cooperation on renewables and low carbon gases
- Rapid roll out of solar and wind energy projects combined with renewable hydrogen deployment to save around 50 bcm of gas imports Increase the production of biomethane to save 17 bcm of gas imports
- Approval of first EU-wide hydrogen projects by the summer
- An EU Save Energy Communication with recommendations for how citizens and businesses can save around 13 bcm of gas imports
- Fill gas storage to 80% of capacity by 1 November 2022 EU-coordination demand reduction plans in case of gas supply disruption

Long-Term Plans

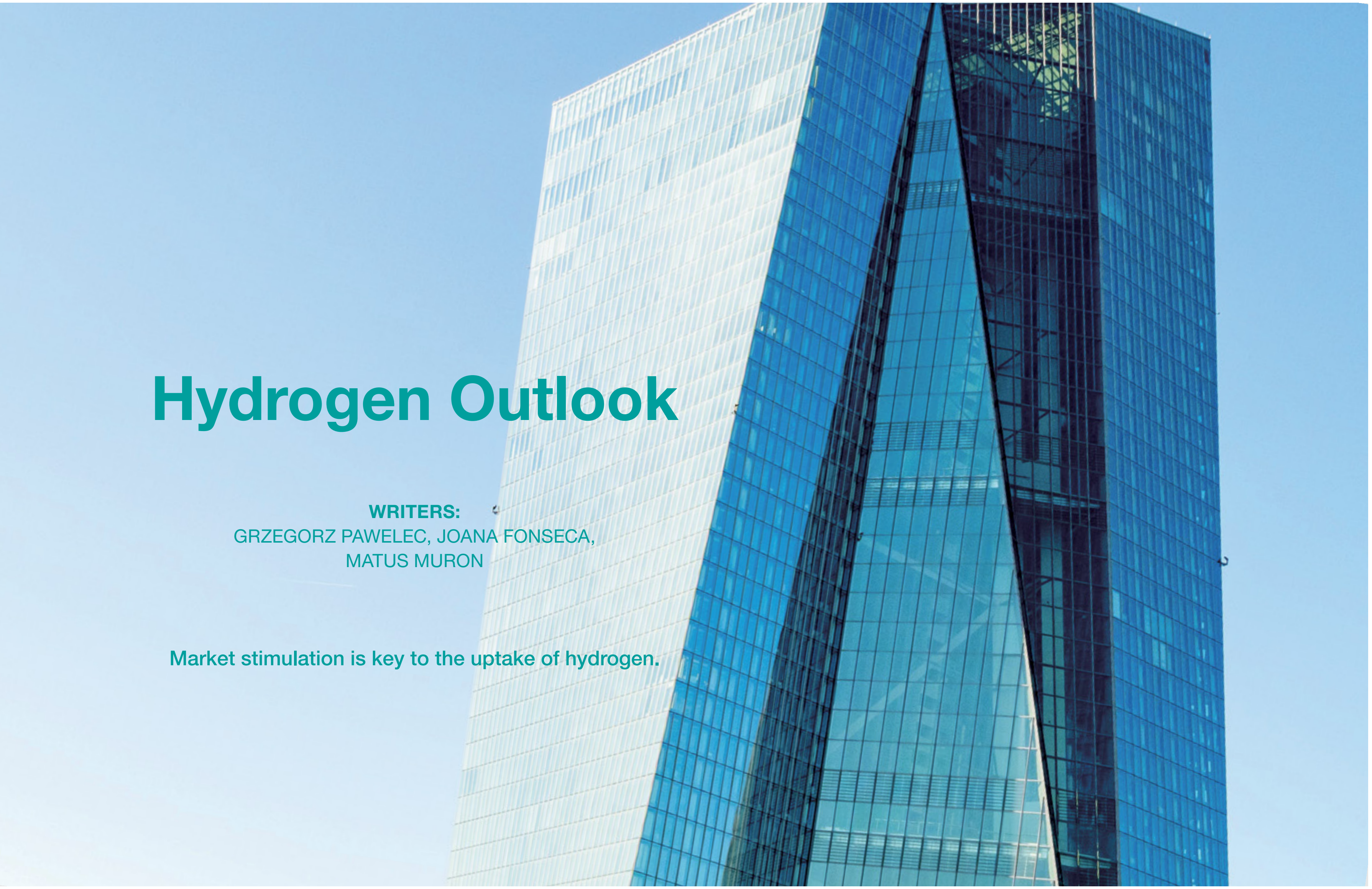
- New national REPowerEU Plans under the modified Recovery and Resilience Fund – to support investment and reforms worth €300 billion
- Boosting industrial decarbonisation with €3 billion of frontloaded projects under the Innovation Fund
- New legislation and recommendations for faster permitting of renewables especially in dedicated 'go–to areas' with low environmental risk
- Investments in an integrated and adapted gas and electricity infrastructure network Increased ambition on energy savings by raising the EU-wide target on efficiency for 2030 from 9% to 13%
- Increase the European renewables target for 2030 from 40% to 45%
- New EU proposals to ensure industry has access to critical raw materials
- Regulatory measures to increase energy efficiency in the transport sector
- A hydrogen accelerator to build 17.5 GW by 2025 of electrolysers to fuel EU industry with homegrown production of 10 million tonnes renewable hydrogen
- A modern regulatory framework for hydrogen

Market Update

Hydrogen Outlook

WRITERS:
GRZEGORZ PAWELEC, JOANA FONSECA,
MATUS MURON

Market stimulation is key to the uptake of hydrogen.



01

The European Hydrogen Strategy identified three main hydrogen development phases: kick-start, ramp-up, and market growth. The hydrogen market is rapidly developing but is following along these main phases.

The kick-start phase, expected to last until 2025, has already begun, with the first pilot multi-MW_{el} electrolysers operating and the first commercial deployments in tens of MW_{el} being deployed in 2022. Expected deployed project sizes are quickly increasing, with projects with up to 200 MW_{el} expected to be deployed by the end of 2024. Despite the existing strategic, political, and industrial commitments to hydrogen deployment, during these years, regulatory clarity, financial incentives, and removal of regulatory hurdles will determine the

Europe's clean hydrogen capacity has grown significantly in the last few years, from 85 MW in 2019 to 162 MW in August 2022.

success of the beginning of the clean hydrogen industry in Europe. By 2025, clean hydrogen will start to be competitive even without incentives in some production locations and industries.

