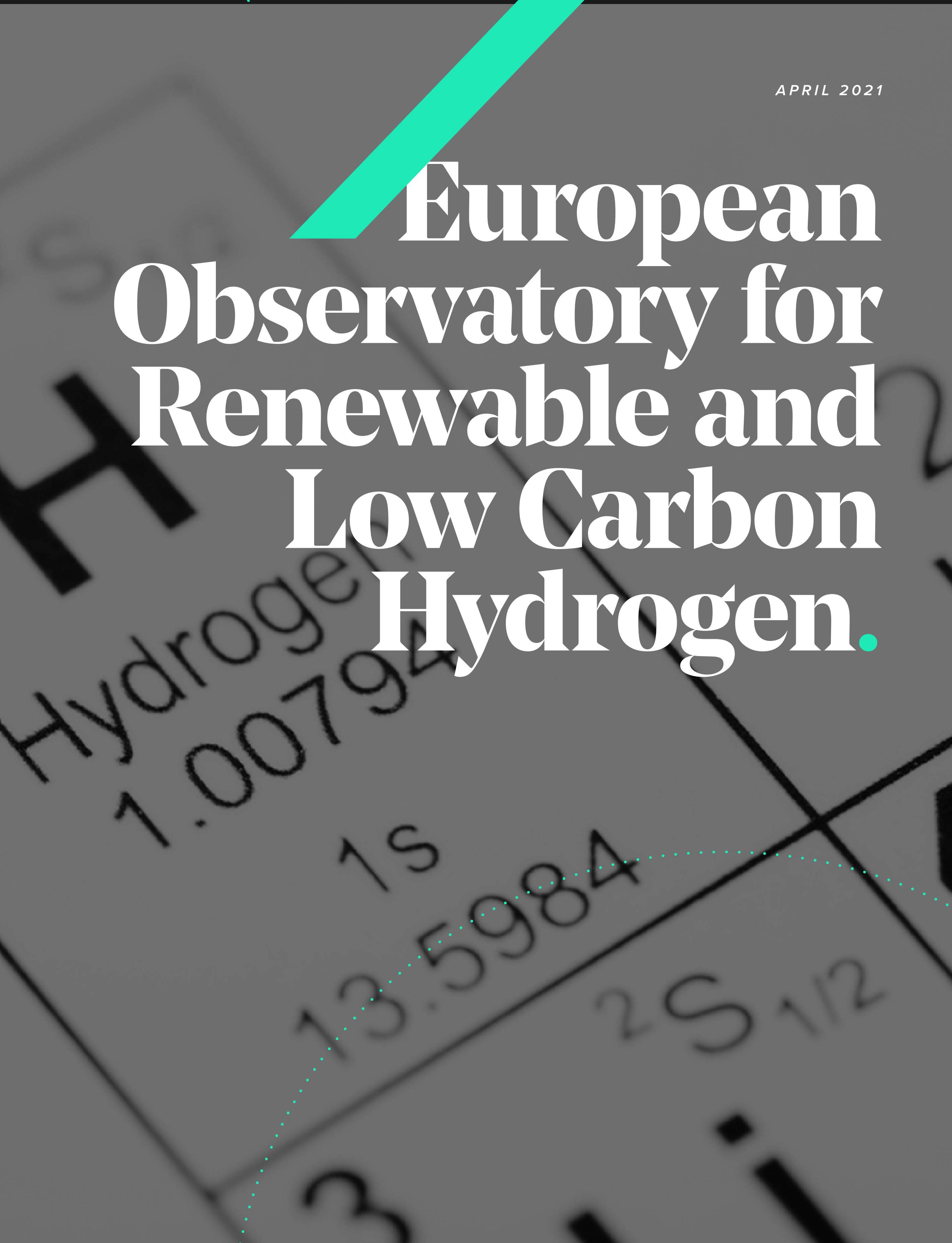
APRIL 2021

European Observatory for Renewable and Low Carbon Hydrogen.



SIAPARTNERS

Sia Partners' Hydrogen Expertise.

Sia Partners, a consulting firm founded in 1999, has been supporting its clients in their Hydrogen ambitions for many years. Following the evolution of the sector, we began to develop our expertise in subjects related to Power and Gas, and then gradually on all uses and links in the hydrogen value chain. Our various supports enabled us to have a sharp understanding of the challenges met by the sector, a forward-looking vision of market development and operational expertise in the implementation of the Hydrogen project.

We rapidly understood the need to decipher the opportunities and challenges of hydrogen in order to make them accessible to as many people as possible. To do this, Sia Partners has been offering articles, studies, and insights into the sector in France since 2017.

In line with the ambitions of the national and European Hydrogen plans, we wanted to extend our analysis to different European countries and focus our analysis on low-carbon technologies for this new Observatory.

Enjoy the read

Our last published studies on Hydrogen

Power-to-Gas in France	The Hydrogen-Energy sector in France - 2019	The Hydrogen-Energy sector in France - 2020	European Observatory for Renewable and Low Carbon Hydrogen
June 2018	January 2019	February 2020	April 2021

Club H_2

Club H_2 was launched over the course of 2019 within the Energy, Utilities & Environment BU of Sia Partners, and today represents 20 consultants who are experts in Hydrogen subjects. The objectives of the Club are threefold:

- Capitalize on the expertise acquired by our consultants through their various missions,
- Build on our capacity to monitor ongoing changes in the sector,
- Offer analyses and studies allowing a better understanding of these transformations.

Our work allows Sia Partners to support its clients, regardless of the maturity of their Hydrogen project.

TABLE OF CONTENTS.

Executive summary.

A few months back, Europe decided to strengthen its investments in renewable and low carbon hydrogen development. This was a solution to fostering a green economic recovery and growth, which also aligns with the goal to become carbon neutral by 2050. As a result, many European countries, as well as the European Union, announced ambitious hydrogen strategies in 2020, focusing on diverse downstream uses and low carbon production technologies.

Our first European Observatory for renewable and low carbon hydrogen compares the positioning of 12 European countries which are engaged in hydrogen deployment. With this Observatory, Sia Partners aims to contribute to a better understanding of hydrogen perspectives, challenges, and opportunities in Europe.

European production capacities of renewable and low-carbon hydrogen currently represent 0.1 Mt/year; less than 1% of total production capacity. However, considering the production projects announced for 2030, production capacities should increase to 7.8 Mt/year thanks to large-scale electrolysis projects but also the development of carbon capture for steam methane reforming processes (SMR + CCUS). When first comparing the data, strong differences in hydrogen quantities and technologies will appear between the 12 countries studied in the observatory.

Nevertheless, producing renewable hydrogen creates multiple challenges:

- Cost competition: considering the current electrolysis technologies, taxes on energy, and electricity prices, it's impossible for low carbon hydrogen produced from grid-connected electrolysis to compete with hydrogen produced by SMR, and SMR+CCUS.
- Given the 2020 carbon content of the European electricity production, hydrogen produced from grid-connected electrolysis cannot be considered low carbon in the majority of the countries studied. To avoid associating CO2 emissions with increasing hydrogen production, the current electrolysis projects will have to be associated with the deployment of an additional 20GW of renewable production capacities by 2030.
- Transport and storage infrastructure will have to scale up to link regions of production and consumption.

The entire hydrogen sector, as well as national governments, have to mobilize in order to overcome these economic, environmental and infrastructure challenges. They must tap into innovation and investments.

Looking at downstream markets, end-uses for low-carbon and renewable hydrogen will become more diverse over time, even if greening the industrial sector remains a priority in many countries. Given this diversification of uses, countries will respond by considering local economic issues (strong industrial presence), energy needs (renewable energy intermittency management) and political priorities (clean mobility, greening of residential heating...).

In order to support the development of a hydrogen economy, governments will rely, not only on public subsidies and investments, but also on the establishment of guarantees of origin and more adequate regulatory frameworks.

Based on our comparative analysis of these different topics, Germany, France and the Netherlands stand out from other European countries as particularly ambitious and promising. These 3 countries have ambitious targets in terms of renewable hydrogen production, transport and downstream uses (mobility and industry). They also benefit from significant public investments. They are followed by the United Kingdom, whose ambitions are slightly behind in terms of hydrogen transport infrastructures and hydrogen mobility targets.

01/

Why carry out a European observatory for renewable and low carbon hydrogen?

A subject for the future ...

Considered in many national and European plans as one of the pillars of an economy. To conform to the Paris Agreements, national and European plans present hydrogen produced in a carbon-free manner as an energy vector that can replace fossil fuels in sectors still responsible for high GHG emissions (industry, transport). In addition, its physical characteristics make hydrogen an effective solution to facilitate the integration of intermittent renewable energies.

.. Complex to understand ...

Even if the hydrogen sector is a **promising energy sector**, its structuration remains **complex**. It is therefore necessary to have a **comprehensive understanding and comparative analyses at different scales**. This observatory aims to offer, both to the general public and to experts, an inventory of the development of **renewable and low-carbon hydrogen in Europe**, with the intention of developing a sector of excellence that generates jobs, requires investments, and which will be essential to achieve carbon neutrality in 2050.
The observatory offers:

- **key indicators by theme allowing decryption of current and future trends,**
- **technological and regulatory focuses as well as comparisons between countries.**

.. Which requires an objective approach ...

The observatory is based on **public data** updated in 2020 and consolidated by Sia Partners. This observatory aims to remain neutral wherever possible in the processing of information. This is in order to represent the general state of the sector in terms of **production, technologies, uses and objectives defined by industry players and governments**.

.. Focused on renewable and low-carbon hydrogen in European countries

In this observatory, we consider **renewable and low-carbon hydrogen production projects, for which the financing and the actors involved are defined for at least the first commercial phases**.
The geographical scope of study for the 2020 edition of the observatory includes **12 European countries:** Germany, Austria, Belgium, Denmark, Spain, France, Italy, Norway, the Netherlands, Portugal, the United Kingdom and Sweden. **These are the European countries which currently have the highest number of projects (in progress or announced) for the production of low-carbon and renewable hydrogen.**

Austria

Belgium

Denmark

France

Germany

Italy

Netherlands

Norway

Portugal

Spain

Sweden

United Kingdom

Ambitions of the observatory

Ambitions:

The Sia Partners observatory is built around 4 ambitions ...

Sharing & Opening

Inventory and sharing of commented and decrypted public data

Neutrality

An external point of view, without preconception, or influence issue

Completeness

An analysis of all the uses and applications of hydrogen, under the scope of technology, business and regulation

European Scale

European countries leading the deployment of hydrogen projects, with comparisons between those countries

The contents of the observatory

Key indicators and analyzes:

The Sia Partners observatory offers key indicators and analyses on the following 8 topics

Upstream

#1 Production capacities

#2 Production processes

#3 Production costs

#4 Carbon footprint

Midstream

#5 Transport and storage infrastructure

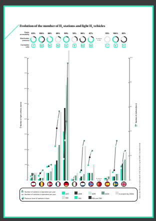
Downstream

#6 Allocation of production capacities for different uses

#7 Deployment of road mobility

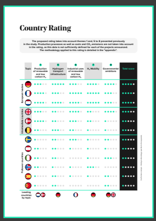
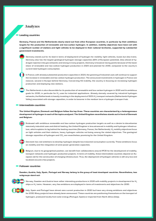
#8 Regulations and strategies

Reading process:
Each topic dealt with by the observatory is the subject of graphic representations of key indicators followed by a Sia Partners analysis.



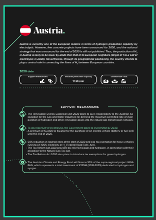
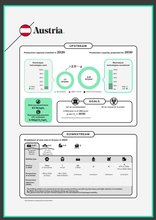

A global ranking:

Based on the comparison of the key indicators, the Sia Partners observatory offers a ranking of the 12 countries considered in the observatory.

Country Profiles:

The observatory offers country profiles that sums up for each country the regulation, and the essential data regarding upstream and downstream topics.

Hydrogen: a Growing Energy Vector

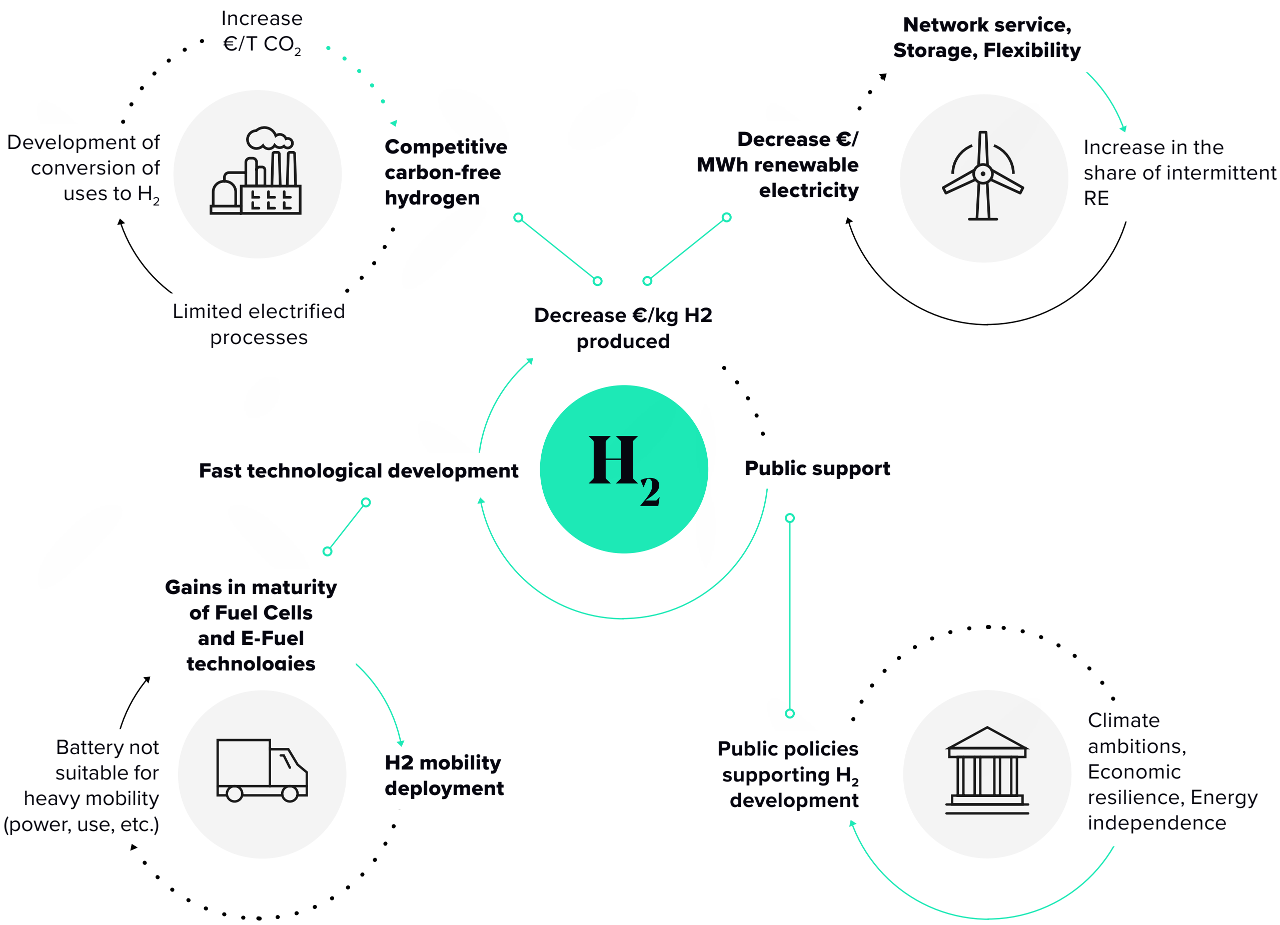
In order to respect the Paris Agreement on climate change, **global greenhouse gas (GHG) emissions must be reduced by 8% / year**

GHG reduction efforts must be focused on the main emission areas: **Energy Production (40%), Transport (24%), Industry (23%)**

At the same time, the **economy** based on carbon-based fossil fuels must undergo a **profound transformation** in order to anticipate a massive break with the existing model (peak oil, depreciation of carbon assets...).

Carbon-free hydrogen is the energy vector which promotes the integration of renewable energies (RE), makes the « hard to abate » sectors greener and builds **a new, more virtuous and resilient economy**

Hydrogen has been used for a long time in some industries (eg. refining, chemicals, aerospace), therefore, it's potential has been apparent for twenty years ...



... hydrogen is now enjoying a new impetus from private and public players, an economic optimum in certain sectors and a confirmed environmental and climate ambition.

The European Union's Hydrogen Strategy

Strong development ambitions...

Hydrogen has become a priority for the European Union (EU), which presented on July 8, 2020, **a Hydrogen Strategy for a carbon neutral Europe**. The objective is to foster the decarbonization of the most difficult sectors to switch to electrification and to promote the deployment of intermittent renewable energies. The EU considers clean hydrogen as one of the main levers to achieve **carbon neutrality by 2050**, in an integrated energy system «associating different energy vectors, infrastructures and consumption sectors».

The Hydrogen Strategy therefore aims to **develop the production of completely carbon-free hydrogen while stimulating demand**. For the EU, hydrogen will make it possible to couple energy systems for greater flexibility and to link renewable electricity production to distant demand centers. In its strategic vision for a climate neutral EU, published in November 2018, the **share of hydrogen in the European energy mix is expected to increase from the current level of less than 2% to 13-14% in 2050**.

The roadmap unveiled by the European Commission in July 2020 foresees the **deployment of 6 GW of electrolyser capacity** supplied with renewable energies to produce up to 1 million tons of renewable hydrogen by 2024. For the 2025-2030 period, the objective is to multiply by 10 the production of renewable hydrogen with at least 40 GW of capacity installed electrolysis. To support its strategy, the EU is planning private and public investments from 180 to 470 billion euros by 2050, with its own support of more than **100 billion euros**.

The EU is working in parallel on the establishment of a legal framework for the development of a European hydrogen market. Today, most members have **included a plan for the development of carbon-free hydrogen** in their national energy and climate plan, or in their post COVID-19 recovery plan.

...based on well-established supports

Investment and structuring programs for the sector have existed for **ten years** at a European level, in particular through the program **Horizon 2020** and the public / private partnership Clean Hydrogen for Europe (previously FCH JU). This partnership is funded by the European Commission, and it financed projects integrating hydrogen technologies (hydrogen stations, hydrogen bus fleets, etc.) with **€1.33 billion of investments** for the period 2014/2020. The European Commission has also set up a group of experts, HyENet (Hydrogen Energy Network), made up of representatives from the ministries in charge of energy within the various European governments, to encourage the national development of hydrogen. Finally, a number of **regulatory frameworks** at a European level are being rolled out, whether that's through the Trans-European Networks for Energy (TEN-E) or the Connection Europe Facility (CEF), in order to facilitate intra-European hydrogen mobility. At the same time, the legislative difficulties which slow down the integration of hydrogen solutions in Europe are highlighted thanks to the Hylaw flagship project.

