Green Hydrogen

Market Scenario and Competitive Landscape

A CURA DI

Ufficio per la Valorizzazione della Ricerca
Martina Lanza

Data 08/04/2022

TABLE OF CONTENTS

Disclaimer

The Desk Analysis is an original informative contribution developed by Area Science Park. The contents may be reproduced, printed or copied exclusively for internal use of the requesting company/institution. It is therefore forbidden to communicate and transfer to third parties, publish or disseminate by any means, in full or in extracts, the contents of the Desk Analysis without prior written authorization from Area Science Park, which will indicate from time to time the conditions for carrying out such operations consistently with the commitments undertaken towards the Information Providers to which it is subscribed.

The information contained in the document comes from a combination of sources (websites or digital documents), cited from time to time, with free access or reserved for Area Science Park as a subscriber. The websites and sources reported in the documentation are independent from Area Science Park and their reporting does not imply the promotion of the organization that owns them.

Area Science Park undertakes to select reliable and scientifically valid sources but cannot be held responsible for the completeness and exhaustiveness of the topics covered, nor for any omissions or inaccuracies.

Desk Analysis does not constitute a consultancy intervention.

Introduction and Methodology

"Market Scenario" is a customized and organized analysis to gather information about target markets and competitive landscape in a particular sector.

"Market Scenario" provides relevant information to identify and analyze market needs, market size and competition in the fields of interest of the customer. A technology or a product developed by the customer can be characterized according to the sectors and potentiality of application, target market, competitive advantages and potential partners of the technology. The analysis is performed with the application of technology and business intelligence tools. The research in the information providers is usually based on the use of keywords or by thematic area, according to the specific topic of interest.

The results of the assessment are data about the target or global market potential, market value and applicability of the technologies or products developed by the customer, the trends of the market of interest, the segmentation of the market (e.g., by application, geography or indication), the supply chain and the competitive advantages of products or technologies, the key players active in the market of interest and the possible direct or indirect competitors of the customer.

Context

The following information are provided in this report:

- An introduction to the **green hydrogen global market**, with various paragraphs analyzing the market from different points of view (Chapter 1).
- Market data and trends of **green hydrogen market segmentation** by technology, by renewable source, by end-use industry and by region (Chapter 2).
- The **competitive landscape**, with a picture of key player operating in the green hydrogen market and a focus on main competitors, that are developers of innovative methods for the production of green hydrogen starting from waste biomass (Chapter 3).

1 Green Hydrogen Global Market

1.1 Market Definition

Green hydrogen is **carbon-free hydrogen** produced by the electrolysis of renewable and nuclear resources. The electrolysis process uses electricity to split water into hydrogen and oxygen; the process takes place in a unit called an **electrolyzer**. Electrolyzers are available in small and large sizes. **Small capacity electrolyzers** are used for small-scale distributed hydrogen production. In the case of **large-capacity electrolyzers**, hydrogen production facilities can be tied directly to renewable or other non-greenhouse-gas-emitting forms of electricity production.

Green hydrogen is among the cleanest fuels that are available in the market. It is more expensive than other types of hydrogen, such as brown hydrogen (produced using coal), grey hydrogen (produced from methane with effluents released in the air), and blue hydrogen (produced from methane with effluents captured and stored underground). However, green hydrogen has **vast potential to decarbonize the existing energy system**: it is a clean fuel that offers a chance to transport renewable energy.

1.2 Market Overview and Dynamics

The global green hydrogen market is growing rapidly. It is estimated to grow to **USD 4,373.4 million by 2026** from USD 444.2 million in 2021, at a Compound Annual Growth Rate (CAGR) of 58.0%. With continued investments, this trend is projected to persist during the forecast period. Due to the target of net-zero emissions, the world is searching for **alternatives for fossil fuels** that are portable and storable for later use. Green hydrogen proves to be an efficient option to store renewable energy. It can be stored directly or in other forms, such as ammonia.

The following figure (Figure 1) analyzes various **drivers, restraints, opportunities, and challenges** in the green hydrogen market.

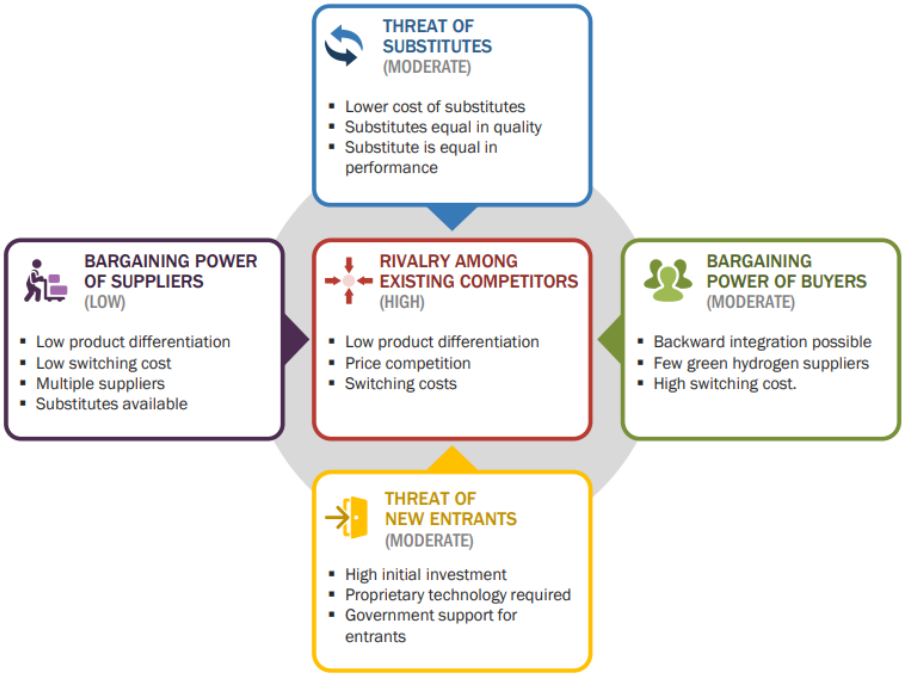
Figure 1. Green hydrogen market dynamics

The market of green hydrogen is not adversely affected by COVID-19 as most of the investments are done on a long-term basis, along with government supports worldwide. Small and innovative companies working in the green hydrogen sector have only faced a shortage of liquidity due to reduced demands.

1.3 Porter's Five Forces Analysis

Porter's Five Forces analysis determines the **competitive intensity and the attractiveness** of the green hydrogen market. It helps in understanding the market dynamics and feasibility of entering the market. This analysis studies the green hydrogen market from five **different perspectives**: competitive rivalry within the industry, the threat of new entrants, the bargaining power of suppliers, the bargaining power of buyers, and the threat of substitute products (Figure 2). Any changes in these forces can have a significant impact on the green hydrogen market.

