FUTURE WATCH
2/2023

BUSINESS
FINLAND

MARKET OPPORTUNITIES IN the hydrogen economy

Prepared for Business Finland

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FROST & SULLIVAN

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Executive Summary

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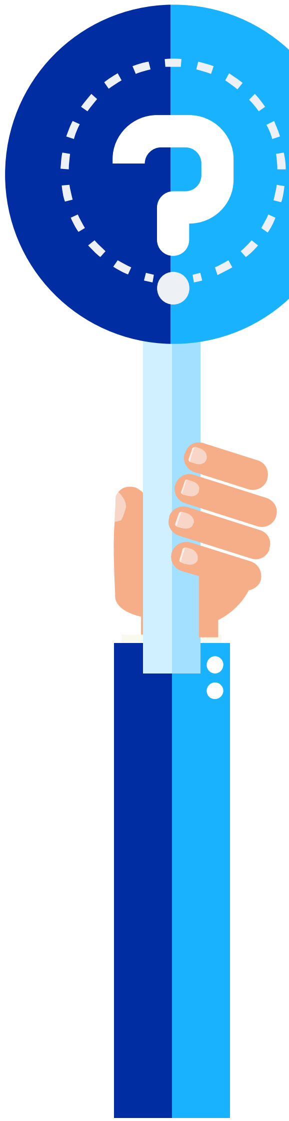
FUTURE WATCH

KEY FINDINGS



Global pace of hydrogen investment shows no signs of stalling, with governments, financial institutions and regulatory authorities sending clear signals that transitioning to low-carbon hydrogen and substantially increasing total hydrogen production volumes is a key strategic priority. Production volumes will surge from the late 2020s, with electrolyser (green) production leading the way. Significant investment in blue (SMR-CCUS) also expected, with methane pyrolysis a longer-term technology.

For the 2020s into the early 2030s, collocating hydrogen near end users will be the priority to minimize transportation challenges. However by the mid-2030s a global trade in hydrogen will start to fully develop, with hydrogen shipped as green ammonia and pipeline infrastructure constructed. In line with production volumes, end user demand will increase significantly in the late 2020s and accelerate in the 2030s. Key user sectors will include ammonia, methanol, iron & steel and chemicals. Maritime and aviation will see strong growth in the mid-2030s.

A significant number of challenges, which create opportunities exist within the hydrogen economy. Accommodating the volume of water required for electrolysers has not been properly considered. The infrastructure challenge is huge and advanced materials will be needed to bring costs down. The buildout of electrolysers will require significant investment. Sustainability issues will need to be addressed. Utilisation of waste end products from SMR-CCUS and methane pyrolysis will need to be handled.

There are significant opportunities for Finland in this space, although there is significant global competition. Its strengths in highly engineered technologies and solutions will provide an excellent fit with some of the challenges highlighted in this document. Cooperation with partners in the Nordic region will help it compete on the global scale.

GLOBAL KEY COUNTRIES/REGIONS HYDROGEN DEVELOPMENTS

Most major global economies have developed hydrogen strategies

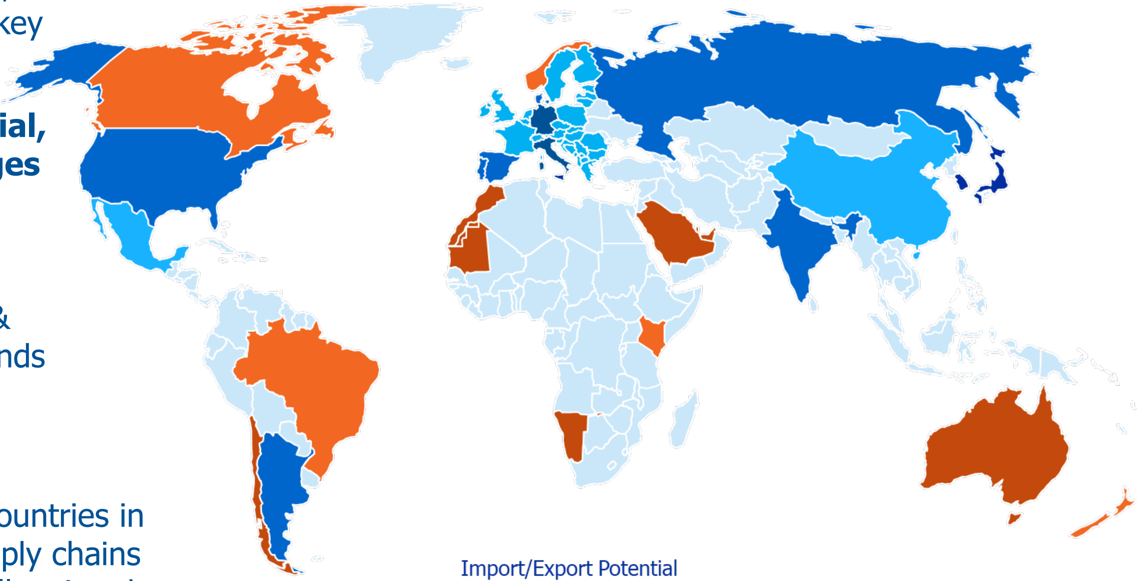
USA: Could the US be self sufficient?
- Inflation Reduction Act likely to boost domestic technology investment (electrolysis & CCUS). Strong support for blue hydrogen from the oil & gas industry.
- Potential to become an exporter, maritime developments will be key

EU: Net importer – but how much will the EU need?
- Strong government support to boost production
- Strong domestic technology OEMs
- Will need imports – Africa key focus – but does not want to be too dependent on anyone

Norway: Green H_2 exporter
- Huge potential for Green & Blue H_2
- Production & utilization of low-carbon ammonia
- Transport within Europe by pipeline

Russia: Self-Consumption
- Has the potential to be a significant producer of blue hydrogen.
- But current political situation limits export potential.

Latin America: Export potential, but some regulatory challenges
- Significant RE potential
- High H_2 production, storage & distribution costs
- Chile leading country – Brazil & Argentina's development depends on politics



China: Will need imports, but strong domestic production
- Potential to become leader in electrolyser & storage technologies – strong domestic OEMs
- Development of "Hydrogen Hubs" focused on H_2 development

Japan & Korea: Importer
- Leading importer of H_2 & ammonia
- Utilization across industries

Africa: Exporter
- Strong interest from European countries in building dedicated hydrogen supply chains
- Political environment can be challenging, but focus is on more politically secure states
- Exporter of green H_2 & low-carbon ammonia via ships & pipelines
- Hub for transport of green H_2 to Europe

Gulf region: Exporter
- Wants to become a leading exporter of green, blue H_2
- Production & utilization of low-carbon ammonia
- Exporter of green H_2 & low-carbon ammonia via ships

Australia: Accelerated growth in H_2 developments
- Potential to become leading exporter of green & blue H_2 & ammonia
- Utilization across industries
- Reducing shipping costs key

Source: Frost & Sullivan

ROADMAP FOR HYDROGEN

The hydrogen economy is essentially a 30-year transitional journey, the course of which will be mapped in this decade

2020 → 2030 → 2040 → 2050

2020 - 2030

- Development of regulations & policies
- Pilot & demonstration projects with large electrolyser capacity
- Feasibility analysis for green hydrogen storage & transport
- Rollout of large-scale RES + electrolyser projects
- Significant decline in cost gap between grey and green hydrogen – parity around 2030
- Ammonia, methanol & steel early industries for green hydrogen

2030 - 2040

- Full commercialization of fuel cells
- Massive ramp up in electrolyser capacity
- Export of green hydrogen via green ammonia
- Decarbonisation of maritime and aviation starts @2035
- Industrial usage significantly increases, with use cases in more industries

2040 - 2050

- Further ramp up of green hydrogen capacity
- Potential for some gas networks transitioning to hydrogen
- Further cost reductions for hydrogen storage & transport
- Growth in volumes of pink/purple hydrogen with potential for dedicated nuclear to hydrogen plants

Source: Frost & Sullivan

KEY BUSINESS OPPORTUNITIES

The development of the hydrogen economy offers a range of business opportunities from supplying related infrastructure solutions to taking advantage of the hydrogen produced

No.	Growth Opportunity	Brief Description
1	Power-to-x	Power-to-X, commonly referred to as P2X or PtX, is a collection of pathways for the conversion, storage, and reconversion of electricity generated from renewable energy sources (RES). X may be heat or chemicals, including hydrogen, syngas, and synthetic fuels.
2	Green Ammonia	Green ammonia produced through the combination of green hydrogen and nitrogen is intended to be used as a zero-carbon fertilizer, fuel, and as an energy carrier.
3	Synthetic Fuels	Synthetic fuels include carbon-neutral liquid fuels such as fuel oil, diesel oil, gasoline, and methanol produced by combining captured CO2 and green hydrogen.
4	Electrolysers+Renewables As Standard	electrolysers are installed on retired oil & gas platforms and can produce green hydrogen through electricity from the nearest offshore wind farm. Green hydrogen produced can be transported back to shore via existing gas pipelines.
5	Utilisation Of Recovered Carbon Black	Recovered carbon black (rCB) produced through pyrolysis is a high-quality carbon black that offers customers an environmentally friendly and cost-effective option for industrial applications.
6	Advanced Material Supply	R&D on advanced materials is crucial for the development of the hydrogen economy. Advanced materials are vital throughout the hydrogen value chain, including hydrogen production, storage, transportation, and utilisation.
7	Water Treatment Systems/Water-as-a-service	Water is the feedstock for green hydrogen production, and the water treatment system must purify it to an ultrapure state. The water treatment solution depends on the electrolyser technology and selected water source; inadequate water treatment can endanger the operation and cause electrolyser damage.
8	Blending Into The Gas Grid	Hydrogen produced through clean pathways can be injected into natural gas pipelines. The blending limit depends on the design and condition of the pipeline and the applications for the blended gas. Some applications include the transport of green hydrogen, industrial heating processes, and power generation.

Source: Frost & Sullivan

KEY BUSINESS OPPORTUNITIES

The development of the hydrogen economy offers a range of business opportunities from supplying related infrastructure solutions to taking advantage of the hydrogen produced

No.	Growth Opportunity	Brief Description
9	Nuclear Produced Hydrogen	Nuclear is a competitive energy source to produce large-scale, low-carbon, cost-effective hydrogen. Nuclear energy creates opportunities to optimize hydrogen production costs and enables decarbonization of hard-to-abate industrial activities.
10	Hydrogen Production From Waste Heat	Hydrogen produced from waste heat can play a significant role in our energy transition because it is a carbon-free fuel and energy carrier equivalent to the green hydrogen produced through electricity from RES.
11	Energy Hubs & Green Hydrogen Production	Energy hubs enable efficient offshore wind power generation and distribution management by serving as connecting points and storage sites for the energy produced by offshore wind. Energy hubs can convert surplus wind power and store it in the form of hydrogen, and can provide a carbon-free energy supply for offshore oil and gas extraction platforms and maritime cargo transport and facilitate the transition toward decarbonization.
12	Circular Economy	The circular economy enables sustainable practices (reduce, reuse & recycle) of handling materials involved in hydrogen production, storage, and transportation.
13	Digital Twin	A digital twin can create a virtual environment of the hydrogen electrolyser plant and provide data and insight into the health of the entire plant, thereby enabling preventative maintenance practices, optimizing plant management, and avoiding costly unscheduled downtime.
14	Digitalization of Hydrogen Industry	Digital technologies play a vital role in delivering the hydrogen economy by accelerating technological innovations, overcoming value chain obstacles, and enabling faster and better scale-up and optimization of the hydrogen value chain through achieving better economics.
15	Aviation & Maritime Fuels	Synthetic fuels, also known as E-fuels, are a promising option for maritime and aviation transport and can deliver significant reductions in carbon emissions
16	Industrial Decarbonization	Green hydrogen generated from RES help decarbonizes industrial processes, which cannot be achieved through electrification, taking us closer to carbon neutrality. Some industries include steelmaking, chemical, cement, and refinery industries.

Source: Frost & Sullivan

Hydrogen Value Chain

IMPORTANCE OF HYDROGEN IN GLOBAL DECARBONISATION

The Hydrogen Economy is one of 5 key pillars in achieving global decarbonisation.

RISE OF RENEWABLES

Increase deployment of renewable energy sources and share of electricity generated from RES in the final energy mix.

Promote utilization of electricity generated from renewables through renewable portfolio standards (RPS) and power purchase agreements (PPAs).

HYDROGEN ECONOMY

Utilising low or zero carbon hydrogen to replace fossil fuels in industrial processes, heating and transportation

DIRECT ELECTRICATION & RENEWABLE HEAT

Greater investment in sustainable renewable heating for homes, businesses and industries

Electrify low-to-medium temperature industrial processes

EMISSIONS MANAGEMENT

Reducing the emissions footprint of existing fossil assets through the deployment of emissions mitigation technologies – both in-process and end of pipe

Carbon, Capture, Storage & Utilisation – ensuring the safe long-term storage of a portion of CO_2 emissions, whilst creating a viable market for the remainder to be utilised in new products and to power industrial processes

ENERGY EFFICENCY

Minimising usage of fossil fuels in industrial processes

Utilising waste heat & energy from industrial processes

Deployment of advanced low carbon technologies in buildings

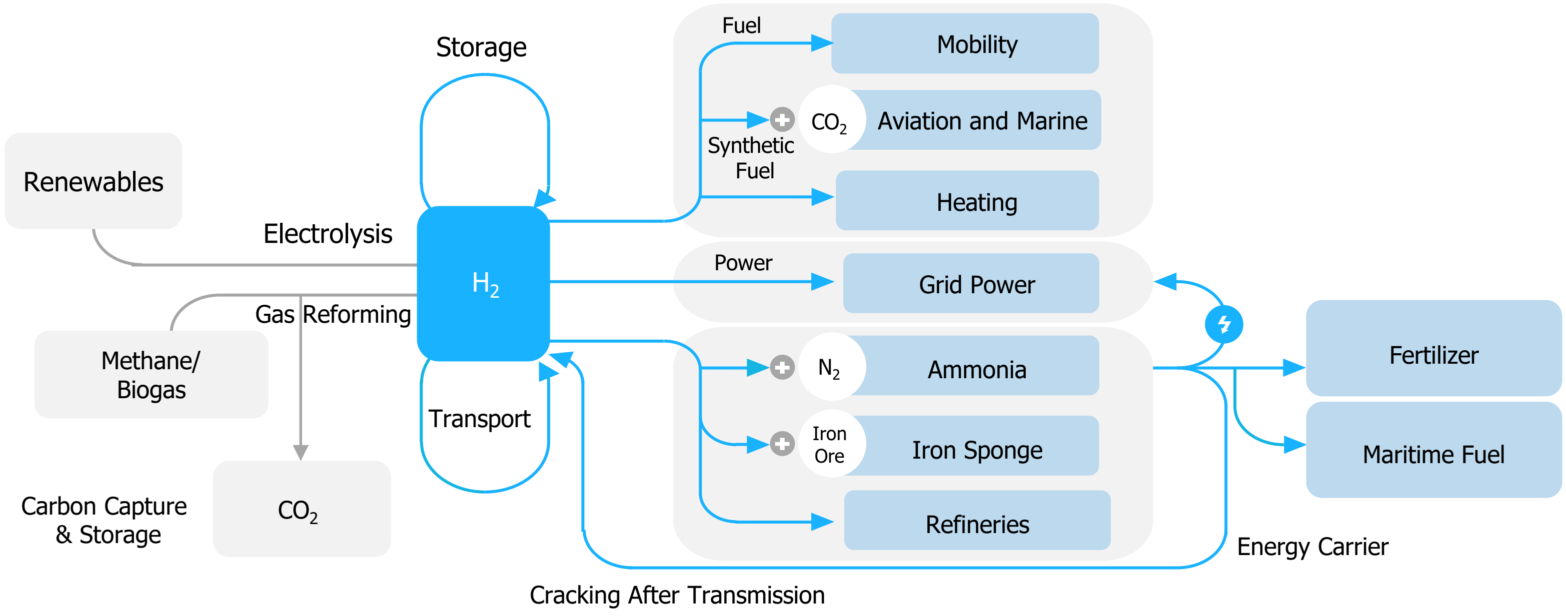
Source: Frost & Sullivan

WHY HYDROGEN?

Interest in hydrogen as a low- or zero-carbon energy carrier has increased significantly. A hydrogen-based economy is possibly the best alternative to the present fossil-fuel-based economy and an answer to the growing concerns over carbon emissions, energy security, and climate change

- Hydrogen can play a significant role in the transition toward carbon neutrality. Its conversion to alternate fuels or chemicals and subsequent recovery from these products is an advantage, making it the most-acknowledged fuel for decarbonization.
- Combining captured CO2 from CCUS technology and hydrogen produces synthetic fuel or other forms of carbon for applications across industries. Hydrogen's use to produce ammonia (NH3) will reduce transport and storage costs, with ammonia's conversion back to hydrogen at the consumer's end.

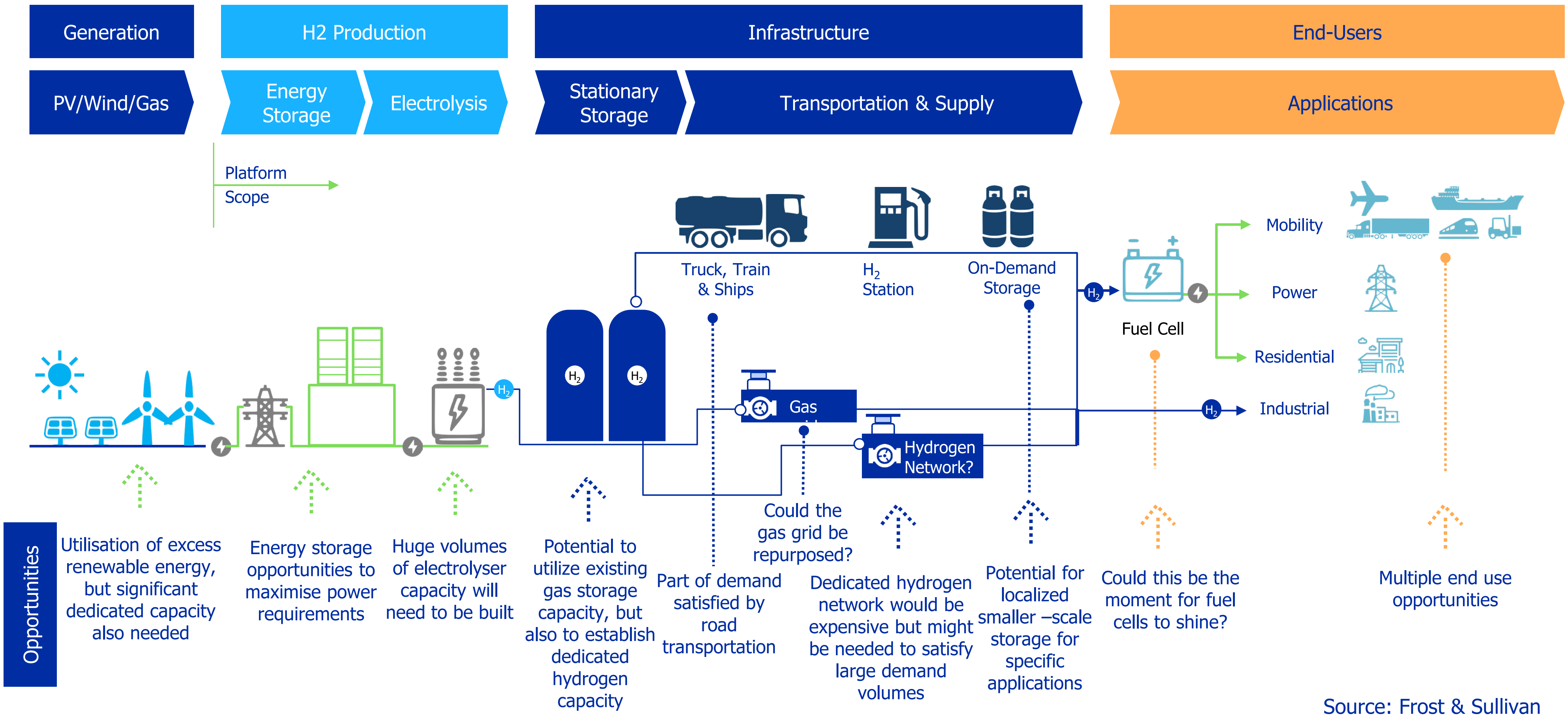
Hydrogen Pathways in the Energy System



N_2 = Nitrogen

Source: Frost & Sullivan

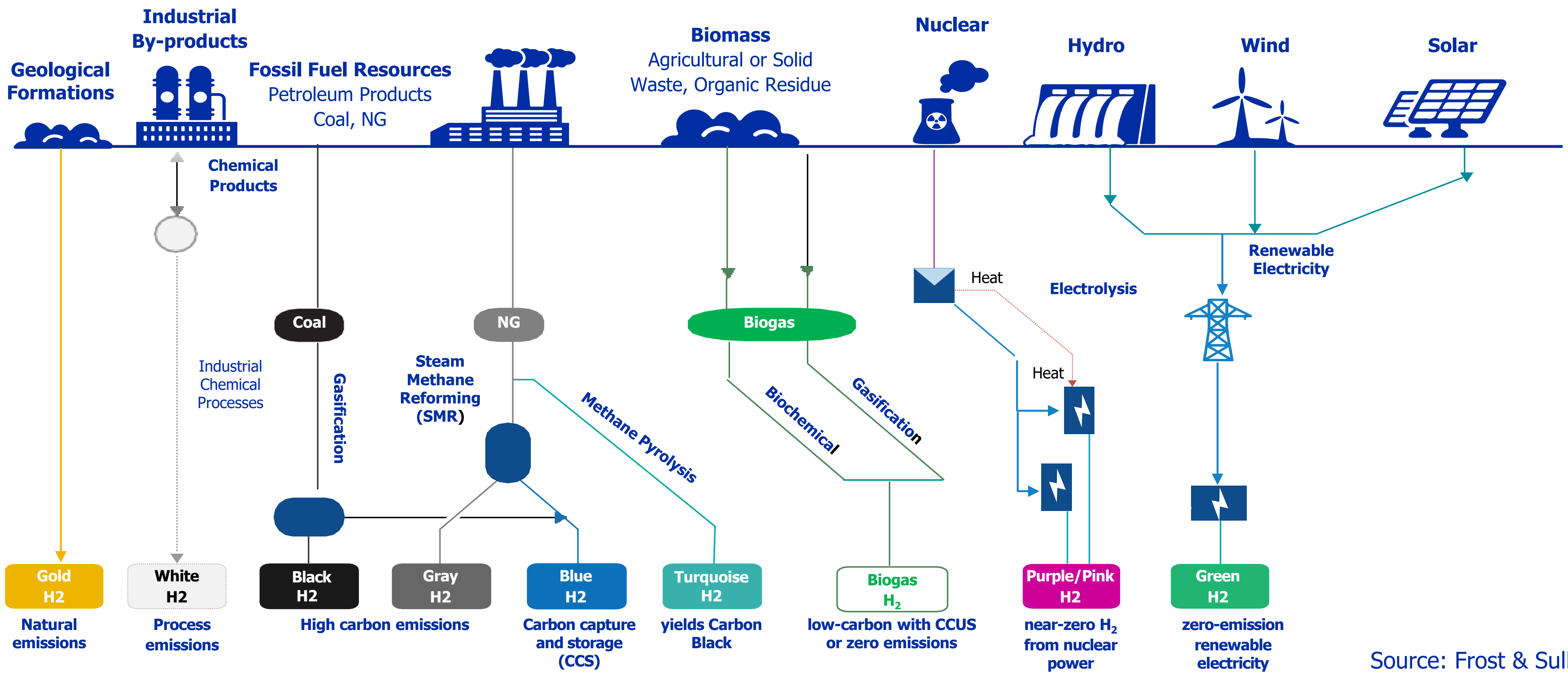
HYDROGEN VALUE CHAIN – PRODUCTION TO END USER



Source: Frost & Sullivan

HYDROGEN PRODUCTION: COLOURS OF THE RAINBOW

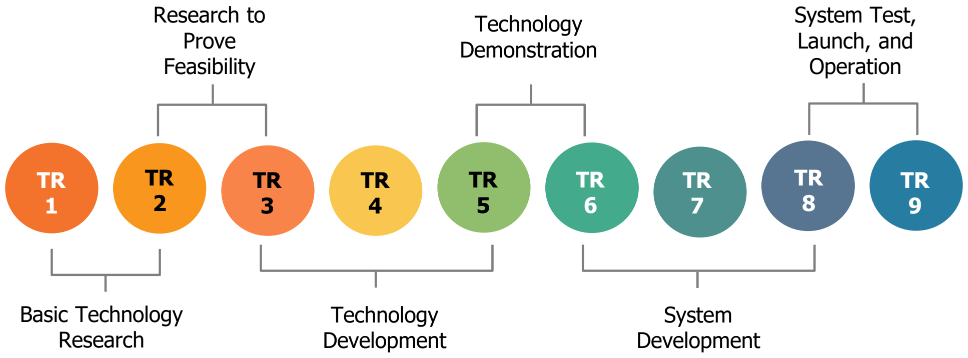
Interest in hydrogen as a low- or zero-carbon energy carrier has increased significantly. A hydrogen-based economy is possibly the best alternative to the present fossil-fuel-based economy and an answer to the growing concerns over carbon emissions, energy security, and climate change



Source: Frost & Sullivan

HYDROGEN PRODUCTION

Large variety of production methods. SMR (without CCUS) dominates current grey production. Water electrolysis (alkaline & PEM) and SMR + CCUS likely to dominate investment to 2030. Post-2030, solid oxide and methane pyrolysis tipped to potentially play a much bigger role. Most technologies have their drawbacks – either absence of feedstock, temperature, or degradation of electrolyte.