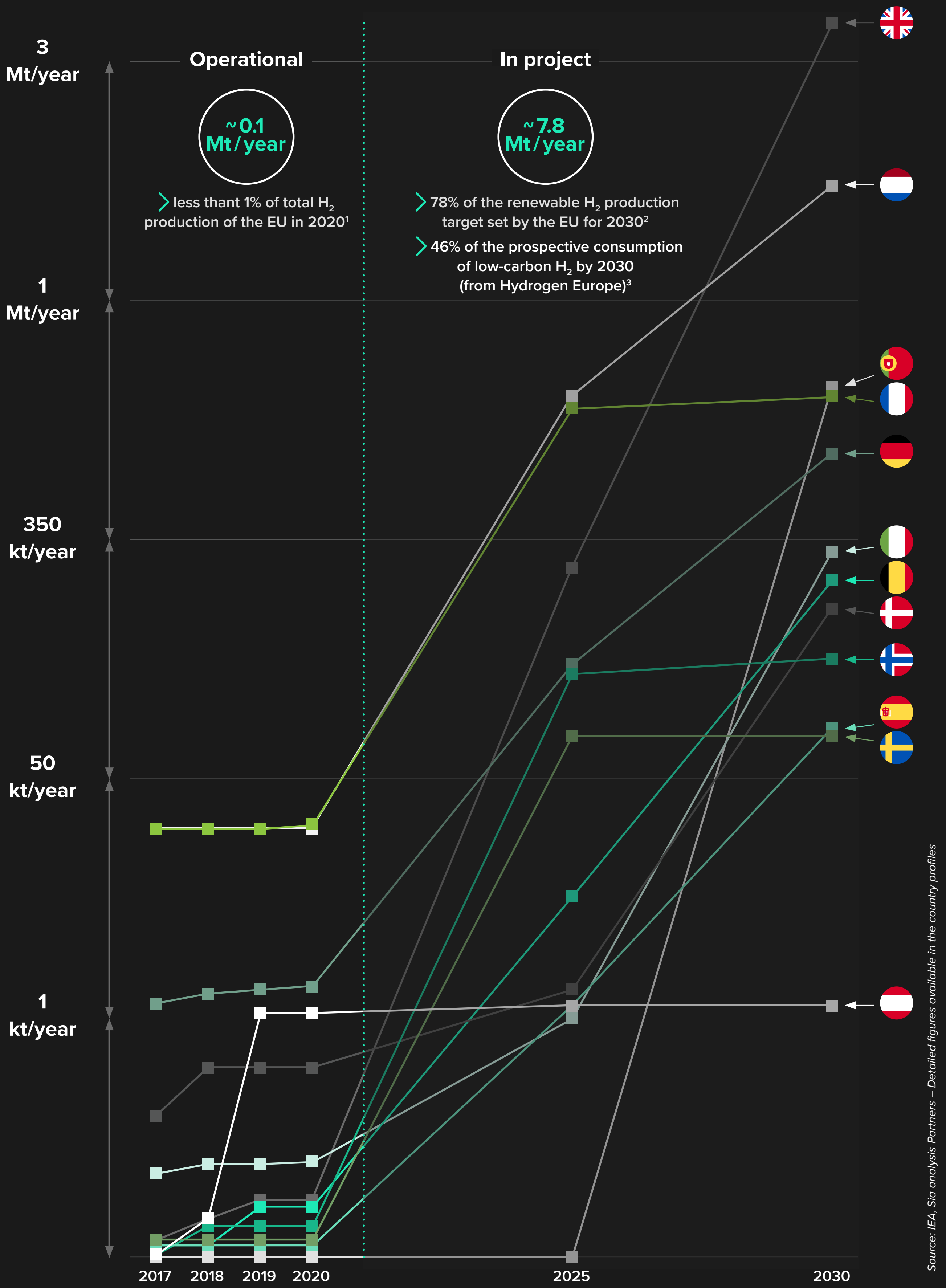
02

Indicators and Comparative Analysis.

Topic #1:
Production Capacities

A strong growth in the production of low-carbon and renewable hydrogen which is nevertheless unevenly distributed among European countries

Renewable and low carbon hydrogen production capacities installed by 2020 and the outlook for 2030



[1] H_2 production in Europe in 2020 (FCHO) – [2] Objective of 10Mt of low-carbon H_2 in 2030 (EU) – [3] Targets for 2030 of 16.9Mt of H_2 low-carbon, Blueprint Hydrogen Europe.

Key facts

A predominance of production capacities by SMR + CCUS[1]

- In 2020, the production of renewable and low-carbon hydrogen is very low and results mainly from two steam reforming projects combining CO_2 capture: the Cryocap project in France (Port Jérôme) and the OCAP project in the Netherlands.

Scaling up production projects

- By 2030, production capacities should increase strongly thanks to large-scale electrolysis projects but also due to the continuation of SMR+CCUS or ATR+CCUS[2] projects: the largest production capacities planned use SMR+CCUS processes (France and the Netherlands in 2020 or United Kingdom by 2030). Electrolysis projects go beyond the demonstrator stage with capacities greater than 1MW.

Production processes that depend on national strategies

- Some countries are engaged in the production of hydrogen in an export logic and adopt production processes that take advantage of the local energy potential: electrolysis connected to solar photovoltaic for the countries of southern Europe (Italy, Spain, Portugal), electrolysis connected to offshore wind power for the Netherlands and Belgium, and SMR+CCUS for Norway and the United Kingdom.

- Sweden and Norway are lagging behind in the development of low-carbon hydrogen production projects, despite significant carbon storage capacities (Sweden) and excess hydroelectricity production (Norway).

Strong growth potential due to untapped resources

- The production capacities of renewable and low-carbon hydrogen by 2030 could increase significantly with the emergence of projects for the recovery of co-produced hydrogen (not counted here and considered by some players to be renewable hydrogen). For example, in France, co-produced hydrogen represents nearly 50% of the total quantities of hydrogen produced in 2020[3].

Key figures

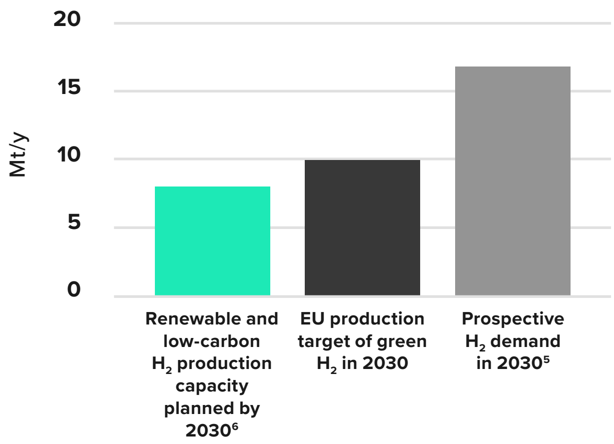
1%

Share of renewable and low-carbon hydrogen in total hydrogen production in Europe in 2020[4]

46%

Estimated share of renewable and low-carbon hydrogen in total hydrogen consumption in Europe in 2030[5]

Contribution of renewable and low carbon hydrogen production projects to European goals for 2030



Scope and assumptions

- Production capacities are based on announcements of project capacities in MW of electrolysis or in H_2 production then converted to t/year*.

- Production projects without indication of commissioning date and/or production power/tonnage are not included in the analysis*.

* Refer to the methodological appendix

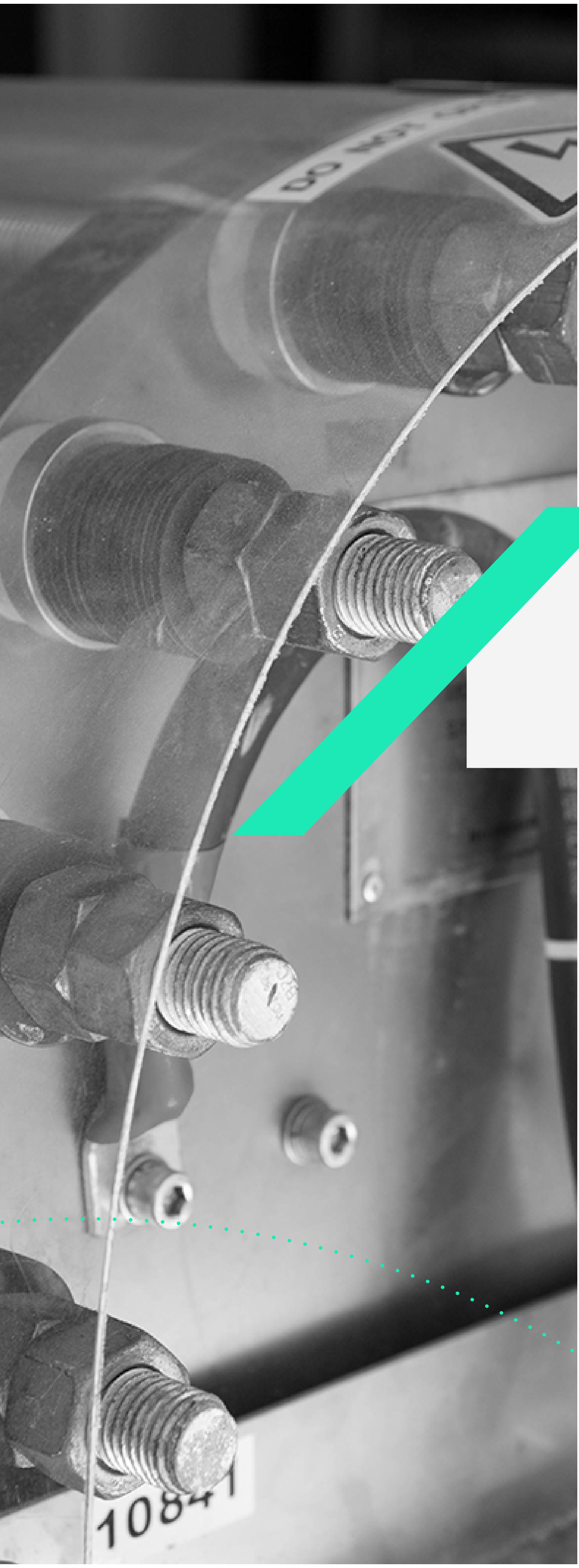
Topic #1: Analysis

[1]SMR+CCUS = methane steam reforming with carbon capture and storage
[2]ATR+CCUS = reforming authotermal with carbon capture and storage
[3]Hydrogène : analyse des potentiels industriels et économiques en France, ADEME, 2019
[4]H_2 production in Europe in 2020 (FCHO)
[5]Source: Hydrogen 2030: The Blueprint (Hydrogen Europe)
[6]Sia Partners Analysis

> European production capacities of renewable and low-carbon hydrogen represent less than 1% of total production capacity.

> Nevertheless, with the proliferation of projects and their move to a commercial scale, the production capacities for renewable and low-carbon hydrogen could represent nearly 40% of total European capacities by 2030.

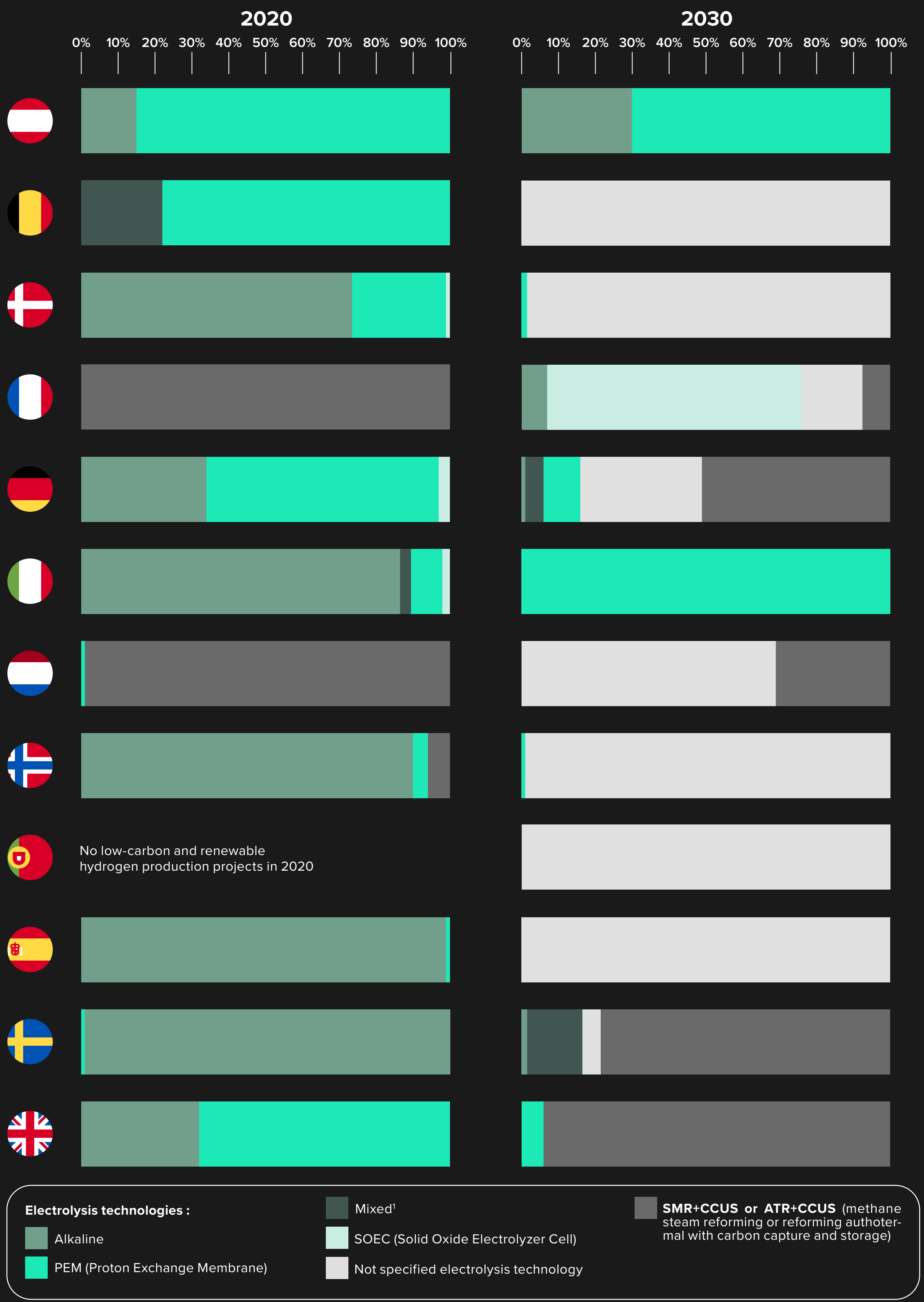
> The increase in these renewable and low-carbon hydrogen production capacities should be supported in the medium term by the United Kingdom and the Netherlands, through large-scale projects of hydrogen production using SMR+CCUS and ATR+CCUS technologies.



Topic #2:
Production Processes

Varied production processes that reflect the constraints and local energy resources of each country

Renewable and low-carbon hydrogen production processes by country in 2020 (operational) and in 2030 (in project)



[1] Several different electrolysis technologies are associated in the project

Topic #2: Analysis

Key facts

Strong growth of electrolysis

• By 2030, nearly half of renewable and low-carbon hydrogen will be produced by electrolysis of water. Taking into account the projects announced to date, electrolysis production capacities should reach 20GW in 2030, which represents 50% of the EU objective of installing 40GW by 2030.

No electrolysis technology predominates

• For the majority of electrolysis projects, the technology used has not yet been defined or communicated.

• Despite a lower final cost of hydrogen production via the Alkaline process, PEM technology dominates in terms of capacities in 2020 and in projects for 2030. Projects for which the technology is not yet defined could turn to PEM technology, whose operating flexibility is more appropriate with fluctuating renewable energy sources.

• France and Norway have SOEC electrolysis projects; a technology that has a higher efficiency than PEM or Alkaline but requires a continuous heat supply to maintain the required operating temperature. This heat supply could be achieved by installing SOEC electrolysers near concentrating solar systems or nuclear reactors.

Use of SMR with carbon capture when possible

• Despite the European Union's strategy of promoting electrolysis, the use of the SMR process will continue: half of the countries considered have plans for 2030 for SMR with CO_2 capture (SMR + CCUS). These projects are nevertheless dependent on the technical feasibility of CO_2 storage and the acceptability of civil society.

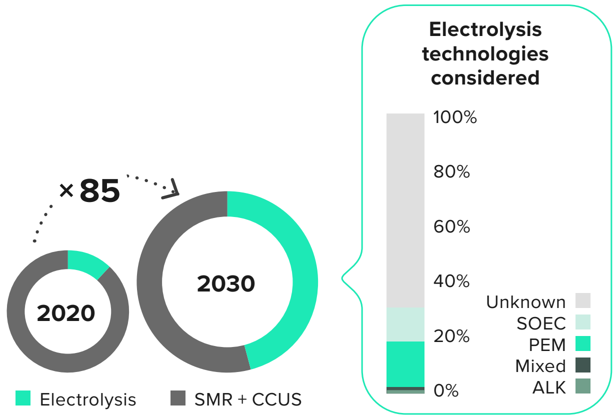
• Countries where local storage or use of CO_2 is possible thus plan to upgrade the existing SMR production sites by integrating carbon capture solutions. The United Kingdom will build new production sites using ATR + CCUS technology. Germany, which cannot store more CO_2 on its territory by virtue of its legislative framework, intends to export captured CO_2 to Norway (H2orizon project).

Little space for new production technologies

• Production processes other than electrolysis or SMR, such as biomass gasification or methane pyrolysis, remain very marginal because they are still at the R&D / demonstrator stage.

Key figures

Evolution of renewable and low carbon H_2 production processes by country between 2020 (operational) **and 2030** (in project)



Scope and assumptions

• Production processes:

"Mixed" brings together all the electrolysis projects with several electrolysis technologies used.

"Other" brings together other production processes such as biomass gasification projects.

• In many announced projects, the electrolysis technology is not yet defined or not yet communicated.

> A great diversity of production processes exists from one country to another, without dominant technology.

> SMR and ATR production processes with CO_2 capture are preferred for projects with high production capacities, but require available underground CO_2 storage capacities.

> For most of the announced projects, electrolysis technologies are not yet defined or communicated. But electrolysis should account for half of the renewable and low-carbon hydrogen produced by 2030.