Figure 2. Porter's five forces analysis: green hydrogen market



1.4 Technology Analysis

The key processes used for manufacturing green hydrogen involve **water electrolysis using electricity produced from renewable energy sources**. The electrolysis process is carried in electrolyzers, and these are mainly of three types: Polymer Electrolyte Membrane (PEM) electrolyzers, Alkaline electrolyzers, and Solid Oxide electrolyzers. **Solid Oxide electrolyzers** are the latest development in electrolysis technology and operate in two major temperature ranges: <100°C producing energy to the hydrogen conversion efficiency of nearly 80%, while working in a high-temperature range >600°C, it is capable of producing nearly 100% conversion efficiency. It can utilize any form of waste heat as well. However, this technology has not been commercialized yet. **PEM** offer a sustainable substitute to alkaline electrolyzers, with nearly 80% energy to hydrogen conversion efficiency in their present state. The technology is still under development and is expected to reach 82–86% efficiency by 2030. **Alkaline electrolyzers** are the oldest process to manufacture green hydrogen. It offers efficiency in the range of 56–73% of energy to hydrogen conversion. The majority of the big current operational and announced projects use alkaline electrolysis due to cost efficiency.

1.5 Supply Chain Analysis

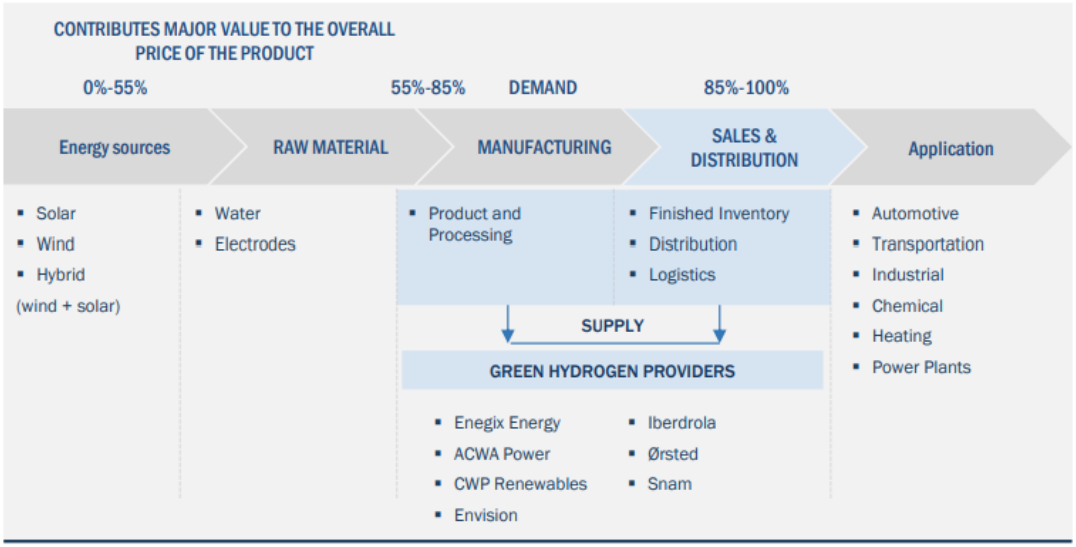
The figure below (Figure 3) shows the **green hydrogen supply chain**. The supply chain includes raw materials, technology, products, and end users. The starting materials for making green hydrogen are water and electricity generated from renewable energy sources such as solar, wind, or hydro. Water is usually kept at temperatures above atmospheric conditions to increase the reaction speed. As reported in the previous paragraph, there are three manufacturing technologies selection of which affect the final cost of the hydrogen produced. Then, hydrogen is either stored or transported directly or by converting in other forms for applications in end-use industries.

Figure 3. Green hydrogen market: supply chain analysis

1.6 Value Chain Analysis

Raw materials used for processing green hydrogen are water and electrodes. The maximum value is added by the energy required to run the manufacturing process. The **manufacturing process** is accountable for roughly 25%-30% of the final green hydrogen cost, while **transportation** attributes nearly 15% to the entire value chain. The transportation infrastructure is not yet fully developed and hence affects the overall cost of green hydrogen.

Figure 4. Green hydrogen market: value chain analysis



1.7 Pricing Analysis

The **major challenge** green hydrogen faces is its **cost**. The average global cost of green hydrogen per kg is nearly **USD 4.7**, which is much higher than other forms of hydrogen that average at around USD 1/kg.

The prices of green hydrogen depend majorly on **renewable energy cost, electrolyzer cost, and transportation costs**. Energy cost contributes to nearly 50%-75% of the final price of green hydrogen, while electrolyzer contributes 20%-40% of the final cost. As the acceptance of solar and wind energy is increasing and the technologies are developed, the cost of electricity production using these sources has decreased, affecting the price of green hydrogen.

On the other hand, **the infrastructure to transport hydrogen is not well developed** and still needs significant investments and

projects to efficiently transport hydrogen from point A to point B. With the changing scenario and increasing investment in R&D, the cost of electrolyzers is reducing, impacting the final cost of green hydrogen. The **technological advancement** in green energy has revolutionized for the past decade, with price drops ranging between 40% and 80% in various components. These factors show an **optimistic future** for the growth of the green hydrogen market to be competitive with other forms of hydrogen in terms of price.

The **average selling price** of green hydrogen in different regions is presented in the following table (Table 1).

Table 1. Average selling price, by region

Region	USD/Kg for 2020	USD/Kg for 2026	Average % Price Change (2021–2026)
Europe	4,77	2,54	-40.4%
Asia Pacific	4,56	2,48	-40.0%
North America	4,73	2,64	-38.6%
Middle East & Africa	4,91	2,96	-33.5%
Latin America	4,46	2,66	-33.8%
Average Global Price	4,7	2,54	-40.0%

1.8 Green Hydrogen Global Projects

With the global advancement and success of existing **green hydrogen projects**, multiple new projects have been announced and are under construction to be operational before 2030. These projects indicate the global faith in green hydrogen and possibly a turnaround in the world energy scenario. **Upcoming projects** for green hydrogen are reported in Table 2.

Table 2. Upcoming projects for green hydrogen

Project	Location	H2 Output (Million tons/year)	Energy Source	Date of completion
Aman	Mauritania	(16-20 GW)	Hybrid	Not finalized
Aqua Ventus	Germany	1	Offshore wind	2035
Asian Renewable Energy Hub	Australia	1,75	Hybrid	2027-28
Base one	Brazil	0,6	Hybrid	2025
Beijing Jingneng Inner Mongolia	China	0.4 - 0.5	Hybrid	2021
Esbjerg	Denmark	Not specified	Wind	2025-27
Geraldton	Australia	(1 million ton green ammonia)	Hybrid	Not finalized
Greater Copenhagen	Denmark	(“250000 tons of sustainable fuel”)	Wind	2030
H2 Sines	Portugal	Not specified	Not specified	2030
H2-Hub Gladstone	Australia	(5000 tons green ammonia)	Not specified	Not finalized
Helios Green Fuels Project	Saudi Arabia	0,24	Hybrid	2025
HNH	Chile	(0.85-1 million ton green ammonia)	Wind	2026
HyDeal Ambition	Western Europe	3,6	Solar	Before 2030

Project	Location	H2 Output (Million tons/year)	Energy Source	Date of completion
HyEnergy Zero Carbon Hydrogen	Australia	(8 GW)	Hybrid	2030
HyEx	Chile	0,124	Solar	2024
Kazakhstan (Unnamed)	Kazakhstan	3	Hybrid	2024-27
Murchison Renewable Hydrogen	Australia	(5 GW)	Hybrid	2028
NorthH2	Netherlands	1	Offshore wind	2040
Oman (Unnamed)	Oman	(14 GW)	Hybrid	2038
Pacific solar Hydrogen	Australia	0,2	Solar	Not finalized
Rostock	Germany	Not specified	Hybrid	Not finalized
SeaH2Land	Netherlands and Belgium	Not specified	Wind	2030
Southwest Ireland (Unnamed)	Ireland	(500 MW green ammonia)	Offshore wind	2028
Western Green Energy Hub	Australia	3,5	Hybrid	After 2028
White Dragon	Greece	0,3	Solar	2029
Yellow sea	China	(2 GW)	Wind	Not finalized

2 Green Hydrogen Market Segmentation

The global green hydrogen market has been segmented by **technology, renewable sources, end-use industries, and region**. Each segmentation is fully analyzed in the following paragraphs.

