AQUA

# OUR PATH TO GREEN HYDROGEN

## The Future of Water: Human and business priority

January 2022

Point-of-View

BDO

# Contents

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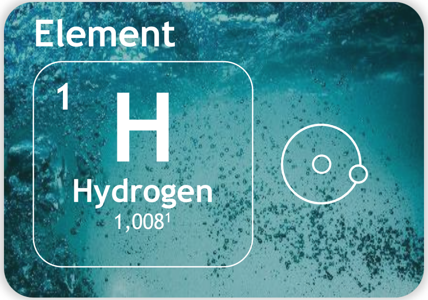
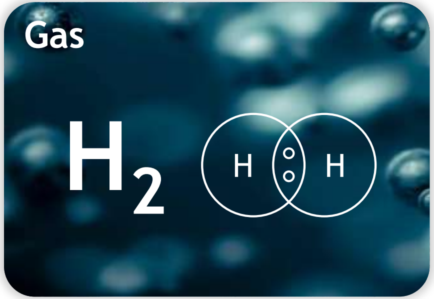
# Did you know that…




## Hydrogen means

«Creator (-gen) of water (hydro-)»:
Its combustion releases only water

H H O $H_2O$




The lightest and the most abundant element in the universe

The cheapest technique for producing hydrogen from hydrocarbons is steam reforming of fossil fuels, which currently accounts for almost 98% of current production

**Fossil fuel** + $H_2O$ > Reforming > $H_2$ $CO_2$

Due to its weight, which is less than air, $H_2$ is rarely found on Earth in its pure form, being locked up in water and hydrocarbons

14x lighter than air

H H

Gaseous at ambient conditions

Colourless, odourless

Source: International renewable energy agency — Green hydrogen: a guide to policy making — [2021]; Media overview
Notes: (1) Atomic mass unit which is defined as precisely 1/12 the mass of an atom of carbon

# On the path to the global economy decarbonisation, hydrogen might be a promising solution for some sectors

**40%**
of $CO_2$ emissions are caused by power generation and buildings' heating

**23%**
of $CO_2$ emissions are generated by the manufacturing industry

**23%**
of $CO_2$ emissions globally are produced by the transport sector

## Easy-to-decarbonise sectors and clean solutions to reduce emissions

### Power generation
**Transition to renewables** such as hydropower, wind or solar instead of fossil fuel is aimed to **decarbonise the economy to a large extent**

### Buildings' heating
Improvements in **energy efficiency** and implementation of **heat pumps** might considerably decrease the carbon footprint of the heating industry globally

### Passenger Transport
Transport is a **large contributor to $CO_2$ emissions** and can be addressed through passenger cars due to the growing number of **battery-powered electric vehicles** on the global market

### Low-temperature industry
Industrial processes that do not require high temperatures **can be largely electrified for reducing the industrial carbon footprint**

## Hydrogen fuel as the most promising solution for hard-to-decarbonise sectors

### Power generation
Seasonal storage of hydrogen is a backup power solution in periods of low wind or solar production, as well as mitigating risks of reduced demand and excess production of renewable energy

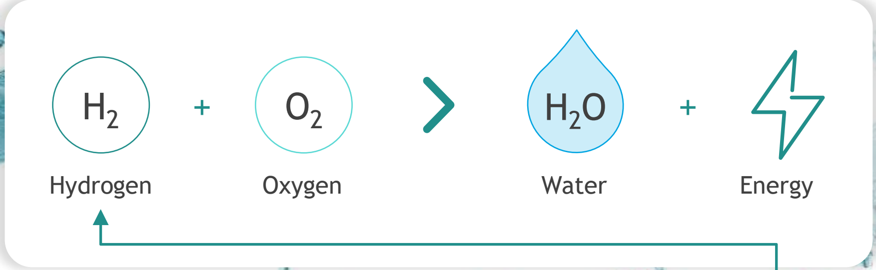
### Transport
**Heavy-duty vehicles and ships are** hard to electrify due to the size and weight of batteries needed for this purpose. Hydrogen appears to be a far better solution through introducing **fuel cells that** contain the fuel with **less weight but higher efficiency**. It might help to reduce the sector's $CO_2$ emissions by 67,0%

### High-temperature industry
Some **industrial processes require high temperatures** such as steel and ceramic production, etc., and may still need fuel to burn. Thus, burning green hydrogen leads to producing no emissions

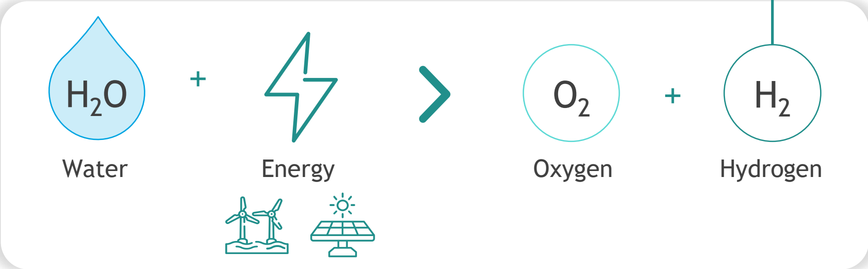
 Source: Goldman Sachs — Green hydrogen — [2021]; IEA — The role of CCUS in low-carbon power systems — [2020]

# Green hydrogen provides clean energy and is expected to significantly contribute to global emissions reduction

## Water and energy are the only products of hydrogen combustion




## Green hydrogen production totally excludes the carbon footprint




### Power generation

Using **100,0% hydrogen fuel** in the hydrogen fuelled turbines for stationary reduces the $CO_2$ emissions of the power plant by 99,0%. **Hydrogen blending with natural gas** is being considered to reduce $CO_2$ emissions as a near-term alternative to operating on 100,0% natural gas.

### Heating

Hydrogen has the potential to **replace methane and natural gas as a source of domestic heat**. Among its benefits is an easier switch vs. other alternatives.

### Transport sector and space exploration

Energy conversion from hydrogen fuel via **fuel cells or internal combustion engines** is an efficient alternative for the transport sector to reduce GHG[1] emissions.

Liquid hydrogen fuel plays an important role in **space exploration** as a **provider of motive power for liquid-propellant rockets.**

### Energy source for manufacturing

Hydrogen can produce **medium and high-grade heat** and hence provide an alternative to fossil fuels in manufacturing processes, such as steel, cement and chemicals production.

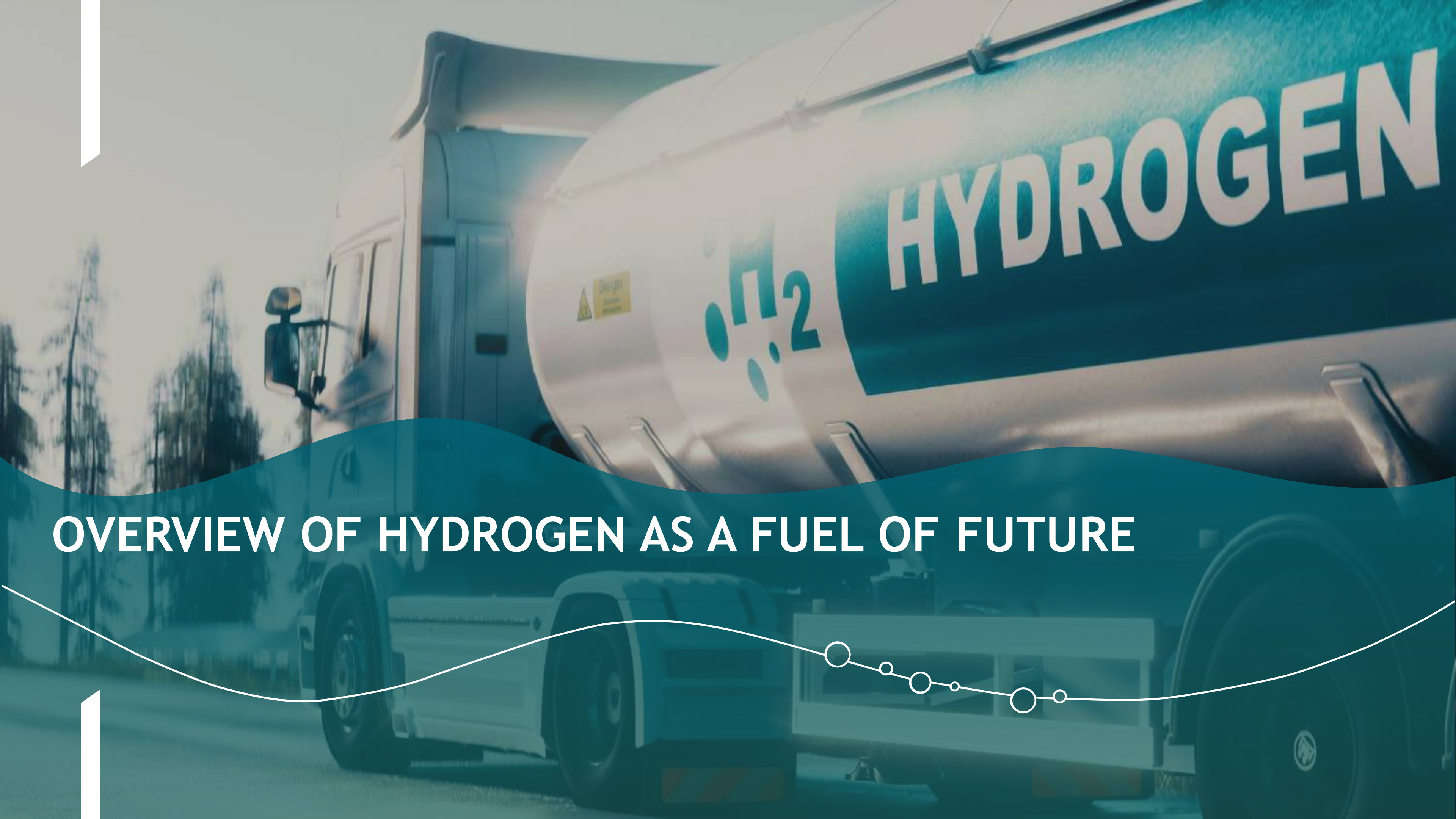
### Non-energy applications

**Hydrogen is primarily used in the refining and chemical industries.** About 55,0% of its use goes to **ammonia production**, 25,0% is used in refining, and about 10,0% is used to produce **methanol.**



