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INDUSTRY TRENDS REPORT

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EXECUTIVE SUMMARY

2023 proved to be something of a reality check for the hydrogen (H2) industry as increased costs and greater scrutiny delayed the launch of many new projects. Nonetheless, there is a consensus the H2 will play a crucial role in the energy transition with geopolitical competition pushing the global market to 523 megatons (MTs) by 2050.

Improvements in storage and transport are combining with a growth in applications while, from a production point of view, ***grey*** is currently the primary form with ***blue*** acting as a transition towards the emerging future of ***pink*** and ***green***.

Blue hydrogen uses ***fossil fuels*** and carbon capture energy and storage and promises to generate revenues of over $3 billion (b) globally by 2030 whereas ***pink*** hydrogen uses ***nuclear power*** and offers both base and peak load capabilities, and ***green*** hydrogen uses ***renewable energy*** and has the potential by 2050 to meet 24% of the world's demand.

Steam methane and autothermal reforming are the principal production pathways for blue and, to a lesser extent, pink hydrogen. It is however the advent of green hydrogen that will truly facilitate the shift to net zero.

Within this, **electrolysers** technologies are at an early stage of development and action is required in several areas to accelerate adoption, but their commercialisation is central to green H2 production with roll out promising environmental and economic benefits.

The leading solutions include alkaline and proton exchange membrane while solid oxide cells are gaining traction and anion exchange membranes emerging. Each approach has its relative advantages and disadvantages, but all are broadly comparable in terms of their energy consumption, reliability and production yield.

Together, annual electrolyser capacity additions for green hydrogen are forecast to grow exponentially from just 4.9 gigawatts (GW) globally in 2023 to over 300 GW in 2030. Uptake will be supported by the use of advanced materials and digital technologies which will combine to improve the efficiency and reduce the cost of electrolysis and green H2.

Alkaline (ALK) accounted for 60% of green H2 production capacity in 2023 and this is reflected in it being the focus area for two of the top three market participants. Plug Power (United States) leads the way with 3 GW of electrolyser manufacturing capacity while LONGi (China) is in second place, having recently unveiled its latest ALK solutions, and John Cockerill (Belgium) holds a 7.5% share and has ambitious expansion plans.

They and the very long tail of international and regional manufacturers face a range of challenging supply chain issues. Access to and the availability of raw materials such platinum, iridium and palladium is a notable hurdle which needs to be overcome for electrolysis to flourish but, despite this, the H2 industry has set out clear roadmap to developing a thriving market for electrolyser technologies supported by sustainable infrastructure.

Within electrolysers, innovation has focused on developing catalysts which are suitable for pure water electrolysis but 95% of available H2O is brackish or salt. There are however four types of **emerging technologies** that leverage saltwater, and which offer comparable or in some cases greater efficiency than current commercialized technology.

Chlorine-free hybrid approaches, for example, use hydrazine as an anolyte and saltwater as the catholyte to produce nitrogen rather than oxygen at the anode. SHYp (United Kingdom) is a start-up that has developed a hybrid membrane-free electrolyser which uses saltwater to produce green hydrogen for many offshore applications.

Outside electrolysers, methane pyrolysis is an alternative which needs no water at all. The process involves the high-temperature cracking of the methane in natural gas into carbon and hydrogen to produce a low emission and high-density fuel.

Plasma methods methane pyrolysis, for example, is very efficient, with strong converted output and reduced fouling issues, but is also expensive, attracting capital and operational costs. SEID (Norway) and HiiROC (UK) are among the companies that are leading developments in this respect, leveraging differentiated cold and thermal plasma technology. Moving forwards, there is the potential for nuclear reactors to be used to generate the high heat that is needed for most plasma pyrolysis hydrogen production processes.

In addition to efficient production, the success of the industry depends on developing effective **storage** and, in this respect, H2 offers both pros and cons.

Overall, despite efficiency concerns, hydrogen compares well with other technologies and has a role to play in providing base and peak energy supply. In the European Union, national and regional governments have provided a supportive regulatory framework and financial platform for storage and the hydrogen economy in general. They and other stakeholders globally are encouraging the roll-out of four hydrogen storage techniques.