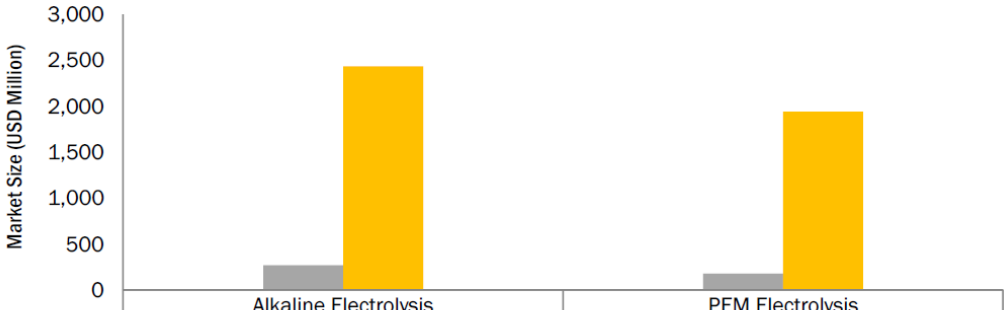
2.1 Market by Technology

Green hydrogen is produced by the electrolysis process. Under this process, by using electric current, water molecules are split into hydrogen and oxygen. **Alkaline electrolysis** and **PEM electrolysis** technologies are among the major manufacturing technologies used to produce green hydrogen. The choice of green hydrogen manufacturing technology largely depends upon the availability of electrolytes and the availability of capital.

The global green hydrogen market is dominated by the **alkaline electrolysis technology** in terms of both value and volume (Figure 5). This large market share is attributed to the various advantages of alkaline electrolysis over PEM electrolysis. Alkaline electrolysis utilizes a variety of electrolytes that are widely available and cheap to produce. Electrolytes used in alkaline electrolysis can be easily replicable or exchangeable and contain a very minimal corrosive impact on both electrodes. This factor positively affects the long life of an electrolyzer. Alkaline electrolysis tends to produce highly pure green hydrogen, as hydrogen ions do not diffuse easily into an electrolyte solution. Due to these advantages, alkaline electrolysis is widely used to produce green hydrogen.

PEM electrolysis technology is expected to grow with a significant CAGR during the forecast period due to its simple installation process and small-scale production of green hydrogen. The major companies have announced large-scale projects that will produce green hydrogen by PEM electrolysis. The large-scale capacity addition for green hydrogen through PEM electrolysis will thus boost the penetration of PEM electrolysis.

Figure 5. Green hydrogen market by technology



	Alkaline Electrolysis	PEM Electrolysis
2021	267.8	176.4
2026	2,435.3	1,938.0
CAGR (2021-2026)	55.5%	61.5%

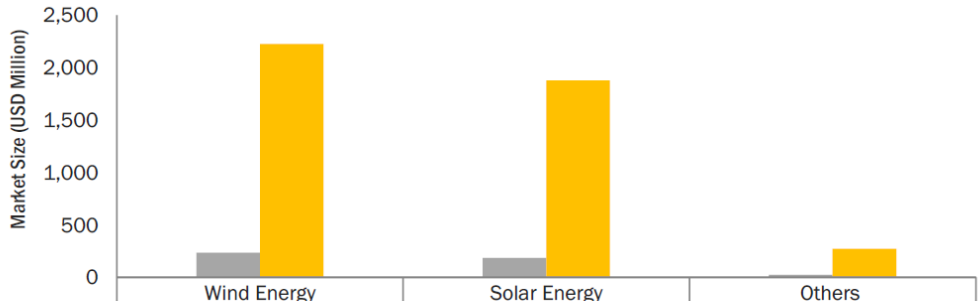
Europe is the largest market for both alkaline electrolysis as well as PEM electrolysis technologies in the green hydrogen market. Projects such as "**hydrogen alliances**" and "**Refhyne**" are boosting the green hydrogen market in Europe.

2.2 Market by Renewable Source

The **energy component of green hydrogen** amounts to 50%-75% of the total cost. That is why energy selection is an important aspect of the green hydrogen economy. The prices of renewable energy sources have been falling for the past decade and are expected to decrease even more. Companies have increased investments in green hydrogen projects across the globe, due to the reducing prices of renewable energy sources. **Solar energy** and **wind energy** are widely used to power electrolyzers based on the local environmental conditions. The market for green hydrogen was led by the **wind energy segment**, accounting for a 52.7% share in terms of value in 2020. It is projected to reach **USD 2,224.7 million by 2026** (Figure 6).

Apart from wind and solar plants, **hydropower plants** are also gaining acceptance. Research is underway to develop geothermal power-based electrolyzers, but as of now, there is no green hydrogen power plant working on geothermal power.

Figure 6. Green hydrogen market by renewable source



	Wind Energy	Solar Energy	Others
2021	234.3	184.6	25.2
2026	2224.7	1876.0	272.6
CAGR (2021-2026)	56.9%	59.0%	61.0%

Others include geothermal, hydropower, and hybrid of wind & solar

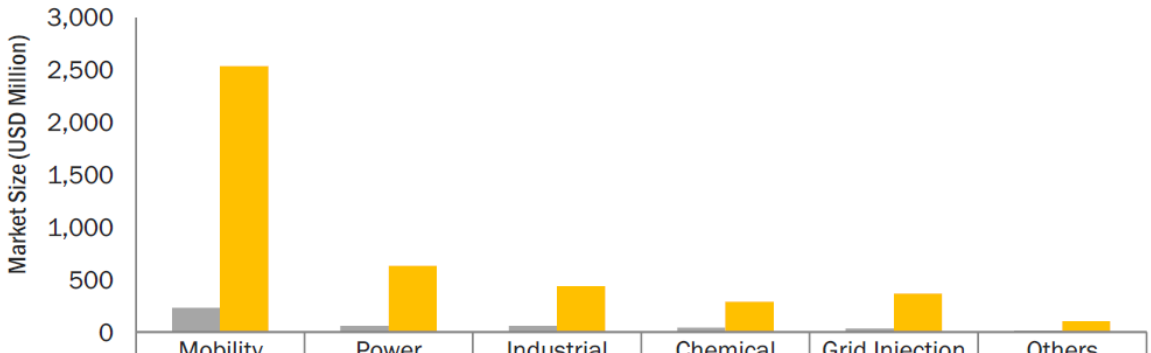
Europe leads the green hydrogen market for all sources due to the **rising environmental awareness**. Most countries are bound by the Paris agreement to cut emissions by 2050 to zero.