Notes: (1) Greenhouse gas

# OVERVIEW OF HYDROGEN AS A FUEL OF FUTURE



# Due to its valuable properties, hydrogen has the potential to become the crucial element of sustainable economy

## Key properties of hydrogen as an energy source

### Availability
Hydrogen is a **frequently-met element** in the Universe

### Non-Toxicity
Hydrogen is a **non-toxic source of energy**, which differs from fossil or nuclear energy

### Efficiency
Hydrogen is viewed as capable of **providing services where electricity is not available**

### Explosiveness
Hydrogen can be explosive with oxygen concentrations ~18,0-59,0%, but it is still **20 times less** explosive than gasoline

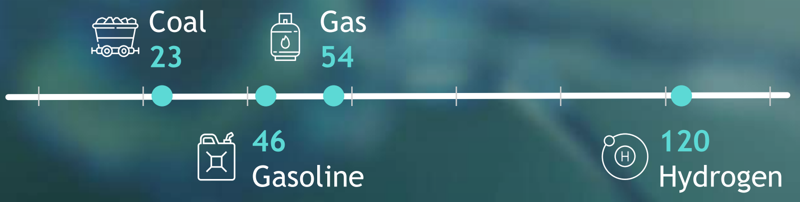
### Production
Hydrogen can **be made with any primary energy source,** including renewables

### Energy storage
Hydrogen is a gas, thus it is **more easily stored than electrical power**

### Low / negligible emissions
Usage of hydrogen fuel leads to lower $H_2O$ emissions, only water vapor and oxygen are emitted

### Expensiveness
Per unit energy, hydrogen produced by steam reforming costs ~ **three times as much as natural gas**

## Energy density of hydrogen, MJ/kg[1]

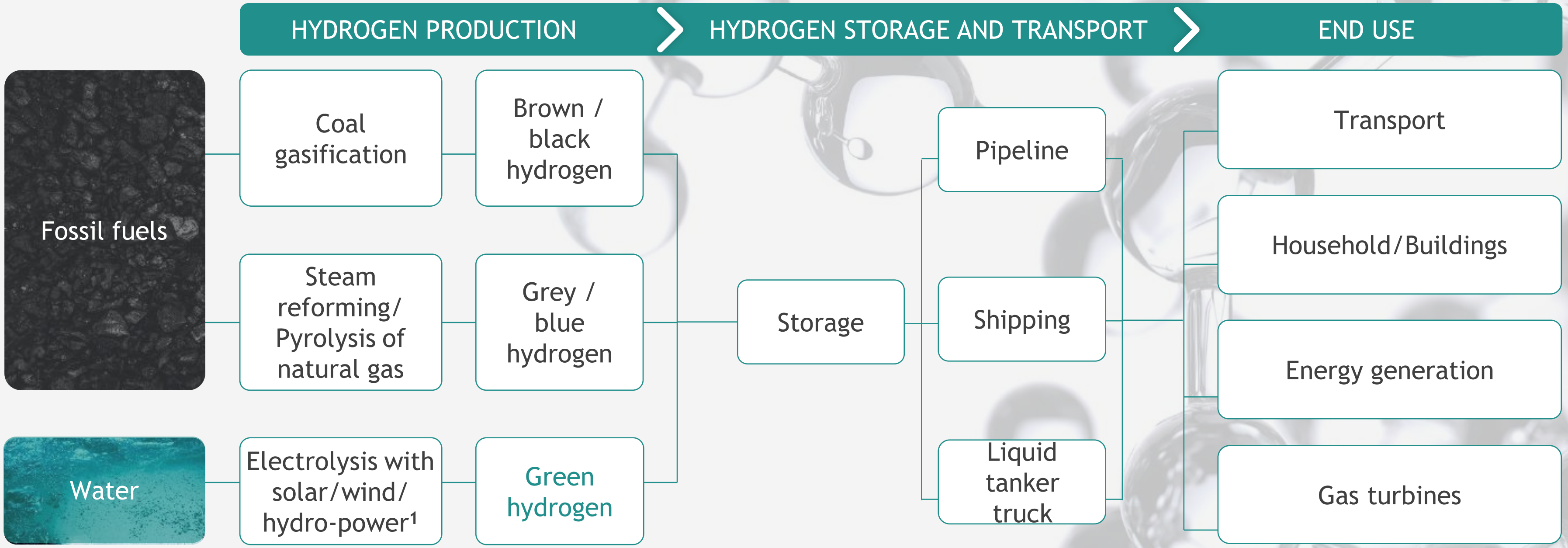



- A kilogram of hydrogen contains **three times more energy** than gasoline and **twice more** than natural gas
- The energy content is a particular advantage in the transport sector, where the energy density of hydrogen is **100 times higher than the density of the most efficient batteries** recently available on the market
- Fuel-cell vehicles are lighter than battery-powered ones due to the higher energy density, therefore, the **hydrogen-fuelled trucks can weigh 50,0% less than the ones powered** by ion-lithium batteries

Source: IEA — Global Energy Review — [2021]; Goldman Sachs — Green hydrogen — [2021]
Notes: (1) Megajoule per kilogram

# The value chain of green hydrogen differs from other types of hydrogen by the zero-carbon production process

**Hydrogen value chain**




Source: IRENA — World Energy Transition Outlook — [2021]; IRENA — Hydrogen from renewable power — [2018]
Notes: (1) Carbon-neutral production process

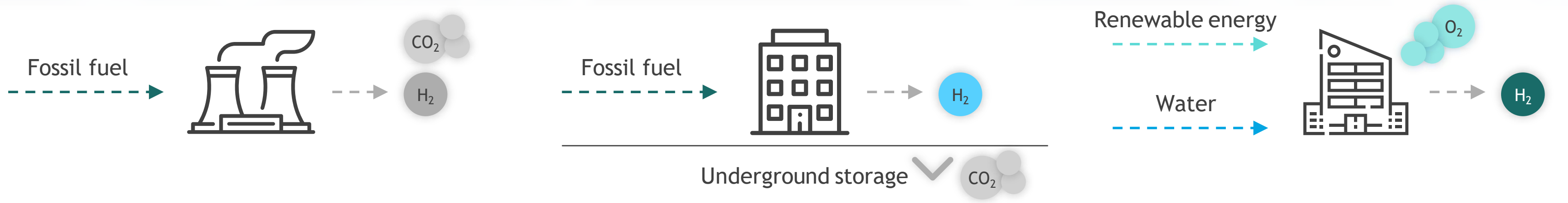
# Green hydrogen is the cleanest of all existing hydrogen types, as it is produced from water using renewable energy

## Hydrogen production process by type of hydrogen

**Hydrogen**

Gaseous chemical element functioning as an energy carrier

**Grey hydrogen** | **Blue hydrogen** | **Green hydrogen**[2]




Hydrogen is produced from fossil fuels through the steam reforming process. $CO_2$ is emitted into the atmosphere

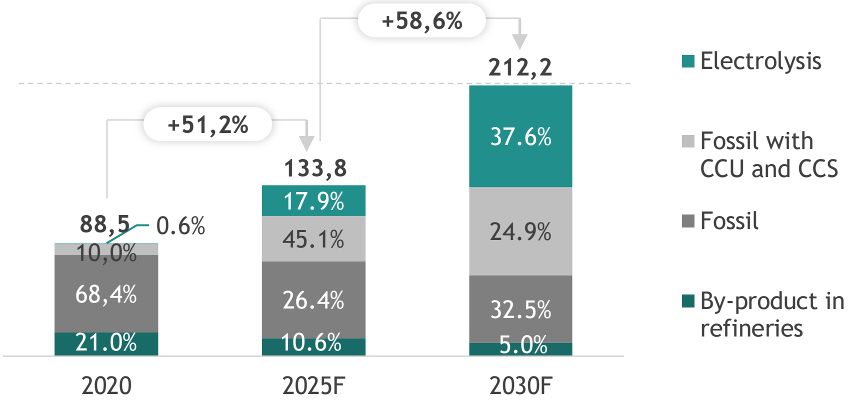
Produced from natural gas through steam reforming with CCS[1] technology, where $CO_2$ emissions produced are then captured and stored

Produced splitting water by electrolysis using renewable energy, where hydrogen and oxygen are the only final products, and oxygen is vented to the atmosphere with no negative environmental impact

Source: World Energy Council – National hydrogen strategies – [2021]; Goldman Sachs – Green hydrogen – [2021]; Statista website
Notes: (1) Carbon capture and storage; (2) Green hydrogen represents all types of hydrogen produced via renewable sources (green, purple/pink, yellow)