Feedstock	Process	TRL	Explanation
Light Hydrocarbons	Steam Reforming (SMR) with CCUS	8-9	Steam reforming of natural gas – so called «blue hydrogen»
	Methane Pyrolysis	5	Methane is decomposed at high temperatures = hydrogen + solid carbon
Biomass	Biochemical Conversion	8-9	Extract the methane which then yields hydrogen
	Gasification	8	Partially combustion to create syngas – then extract the hydrogen
	Pyrolysis	6	Reacting biomass at high temperatures results in hydrocarbon liquid and syngas
Water Electrolysis	Alkaline	9	Low temp electrolysis (70.C – 90.C) using a liquid alkaline electrolyte
	Proton Membrane	8	Low temp electrolysis (50.C – 80.C) using a solid acidic membrane electrolyte
	Solid Oxide	5-7	High temp. Electrolysis (600.C – 900.C) using a solid oxide electrolyte
	Anion Exchange	3-5	Low temp electrolysis (40.C – 60.C) using an anion exchange membrane and alkaline electrolyte
Water & Solar	Solar Thermochemical	5	Conversion of solar thermal energy into chemical energy

Source: Frost & Sullivan

HYDROGEN PRODUCTION: WATER ELECTROLYSIS

Low temperature electrolysis currently dominates total hydrogen production

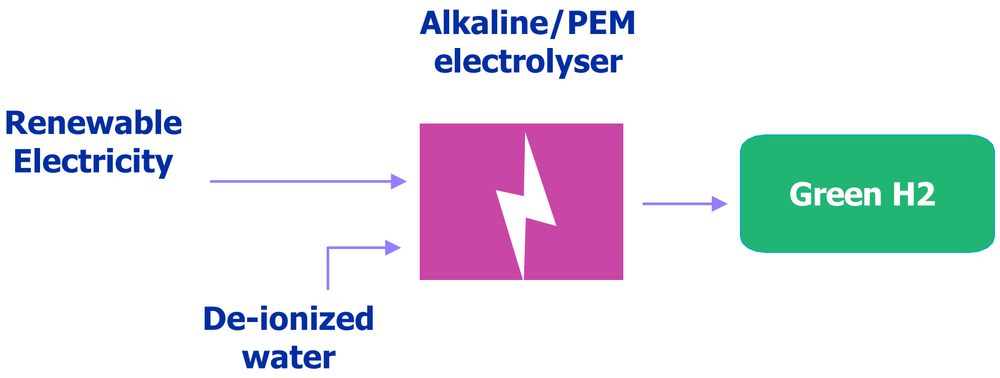
Water electrolysis is considered as a core clean energy storage and conversion technology realizing the hydrogen economy, and includes two routes:

1. Low-temperature water electrolysis
2. High-temperature water electrolysis

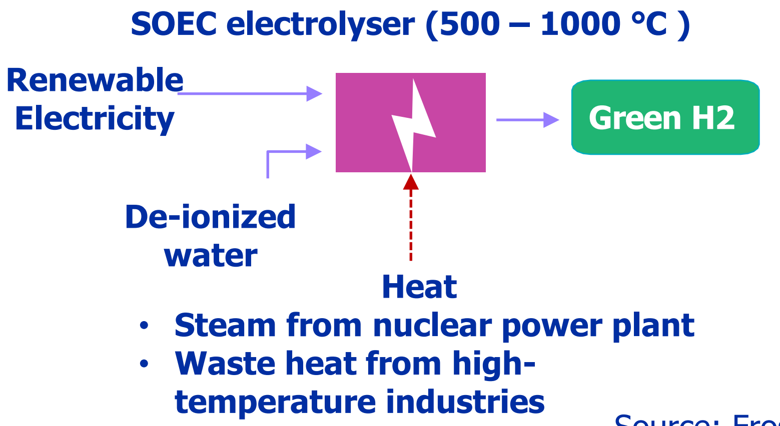
The current low-temperature electrochemical water splitting technologies include alkaline (AWE), proton exchange membrane (PEMWE), and anion exchange membrane (AEMWE) water electrolyses.

The present high-temperature water electrolysis technologies include the solid-oxide electrolysis cells (SOEC). Both routes demonstrate great potential to promote the hydrogen economy

Low Temperature Electrolysis



High Temperature Electrolysis



Source: Frost & Sullivan

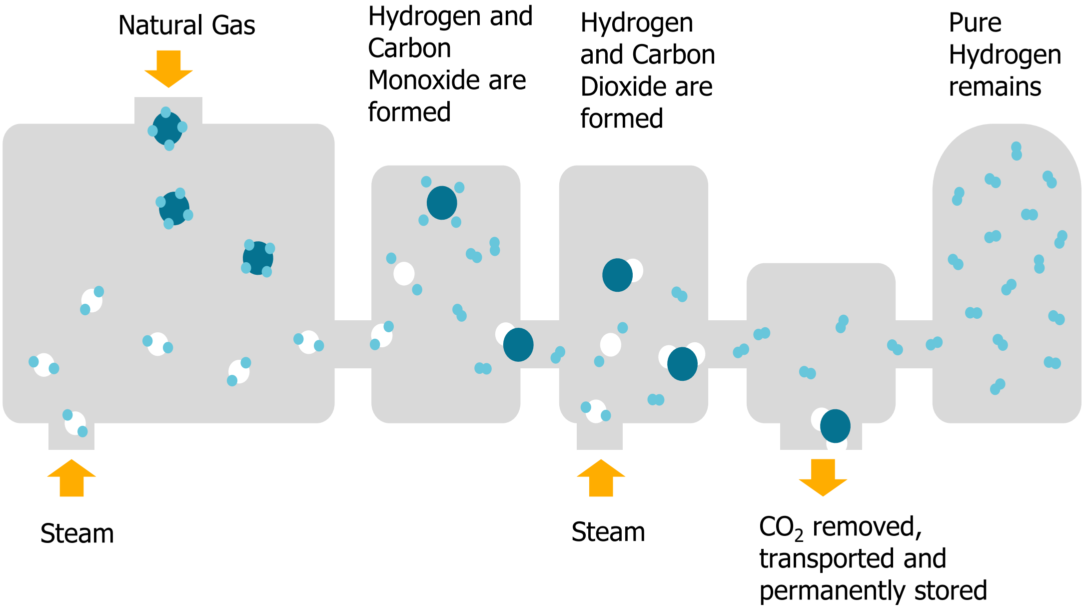
HYDROGEN PRODUCTION: BLUE HYDROGEN

With low production costs, blue hydrogen could meet the demand for hydrogen across growing applications in the short to medium term and reduce the costs associated with production from RES

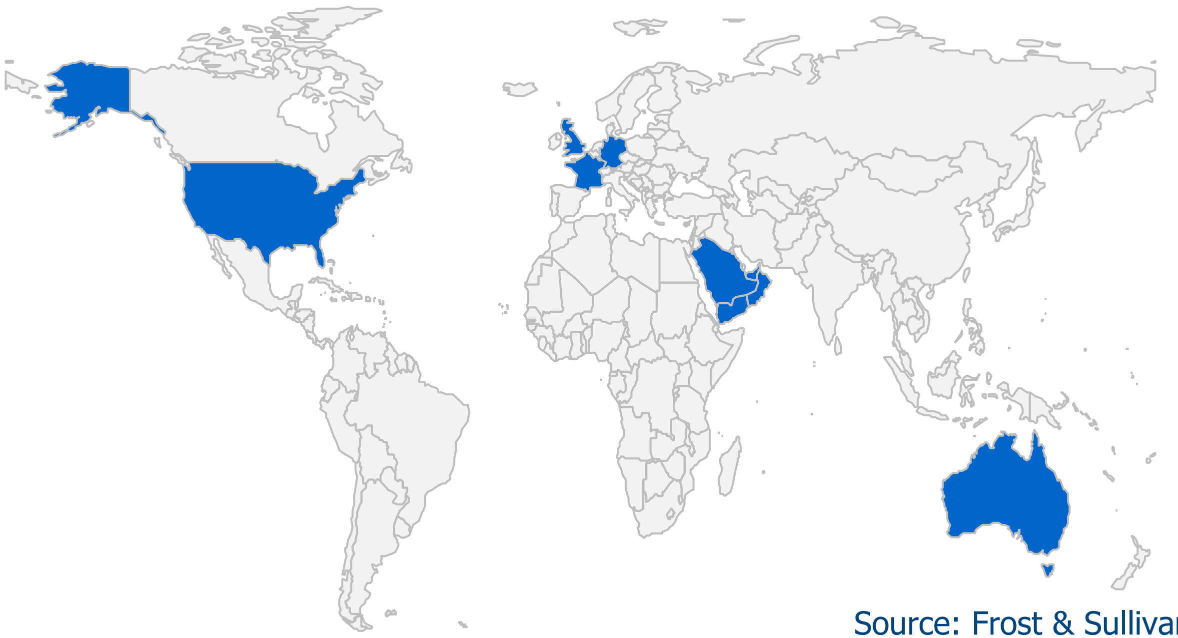
Blue hydrogen is derived from natural gas through steam methane reforming (SMR). The carbon dioxide emissions are then captured and stored underground using Carbon Capture, Utilization, and Storage (CCUS) technology leaving nearly pure hydrogen.

The US, Europe, the Middle East and Australia are the key markets for blue hydrogen – these areas already have significant amounts of grey hydrogen that can be retrofitted.

Blue Hydrogen Production Process



Key Geographic Hotspots



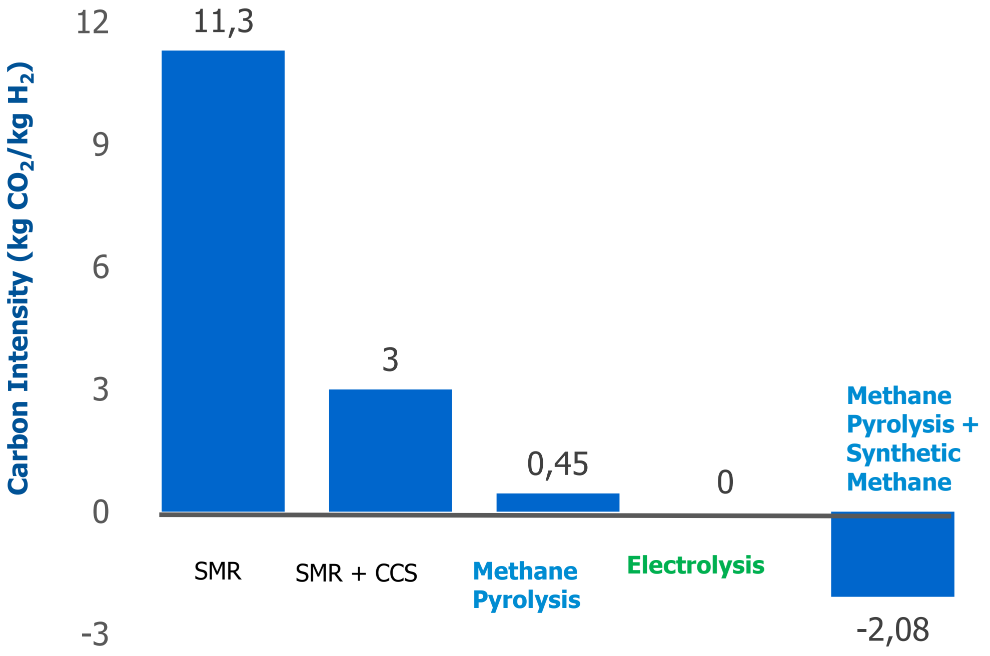
Source: Frost & Sullivan

HYDROGEN PRODUCTION: METHANE PYROLYSIS

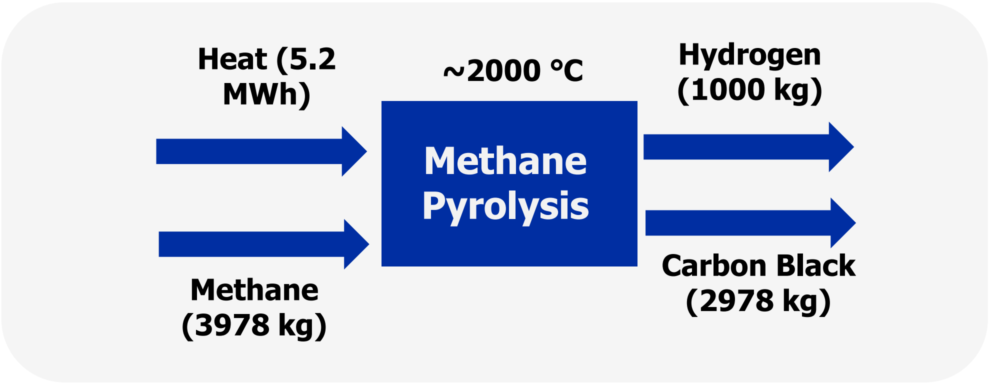
Decomposition of natural gas into hydrogen and carbon black with negative carbon emissions

Methane pyrolysis involves the decomposition of methane (CH_4) or natural gas into hydrogen and carbon black with zero CO2 emissions or negative emissions (if the methane is produced through CO2 from CCS Technology). Both hydrogen and carbon black have a variety of industrial applications and could play a crucial role in the decarbonization of industries. Active developments are taking place in the USA, Canada, and Europe.

Potential Reduction in Carbon Emissions



Methane Pyrolysis – Hydrogen Production Pathways



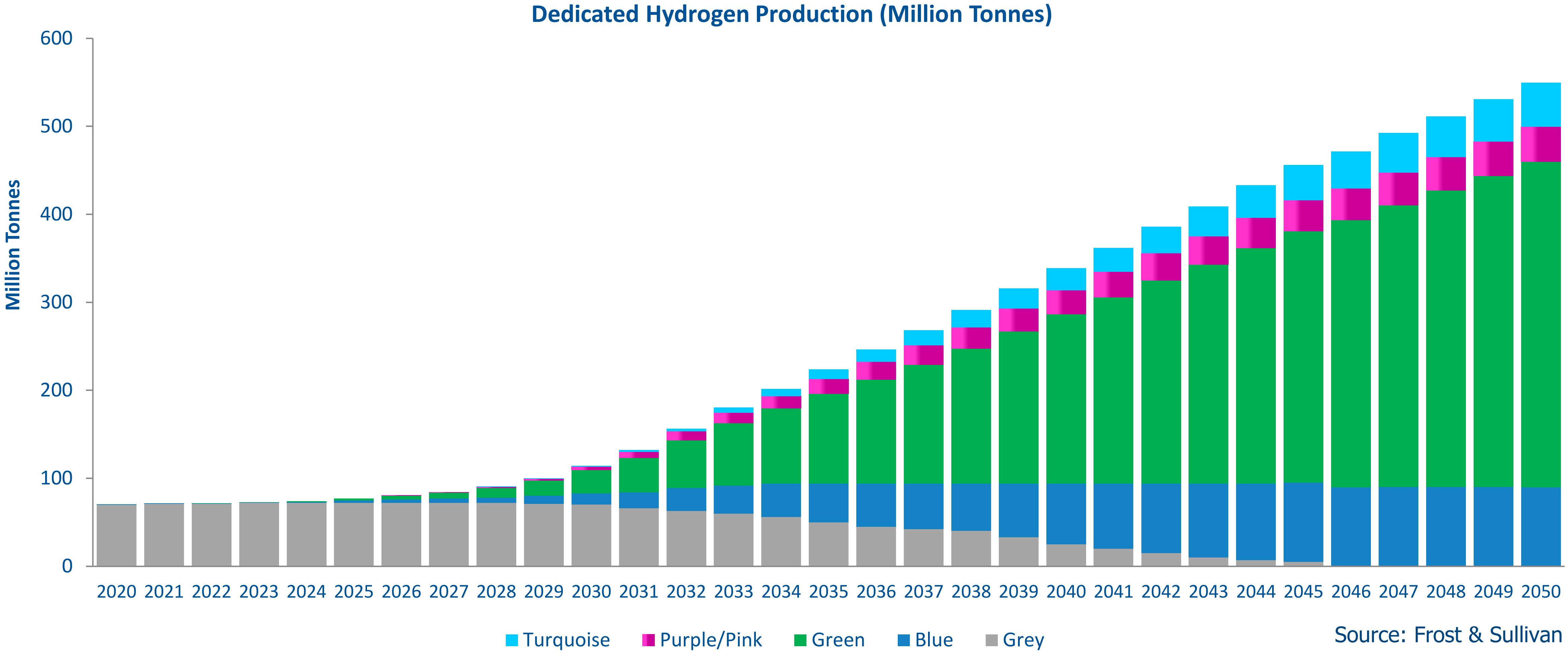
Key Companies

C-ZERO, hycamite, monolith, AkerSolutions, HiiROC, GAZPROM, BASF, EKONA, HazerGroup

Source: C-Zero, Monolith, Frost & Sullivan

GLOBAL HYDROGEN PRODUCTION FORECASTS

A significant percentage of blue hydrogen will be grey hydrogen retrofitted, but there will be some new dedicated projects. Unabated grey hydrogen will go from being the most important source of production in 2030 to zero by 2045. Green dominates from 2033 onwards. Purple/pink depends on nuclear policies and costs, turquoise dependent on technology innovation over the remainder of the 2020s



Source: Frost & Sullivan

HYDROGEN PRODUCTION: COUNTRY TECHNOLOGY FOCUS

Most major global economies have developed hydrogen strategies

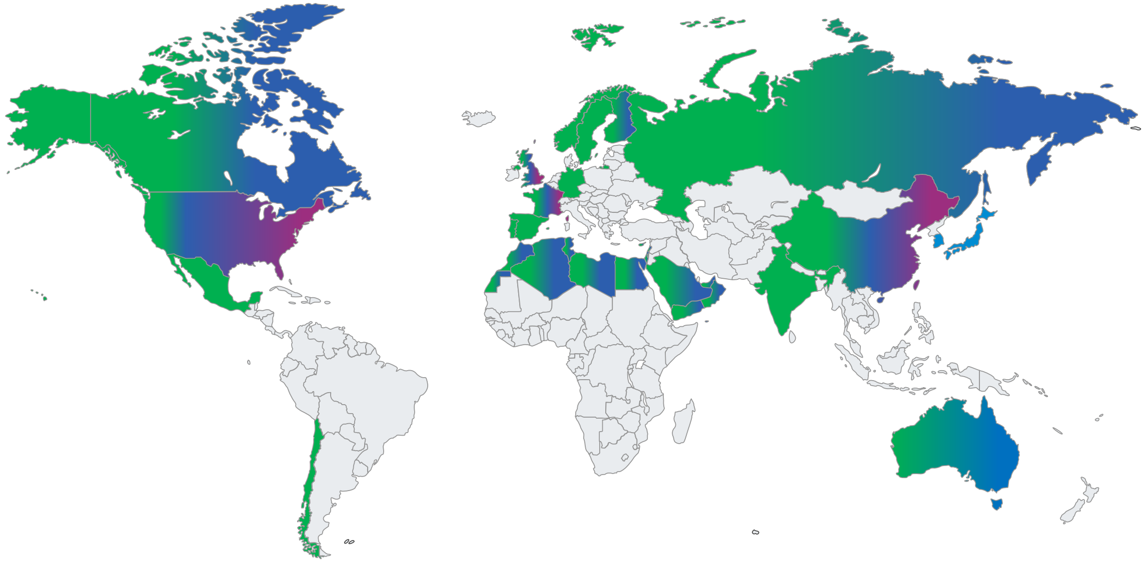
USA: Infrastructure Investment & Jobs Act to Drive Hydrogen Economy
- Support all forms of zero/low-carbon hydrogen production methods
- Incentives for H_2 based on carbon footprint

EU: Green H_2 Dominates
- Most European countries support Green H_2
- UK & France support all forms of zero/low-carbon hydrogen production methods
- Internal import & export through interconnections & Energy Hubs
- Incentives for H_2 based on carbon footprint

Norway: Green H_2 exporter
- Huge potential for Green H_2
- Production & utilization of low-carbon ammonia
- Transport within Europe by pipeline

Russia: Green & Blue H_2
- Has the potential to be a significant producer of green & blue hydrogen
- Current political situation limits export potential.