Geological storage, where H2 is held in depleted gas reservoirs and rock or salt caverns, is currently the most widely used method, but will be overtaken in relative terms by liquid and hybrid storage by the year 2030. ***Surface gaseous*** leverages cylinders, spherical pressure vessels or tanks while ***solid-state*** stows hydrogen in metal, intermetallic and complex hydrides and ***liquid*** uses liquid organic hydrogen carriers and cyrocompressed storage. Within this latter group, market participants are investigating the use of ammonia as a carrier while methanol is emerging as a cheap and environmentally friendly alternative.

Overall, the storage value chain remains fragmented with compressors accounting for the greatest expense and tanks needing upgrades for hydrogen. Partnerships and the provision of industry agnostic solutions will be key to creating a supply-side ecosystem which is ready to meet growing demand.

In its latest data release, the Hydrogen Council estimated that almost all the demand for hydrogen in 2020 stemmed from existing industry use.

As large-scale solutions develop, fuel cells (FCs) offer an immediate way in which to store H2 in small quantities and make it available for **application** as a power source. In the energy industry, stationary FCs are used to power data centers and combined heat and power plants. In the automotive industry, they deliver a denser alternative to electric vehicle batteries, reducing weight and volume and extending their driving range.

FCs are applicable to both private and commercial vehicles, notably in the medium and heavy categories, where manufacturers are testing long-haul trucks. Interest in the area is expected to continue heighten as economies of scale reduce costs and action is taken to reduce indirect emissions from production.

However, improvements to the H2 distribution infrastructure will be key to expansion. In the United States alone, there are ambitious plans to install 7,200 refuelling stations by 2035, while the European Union has introduced supportive regulations. More broadly, the ideal scenario is to collocate the H2 producer and the off taker but, even in this context, hydrogen will need to be moved from A to B.

Trucks and *ships* provide readily available but low volume **transportation** solutions. Dedicated and converted H2 *pipelines* offer an alternative and can be effective carriers where consistent and certain supply justifies the high investment. Their roll-out is being assisted by the development and deployment of new advanced materials which make pipelines more robust, flexible and lightweight.

In the meantime, the industry is looking to leverage the hydrogen extraction process to develop "e-fuels", including e-gasoline, e-diesel and e-kerosene.

There exist different approaches to e-fuel production which are spread across ***power-to-gas*** and the predominant ***power-to-liquid*** methodologies with the main advantage being that they offer a drop-in substitute to petrol which can be distributed through the same pumps and used in internal combustion engines. More broadly, the ***power-to-gas*** pathway can leverage hydrogen to supply ammonia for fertilizers and syngas for industrial heat and power while the ***power-to-liquid*** pathway can generate sustainable fuels also for marine purposes and to produce methanol or di-methyl ether.

Hydrogen is finding its application not only for ground but also airborne vehicles with fuel cells an emerging power source of unmanned aerial systems. Here, the market is small but growing rapidly to reach $212.3 million globally in 2032. Further afield, liquid hydrogen is emerging as a strong candidate for propelling future space vehicles into orbit and is being tested by NASA as well as other stakeholders.

This report examines all of these areas with a focus on the current and emerging technologies and use cases which will underpin the evolving H2 economy.

INTRODUCTION

2023 proved to be something of a reality check for the hydrogen industry as increased costs and greater scrutiny delayed the launch of many new projects

Overall, the volume of final investment decisions (FIDs) for hydrogen (H2) projects has been low over the last twelve to eighteen months. The results from utilizing H2 in some sectors have proved disappointing while the projected budgets have made this unfeasible. In parallel, technology suppliers have struggled to provide clear evidence that they will be able to drive efficiencies and progress in clarifying key legislation and incentives has been slow.

However, none of these factors changes the fact that hydrogen will play a very significant role in the ongoing energy transition.