2.3 Market by End-Use Industry

Based on end-use industries, the green hydrogen market is divided into **mobility, chemical, power, grid injection, industrial, and others**. The others segment consists of combined heat and power (CHP) and domestic heating. **Mobility** is the largest end-use industry of the green hydrogen market, accounting for a 49.9% share of the overall market, in terms of value, in 2020. It is also the fastest-growing sector at a CAGR of 61.3% between 2021-2026 (Figure 7).

The segments of greatest interest for the purposes of this report are **mobility, industrial and chemical**: they are further described in the following paragraphs.

Figure 7. Green hydrogen market by end-use industry



	Mobility	Power	Industrial	Chemical	Grid Injection	Others
2021	232.1	60.4	57.8	41.0	36.3	16.5
2026	2535.1	633.5	438.8	291.1	368.8	106.1
CAGR (2021-2026)	61.3%	60.0%	50.0%	48.0%	59.0%	45.0%

2.3.1 Mobility

Green hydrogen is widely used in the **mobility industry** as it can store more energy per unit weight than fossil fuels and electric batteries. It is used as a secondary power source in power plants or is injected into the grid for various end uses.

The mobility segment in the green hydrogen market includes **vehicles used in road/off-road transportation, rail, maritime, or aviation**. Green hydrogen is a viable and practical substitute for the automotive industry. Green hydrogen-based vehicles are optimal for mining vehicles, trains, aircraft, lorries, buses, and even maritime transport.

Moreover, **increasing government support** through favorable fiscal policies for green hydrogen, especially in the European countries, is expected to dive the green hydrogen market in the mobility end-use segment. **Europe** dominated the green hydrogen market in the mobility end-use industry in 2020. This is due to aggressive targets to achieve net-zero emissions by the countries in the European Union. **Germany and France** are at the forefront of the green hydrogen development in Europe. The Asia-Pacific region (**APAC**) is close behind Europe to capture the green hydrogen mobility market. Countries like China, Japan, and Australia are investing heavily to develop infrastructure to commercialize green hydrogen-based mobility solutions profitably.

2.3.2 Industrial

Green hydrogen has multiple applications in the **industrial sector**. It is majorly used as a **reduction agent** to substitute carbon-based coke to decarbonize iron and steel production. It acts both as fuel and reducing agent and very efficiently replaces coke. **Other industrial applications** include protective gas in float glass production, generator cooling, corrosion protection in power plants, carrier gas in semiconductors, nitrogen purification, and research applications. Another major application area of green hydrogen is **oil refining**, although this will not serve the purpose of decarbonization but can curb it to some extent.

Continued efforts and development of price-competitive green hydrogen have opened **new opportunities in the industrial sector**. It serves both as a power source and as raw material in the production process. Europe is the biggest market for green hydrogen in the industrial sector. China is aggressively trying to decarbonize its industrial sector with its aim to half its emissions by 2040.

2.3.3 Chemical

Green hydrogen is mostly used to **manufacture ammonia, methanol, and other intermediates**. Ammonia is used to produce fertilizers, or as fuel in the shipping industry. It is also gaining acceptance as an environmentally friendly refrigerant (R-717). Another major application of green hydrogen is in producing methanol that is used mostly as eco-friendly fuel in vehicles. Apart from these applications, green hydrogen also has its applications in manufacturing multiple other chemicals such as alcohols, saturated compounds, hydrogen peroxide, cycloalkanes, and amines. Previously, the supply of hydrogen was made majorly in the form of grey or brown hydrogen, which causes a lot of pollution. However, the market in the chemical industry is showing a slower growth rate due to the **price-sensitive consumer base.**

The **chemical industry** comprises 4% of the total carbon emissions in Europe, of which only 1% comes from process needs, 2.2% from heat generation, while 0.8% from ammonia production. Although the industry is not a major polluter yet, efforts have begun to cut down the emissions, and green hydrogen offers a great to do it. **Europe** is at the forefront, with nearly 47.6% market share by value in 2020. It is also the fastest growing because green hydrogen is now available in the region, and industry giants are adopting it in their process as part of their Corporate Social Responsibility (CSR) and to cut emissions down.

Increasing acceptance of ammonia and methanol fuel is another major reason for the growth of green hydrogen in the chemical industry. Hydrogen is a major ingredient in producing these fuels. The source of hydrogen decides the carbon footprint and hence, green hydrogen is widely accepted to reduce net carbon emissions.

Power-to-Chemicals: The Cost of Electrifying Chemical Production

The chemical industry will remain firmly linked to the oil and gas sector in the near future, but **emerging power-to-chemical electrolysis technologies** could provide an opportunity for the chemical sector to decarbonize its supply chain and use renewable electricity as an alternative to oil and gas feedstock, changing the status quo in niche subsectors:

- Innovations in CO_2 electrolysis will lead to the displacement of natural gas for pure carbon monoxide and formic acid production in 2050.
- Rising carbon taxes will have minimal impact on the electrification of chemicals, as carbon capture and storage (CCS) will become the favored option for decarbonization.
- Only an electricity price below $0.01/kWh has the potential to initiate the widespread electrification of the chemical industry and cause a sharp decline in oil and gas demand.

Figure 8 examines the **economics of power-to-chemicals**.

Figure 8. Relative cost of power-to-chemicals to carbon capture and storage

2.4 Market by Region

The green hydrogen market is segmented into five regions: **North America, Europe, APAC, Latin America, and the Middle East & Africa (MEA)**. **Europe** is the largest and fastest-growing green hydrogen market, with the market size in the region projected to reach **USD 2,697.8 million by 2026** (Table 3). The mobility sector is the major consumer of green hydrogen in the region. The presence of **many green hydrogen producers** makes the region the most important market for green hydrogen. The presence of the highly advanced green hydrogen players and high demand from the mobility and power industries in **Germany** are expected to drive the market between 2021 and 2026. The usefulness of green hydrogen in other end-use industries, such as chemical and grid injection, will also boost the demand.

Table 3. Green hydrogen market by region

Region	2021	2026	CAGR (2021–2026)
Europe	254,6	2,697.8	60.3%
APAC	126,9	1,203.3	56.8%
North America	49,9	398,2	51.5%
MEA	4,6	28,9	44.6%
Latin America	8,2	45,1	40.7%
Total	444,2	4,373.4	58.0%

The **biggest challenge in the market is the initial investment** required to set up a production plant and the transportation costs associated with its postproduction. In most cases, there is huge government funding. However, due to the pandemic, governments throughout the globe will have pressure to kick start their national economies, giving lesser importance to the climate objectives. The market is expected to recover by 2026 and expand due to the **rising demand for cleaner fuel from the European and APAC regions**. The increasing demand for lightweight, fuel-efficient vehicles worldwide that utilize fuel cells operating on hydrogen can also act as a key factor for the growth of the market.