Chile: Major Green Hydrogen Market
- Potential to become a major producer of green hydrogen at lowest costs
- High potential to become leading exporter of Green H_2 via ships



China: Energy Plan to Support all H_2 Production Methods
- Support all forms of zero/low-carbon hydrogen production methods
- Development of "Hydrogen Hubs" focused on H_2 development

Japan & Korea: Partial support for Blue H_2
- Potential Leader in Fuel Cell Technologies
- Leading importer of H_2 & ammonia
- Utilization across industries

Northern Africa: Support for Blue & Green Hydrogen
- Tremendous potential for Green & Blue H_2
- Potential export of H_2 to European Countries via ships & pipelines

Australia: Green & Blue H_2 to dominate
- Potential to become leading exporter of Green & Blue H_2 & ammonia
- Utilization across industries
- Transport by ship

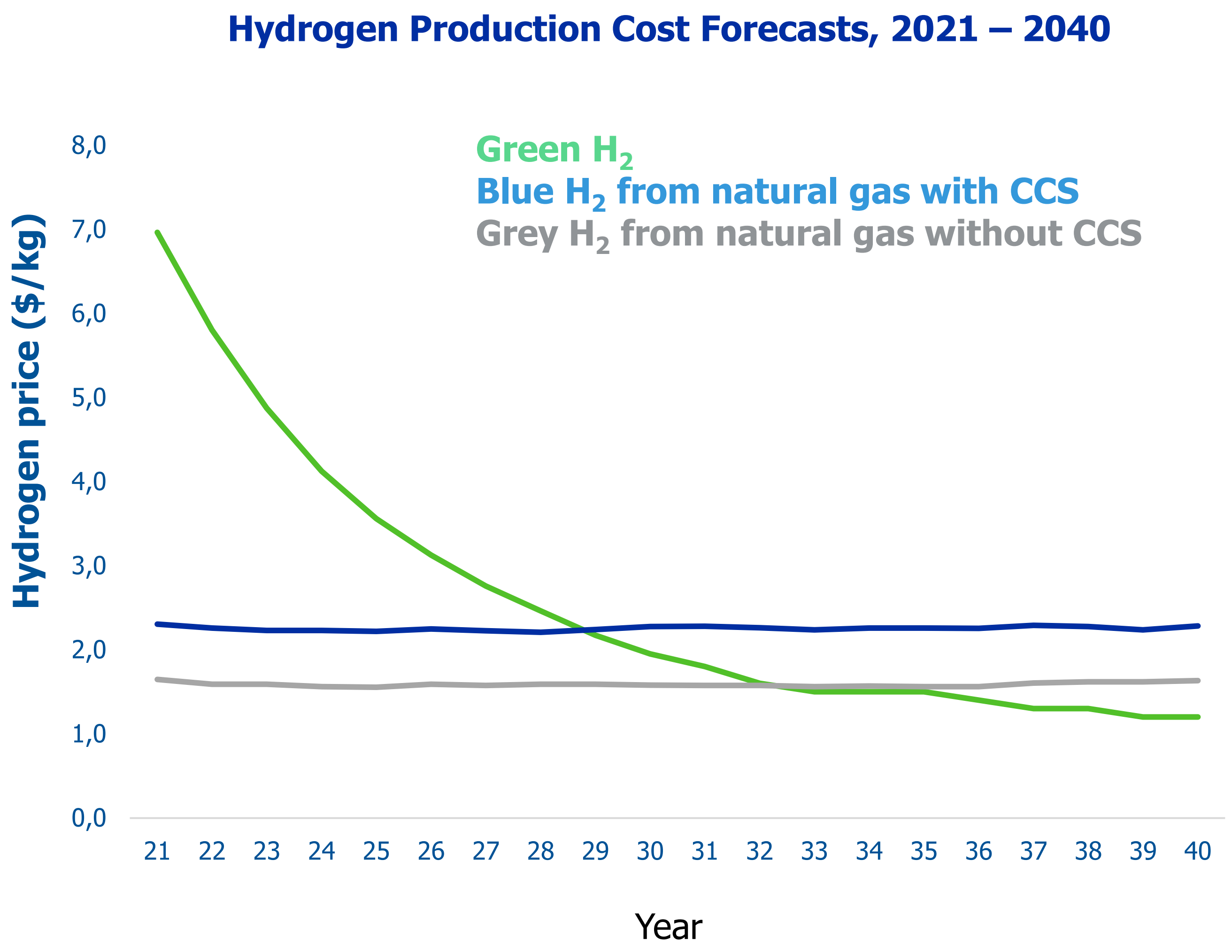
Gulf region: Green & Blue H_2 to dominate
- Potential to become leading market for Green & Blue H_2
- Production & utilization of low-carbon ammonia
- Exporter of Green H_2 & low-carbon ammonia via ships

Hydrogen Color Preference — **Green** — **Blue** — **Green + Blue** — **All Low-Carbon H_2 Production methods**

Source: Frost & Sullivan

HYDROGEN PRODUCTION COST PROJECTIONS

Green hydrogen could be cheaper than blue hydrogen by 2030 and close to the price for grey hydrogen. This will likely accelerate global investment further.



Grey hydrogen to dominate until 2035

The most significant amount of hydrogen is grey hydrogen accounting for almost 97% of global production. Most green hydrogen projects are currently based on electrolysis and are in the pilot & construction phases, with the first projects expected to come online by 2024. Other forms of hydrogen production such as pyrolysis are still under development. The viability of CCUS is still being debated, but a significant percentage of grey hydrogen projects are expected to become blue hydrogen in the future.

Green hydrogen cheaper than grey (for now)

The recent surge in the price of natural gas in Europe has led to green hydrogen becoming cheaper to produce than grey and blue hydrogen across North America & Europe in 2022.

Hydrogen production costs from other sources to decline

Continued support from the US and some European governments towards other forms of hydrogen production (nuclear power, methane pyrolysis, from waste, biogas) will bring down the costs associated with production. Scaling up the technology on a gigawatt scale will also bring down the CAPEX costs for the developer.

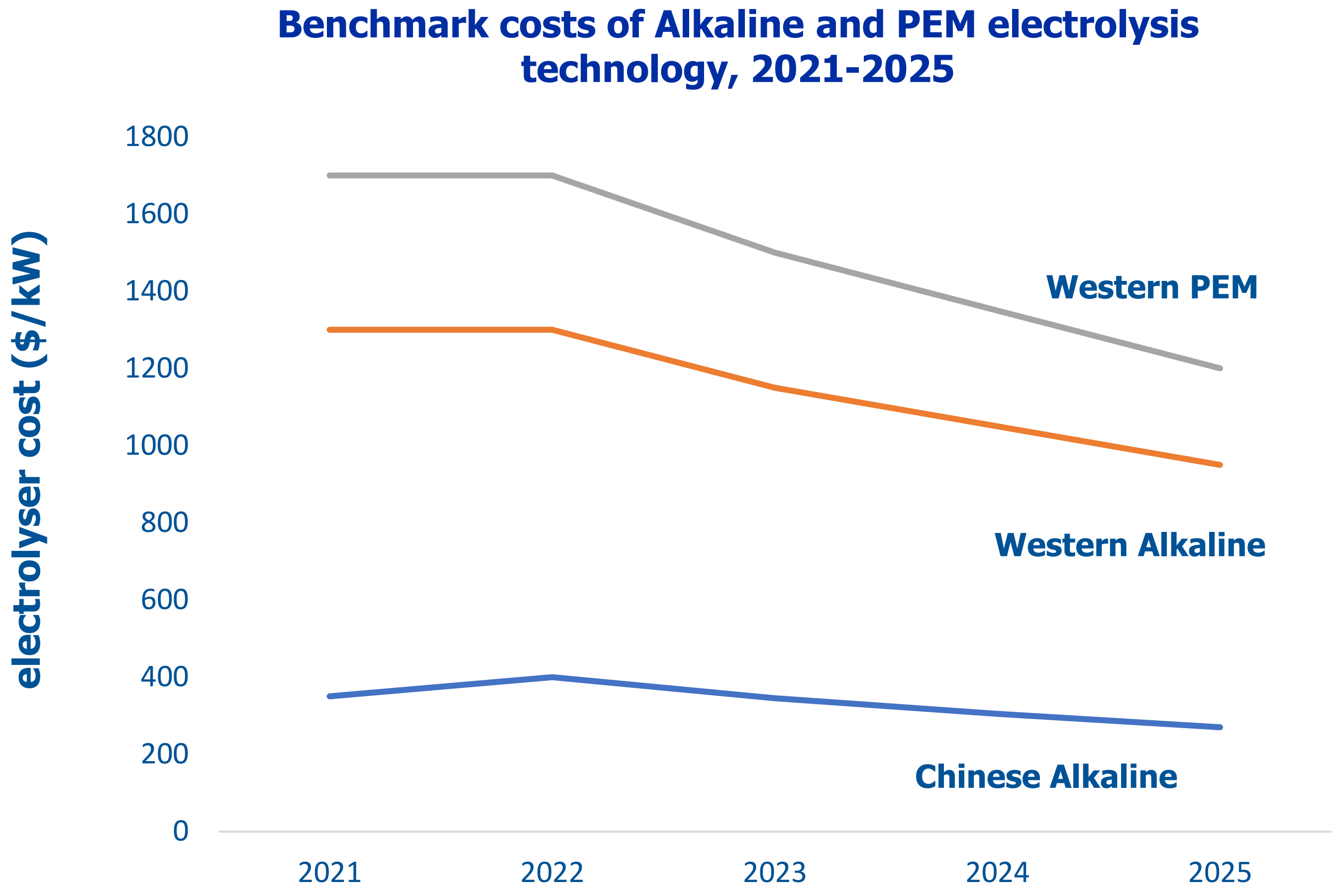
Green hydrogen to become cheaper than blue

With high-scale LTE projects planned and a reduction in the cost of hydrogen electrolysers, coupled with ever-cheaper renewable energy, green hydrogen will be cheaper to produce than blue hydrogen by around 2030.

Source: Frost & Sullivan

HYDROGEN PRODUCTION: WATER ELECTROLYSIS COSTS

electrolyser costs are also set to fall, driving hydrogen production costs further down



High capital costs are a significant barrier

The electrolyser stack accounts for almost 50% of the CAPEX of the electrolysis plant. The high capital and operating costs of electrolysis technology are the most significant obstacle to the widespread commercialization of the technology, and electrolysis must become more competitive in both capital and installed costs.

Technology innovations, scaling up & supportive government policies to reduce costs

The cost of electrolyser systems should come down to address the growing need for green hydrogen. Cost reductions can be achieved through crucial strategies such as improved electrolyser design and construction, scaling up of the technology, innovations in electrolyser materials, increasing efficiency and flexibility of operations, and support mechanisms and incentives from the government.

China's electrolyser technology advantage

Due to cheaper labor, a robust supply chain network for electrolyser raw materials, and government support, Chinese factories can produce electrolysers at a lower cost compared to US and European competitors, giving them an edge. electrolyser products made in China will become more prominent in 2025-30, bringing down the cost further.

Source: Frost & Sullivan

HYDROGEN STORAGE: GASEOUS, LIQUID, GEOLOGICAL

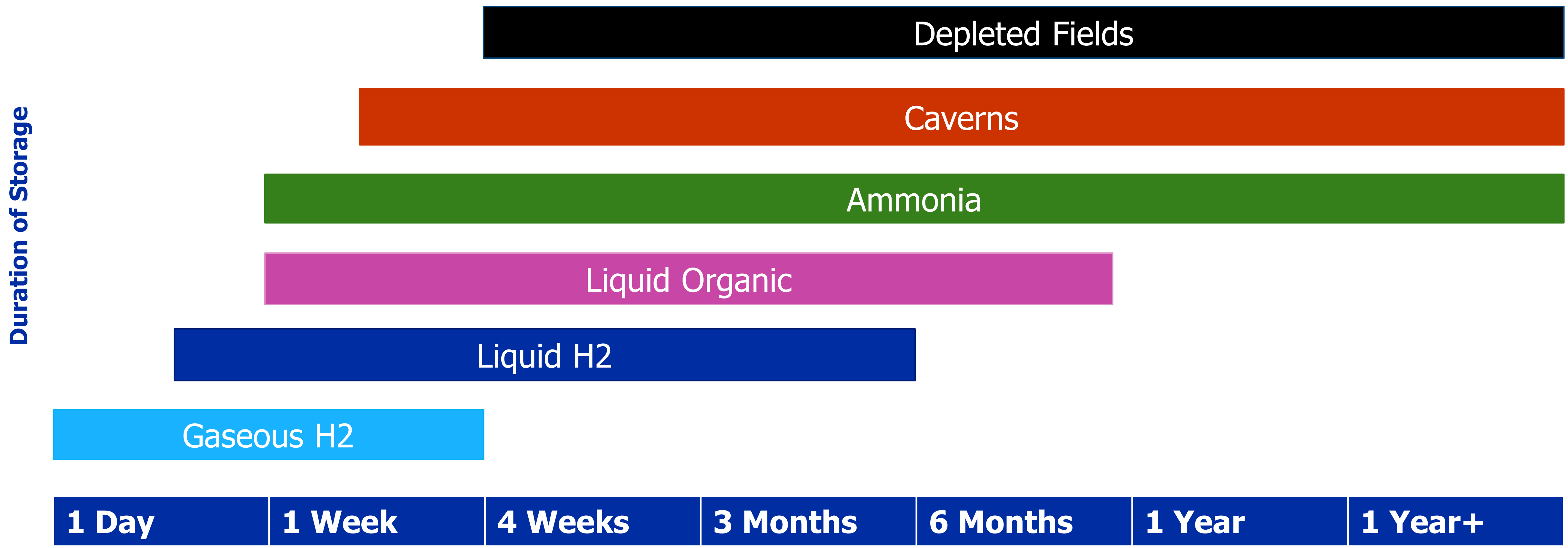
Reducing costs will be key, but large volumes of storage are vital for the hydrogen economy and with long construction lead times, significant process needs to be made in identifying sites, conducting feasibility assessments and boosting technological innovation.

Storage Medium	Current Cost Range (Euro/kg)	Key Comments
Salt Caverns	0.3 – 0.9	Currently used for storing natural gas, can be repurposed for hydrogen and there are more sites available across Europe.
Gaseous	0.3 – 1.1	Standard storage option currently used, whereby the hydrogen is usually stored in metal containers. Hard to scale up to the future needs of the industry.
Rock Caverns	0.9 – 3.5	Similar geological conditions to salt caverns, but far less knowledge.
Depleted Fields	1.6 – 2.6	More expensive alternative to salt caverns but would provide a significant volume of much needed storage and would be a way of re-using an oil & gas asset.
Ammonia	2.6 – 3.5	Green ammonia as an energy carrier is a very exciting prospect for global transportation and storage of hydrogen if cost reductions can be achieved.
Liquid H2	4.0 – 5.9	In the liquefaction process, hydrogen is precooled by the evaporation of liquid nitrogen. This can then be transported and stored. However it is an energy intensive process, so the costs are relatively high.
Liquid Organic (LOHC)	4.0 – 6.8	LOHC is an organic oil-like substance that binds hydrogen chemically. In its liquid state the hydrogen is not volatile. It can be transported over long distances and required high temperature heat to be regasified. Established in the petrochemical industry, but more research work needed to commercial it for hydrogen.

Source: Agora Energiewende (data), Frost & Sullivan

HYDROGEN STORAGE: DURATION

Storage duration times depend largely on the state the hydrogen is kept in and the time it would take to move the hydrogen to the relevant storage point. Technically hydrogen could be stored in a depleted field for a very short time, but the transportation time would make it unviable. The future is likely to see multiple sources of hydrogen storage required to suit different use cases.



Source: Frost & Sullivan

HYDROGEN TRANSPORTATION: MULTIPLE OPTIONS

Dedicated hydrogen transportation infrastructure will be required as the current gas grid will need to be operational for some time. Some local parts of the grid could potentially be converted. Transportation costs significantly add to the cost of hydrogen, so the best option till 2030 at least will be to use the hydrogen as close as possible to source.

Transport Method	Distance (km)	Cost ($ per KgH_2) – increases with distance	Key Comments
Trucks	<1,000	$0.5 - $2	The hydrogen is compressed and transported in the same way as industrial gases. However to transport substantial amounts would require changes to transport safety regulations. Viable solution for short distances – 1,000 km is technically possible but unlikely.
Rail	800 – 1,100	$0.5 - $2	Similar transportation method as for trucks. Not a viable solution for high volumes unless it is stored as ammonia.
Pipeline	1,000 – 4,000	$3 - $7	High upfront capex costs and securing the necessary planning approvals are the two main challenges. A number of European countries have struggled with major infrastructure project approvals due to legal challenges.
Shipping	>4,000	$6	Kawasaki has constructed a ship to transport liquified hydrogen – the initial plan was to create a route between Australia and Japan. Majority view is that ammonia will be utilized a carrier. The ships themselves could also be powered by ammonia. But this will remain an expensive option for some time.

Source: IEA, Frost & Sullivan

HYDROGEN VALUE CHAIN – KEY PLAYERS

Hydrogen economy requires huge infrastructure investment, providing opportunities for a diverse range of companies

Electrolysers	Storage	Transportation	Fuel Cells	End Users

Electrolysers	Storage	Transportation	Fuel Cells	End Users
LONGi	H2GO Power	RYZE Hydrogen	Bloomenergy	ArcelorMittal
John Cockerill	INOXCVA	DEKRA	fuelcellenergy	British Steel
ohmium	vallourec	bp	ceres	Dow
Plug Power	Air Liquide	Shell	cellcentric	Koch
Siemens	Linde	snam	Cummins	Rio Tinto Alcan
ITM Power	Praxair	NanoSUN	sunfire	BASF We create chemistry
nel	McPhy energy	fluxys	Plug Power	

Source: Frost & Sullivan

HYDROGEN VALUE CHAIN – LEADING FINNISH COMPANIES

Finland has extensive industrial experience across the hydrogen value chain, and conditions for producing and using clean hydrogen are ideal. Many Finnish technological companies are developing and supplying equipment and services for hydrogen production, distribution, storage, and use.

Energy Companies

- Fortum
- EPV
- Pori Energia
- Flexens
- Energiequelle

Hydrogen Storage/Transport/Distribution

- Gasgrid
- Atlas Copco
- Air Liquide
- WEGA
- Gasum
- Rejlers

Hydrogen Infrastructure/Components/Service Providers

- ABB
- Air Liquide
- Wärtsilä
- AGCO Power
- AFRY
- Convion
- Enersense
- Elomatic
- Viafin Gas
- Woikoski
- YTM-Industrial
- Valmet

Hydrogen Production

- Air Liquide
- Hycamite
- Linde
- Woikoski
- Hankotec
- Neste
- P2X Solutions
- Q Power

Hydrogen Utilization

- Boliden
- Neste
- Stora Enso
- Metsä
- Danfoss
- SSAB
- Terrafame
- Borealis
- Fazer
- Kemira
- Ovako

Key Organizations

- Business Finland
- VTT

Source: H2Cluster Finland, Frost & Sullivan

Global & Regional Outlook

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FUTURE WATCH

MARKET DRIVERS

The need to decarbonise the global economy, backed up by regulatory support, incentives and economies of scale, will be key to the development of the global economy.