In 2024, the industry should achieve greater regulatory certainty which, in turn, will enable more FIDs while increased scrutiny from investors will likely mean stronger business cases for the projects that are put forward. Reducing activity in sectors where a better decarbonization alternative exists will shift the focus to areas where H2 is the best fit. Challenges remain but there is a strong will amongst market participants to prosper.

Nonetheless, there is a consensus the H2 will play a crucial role in the energy transition with geopolitical competition pushing the market to 523 MT by 2050

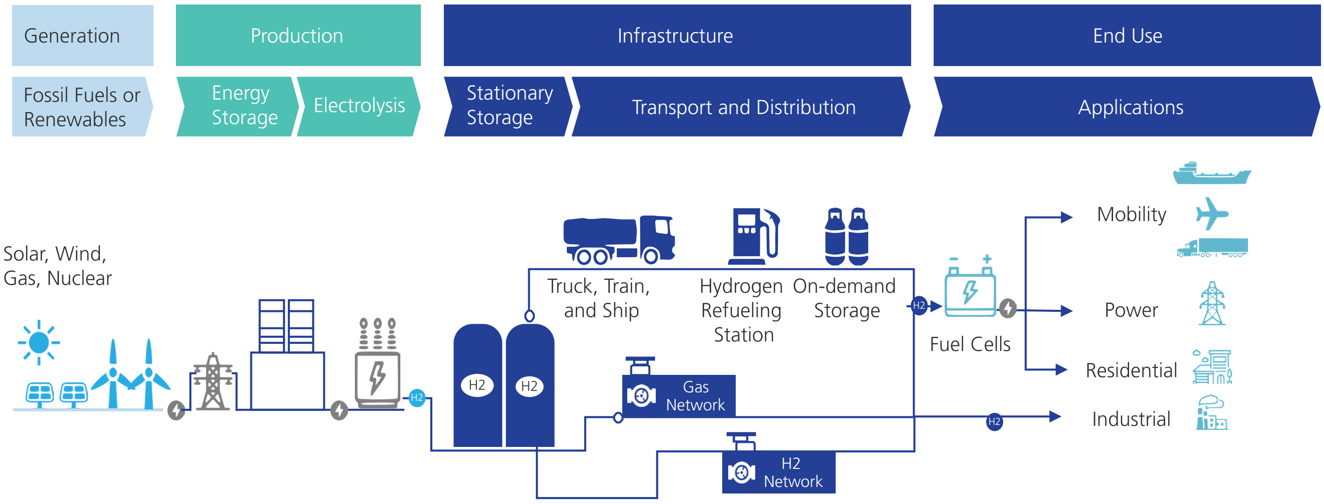
Crucially, although there is rivalry across and between countries, there is broad agreement across the major powers that progress needs to be made in the hydrogen sector as part of global efforts to tackle climate change. China and the United States have, for example, both committed to reducing greenhouse gas (GHG) emissions stemming from their economies and the use of hydrogen as a low-carbon energy source is a key element of achieving that.

The International Energy Agency (IEA) estimates that emissions from the power sector alone reached 37 gigatonnes (Gt) of carbon dioxide (CO2) in 2022. Policymakers across the world are therefore striving for a shift to net zero by ensuring a renewed focus on energy efficiency and electrification and an increase in the share of renewables in the global energy mix.

In this regard, low-emission fuels, such as hydrogen and its derivatives, present themselves as ideal feedstock that will significantly contribute to reaching this target, in particular in hard-to-abate industries. Demand for hydrogen as a low-carbon fuel has been steadily increasing; it reached 95 megatons (Mt) in 2022 and is expected to reach around 523 Mt by 2050.

Hydrogen's significance is reflected in its increasing share in emission-reduction strategies. Governments across the continents have been actively formulating long-term roadmaps to achieve economies of scale and deploy pathways for the increased production of H2. By 2050, according to the International Renewable Energy Agency (IRENA), it is projected to meet 14% of the world's total final energy consumption (TFEC), an increase from just 1% in 2020.