During the ramp-up phase from 2025 to 2035, hydrogen will shift from local to regional and national applications as large-scale storage, hydrogen transportation infrastructure backbones, and hydrogen valleys will be realised while being supported by appropriate measures to stimulate supply and demand. Most hydrogen production and end-uses will have achieved commercial competitiveness at the end of the ramp-up phase. We will witness industrial multi-GW electrolyser deployments. Throughout this period, hydrogen will benefit from further regulatory support including auctions, tenders, quotas, investment support, and tax relief – to allow industrials to invest.

After achieving commercial competitiveness, the post-2035 phase will focus on market growth without any supporting frameworks. Hydrogen will continue to replace unabated fossil fuels across various industries, mobility applications, seasonal

02

01 European Central Bank in Frankfurt, Germany. **Source:** Dimitry Anikin / Unsplash

02 Fertilizer. **Source:** Criniger Kolio / Shutterstock

03 Freight Containers on a Ship. **Source:** Andy Li

storage, and other end-uses. 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.

However, this ambitious growth will depend on developing the entire hydrogen ecosystem, including component manufacturing. These include storage tanks, fuel cells, and electrolysers. There must be sufficient market incentives to build these manufacturing capacities.

While Europe has been dubbed a leader in hydrogen development due to its ambitious policy, other ambitious hydrogen players emerged worldwide in 2022. The US committed $8 billion for its hydrogen hubs and a tax credit of up to $3/kg, which can make electrolytic hydrogen production competitive with steam reforming. Countries around the world are competing to become exporters of hydrogen or hydrogen derivatives, such as Australia, Egypt, Chile, Namibia, and others. China is beginning to challenge Western technologies on cost and, if left unchecked, could take a significant share of the component market.

Clean hydrogen consumption in industry

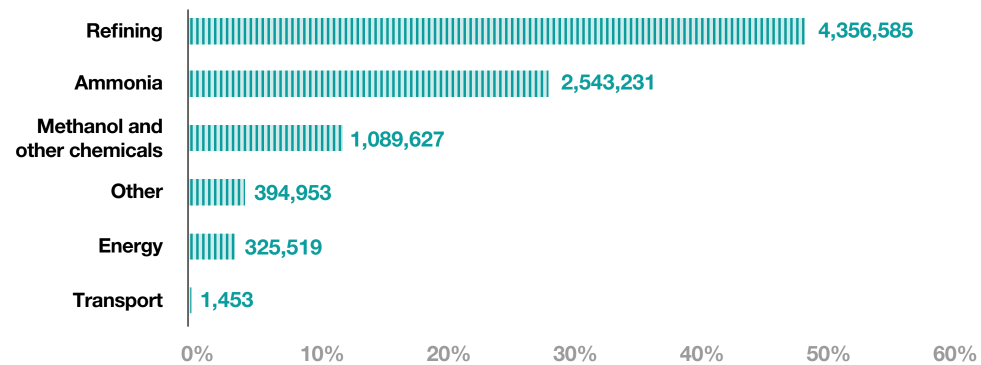
Even if the role of clean hydrogen in the energy transition has only come to the spotlight in recent years, hydrogen has already been used in industry for over a century, especially as a feedstock in chemical processes. The total demand for hydrogen in 2020 in Europe has been estimated at 8.7 Mt, with the largest share of demand coming from refineries and ammonia production facilities. Together, these two sectors consumed almost 80% of total hydrogen consumption in the EU, EFTA, and the UK. About 13% is consumed in the production of other chemicals. Emerging hydrogen applications for clean hydrogen, like the transportation sector, comprised in 2020 only a minuscule portion of the market (<0.1%). **(Fig.1)**

03

Currently, the industry relies on fossil-fuel-based hydrogen to fulfil its demand. With constant pressure to reduce CO_2 emissions and ambitious targets being put in place, many hydrogen-consuming sectors are now transitioning from fossil-based hydrogen to clean hydrogen. This is the case for refineries, where hydrogen is already used to reduce sulphur content in diesel fuel, and the transition into using clean hydrogen reduces the sector's emissions.

Similarly, the ammonia production process is a big hydrogen consumer that can benefit from adopting

Figure 1: Total demand for hydrogen in 2020 by application[1]
Source: Fuel Cells and Hydrogen Observatory



The steel sector has the largest clean hydrogen projects in the pipeline for operating by 2030.

-Hydrogen Europe's Clean Hydrogen Monitor

clean hydrogen. Although it is usually used as a feedstock for fertiliser production, ammonia has recently attracted much attention for its potential as an energy carrier and/or fuel. It is already considered a suitable e-fuel for maritime applications. In the same way, clean hydrogen could help reduce the emissions of producing methanol, used in chemical processes and recently as an e-fuel. E-fuels are synthetic hydrogen-based fuels that can be burned in internal combustion engines and are synthesised artificially when CO and CO_2 react with hydrogen. Provided that carbon is captured from the atmosphere or comes from otherwise unavoidable emissions and renewable electricity is used during the synthesis, e-fuels such as e-methanol, e-ammonia, e-diesel, e-L(N)Gand e-kerosene are great low-carbon alternatives in mobility.

The steel sector is currently not a massive consumer of hydrogen but will most likely become one as it transitions into greener processes. Conventionally, primary steel is produced in Blast Furnace/Basic Oxygen Furnace (BF/BOF) plants, where coal is the reducing agent to transform iron ore into hot metal, and fossil fuels are burned to provide the required heat, resulting in intense CO_2 emissions. Secondary steel, produced from steel scrap in an Electric Arc Furnace (EAF), is already less emitting, depending on the carbon intensity of the electricity. Still, the resulting steel grade is more limited. In a new and greener process, hydrogen acts as the reducing agent to produce Direct Reduced Iron (DRI), which is then converted into hot metal in an EAF. If the hydrogen used is clean and the electricity that fuels the EAF, almost all the emissions from steel production can be abated. The steel industry is, in fact, the sector that currently has the largest clean hydrogen projects in the pipeline to begin operations by 2030, according to Hydrogen Europe's Clean Hydrogen Monitor.