Drivers	1–2 Years	3–4 Years	5–9 Years
Most major industrialised nations now have a hydrogen economy strategy. This usually involves a mix of targets, regulatory support and incentives. The EU has set a target of 40GW of electrolyser capacity by 2030 and is proving funding to support this, with more likely to come. The Inflation Reduction Act in the US provides subsidies and tax credits for hydrogen production. These are just two examples of a raft of global measures that are driving investment.	**High**	**High**	**Medium**
In order to decarbonise the global economy, a significant portion of unabated fossil fuels must be replaced with either abated fossil fuels or fuels from renewable sources. A number of industrial applications, particularly those that require high temperature heat, are amongst the hardest to decarbonise and currently lack viable technology alternatives.	**Medium**	**High**	**High**
Electrolysers will be the key production technology for hydrogen. A market size of 500MW in 2022 is forecast to become a 75GW market by 2030, meaning it will be 150 times larger and bringing huge capital investment. The implications of this will be significant cost reductions as economies of scale are reached and this will in turn drive hydrogen investment.	**Medium**	**High**	**High**
Security of supply is increasingly becoming an important factor in hydrogen strategies. Many countries that have long been dependent on fossil fuels have been acutely reminded of the challenges this poses in 2021 and 2022 as the price of oil & gas has been high and volatile. As a result, countries are increasingly focused on increasing domestic production to reduce export dependency and signing long-term cooperation deals with suppliers.	**Medium**	**High**	**High**

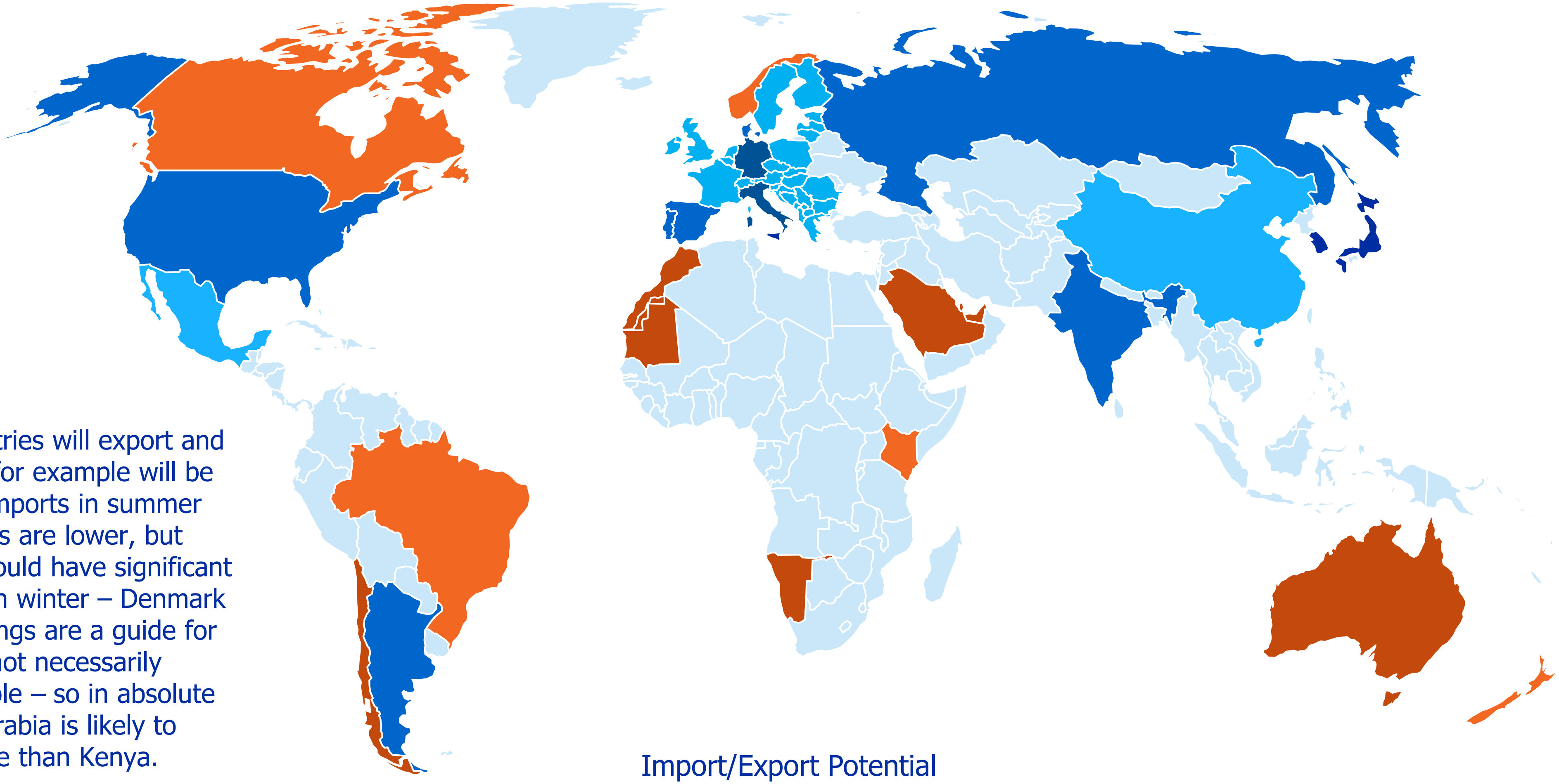
MARKET RESTRAINTS

Given the scale of the requirements, meeting these in terms of equipment and materials are the immediate challenges

Restraints	1–2 Years	3–4 Years	5–9 Years
Electrolysers are the key production technology for the hydrogen economy and the scale up that is going to happen is a key driver. However in the short-to-medium term, capacity is relatively constrained. Manufacturers are investing in new facilities and increasing the average sizes of their product range – but they cannot currently meet the requirements of the market. This will cause some project delays and remain an issue into the medium-term – 2025/26.	**Medium**	**Medium**	**Low**
Raw material and component supply has proved a significant challenge in 2022. PEM electrolysers, most of which require iridium, have seen prices of that material increase and supply tighten. Balance of plant components have been caught up in the supply chain disruption that has resulted from the covid-19 pandemic. Both of these factors will improve in the medium-to-longer-term as component supply chains rebalance and manufacturers work to build material supply chains and look for alternatives for those that are in short supply.	**Medium**	**Low**	**Low**
Hydrogen does have a complimentary solution that could also compete in some cases – electrification. For many applications, electrification is the more logical option. It avoids the need to convert electricity into hydrogen (which results in a significant loss of energy). Many electrification technologies currently have relatively low technology readiness levels, but the investment in these technologies is high as OEMs see a huge opportunity. If these technologies gain momentum, it could reduce overall hydrogen demand in the longer-term and the prospect of these technologies may prompt some companies to delay early investments	**Low**	**Low**	**Low**

GLOBAL OPPORTUNITY

A number of countries are keen to replicate successes with commodities and fossil fuels and become major exporters of hydrogen. Potential importers are looking to secure long-term supplies, but are also trying to minimise import dependency.



Note: Many countries will export and import – Europe for example will be more reliant on imports in summer when wind speeds are lower, but some countries could have significant export potential in winter – Denmark for example. Ratings are a guide for the country and not necessarily directly comparable – so in absolute tonnage, Saudi Arabia is likely to export much more than Kenya.

Import/Export Potential

Major Importer	Moderate Importer	Neutral	Moderate Exporter	Major Exporter

Source: Frost & Sullivan

GLOBAL KEY COUNTRIES/REGIONS HYDROGEN DEVELOPMENTS

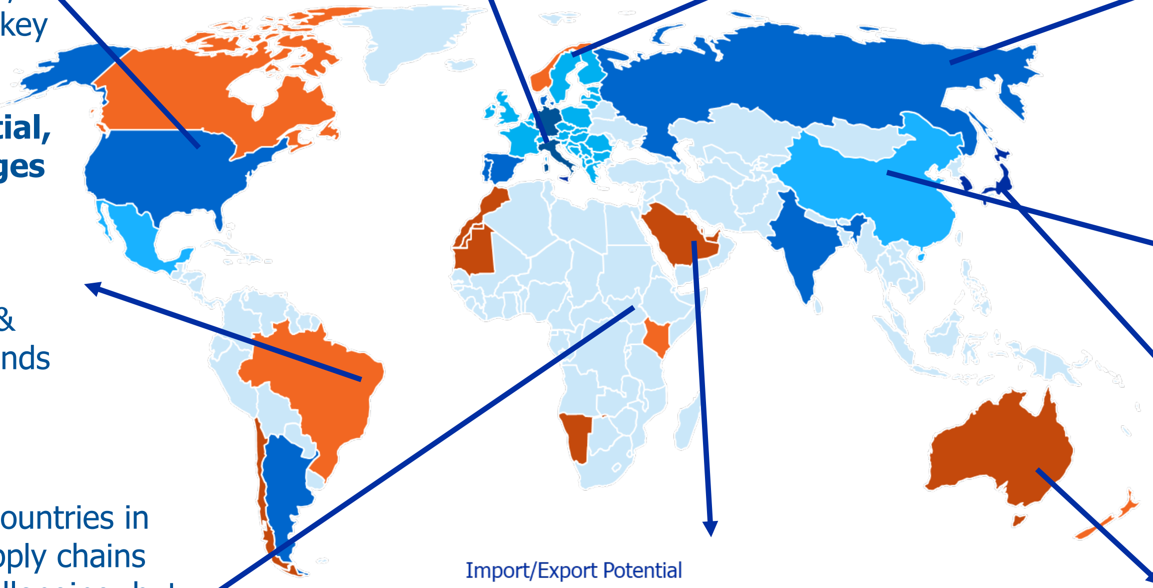
Most major global economies have developed hydrogen strategies

USA: Could the US be self sufficient?
- Inflation Reduction Act likely to boost domestic technology investment (electrolysis & CCUS). Strong support for blue hydrogen from the oil & gas industry.
- Potential to become an exporter, maritime developments will be key

Latin America: Export potential, but some regulatory challenges
- Significant RE potential
- High H_2 production, storage & distribution costs
- Chile leading country – Brazil & Argentina's development depends on politics

Africa: Exporter
- Strong interest from European countries in building dedicated hydrogen supply chains
- Political environment can be challenging, but focus is on more politically secure states
- Exporter of green H_2 & low-carbon ammonia via ships & pipelines
- Hub for transport of green H_2 to Europe

EU: Net importer – but how much will the EU need?
- Strong government support to boost production
- Strong domestic technology OEMs
- Will need imports – Africa key focus – but does not want to be too dependent on anyone



Gulf region: Exporter
- Wants to become a leading exporter of green, blue H_2
- Production & utilization of low-carbon ammonia
- Exporter of green H_2 & low-carbon ammonia via ships

Norway: Green H_2 exporter
- Huge potential for Green & Blue H_2
- Production & utilization of low-carbon ammonia
- Transport within Europe by pipeline

Russia: Self-Consumption
- Has the potential to be a significant producer of blue hydrogen.
- But current political situation limits export potential.

China: Will need imports, but strong domestic production
- Potential to become leader in electrolyser & storage technologies – strong domestic OEMs
- Development of "Hydrogen Hubs" focused on H_2 development

Japan & Korea: Importer
- Leading importer of H_2 & ammonia
- Utilization across industries

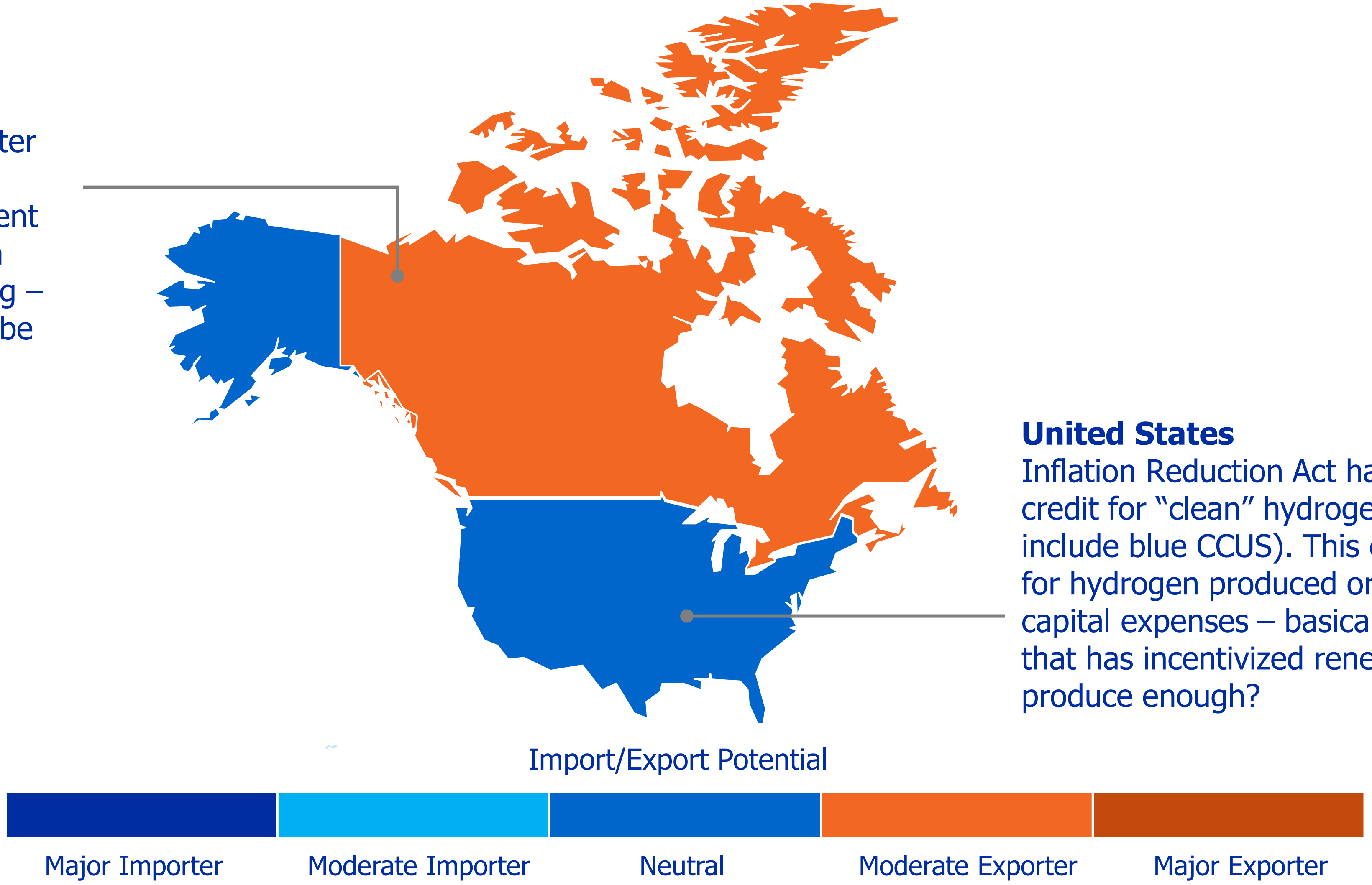
Australia: Accelerated growth in H_2 developments
- Potential to become leading exporter of green & blue H_2 & ammonia
- Utilization across industries
- Reducing shipping costs key

Source: Frost & Sullivan

NORTH AMERICA OPPORTUNITY

Can the US really be self-sustaining in hydrogen? Huge investment in renewables, strong nuclear potential from existing plants, potential for dedicated next generation nuclear plants for hydrogen production.

Canada
Keen to be an exporter and has signed a cooperation agreement with Germany with a view to future trading – cost of shipping will be key for the future.



United States
Inflation Reduction Act has created a tax credit for "clean" hydrogen (which will include blue CCUS). This can either be credit for hydrogen produced or a tax credit to capital expenses – basically the credit system that has incentivized renewables. Can the US produce enough?

Source: Frost & Sullivan

EUROPE OPPORTUNITY

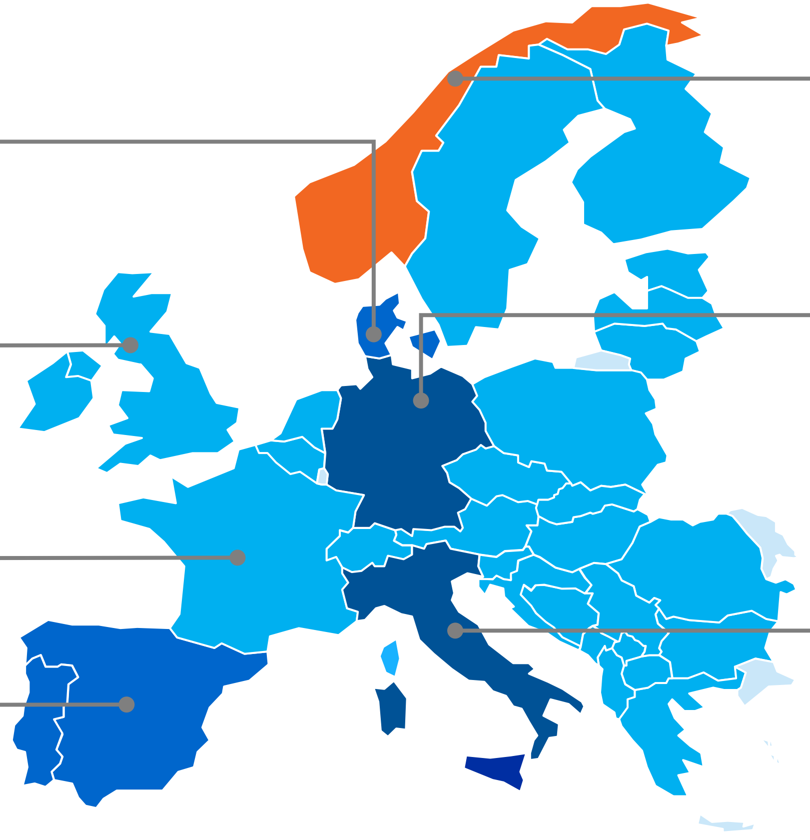
Despite substantial incentives, most of Europe is likely to require at least some hydrogen imports in order to meet demand.

Denmark
Denmark's wind power capacity could mean it is net-neutral, with dedicated hydrogen production from offshore wind and the utilization of excess wind power in winter offset by modest exports.

UK & Ireland
Significant imports will be needed, although dedicated offshore wind in the longer-term will help reduce total import levels.

France
Utilisation of nuclear plants for hydrogen production will boost domestic production in the longer-term, but imports will be needed.

Spain & Portugal
With the potential for excess renewable energy, there is the potential for both countries to be net-neutral.



Norway
Hydropower should enable Norway to export to neighbours.

Germany
Germany's huge industrial sector will need to rely on a significant volume of imported hydrogen.

Italy
Significant imports will be needed to meet Italy's demand.

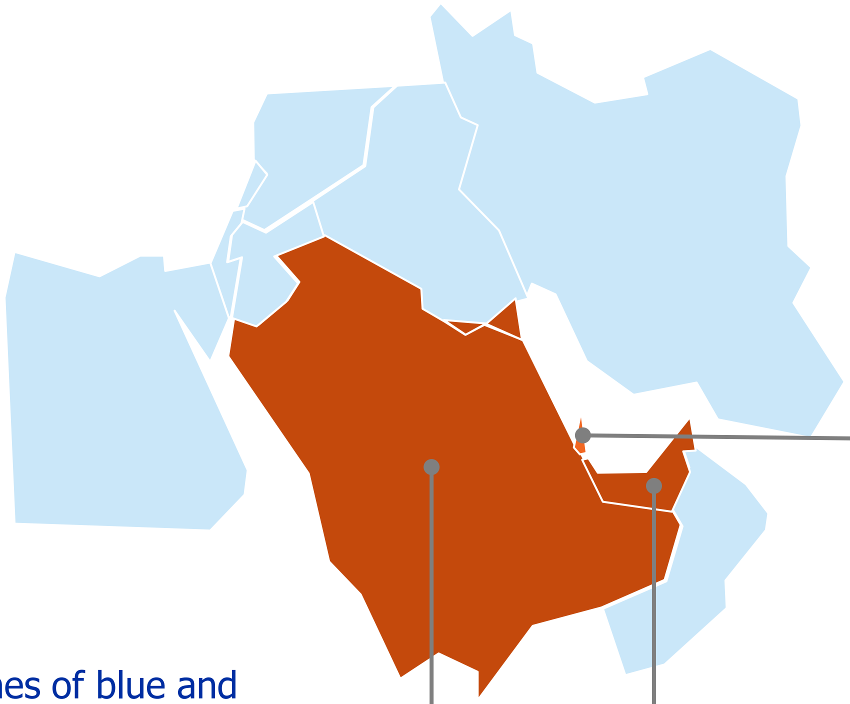
Import/Export Potential

Major Importer | Moderate Importer | Neutral | Moderate Exporter | Major Exporter

Source: Frost & Sullivan

MIDDLE EAST OPPORTUNITY

The gulf will be looking to cement its position in the future as a major energy provider.



Qatar
Investing $1 billion into the production of blue ammonia.

Saudi Arabia
Current target is 3 million tonnes of blue and green hydrogen by 2030, but this is likely to be revised upward as Saudi Arabia wants to retain its position in the global market.

UAE
200,000 tonnes of green hydrogen by 2030, but this will increase, and the UAE is also focused on blue hydrogen.

Import/Export Potential

Major Importer | Moderate Importer | Neutral | Moderate Exporter | Major Exporter

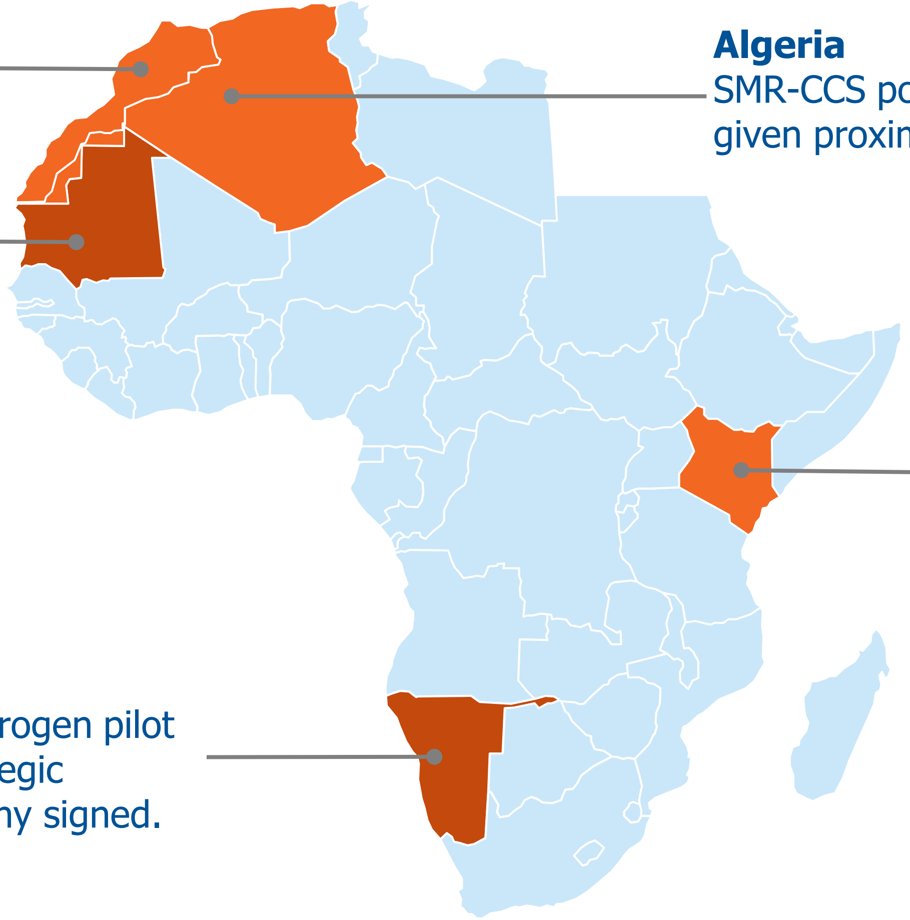
Source: Frost & Sullivan

AFRICA OPPORTUNITY

Significant business opportunity for African to provide green hydrogen to Europe

Morocco
Increasing seen as stable energy partner, located close to Europe

Mauritania
Total is evaluating locating a 10GW electrolyser powered by onshore solar and wind. Aman project proposed by CWP Global would involve 30GW of electrolysers.



Algeria
SMR-CCS potential for Europe given proximity

Kenya
President Ruto announced at COP27 that the country would target 30GW of hydrogen from solar, wind and geothermal.

Namibia
4 Power-to-X green hydrogen pilot projects launched. Strategic partnership with Germany signed.

Import/Export Potential

Major Importer | Moderate Importer | Neutral | Moderate Exporter | Major Exporter

Source: Frost & Sullivan

APAC OPPORTUNITY

Australia will be aiming to be a significant player on the global stage once the maritime transport of hydrogen starts.

Japan & South Korea
Both countries are investing significantly in hydrogen production, but will be reliant on imports to meet demand

Australia
Targeting 10 million tonnes of blue and green hydrogen by 2030. Self consumption the immediate priority, but Australia will be looking to ship into the global market, particularly to Japan and South Korea.