IMPROVEMENTS IN STORAGE AND TRANSPORT ARE COMBINING WITH A GROWTH IN APPLICATIONS ...



... while, from a production point of view, *grey* is currently the primary form with *blue* acting as a transition towards the emerging future of *pink* and *green*

Brown H2 production involves the gasification of coal whereas **grey** hydrogen leverages natural gas and steam reforming. In both cases, the heat source is a *fossil fuel* which means that these widely used processes are carbon-intensive with high emissions.

Blue H2 also uses *fossil fuels* and conventional production techniques together with carbon capture, utilization and storage (CCUS). The adoption of CCUS solutions improves the technology's environmental credentials and, since they are more scalable, directly influences hydrogen costs.

Green H2 generation involves the electrolysis of water using *renewable energy* sources. While it is not yet cost-competitive on a commercial scale, it holds significant importance for the renewable approach and will be the primary production method in the future. **Pink** H2, like green, uses electrolysis of water but this is powered by *nuclear energy*.

Grey H2 currently serves as the primary form of hydrogen globally while blue H2 is acting as a transitional form. The high upfront capital requirements for green H2 production pose a challenge but governments and the private sector are allocating extensive funding for the deployment of green hydrogen in various applications, such as steel production and the transport sector.

Blue hydrogen uses *fossil fuels* and carbon capture energy and storage and promises to generate revenues of over $3b globally by 2030

Securing sufficient low-carbon hydrogen to meet demand will be a significant challenge. Green hydrogen forms part of the story but **blue hydrogen** enables the production of H2 from a baseload power source which means that it provides guaranteed availability. It also offers the potential to decarbonize existing grey hydrogen projects which can be retrofitted with carbon capture technology although virgin projects should be the priority to boost supply.

Carbon capture projects are complex and capital-intensive. The Gorgon liquefied national gas plant in Australia, for example, is the world's largest and (although not directly hydrogen-related) is only operating at a third of capacity, having faced several technical challenges. Addressing these obstacles and bringing down costs is vital to the success of blue hydrogen, otherwise projects will struggle for viability.

It is clear that incentives are needed with the United States (US) expected to extend tax credits to carbon capture projects. China and the US have also agreed to cooperate on the development of large-scale carbon capture, usage and storage solutions which bodes well since the conventional oil and gas (O&G) industry, which typically drives the technology's development, does not have a track record of rapid innovation and cost reduction.

Improving the financials of blue H2 can also be achieved via;

- *Solution modularization*, which avoids the need for expensive bespoke projects
- *Infrastructure sharing*, with the establishment of "hydrogen hubs" that bring companies together to share storage and pipeline costs
- *As-a-service propositions*, which allow suppliers to execute entire hydrogen projects or, at the very least, seamlessly partner with other players to do so

Pink **hydrogen uses** ***nuclear power*** **and offers both base and peak load capabilities**

Blue hydrogen is not the only possible baseload power source for H2 production. Nuclear energy also offers significant potential for the generation of **pink hydrogen**.

Nuclear plants usually have capacity factors of approximately 90% which means that they operate 24/7, apart from maintenance outages, while for most countries in which they are present they are a key source of electricity. However, due to the growth in renewables, there are increasingly more periods where electricity is generated in excess. In some cases, this leads to nuclear plants no longer being cost-competitive.

In these situations, nuclear plants can be utilized to produce hydrogen via a solid oxide electrolyzer (SOE). SOEs are highly efficient and need a continuous supply of electricity which makes them a perfect match for nuclear power. They also require high temperatures, usually above 700 degrees Celsius (C), while the nuclear reaction process results in significant volumes of waste heat that can help power the electrolyzer, reducing the amount of electricity required, lowering overall plant emissions and boosting energy efficiency.

SOE technology, which is examined in further detail in the second chapter of this report, is proven and many companies either have a commercialized solution or are in the final stages of product development. Bloom Energy (US) and Topsoe are amongst the most prominent suppliers. Bloom Energy increased its production to 2 gigawatts (GW) in 2023 while Topsoe, a Danish manufacturer, is building a 500-megawatt (MW) facility that will go live in 2024 and has options to scale this up to 5 GW if targets are achieved.