The total planned consumption of low-carbon hydrogen in the industrial projects, in already announced projects tracked by Hydrogen Europe, amounts to 6.1 Mt H_2/year by 2030, with over half of it concerning the steel sector's ambitions alone. **(Fig. 2)**

Based on the plans announced by industrial off-takers, Germany is the country within the EU+EFTA+UK with the most significant ambitions for clean hydrogen consumption in industry, with a total of 2,112 kt H_2/y planned consumption by 2030. **(Fig. 3)**

Figure 2: Planned clean hydrogen annual consumption in announced projects by 2030 by the industrial sector.
Source: Clean Hydrogen Monitor 2022, Hydrogen Europe

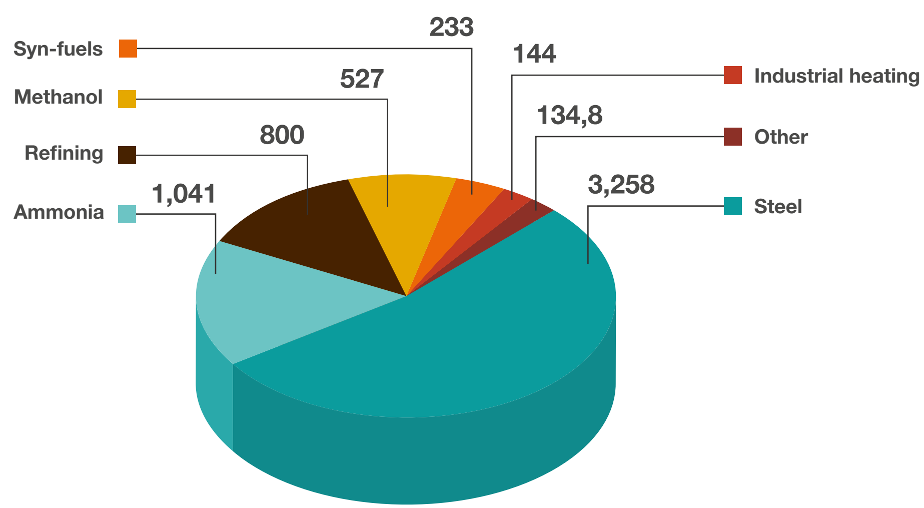
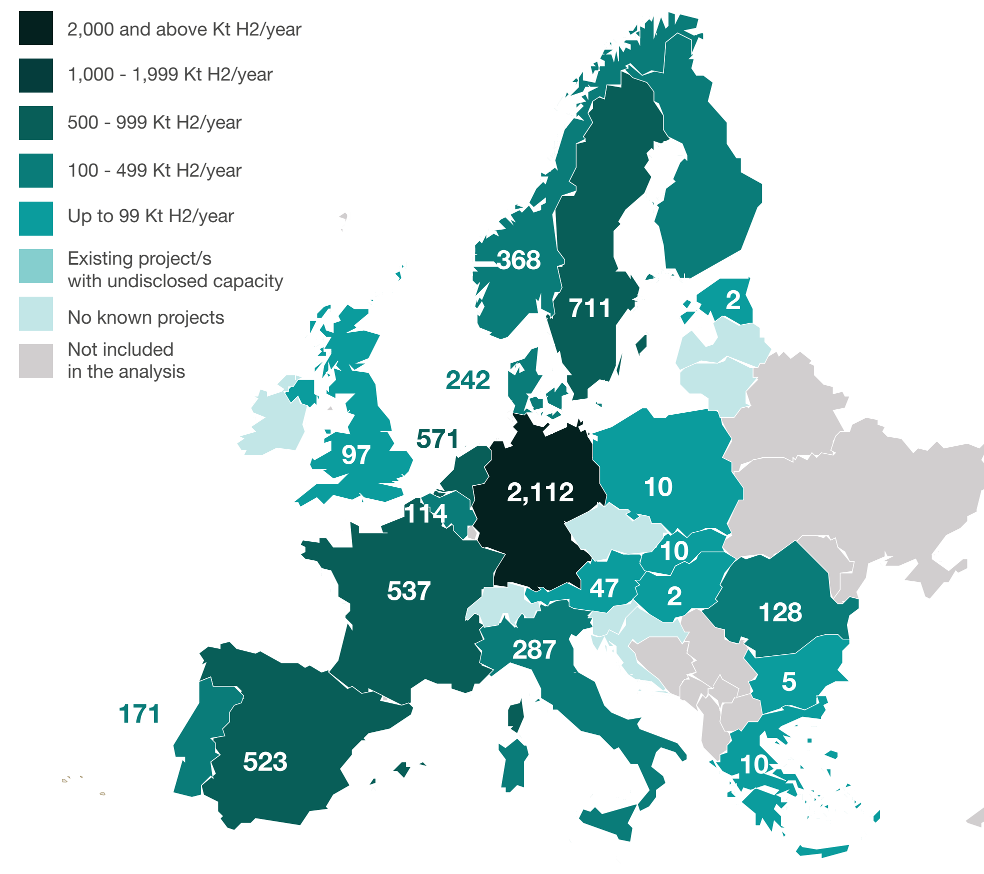


Figure 3: Map of total planned clean hydrogen consumption in the industry by 2030 (including non-disclosed date of operation projects) in the EU+EFTA+UK region, in kt H2/year.
Source: Clean Hydrogen Monitor 2022, Hydrogen Europe



Hydrogen production market and clean hydrogen production market

Most of the current hydrogen production is from fossil fuels. According to the Clean Hydrogen Monitor, there were 504 hydrogen production points in the EU, EFTA, and the UK, with a production capacity of 11.5 Mt of hydrogen per year in 2020. The captive reforming, merchant reforming, and by-production from ethylene and styrene methods constituted 95.6% of the total hydrogen production capacity. By-product electrolysis (i.e., capacity from chlor-alkali and sodium chlorate processes) accounted for 3.7%. Reforming with carbon capture provided 0.5% of total hydrogen production capacity. Water electrolysis, or power-to-hydrogen, accounted for only 0.25% of total hydrogen production capacity as of 2020.[2] **(Fig. 4)**

For reference, the REPowerEU communication has set an ambitious renewable hydrogen production target for 2030 of 10 million tonnes. This is more than the current hydrogen demand of 8.7 Mt and is close to the total current hydrogen production capacity of 11.5 Mt developed over several decades.