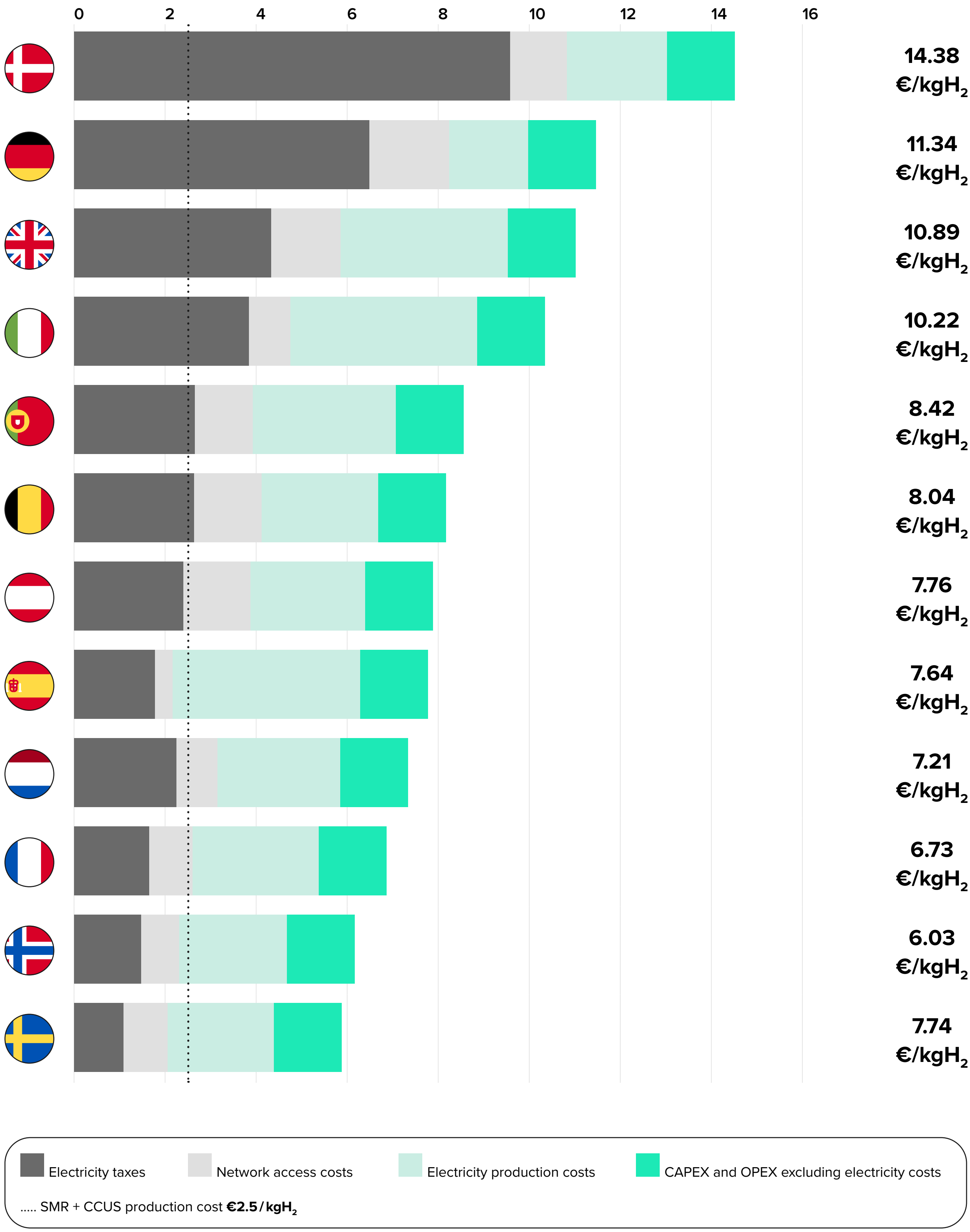
> For electrolysis, the choice of technology will depend on local constraints: alkaline or SOEC electrolysis could be more appropriate where the heat supply is available, and PEM electrolysis where the need for integration of renewable energy is strong.

Topic #3:
Production costs of electrolysis connected to the electric national grid

Heterogeneous grid-connected electrolysis production costs strongly depend on the purchase cost of electricity

Electrolysis production will increase sharply in the coming years with large-scale projects connecting to electricity networks. Sia Partners analyzes the costs of hydrogen production from grid-connected electrolysis, if production is not exempt from grid connection tarifs.

Hydrogen production costs from grid-connected electrolysis in 2020 (in €/kgH_2)*



*Analysis prior to exemptions from network access costs which can be applied.

Key facts

High production costs with electrolysis[1]

- The cost of hydrogen produced by electrolysis connected to the electricity network (from €6/kgH_2 to €14/kgH_2) in 2020 is much higher than the cost of hydrogen produced by SMR + CCUS, estimated around €2.5/kgH_2 on average.

- These 2020 grid-connected electrolysis production costs differ greatly from one country to another due to disparities in electricity prices. However, systematically, the electricity OPEX represents more than 80% of the cost of producing hydrogen from grid-connected electrolysis.

Low competitiveness with high carbon H_2 production

- On average, grid access costs and electricity taxes represent nearly 50% of the cost of hydrogen produced by electrolysis[1] and alone exceed the cost of production with SMR (high carbon H_2 production).

Cost reduction levers available

- One of the levers for lowering the electrolysis production cost is the exemption from taxes on electricity. This exemption is already in place in Norway for instance. In countries where renewable energy is very competitive, connecting electrolysers directly to renewable production capacities may be relevant.

- The second lever for lowering costs lies in improving the yields of electrolysers. Electric OPEXs represent nearly 80% of the price of hydrogen produced by electrolysis connected to the network. Lower electricity consumption per kg of hydrogen produced will have a direct impact on the cost per kg of hydrogen. The different electrolysis technologies can thus have an important role to play in lowering the costs of hydrogen production.

Key figures

83%

Average share of electricity OPEX (cost of purchasing electricity) in the price of H_2 produced by electrolysis connected to the network

x3

On average, the price of hydrogen produced by electrolysis connected to the grid is 3 times higher than that of an SMR with carbon capture but depends mainly on the cost of national electricity

Scope and assumptions

- In the cost model, the characteristics and technical yields of electrolysers are considered constant from one country to another. The variations in the cost of producing hydrogen are therefore solely due to variations in the costs of electricity.

- The electricity prices used in the cost model are the average prices over a year. The modeling does not include smart technologies on the electrolysers to optimise its operating time to periods of electricity surplus.

[1] Electrolysis connected to the national electricity grid

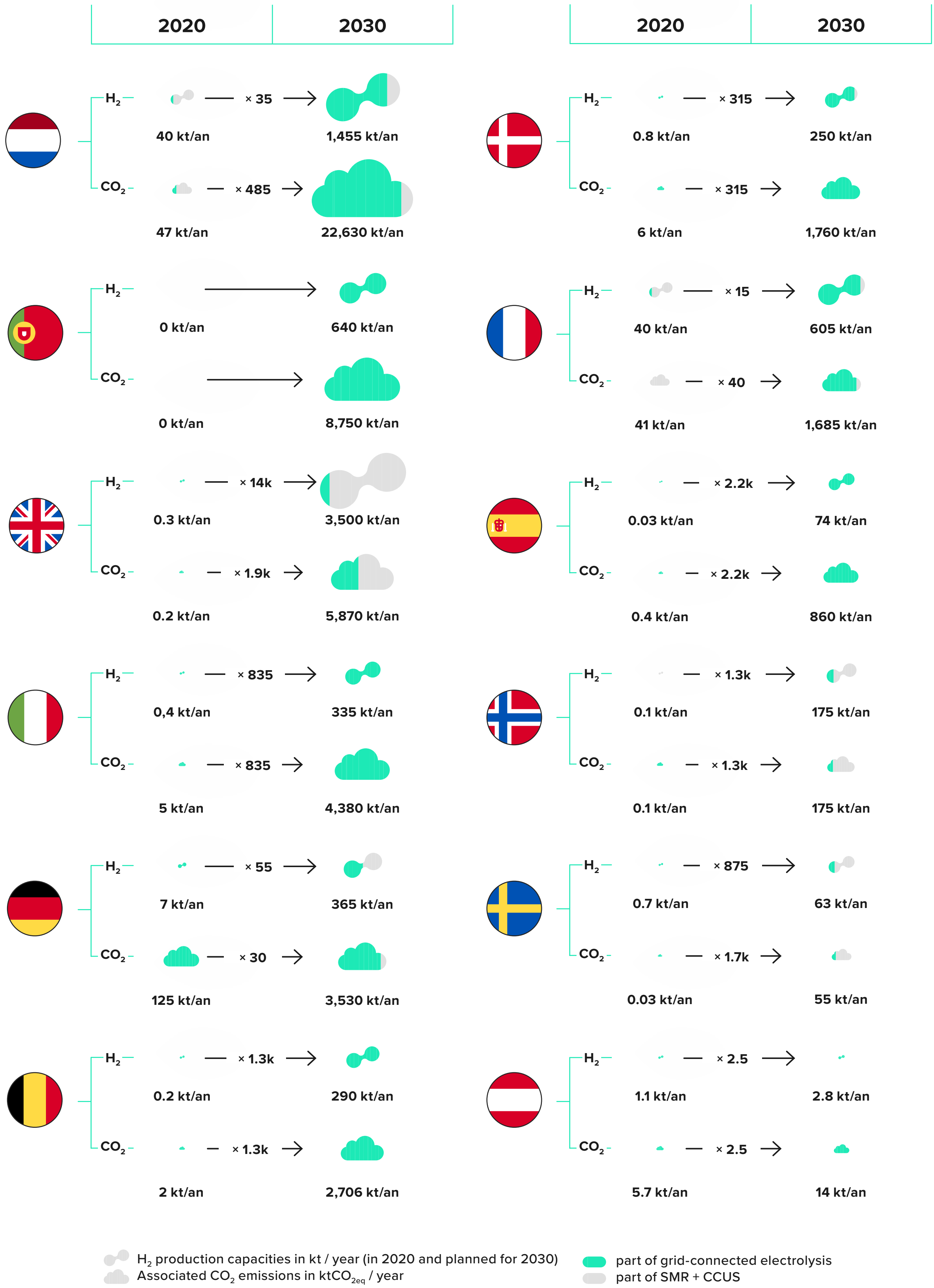
- **Grid-connected electrolysis production costs vary** between countries due to variations in the price of electricity but above all **due to grid access costs and taxes**. This stops electrolysis connected to the grid from being competitive with production by SMR or even by SMR + CCUS.

- **To reduce these costs**, electrolysis efficiency must improve and government measures must be put in place to exempt hydrogen producers from electricity taxes.

Topic #4:
Associated CO_2 emissions

A significant gross carbon impact for some countries, particularly in relation to the carbon content of national electricity mixes

The massive development of low carbon hydrogen production will have an environmental impact through associated CO_2 emissions. Sia Partners analyzes the impact in terms of CO_2 emissions of current and projected hydrogen production, in a scenario where the electrolysis projects will be connected to the national electricity grid. The impacts of grid-connected electrolysis and SMR+CCUS projects are estimated separately.



Topic #4: Analysis

Key facts

A significant carbon footprint for electrolysis connected to the grid, depending on the country

- Except for Sweden, Norway and France, the carbon content of national networks' electricity does not allow the production of low-carbon hydrogen by electrolysis[1]. To reduce the carbon impact of production by electrolysis, electrolysers will have to be connected directly to renewable production capacities or supplied with green electricity that is associated with guarantees of origin. This supply of green electricity is particularly necessary in countries where the electricity mix is particularly carbon-intensive, such as Germany and the Netherlands.

Without greening the electricity mix, gross CO_2 emissions will sharply increase by 2030

- Assuming that all the electrolysis production projects announced by 2030 will be connected to the electricity grid – and under the hypothesis that the carbon content of the electricity mix remains the same in 2030 – , the CO_2 emissions generated by all the projects should rise from 0.2 $MtCO_{2eq}$ in 2020 to 52 $MtCO_{2eq}$ in 2030, reaching the equivalent of today's annual emissions of a country like Portugal[2]. These gross emissions must however be compared with the significant decarbonisation mechanisms that these projects should generate by replacing the use of fossil resources.

The development of electrolysis must be accompanied by new renewable capacities

- If all electrolysis production projects had to be connected to renewables, this would represent a need for renewables production capacities of more than 20 GW in 2030, i.e. the equivalent of today's installed electrical renewable capacities in the Netherlands[3].

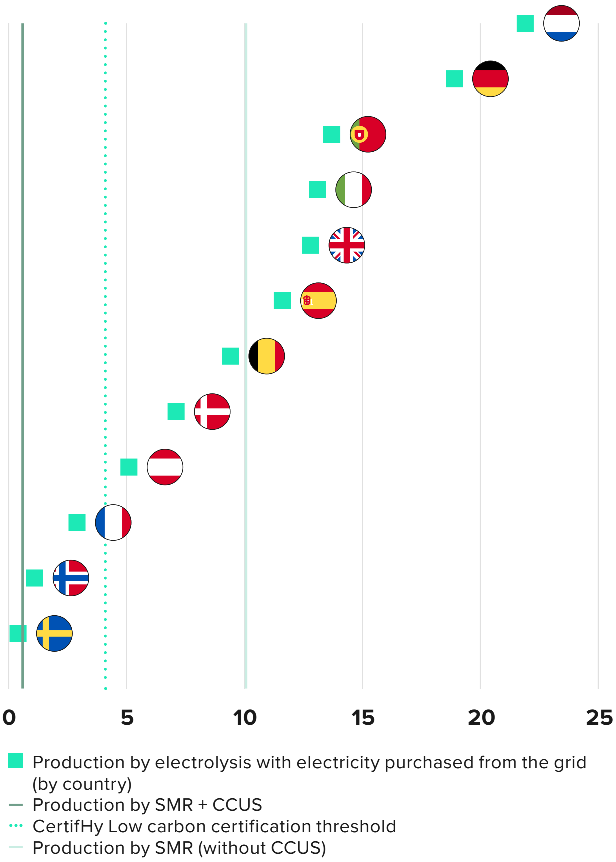
The use of SMR + CCUS can facilitate low-carbon production

- In all countries except Sweden, hydrogen production by SMR+CCUS is less carbon intensive than electrolysis using electricity withdrawn from the network,

- However, the amounts of CO_2 to be stored annually by 2030 are significant: the identified projects represent a storage requirement of 37 $MtCO_{2eq}$ in 2030, equivalent to Norway's current annual emissions[4].

Key figures

Average carbon content of H_2 production by technology and country (in $kgCO_{2eq}/kgH_2$)



Scope and assumptions

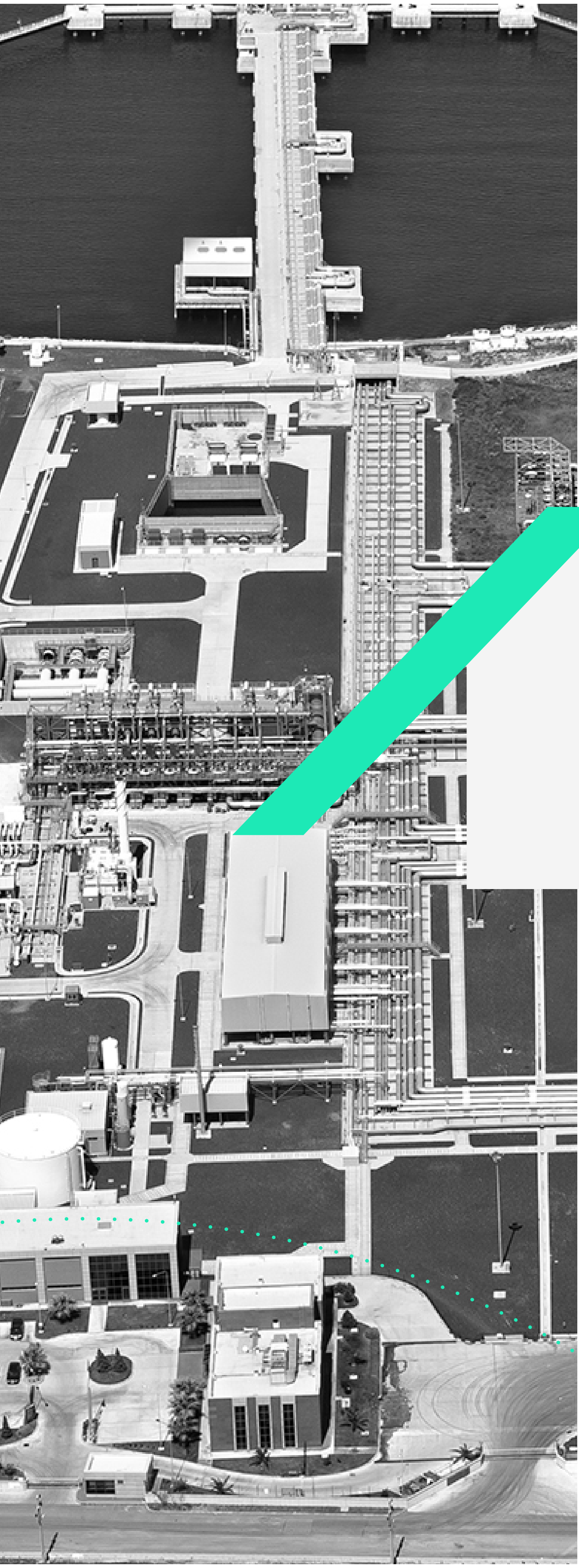
- In the proposed model, the estimates of CO_2 emissions for 2030 are calculated on the basis of the production capacities of projects announced by 2030.

- For CO_2 emissions associated with H_2 production by electrolysis, the model considers the theoretical situation where all the electrolysers withdraw electricity from the network. The associated carbon footprint is therefore linked to the carbon intensity of the country's electricity mix. In addition, the modeling was carried out with a constant carbon intensity of the energy mix (that of 2030 therefore corresponds to that of 2020) in order to highlight the necessary greening of European electricity networks.

[1] With regard to the low carbon threshold CertifHy
[2] Portugal's annual emissions of around 47 $MteqCO_2$ (IEA)
[3] Dutch National Energy & Climate Plan, 2019
[4] Norway's emissions in 2019: 36 $MteqCO_2$ (IEA)

> In the majority of European countries, the production of hydrogen by electrolysis connected to the grid cannot be considered low carbon (according to the CertifHy threshold), due to the still highly carbon-intensive national electricity mixes. Thus, the deployment of low-carbon hydrogen production capacities will require the parallel deployment of significant renewable electricity production capacities (more than 20 GW by 2030).

> The use of SMR + CCUS can constitute an interesting alternative to greening the electricity grid and promoting electrolysis, but presents other challenges, particularly in terms of available storage capacities and energy independence.