For nuclear technology suppliers, H2 production is an attractive complementary solution and should form a key part of the business case for plant life extensions, particularly in the US, but countries in Europe seeking to exit coal will have only limited spare capacity.

Source: Frost & Sullivan

Green hydrogen uses *renewable energy* and has the potential by 2050 to meet 24% of the world's demand through an additional $160b of finance

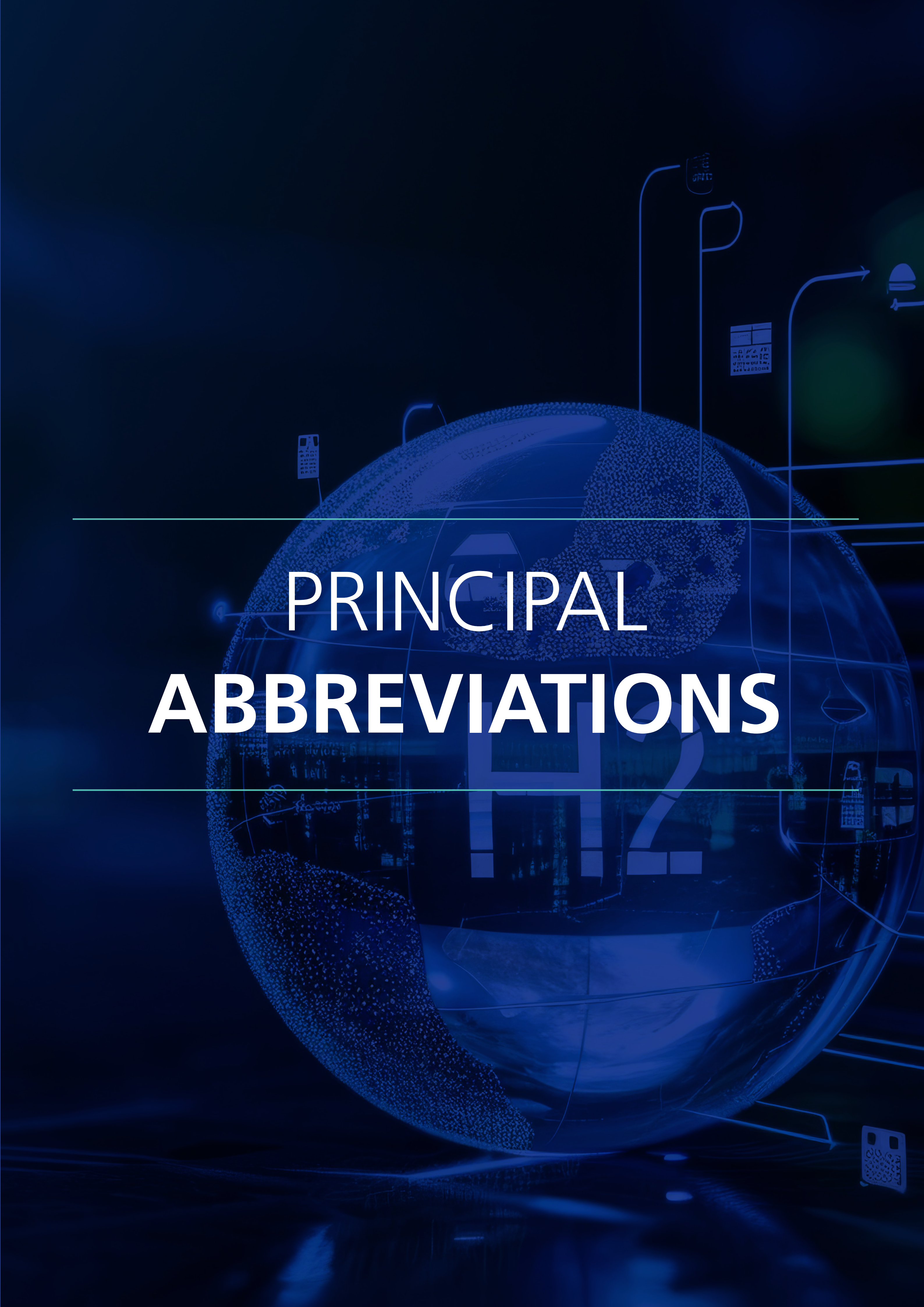
The ***hydrogen economy*** refers to a future scenario where countries would rely on H2 as a carbon-free energy source that could be used as a commercial fuel and would deliver most of a nation's energy and energy-related services.