Germany, Netherlands, Poland, Italy, and France have the largest hydrogen production capacity. These five countries account for 55% of the total hydrogen production capacity of the EU, EFTA, and the UK. Figure 4 below provides an overview of total hydrogen production capacity by country. **(Fig. 5)**

Figure 4: Hydrogen generation capacity in the EU, EFTA, and the UK by technology in 2020.
Source: Clean Hydrogen Monitor 2022, Hydrogen Europe

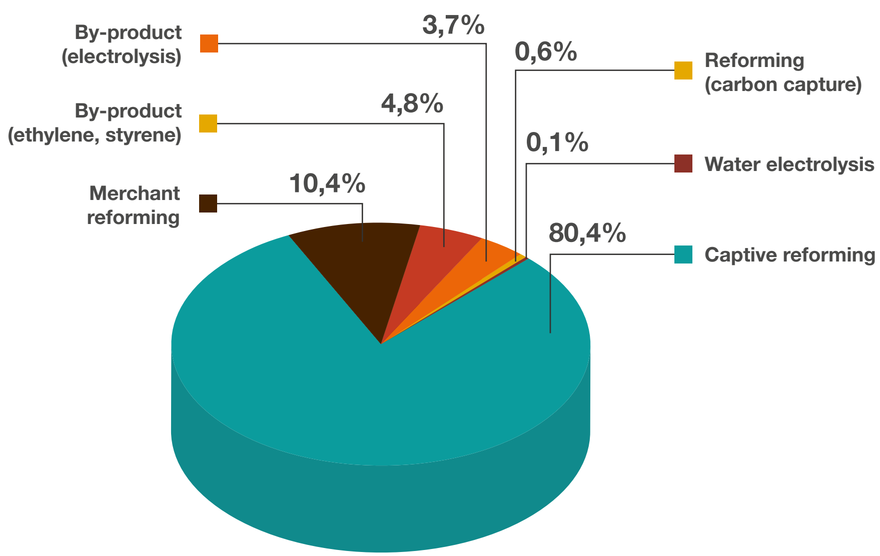


Figure 5: Total hydrogen production capacity by country[3] (in million tonnes per year)
Source: Fuel Cells and Hydrogen Observatory

Clean Hydrogen Capacity

While power-to-hydrogen technology has been available and utilised for decades, new MW-scale commercial facilities are being put into operation.

There was approximately 162 MW of operational electrolysis capacity in Europe by August 2022, according to the Clean Hydrogen Monitor 2022.[4] According to the International Energy Agency, this is compared to about 510 MW deployed globally.[5]

This capacity in Europe has grown significantly in the last few years, from 85 MW in 2019 to 162 MW in August 2022. The average project size gradually increased from 0.9 MW in 2019 to 1.1 MW in 2022. Another sign of this market's gradual development 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, and a 20 MW installation came online in 2022. There are multiple electrolysers of between 50 MW and 100 MW that are in advanced stages of development and are currently scheduled to become operational in 2023. According to the current industry ambitions, several projects in hundreds of MW scale are expected to be operational in Europe by 2024. Unfortunately, many of these projects have been postponed from initially being scheduled for 2023.

As of right now, the largest current 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 decarbonisation plans. An example is the decarbonisation of an ammonia plant or refinery where the owner starts with a small electrolyser as a pilot test, replacing their current fossil hydrogen supply with renewable hydrogen production before committing further and increasing the installed electrolyser capacity.

04

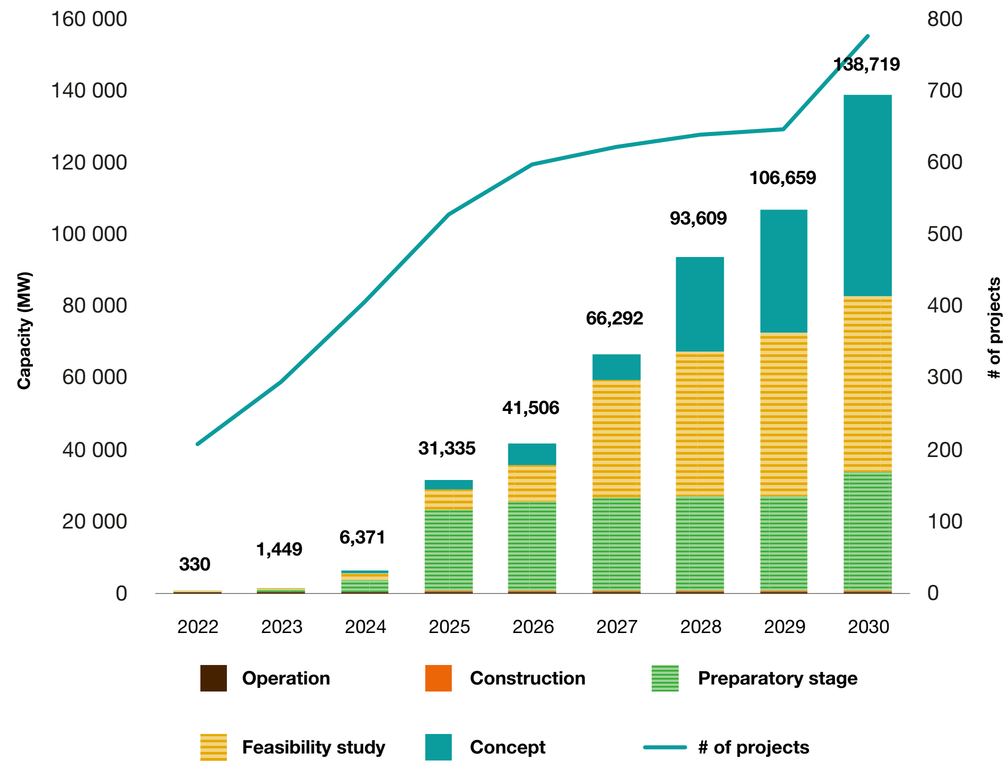
Some smaller but numerous projects in the late stages of development are focused on producing hydrogen for new mobility applications such as fuel cell electric passenger cars, buses, or smaller maritime vessels. These production sources are often distributed and located onsite at a refuelling depot/station.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

As for the future, the REPowerEU ambition of producing 10 Mt of renewable hydrogen by 2030 will require up to 140 GW of electrolysis capacity,[6] depending on electrolyser utilisation in the individual projects. However, according to the Clean Hydrogen Monitor 2022, industry ambitions based on announced projects already amount to 138 GW. Nevertheless, it is essential to note that these projects range from concepts to those under construction, and not all of them are to be realised. The graph below outlines the operational and planned projects according to industry ambitions by 2030. **(Fig. 6)**

04 Hydrogen production plant in Iceland.
Source: Glenmore / Shutterstock

In addition to renewable hydrogen, companies are planning to continue producing fossil fuel-based hydrogen but adding carbon capture technologies to reduce their CO_2 emissions significantly. This is what the public calls blue hydrogen. According to the Clean Hydrogen Monitor 2022, only three operating plants produce hydrogen with carbon capture. However, companies have announced plans for numerous large-scale plants around Europe amounting to 17 GW_{LHV} of capacity by 2030. The most planned capacity is in the UK, followed by Norway, Netherlands, Germany, and other countries.