Import/Export Potential

Major Importer | Moderate Importer | Neutral | Moderate Exporter | Major Exporter

Source: Frost & Sullivan

LATIN AMERICA OPPORTUNITY

Chile the standout country – many countries likely to be hampered by domestic political and regulatory challenges.

Mexico
Likely to be an importer. Investment climate very uncertain due to the political situation within the country.

Brazil
Significant renewable energy capacity should give it the potential to be a net-exporter, but policies and regulations unclear.

Chile
In the short-to-medium term, decarbonising its own industries will be the priority, but Chile is positioning itself to be a significant exporter when global trading increases.

Argentina
Potential for blue-hydrogen exports, but investment climate in the country is very uncertain.

Import/Export Potential

Major Importer | Moderate Importer | Neutral | Moderate Exporter | Major Exporter

Source: Frost & Sullivan

CHINA OPPORTUNITY

China will have huge levels of hydrogen demand as it looks to decarbonise its industrial sector. Blue, green and pink/purple will all play a significant role in production volumes and are likely to limit China's imports from the global market.

China

China is investing massive amounts into hydrogen production and has a significant number of domestic electrolyser companies that produce at cost levels much lower than the global average. However the huge level of China's future demand means some level of imports will be required. How much could significantly impact the dynamics of the global market.

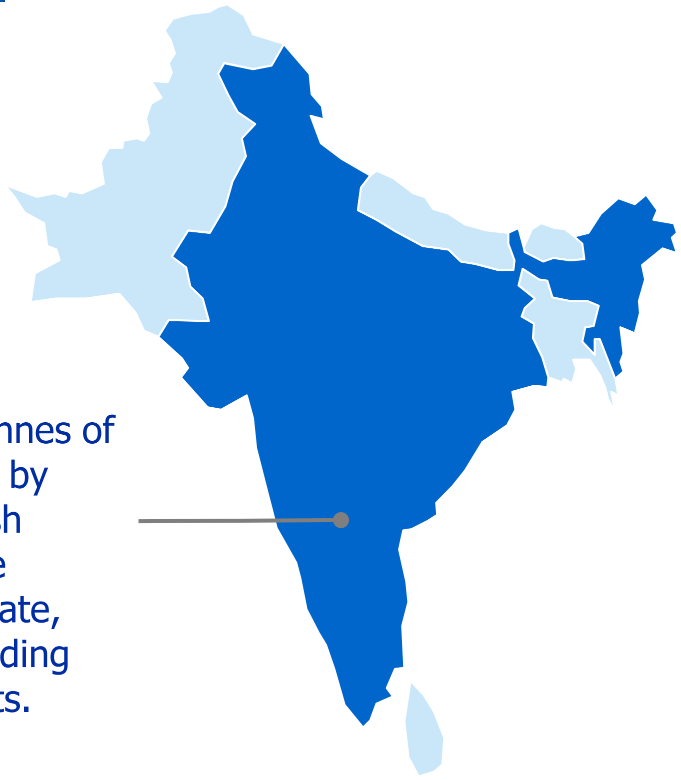
Import/Export Potential

Major Importer | Moderate Importer | Neutral | Moderate Exporter | Major Exporter

Source: Frost & Sullivan

SOUTH ASIA OPPORTUNITY

India's big industrial tycoons have embraced the energy transition, creating the possibility that India could be a significant producer of hydrogen via low-cost renewables.



India
India has a target of 15 million of tonnes of blue and green hydrogen production by 2030 and India's richest man, Mukesh Ambani has announced that Reliance Industries, India's largest conglomerate, will begin its transition in 2025, including sizable production facility investments.

Import/Export Potential

Major Importer | Moderate Importer | Neutral | Moderate Exporter | Major Exporter

Source: Frost & Sullivan

EUROPEAN DEEP DIVE

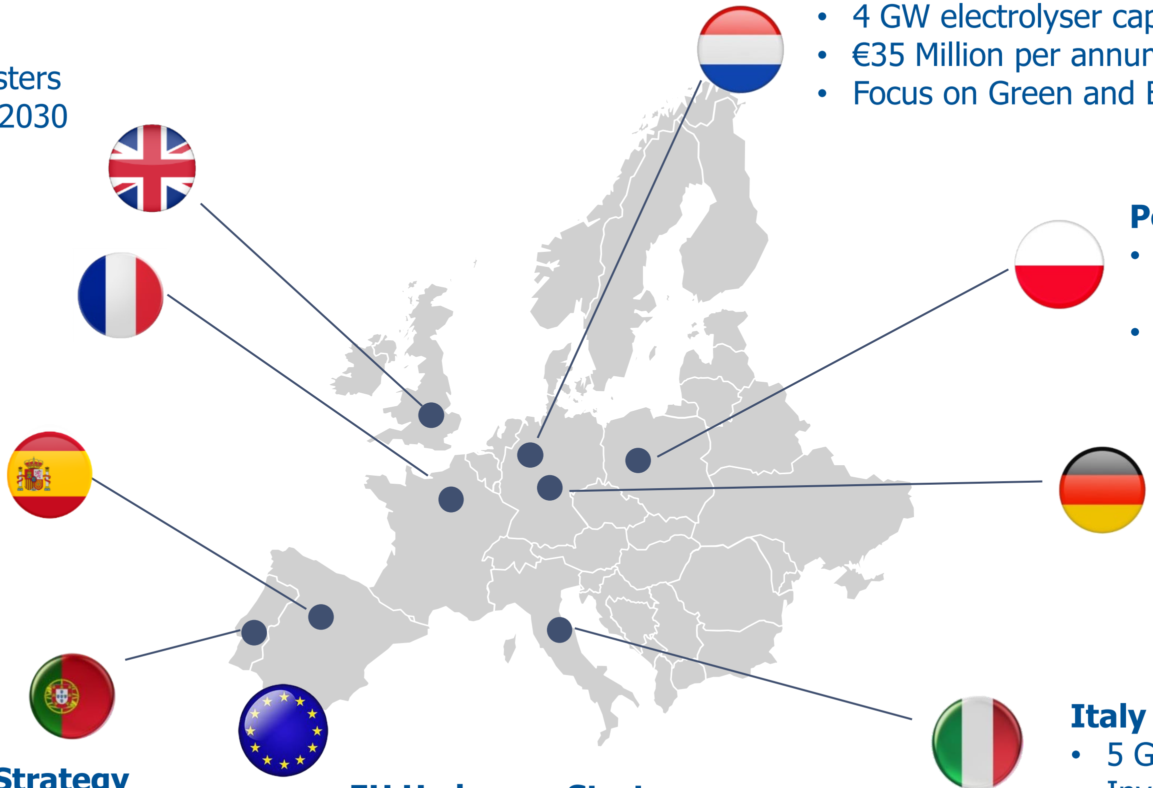
European governments have setup their H2 strategies and have announced budgets for funding

UK 10 point plan
- £4 Billion investment required
- CCS supported with £1 Billion in 4 clusters
- Electrolyser capacity target: 5 GW by 2030

France Hydrogen Strategy
- Transport and industry are key sectors
- Investments > €7 Billion to 2030
- Electrolyser capacity target : between 6.5 & 10 GW by 2030

Spain Hydrogen Strategy
- Electrolyser capacity target : 4 GW by 2030
- Investment of €8.9 Billion in funding
- 2030 target for 25% share of industry demand

Portugal Hydrogen Strategy
- 2 GW electrolyser capacity by 2030
- €7Bn in funding
- Sines 1GW H2 project



Netherlands Klimaatakkoord
- 4 GW electrolyser capacity by 2030
- €35 Million per annum
- Focus on Green and Blue H_2

Poland Hydrogen Strategy
- 2 GW electrolyser capacity by 2030
- Investment of 1 Billion PLN

Germany Hydrogen Strategy
- 10 GW electrolyser capacity by 2030 (Push for 30 GW by 2030)
- Investment > €9 Billion to 2026

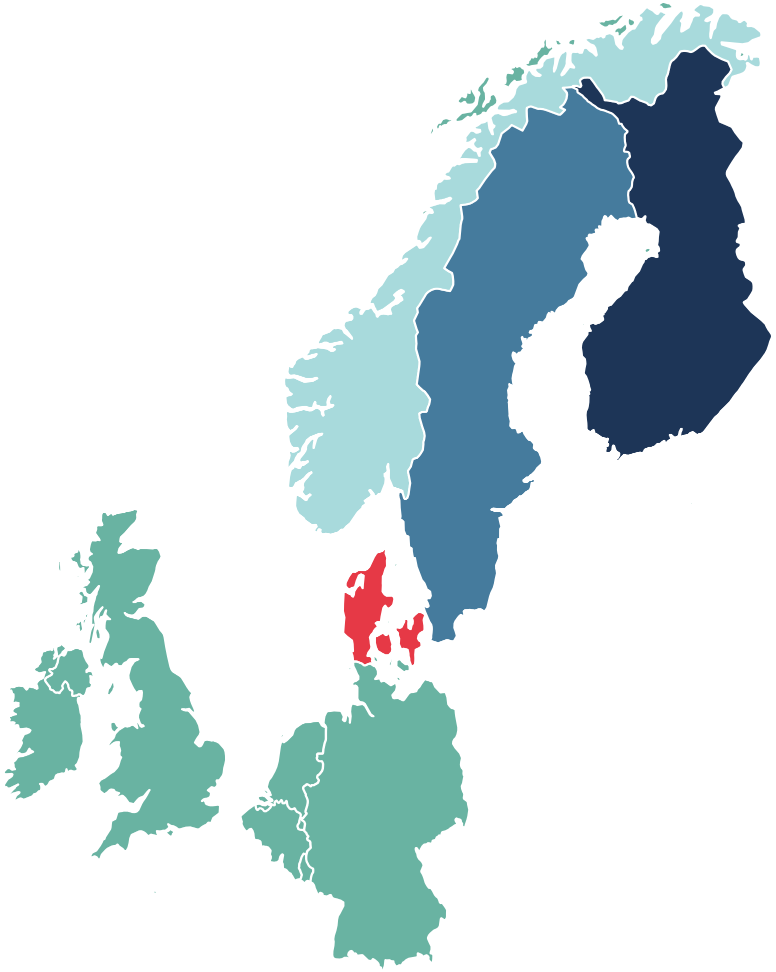
Italy Hydrogen Strategy (Draft)
- 5 GW electrolyser capacity by 2030
- Investment of €5 Billion
- Target of 2% penetration on final energy demand

EU Hydrogen Strategy
- 40 GW electrolyser capacity by 2030
- Investments > €450 Billion
- Key focus areas: Industry & transport

Source: Frost & Sullivan

SPOTLIGHT ON THE NORDICS

Strong cooperation across Nordic countries, backed by an excess of renewable energy, and the potential for development of offshore wind presents a massive opportunity to scale up the green hydrogen economy



Norway

Low-carbon electricity mix to boost hydrogen economy

Norway's energy supply has a low carbon intensity because of its hydropower-dominated electricity system. The country's hydrogen strategy identifies hydrogen as a clean energy carrier to decarbonize hard-to-abate sectors, including industry, oil and gas extraction, and transportation (commercial and passenger vehicles and maritime). Norway is in a good position regarding renewable energy, existing compatible infrastructure, and technological expertise to develop and lead the transition to a hydrogen economy.

Norway to leverage its extensive industrial experience

Norway has extensive industrial experience across the hydrogen value chain, and conditions for producing and using clean hydrogen are ideal. Many Norwegian technological companies are developing and supplying equipment and services for hydrogen production, distribution, storage, and use.

Sweden

High potential for green hydrogen developments

Sweden is in a good position regarding RES, existing compatible infrastructure, and technological expertise to develop and lead the transition to a green hydrogen economy.

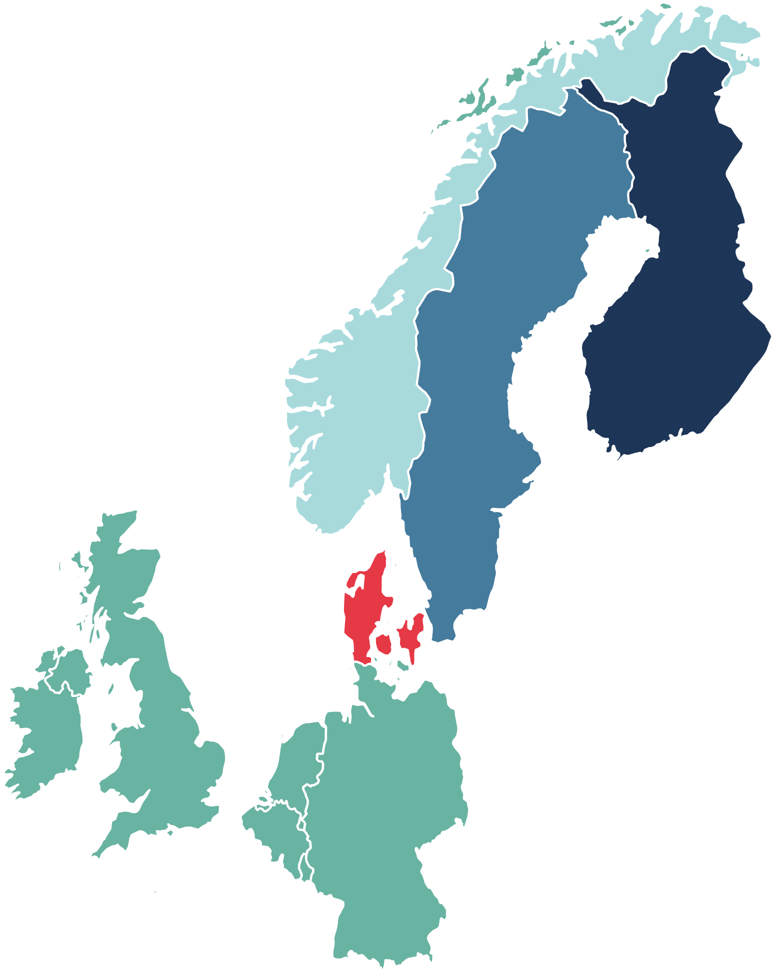
Ammonia & refineries to drive demand for hydrogen

Sweden has the largest heavy industry sector among the Nordic countries and has a substantial demand for green hydrogen. The ammonia and refinery industry accounts for about 90% of the hydrogen produced and used in Sweden today, while the chemicals & metallurgical industry, account for the remaining share.

Source: Frost & Sullivan

SPOTLIGHT ON THE NORDICS

Nordic countries have the potential to become the first movers on the green hydrogen scene, there needs to be support both from the public and private sector to compensate for the high capital costs



Finland

The hydrogen market inclined toward green hydrogen

Finland already has a hydrogen market driven by refining and petrochemical companies, and these companies are exploring opportunities to invest and produce green hydrogen, through which they can reduce their carbon footprint.

Decarbonization strategies to push for clean hydrogen demand across industries

The Finnish government has set a national carbon neutrality target in 2035, fast-tracking decarbonization strategies across energy-intensive sectors. Decarbonizing energy-intensive industries will be a crucial challenge in the country's carbon-neutral energy transition, and clean hydrogen is expected to play a critical role.

Denmark

High renewable energy potential

With substantial renewable energy potential, extensive investments in hydrogen research, and a growing number of pilot and demonstration projects, Denmark is in a favourable position to become one of the prominent players in the hydrogen economy.

PtX strategy for the development and promotion of hydrogen & green fuels

The government seeks to use PtX to produce hydrogen and other green fuels to decarbonize carbon-intensive industries and transport. Denmark aims to become one of the leading exporters of green hydrogen and use green e-fuels to decarbonize its difficult-to-abate sectors, such as shipping, aviation, and heavy road transport.

Source: Frost & Sullivan

Key Business Opportunities

FROST & SULLIVAN

FUTURE WATCH

ROADMAP FOR HYDROGEN

The hydrogen economy is essentially a 30-year transitional journey, the course of which will be mapped in this decade

2020 | 2030 | 2040 | 2050

2020 - 2030

- Development of regulations & policies
- Pilot & demonstration projects with large electrolyser capacity
- Feasibility analysis for green hydrogen storage & transport
- Rollout of large-scale RES + electrolyser projects
- Significant decline in cost gap between grey and green hydrogen – parity around 2030
- Ammonia, methanol & steel early industries for green hydrogen

2030 - 2040

- Full commercialization of fuel cells
- Massive ramp up in electrolyser capacity
- Export of green hydrogen via green ammonia
- Decarbonisation of maritime and aviation starts @2035
- Industrial usage significantly increases, with use cases in more industries

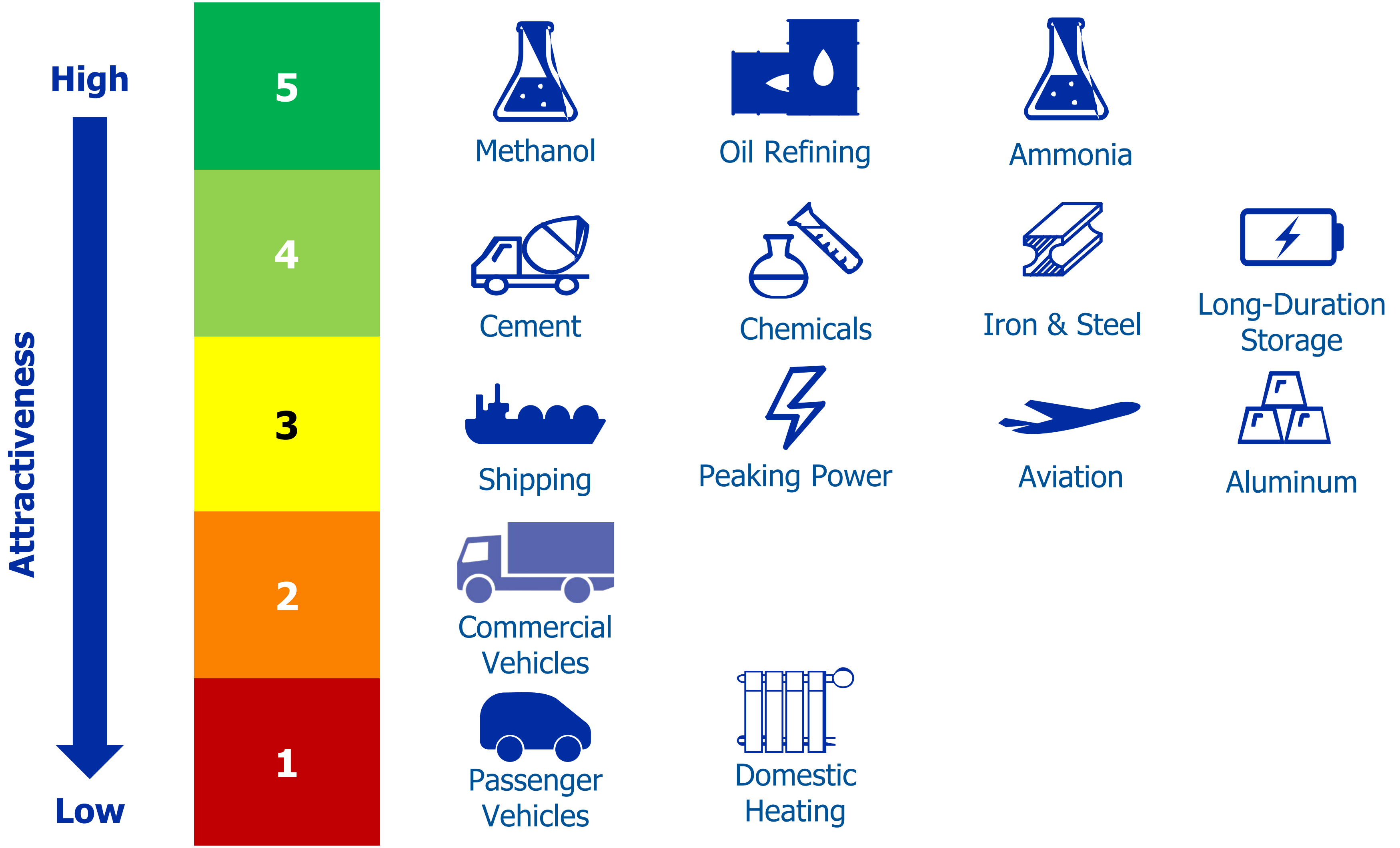
2040 - 2050

- Further ramp up of green hydrogen capacity
- Potential for some gas networks transitioning to hydrogen
- Further cost reductions for hydrogen storage & transport
- Growth in volumes of pink/purple hydrogen with potential for dedicated nuclear to hydrogen plants

Source: Frost & Sullivan

KEY END USERS FOR HYDROGEN

High temperature heavy industrial processes offer the best sector opportunities for hydrogen



Source: Frost & Sullivan

KEY BUSINESS OPPORTUNITIES

The development of the hydrogen economy offers a range of business opportunities from supplying related infrastructure solutions to taking advantage of the hydrogen produced

No.	Growth Opportunity	Brief Description
1	**Power-to-X**	Power-to-X, commonly referred to as P2X or PtX, is a collection of pathways for the conversion, storage, and reconversion of electricity generated from renewable energy sources (RES). X may be heat or chemicals, including hydrogen, syngas, and synthetic fuels.
2	**Green Ammonia**	Green ammonia produced through the combination of green hydrogen and nitrogen is intended to be used as a zero-carbon fertilizer, fuel, and as an energy carrier.
3	**Synthetic Fuels**	Synthetic fuels include carbon-neutral liquid fuels such as fuel oil, diesel oil, gasoline, and methanol produced by combining captured CO2 and green hydrogen.
4	**Electrolysers+Renewables As Standard**	electrolysers are installed on retired oil & gas platforms and can produce green hydrogen through electricity from the nearest offshore wind farm. Green hydrogen produced can be transported back to shore via existing gas pipelines.
5	**Utilisation Of Recovered Carbon Black**	Recovered carbon black (rCB) produced through pyrolysis is a high-quality carbon black that offers customers an environmentally friendly and cost-effective option for industrial applications.
6	**Advanced Material Supply**	R&D on advanced materials is crucial for the development of the hydrogen economy. Advanced materials are vital throughout the hydrogen value chain, including hydrogen production, storage, transportation, and utilisation.
7	**Water Treatment Systems/Water-as-a-service**	Water is the feedstock for green hydrogen production, and the water treatment system must purify it to an ultrapure state. The water treatment solution depends on the electrolyser technology and selected water source; inadequate water treatment can endanger the operation and cause electrolyser damage.
8	**Blending Into The Gas Grid**	Hydrogen produced through clean pathways can be injected into natural gas pipelines. The blending limit depends on the design and condition of the pipeline and the applications for the blended gas. Some applications include the transport of green hydrogen, industrial heating processes, and power generation.