In this context, **green hydrogen** – generated from renewable energies – would replace the need for traditional carbon-intensive fossil fuels as part of the conventional energy mix. Applications could include electricity generation and transportation as well as storing energy from intermittent renewable sources.

There are currently early signs that suggest that this status quo could become a reality with H2 fuel cells seeing investments of more than $240 billion globally in 2022 alone and a growing understanding that green hydrogen could save about 60 gigatons of carbon emissions by 2050 as part of a market that will be valued at $89.45b by 2030. By 2040, companies will produce green hydrogen at scale, as the costs of the technology fall by more than 60%

This report examines each of these areas with a focus on the current and emerging technologies and use cases which will underpin the evolving H2 economy

Source: Frost & Sullivan



PRINCIPAL **ABBREVIATIONS**

AEM	*Anion exchange membrane*
AI	*Artificial intelligence*
ALK	*Alkaline electrolyzer*
ATR	*Autothermal reforming*
B	*Billion*
BOG	*Boil-off gas*
C	*Celsius*
CCfD	*Carbon contracts for difference*
CCUS	*Carbon capture, utilization and storage*
CFRP	*Carbon fiber reinforced polymer*
ClER	*Chlorine evolution reaction*
CO2	*Carbon dioxide*
DAC	*Direct air capture*
EU	*European Union*
FID	*Final investment decision*
FiT	*Feed-in-tariff*
GHG	*Greenhouse gas*
Gt	*Gigatonne*
GW	*Gigawatt*
H2	*Hydrogen*
HER	*Hydrogen evolution reaction*
HzOR	*Hydrazine oxidation reaction*
IoT	*Internet of things*
KOH	*Potassium hydroxide*

kW	*Kilowatt*
LNG	*Liquid natural gas*
LOHC	*Liquid organic hydrogen carrier*
M	*Million*
MeOH	*Methanol*
MOF	*Metal-organic framework*
Mt	*Megaton*
MW	*Megawatt*
O&G	*Oil & gas*
OER	*Oxygen evolution reaction*
PEM	*Proton exchange membrane electrolyzer*
PFSA	*Perfluorosulfonic acid*
PGM	*Platinum group metal*
pH	*Potential of hydrogen*
R&D	*Research & development*
RES	*Renewable energy source*
SMR	*Steam methane reforming*
SOE	*Solid oxide electrolyzer*
SOEC	*Solid oxide electrolyzer cell*
TFEC	*Total final energy consumption*
TPE	*Thermal Plasma Electrolysis*
UK	*United Kingdom*
US	*United States*
V	*Volt*

Source: Frost & Sullivan

ABOUT INTESA SANPAOLO INNOVATION CENTER:

Intesa Sanpaolo Innovation Center is the company of Intesa Sanpaolo Group dedicated to innovation: it explores and learns new business and research models and acts as a stimulus and engine for the new economy in Italy. The company invests in applied research projects and high potential start-ups, to foster the competitiveness of the Group and its customers and accelerate the development of the circular economy in Italy.

Based in the Turin skyscraper designed by Renzo Piano, with its national and international network of hubs and laboratories, the Innovation Center is an enabler of relations with other stakeholders of the innovation ecosystem - such as tech companies, start-ups, incubators, research centres and universities - and a promoter of new forms of entrepreneurship in accessing venture capital. Intesa Sanpaolo Innovation Center focuses mainly on circular economy, development of the most promising start-ups, venture capital investments of the management company Neva SGR and applied research

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