Figure 6: Cumulative planned and operational PtH projects by the year 2022 - 2030 in MW and # of projects[7]
Source: Clean Hydrogen Monitor 2022, Hydrogen Europe



While the business case outcomes vary depending on the location, industry, and CO_2 price, large-scale emergence of the production side of the market will continue to rely on either supply side or demand side market stimulation, willingness to pay by off-takers, and cost of alternatives such as natural gas. ●

1 The category other refers to hydrogen consumption in glass manufacturing, food processing, hydrogen production that was not allocated to an end-user, and net imports into the country.

2 0.25% refers to 162 MW_{el} operational by August 2022 as a percentage of the 2020 total.

3 Production capacities for Slovenia and Iceland are less than 50,000 t/y, so they show as 0.00 Mt.

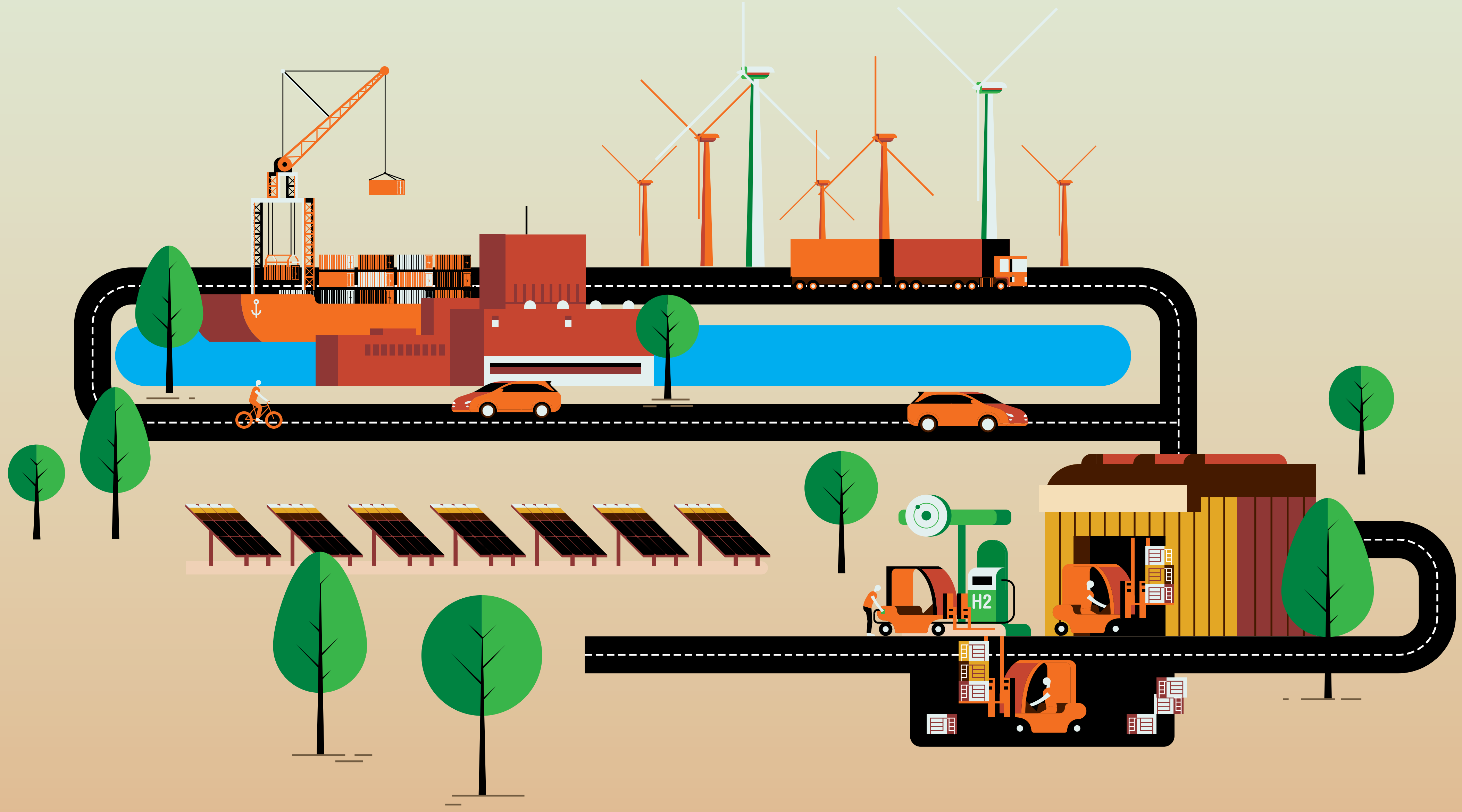
4 Several more projects have come online since then, including an 8.7 MW project in Germany, bringing the total to more than 170 MW.

5 IEA, Global Hydrogen Review, September 2022

6 Electrolyser Summit Joint Declaration, European Commission, May 2022, https://ec.europa.eu/docsroom/documents/50014/attachments/1/translations/en/renditions/native

7 The value for 2022 refers to projects that are already operational and planned to be operational by the end of 2022.

Beyond Europe



The East Africa Hydrogen Corridor

WRITERS:
TOBY GREENBURY, SIEGFRIED HUEGEMANN,
BAMIDELE ADEBISI, INNOCENT UWUIJAREN

We are getting closer to realising the potential of green hydrogen in Africa.

01

The world cannot decarbonise without green hydrogen from Africa

Introducing the Africa Hydrogen Partnership

The African Hydrogen Partnership (AHP) is the only continent-wide African umbrella non-profit association dedicated to the development of green and natural hydrogen that is sourced in Africa. AHP also helps advance the development of hydrogen-based chemicals, fuel-cell technologies and hydrogen-related business opportunities in Africa.

Including a broad range of stakeholders, hydrogen associations have emerged around the world to speed up the green hydrogen revolution and make it happen as efficiently as possible. AHP focuses on promoting green hydrogen in Africa and is committed to sourcing hydrogen produced from water by electrolysis powered by renewable energy. This ‘green hydrogen’ is clean to produce and to consume, with the only emission being water.

In early 2021, AHP started taking in members and only accepts corporate or institutional members (not individual members) but accepts members from anywhere in the world. AHP maintains that the world cannot decarbonise without green hydrogen from Africa, and believes that if the countries in Africa that are able to produce green hydrogen at a competitive cost can do so, then they will become significant energy producers which will revolutionise their economies. The realisation is fast gaining traction.