Topic #5:
Hydrogen transport and storage infrastructure

Transport and storage infrastructure will have to scale up to link regions of production and consumption

Transport and distribution networks (gas pipelines)					Maritime / River hubs		Geological storage	
Network injection		**100% H_2 networks**						
Upper limit of the accepted H_2 rate in today's natural gas networks[1]	Existence of projects aimed at developing H_2 injection[1]	100% H_2 network industrial operators	Participation of TSOs in the pan-European EHB[2] project	Target date for the deployment of 100% H_2 networks by TSOs[3] and DSOs (chosen method)	Hydrogen hub port projects (or considered)	Hydrogen waterway transport projects	Geological disposal methods considered[3]	Estimated potential for storage in salt caverns[4] of which onshore capacities
4%	✓	–	–	2040 (unknown)	–	Blue Danube	Depleted deposit	–
0%	✓	Air Liquide	FLUXYS	2030 (conversion and construction)	Antwerp Zeebrugge	–	Aquifer	–
0%	✓	–	ENERGINET	2030 (construction)	–	–	Saline cavity Aquifer	**8 PWh** (650 TWh)
6%	✓	Air Liquide	GRTgaz, Teréga	2030 (conversion and construction)	–	Normandy hydrogen plan	Saline cavity Aquifer	**510 TWh** (510 TWh)
2-10%	✓	Linde, Air Liquide	ontras Gastransport GmbH, Open Grid Europe The Gas Wheel	2030 (conversion and construction)	Hamburg, Emden	Blue Danube	Saline cavity Depleted deposit	**35 PWh** (10 PWh)
1%[5]	✓	–	snam	2030 (conversion and construction)	–	–	Depleted deposit	–
0.02%	✓	Air Liquide, Air Products, gasunie	gasunie	2030 (conversion and construction)	Rotterdam, Hydroports (Amsterdam, Dan Helder, Groningen)	–	Saline cavity	**10 PWh** (400 TWh)
0%	Scenario considered	–	–	2035 (unknown)	–	–	–	**8 PWh** (0 TWh)
0%	✓	–	–	–	Sines	–	Saline cavity	**3.2 PWh** (350 TWh)
5%[5]	✓	–	enagas	2030 (conversion)	–	–	Aquifer	**1.2 PWh** (300 TWh)
0%	✓	–	SWEDEGAS	2030 (construction)	–	–	–	–
0.1%	✓	Air Products, Linde	–	2030-2035 (conversion)	–	–	Depleted deposit Saline cavity	**9 PWh** (1.2 PWh)

[1] ACER, 2020 – [2] Members of the European Hydrogen Backbone in 2020 – [3] EHB and national strategies (2020) – [4] Caglayan & al, 2019 –
[5] Limit rate applying to all gas called «unconventional»

Key facts

Current situation: Hydrogen transport is relatively localized and takes place between production centers and places of consumption (industrial areas, refueling stations). This transport takes place mainly by road and for some industries via 100% dedicated H_2 networks, operated by private companies such as Air Liquide, Linde and Air Products with a cumulative network of 1,700 km.

From 2030, the development of hydrogen uses should foster an increase in the volume of hydrogen transported and boost the number of production and consumption sites, favoring the emergence of new modes of transport

- In the short term, blending hydrogen into the natural gas network is seen as an interesting solution for the first operational projects. Some countries are already testing injection of hydrogen into natural gas transport networks and authorizing varying proportions of hydrogen into their national natural gas network.

- In the medium term, projects led in particular by gas transmission system operators (TSOs) are planning to develop 100% hydrogen transport networks in newly constructed H_2 or converted gas pipelines. TSOs gathered in the European Hydrogen backbone (EHB) plan to set up a connected European transport network by 2040, for a total estimated cost between 27 and 64 billion euros.

- Finally, long-distance maritime transport projects are being built on a European or even international scale, with ports positioning themselves as export hubs for hydrogen (port of Sines in Portugal) or import (port of Rotterdam and project Hydroports in the Netherlands).

Alongside transport, a certain number of national strategies are planning to implement **large-scale hydrogen storage capacities**, in order to make hydrogen a flexible asset of the energy system (or even to allow its inter-seasonal storage). Among the geological storage methods considered (depleted deposits, salt cavities, aquifers), storage in salt cavity seems the most promising for 100% hydrogen storage, due to its tightness, a limited minimum filling requirement and low bacterial activity. Germany holds around 40% of the storage potential in terrestrial salt caverns in Europe.

Key figures

€27-64 billion

Estimation of the investments necessary for the construction of the Europe Hydrogene Backbone[1]

85 PWh

Total technical potential of hydrogen storage in salt cavities in Europe, the equivalent of **more than 50 times** the current underground gas storage capacities in Europe[2]

Scope and assumptions

- Road transport by truck, which is more diffuse and therefore less traceable, was therefore not included in the comparison table.

- Only geological storage is the subject of an indicator in the comparison table due to its more systemic scope and its closer association with hydrogen transport. The estimated storage potential is based on a technical study taking into account not only geological and technical criteria, but also geographic, ecological and economic criteria.

[1] European Hydrogen Backbone, 2020
[2] Sia Partners analysis based on Caglayan & al. (2019) and Gas infrastructure Europe (2018) data

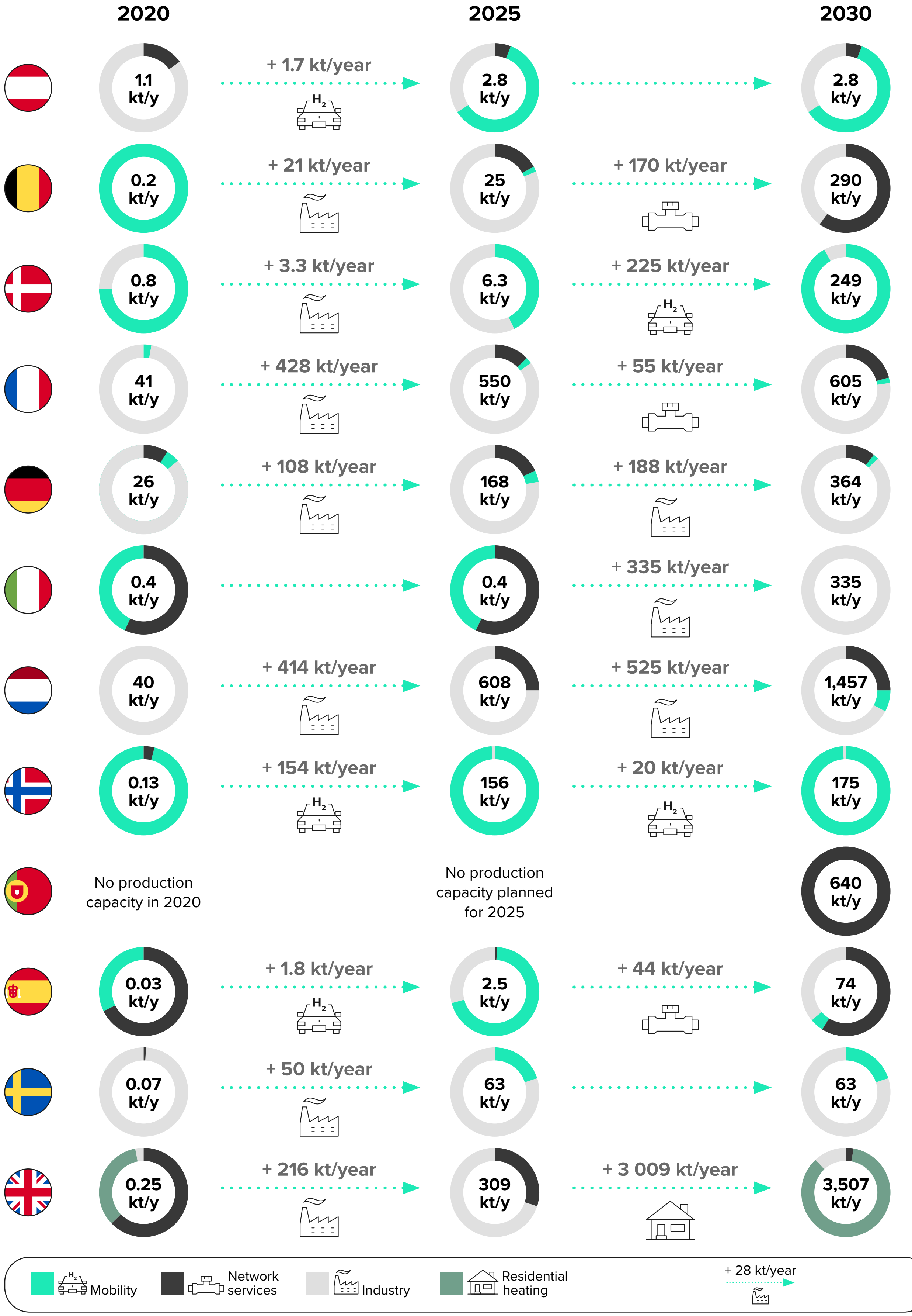
- In 2020, only the highly industrialized regions of the Netherlands, Germany, France, Belgium and the United Kingdom have a hydrogen transport infrastructure thanks to their industrial networks.

- In order to support **the massification of hydrogen demand**, the countries studied, and in particular **the gas infrastructure managers of these countries, are exploring various hydrogen transport solutions**. The countries along the North Sea are positioning themselves to be the forerunners of the development of 100% hydrogen networks.

Topic #6:
Allocation of production capacities for different uses

Until 2025, hydrogen allocation mainly goes towards industrial uses but will depend on national hydrogen strategies by 2030

Planned uses for renewable and low-carbon hydrogen production capacities in 2020 (installed capacities) and by 2025 and 2030 (planned capacities).



Caption: Uses dedicated to production capacities

Uses experiencing the strongest increase in dedicated production capacities

Source: Sia Partners analysis based on IEA data

Key facts

Allocation mainly towards industrial uses

- In 2020, the production of renewable and low-carbon hydrogen is still too low to distinguish priority uses apart from Germany, France, Austria or the Netherlands, where priority is already given to the greening of industrial uses. In the short term, the first uses of renewable and low carbon hydrogen should be observed in the industrial sector.

A prevalent use for mobility

- Although mobility currently accounts for a limited hydrogen consumption, it remains the main use of renewable and low-carbon hydrogen for some low-producing countries. Mobility is clearly identified in national strategies as a priority axis for the development of renewable and low-carbon hydrogen. However, because hydrogen mobility should be based quite largely on decentralized production capacities (or those not yet specified) – and our analysis only identifies projects with a production capacity greater than 100 kW – mobility appears to have a relatively minor role in 2030 in total hydrogen consumption.

In the longer term, an asset for energy flexibility

- The use of hydrogen as a means of storage and flexibility for the electricity network is mainly considered in countries with a high concentration of renewable energy (Netherlands, Belgium, Spain, Portugal). These projects are not expected to be operational before 2030.

UK's specific stationary applications

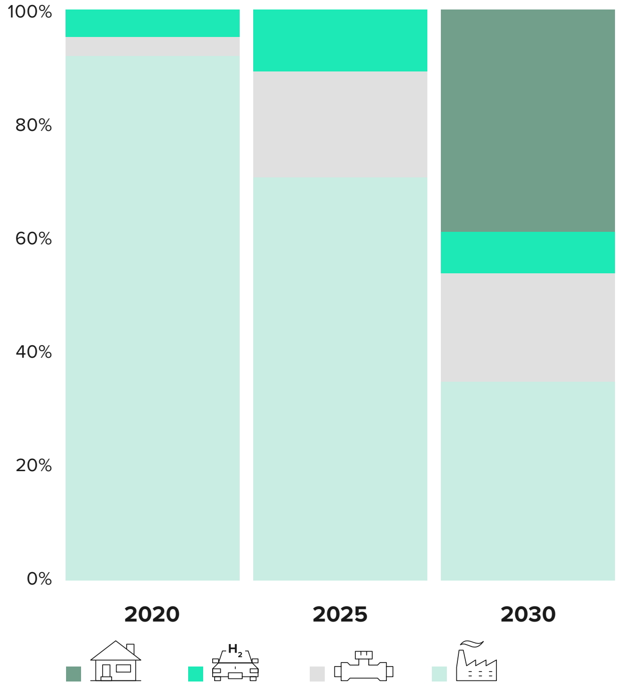
- The United Kingdom stands out with its ambitious projects of 100% hydrogen networks for residential heating (such as the H21 and Hy4Heat projects). Only small-scale projects exist in other countries for this specific end-use.

Towards differentiation uses

From 2030, the results of our study reflect the differentiated strategies and uses between countries: industry in Germany, France and the Netherlands, residential heating in the United Kingdom, network services for the integration of renewable energy in Belgium and Portugal, and mobility in Denmark and Norway.

Key figures

Change in the planned uses of renewable and low-carbon H_2 between 2020 and 2030 within the 12 countries



Industry:
Industrial applications in refining, ammonia, metallurgy, or chemicals.

Residential heating:
Injection into 100% H_2 networks for residential heating.

Mobility:
Production of H_2 or CH_4 on a large scale (more than 100kW and powering several recharging stations) for road, rail, maritime or air mobility applications.

Network Services:
Network management through: H_2 storage, H_2 or CH_4 injection in the natural gas network, or transformation into electricity.

Scope and assumptions

- For multiple-use projects, production capacities are associated with the predominant use.

- The production capacities dedicated to mobility represent a low estimate: electrolysis projects in stations of less than 100kW are not taken into account in the calculation of the observatory's various indicators.

Topic #6: Key takeaways

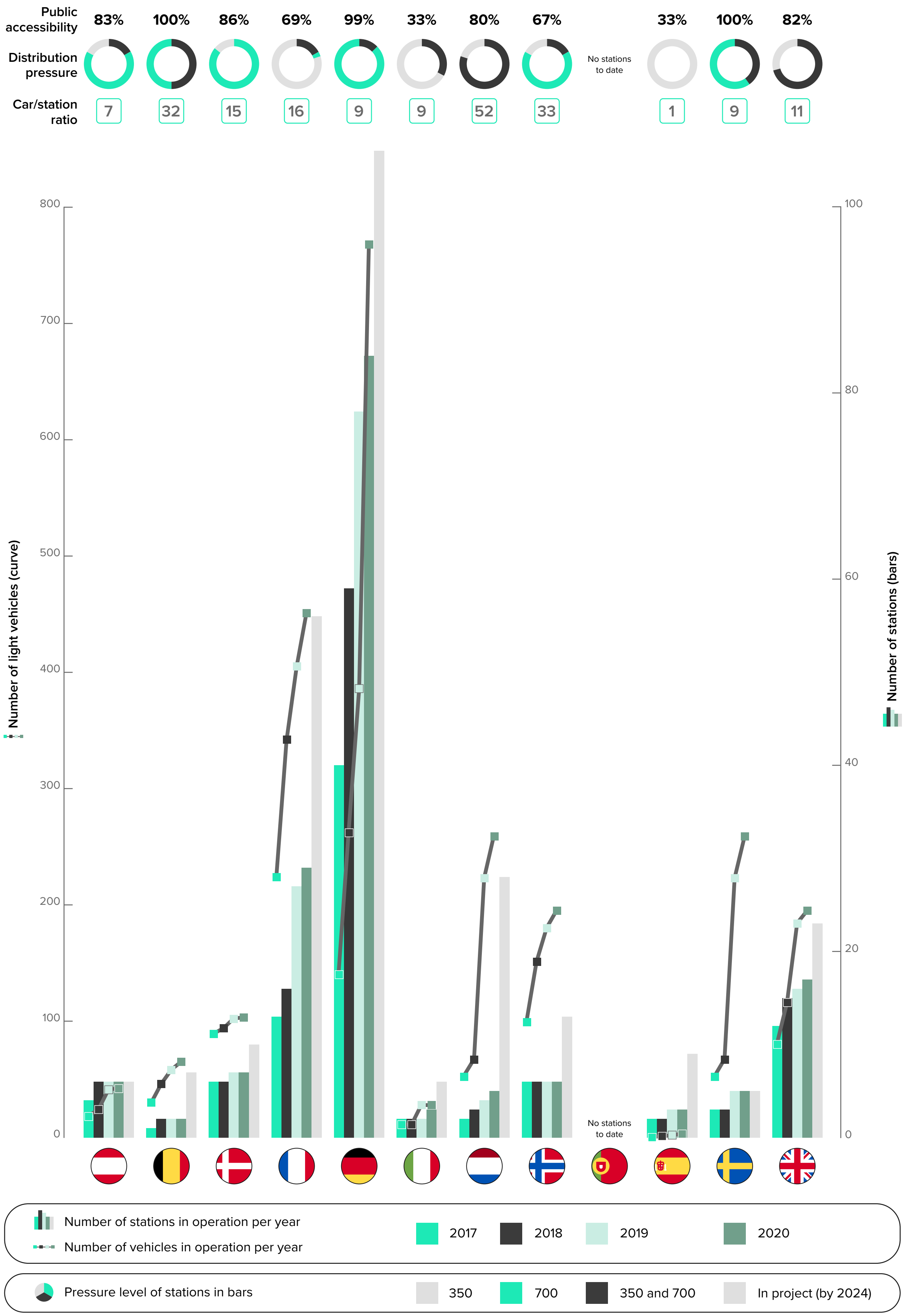
> **Uses for low-carbon and renewable hydrogen will become more diverse over time, even if industrial uses will remain a priority.**

> **Along this general diversification of uses, countries favor a response to local economic issues (strong industrial presence), energy needs (renewable energy intermittency management) or political priorities.**

Topic #7:
Focus on H_2 Road Mobility

A commitment to develop hydrogen mobility but few vehicles are in circulation

Evolution of the number of H_2 stations and light H_2 vehicles



Source: Sia Partners analysis based on H2 stations.org and EAFO consolidated data.

Key facts

General growth

- Since 2017, the deployment of H_2 fueling stations is accelerating in Germany in particular with more than 85 stations in service at the end of 2020. Only Portugal has not yet inaugurated any stations. The number of light vehicles also logically follows growth in all countries. By 2023, the number of stations should continue to increase and almost double, pushing for a rise in hydrogen road mobility for heavy-duty vehicles in particular. Hydrogen can overcome the drawbacks of electric mobility, allowing for long distance travels.

But deployment remains weak

- Despite growth, the number of stations and vehicles is still very marginal: hydrogen stations operational in 2020 in the 12 countries represent only 0.2% of service stations. Buses and heavy H_2 vehicles are also very underdeveloped with just over 100 vehicles in circulation.

- H_2 vehicles in circulation come mainly from fleets of company vehicles (taxis, utility vehicles, dumpsters) or public transport (buses).

- Apart from Germany, the construction of stations is either the result of territorial projects with European funding or to meet the hydrogen needs of captive fleets.

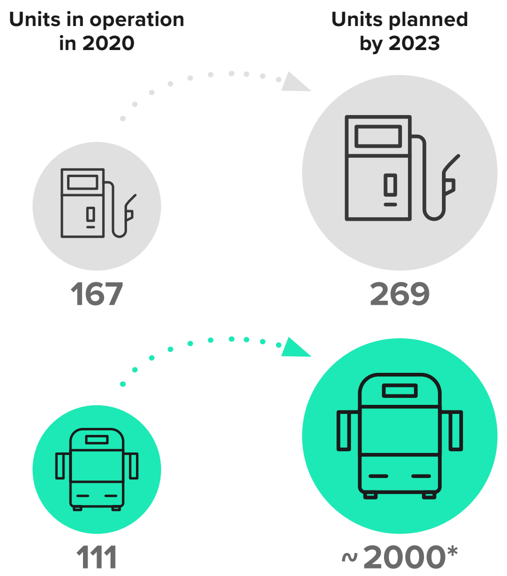
Different bunkering pressures, a sign of different strategies

- The lack of consensus across Europe on the standard refueling pressure results in heterogeneities from one country to another: Germany, Austria and Norway are developing 700 bar stations while France and Italy are deploying 350 bars, more suitable for heavy vehicles. These differences reflect distinct strategies in the development of hydrogen mobility. However, still few stations are publicly accessible for heavy vehicles.