Source: Frost & Sullivan

KEY BUSINESS OPPORTUNITIES

The development of the hydrogen economy offers a range of business opportunities from supplying related infrastructure solutions to taking advantage of the hydrogen produced

No.	Growth Opportunity	Brief Description
9	**Nuclear Produced Hydrogen**	Nuclear is a competitive energy source to produce large-scale, low-carbon, cost-effective hydrogen. Nuclear energy creates opportunities to optimize hydrogen production costs and enables decarbonization of hard-to-abate industrial activities.
10	**Hydrogen Production From Waste Heat**	Hydrogen produced from waste heat can play a significant role in our energy transition because it is a carbon-free fuel and energy carrier equivalent to the green hydrogen produced through electricity from RES.
11	**Energy Hubs & Green Hydrogen Production**	Energy hubs enable efficient offshore wind power generation and distribution management by serving as connecting points and storage sites for the energy produced by offshore wind. Energy hubs can convert surplus wind power and store it in the form of hydrogen, and can provide a carbon-free energy supply for offshore oil and gas extraction platforms and maritime cargo transport and facilitate the transition toward decarbonization.
12	**Circular Economy**	The circular economy enables sustainable practices (reduce, reuse & recycle) of handling materials involved in hydrogen production, storage, and transportation.
13	**Digital Twin**	A digital twin can create a virtual environment of the hydrogen electrolyser plant and provide data and insight into the health of the entire plant, thereby enabling preventative maintenance practices, optimizing plant management, and avoiding costly unscheduled downtime.
14	**Digitalization of Hydrogen Industry**	Digital technologies play a vital role in delivering the hydrogen economy by accelerating technological innovations, overcoming value chain obstacles, and enabling faster and better scale-up and optimization of the hydrogen value chain through achieving better economics.
15	**Aviation & Maritime Fuels**	Synthetic fuels, also known as E-fuels, are a promising option for maritime and aviation transport and can deliver significant reductions in carbon emissions
16	**Industrial Decarbonization**	Green hydrogen generated from RES help decarbonizes industrial processes, which cannot be achieved through electrification, taking us closer to carbon neutrality. Some industries include steelmaking, chemical, cement, and refinery industries.

Source: Frost & Sullivan

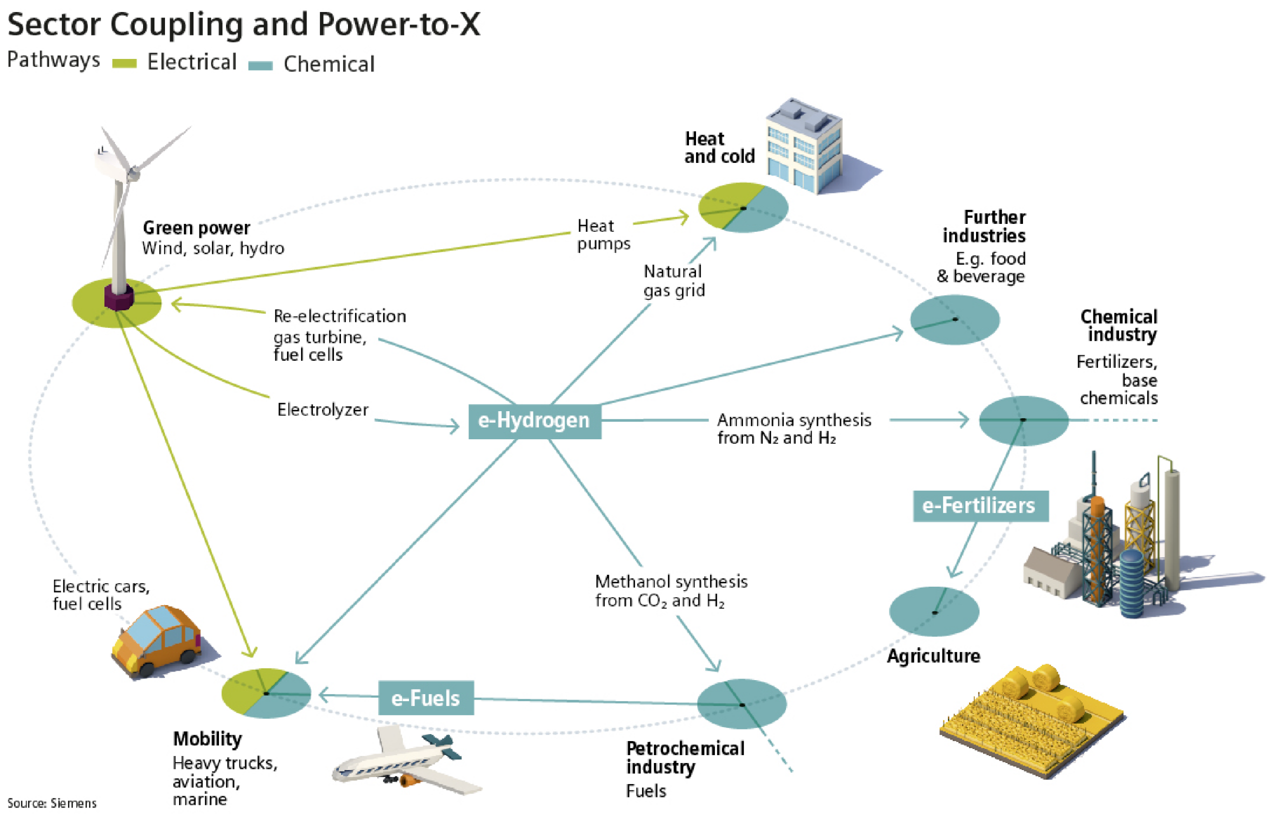
OPPORTUNITY 1: POWER-TO-X

The continued growth of renewable energy is going to result in times of significant surplus energy. Part of this energy will be stored for use later – either in batteries or non-battery systems. However relying on storage alone will be challenging; and storage will require significant capital investment. A compromise alternative is to use the excess energy to create alternative sources of energy that can be deployed in industrial processes, including hydrogen.

- Green hydrogen produced through electrolysis can subsequently be converted into different forms, like synthetic methane or other synthetic fuels or chemicals, through the addition of CO_2.

- The biggest advantage of PtX technology is that it enables sector coupling, which means that renewable energy can be converted into other forms and consumed across other energy consuming sectors, thereby decarbonizing them.

- Different forms of PtX technology include:
  - PtG: Power-to-Gas (including green hydrogen alone or mixed with natural gas)
  - PtL: Power-to-Liquid (synthetic fuels and industrial feedstock)
  - PtC: Power-to-Chemicals (chemicals for industrial applications)
  - PtH: Power-to-Heat (heat pumps)
  - PtH_2: Power-to-Hydrogen (via electrolysis)
  - PtP: Power-to-Power (using green hydrogen and fuel cells to generate electricity)



Source: Siemens, Frost & Sullivan

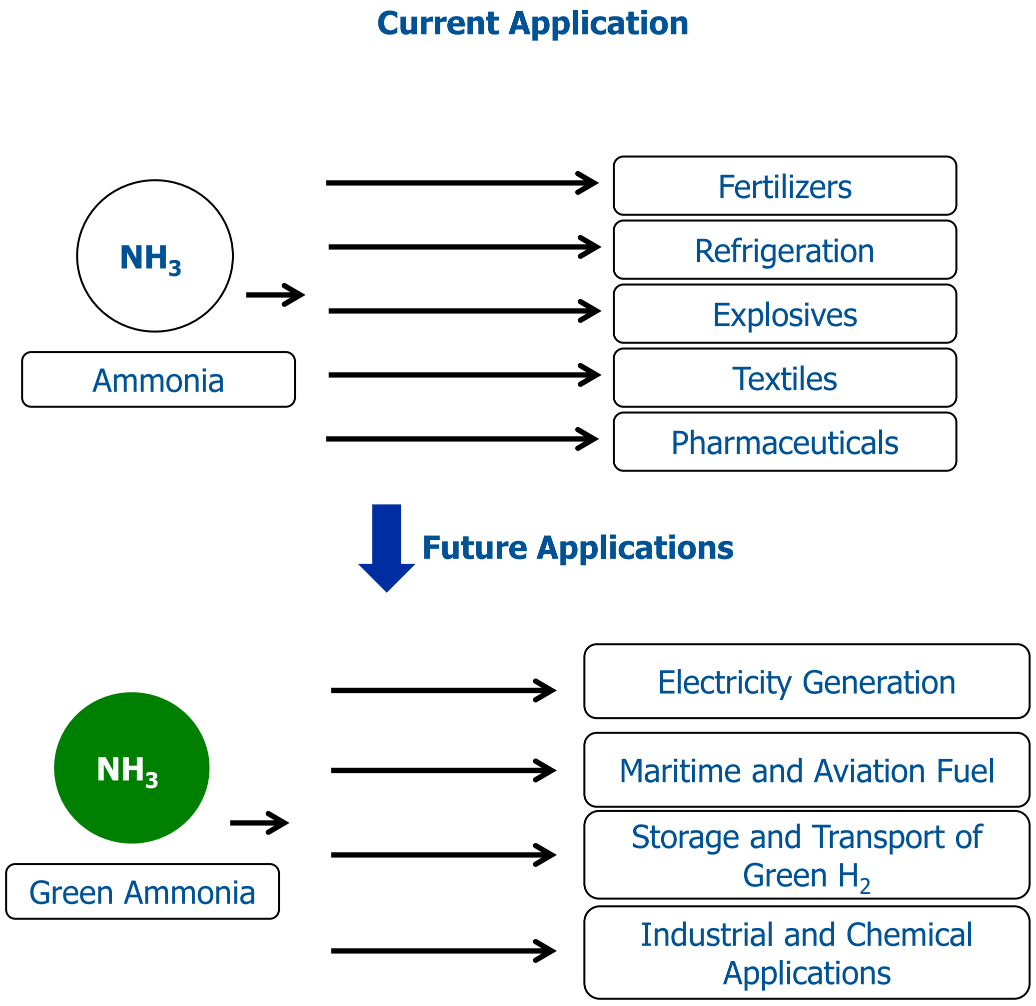
OPPORTUNITY 2: GREEN AMMONIA

Zero-carbon fertiliser, fuel and energy store

- Green ammonia is considered a cost-effective way to store and transport large amounts of green hydrogen and renewable energy.

- Green ammonia is produced through the Haber-Bosch process, by passing pure nitrogen air through green hydrogen from renewable energy. As a zero-carbon source, green ammonia has several applications, including:
  - Long duration storage of green hydrogen/renewable energy;
  - Fuel for power generation;
  - Fuel for maritime, aviation, and fuel cells vehicles;
  - Feedstock as green fertilizer; and
  - Industrial feedstock.

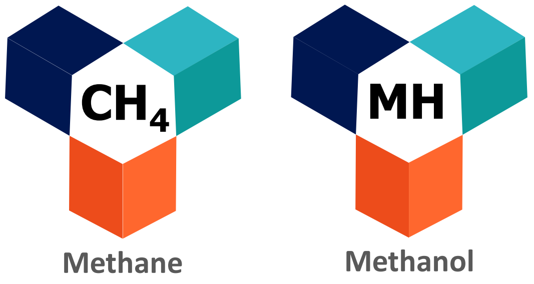
- Green ammonia will enable a cost-effective means of transporting renewable energy from regions of high production to those of low renewables production. This will create opportunities for the international trading of green hydrogen.



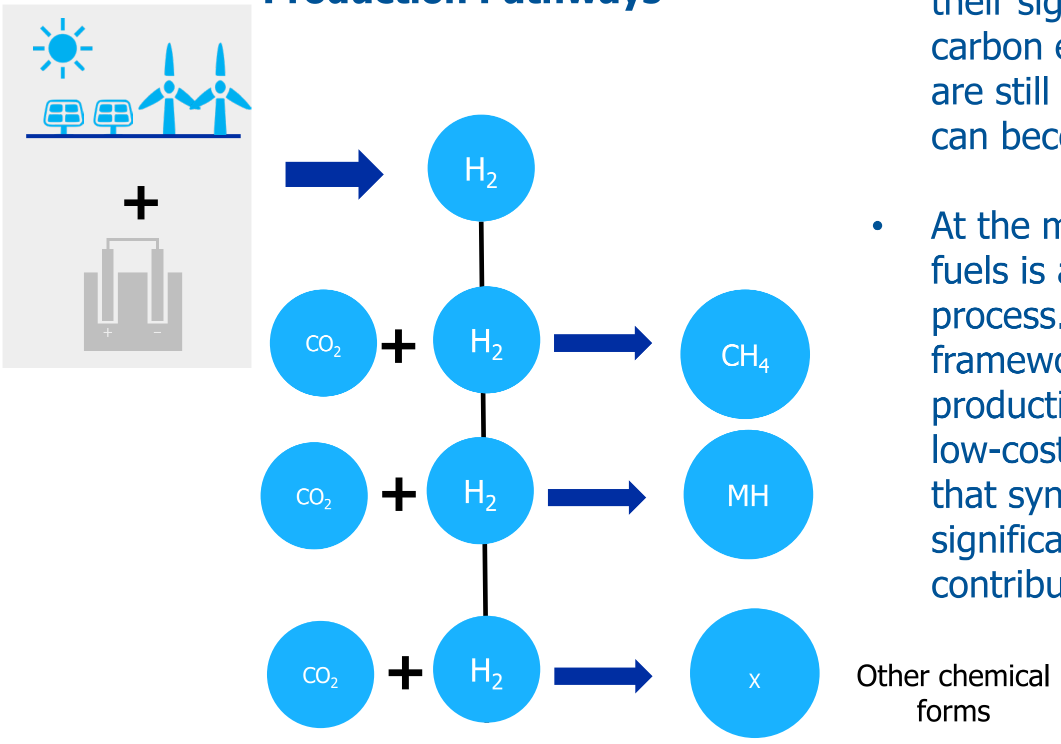
Source: Frost & Sullivan

OPPORTUNITY 3: SYNTHETIC FUELS

Synthetic Fuels – The Next Revolution?

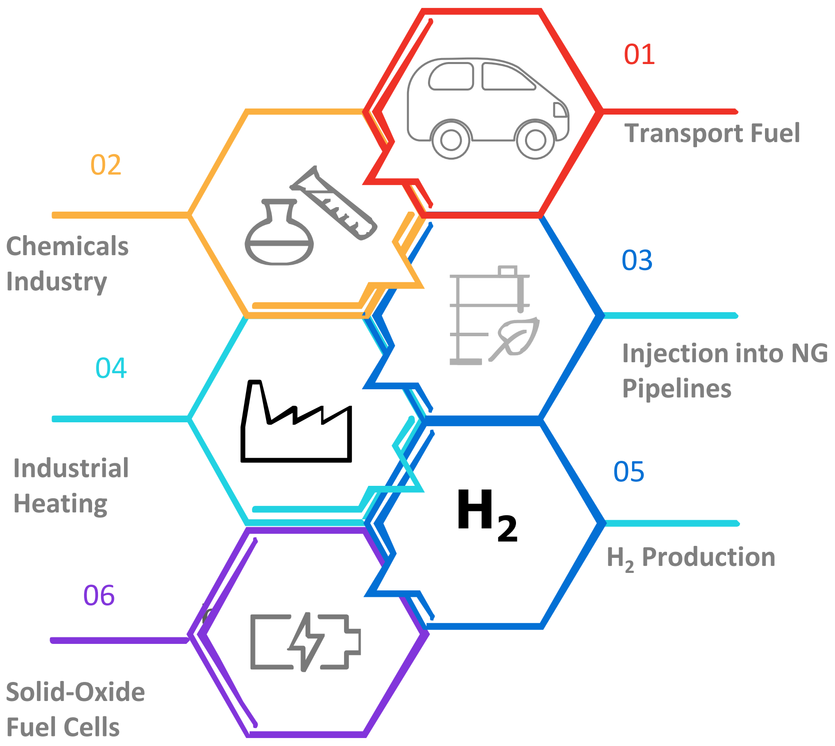


Production Pathways



- Synthetic fuels are manufactured by combining green hydrogen with captured CO_2. This way, CO_2 becomes a raw material from which chemical companies can produce synthetic methane (substitute for natural gas), methanol, gasoline, and diesel. Despite their significant potential to reduce carbon emissions, considerable efforts are still needed before synthetic fuels can become established.
- At the moment, producing synthetic fuels is a complex and expensive process. Supportive regulatory frameworks, technological innovations, production ramp-up, and availability of low-cost green hydrogen could mean that synthetic fuels becoming significantly cheaper could significantly contribute to limiting global warming.

Applications

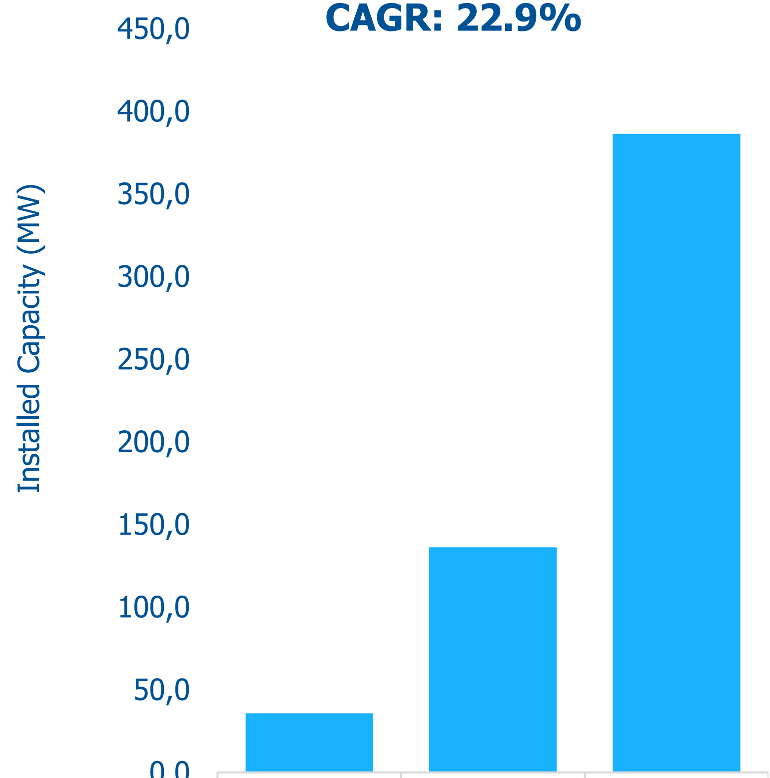


Source: Frost & Sullivan

OPPORTUNITY 4: ELECTROLYSERS+RENEWABLES AS STANDARD

The likely demand for hydrogen means that dedicated renewables for hydrogen production will be needed. There is huge potential to install electrolysers on offshore oil & gas platforms (where fields have been depleted) and power them with offshore wind turbines. These could be floating or fixed foundation turbines. The hydrogen can then be directly piped to shore to be utilised.

Installed Capacity Offshore Wind, Global, 2022 – 2030, CAGR: 22.9%



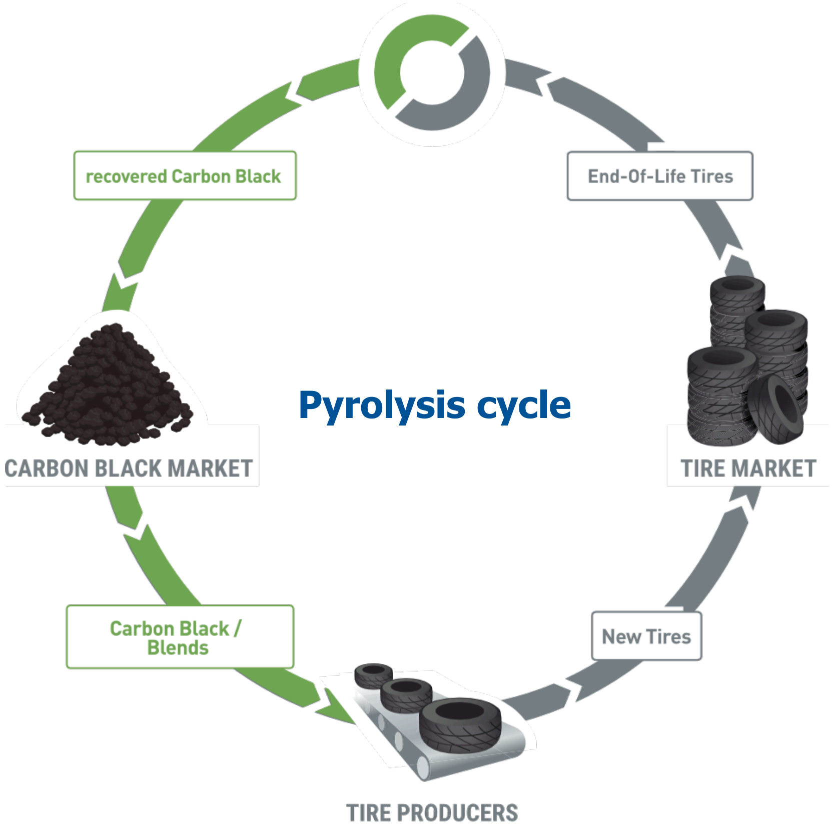
	2020	2025	2030
Annual Capacity	35,8	136,1	386,3

Image Source: Ramboll, Source: Frost & Sullivan

OPPORTUNITY 5: UTILISATION OF RECOVERED CARBON BLACK

Recovered Carbon Black (rCB) is the residue from the methane pyrolysis process that splits hydrogen from carbon. By utilising this residue, hydrogen producers can generate an additional revenue stream. This benefits the global sustainability agenda, as it can completely or partially replace carbon black across a variety of industrial segments.