Matching Supply and Demand for Hydrogen

In 2022, the International Renewable Energy Agency (IRENA) published a world map showing the potential of various regions around the world for producing green hydrogen; and Sub-Saharan Africa is shown to have, by some margin, the best potential of all.

Historically, there has been a perception that a gap exists between supply and demand for carbon-free hydrogen, with both sides lacking 'secure volumes' from the other, and that this central problem needs to be overcome before large-scale commercialisation of green hydrogen can get underway. But the real issue is that the commercialisation of low carbon hydrogen will not be possible until green hydrogen can be sold at a competitive price (in relation to fossil fuels) and once this happens then the 'chicken-and-egg' impasse will disappear.

Once green hydrogen can be sold at a competitive price, supply and demand of the market will develop automatically. In the first instance, we will see this happen where green hydrogen can be provided at the right price for domestic consumption in Africa. At a later date, this will happen in relation to green hydrogen produced for export as well. Whether green hydrogen can be provided at a competitive price depends on where the green hydrogen is going to be consumed: broadly speaking, whether that price is equal to or less than the price at which fossil fuels are sold in the same place, while considering the cost of transportation.

Although it may not make economic sense to export large amounts of green hydrogen to Europe in 2022 (even assuming that the necessary infrastructure had been created) there are a number of scenarios where green hydrogen can be produced profitably and delivered in Africa for domestic consumption. For instance, in many parts of Africa green fertiliser locally produced from green hydrogen will be significantly cheaper than imported grey fertiliser made from natural gas. This is principally because of the high cost of natural gas and the high cost of transportation internationally and within Africa.

02

03

Making fertiliser more sustainable

Some of the best agricultural land in the world is in Africa but it is not as productive as it could be. Some of this is political, but it is also because the land is simply under-fertilised. As a continent, Africa is shockingly under-fertilised, in comparison to other parts of the world. For instance, the fertiliser per hectare of cropland in Africa is five times less than the global average. And because the inherent demand for fertiliser is already there, fertiliser plants in those parts of Africa should be capable of being financed and built today.

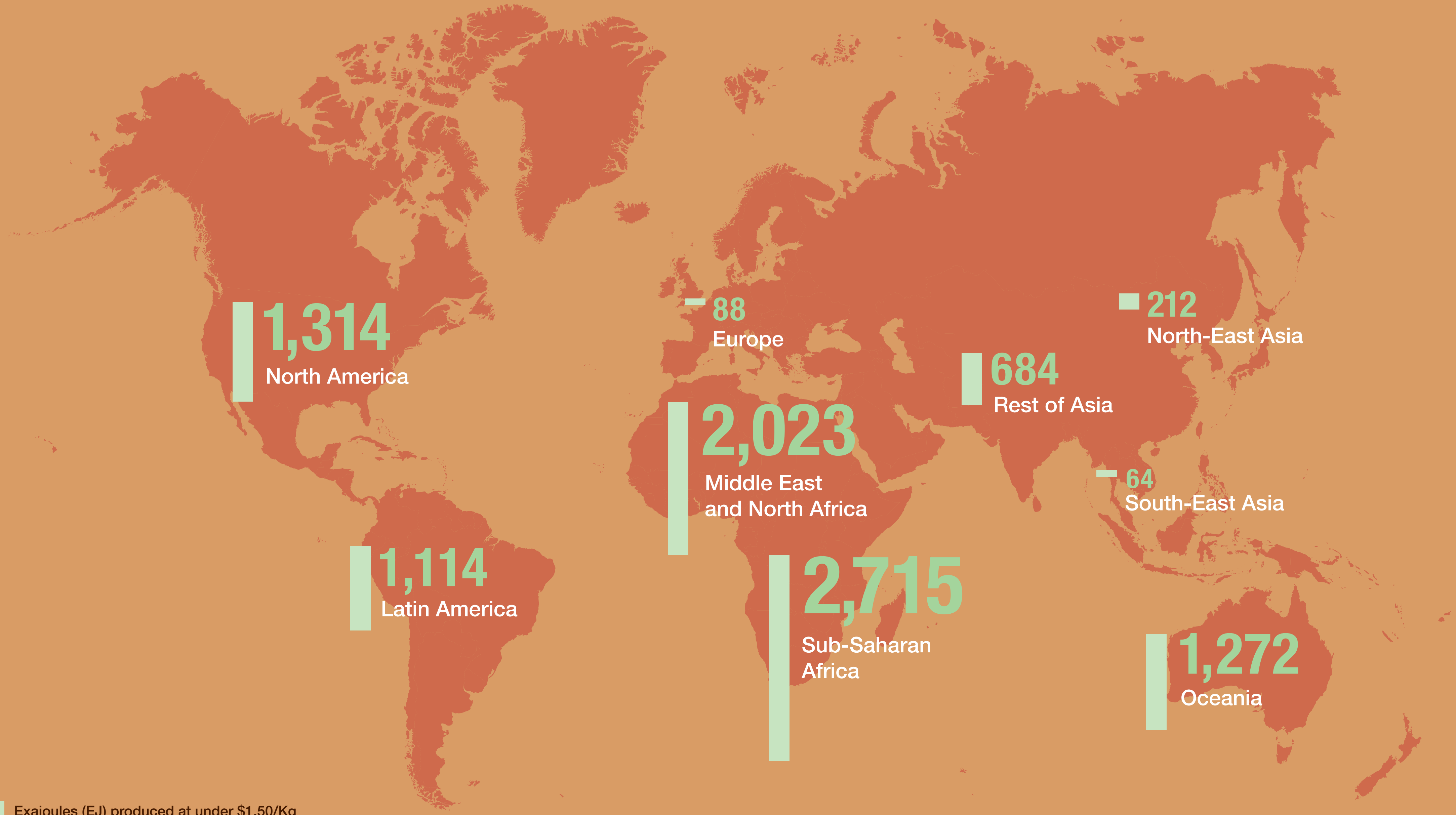
01 Tsavo East National Park Kenya, Kenya.
Source: Damian Patkowski / Unsplash

02 Boy playing 'cat's cradle'. Uganda.
Source: Alex Radelich / Unsplash

03 Maasai Mara, Kenya.
Source: Pop & Zebra / Unsplash

As a continent, Africa is shockingly under-fertilised, in comparison to almost all of the rest of the world.