2.4.1 Focus on Europe

The European region is segmented into **Germany, Austria, Denmark, the UK, France, and Rest of Europe (Russia, the Netherlands, Spain, Poland, Belgium, and Sweden)**. It is the largest market for green hydrogen globally. Currently, less than 2% of Europe's energy consumption comes from hydrogen, that is mainly used for making chemical products, such as plastics and fertilizers, and 96% is made from natural gas, emitting significant amounts of CO2 in the process. The

European Green Deal aims at reducing greenhouse gas emissions and preparing Europe's industry for a climate-neutral economy.

In July 2020, the European Commission published the EU hydrogen strategy. It was designed with a phased approach, and its goal is to **increase hydrogen shares from less than 2% up to 13%-14% by 2050**. The priority is to develop clean, renewable hydrogen with cumulative investments between Euro 180 and Euro 470 billion in Europe by 2050. A green hydrogen economy will also create 1 million **new jobs for highly qualified personnel** in Europe by 2030 and up to 5.4 million by 2050. The plans are to install at least 6 GW of renewable hydrogen electrolyzers by 2024 and 40 GW by 2030 in Europe. The **European Clean Hydrogen Alliance** was also announced as part of the new industrial strategy for Europe in March 2020 and launched on 8 July 2020, at the same time as the EU hydrogen strategy.

The EU-funded Djewels project, which will build a 20MW electrolyzer to help ensure low-cost green hydrogen for its customers, and STORE&GO that supports new technologies to feed renewable methane into the gas grid, and thereby helps ensure sustainable energy supply in Europe are key examples of important **green hydrogen projects** which have been undertaken in Europe. A 6MW electrolyzer has been developed under the EU-funded H2 project. It supplies green hydrogen to a steel plant in Linz, Austria, and provides electricity grid services due to its flexible power consumption.

Major **automotive manufacturers** in the European region, such as Porsche, Ducati, BMW, and Audi, are focusing on the downsizing concept of car engines and manufacturing lightweight and fuel-efficient engines, which will also drive up the growth of the green hydrogen market.

The **European Union Automotive Fuel Economy (UNEP) standard** has challenged automotive original equipment manufacturers (OEMs) to decrease carbon emissions by using lightweight materials, which is further driving the market in this region. In the first half of 2020, the EU automotive industry suffered production losses of 3.6 million vehicles, which reflects a loss of USD 114.2 billion. This has resulted in the decline of the green hydrogen market in the European region as well. However, it is expected that the **mobility and power sectors** in Europe will recover, and the green hydrogen market will grow exponentially by 2026.

In the following figures we report a summary scheme for European (Figure 9), North American (Figure 10) and APAC (Figure 11) markets.