# Green hydrogen demand is projected to increase rapidly due to technology improvement and costs optimisation

## Global hydrogen demand by production technology up to 2030[1,2], million tonnes




- The use of low-carbon hydrogen in **refining faces an economic barrier** due to its higher cost compared to unabated fossil-based hydrogen
- **The solution to an uncompetitive cost will presuppose a drop in electrolysis costs** and in the price of renewable electricity, as well as an increase in load factors
- The competitiveness of hydrogen **can be boosted by hydrogen injection into the gas grid**, which decreases the natural gas consumption

## Green hydrogen industry drivers

- **The price** for solar- and wind-produced electricity **tends to decrease**
- Increasing government support due to **net-zero GHG emission pledges**
- Countries' interest to become **net exporters of green hydrogen**
- Hydrogen-related technologies are ready for **commercialisation**

## Entry barriers

- Currently green hydrogen is **three times more expensive** than grey hydrogen
- **5,0 thousand km of hydrogen** pipelines against **100,0 million km of natural gas** pipelines worldwide
- **Energy losses** while producing hydrogen through electrolysis are **~30,0-50,0%**
- **Lack of value recognition** as hydrogen is not counted in official energy statistics of total energy consumption

Source: IEA — Hydrogen: more efforts needed — [2021]; IEA — The future of hydrogen: seizing today's opportunities — [2019]
Notes: (1) According to the countries' specific Net Zero Scenarios, which are aimed at achieving net-zero emissions over the coming decades; (2) Forecast is based on the Net Zero Emissions scenario

# 2. GREEN HYDROGEN: PRODUCTION PROCESS

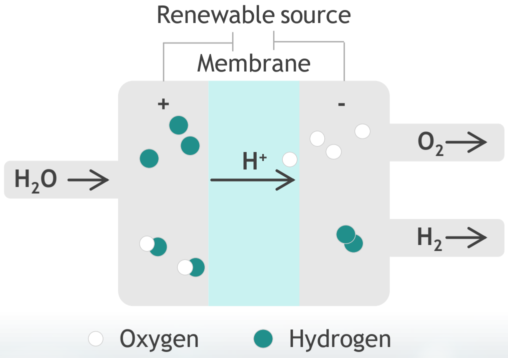
# Green hydrogen is being produced from water using electrolysis technology and renewable energy

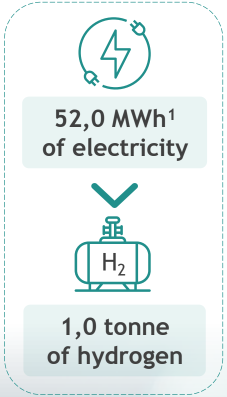
## Concept of electrolysis

**Electrolysis** is a process of using electricity to split chemical compounds into separate molecules. An electrolysis unit is called an **electrolyser.**

It is often used to refer to the electrolysis of **water specifically**, whereby water is split into hydrogen and oxygen.

Electrolysis technologies have experienced significant developments by **increasing system effectiveness** to more than 80,0% **and prolonging the operational lifetime of the process** to 80,000 hours.




## Commercialised electrolysis technologies[2]

### Proton exchange membrane (PEM)

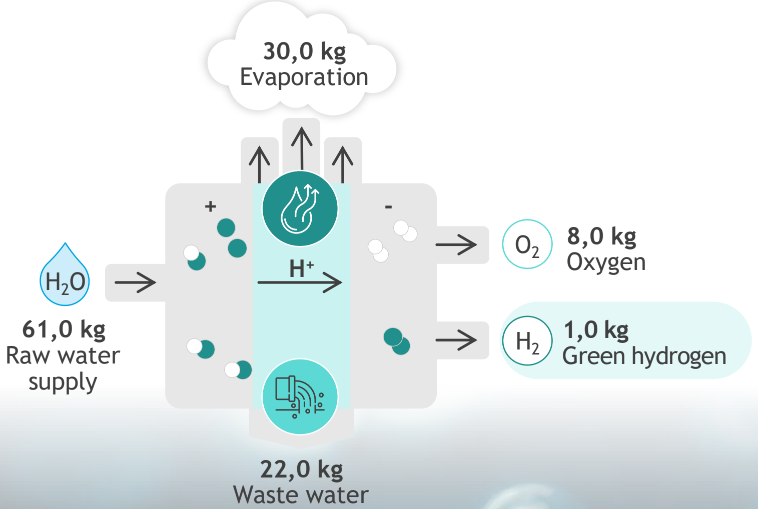
- PEM electrolysers tend to have a **lower plant $CO_2$ footprint** in comparison with alkaline membrane electrolysers
- The PEM electrolysis process tends to be **more flexible in producing green hydrogen with various renewable energy sources**
- Due to the PEM electrolyser's technical specification, **PEM technology is more suitable for large-scale hydrogen production**

### Alkaline

- The alkaline membrane electrolysers **offer the cheapest cost per kW as well as cheaper capital costs** compared to PEM technology
- Due to the low cost of supplies, labour accounts for a **major expense of the alkaline electrolyser**, assuming significant economies of scale
- The alkaline electrolyser's technical specification makes **it best suited for small- and medium-scale hydrogen production**

Source: Goldman Sachs – Green hydrogen – [2021]; Media overview
Notes: (1) Megawatt hour; (2) There are four types of electrolyser: Alkaline and polymer electrolyte membrane (PEM) are already commercial, while anion exchange membrane (AEM) and solid oxide are currently at lab scale

# On average, 61 kg of raw water is required for the full production cycle of 1 kg of green hydrogen




## Water supply and disposal factors in green hydrogen production

### Raw water requirements

61,0 kg of raw water is averagely needed to produce 1 kg of green hydrogen. While 20,0%-40,0% of this water is sent to waste due to high purity electrolyser necessities.

### Water for cooling of electrolysers

The electrolysis requires from 30,0 to 40,0 kg of raw water per 1 kg of hydrogen for operations in the cooling system, which also accounts for evaporation and drift losses.

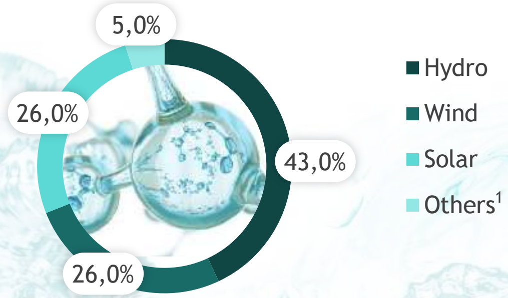
### Water disposal

Due to the quality of water after the production of hydrogen, it should be utilised with special facilities to avoid waste water discharge into the environment.

 Source: DENA German Energy Agency — Global Alliance Powerfuels Brief — [2021]; Media overview

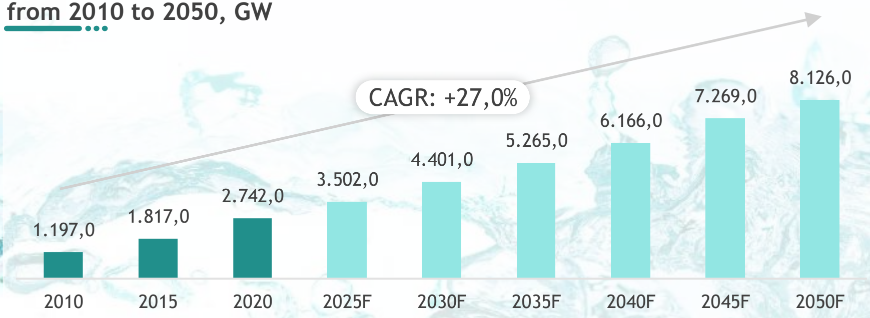
# The growth of the renewable energy generation capacity secures future energy supply for the hydrogen production

## Shares of renewable generation capacity by energy source, 2020




- The main sources of the renewable generation capacity are **hydropower, wind and solar energy** that together with the other sources brought **2.742,0 GW in 2020 worldwide**
- **Hydropower** accounted for **the largest share of the global total renewable generation capacity** produced in 2020 with 1.179,1 GW, while wind and solar energy represented equal shares with 712,9 GW each
- Asia is considered to be the **leading region in terms of renewable capacity installed in 2020** and constituted 46,0% of the global total capacity

## Dynamics of installed renewable energy generation capacity worldwide from 2010 to 2050, GW

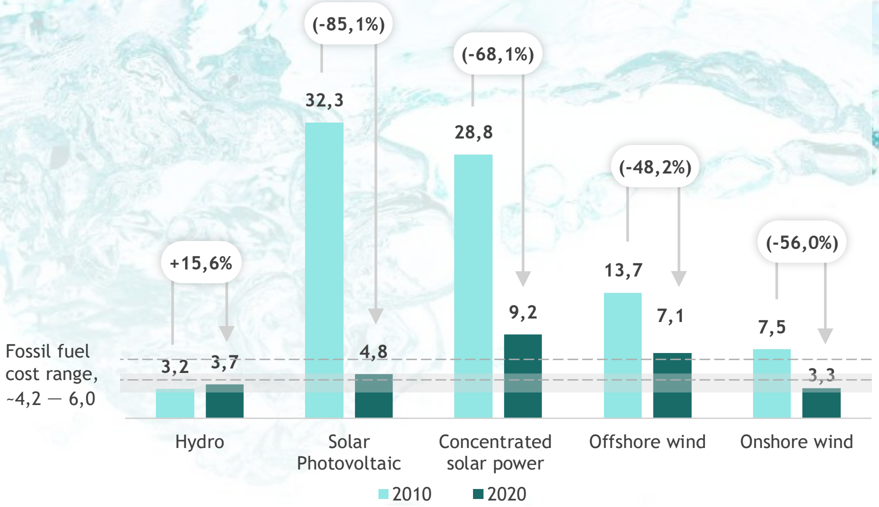



- The **installed renewable energy generation capacity** has been steadily **increasing since 2010** and **rose by 2,3 times over 2010-2020**
- Over 2010-2050, the installed renewable energy generation capacity **is forecasted to grow significantly at a CAGR of 27,0%** and reach **8.126,0 GW in 2050,** which is **almost 3,0 times higher compared to 2020**
- **All renewable energy sources** demonstrate a stable increase in capacities, with China and the USA contributing the most in the **growth of the total generation capacity worldwide over 2010-2020**