Technical Potential for Producing Green Hydrogen



Exajoules (EJ) produced at under $1.50/Kg

Source: IRENA (2022) Geopolitics on Hydrogen (Adaptation)

04

05

04 Dar es Salaam, Tanzania. **Source:** Patricia Hokororo / Unsplash

05 Victoria, Dar Es Salaam, Tanzania. **Source:** K15 Photos / Unsplash

06 Lilac-breasted Roller, Lewa Wildlife Conservancy, Isiolo, Kenya. **Source:** David Clode / Unsplash

These fertiliser plants can use green hydrogen as a feedstock – rather than as an energy vector; and they will be able to produce green hydrogen for hydrogen-powered vehicles and green ammonia for ammonia generators. In 2022, some 600-700 million people in Africa are still not connected to the electricity grid. Ammonia generators could help provide much needed power for lighting and cooking in people's homes. With time and in the right locations, green ammonia can be used for shipping or maritime purposes. In addition, baseload renewable power plants, using hydrogen to balance the intermittency of renewable energy, will also make financial sense, in some regions.

Spotlight on Somaliland and Tanzania

All of the required technologies are well established as the green hydrogen revolution begins to get underway, with new technologies and further improvements increasing competitiveness. The development of a new market only really starts with the development of a profitable business. This itself attracts new businesses into the sector and provides the funds for them to grow and develop. This thought was behind AHP's delegation to **Somaliland** and Tanzania: to see what hydrogen-related businesses could be established in these countries today.

The delegation consisted of AHP members, which either together or separately have the capability to build green fertiliser plants in Africa and other facilities to meet existing needs in Africa, including baseload renewable energy and waste-to-energy hydrogen plants, as well as ammonia generators. Preliminary calculations and initial discussions were promising but there is no substitute for actually seeing and going to the countries concerned.

The wind and solar maps show that Somaliland had formidable onshore wind and solar but experiencing it in person was deeply impressive. Somaliland is a potential future hydrogen superpower, located in an increasingly key location. Yet Somaliland is a country where, due to the cost of fossil fuels, electricity is very expensive. Given this, Somaliland is an ideal country for green hydrogen to be deployed now.

Somaliland has a population of around 5 million people and is the size of England and Wales. Its immediate neighbour is Ethiopia with large fertile regions and a population of more than 110 million people. Tanzania has a population of more than 60 million people and large fertile areas in most of its political districts.

Tanzania is blessed with hydropower, geothermal energy and the potential for harvesting wind and solar energy. In central and western Tanzania there is a very strong potential for producing solar and onshore wind power – the least expensive renewable energy sources. Additionally, there are large open (arid) spaces in these regions which allow the construction of larger renewable energy facilities while minimising the impact on the environment. Tanzania is planning a major new Port at Bagamoyo, which has significant green hydrogen implications, as does the Port of Berbera in Somaliland.

In 2022, 600-700 million people in Africa are not connected to the electricity grid.

06

The delegation made presentations and held discussions in Somaliland with the private sector, but in Tanzania most of our discussions were with senior officials (including the Minister of Foreign Affairs) and officials in Dar es Salaam, Bagamoyo and Zanzibar. In both countries there was great interest in developing hydrogen and several opportunities were identified and will be followed up by the companies involved, supported as required by the AHP. And when one or more sectors are underway, it will be possible to turn to other sectors which will then become more connected and attractive.

The East African Green Hydrogen and Fertiliser Corridor

East Africa has great potential for producing low-cost green hydrogen that will benefit its large populations as well as its strong domestic and agricultural sectors. For these socio-economic reasons, the AHP is focusing on creating a Green Hydrogen and Fertiliser Corridor for East Africa:

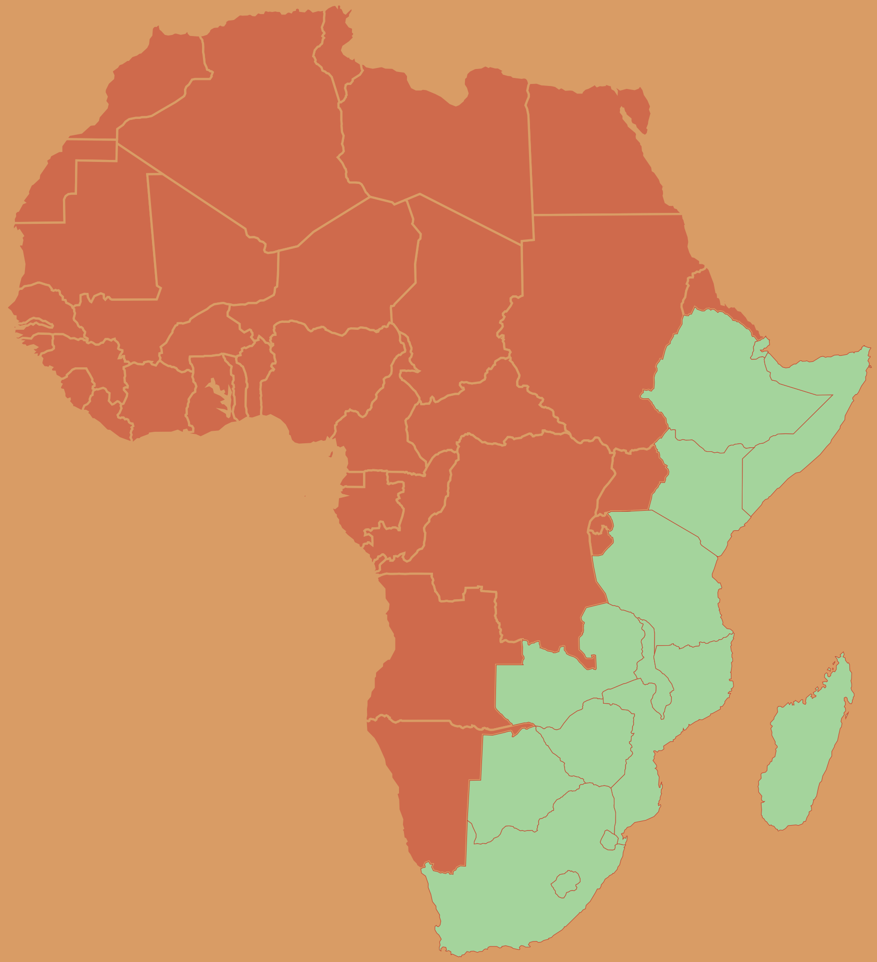
The Hydrogen Ecosystems involved will include:

- baseload renewable power supply using hydrogen
- green fertiliser production
- grid independent power supply
- waste-to-(hydrogen)power
- maritime shipping sector
- mining, land transport, industry

The East African Green Hydrogen and Fertiliser Corridor will:

- use CO_2 emission-free technologies
- develop East Africa as a highly productive agricultural region
- mitigate the risks associated with food shortages and related market risks
- support socio-economic development as well as the creation of jobs and wealth

We will achieve the first large-scale commercialisation of clean, sustainable and renewable green hydrogen worldwide.