Announcements of future developments by valleys

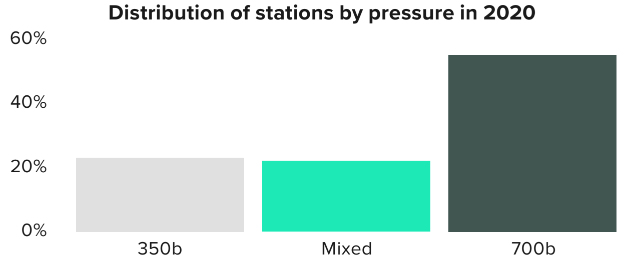
- Many hydrogen valleys for mobility have been announced as the Scandinavian-Mediterranean Corridor. This project aims to deploy 218 stations and 40,000 heavy vehicles by 2030 in the countries concerned (Sweden, Denmark, Netherlands, Germany, Austria, Italy).

Key figures



* Includes the 1000+ buses planned in Norway, Germany, Belgium, Sweden and the Netherlands through the H2bus project

Distribution of stations by pressure in 2020



Scope and assumptions

- All types of light vehicles are considered: utility, commercial, taxi, etc.

- Several sources were crossed including national registration data and EAFO data in order to obtain the number of vehicles in circulation.

- The time range of planned stations extends to 2024 for the announced stations. Since the implementation time is less than 4 years, new unannounced projects may become operational by 2024.

> The development of **hydrogen road mobility is accelerating in all European countries**. Germany is the most advanced country in the development of infrastructure for hydrogen road mobility with more than 100 operational charging stations. Despite this advance, **the number of vehicles per station remains low**, a trend found in most European countries.

Topic #8:
H_2 regulations and strategies

Ramping up support mechanisms and investments to meet the 2030 objectives

Ramping up support mechanisms and investments to meet the 2030 objectives

	Support mechanisms				Investments	H_2 production targets	Mobility objectives		
	H_2 strategy / roadmap	Certificates or quotas	Subsidies	Tax exemptions	Amount of subsidies & public investments	🏛 *Set by institutional players* 👥 *Set by private players* 🌍 *Specific to low carbon and renewable H_2*	H_2 stations	Light vehicles	Heavy vehicles
🇦🇹	✓		✅	✅	**€1 bn** by 2030	🏛🌍 **0,1 to 0.2Mt/y** (2030)	–	–	–
🇧🇪	✅	✓	✅	✅	Funding on a case-by-case basis without a defined global envelope	🏛🌍 **0.09Mt/y** (2030)	**20** (2030)	**18k** (2030)	**265** (2030)
🇩🇰			✅	✅	~ **€30M** until now for the sector which invests €5M/y in R&D	👥🌍 **2.3 Mt/y** (2030)	–	–	–
🇫🇷	✅	✅	✅	✅	**€3.4 bn** by 2023 then €3.8 bn by 2030	🏛🌍 **0.65 Mt/y** (2030) 👥🌍 **1,9Mt/y** (2030)	**400 to 1000** (2028)	**20k to 50k** (2028)	**800 to 2000** (2028)
🇩🇪	✅		✅	✅	**€9 bn** by 2030	🏛 **2.25Mt/y** (2030) 🏛🌍 **0.5Mt/y** (2030)	**400** (2025) **1000** (2030)	**100k** (2025)	–
🇮🇹	✓		✅	✅	**€10 bn*** by 2030 + €418M by 2025 in mobility	🏛 **0,7Mt/y** (2030) 🏛🌍 **0,5Mt/y** (2030) 👥 **0.8Mt/y** (2030)	**350** (2030)	**25k** (2025) **390k** (2030)	**1000** (2025)
🇳🇱	✅	✅	✅	✅	**+ €35M/y** + investments included in €25 bn* by 2030 in RE	🏛🌍 **0.5Mt/y** (2030) 👥 **1.4Mt/y** (2030)	**50** (2025)	**15k** (2025)	**3000** (2025)
🇳🇴	✅		✅	✅	~ **€15M** announced so far	–	–	–	–
🇵🇹	✅		✅	✅	**€7 bn* to €9 bn*** by 2030 including €40M in 2020	🏛🌍 **0.23Mt/y** (2030)	**50 to 100** (2030)	–	–
🇪🇸	✅	✓	✅	✅	**€8.9 bn*** by 2030 + €125M in 2020	🏛🌍 **0.4 Mt/y** (2030)	**100 to 150** (2030)	**5k to 7.5k** (2030)	**150 to 200** (2030)
🇸🇪	✓		✅	✅	Unknown	–	**150** (2030)	–	–
🇬🇧	✓		✅	✅	~ **€600M + €1.1 bn** for CCUS by 2025	🏛🌍 **1.05Mt/y** (2030) 👥 **13,5Mt/y** (2030)	**1150** (2030)	**1.6M** (2030)	**500** (2030)

* Funds that may come from budgets other than government (EU, private investments)

✅ Published items ✓ Items announced but not published

- The announcement of massive public investments allocated to hydrogen development in the German roadmap in June 2020 was followed by the publication of national hydrogen strategies by many other European countries, who increased their objectives and investments.

- Governments are insisting on the development of renewable or low carbon hydrogen to intensify the greening of the economy, encouraged in particular by the establishment of guarantees of origin and more precise regulatory frameworks.

03

Rating.

Country Rating

The following rating takes into account themes 1 and 5 to 8 presented previously in the study. Production processes as well as costs and CO_2 emissions are not taken into account in the rating, as this data is not sufficiently defined for each of the projects announced. The methodology applied to this rating is detailed in the "appendix".

	Topic	#1 Production of renewable and low carbon H_2	#5 Hydrogen transport infrastructure	#6 Industrial uses of renewable and low carbon H_2	#7 H_2 Mobility	#8 Governmental ambitions	Total score
European leaders	🇩🇪	●●●○○	●●●●●	●●●○○	●●●●○	●●●●○	●●●●○
	🇫🇷	●●●●○	●●●○○	●●●●●	●●●●●	●●●○○	●●●●○
	🇳🇱	●●●●○	●●●●○	●●●●○	●●●●●	●●●○○	●●●●○
Intermediate countries	🇬🇧	●●●○○	●●○○○	●●●●○	●●○○○	●●●●○	●●●○○
	🇩🇰	●●●●○	●●○○○	●●●○○	●●○○○	●○○○○	●●○○○
	🇧🇪	●●○○○	●●●○○	●●○○○	●○○○○	●○○○○	●●○○○
Follower countries	🇸🇪	●○○○○	●●○○○	●●●○○	●○○○○	●●○○○	●●○○○
	🇦🇹	●●○○○	●●○○○	●○○○○	●○○○○	●○○○○	●●○○○
	🇮🇹	●●○○○	●●○○○	○○○○○	●○○○○	●●●○○	●●○○○
	🇳🇴	●●○○○	●○○○○	●○○○○	●●●○○	○○○○○	●○○○○
	🇪🇸	●○○○○	●●○○○	●○○○○	●○○○○	●●○○○	●○○○○
	🇵🇹	●○○○○	●●○○○	○○○○○	○○○○○	●●○○○	●○○○○
	Leading countries by topic	🇳🇱 🇩🇰	🇩🇪	🇫🇷	🇩🇪	🇩🇪 🇬🇧	

Sia Partners analysis - Rating methodology specified in the appendix.

Analysis

Leading countries

Germany, France and the Netherlands clearly stand out from other European countries, due to their ambitious targets for the production of renewable and low-carbon hydrogen. In addition, mobility objectives have been set with a significant number of stations and light vehicles to be deployed in their national territories, supported by substantial government investments.

Germany stands out for its lead in terms of deployment of hydrogen for mobility: light vehicles, buses but also trains. Germany also has the largest geological hydrogen storage capacities (40% of European potential). Ahead of hydrogen injection into gas networks and strong in many projects, Germany is nonetheless losing points because of their low share of renewable and low-carbon hydrogen production in 2020 and planned for 2030, compared to the country's current total hydrogen consumption.

In France, with substantial production capacities in 2020, the greening of industrial uses will continue to support the increase in renewable and low carbon hydrogen production. The announced investments in hydrogen in France are massive, second in Europe behind Germany. Concerning H_2 mobility, the country is focusing on increasing hydrogen production and deploying new stations.

The Netherlands is also discernible for its production of renewable and low-carbon hydrogen in 2020 and its ambitious goals for 2030, in particular for their H_2 uses for industrial applications. Already densely covered by industrial hydrogen networks, the Netherlands is heavily investing in the deployment of 100% H_2 transport networks (Netherlands Hydrogen Valley) associated with storage capacities, in order to become a hydrogen transport hub in the medium term.

Intermediate countries

The United Kingdom, Denmark and Belgium follow the top three. These countries are characterized by a heterogeneous development of hydrogen in each of the topics analyzed. The United Kingdom nevertheless stands out compared to Denmark and Belgium:

With ambitious renewable and low-carbon hydrogen production targets and a desire to massively decarbonize industrial uses and district heating, the United Kingdom is less advanced in mobility and hydrogen infrastructure, which explains its lag behind leading countries (Germany, France, the Netherlands). H_2 mobility objectives focus on light vehicles and their stations, heavy hydrogen vehicles are not included in the stated objectives. The geological storage capacities of hydrogen and CO_2 are nevertheless promising for the United Kingdom.

Denmark has real ambitions to develop hydrogen despite low industrial consumption. These ambitions focus on mobility and the integration of wind power generation capacities.

Belgium, due to its geographical position, can benefit from collaborations around IPCEI for the development of mobility, transport networks and hydrogen production projects. In terms of mobility, these intermediate countries depend on European aid for the construction of charging infrastructure. Thus, the deployment of hydrogen vehicles is still very low and localized around a few projects.

Follower countries

Sweden, Austria, Italy, Spain, Portugal and Norway belong to the group of least developed countries. Nevertheless, two subgroups stand out:

Norway, Sweden and Austria have rather interesting productions in 2020 with mobility projects in development for H_2 ships or H_2 trains. However, very few ambitions are displayed in terms of investments and objectives for 2030.

Italy, Spain and Portugal have almost zero current production in 2020 but have very strong ambitions and objectives for 2030. Many projects have already been announced. These countries are positioning themselves on the transport of hydrogen, produced locally from solar energy (Portugal, Spain) or imported from North Africa (Italy).

- **Out of all the countries studied and rated, 3 countries stand out from the others.**

- **Germany is often the leading country by topic but has a low renewable and low carbon H_2 production capacity projected for 2030 compared to its hydrogen consumption.**

- **France's score is driven by its significant amount of production capacity in project for 2030, as well as by its high renewable and low carbon industrial H_2 consumption projected for 2025.**

- **Finally, the Netherlands have strong ambitions in terms of production, industrial uses and H_2 transport infrastructure.**

04/

Country Profiles.

Reading grid for country files

Legend

Support mechanisms

H_2 strategy or roadmap

Clarification of the regulatory framework

Certificates or quotas

Subsidies

Exemptions

Projects led by the regions

Downstream uses

Mobility

Network services

Industry

Residential heating

Austria.

Austria is currently one of the European leaders in terms of hydrogen production capacity by electrolysis. However, few concrete projects have been announced for 2030, and the national strategy that was announced for the end of 2020 is still not published. Thus, the production of H_2 in Austria is likely to be lower by 2030 than that of its European neighbors (target of 1 to 2 GW of electrolysis in 2030). Nevertheless, through its geographical positioning, the country intends to play a central role in connecting the flows of H_2 between European countries.

2020 data

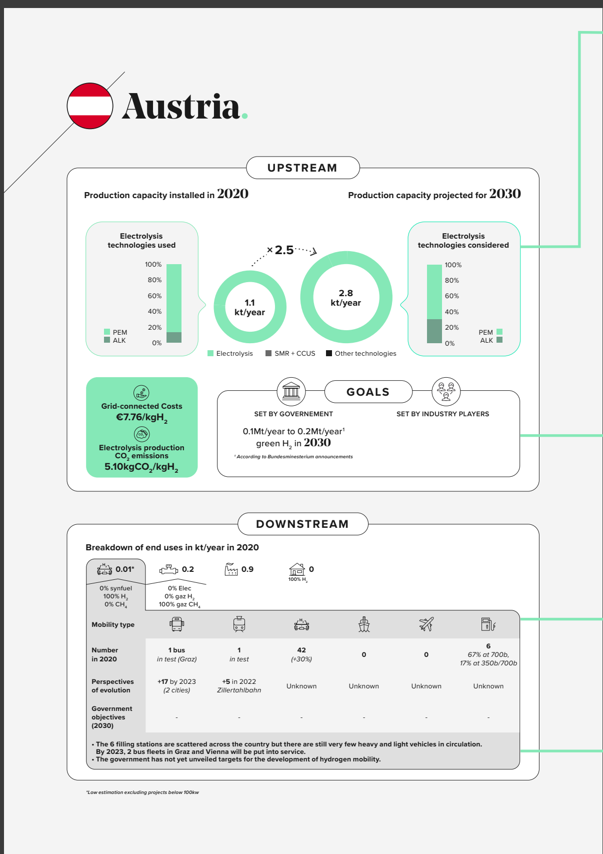
Support mechanisms	Installed production capacity	Downstream uses
	1.1 kt/year	

SUPPORT MECHANISMS

- The Renewable Energy Expansion Act 2020 plans to give responsibility to the Austrian Association for the Gas and Water Industries for defining the maximum permitted rate of incorporation of hydrogen and other renewable gases into the natural gas transmission network.
- To develop 1GW of electrolysis, the Government plans to invest €1bn by 2030.
- A premium of €3,000 to €5,000 for the purchase of an electric vehicle (battery or fuel cell) until the end of 2020.
- 50% reduction in road toll rates at the start of 2020 and eco-tax exemption for heavy vehicles running on 100% electricity or H_2 (Federal Road Tolls Act).
- The Tax Reform Act 2020 provides tax relief on biogas and hydrogen, in connection with their allocation to the Natural Gas Tax Act.
- The Tax Reform Act 2020 also plans to introduce tax exemptions for green hydrogen.
- The Austrian Climate and Energy Fund will finance 30% of the supra-regional project WIVA P&G, which represents a total investment of €125M (2018-2025) dedicated to hydrogen and syngas.

Summary of the hydrogen development progress

Regulatory framework and support mechanisms for the development of production and use of hydrogen



Austria.

UPSTREAM

Production capacity installed in 2020

Production capacity projected for 2030

Grid-connected Costs
€7.76/kgH_2

Electrolysis production CO_2 emissions
5.10kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

0.1Mt/year to 0.2Mt/year[1] green H_2 in 2030

[1] According to Bundesminesterium announcements

SET BY INDUSTRY PLAYERS

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

Mobility	Network services	Industry	Residential heating
0.01*	0.2	0.9	0
0% synfuel 100% H_2 0% CH_4	0% Elec 0% gaz H_2 100% gaz CH_4		100% H_2

Mobility type	Bus	Train	Car	Ship	Plane	Filling station
Number in 2020	1 bus *in test (Graz)*	1 *in test*	42 *(+30%)*	0	0	6 *67% at 700b, 17% at 350b/700b*
Perspectives of evolution	+17 by 2023 *(2 cities)*	+5 in 2022 *Zillertahlbahn*	Unknown	Unknown	Unknown	Unknown
Government objectives (2030)	-	-	-	-	-	-

- The 6 filling stations are scattered across the country but there are still very few heavy and light vehicles in circulation. By 2023, 2 bus fleets in Graz and Vienna will be put into service.
- The government has not yet unveiled targets for the development of hydrogen mobility.

*Low estimation excluding projects below 100kw

Renewable and low-carbon hydrogen production capacities

×15 Increase in production capacities between 2020 and 2030, on the basis of announced projects

Production targets

Government set

Set by industry players

The electrolysis production capacity objectives (in MW) have been expressed as production objectives in kt / year. See the methodological appendix for the conversion ratios used

Focus on hydrogen mobility deployment

+28 Annualized growth in the number of vehicles between 2017 and 2020

National mobility strategy summary

Austria.

Austria is currently one of the European leaders in terms of hydrogen production capacity by electrolysis. However, few concrete projects have been announced for 2030, and the national strategy that was announced for the end of 2020 is still not published. Thus, the production of H_2 in Austria by 2030 is likely to be lower by 2030 than that of its European neighbors (target of 1 to 2 GW of electrolysis in 2030). Nevertheless, through its geographical positioning, the country intends to play a central role in connecting the flows of hydrogen between central European countries.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	1.1 kt/year	

SUPPORT MECHANISMS

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- A premium of €3,000 to €5,000 for the purchase of an electric vehicle (battery or fuel cell) until the end of 2020.

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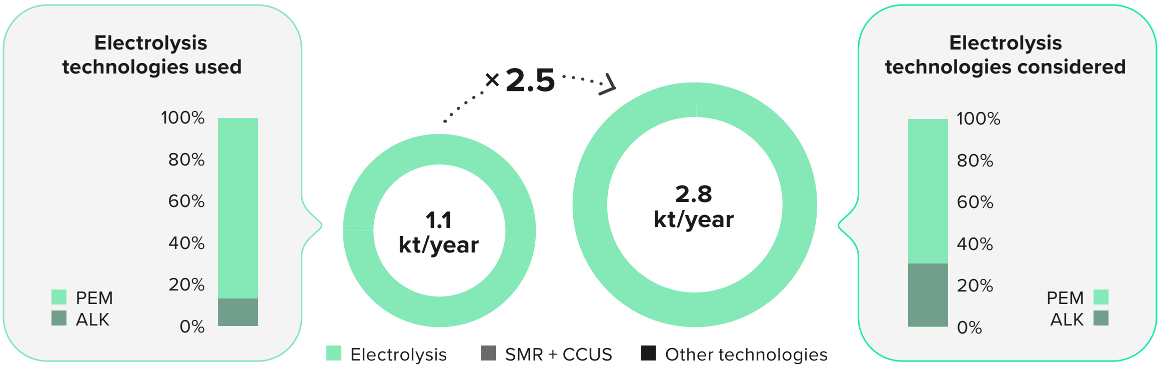
Austria.

UPSTREAM

Production capacity installed in 2020 | **Production capacity projected for 2030**



Grid-connected Costs
€7.76/kgH_2

Electrolysis production CO_2 emissions
5.10kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

0.1Mt/year to 0.2Mt/year[1]
green H_2 in 2030

[1] *According to Bundesminesterium announcements*

SET BY INDUSTRY PLAYERS

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

Mobility	Industry	Industry (process)	Buildings
0.01*	0.2	0.9	0
0% synfuel 100% H_2 0% CH_4	0% Elec 0% gaz H_2 100% gaz CH_4		100% H_2

Mobility type	Bus	Train	Car	Ship	Plane	Filling stations
Number in 2020	**1 bus** *in test (Graz)*	**1** *in test*	**42** *(+30%)*	**0**	**0**	**6** *67% at 700b,* *17% at 350b/700b*
Perspectives of evolution	**+17** by 2023 *(2 cities)*	**+5** in 2022 *Zillertahlbahn*	Unknown	Unknown	Unknown	Unknown
Government objectives (2030)	-	-	-	-	-	-

- **The 6 filling stations are scattered across the country but there are still very few heavy and light vehicles in circulation. By 2023, 2 bus fleets in Graz and Vienna will be put into service.**
- **The government has not yet unveiled targets for the development of hydrogen mobility.**

**Low estimation excluding projects below 100kw*

Belgium.