Sources: IEA – Global Energy Review – [2021]; IEA website; Statista website; IRENA IREA – Renewable capacity highlights
Notes: (1) Other renewables include bioenergy, geothermal and marine energy with a combined share of 5,0% of the total renewable generation capacity

# The significant drop in renewables prices has already improved the economy of green hydrogen production

**Global LCOEs[1] of different types of renewable energy sources, 2020 vs 2010, Eurocents\KWh**




**Key insights**

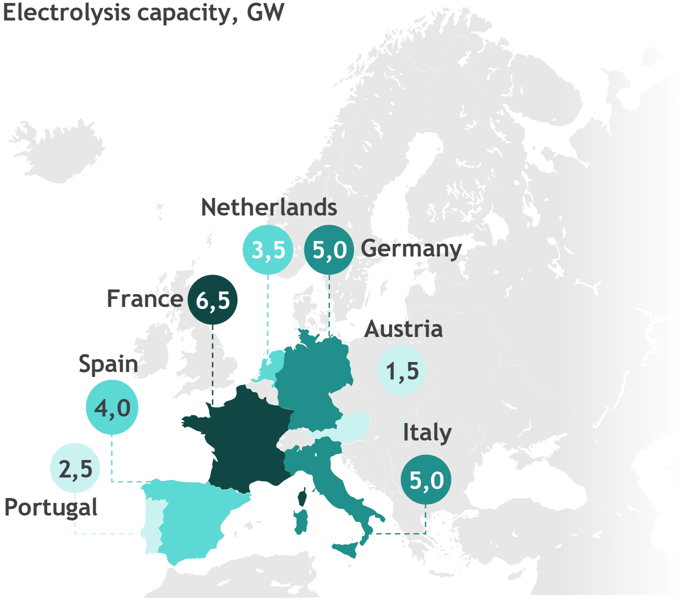
- For the last 10 years, the global weighted-average LCOE for hydropower increased by **15,6%**, but **this was still lower than the cheapest new fossil fuel-fired electricity option**
- **The global weighted-average LCOE of utility-scale solar energy dropped by 85,1%** between 2010 and 2020. This occurred due to the global cumulative installed capacity of all solar PV increase from 42,0 GW in 2010 to 714,0 GW in 2020
- **The global weighted-average cost of electricity from concentrated solar power declined by 68,1%,** with just two projects commissioned in 2020 — both in China
- **For offshore wind, the global weighted-average LCOE fell by 48,2%** within the mentioned timeframe. This has transformed the outlook for offshore wind, with a cumulative installed capacity of offshore wind at just 34,0 GW at the end of 2020
- **For onshore wind projects, the global weighted-average cost of electricity over the period fell by 56,0%.** The onshore wind cost decline was caused by both the decline of turbine prices and the higher capacity of modern turbines

Source: IRENA — Renewable power generation costs in 2020 — [2021]
Notes: (1) Levelized Cost of Electricity is an economic measure used to compare the lifetime costs of generating electricity across various generation technologies

# Many European countries outlined investment targets to increase the electrolysis capacity in the region by 2030

**Estimated green hydrogen electrolysis capacity and investment volume in selected European countries by 2030**

### Electrolysis capacity, GW




### Investments, Bn Euro

| | | |
|---|---|---|
| France | 7,2 | France is a country with the most ambitious target among the EU members for the increase of electrolysis capacity up to 6,5 GW by 2030. For this purpose, France plans to invest 7,2 Bn Euro, with 2,0 Bn Euro already available from recovery funds. |
| Germany | 9,0 | 7,0 Bn Euro are to be invested in German businesses engaged in electrolysis-related and research activities, 2,0 Bn Euro – in international partnerships. The 2030 target includes reaching up the 5,0 GW electrolysis capacity, while the 2035 target comprises adding another 5,0 GW to the country's electrolysis capacity. |
| Italy | 10,0 | The investments will be directed at the achievement of the 2030 target, namely reaching 5,0 GW of electrolysis capacity and a 2,0% share of hydrogen in final energy demand. By 2050, Italy strives to establish $H_2$-based generation and home heating systems. |
| Spain | 8,9 | A 60-point plan sets a goal of 4,0 GW electrolysis by 2030, backed by a system of Guarantees of Origin, with green hydrogen quotas for the industry. The Plan is projected to cost 8,9 Bn Euro over 10 years, and investments will be taken mostly from the private sector. Spain produces 500,000 Mt[1] of $H_2$ per year, and according to the Plan, Spain targets to move 25,0% of this demand to green hydrogen by 2030. |
| Portugal | 8,0 | Portugal targets the increase up to the 2,0-2,5 GW electrolysis capacity by 2030, and up to 5,0 GW by 2050. 10,0 – 15,0% of $H_2$ are planned to be injected into the gas grid by 2030, rising to 75,0 – 80,0% by 2050. Total energy consumption targets are 2,0% – 5,0% hydrogen by 2030, and 15,0% – 20,0% by 2050. |

Source: Statista – Hydrogen: fuel of the future? – [2021]; S&P Global – Hydrogen fever in EU puts 2024 target of 6-GW electrolyser capacity in reach – [2021]

Notes: (1) Megatonne

# However, poor access to fresh water in some regions might limit the potential of green hydrogen production

## Average exposure to water stress[1] by country


**17 countries are facing 'critical' water stress** worldwide. **12 out of 17** most water-stressed countries are **located in the Middle East and North Africa region.**

While freshwater capacity in some regions is limited, **the Middle East and North America** have high solar radiation levels, which can contribute significantly to green hydrogen production.

**Thus desalination can play an essential role** as a supportive technology for green hydrogen production for the regions, which lack freshwater capacity, as seawater is a relatively abundant resource in many places.

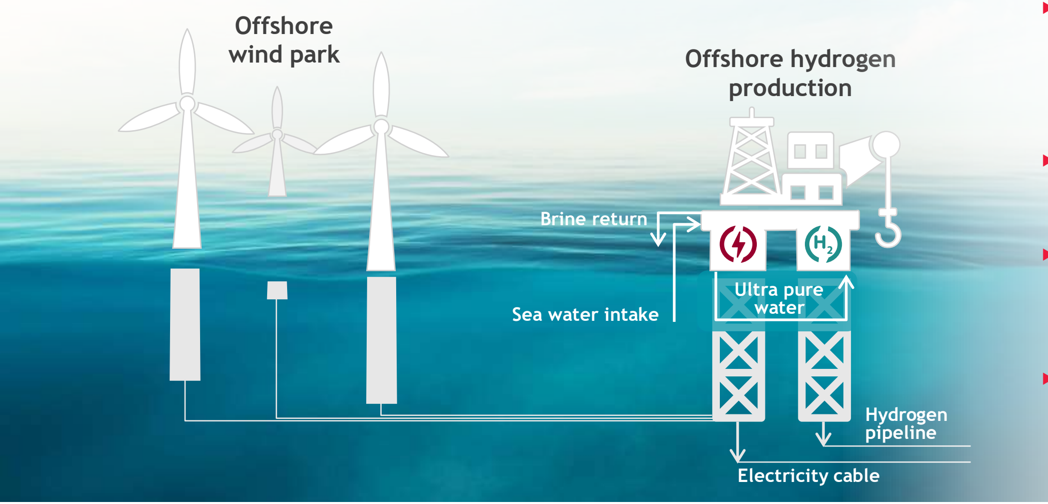
Source: DENA German Energy Agency – Global Alliance Powerfuels Brief – [2021]

Notes: (1) Based on the ratio of total withdrawals to total renewable supply

# Desalination technology is an optimal solution for the production of green hydrogen in water-stressed regions

The offshore green hydrogen production powered with renewable energy was introduced in 2019 by the researchers from Wageningen University & Research together with Hydron Energy[1]. The project is designed to potentially decrease future costs of green hydrogen production.