Figure 9. Green hydrogen market in Europe

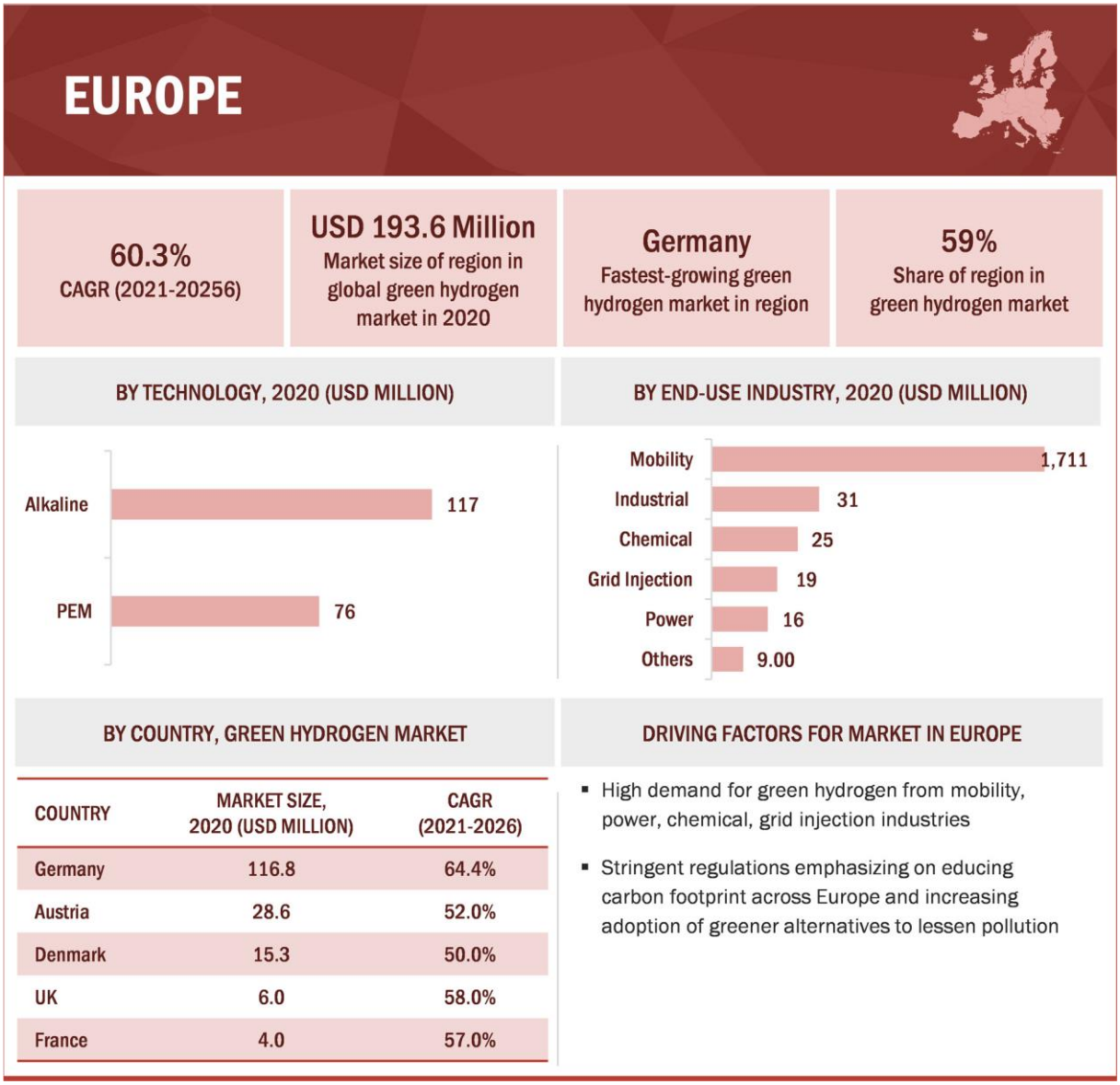


Figure 10. Green hydrogen market in North America

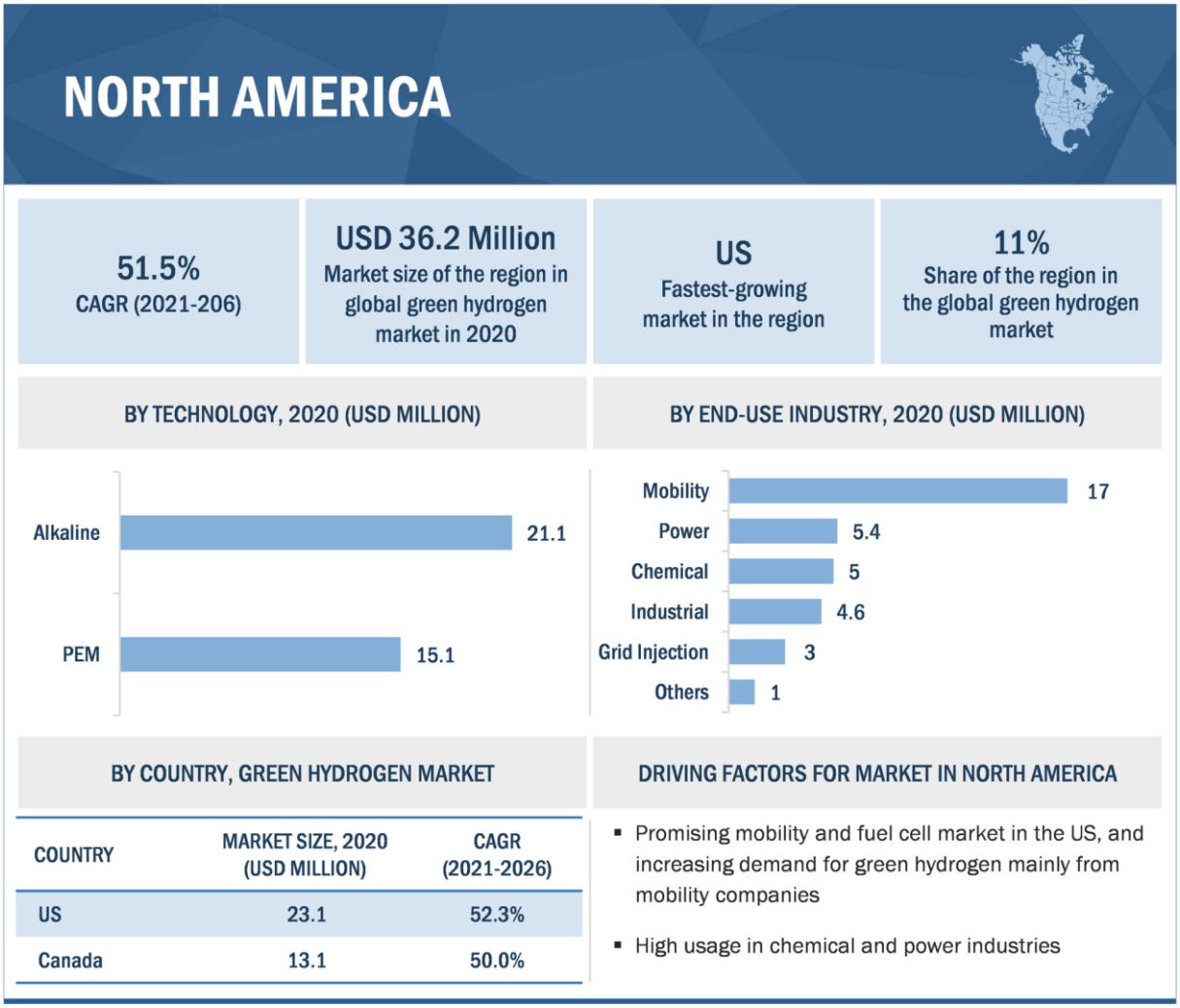
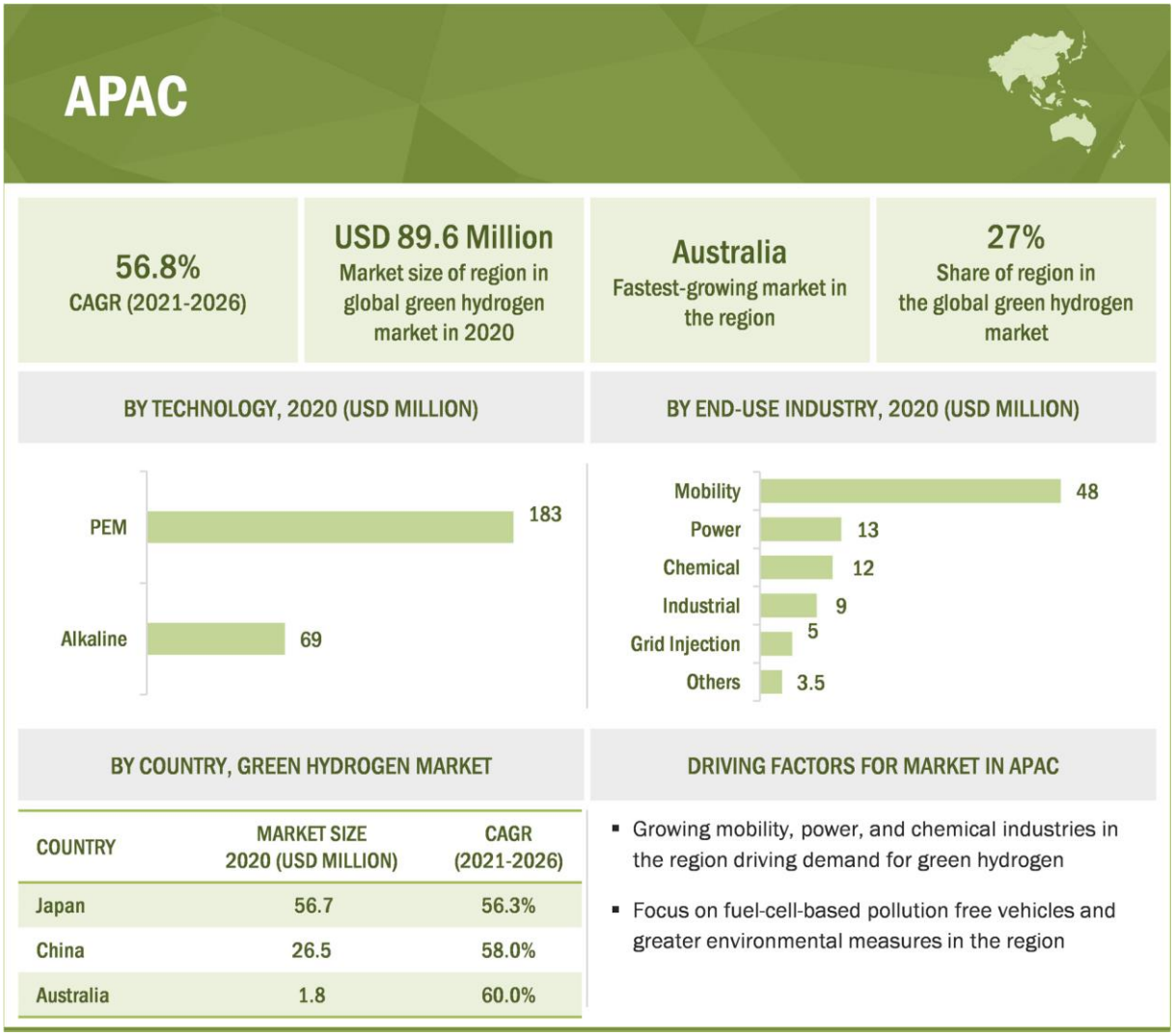