While hydrogen plans are being finalized at federal and regional levels, Belgian authorities are expected to grant massive support to hydrogen projects as part of the recovery plan. Focus areas are towards the development of H_2 applications in the mobility and industrial sectors in Wallonia, Antwerp and Ghent and to create a major hub for importing H_2 to the EU. The federal government should publish a hydrogen strategy in the coming months to boost its applications.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	0.2 kt/year	

SUPPORT MECHANISMS

- From 2025 onwards, only hybrid, electric or hydrogen buses will be able to serve city centers in the Flemish region and the majority of the bus fleet should be converted in the Walloon region by 2030.
- Initiatives to transport hydrogen in gas networks have started.

- An official call for proposals has been launched to finance hydrogen projects, within the framework of the Important Project of Common European Interest (IPCEI) and the recovery plan.
- Grants for bus projects have been set up, such as in Charleroi, with a loan of €5M. Ecological bonuses are also set up by the Flemish government to support H2 mobility.

- Tax exemptions for the purchase and circulation of hydrogen vehicles (only in Flanders).

Hydrogen strategy declined by each region:

- Flanders takes advantage of its ports and industrial ecosystems to support CCUS projects. This comes together with the objective of a «CO_2 neutral Flemish region» and the establishment of guarantees of origin for low carbon H_2.
- Wallonia has produced a hydrogen roadmap through the TWEED cluster (Technology of Wallonia Energy, Environment and sustainable Development)
- Brussels-Capital is less advanced on measures to support hydrogen and accelerate decarbonization.

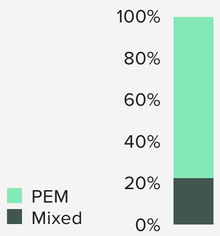
Belgium.

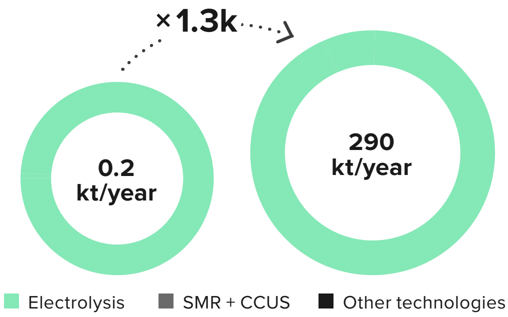
UPSTREAM

Production capacity installed in 2020

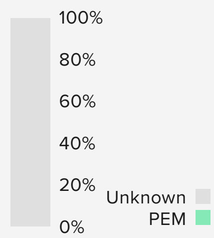
Production capacity projected for 2030

Electrolysis technologies used





Electrolysis technologies considered



Grid-connected Costs
€8.04/kgH_2

Electrolysis production CO_2 emissions
9.36kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

0.09Mt/year* of green H_2 in 2030

**According to the Wallonian program and the Flemish Energy section in the Belgian 2018 national plan*

SET BY INDUSTRY PLAYERS

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

- **0.2*** — 0% synfuel, 100% H_2, 0% CH_4
- **0** — 0% Elec, 0% gaz H_2, 0% gaz CH_4
- **0**
- **0** — 100% H_2

Mobility type						
Number in 2020	**5** *including 5 buses*	**0**	**65** *(+29%)*	**1** *Hydroville*	**0**	**2** *50% 700b, 50% 350b/700b*
Perspectives of evolution	**+10** by 2024 *(1 city)*	Unknown	**+60** by 2021 *Hype taxis*	Unknown	Unknown	**+5** by 2024
Government objectives (2030)**	**265**	-	**18,120**	-	-	**20**

- **With the Netherlands, Belgium and Luxembourg are creating a hydrogen mobility corridor. It is however, still at an early development stage and has a limited number of stations (fewer than 10).**
- **A concrete action plan including regulations has been in place since 2015 to support the sector.**

**Low estimation excluding projects below 100kw*

***Objectives from the NECP for Wallonia only*

Denmark.

With strong wind power potential, Denmark plans to deploy large-scale hydrogen projects along its wind power sites to store electricity in times of overproduction. In terms of mobility, while FCH-JU funds should allow the deployment of large bus fleets, the government has yet to announce major measures to accelerate the deployment of hydrogen.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	0.8 kt/year	

SUPPORT MECHANISMS

- €9.5M of government supports towards investments in hydrogen charging infrastructure.
- €17M for 2 Power-to-X projects.
- R&D investments for hydrogen represent an important part of the Danish EUDP program but they are decreasing

- Tax exemptions on vehicle registration tax for hydrogen vehicles.
- Reduction of €5,000 on parking fees for electric vehicles, including FCEV.
- The six largest cities in the country have announced that they want to buy only electric buses (BEV or FCEV) from 2021. Copenhagen wants to fully electrify its bus fleet by 2025.

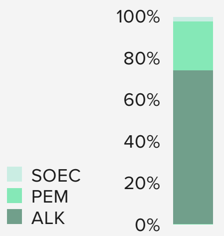
Denmark.

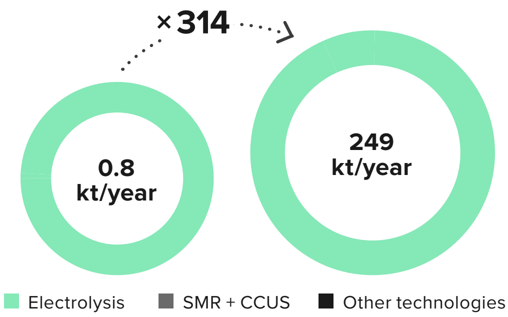
UPSTREAM

Production capacity installed in 2020

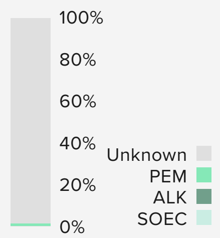
Production capacity projected for 2030

Electrolysis technologies used





Electrolysis technologies considered



Grid-connected Costs
€14.38/kgH_2

Electrolysis production CO_2 emissions
7.06kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

SET BY INDUSTRY PLAYERS

2.3Mt/year* of green H_2 in 2030

** Based on Orsted Renewable Hydrogen Denmark 2019*

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

Mobility	Pipeline	Industry	Buildings
0.6*	**0**	**0.2**	**0**
0% synfuel 100% H_2 0% CH_4	0% Elec 0% gaz H_2 0% gaz CH_4		100% H_2

Mobility type	Bus	Train	Car	Ship	Plane	Refueling stations
Number in 2020	**3** *including 3 buses*	**0**	**103** *(+5%)*	**0**	**0**	**7** *86% 700b*
Perspectives of evolution	**+210** by 2024 *(>2 cities)*	Unknown	**100%** green taxis (2025)	**+1** by 2027	Unknown	**+3** by 2024
Sector objectives (2030)	-	-	**75,000**	-	-	**150**

- **Denmark targets mobility as a priority use of H_2 .**
- **The government has not yet defined objectives for its development but is preparing a roadmap for hydrogen in transport up to 2030.**

**Low estimation excluding projects below 100kw*

France.

The French sector is stepping up in the development of hydrogen. Many regions, which are strongly mobilized alongside the industry, have responded to ADEME's calls for projects. The national hydrogen strategy, unveiled in September 2020, provides the hydrogen sector with €7.2 billion of public investment by 2030. Meanwhile, regions are to define H_2 deployment roadmaps to create territorial ecosystems associating production and uses for industry and mobility uses.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	41 kt/year	

SUPPORT MECHANISMS

- Establishing a framework for charging stations which distribute hydrogen.

- Implementation of a traceability system in 2020, which tracks the origin of hydrogen used in the industry.

Hydrogen recovery plan: €7.2bn (September 2020)

- €625M in 2020 from 2 calls for projects on H_2 regional hubs and on H_2 technological bricks.
- €1.5bn dedicated to the construction of a major project of common European interest (PIIEC) on hydrogen.
- €650M dedicated to the support mechanism for the production of renewable and low-carbon hydrogen.
- €65M dedicated to research programs led by the ANR.

Mobilization of PIA (future investment plan) mechanisms.

- €3.8bn between 2023-2030 to strengthen the production of electrolysis.

Economic recovery plan (May 2020)

€7,000 for individuals and €5,000 for companies for the purchase of an H_2 vehicle. An additional €5,000 conversion bonus for the first 200,000 vehicles purchased.

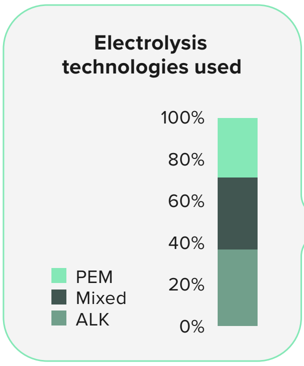
Tax exemptions for the purchase of hydrogen vehicles and for the tax on company vehicles
Tax exemptions from the electricity network access charge for hydrogen production through electrolysers.

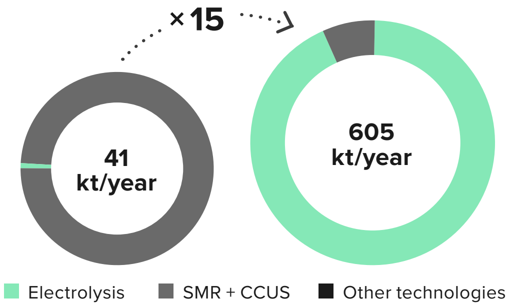
- French regions are setting up hydrogen roadmaps and supporting projects on their territories worth several million euros.

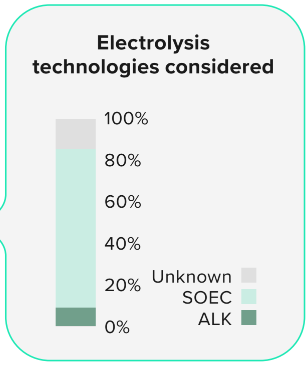
France.

UPSTREAM

Production capacity installed in 2020 | **Production capacity projected for 2030**







Grid-connected Costs
€6.73/kgH_2

Electrolysis production CO_2 emissions
2.91kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

0.65Mt/year[1] of green H_2 in 2030 with up to 0.4Mt/year[2] for the industry (2028)

[1] 2020 H_2 strategy. [2] Plan Hulot

SET BY INDUSTRY PLAYERS

1.9Mt/year* in 2030

**According to Afhypac*

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

- **1.1*** — 0% synfuel, 100% H_2, 0% CH_4
- **0.3** — 46% Elec, 53% gaz H_2, 1% gaz CH_4
- **39**
- **0** — 100% H_2

Mobility type	Bus	Train	Car	Ship	Aircraft	Station
Number in 2020	**22** *including 21 buses*	**0**	**459** *(+26%)*	**1** *Navhibus*	**0**	**29** *(+31%) 80% to 350b, 17% 350b/700b*
Perspectives of evolution	**+136** by 2024 *(13 cities)*	**+14** from 2022 *Project Regiolis H_2*	**+500** by 2021 *Hype Project*	**+6** by 2022	*Zero carbon aircraft project by 2035*	**+28** by 2024
Government objectives (2028)	**800 to 2,000**	-	**20,000 to 50,000**	-	-	**400 to 1 000**

- **France currently prioritizes heavy mobility with 350b distribution stations, and fleets of light vehicles for professionals (e.g. Hype taxis).**
- **The deployment of mobility infrastructures depends on the involvement of each region.**

**Low estimation excluding projects below 100kw*

Germany.

On June 3 2020, Germany took advantage of its EU presidency to announce its hydrogen strategy, and position itself as a driving force for its development in Europe. The adoption of Germany's 'A better future' package will add €9bn to the development of hydrogen in Germany, including €2bn for the development of international partnerships. Germany is also working to harmonize standards for hydrogen use in Europe.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	6.6 kt/year	

SUPPORT MECHANISMS

- Project to set up a minimum quota of 2% electricity from hydrogen for aviation by 2030, with funding of €25M between 2020 and 2024 for research into hydrogen-based technologies.

- €9bn for the acceleration of H_2 commercialization in the recovery plan, including €3.6bn within the National Innovation Program (NIP), €3.4bn for mobility infrastructures and the rest for international partnerships.
- Financial support for R&D of €100M to €150M per year between 2020 and 2023 under the Research program for energy (includes the funding of 11 R&D projects for a production capacity of 330MW).
- €200M per year to accelerate the commercialization of technologies, through the Climate energy fund.
- €1bn over the period 2020-2023 for the decarbonization of hydrogen in industry.
- Support of €25M over 4 years for H_2 marine technologies.
- Subsidies for the purchase of vehicles and for the construction of hydrogen filling stations.

- Tax exemptions for the circulation of hydrogen vehicles.

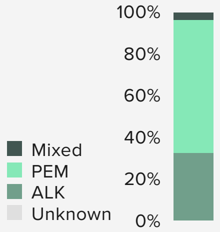
- The HyLand NIP competition supports the implementation of hydrogen projects at regional levels.

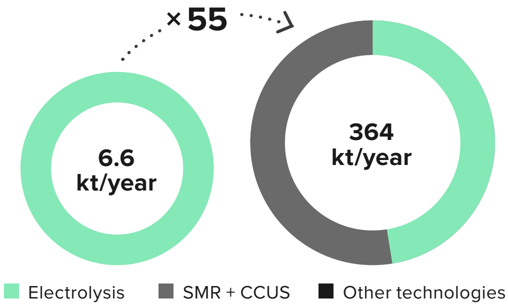
Germany.

UPSTREAM

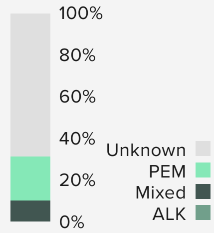
Production capacity installed in 2020 — **Production capacity projected for 2030**

Electrolysis technologies used





Electrolysis technologies considered



Grid-connected Costs
€11.34/kgH_2

Electrolysis production CO_2 emissions
18.95kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

2.25Mt/year* in 2030 including
0.5Mt/year* of H_2 green

According to Nationale Wasserstoffstrategie

SET BY INDUSTRY PLAYERS

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

- **1.3*** — 1% synfuel, 20% H_2, 79% CH_4
- **2.5** — 28% Elec, 67% gaz H_2, 5% gaz CH_4
- **2.9**
- **0** — 100% H_2

Mobility type	Bus	Train	Car	Ship	Plane	Station
Number in 2020	**45** *including 44 buses*	**2**	**763** *(+76%)*	**0**	**0** *Hy4 project*	**84** *(+28%) 85% at 700b*
Prospects of evolution	**+79** by 2024 *(7 cities)*	**+41** by 2022	Unknown	**+11** by 2024	Unknown	**+22** by 2024
Government objectives (2025)	-	-	**100,000**	-	-	**400**

- **Germany is actively developing a network of hydrogen filling stations for light vehicles at 700 bars. 99% of the stations are open to the public.**
- **The first H_2 trains are already in circulation in Germany. Development prospects are significant, as 40% of the German rail network is diesel fueled.**

Low estimation excluding projects below 100kw

Italy.

Hydrogen is still underdeveloped in Italy, but many projects and regulations have emerged over the past 4 years to produce more H_2 from solar energy for mobility and for fertilizers. The government announced in November 2020 that it was aiming for €10 billion of investments, with a 5GW electrolysis target by 2030. In addition, Italy wishes to have a strategic role in transporting H_2 produced in North Africa to the EU by 2030-2050.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	0.4 kt/year	

SUPPORT MECHANISMS

- A 2018 decree facilitates the construction and management of charging stations to align with European standards. The set objective is for hydrogen to represent 1% of fuels by 2030.
- The regulations must still evolve to allow easier use of H_2 for non-industrial applications.

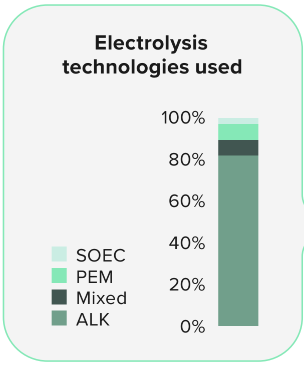
- At the end of November 2020, the preliminary guidelines of the national hydrogen plan suggest an investment of €10bn with €5-7bn for 5GW electrolysis production by 2030, €2-3bn for the distribution and consumption of hydrogen for mobility, €1bn for R&D and the remaining funds for the development of gas infrastructure. The funds would come from the national budget, the Next budget Generation EU and the 2021-27 national plan.
- Financial support for hydrogen research comes mainly from the European Union through the FCH-JU but Italy also supports 5 projects worth €8.5M.
- For mobility, €418M is expected for the period 2021-2025 of which 40% would come from the EU and the rest from the Italian government.

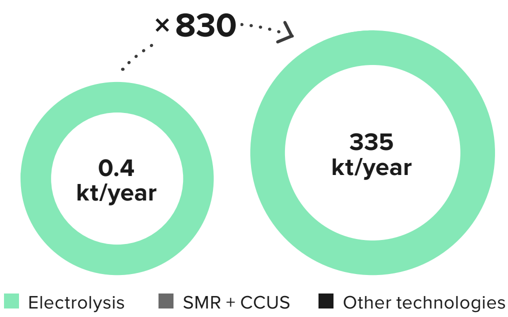
- Tax exemptions for 3 to 5 years for the circulation of hydrogen vehicles.

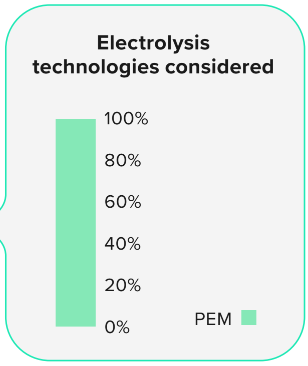
Italy.

UPSTREAM

Production capacity installed in 2020 | **Production capacity projected for 2030**







Grid-connected Costs
€10.22/kgH_2

Electrolysis production CO_2 emissions
13.06kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

0.7Mt/year[1] of which 0.5Mt/year of green H_2 in 2030

[1]According to Strategia Nazionale Idrogeno Linee Guida Preliminari 2020

SET BY INDUSTRY PLAYERS

0.8Mt/year[2] in 2030

[2]According to SNAM potential of H_2 in Italy 2019

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

- Mobility: **0.2*** — 19% synfuel, 81% H_2, 0% CH_4
- Industry: **0.2** — 0% Elec, 100% gaz H_2, 0% gaz CH_4
- Power: **0**
- Buildings: **0** — 100% H_2

Mobility type	Buses	Trains	Cars	Ships	Planes	Stations
Number in 2020	**8** *including 8 buses*	**0**	**28** *(+37%)*	**0**	**0**	**3** *66% 350b*
Perspectives of evolution	**+12** by 2024 *(1 city)*	**6** Coradia Stream (2023)	Unknown	Unknown	Unknown	**+3** from here 2024
Government objectives (2025)	**1000**	-	**25,000**	-	-	**350** (2030)

• **Today, the only H_2 mobility projects are the result of European programs led by the FCH-JU. For 2030, the objective in terms of mobility is to reach 1% of the national light vehicle fleet (ie approximately 300,000 vehicles) and 2% of trucks (ie 4,000 trucks) powered by H_2 fuels. Substantial efforts will be necessary to achieve this goal.**

**Low estimation excluding projects below 100kw*

Netherlands.