## Offshore green hydrogen production from sea water

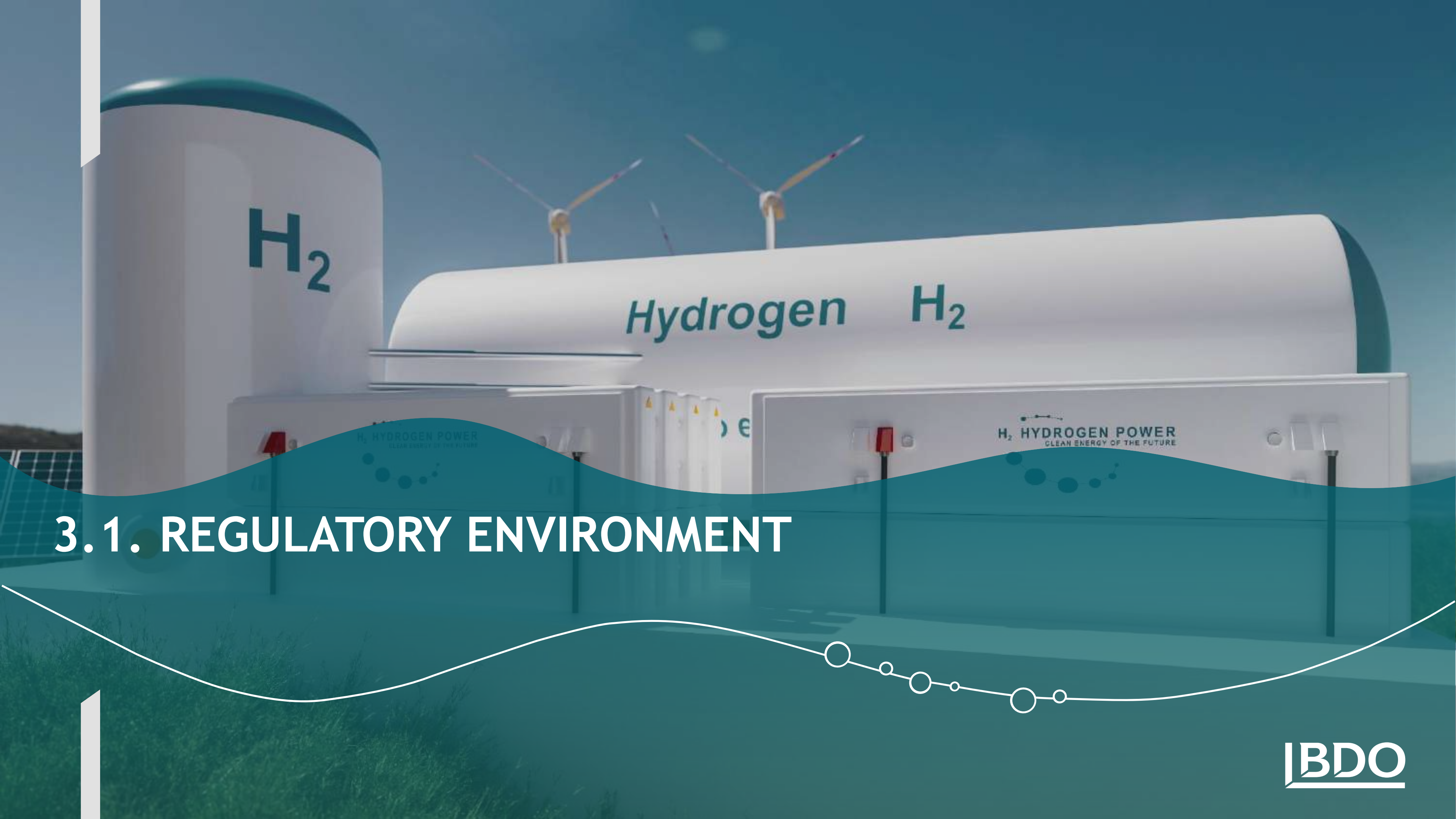



- Most of the desalination plants still **rely on fossil power fuels**, which may result in an increase in $CO_2$ emissions globally. For example, in Europe desalinated water production brings 44,0% higher $CO_2$ emissions than from tap water. Therefore, technologies of **offshore desalination powered with RES[2] are needed**
- The desalination process carries some **environmental implications, such as rejected brine[3]**, which can damage the ecosystem. However, there are brine disposal regulations adopted at a global scale
- Nowadays, there are **only a few commercial-scale renewable energy desalination units worldwide**. However, other big players in the green hydrogen pipeline will be included by 2035, among them TotalEnergies' HyEnergy (Australia) and Aquaventus (Germany)
- **The demand for desalinated water can experience a fivefold boost** from its current needs, up to 526,0 million cubic metres **due to the completion of all hydrogen projects** in regions with water stress levels above medium

Source: PWC Strategy& – The dawn of green hydrogen – [2020]; Wageningen University & Research website; Rystad Energy website; Media overview
Notes: (1) Dutch company focusing on the development of innovative renewable energy solutions based on hydrogen production; (2) Renewable energy sources; (3) Hyper-saline discharge stream which may further contain process chemicals and metals


# 3. HYDROGEN INDUSTRY NOWADAYS

# 3.1. REGULATORY ENVIRONMENT

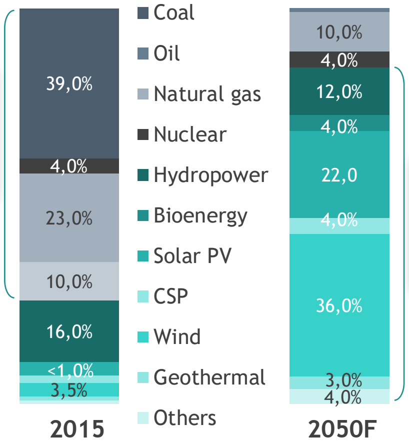


# Transition to sustainable technologies is now promoted by international treaties, such as the Paris Agreement

The **Paris Agreement** is an international treaty under the UNFCCC[1] that **was adopted in Paris on 12 December 2015** and **entered into force on 4 November 2016**. Its goal is to slow down the global average temperature rise and achieve net zero $CO_2$ emissions by 2050. Currently, **196 countries-participants** have joined the Agreement. Since its entry into force, the number of low-carbon regulations has increased all around the world.

## Electricity generation according to the Paris Agreement scenario, by share

**76,0%** of electricity is generated from **non-renewables.**




**85,0%** of generated electricity comes from **renewables.**

## Energy transition insights

The transition to renewable energy supply **is an undergoing transformation** driven by environmental causes and a decrease in the cost of renewable electricity generation.

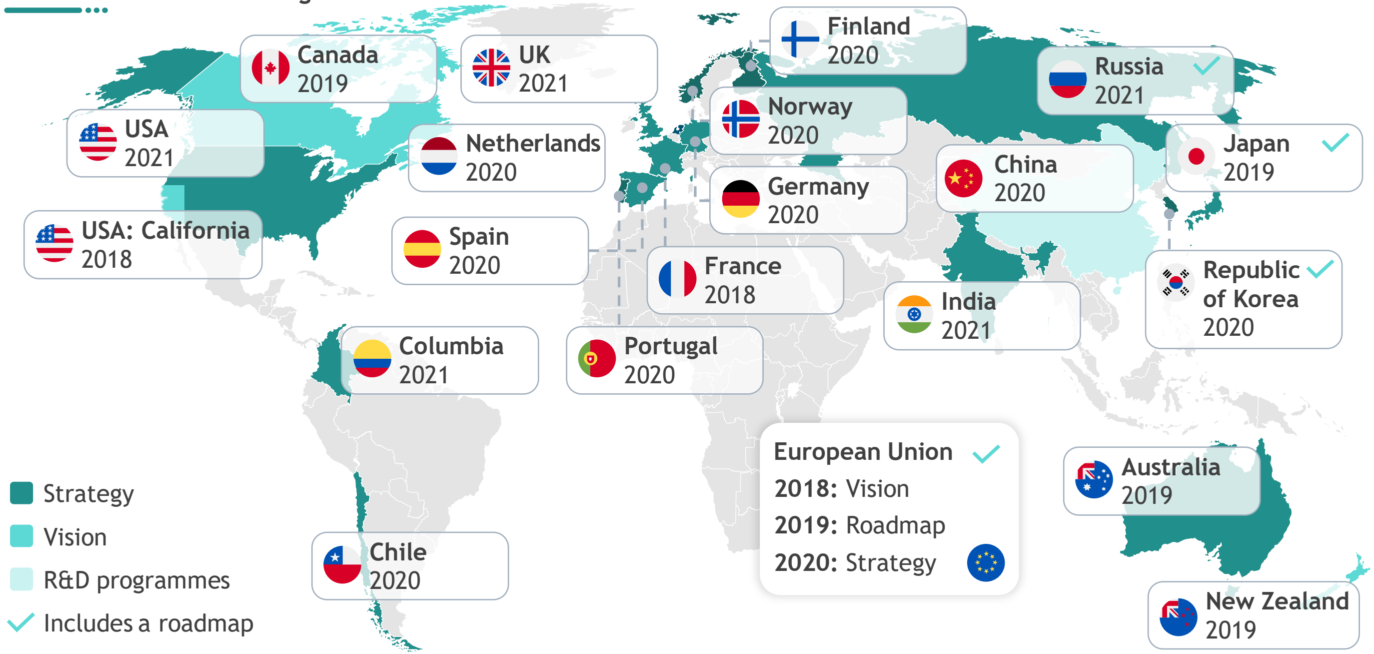
The result of the transformation can be seen through the **77,0% decline in solar PV generation cost** in the period between 2010 and 2018.