Figure 11. Green hydrogen market in APAC

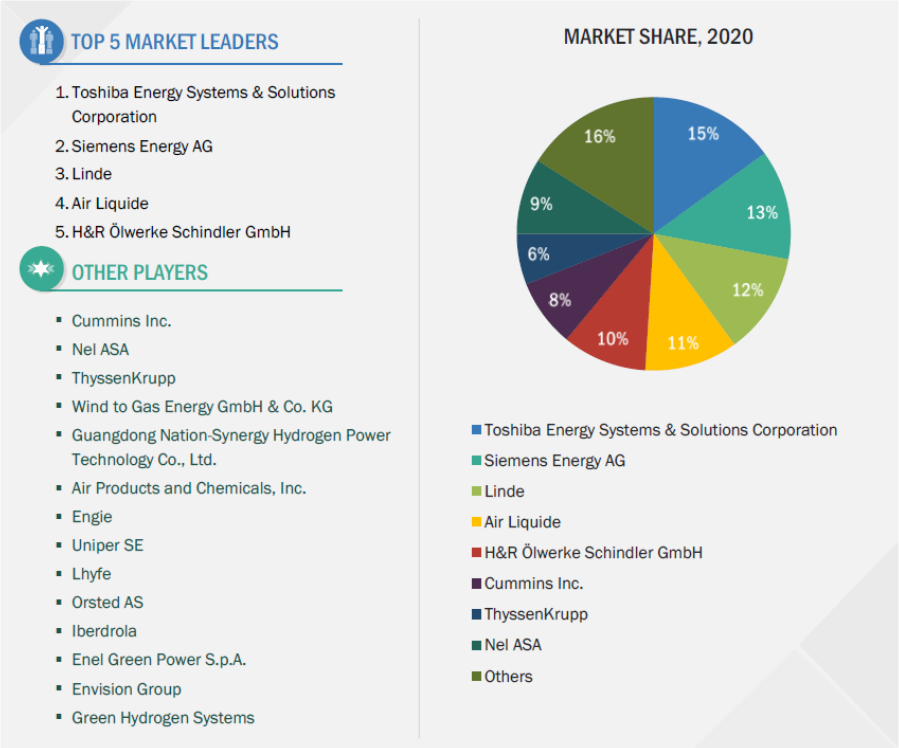


3 Competitive Landscape

The green hydrogen market is still developing, with not too many players present in the ecosystem. **Key players** in the green hydrogen market are Siemens Energy AG (Germany), Toshiba Energy Systems & Solutions Corporation (Japan), Nel ASA (Norway), Linde (Ireland), Cummins Inc. (US), H&R Ölwerke Schindler GmbH (Germany), Wind to Gas Energy GmbH & Co. KG (Germany), Guangdong Nation-Synergy Hydrogen Power Technology Co., Ltd. (China), Air Liquide (France), and Air Products and Chemicals, Inc. (US).

The global green hydrogen market is dominated by **five players**, Toshiba Energy Systems & Solutions Corporation, Siemens Energy AG, Linde, Air Liquide, and H&R Ölwerke Schindler GmbH. These companies are backed by their technological capabilities, geographical presence, wide product portfolio, and adoption of growth strategies. The **market ranking** reported in Figure 12 is based on green hydrogen product offerings, geographical presence, revenue, and recent developments.

Figure 12. Market share of top companies in green hydrogen market



The **competitive leadership mapping** reported in Figure 13 explains the business strategies and product offerings of key players operating in the green hydrogen market. They are classified as stars, pervasive, participants, and emerging leaders in the market, according to their product footprint and market share/rank.

The **small and medium-sized enterprises (SME) evaluation matrix** of the green hydrogen market explain the business strategies and product offerings of smaller players operating in the market (Figure 14). The matrix is classified into four groups: progressive companies, responsive companies, dynamic companies, and starting blocks, according to the excellence of their business strategy and the strength of their product portfolio.

Figure 13. Green hydrogen market (global) competitive leadership mapping, 2020

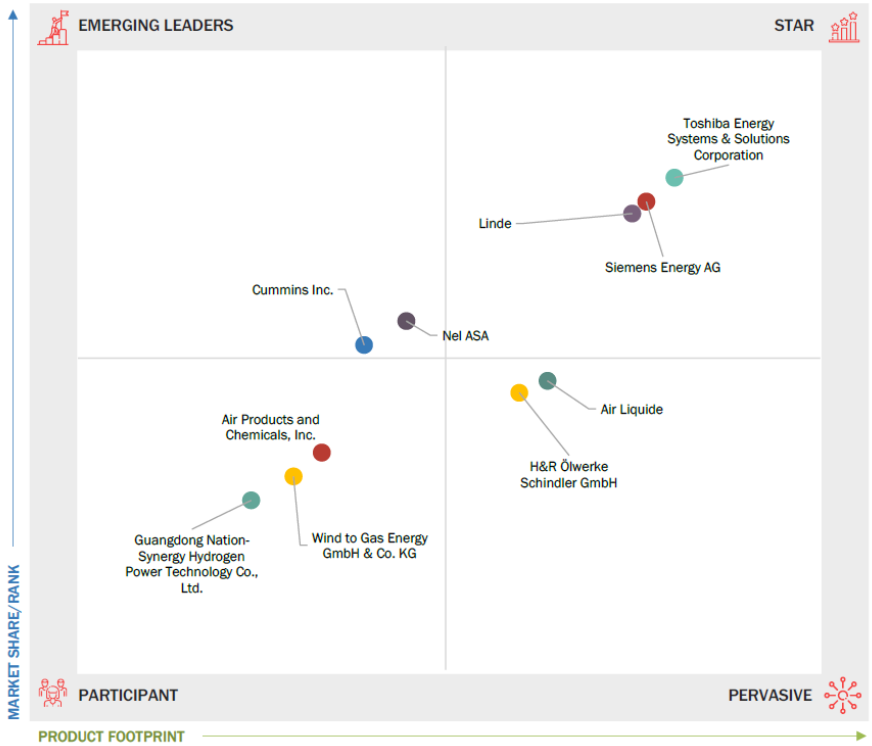
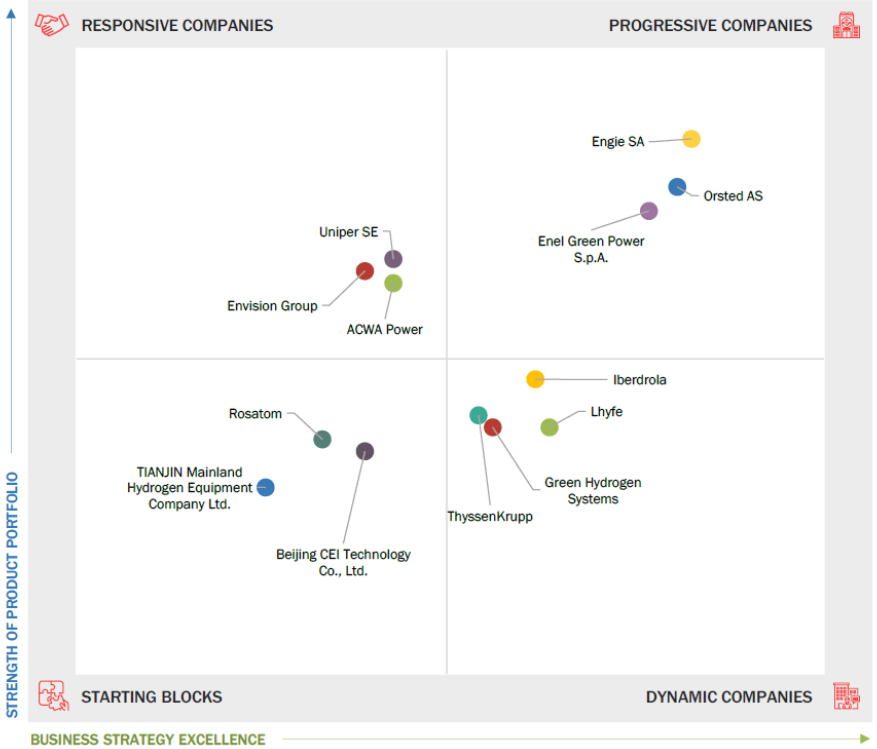