In April 2020, the government detailed its H_2 strategy. The sector has enormous potential, thanks to off-shore wind power production in the North Sea. Thus, 3 to 4 GW of electrolysis production are envisaged by 2030 with projects already under construction. The majority of projects aim to decarbonize industrial uses and replace the hydrogen produced by SMR in Delfzijl, Rotterdam and Zeeland. Private players have announced even more ambitious targets of 6GW and €9bn in investments for North Holland. The country is also one step ahead with its portal hydrogen infrastructures, and is planning to become a hydrogen hub for Europe.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	40 kt/year	

SUPPORT MECHANISMS

- Definition of H_2 infrastructure needs based on studies of Gasunie and TenneT for an H_2 network.
- Objective of 14% renewable fuels in air transport by 2030, thanks to synthetic fuels produced from hydrogen.

- Establishment of a Guarantee of Origin system under the RED II directive and under the responsibility of Vertogas. Harmonization of objectives with European countries.

- Public investments to reach €17.5bn to €25bn by 2025, including €15bn to create wind capacity.
- Subsidy of €35M per year for the operation of wind farms with hydrogen production.
- Up to 100% subsidies for the installation of H_2 stations.
- Subsidies (SDE ++: support policy for an effective reduction of carbon emissions) to decarbonize the industry for which the marginal costs of the transition to H_2 renewable are the weakest. Budget of €4bn in 2020.

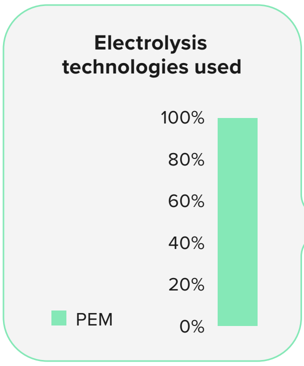
- Tax exemptions for the purchase and circulation of hydrogen vehicles.

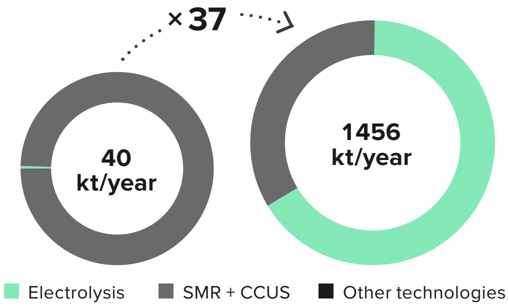
- As part of the sustainable purchasing program, the state or regional authorities are clients of hydrogen projects.
- For maritime transport, a green recovery plan will stimulate the use of H_2 to decarbonize transport.

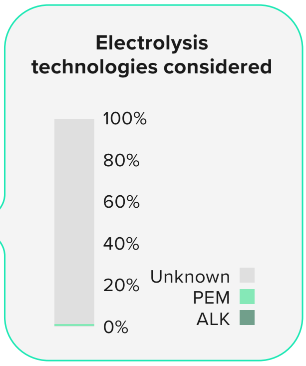
Netherlands.

UPSTREAM

Production capacity installed in 2020 | **Production capacity projected for 2030**







Grid-connected Costs
€7.21/kgH_2

Electrolysis production CO_2 emissions
21.86kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

0.5Mt/year[1] of low carbon H_2 in 2030

[1]According to government strategy

SET BY INDUSTRY PLAYERS

1.4Mt/year[2] in 2030

[2]According to Waterstofroutes Nederland by CE Delft

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

Mobility	Energy (gas)	Industry	Buildings
0.2*	**0.01**	**40**	**0**
0% synfuel 100% H_2 0% CH_4	0% Elec 100% gaz H_2 0% gaz CH_4		100% H_2

Mobility type	Bus	Train	Car	Ship	Plane	Refuelling station
Number in 2020	**17** *including 10 buses*	0	**259** *(+71%)*	0	0	**5** *(+31%)* *80% 350b/700b*
Perspectives of evolution	**+50** by 2024 *(3 cities)*	**Ilint test** (2020) *2 regions (2035)*	Unknown	**+11** by 2025	Unknown	**+23** by 2024
Government objectives (2025)	**3,000**	-	**15,000**	-	-	**50**

- **Hydrogen is considered a promising sector for post-2030 mobility, particularly for achieving carbon neutrality in urban logistics, long-distance transport, maritime industry and aviation.**

**Low estimation excluding projects below 100kw*

Norway.

Norway has CO_2 storage cavities allowing the use of large-scale SMR+CCS units. They can also take advantage of hydroelectric renewable electricity to produce renewable hydrogen by electrolysis. The country plans, in its hydrogen strategy published in June 2020, to commit to these two areas of hydrogen production for road and maritime mobility and for some industrial processes.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	41 kt/year	

SUPPORT MECHANISMS

- Action plan for alternative fuels in transport (2019): designation of the entities in charge of regulation, in particular the DSB for safety issues.

- The Norwegian Research Council's Energix program (€11M) includes hydrogen technologies.
- PILOT-E financing scheme, supported by Innovation Norway, Enova & Research Council.
- Hydrogen strategy: €2M increase in the Klimasats fund dedicated to low carbon high speed ships.
- Grant of €10,000 for the purchase of a hydrogen taxi.

- Tax exemption on the consumption of electricity used for electrolysis.
- Hydrogenated vehicles: exemption from purchase taxes, reduced VAT rate, exemption from road insurance tax.

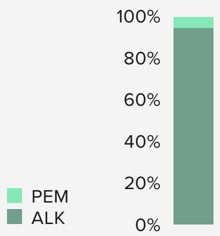
Norway.

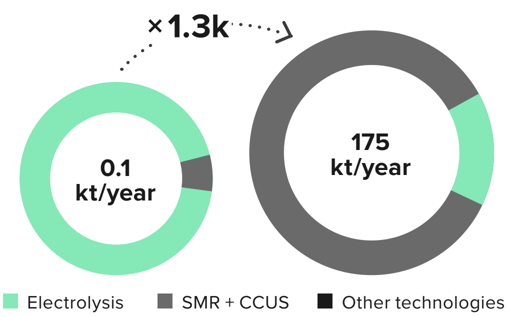
UPSTREAM

Production capacity installed in 2020

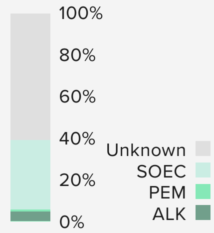
Production capacity projected for 2030

Electrolysis technologies used





Electrolysis technologies considered



Grid-connected Costs
€6.03/kgH_2

Electrolysis production CO_2 emissions
1.06kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT	SET BY INDUSTRY PLAYERS
Not communicated	*Not communicated*

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

Mobility	Industry	Industrial	Building
0.1*	0.01	0	0
0% synfuel 100% H_2 0% CH_4	46% Elec 53% gaz H_2 1% gaz CH_4		100% H_2

Mobility type	Buses	Trains	Cars	Ships	Planes	Stations
Number in 2020	4	0	195 *(+25%)*	0	0	6 *67% to 700b,* *17% 350b/700b*
Perspectives of evolution	+70 trucks by 2023	Unknown	Unknown	+4 by 2023	Unknown	+7 2024
Government objectives (2030)	-	-	-	-	-	-

• Norway is one of the most advanced countries in terms of maritime mobility with several H_2 station projects in port areas. Concerning road vehicles, the explosion of an H_2 station in the suburbs of Oslo ended the service of 5 H_2 buses.

**Low estimation excluding projects below 100kw*

Portugal.

Portugal wants to become a central player in the hydrogen economy, with export production around the port of Sines. However, the country has not yet developed any projects: the first electrolysis pilot project is expected for 2022 and won't be connected to renewable electricity. According to the hydrogen national strategy, published in August 2020, which sets a target of 2 to 2.5 GW of electrolysis, many projects should begin to emerge by 2030.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	0 kt/year	*no uses in 2020*

SUPPORT MECHANISMS

- The government should amend the decree on gas distribution and storage to add a section specific to hydrogen. The government aims to regulate the production and injection of hydrogen.

- In the national hydrogen strategy, investments in H_2 by 2030 are estimated to be between €7bn and €9bn. The funds would be both public (including European aid) and private. For 2020, the government has supported projects worth €40M.
- €450M of public investment for the port of Sines out of the €1.5bn estimated to be necessary.
- Subsidy of €1,125 for the purchase of an electric vehicle.
- VAT deduction on the purchase of FCEV up to €50,000 for company fleets

- Implementation of a system of guarantees of origin for renewable gases including hydrogen.

- Project "Green Flamingo" around the port of Sines, in order to make it a hydrogen production hub.
- Objective of filing an IPCEI file to obtain additional EU funding for the development of H_2.

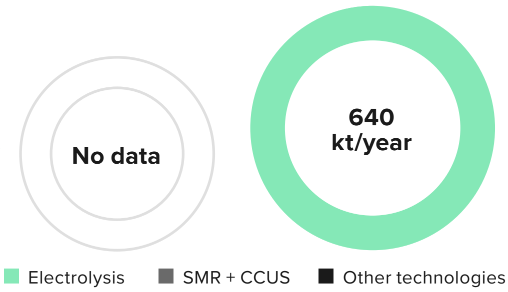
Portugal.

UPSTREAM

Production capacity installed in 2020 | **Production capacity projected for 2030**

Electrolysis technologies used

No renewable and low-carbon hydrogen production capacity in 2020



Electrolysis technologies considered

Electrolysis technologies not communicated to date

Grid-connected Costs
€8.42/kgH_2

Electrolysis production CO_2 emissions
13.68kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

0.23Mt/year* of green H_2 in 2030

*According to the Plano National do Hydrogen

SET BY INDUSTRY PLAYERS

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

0*	0	0	0
0% synfuel 0% H_2 0% CH_4	0% Elec 0% gaz H_2 0% gaz CH_4		100% H_2

Mobility type						
Number in 2020 (growth)	0	0	0	0	0	0
Perspectives of evolution	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Government objectives (2030)	-	-	-	-	-	50-1 000

- Portugal currently has no H_2 infrastructure and no local low-carbon production.
- By 2030, as well as the growth in hydrogen production, the country wants to build 50 to 100 H_2 stations and have 1% to 5% of road transport energy consumption provided by hydrogen, and 3% to 5% for domestic maritime transport.

*Low estimation excluding projects below 100kw

Spain.

In October 2020, Spain published its H_2 roadmap with the objective of producing renewable H_2 by 2024 and of reaching 4 GW of installed electrolysis by 2030. This hydrogen will be used to green the industry and will then be used for mobility. The 1st major project is built around the IPCEI Green Spider. If other projects are planned, they have not yet been completely defined. By 2030, Spain wishes to export the H_2 produced from solar energy and to account for 10% of the total H_2 production capacity in Europe.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	0.03 kt/year	

SUPPORT MECHANISMS

- The H_2 Roadmap includes areas of regulatory simplification, aiming to define specific legislation for H_2 stations, as well as for electrolysis and Power-to-X installations.

- The roadmap also sets out the ambition to create a system of guarantees of origin for renewable hydrogen, in collaboration with European institutions.

- Roadmap: it is estimated that €8.9bn, from public and private funds, will be needed for the development of renewable H_2, as well as its uses.
- MOVES II Plan, €100M: Subsidy for individuals from €1900 to €2600 for the purchase of a hydrogen car, and up to €6000 for a van or commercial vehicle. The ICO-Covid Plan publicly guarantees up to 80% of the purchase of low-emission vehicles.
- REINDUS industrial competitiveness strengthening program: a budget of €25M in loans for H_2 mobility.

- Exemption from vehicle registration tax for H_2 vehicles. In the Canary Islands, exemption also from VAT.

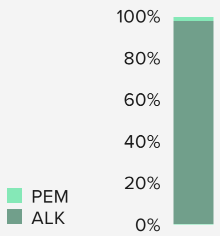
- Ongoing territorial projects, such as the Green Hysland project in Mallorca.
- The government roadmap identifies other potential territorial projects, in particular, around the petrochemical centers of Huelva, San Roque-Los Barrios, Cartagena, Sagunto, Tarragona, Bilbao, Avilés-Gijón, Coruña and Puertollano.

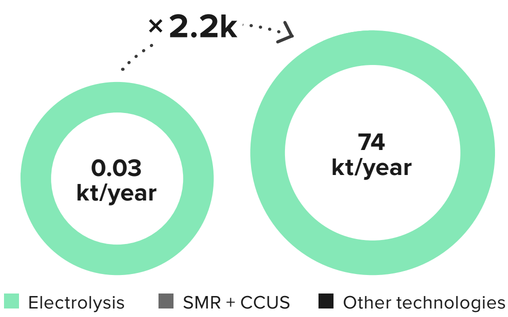
Spain.

UPSTREAM

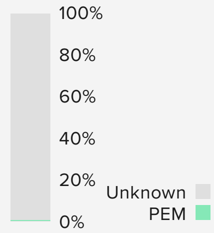
Production capacity installed in 2020 | **Production capacity projected for 2030**

Electrolysis technologies used





Electrolysis technologies considered



Grid-connected Costs
€7.64/kgH_2

Electrolysis production CO_2 emissions
11.60kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

0.4Mt/year* of green H_2 in 2030

Hoja de ruta del Hidrogeno

SET BY INDUSTRY PLAYERS

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

- **0.01*** — 0% synfuel, 100% H_2, 0% CH_4
- **0.02** — 0% Elec, 70% gaz H_2, 30% gaz CH_4
- **0**
- **0** — 100% H_2

Mobility type						
Number in 2020	0	0	3	0	0	3 *100% 350b*
Perspectives of evolution	**+8** by 2021 *(1 city)*	**+Talgo** (2023)	Unknown	Unknown	Unknown	**+6** by 2024
Government objectives (2030)	**150-200**	2 lines	**5000-7500**	-	-	**100-150**

- **Spain remains rather conservative in terms of H_2 mobility objectives compared to other European countries but offers action plans to develop all types of mobility.**
- **Very few vehicles are in circulation and only 3 stations are operational. However, their pressure of 350 bars is suitable for the deployment of heavy or utility vehicles**

*Low estimation excluding projects below 100kw

Sweden.

Sweden does not yet have a hydrogen strategy. The development of hydrogen is not a priority despite the high production of renewable energy. Only certain industrial and transnational projects for mobility are supported. Thus, in 2030, Sweden is not positioning itself to be a hydrogen leader but is involved in projects such as the Scan-Med Corridor and H_2 mobility in Scandinavia.

2020 data

Support mechanisms	Installed production capacity	Downstream uses
	0.07 kt/year	

SUPPORT MECHANISMS

- Co-financing of €2.2 million by the Sweden Energy Agency of the HYBRIT industrial project, which aims to produce steel without fossil combustion.
- Grant from the Swedish Energy Agency in the amount of €0.8 million for the Preem refinery project at Lysekil, which combines CCS and the production of hydrogen by electrolysis.
- Subsidy of around €10,000 for the purchase of an FCEV emitting less than 70g CO_2 / km.
- In 2018, Sweden ended subsidies for the production of grey H_2 to favor low carbon H_2.

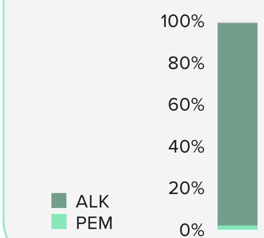
- Profit tax deduction mechanism for companies with an electric vehicle fleet.

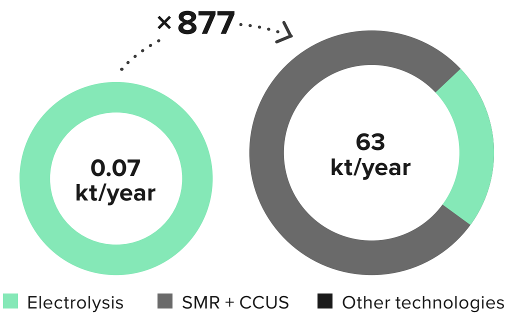
- 4 regions are members of HyER to develop H_2 mobility even though it is not a national priority.

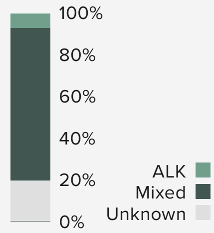
Sweden.

UPSTREAM

Production capacity installed in 2020 — **Production capacity projected for 2030**







Grid-connected Costs
€5.74/kgH_2

Electrolysis production CO_2 emissions
0.45kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT	SET BY INDUSTRY PLAYERS
Not communicated	*Not communicated*

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

Mobility	Industry (gas)	Industry	Buildings
0.01*	0.01	0.07	0
0% synfuel 100% H_2 0% CH_4	0% Elec 0% gaz H_2 100% gaz CH_4		100% H_2

Mobility type	Bus	Train	Car	Ship	Plane	Refueling station
Number in 2020	0	0	46	0	0	5 *60% to 700b, 40% 350b/700b*
Perspectives of evolution	**+4** by 2024 *(2 cities)*	**Inlandsbanan** Feasibility study	Unknown	Unknown	Unknown	Unknown
Government objectives (2030)	-	-	-	-	-	**150**

- **Sweden mainly plans to use hydrogen for the greening of industry and few resources are currently being implemented to develop H_2 mobility.**
- **However, the involvement in the H_2 corridor between Scandinavia and the Mediterranean should boost the development of H_2 refueling stations and heavy vehicles.**

Low estimation excluding projects below 100kw

United Kingdom.

The national hydrogen strategy should be unveiled in the first half of 2021. A roadmap for the development of CCUS by 2030 was set in 2018 and the sector is working with the government to ensure that 1.5 billion pounds are invested. The country therefore plans to be the European leader in the supply of low-carbon hydrogen and its use for heating, thanks to large-scale projects such as H21 in Leeds where the hydrogen will be produced by SMR with CCS.

2020 data

Support mechanisms

Installed production capacity
0.25 kt/year

Downstream uses

SUPPORT MECHANISMS

- Several government studies have been conducted on the potential use of hydrogen in heating networks, mobility and on hydrogen production from wind energy. These studies had little impact on the development of the sector apart from making hydrogen projects eligible for subsidies linked to renewable energies.

- Support of €26M for 9 CCUS projects and €100M for the production of low carbon hydrogen over the last 4 years. **€1.1bn in funding by 2025 to continue the deployment of CCUS in 4 industrial clusters.**
- Support of nearly €265M by 2024/2025 within the Net Zero Hydrogen Fund for the production of low carbon H_2.
- Support of €15.2M for the deployment of 5 charging stations and light hydrogen vehicles.
- Under the fund for the energy transformation of industry (IETF), investments of €32M in 2020 and €312M between 2021-2024.