**Some countries have higher than average global indicators** in the wind and solar PV integration, such as **Denmark** and **Ireland** with the share of wind sourced energy of **44,0% and 27,0% accordingly.**

Source: IRENA — Innovation landscape for a renewable-powered future — [2019]
Notes: (1) United Nations Framework Convention on Climate Change

# Global commitment to reach carbon neutrality by 2050 has fostered the development of various hydrogen strategies

## Selected countries' strategies




### Key insights

- Hydrogen roadmaps, vision documents and strategies contain **clear long-term policies that enable investors to assess** the prospects for **future markets** and **invest** in infrastructure
- **17 countries have already developed** the national hydrogen strategies
- Strategy-associated **investments vary from 41,0 Mn Euro to 470,0 Bn Euro**, depending on the region

Source: Statista – Hydrogen: fuel of the future – [2021]; Forbes – California Legislators Push $300 Million Hydrogen Plan – [2021]

Note: (1) California has developed an individual hydrogen strategy, with separate from the US financing schemes

# Hydrogen strategies imply increased investments to set up the role of hydrogen in the future sustainable economy

## Selected countries' hydrogen strategies

| Country | Published | Key purpose | Investments | Major effects |
|---|---|---|---|---|
| Australia | 2019 | Creating a clean, innovative, safe and competitive hydrogen market that provides benefits for Australians and makes the country a major player in the global hydrogen market by 2030. | The Australian government has already committed over 120 Mn Euro to hydrogen-related projects. | Creation of clean hydrogen supply chains, significant economic growth by 2050. |
| Chile | 2020 | Establishing Chile as a frontrunner in the green hydrogen generation and export market. | The government has launched funding rounds of up to 41,0 Mn Euro for selected projects. | Revenues from exports of green hydrogen are estimated to represent 10,0% of the current Chilean GDP by 2050, with Chile being a key exporter on the markets of Japan and South Korea. |
| Canada ✓ | 2020 | Making Canada a global industrial leader of clean renewable fuels. | The budget sets reserves of 19,0 Bn Euro in the new direct spending and tax relief measures to build a greener economy. | Creation of 350,000 jobs in R&D, manufacturing, and services; the domestic hydrogen market generating more than 44,0 Bn Euro in revenue per year by 2050. |
| European Union ✓ | 2020 | Turning clean hydrogen into a viable solution to decarbonise different sectors over time. | Cumulative investments in renewable hydrogen in Europe could go up to 470,0 Bn Euro by 2050. | Reduction of greenhouse gas emissions by at least 50,0-55,0% in a cost effective way; creation of 1 million additional jobs by 2030. |
| France ✓ | 2020 | Making France 'the carbon-free leader of tomorrow'. | 7,0 Bn Euro is planned to be invested into green hydrogen production before the end of 2030. | Industry decarbonisation, saving 6,0 million tonnes of $CO_2$ by 2030; wide-spread use of hydrogen as a fuel; creation of up to 150,000 additional jobs. |
| United Kingdom ✓ | 2021 | Developing a thriving low carbon hydrogen sector in the UK. | The strategy pledges 270,0 Mn Euro for government co-investment in production capacity through the Net Zero Hydrogen Fund. | 20,0-35,0% of the UK's energy consumption in 2050 to be met with hydrogen; creation of up to 9,000 additional jobs by 2030. |

Carbon neutrality by 2050 ✓

Source: CMS – Hydrogen Laws and Regulations by countries – [2021]; McCarthy Tétrault – Federal Budget 2021: Incremental Support for Canadian Hydrogen Industry – [2021]; Media overview

# Chile, Germany, Norway, Switzerland, and California in the USA have already implemented green hydrogen frameworks

| Government | China | Germany | Norway | Switzerland | California (USA) | European Union | Germany | India | Portugal |
|---|---|---|---|---|---|---|---|---|---|
| Status | **In force** | **In force** | **In force** | **In force** | **In force** | **Proposed** | **Proposed** | **Proposed** | **Proposed** |
| Policy type | Financial rewards | Auctions | Public procurement requirement | Tax | Mandate | Quota | Carbon contracts for difference | Quota | Quota |
| Description | The pilot programme is designed to incentivise cities in regards to meeting certain technical standards by FCEV's[1]. | The $H_2$ Global programme intends to involve ten-year purchase agreements for hydrogen-based products from a tender perspective. | The biggest ferry connection in Norway has been announced to become hydrogen-fuelled transport. | The state swarm the road tax on freight carriers in Switzerland for trucks weighing more than 3,5 tonnes. | The state government executive order obligates all vehicles sold in the state to be emissions-free by 2035. | The European Commission has offered a Renewable Energy Directive modification to mandate 50,0% renewable hydrogen consumption in the industry by 2030. | The National Hydrogen Strategy introduced a CCfD[2] programme, which regulates the difference between $CO_2$ abatement costs and the price for EU ETS[3]. | Starting from 2023-2024, 10,0% of demand for hydrogen in refineries and 5,0% of demand for fertiliser production should be covered with green hydrogen. | Targets have been set by the National Hydrogen Strategy to blend from 10,0% to 15,0% of hydrogen in natural gas by 2030. |

Source: IEA — Global Hydrogen Review — [2021]

Notes: (1) Fuel cell electric vehicles; (2) Carbon Contracts for Difference; (3) European Union Emissions Trading System

# Despite the introduction of hydrogen initiatives globally, the local regulation of the industry is still underdeveloped

Currently, the legal framework that regulates the green hydrogen sphere is rather modest in the countries that have already established their hydrogen strategies. Key global government initiatives include exemptions from charges, surcharges, levies, various forms of financing, implementing measures that foster the market.

## Selected countries' regulations

### The Renewable Energy Act, 2021

- exempts German producers of green hydrogen from having to **pay the renewables surcharges on the power they use**
- fully releases companies producing hydrogen with **renewable electricity sources from the levies**
- provides with **annual monitoring of target achievement**, which can be used to make adjustments if it is necessary

### The Law-Decree, 2021

- establishes **two traceability systems for hydrogen production**, so that consumers are aware that purchasing a guarantee entails supporting green energy
- supports green hydrogen production and reflects in a form of either an **operating aid or a combination of financial aid and investments**
- amends **a number of legal documents** in order to promote sustainable hydrogen

### The Decree-Law, 2020

- guarantees that the production of green hydrogen is a **liberalised activity** with low administrative requirements of eligibility
- encourages consumers to purchase a certain share of gases of **renewable origin or low-carbon gases**
- allows producers of renewable or low carbon gases to **use the product for self-consumption, injection into the public gas network, and export**

 Source: CMS — Hydrogen Laws and Regulations by countries – [2021]

# 3.2. COUNTRIES' INITIATIVES

# More than half of all hydrogen projects announced worldwide are attributed to European countries

## Projects distribution across the globe

126 Europe

46 Asia

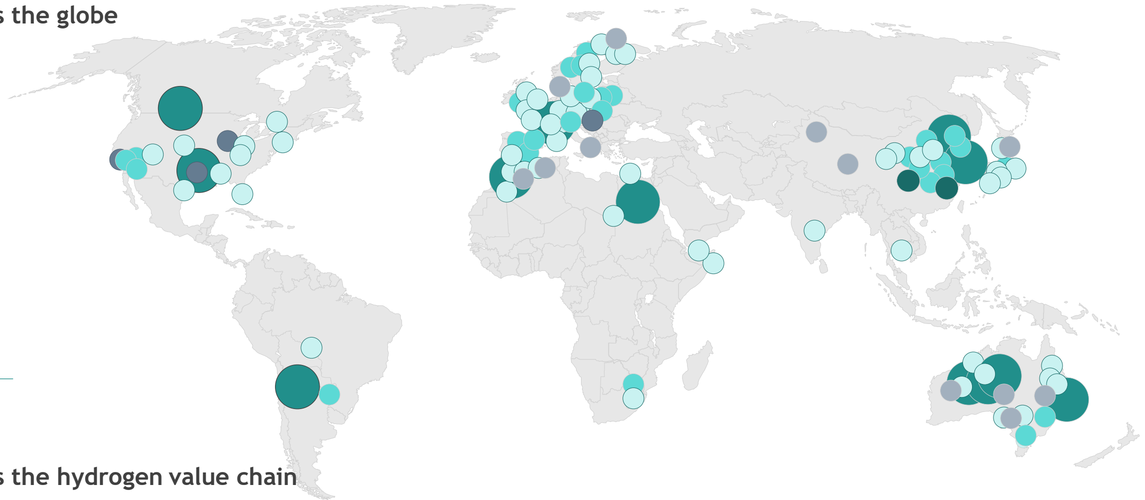
24 Oceania

19 North America

8 Middle East and Africa

5 Latin America

228 Projects in total



**Projects** announced in **Europe** are expected to **cover the entire hydrogen value chain.**

The **industrial usage** of hydrogen is a **major focus** of the projects announced in **Korea, Japan, and Europe.**

**Transport applications** are another **key aspect** of new hydrogen projects in **Korea and Japan.**

## Projects distribution across the hydrogen value chain

**17**
**Giga-scale production:** renewable hydrogen projects and low-carbon hydrogen projects.

**90**
**Large-scale industrial usage:** refinery, ammonia, power, methanol, steel, and industry feedstock.

**53**
**Transport:** trains, ships, trucks, cars, and other hydrogen mobility applications.

**45**
**Integrated hydrogen economy:** cross-industry and projects with different types of end-uses.

**23**
**Infrastructure projects:** hydrogen distribution, transportation, conversion, and storage.

Source: The Hydrogen Council — Hydrogen Insights 2021: A Perspective on Hydrogen Investment, Deployment and Cost Competitiveness — [2021]

# Developed countries in Europe, APAC, and the Americas are leading in the green hydrogen projects implementation

## Sweden: HYRIT[1]

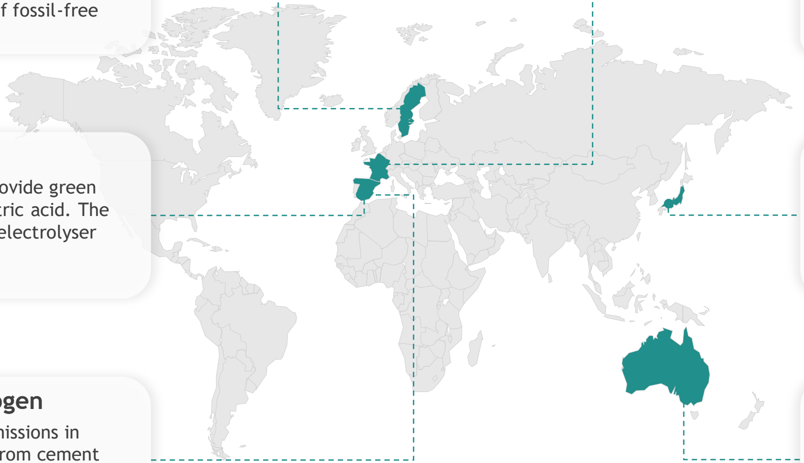
A joint venture is set to develop a fossil-free steelmaking process. A plant with a 4,0 MW electrolyser was established in 2020 and it is expected to produce 1,0 million tonnes of fossil-free fuel with green hydrogen by 2025.