Figure 14. Small and medium-sized enterprises mapping, 2020



3.1 Main competitors

Another information provider, Lux Research, provides additional information about companies involved in green hydrogen market. The database contains information about startup and SMEs active in a market sector of interest and the relative innovative solutions they are developing. Therefore, it allows to find **competitors for the specific technology** under consideration.

Companies involved in the development of solutions for green hydrogen production by biomasses through an electrochemical reforming process have not been found. However, there are some companies that can be considered as "**main competitors**": they have developed innovative methods for the **production of green hydrogen from renewal energy and biomass waste**. As already mentioned, none of them apply an electrochemical reforming technology: they employ other kind of processes, and mainly **gasification systems**. Neither they obtain sustainable chemicals of industrial interest as co-products. They are listed in Table 4 (the list is not to be considered exhaustive).

Biomass gasification systems were excluded from the analysis carried out by MarketsandMarkets (from which we extracted global market information and segmentations), as they represent a small niche of the global green hydrogen market. Therefore, information provided by the two databases complement each other.

Table 4. Developers of innovative methods for the production of green hydrogen from renewal energy and biomass waste

Company	Location	Business/Products
All Power Labs	United States	Small-scale gasification system for power generation (*it is not clear if they produce hydrogen*)
Concord Blue	Germany	Thermal decomposition of organic waste to produce syngas; its patented technology transforms nearly any form of waste into a variety of renewable fuels, including **hydrogen** and electricity, with virtually no pollutants
Cortus Energy	Sweden	Gasification of cellulosic feedstock to synthetic gas (syngas) for power and heat, synthetic natural gas (SNG), and **hydrogen**
Enerkem	Canada	Renewable syngas from gasification of MSW, biomass, and waste plastic. It announced multiple projects that will integrate low-carbon drop-in fuel production with **green hydrogen**
ETIA	France	Torrefaction and pyrolysis of agricultural and industrial waste feedstock. In-house R&D is developing waste tire pyrolysis and **renewable hydrogen** production processes
Gas Technology Institute	United States	Gasification process (dubbed IH2) to convert biomass into drop-in fuels. The process has four components: feedstock conditioning, two-part catalytic conversion of biomass, and **renewable hydrogen** production
PowerHouse Energy Group	United Kingdom	High-temperature gasification of waste to **hydrogen**
Proton Power	United States	Patented cellulosic to **hydrogen** power (CHyP) process to produce high energy content syngas via a gasification and pyrolysis process
Ways2H	United States	**Waste-to-hydrogen** using alumina balls as heat carriers for thermochemical conversion

4 Conclusions

Green hydrogen market represents a **small segment** of the global hydrogen market but will experience **unprecedented growth** in the coming years. It is also expected that by the year 2030, green hydrogen would take up to 10% of all hydrogen. Green hydrogen is gaining mass acceptance as it offers **high efficiency** in conversion and is capable of **storage** for a longer period. It is the cleanest source of energy, as it has no carbon emissions associated with it. With the increasing demand for non-polluting sources of energy, green hydrogen is a viable solution. As a matter of fact, **green hydrogen has the potential to decarbonize the existing energy system**: it is a clean fuel that offers a chance to transport renewable energy.

Technological advancements and **high demand** for portable and storable alternative/green fuels are the main drivers pushing the growth of the green hydrogen market; there is also a **growing interest by governments** in supporting green hydrogen initiatives, with investments and favorable policies. However, there are also some barriers to the growth of the market, that is still under-developed; the biggest challenge in the market is the **initial investment** required to set up a production plant and the transportation costs associated with its postproduction. Therefore, the major problem green hydrogen faces is its cost. The **average global cost** of green hydrogen per kg is nearly USD 4.7, which is much higher than other forms of hydrogen that average at around USD 1/ kg.

Green hydrogen is produced by the electrolysis process. Regarding the segmentation by technology, the market is dominated by the **alkaline electrolysis technology** in thanks to the various advantages of alkaline electrolysis over PEM electrolysis, with **PEM electrolysis technology** expecting to grow at a higher CAGR during the forecast period due to its simple installation process and small-scale production of green hydrogen.

Selection of the **energy source** is an important issue, as the energy component of green hydrogen amounts to 50%-75% of the total cost. The market for green hydrogen was led by the **wind energy segment** in 2021, and both solar and wind sources of energy will experience a great growth during the forecast period.

Mobility is the largest end-use the fastest-growing industry sector of the green hydrogen market, in terms of value, with industrial and chemical also experiencing a notable growth during the forecast period.

Regarding the segmentation of the market by region, **Europe** is the largest and fastest-growing green hydrogen market, with the mobility sector as the major consumer of green hydrogen in the region. The presence of the highly advanced green hydrogen players and high demand from the mobility and power industries in **Germany** are expected to drive the market in the region in the forecast period.

Within the analyzed market, have been considered as **main competitors** those companies involved in the development of innovative methods for the production of green hydrogen from renewal energy and biomass waste. None of the companies found apply an electrochemical reforming process.

The technology under study is highly innovative but it is still in an early stage of development, representing a **niche of the market** of reference. However, it could have good application opportunities in the green hydrogen market, with some players that can be potentially interested in implementing it in their industrial processes.

5 Sources

Lux Research (Home | Lux Research (luxresearchinc.com)) – Lux is a research and advisory firm, focused on sustainable innovation that is commercially viable. Lux's diverse team of analysts work cross-functionally across industries as well as technologies, using proprietary research methodologies to unlock unique insights. The information of interest is contained in the section "Companies" and in the report "Power-to-Chemicals: The Cost of Electrifying Chemical Production", March 2020.

MarketsandMarkets Knowledge Store (https://www.mnmks.com/) – Multisectoral database that collects market research reports in various technological fields and designed to process some information interactively. More than 1,200 market reports are published each year[1]. The information presented are contained in the Report "Green Hydrogen Market – Forecast to 2026", July 2021.

[1] *© MarketsandMarkets (MnM) 2022. All rights reserved. The MnM Report represent data, research opinions, and/or viewpoints published as a part of a service by MnM and are not representations of fact. The MnM Reports are relevant only as to their original date of publication, and not of the date of this document, and the viewpoints and/or opinions expressed in the original MnM Report(s) are subject to change without notice.*