Pyrolysis Process



10% to 30% Substitution of Virgin Carbon Black

Passenger Car/Light truck tire tread, Heavy duty conveyor belts(mining) etc., High Pressure Hoses, Transmission Belts

30% to 50% Substitution of Virgin Carbon Black

Industrial/Agricultural tire tread and carcass, Light/Moderate duty conveyor belts, Rubber sheeting/Geomembranes, Wire/Cable jacketing, Gaskets & seals, Rubber roofing

50% to 100% Substitution of Virgin Carbon Black

Plastic Master Batch(for general plastic compounds, Polyolefin Films(trash bags, agricultural films), Plastic Pipes, Plastic Tanks, Newspaper Inks, Passenger Car/Light truck tire inner liners

Source: Capital Carbon, Frost & Sullivan

OPPORTUNITY 6: ADVANCED MATERIAL SUPPLY

The hydrogen industry is increasingly turning to companies involved in R&D in materials science (polymers & composites) and additive manufacturing (AM) to manufacture complex multi-functional components for hydrogen production, storage, and transportation

- For hydrogen to become the mainstream energy carrier, it has to overcome two main obstacles: hydrogen production and storage. Advanced materials (polymers and composites) play an essential role in the hydrogen industry, and R&D focus on developing novel materials would close the knowledge and technology gap and contribute to an eventual transition into a hydrogen and renewable-based economy.
- AM, also known as 3D printing, is a transformational technology that enables the creation of three-dimensional lighter and more substantial parts and systems. AM offers tremendous opportunities in hydrogen production and storage. AM is perceived as a way to develop cost-efficient FCs as it provides flexibility in the designing and manufacturing FCs.
- Applying AM for R&D involved in FCs (Polymer Electrolyte Membrane Fuel Cell (PEMFC), Solid Oxide Fuel Cell (SOFC), Microbial Fuel Cell (MFC), and Laminar Flow-based Fuel Cell (LFFC)) has become an emerging focus within the FC research community.

Application Segments for Advanced Materials & Composites

Catalysts for Fuel Cells

Materials for Pure H2 Pipelines

Materials for Hydrogen Storage

Application Segments for Additive Manufacturing

FC Valves, Injectors

FC Catalysts

Materials for Hydrogen Storage

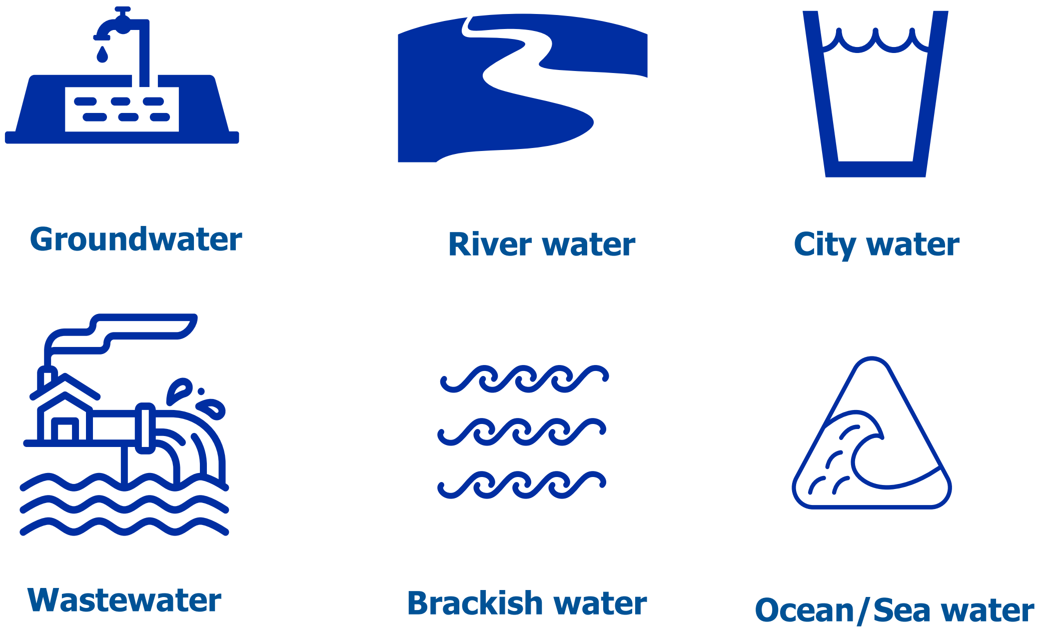
Source: Frost & Sullivan

OPPORTUNITY 7: WATER TREATMENT SYSTEMS/WATER-AS-A-SERVICE

The water treatment methods for the feed water for electrolysis depend on the source of water and the electrolyser technology used for hydrogen production.

- The electrolysis process can use different water sources to produce hydrogen. Before being used in the electrolysis process, the water goes through several phases of water treatment and filtration to ensure maximum purity.
- Water utilities are currently exploring the concept of "WaaS" - water as a service to supply feed in water to electrolysis plants. WaaS includes water delivery, treatment, or analytics services and is billed as an operating cost.
- With the growing offering of IoT, AI, analytics, and 5G technologies, the WaaS has become an attractive means of selling a water solution and will grow with the expanding hydrogen industry.

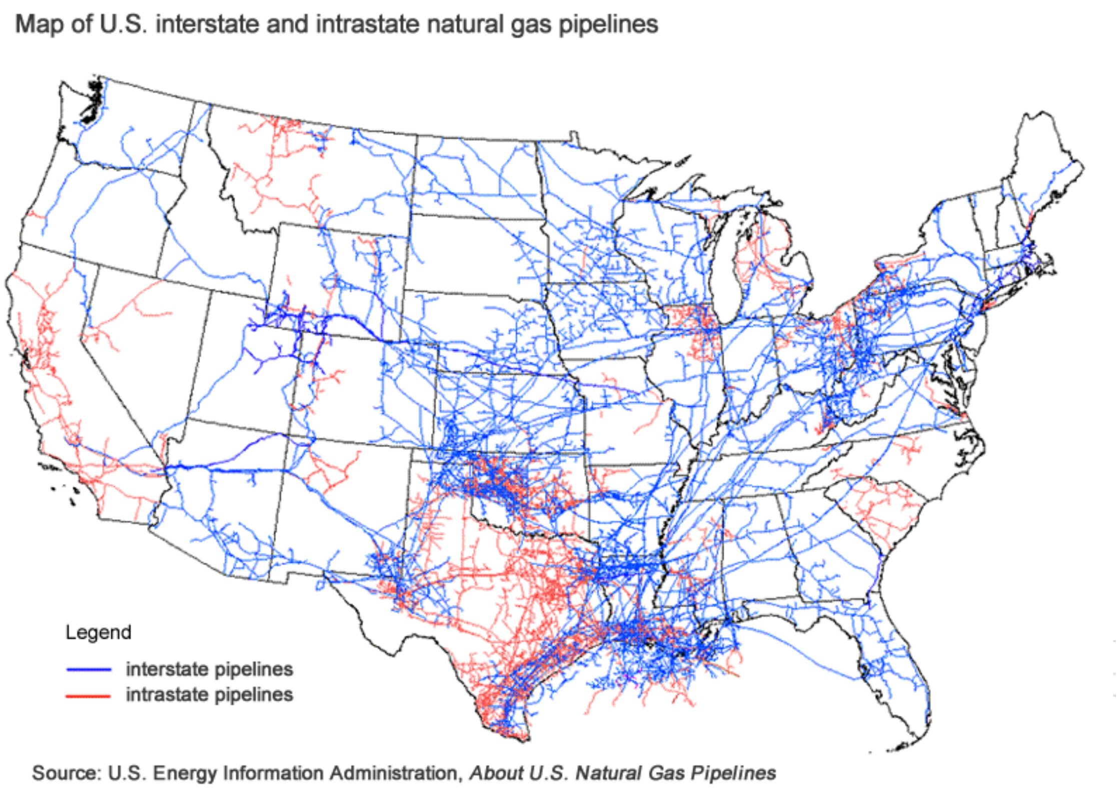
Water Sources



Source: RODI; Frost & Sullivan

OPPORTUNITY 8: BLENDING INTO THE GAS GRID

Existing gas pipeline infrastructure will be needed until at least 2040, as many households and businesses will remain dependent on natural gas, despite increasing sales of heat pumps. However the gas grid can be partially decarbonised by the injection of a percentage of natural gas. The exact percentage varies depending on individual grid conditions, but 15%-20% is an approximate average, with 20% largely the technical limit. This could be deployed when there is excess hydrogen production from renewable energy.



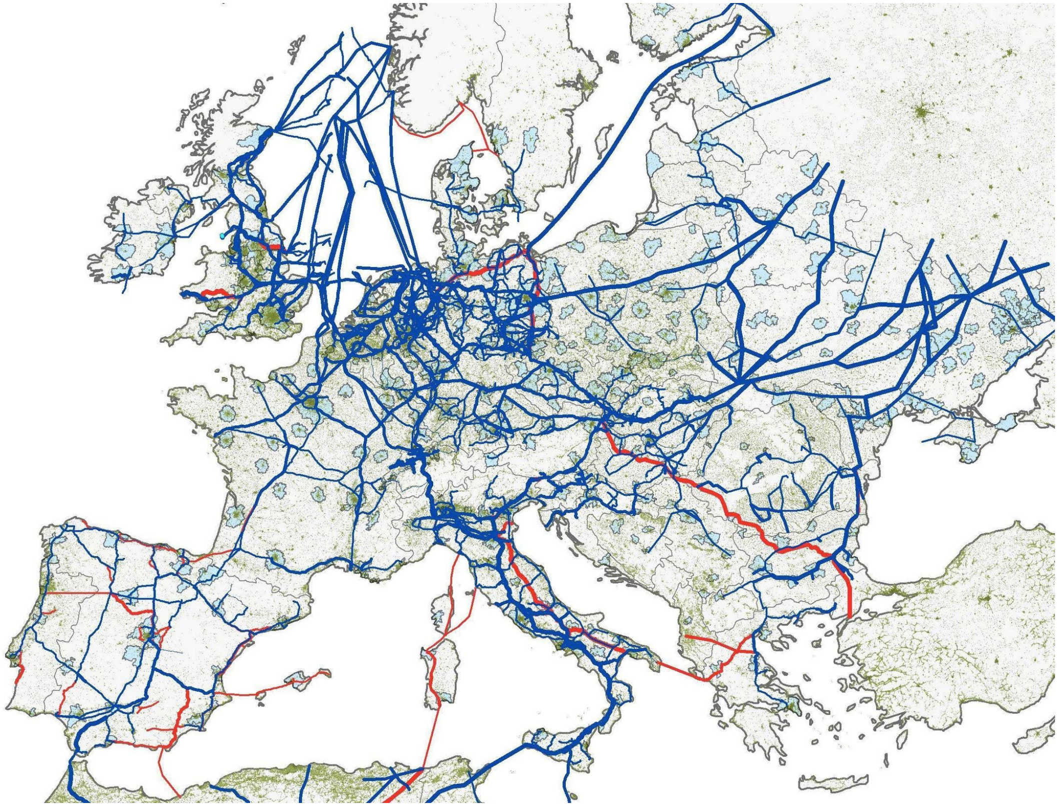
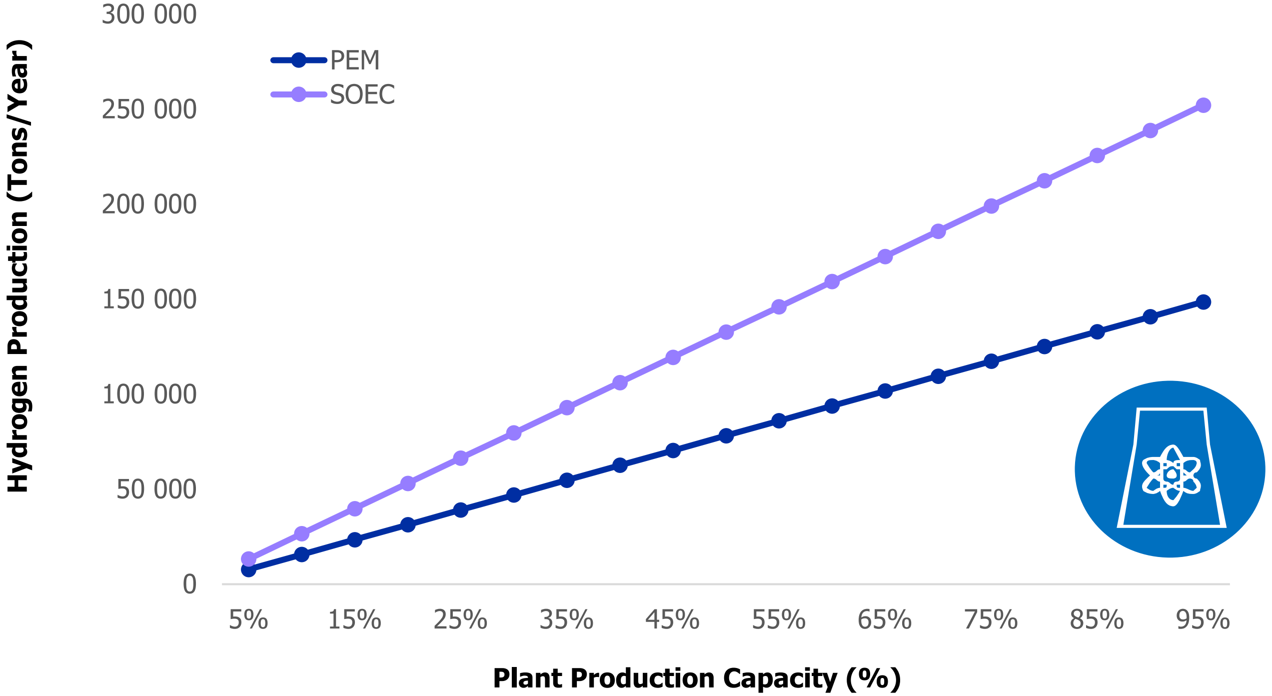


Image Source: EIA, European Commission; Source: Frost & Sullivan

OPPORTUNITY 9: NUCLEAR PRODUCED HYDROGEN

Utilities operating nuclear power plants can utilise any excess electricity as well as the heat generated to power an electrolyser and produce hydrogen.

- Nuclear plants produce electricity, but also significant volumes of heat. Utilities can pair them with a more efficient high-temperature steam electrolyser (HTSE) like a solid oxide electrolyser cell (SOEC), which uses less electricity per kilo of hydrogen produced than the LTE.
- Some of the advantages of producing hydrogen from nuclear power plants are:
  - A new market opportunity—green hydrogen can be traded in the energy market and sold during peak demand when the price is higher, or it can be transported for use in mobility or as a chemical feedstock in the industrial segment.
  - Help integrate more RES into the grid - nuclear-produced hydrogen (NPH) could be stored and utilized for grid balancing operations.
  - Reduce carbon emissions from power generation.
  - Focus toward SMRs for hydrogen production
- In the future, small modular reactors (SMRs) present a significant possibility for producing green hydrogen and generating electricity for the grid. SMRs are starting to gain attention and slowly develop worldwide as they are a safer and cheaper form of nuclear power.



- A nuclear power plant providing 1 GW of power for hydrogen production year-round could produce between 150,000 and 160,000 metric tons of hydrogen per year using PEM electrolyser. Between 180,000 and 250,000 metric tons of hydrogen could be produced if same plant utilized SOEC electrolyser.

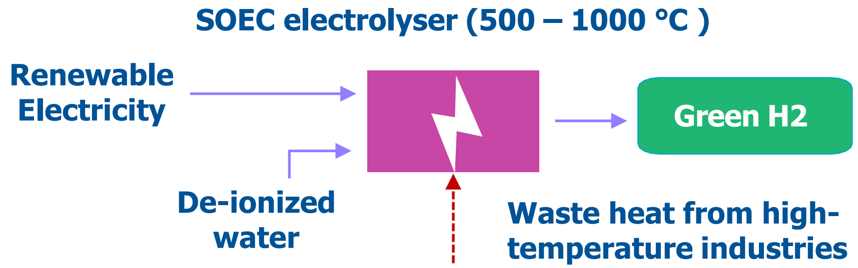
Assumptions: 1 GW SOEC . Electrical Energy Required to Produce Hydrogen (kWh/kg): 35 kWh/kg (SOEC) & 56 kWh/kg (PEM);

Source: Frost & Sullivan

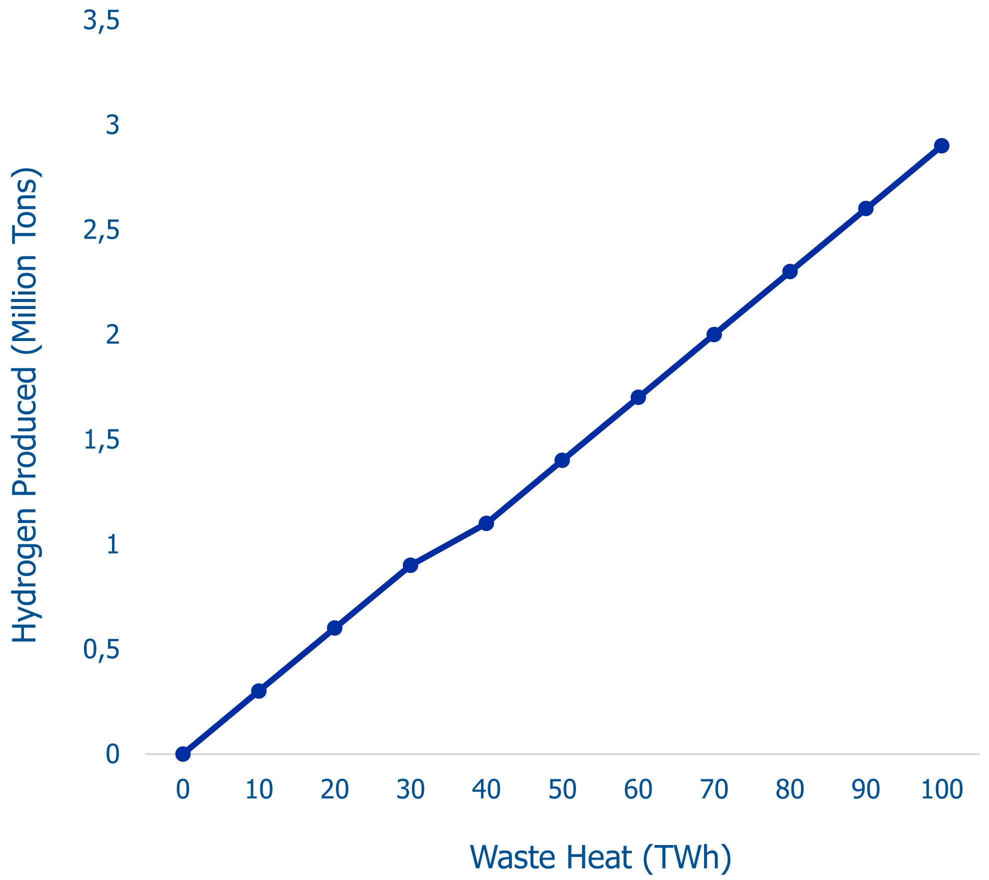
OPPORTUNITY 10: HYDROGEN PRODUCTION FROM WASTE HEAT

Powering the hydrogen economy from waste heat

The heat from industrial processes is challenging to capture, store, and transport. Therefore, capturing and storing low-grade heat provides a significant opportunity for decarbonization by producing low-carbon hydrogen. Solid oxide electrolysers operating at temperatures > 600 °C can utilize the waste heat from heavy industries, including steel-making and glass manufacturing companies, and produce hydrogen, which could be used as feedstock for industrial processes.



Sources of Waste Heat	Temperature (°C)
Nickel Refining Furnace	1370 - 1650
Aluminium Refining Furnace	650 - 760
Zinc Refining Furnace	760 - 1110
Copper Refining Furnace	760 - 815
Steel Heating Furnace	925 - 1050
Steam Boiler Exhausts	230 - 480
Heat treating Furnaces	425 -650
Glass Melting Furnaces	1000 - 1050
Solid Waste Incinerators	650 - 1000
Gas Turbine Exhaust	1000



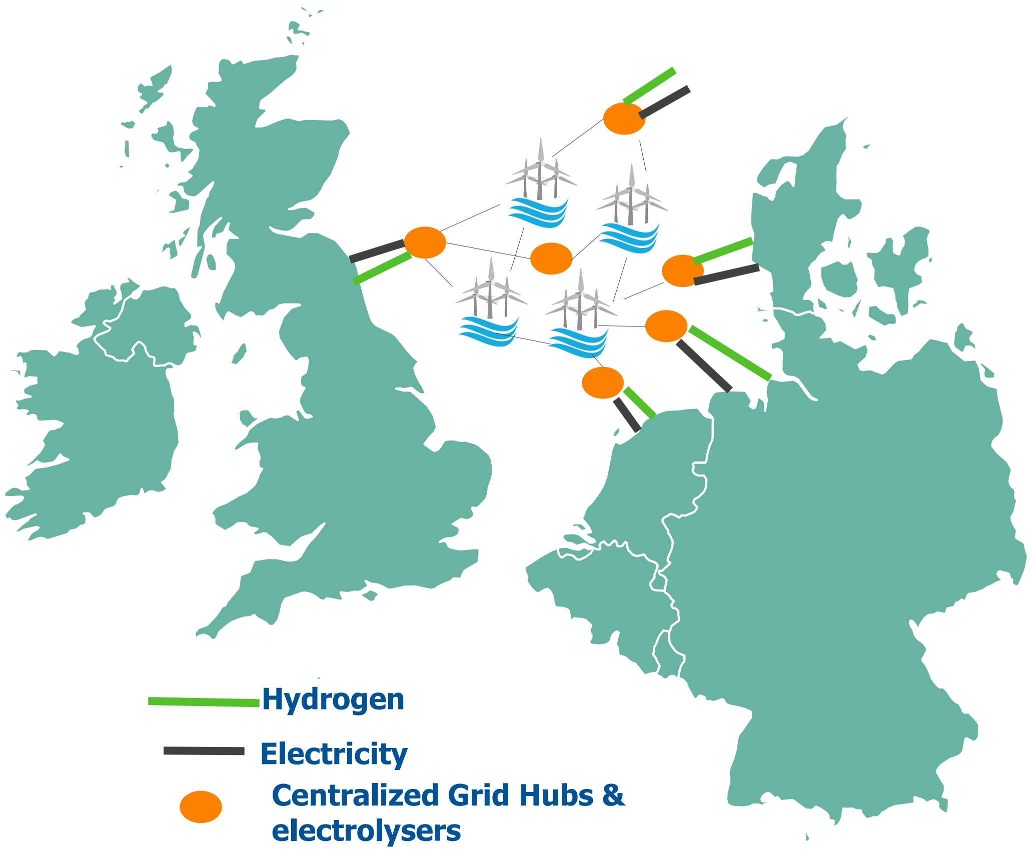
SOEC Electrical efficiency: 35 kWh produces 1 kg H_2

Source: Frost & Sullivan

OPPORTUNITY 11: ENERGY HUBS & GREEN HYDROGEN PRODUCTION

Hybrid solutions allow the creation of a SMART ENERGY HUB accelerating our transition towards low-carbon economy

- The European region has a massive offshore wind energy potential, and the area is currently accelerating its offshore developments and investing massively in new offshore projects. Frost & Sullivan's analysis shows that significant offshore activities are likely to happen in the European region, particularly in the North Sea, including projects across floating offshore wind, green hydrogen production, and the creation of energy hubs.
- The energy hubs will connect all offshore wind farms, which means that not all wind farms will have to be connected separately to the electricity grid on land but can be connected to the energy hubs in deep waters, which means that fewer power cables are needed to bring the energy to land, which saves money and takes up less space on the coast. The energy hubs make it possible to connect to other North Sea countries, increasing energy security, and could also be used to make green hydrogen and share excess energy produced with its neighbours.