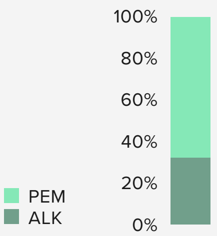
- Tax exemptions for the purchase and circulation of hydrogen vehicles.

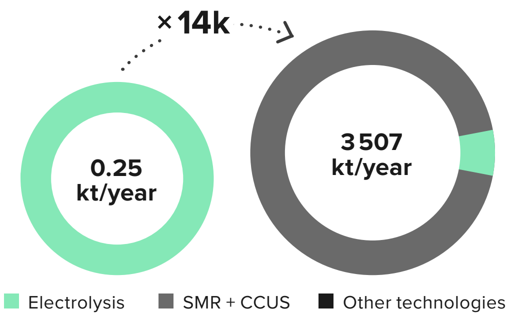
United Kingdom.

UPSTREAM

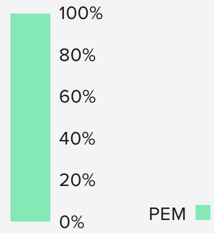
Production capacity installed in 2020 — **Production capacity projected for 2030**

Electrolysis technologies used





Electrolysis technologies considered



Grid-connected Costs
€10.89/kgH_2

Electrolysis production CO_2 emissions
12.78kgCO_2/kgH_2

GOALS

SET BY GOVERNEMENT

1.05Mt/year[1] of low carbon H_2 in 2030

[1]According to Energy White Paper December 2020

SET BY INDUSTRY PLAYERS

13.5Mt/year[2] in 2050

[2]According to HyImpact, Element Energy 2019

DOWNSTREAM

Breakdown of end uses in kt/year in 2020

- **0.01*** — 0% synfuel, 100% H_2, 0% CH_4
- **0.16** — 100% Elec, 0% gaz H_2, 0% gaz CH_4
- **0.01**
- **0.08** — 100% H_2

Mobility type						
Number in 2020	**20** *including 20 buses*	**0**	**195** *(+35%)*	**1** *Hydrogenesis*	**0**	**17** *(+31%) 70% 350b/700b*
Perspectives of evolution	**+330** by 2024 *(> 5 cities)*	**Breeze** (2023)	Unknown	Unknown	Unknown	**+6** by 2024
Government objectives (2030)	**500**	-	**1,600,000**	-	-	**1150**

- **The mobility sector is structured around H2mobilityUK which drew up a roadmap for 2025.**
- **Mobility is not perceived as a priority use, so no objective has been defined. However, the maritime and rail sectors have a high development potential with the production of H_2 around the North Sea and the need to replace 2/3 of non-electrified railway equipment.**

**Low estimation excluding projects below 100kw*

05/

Methodology & Glossary.

Methodology for the key thematic indicators

Topic	Topic 1: Low-carbon production, growth and prospects	Topic 2: Focus on technological diversification
Goal	Identify the main production growth trends by country and highlight the scale of renewable and low carbon hydrogen production.	Specify the technologies used with regard to production objectives to highlight carbon-free hydrogen strategies.
Unit	Production capacity in kt/year.	Production capacity in kt/year.
Assumptions	• Only projects with a production capacity greater than 0.01 MW were considered. Local electrolysis projects for hydrogen stations are ignored. • Projects are counted only if funding and actors are defined - at least for the early stages of development for projects with multiple time horizons. • Electrolysis capacities in MW are converted into theoretical production capacities in Nm^3/h using IEA conversion factors: 1 MW of ALK electrolysis = 1 / 0.0046 Nm^3/h 1 MW of PEM electrolysis = 1 / 0.0047 Nm^3/h 1 MW of SOEC electrolysis = 1 / 0.0038 Nm^3/h 1 MW of undefined electrolysis = 1 / 0.0045 Nm^3/h • These capacities in Nm_3/h are subsequently converted into t/year by applying a factor 8760 to arrive at a high estimate (upper limit) of the hydrogen production capacity in Mt / year.	• Same assumptions as Topic 1 • Biomass pyrogasification or biomethane reforming technologies are grouped together in the “other” category because they are marginal with respect to production by electrolysis or by SMR + CCUS. • Conversion to t/year of H_2 is constant for each electrolyser technology regardless of the operating context of the electrolyser (operation in a period of electrical overproduction, constant, etc.) because maximum capacities are calculated.
Perimeter	Operational projects: production capacities commissioned before June 2020. Projected capacities: production capacities whose commissioning is expected between July 2020 and 2030.	Operational projects: production capacities commissioned before June 2020. Projected capacities: production capacities whose commissioning is expected between July 2020 and 2030.
Sources	Sia Partners’ database is built from IEA’ database, which is consolidated with formal announcements of project and their adjusted capacity up to october 2020.	Sia Partners’ data base is built from IEA’ database, which is consolidated with formal announcements of project and their adjusted capacity up to october 2020.

Methodology for the key thematic indicators

Topic	Topic 3: Production costs	Topic 4: Associated CO_2 emissions
Goal	Compare the average production costs for each country according to their electricity mix.	Compare CO_2 emissions linked to the production of hydrogen from electrolysis connected to the electricity network (dependent on each country's energy mix) or by SMR + CCUS. These emissions are adjusted to take into account the quantities of hydrogen produced in 2020 and the technological mix and for 2030, projects from Sia Partners' database. The emissions are also put into perspective with the low carbon hydrogen level Certifhy through $kgCO_2$ emitted per kgH_2 produced.
Unit	€/kgH_2	$kgeqCO_2$ and $kgeqCO_2$ / kgH_2.
Assumptions	• Constant CAPEX for each country of €1,000/kW in 2020 with an efficiency of 59% in 2020. 5500h of operation per year. Thus, 1MW of electricity leads to a production of around 100 tonnes per year. • Average price of electricity for manufacturers consuming 2 to 19 GWh/year according to Eurostat. • The production cost of SMR + CCUS of €2.5/kg is considered to be the same from one country to another.	• Average carbon content of the network for each country is considered with an electrolysis efficiency of 59%. • The analysis is carried out with constant carbon content of the network from 2020 to 2030. • Emissions linked to SMR + CCUS of 1 $kgCO_{2eq}/H_2$ only take into account the production of hydrogen. No increase has been retained to take into account the transport of natural gas consumed by SMR + CCUS.
Perimeter	Operational data (2020).	2017 to June 2020 for operational projects. July 2020 to 2030 for planned projects.
Sources	Sia Partners' database built from IEA' database consolidated with formal announcements of project and their adjusted capacity up to october 2020. Eurostat data for electricity prices, taxes and network access costs.	Eurostat data for electricity prices, taxes and network access costs. Ademe and FCH-JU data for the characteristics of electrolysers.

Methodology for the key thematic indicators

Topic	Topic 5 : Hydrogen transport and storage infrastructure	Topic 6 : Allocation of production capacities to different uses
Goal	Compare the position of the studied countries with regards to transport and storage of hydrogen. Identify the countries engaged in the development of hydrogen transport and storage infrastructure, necessary to scale up the use of hydrogen.	Compare the different uses of hydrogen by country. Identify the short term uses for which renewable and low carbon hydrogen is the most accessible, and in the medium / long term, the positioning of countries in terms of hydrogen strategy and uses.
Unit	–	Production capacity in kt/year.
Assumptions	• H_2 Transport: the study focuses on gas pipeline transport networks and boat transport, which is less decentralized than road transport. • Storage of H_2: the study focuses on large-scale geological storage. If the different geological storage methods are mentioned, only the storage capacities in salt cavities are considered in the calculation of the country rating.	• Predominant use defined for each project even when several uses coexist. • For mobility uses, only take into account production projects of more than 100 kW. Local electrolysis projects for mobility are ignored. • Conversion of theoretical capacities in t/year (conversion factor of the IEA). • Projects are taken into account if funding and the actors are defined except where several project phases exist (IEA database).
Perimeter	Precision of the date for each of the objectives (from today to 2035).	2017 to June 2020 for operational projects. July 2020 to 2030 for planned projects.
Sources	• Sia Partners' analysis. • Injection into networks: ACER Report on NRAs Survey, 2020. • European Hydrogen Backbone, 2020. • Storage capacities in saline cavities: Caglayan & al., 2019.	Completed and consolidated IEA database with announcements of project formalization and capacity adjustments.

Methodology for the key thematic indicators

Topic	Topic 7: Deployment of road mobility	Topic 8: H_2 regulations and strategies
Goal	Compare the development of hydrogen road mobility between countries: number of charging stations, number of light vehicles, ratio of vehicles per stations and structure to accommodate heavy vehicles including buses (refueling pressure). The country analyses integrate estimates of the number of maritime and aviation projects, and future developments and objectives. The aim is to analyze the efforts made by each country to develop hydrogen mobility.	Synthesize and compare the different support mechanisms put in place from one country to another: planned investments, renewable and low-carbon hydrogen production targets set for 2030 by governments and national actors, as well as objectives in terms of mobility.
Unit	Number of units for each indicator. Share of stations with each level of pressure and accessibility to public.	–
Assumptions	• The stations considered are taken from public databases extending until 2024 for the stations in project. • As the commissioning time of a station project is less than 4 years, as yet unannounced projects may see the light by 2024. • Test or demonstration projects lasting a few weeks are not considered if there is no confirmation of commercialization. • Closed stations or discontinued bus programs are not taken into account in the data.	The installed electrolysis capacity objectives in GW are converted into production capacities in Mt/year. The conversion ratio used is 0.1Mt of H_2 per year for 1 GW of electrolysis.
Perimeter	2017 to June 2020 for operational projects. July 2002 to 2024 for planned projects.	Precision of the target date of application for each objective in brackets.
Sources	H2stations.org consolidated data for the stations. Consolidated fuelcellbuses.eu data for buses. Consolidated EAFO database for light vehicles and IPHE for objectives. Various sources assembled by Sia Partners for maritime, aviation and other vehicles.	Data consolidated from national hydrogen plans and other publicly accessible data.

Country rating criteria

Theme	Production of renewable and low carbon H_2	Transport & storage infrastructure	Industrial uses of renewable and low carbon H_2
Evaluation criteria	**A-** Renewable and low-carbon hydrogen production capacity in 2020 B- Renewable and low-carbon hydrogen production capacity planned for 2030 C- Share of renewable and low-carbon hydrogen in total hydrogen production in 2020[1]	**D-** H_2 injection mixed in gas networks **E-** H_2 transport in dedicated networks **F-** H_2 transport by sea / river **G-** H_2 storage capacities in salt cavities	**H-** Renewable and low-carbon hydrogen production capacity planned for 2025 and dedicated to industrial uses **I-** Share of renewable and low-carbon hydrogen in the country's industrial consumption in 2025 (industry base 2020)[1]
Data associated with the evaluation criteria	**A-** Renewable and low-carbon hydrogen production capacities of operational projects in 2020. **B-** Renewable and low-carbon hydrogen production capacities operational by 2030[2] . **C-** Ratio of renewable and low-carbon hydrogen production capacities of operational projects in 2020 compared to the country's total hydrogen production capacities in 2020[1].	**D-** Regulatory limit rate for hydrogen injection into natural gas networks and establishment of projects to inject hydrogen into natural gas networks **E-** Presence in the country of 100% H_2 transport networks, participation of national gas operators in the European Hydrogen Backbone project and presence of projects to set up 100% H_2 transmission networks. **F-** Presence of operational or announced hydrogen port hubs and maritime and river transportation projects **G-** Geological hydrogen storage capacities in salt cavities	**H-** Renewable and low-carbon hydrogen production capacities operational for 20252 and intended for industrial uses. **I-** Ratio of renewable and low-carbon hydrogen production capacities for industrial use by 2025 to the country's total hydrogen production, for industrial use in 2020[1].
Calculation of the evaluation criteria score	**A-** Score of 0 to 5 obtained by comparing the capacities of different countries **B-** Score of 0 to 5 obtained by comparing the capacities of different countries **C-** Score from 0 to 5 obtained by comparing ratios of different countries	**D-** Average score of 0 to 5 obtained by comparing the authorized limit rates and the existence of hydrogen injection projects **E-** Score from 0 to 5 **F-** Score of 0 to 5 obtained by comparing the number of projects in the different countries **G-** Score from 0 to 5 obtained by comparison of geological storage capacities in different countries	**H-** Score of 0 to 5 obtained by comparing the capacities of different countries **I-** Score from 0 to 5 obtained by comparing ratios of different countries
Calculation of the average score	Average of the 3 scores associated with the 3 evaluation criteria	Average of the 4 scores associated with the 4 evaluation criteria	Average of the 2 scores associated with the 2 evaluation criteria

[1] Source: Hydrogen production, FCHO (2020)
[2] Projects announced before July 2020

Country rating criteria

Theme	Mobility	Ambitions governmental
Evaluation criteria	**J-** Deployment of heavy H_2 vehicles **K-** Deployment of light H_2 vehicles **L-** Deployment of H_2 stations **M-** Deployment of rail mobility **N-** Deployment of maritime / river mobility	**O-** Ambition to deploy H_2 stations, and light and heavy H_2 vehicles between 2025 and 2030 **P-** Ambition to produce of renewable and low-carbon hydrogen between 2025 and 2030 **Q-** Public investments between 2020 and 2030
Data associated with the evaluation criteria	**J-** Ratio of the number of heavy H_2 vehicles (buses, trucks) registered to the total number of heavy vehicles registered[1] **K-** Ratio of the number of light H_2 vehicles operational to the total number of light vehicles in circulation[2] **L-** Ratio of the number of H_2 stations operational to the number of petrol stations in the country[1] **M-** Number of operational and announced projects in rail mobility **N-** Number of operational and announced projects in maritime and river mobility	**O-** Respective ratios of the number of H_2 stations, the number of light H_2 vehicles and the number of heavy H_2 vehicles set in government roadmaps to the number of gas stations in the country, the number of light vehicles in circulation and the number of heavy vehicles registered **P-** Renewable and low-carbon hydrogen production targets set in government roadmaps **Q-** Annual investments announced between 2020 and 2030
Calculation of the evaluation criteria score	**J-** Score from 0 to 5 obtained by comparing ratios of different countries **K-** Score from 0 to 5 obtained by comparing ratios of different countries **L-** Score from 0 to 5 obtained by comparing ratios of different countries **M/N-** Score of 0 to 5 obtained by comparing the number of projects in the different countries - with a double weighting given to operational projects	**O-** Average score of 0 to 5 obtained by respective comparisons of the 3 ratios for each country **P-** Score of 0 to 5 obtained by comparing the objectives of the different countries **Q-** Score of 0 to 5 obtained by comparing announced investments - with a double weighting for public investments
Calculation of the average score	Average of the 5 scores associated with the 5 evaluation criteria	Average of the 3 scores associated with the 3 evaluation criteria

[1]Source: Eurostat
[2]Source: Fuelseurope

H_2 Glossary

ALK (Alkaline electrolysis):

Most widespread and mature electrolysis technology in the industry, it comes in the form of small or medium capacity modules. Alkaline electrolysis shows rather low investment costs and a yield of 68% to 77%. However, to work optimally, the alkaline electrolysis must be heated to 80° C which is hardly compatible with intermittent operation.

ATR (Autothermal Reforming):

Similar to SMR technology but more compact, it allows high production capacities and produces a quantity of CO_2 lower than SMRs because it operates at higher temperatures.

CAPEX/OPEX:

CAPEX (Capital expenditure) corresponds to the total tangible and intangible investment expenditure dedicated to the purchase of professional equipment. OPEX (Operating expenses), are expenses incurred by a company for the needs of its business.

CCUS (Carbon Capture, Usage and Storage):

Allows carbon to be captured and stored in underground cavities or used for example in agriculture to enrich greenhouses with CO_2. The CO_2 capture rate is around 90% for SMRs and 95% for ATRs.

Certif'Hy:

The CertifHy Certification System intends to inform consumers about the origin of hydrogen. It is a European GO scheme that sets out statements and principles regarding the operation of the scheme

Guarantee of Origin (GO):

trackable commodity that represents a claim to the environmental benefits of renewable power generation. GOs are traded electronically in the voluntary market for renewable energy certificates and are not tied to the physical delivery of electricity.

Hydrogen vehicle:

a vehicle that uses hydrogen fuel for motive power, a light vehicle is a car. The principle of operation of the hydrogen car that the fuel cell and the electric motor are the same. The fuel cell oxidises the hydrogen contained in a tank using oxygen from the air, producing electricity and water vapor. A hydrogen car is therefore an electric car that produces its own electricity.

Low-carbon hydrogen:

Fossil-based hydrogen with CCUS and electricity-based hydrogen on the grid with renewable electricity guarantees.

Renewable hydrogen:

Hydrogen produced by electrolysis of water using renewable electricity or using “other” low-carbon technologies.

IPCEI (Important Project of Common Interest):

Financial aid from the European Commission for projects involving more than one Member State, with significant impact on competitiveness, sustainability, or value creation across the EU and usually for the first industrial deployment of innovative technologies

Mixed Electrolysis:

Electrolysis project with several combined electrolysis technologies.

Unknown (electrolysis):

Electrolysis project for which the technology has not yet been defined or not communicated (NC).

Other:

Encompasses carbon-free H2 production technologies other than electrolysis or SMR + CCUS: biological methanation, biomass gasification, etc.

H_2 Glossary

PEM (Electrolyte technology solid with proton conductive polymer membrane):

Electrolysis is more suited to renewable energies but its cost remains higher than alkaline despite the prospect of a greater drop.

Power-to-X:

Further products can be made from hydrogen (ammonia, methanol, methane, etc.). As long as these products are produced using “green” hydrogen, the overarching term “Power-to-X” (PtX) is used.

Pyrogasification:

involves the thermo-chemical processing of many different sources, such as wood waste, residues from waste management, and most organic waste to zero-carbon renewable gas

SOEC (Electrolysis by Solid Oxide technology Electrolysis Cell):

High-temperature electrolyzer with an average efficiency greater than 80%. However, the system must be supplied with electricity and heat to keep the temperature high. It is therefore not compatible with fluctuations in the energy supply. However, it is particularly interesting for the storage of H_2 as a means of flexibility in Power-to-Gas-to-Power because it can operate reversibly.

SMR (Steam Methane Reforming):

Consists of transforming natural gas to produce H_2, CO and a small amount of CO_2. SMR technology today offers lowest costs and best energy efficiency. It represents 95% of European production.

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Sia Partners is a next generation management consulting firm and *pioneer of Consulting 4.0*. We offer a unique blend of AI and design capabilities, augmenting traditional consulting to deliver superior value to our clients. Counting 1,800 consultants in 18 countries, we expect to achieve USD 300 million in turnover for the current fiscal year. With a global footprint and expertise in more than 30 sectors and services, we optimize client projects worldwide. Through our *Consulting for Good* approach, we strive for next-level impact by developing innovative CSR solutions for our clients, making sustainability a lever for profitable transformation.

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