A corridor consisting of several neighbouring countries will allow developers to diminish their (national) risks and to interconnect the evolving hydrogen ecosystems in different regions of East Africa. Additionally, market and default risks will be reduced by working with green hydrogen programmes for a variety of market sectors, such as power supply using green hydrogen, green hydrogen as a feedstock for green fertiliser production or as a fuel for the maritime transport sector. Risk reduction will lead automatically to lower financing costs. Economically and commercially feasible green hydrogen and fertiliser business development opportunities already exist in East Africa now.

Acknowledgements

Hydrogen Europe and REVOLVE are grateful to the African Hydrogen Partnership (AHP) for their participation in the 2022 edition of the 'Beyond Europe' focus on Africa. We are also very grateful to our respective teams for the time and effort put into making this report a success.

Thank you!

Contact

For print copies, corrections, or other inquiries, please contact:

Michela Bortolotti, Director of Communications

Hydrogen Europe Secretariat (White Atrium)
Avenue de la Toison d'Or 56- 60
1060 Brussels, Belgium

T: +32 2 540 87 75 **E:** m.bortolotti@hydrogeneurope.eu

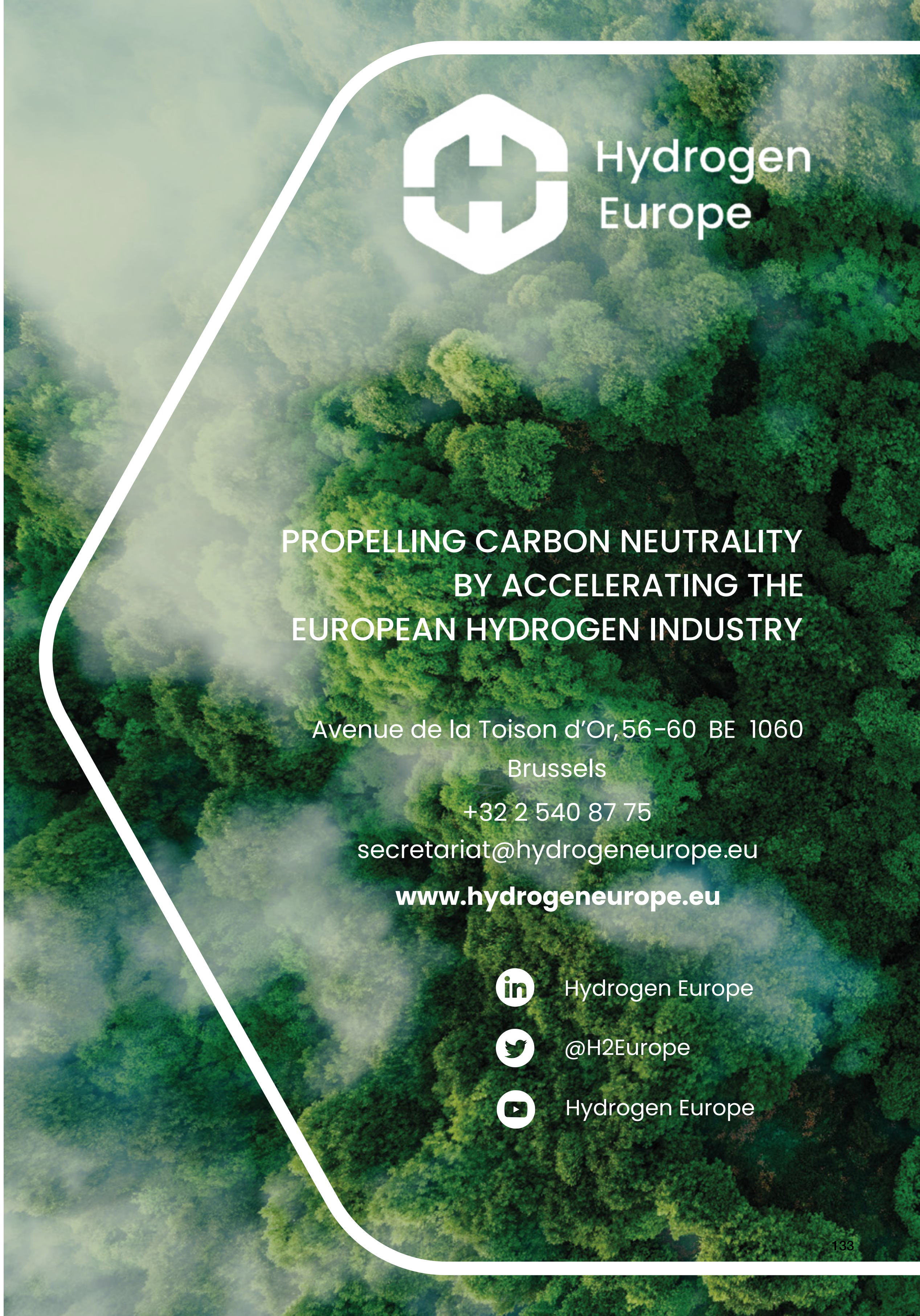
Disclaimer

This special report on **Hydrogen, Enabling A Zero-Emission Society** is produced by Hydrogen Europe and curated by REVOLVE. All opinions expressed in the content provided are those of the authors and their respective companies and do not necessarily reflect the opinions of REVOLVE or Hydrogen Europe. Any errata that may be present in the core content of this report are the responsibility of the producers and curators and in no way can be attributed to the Members of Hydrogen Europe. If you spot are errors, please contact: secretariat@hydrogeneurope.eu and info@revolve.media.

Colophon

This report is printed on 100% recycled and chlorine-free paper by ARTOOS Group that is conscientious of its environment footprint caused by printing and therefore offsets its emissions with carbon credits in a sustainability project. ARTOOS calculates the emissions causes by the amount of paper used and printed, and then the partner purchases the certificate from ARTOOS.
For this report, ARTOOS will contribute to the Clean Drinking Water "Spouts" Project in Uganda.
More details on ARTOOS sustainability here: www.artoosgroup.eu/mvo/

artoos group
✔ SUSTAINABLE DEVELOPMENT
✔ ISO 14001
✔ 100% GREEN POWER
RECYCLED
Paper | Supporting responsible forestry
FSC® C007370
PRINTED CLIMATE NEUTRALLY
CERT. NR : 53520-2211-1002



A Special Report by

REVOLVE