## Spain: Green H2F Puertollano I

The two sites project is established to provide green hydrogen for ammonia production and nitric acid. The green hydrogen is produced with a PEM[2] electrolyser that takes energy from a solar PV plant.

## Majorca: Power-2-Green Hydrogen

The project is designed to reduce $CO_2$ emissions in Majorca, due to significant implications from cement production. Green hydrogen is dedicated to mainly use for the island's public transport and backup energy supply for buildings.



## Germany: Westküste 100

The project is targeted to produce green hydrogen for industrial needs. Additionally, produced hydrogen can be combined with captured $CO_2$ to produce synthetic methanol to reduce $CO_2$ emissions.

## Japan: FH2R[3]

Fukushima Prefecture produces around 1.200,0 normal cubic metres of hydrogen hourly with an alkaline electrolyser. The electrolyser is supplied with on-site solar PV. Produced green hydrogen is used for fuel-cell vehicles.

## Australia: QNP[4]

The facility produces ammonium nitrate and is expected to produce 3.500,0 tonnes of green hydrogen to make 20.000,0 tonnes of green ammonia yearly and, thus, displace 20,0% of currently used ammonia.

Source: IRENA — Coalition Green Hydrogen — [2021]
Notes: (1) Hydrogen Breakthrough Ironmaking Technology; (2) Polymer electrolyte membrane; (3) Fukushima Hydrogen Energy Research Field; (4) Queensland Nitrate

# Energy companies around the globe have already invested in pilot projects related to green hydrogen

## Global companies' focus

| | |
|---|---|
| 2018 | The **H&R Ölwerke Schindler** refinery in Hamburg and the **Refhyne** project at the **Shell Rhineland Refinery** started to use electrolytic hydrogen in refining operations. The REFHYNE project is at the forefront of efforts to provide Europe with 'clean refinery hydrogen'. The project is intended to install and run Europe's largest PEM electrolyser at the Shell Rhineland Refinery in Wesseling, Germany, using funding from the European Commission's Fuel Cells and Hydrogen Joint Undertaking. |
| 2020 | The largest industrial gas company **Linde**, in collaboration with **Alstom**, develops the first green hydrogen refuelling station for passenger trains in Germany. The station is planned to provide fuel for 14 hydrogen-powered passenger trains that will be supplied by Alstom to the regional rail traffic supplier LNVG. The hydrogen refuelling station will have a daily capacity of roughly 1,600 kg, making it one of the largest hydrogen refuelling stations ever built in terms of nameplate capacity. |
| 2021 | The Indian government pushes state fossil fuel companies **IndianOil, GAIL, HPCL, and BPCL** to invest in the green hydrogen industry to accelerate the adoption of green sources of energy. IndianOil, the country's largest fossil fuel retailer, plans to build a hydrogen distribution network in the future and is already testing the fuel's technology and economics in a partnership with renewable energy firms. |
| 2022 | **Sojitz, CS Energy Ltd, and Japan's Nippon Engineering Consultants Co Ltd** aim to produce hydrogen as transport fuel to the Pacific Island countries. This demonstration project uses solar electricity to generate green hydrogen in Queensland, Australia, which will subsequently be transferred to Pacific Island countries for use in small fuel cells and hydrogen fuel vessels, potentially popularising hydrogen use on islands. |

Souse: Media overview

Notes: (1) Carbon capture, utilisation and storage

# 4. FUTURE OUTLOOK

# The cost-effectiveness of green hydrogen, its higher energy output & sustainability make it a fuel of the future

## Green hydrogen industry development path

**Increasing investment**
Investments in hydrogen projects are growing rapidly in all regions of the world

**Decreasing transportation costs**
Cost-efficient transmission and distribution of hydrogen reduce hydrogen prices for the end-use

1 2 3 4 5

**Growing geography**
Nowadays, more and more countries around the globe develop hydrogen strategies and roadmaps

**Declining production costs**
The decline in costs for renewable energy leads to a decrease in the green hydrogen production cost

**Active use in different economic sectors**
Cost-efficiency and high energy output lead to more active usage of green hydrogen in different sectors of economy

## Future potential of green hydrogen

Sustainable
With high energy output
Cost-effective

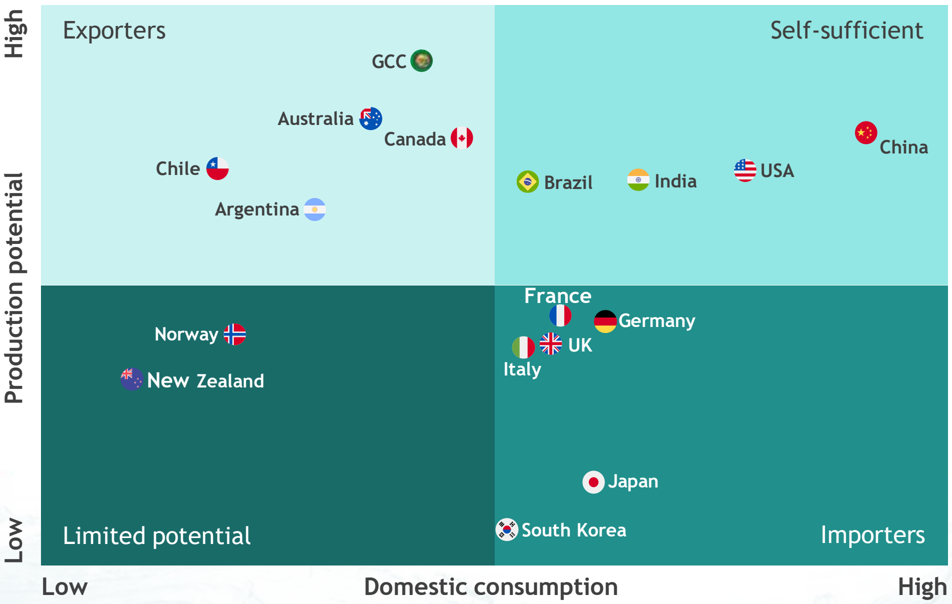
**Green hydrogen is forecasted to become an essential fuel for core economic sectors in the future**

Power generation
Industry
Transportation
Construction
Space exploration

 Source: BDO Centers analysis

# The geography of hydrogen production will expand, while some countries have the potential to be market leaders

## Countries' potential on hydrogen market



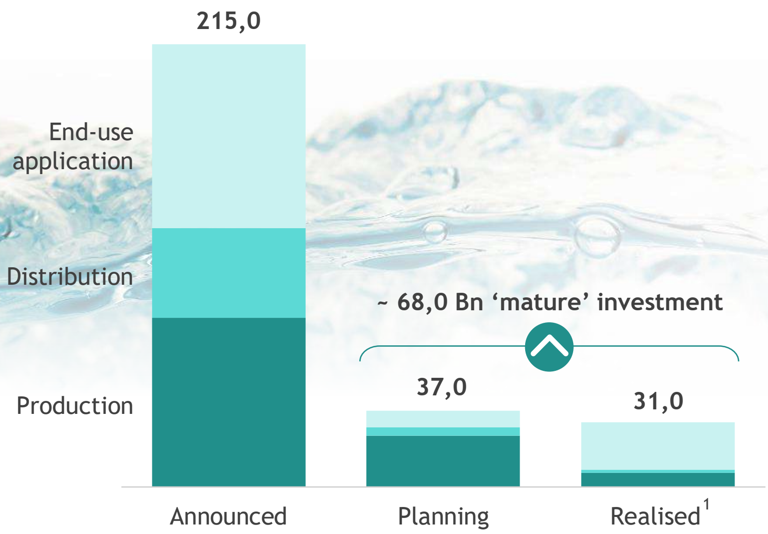

## Key insights

- The global shift of regulators, investors, and consumers towards decarbonisation defines a crucial role of **green hydrogen as an essential emission-free fuel of the future**
- In 2021, over 30 countries have released hydrogen development roadmaps and more than 200 hydrogen projects were announced. **The number of countries, which are actively developing hydrogen strategies, is projected to grow further**, driven by the cost reduction for production, transmission, distribution, retail, and application of green hydrogen
- The potential of countries to become leaders in green hydrogen production is evaluated by several criteria, such as **ease of access to water, high-yield renewable resources, and large areas of barren flat land**
- Some countries, such as **Argentina, Australia, Canada, Saudi Arabia, and Chile, are projected to become the largest exporters of green hydrogen** in the future due to the favourable production conditions and domestic demand being below production capacity

Source: The Hydrogen Council – Hydrogen Insights 2021: A Perspective on Hydrogen Investment, Deployment and Cost Competitiveness – [2021]; Strategy& – The dawn of green hydrogen – [2020]
Notes: (1) Gulf Cooperation Council

# The global investments in hydrogen are projected to increase fast, namely sixfold by 2025 and 16-fold by 2030

## Hydrogen investments by 2030, Bn EUR




## Key insights

- In response to government commitments to decarbonisation, the announced hydrogen investments have been accelerated rapidly. **A sixfold increase** is projected in **total hydrogen investments by 2025** and a **16-fold increase by 2030**
- The total investment in hydrogen is forecasted to surpass **280,0 Bn Euro, including 68,0 Bn Euro in mature[2] projects** by 2030
- **Globally, 228 large-scale projects were** announced across the hydrogen value chain. Europe, Asia, and Australia account for **85,0% of such projects**

## Potential benefits of the hydrogen economy development by 2050

**~30**
million new jobs

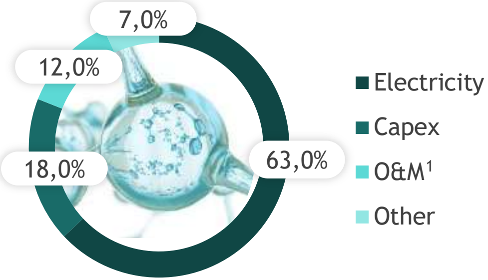
**~2,0 Tn Euro**
annual contribution to the global economy

**12,0%**
of global energy demand covered by hydrogen

Source: The Hydrogen Council — Hydrogen Insights 2021: A Perspective on Hydrogen Investment, Deployment and Cost Competitiveness — [2021]; IRENA — Energy Transition Outlook — [2020]; Climate Champion - How will hydrogen create jobs? - [2021]
Notes: (1) Projects where a final investment decision has been taken, under construction, commissioned and operational; (2) On the planning stage or realised

# A drop in production costs will decrease the price of green hydrogen, advancing its competitiveness among other fuels

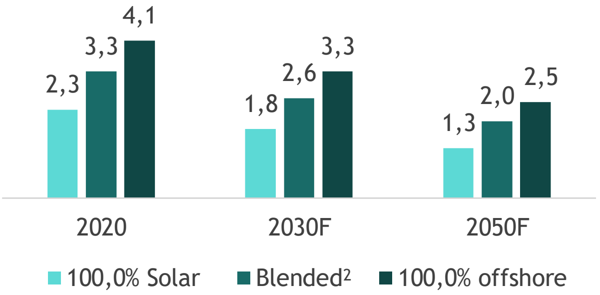
**Breakdown of the green hydrogen production cost, 2020-2050F average**




**Forecasted decrease in renewables cost by 2030**

- 35,0% CSP
- 58,0% Solar PV
- 55,0% Wind offshore
- 25,0% Wind onshore

**Price of green hydrogen, Euro per kilogram of hydrogen**




- **The cost of green hydrogen production** is highly dependent on **the cost of electrolysis** and respective consumption of electricity, as the estimated average **electricity costs account for about 63,0% of the total production cost** for green hydrogen
- In the future, green hydrogen production will **benefit from the significant decrease in the costs of renewable energy:** from 25,0% to 58,0% by 2030 depending on the source used. This will drive the **decrease of green hydrogen prices**, thus making it more competitive with other types of fuel
- Accelerated by lower prices for the end-use, the global demand for green hydrogen is projected to reach **530,0 million tonnes by 2050**

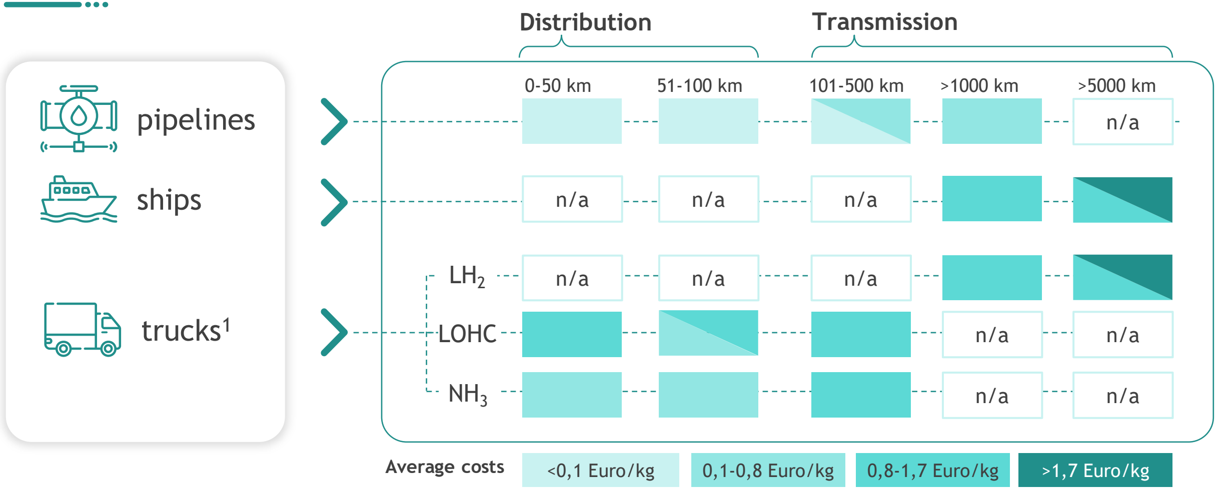
Sources: IRENA – Global Renewables Outlook – [2020]; IRENA – Energy Transition Outlook – [2020]; Goldman Sachs – Green Hydrogen: The next transformational driver of the Utilities industry – [September, 2020]

Notes: (1) Operations and maintenance; (2) Blended energy consists of 40% offshore wind, 40% solar, and 20% onshore wind

# Cost-efficient transmission and distribution are required to unlock hydrogen usage in the upcoming decades

- With the hydrogen production cost decrease, **transmission and distribution costs are the next frontier** in reducing the hydrogen price for the end-use
- The development of an **optimal network of pipelines** linked with the **ship routes** and **the short-distance trucks transportation infrastructure** is becoming a crucial milestone to fully unlock the hydrogen usage potential
- **By 2030**, assuming the development of at-scale production and transportation infrastructure, **global transportation costs of hydrogen might reach 1,5-2,3 Euro/kg**

## Hydrogen distribution options and average transportation cost by 2030s



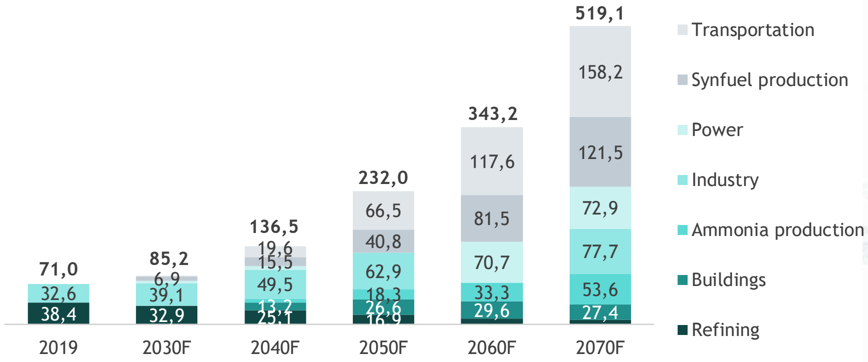

## Examples of estimated cost of green hydrogen transportation (selected routes)

| | |
|---|---|
| pipeline (2.800 km) | 0,4 Euro/kg |
| ship (8.700 km) | 2,0-4,5 Euro/kg[2] |
| ship (7.000 km) | 1,5-2,3 Euro/kg[3] |

Source: The Hydrogen Council – Hydrogen Insights 2021: A Perspective on Hydrogen Investment, Deployment and Cost Competitiveness – [2021]
Notes: (1) The cost includes conversion into a carrier and varies depending on the type of carrier: LH2 - liquid hydrogen, LOHC - liquid organic hydrogen carriers, NH3 - ammonia; (2) Including conversion to a carrier, dehydrogenation, and shipment to a decentralised user; (3) Including hydrogenation and dehydrogenation

# In the future green hydrogen is forecasted to become an essential sustainable fuel for core economic sectors

## Forecasted global demand on hydrogen, million metric tonnes (Mt)




- Hydrogen has the potential to become a major contributor to the transition towards a clean energy economy in the future. In the Sustainable Development Scenario[1], the **global demand for hydrogen** is forecasted **to increase sevenfold to 519,1 Mt by 2070**
- In 2070, the direct use of hydrogen in **the transport sector for cars, trucks, and ships** will account for **30,0%** of total hydrogen usage, and **23,0%** will be used in the production of **synthetic kerosene for the aviation sector**. **Industry[2]** will account for almost **15,0% of demand for hydrogen** mostly for chemicals as well as iron and steel production

For decades, **liquid hydrogen** has served as **powerful rocket fuel**, delivering crew and cargo to space. With the expansion of hydrogen production technology and the gradual decrease in the cost of renewable energy, **green hydrogen has the potential to become an accelerating power of sustainable space exploration.**

## Application of hydrogen in space

**Rocket fuel**

Generation of $LH_2$ on Earth => rocket propellant

**Fuel for missions (transportation, electrical power)**

Extra terrestrial water => generation and recycling of hydrogen

**Water source for missions**

Hydrogen + exhaled $CO_2$ => water renewal

Source: IEA — Global Energy Review — [2020]; NASA — Space Application of Hydrogen and Fuel Cells — [May, 2021];
Notes: (1) Net zero emissions scenario; (2) Primarily as a feedstock for chemicals production and reducing agents in icon and steel manufacturing

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