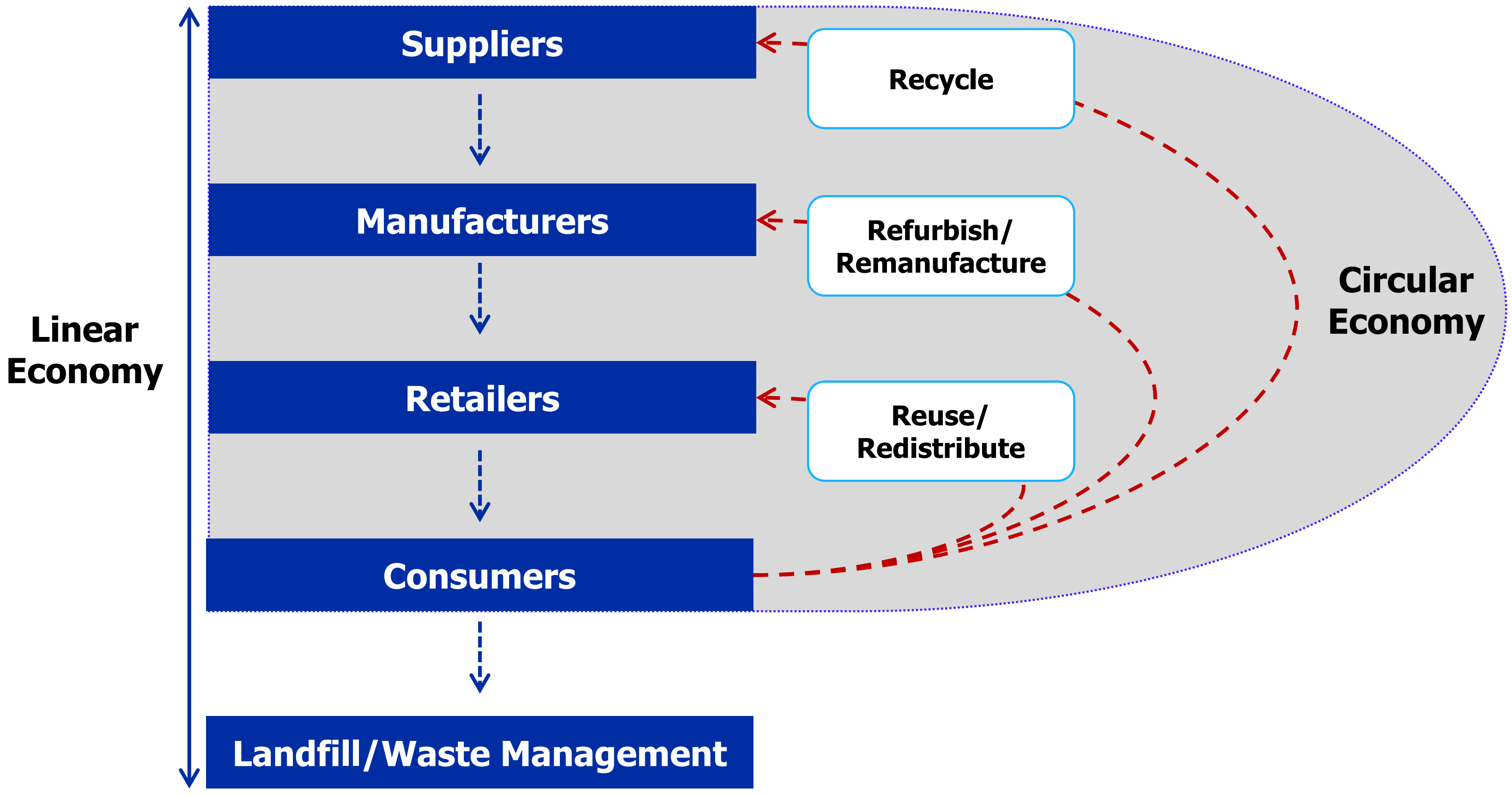


Source: Frost & Sullivan

OPPORTUNITY 12: CIRCULAR ECONOMY

Circular economy will promote the efficient use of materials available for production, storage and transport of hydrogen and support resource optimization.

Circular economy refers to an industrial economy that, contrary to the traditional linear economy, reclaims used materials and recycles them as secondary raw materials for new products



Circular Economy in Hydrogen Value Chain

- Product design – designing out waste, materials use, upgradeability of materials used in electrolysers, hydrogen storage and transport
- New business models – service-based solutions
- Reverse cycles – "closed loop" recycling, reuse and refurbishment
- Breakthrough innovation – such as 3D printing that eliminates waste

Source: Frost & Sullivan

OPPORTUNITY 13: DIGITAL TWINS

A digital twin can simulate the working conditions of the hydrogen electrolyser plant, including control and safety schemes and operating procedures. In addition, the Digital twin technology can also provide data and insight into equipment and system health, helping plant operators optimize preventative maintenance practices and avoid costly unscheduled downtime, maximizing operational efficiencies and increasing plant productivity and profitability.

Smart embedded sensors gather data

Connectivity modes (moving toward 5G) send data to cloud-based repositories

Contextual data (e.g., weather reports) enhances asset-based data

Instance-based digital replicas are produced, unique to the individual asset and maintained in real time

In the short-term, many of the large-scale hydrogen plants will be built within existing industrial clusters such as refineries, ammonia plants, steel mills, harbour/ports or even offshore. Given the investment costs of electrolyser plants, digital twins are likely to become a prevalent feature of future value propositions, particularly if they can contribute to operational cost reductions and optimized performance. Digital twins used for asset lifecycle management will provide plant operators with unprecedented insight into the health and functioning of electrolyser plants.

Source: Frost & Sullivan

OPPORTUNITY 14: DIGITALIZATION OF HYDROGEN INDUSTRY

Digital technologies play a vital role in delivering the hydrogen economy by accelerating technological innovations, overcoming value chain obstacles, and enabling faster and better scale-up and optimization of the hydrogen value chain through achieving better economics.

Accelerate Hydrogen Production Innovation (Process Modeling & Economics)
- Accelerate research-to- construction pipeline
- Improve conversion processes
- Exhaustively evaluate alternatives
- Improve fuel cell economics
- De-risk storage and transport

Blue Hydrogen and Ammonia Asset Optimization (Digital Twin, Energy Modeling)
- Optimize energy use
- Optimize production
- Carbon capture

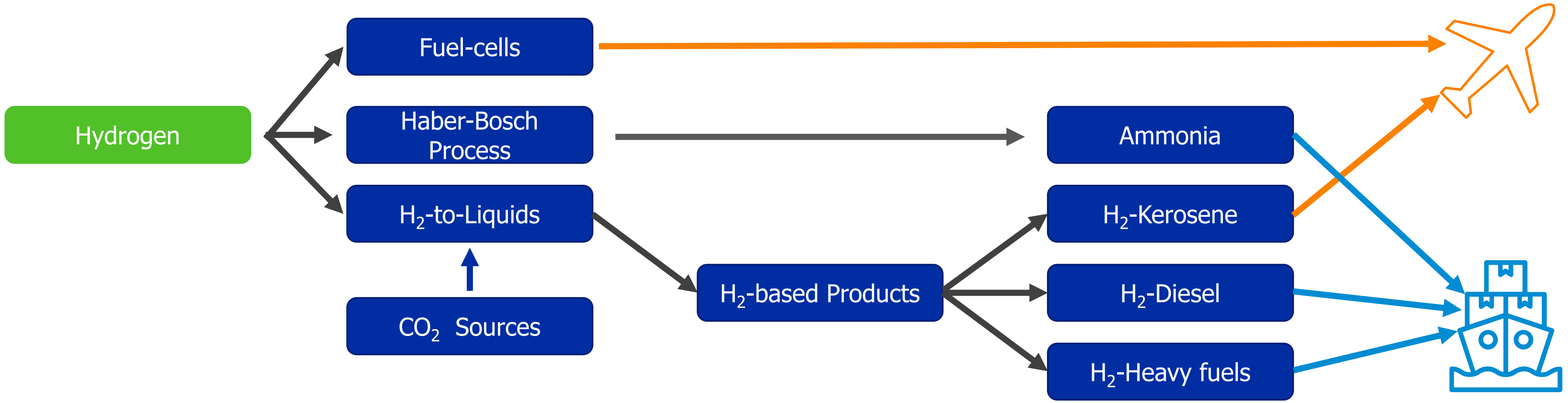
De-risk and Optimize the Hydrogen Value Chain (Systems Risk Modeling, Planning & Scheduling)
- Build the right value chain
- Optimize integration with natural gas networks

Plant Design and Operation (Process Modeling)
- Need to scale
- Operate complex plants with minimum/zero staff

Source: Aspen Technology, Frost & Sullivan

OPPORTUNITY 15: AVIATION & MARITIME

- Aviation and shipping account for 22% of total transport-related CO2 emissions. The potential role of hydrogen in decarbonizing the aviation and maritime industry could come in two forms: (a) in its pure form with the use of fuel cells (short and potential medium-haul flights/boats/ferries) and (b) in the form of synthetic fuels, including ammonia, kerosene, and diesel whose production involves combining zero or low-carbon hydrogen with captured CO2.
- Using fuel cells and liquid hydrogen tanks adds additional weight and is unsuited for long-haul flights or ships. However, fuel cells are best suited for short-to medium-range flights and boats/ferries, which could drastically reduce carbon emissions.
- Synthetic fuels (power-to-liquid, short: PtL or e-fuels) are produced converting renewable electricity into hydrogen, which is further converted to liquid fuels and is emerging as an exciting option to decarbonize future aviation and maritime industry. They are expected to enter the market at a large scale in the late 2020s and become cheaper in the mid-2030s. One of the significant advantages of synthetic fuels is that they can be transported and distributed via the existing network of fossil-fuel infrastructure, including pipelines and filling stations.
- Synthetic fuels are up to two to eight times more expensive than their traditional counterpart. In the future, low costs of renewable electricity will enable low green-hydrogen production costs and, ultimately, low PtL costs.

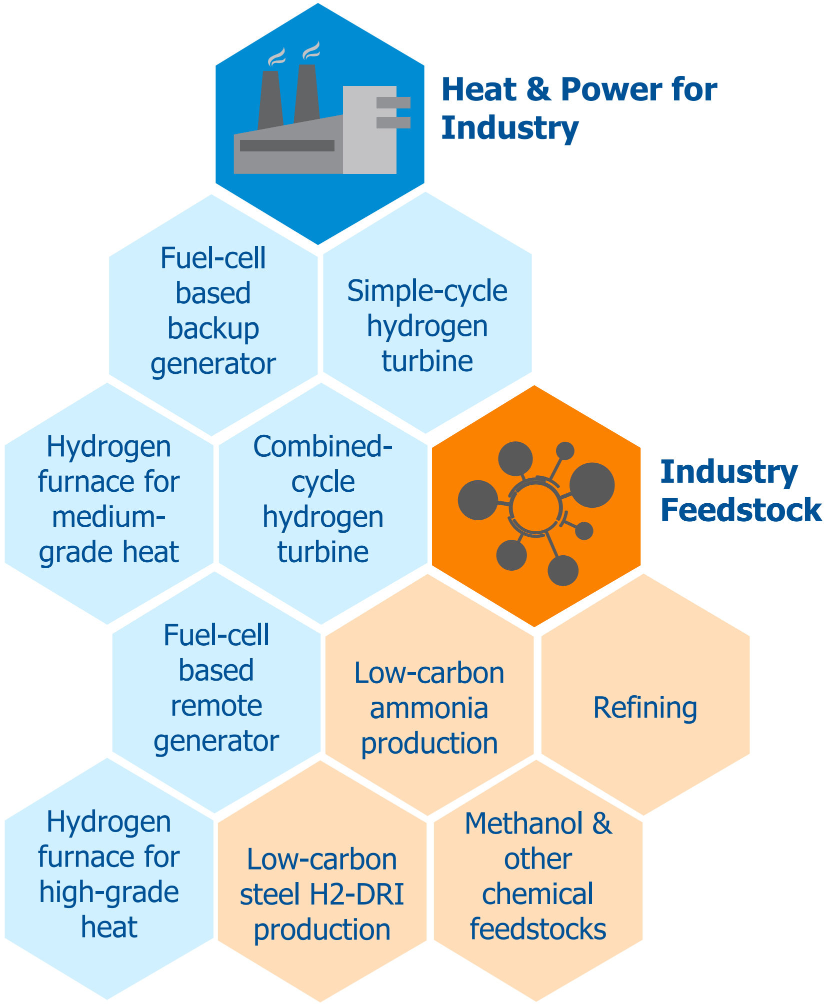


Source: Frost & Sullivan

OPPORTUNITY 16: INDUSTRIAL DECARBONISATION

Since 2010, industrial carbon emissions have continued to increase compared to other segments (energy sector, transport, buildings and agriculture, forestry and other land uses). Currently, industrial CO2 emissions represent an average of 29% of the global CO2 emissions during an average year.

- The industrial sector largely depends on fossil fuels to meet their energy demand. Heat makes up two-thirds of industrial energy demand across all industrial processes and almost one-fifth of global energy consumption, almost entirely powered by fossil fuels.
- Decarbonization of the industrial sector thus requires replacing the fossil fuel-based heating systems. However, this change is difficult across many industrial segments (steel, cement and other metals), since some of the industrial processes require high temperatures, which can be attained only using a fossil-fuel-based system.
- To decarbonize industries, utilization of green or low-carbon hydrogen as an option to supply heat or as a feedstock is a promising alternative. It enables high process temperatures to be achieved in a tailor-made and efficient way and allows the utilization of RES.
- Industrial sectors of particular interest for green hydrogen-enabled decarbonisation include:
    - Industrial processes which currently use high carbon hydrogen (e.g., grey hydrogen) or ammonia as a chemical feedstock
    - Processes that rely on fossil fuels to reach extremely high temperatures (c. 1000 deg.C).
    - Other industrial processes that are difficult to electrify.



Source: Frost & Sullivan

KEY BUSINESS OPPORTUNITIES – CHALLENGES TO ADDRESS

No.	Growth Opportunity	Challenges
1	**Power-to-X**	High energy and capital costs, lack of supportive government regulations, and low-technology readiness level of technologies involved in P2X are the critical challenges in implementing P2X solutions.
2	**Green Ammonia**	The widespread adoption of green ammonia will be primarily influenced by factors such as the cost and availability of green hydrogen, existing transport, storage and distribution infrastructure, policy and incentives for uptake, and social acceptance.
3	**Synthetic Fuels**	Currently, the adoption of synthetic fuels is still in the early stages. High production and capital costs, lack of infrastructure, and supportive regulatory frameworks are the critical challenges for synthetic fuels. To be competitive in the market, synthetic fuels have to be equal to or below the cost and performance level of conventional fuels.
4	**Electrolysers+Renewables As Standard**	Hydrogen production through electrolyser plants installed in retired or functional oil & gas platforms and transport to onshore bases are still in their early stages. Even the pilot projects are in the planning mode, and it would take at least 5-10 years for this technology to scale up and bring down the costs associated with a few more years to witness projects coming online.
5	**Utilisation Of Recovered Carbon Black**	No active recovered carbon black plants are operating, although efforts are being made to build a recycling carbon black plant. In addition, mixing virgin carbon black produced through methane pyrolysis with recovered carbon black for industrial applications is still yet to begin.
6	**Advanced Material Supply**	The technological readiness level and R&D involved in developing new materials for hydrogen production, storage, and transport are still under development, and it would require considerable investments and timeframe for testing and commercialization of materials and bring down the cost economics.
7	**Water Treatment Systems/Water-as-a-service**	Many large-scale electrolyser plants are being constructed near solar, onshore, and offshore wind farms far away from urban areas. In this case, water supply and treatment and the maintenance of plants remain a crucial challenge as electrolyser plants require pure deionized water for hydrogen production and need regular maintenance checks.
8	**Blending Into The Gas Grid**	Pipeline safety and infrastructure upgrade costs, loss of energy density, and the long-term cost discrepancies compared to the electrification of natural gas-fired heat applications are some of the critical challenges that need to be overcome to drive the blending of green hydrogen with natural gas.

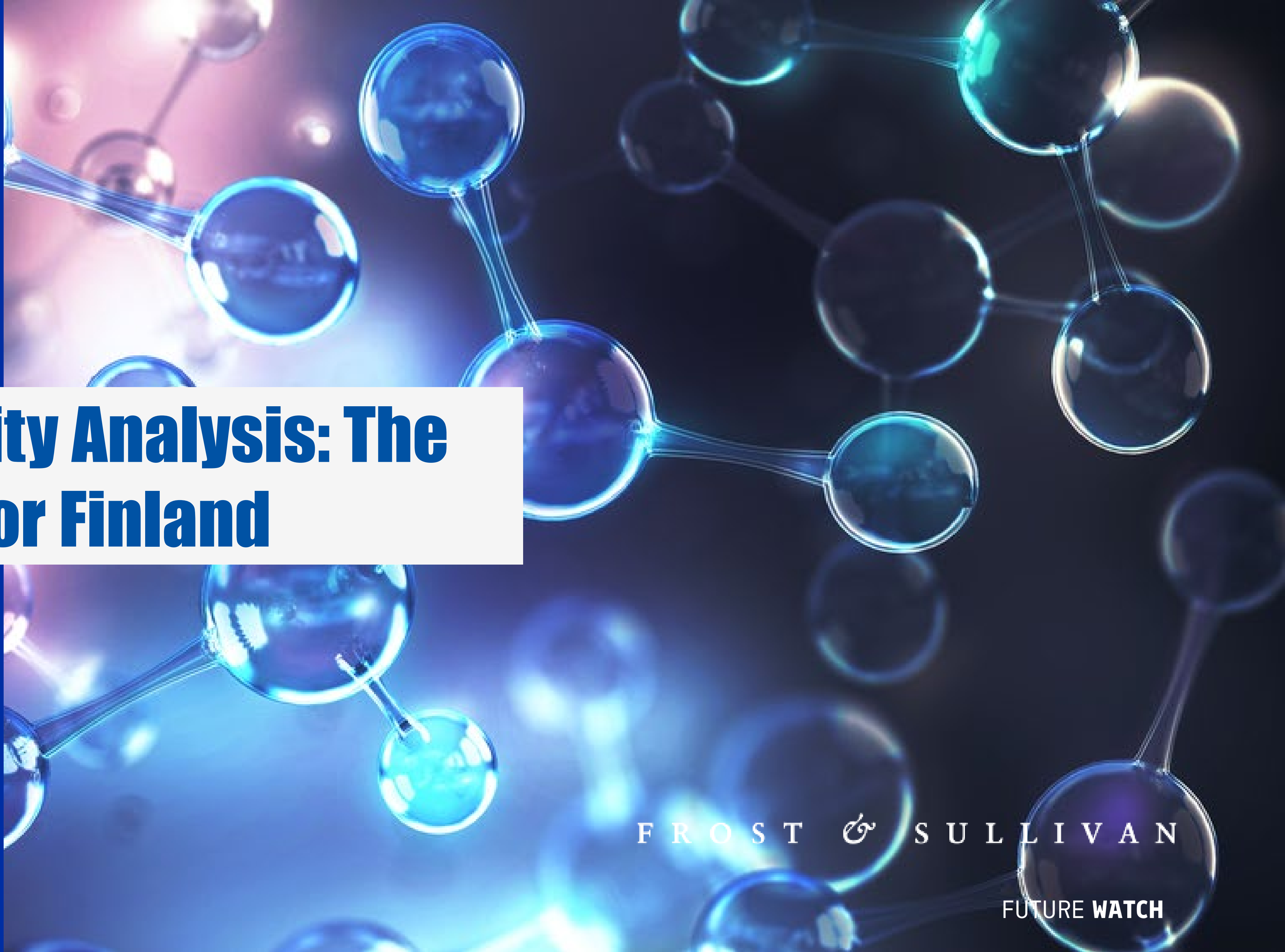
Source: Frost & Sullivan

KEY BUSINESS OPPORTUNITIES – CHALLENGES TO ADDRESS

No.	Growth Opportunity	Challenges
9	**Nuclear Produced Hydrogen**	With the closure of coal power plants and the reduction in the share of electricity generated from fossil fuels across many countries, many nuclear power plants are already operating at total capacity. In addition, the development of solid oxide electrolyser (SOEC) technology for the efficient production of hydrogen from nuclear is still in its early stages.
10	**Hydrogen Production From Waste Heat**	Low technology readiness levels, high costs, and lack of pilot projects are the key challenges involved in adoption of waste heat systems for hydrogen production
11	**Energy Hubs & Green Hydrogen Production**	Substantial capital investments in logistics and the construction of energy hubs present a significant challenge for today.
12	**Circular Economy**	Lack of regulations supporting the circular economy, lack of infrastructure for waste treatment, lack of recycling technology, and poor business model plan are the critical challenges for adopting the circular economy in the hydrogen value chain.
13	**Digital Twin**	The digital twin technology should be able to simulate both simple and complex processes involved in electrolyser plants. Plant operators must become aware of and deploy digital technologies across hydrogen electrolyser plants to implement a digital twin successfully.
14	**Digitalization of Hydrogen Industry**	The adoption of digital technologies in the green hydrogen value chain needs to be improved and expanded. The transition to a green hydrogen economy would require significant investments in digital technologies and new infrastructure to produce, store, transport, and deliver hydrogen to end-user segments.
15	**Aviation & Maritime Fuels**	Lack of supportive regulatory frameworks, support mechanisms, and clarity and alignment across government and regulatory bodies regarding synthetic fuels are the significant barriers that synthetic fuels must overcome.
16	**Industrial Decarbonization**	The cost of utilizing green hydrogen for industrial decarbonization will be high. While efforts are underway, a framework of incentives and support grants is needed to boost investment further and drive the adoption of cost-effective hydrogen technology solutions for the decarbonization of the industries.

Source: Frost & Sullivan

Opportunity Analysis: The So What for Finland



KEY BUSINESS OPPORTUNITIES – FIT FOR FINLAND

No.	Growth Opportunity	What is in it for Finland?	Recommendations for Finland
1	**Power-to-X**	Finland aims to achieve carbon neutrality by 2035. Power-to-X (P2X) will not only play a significant role in achieving emission reduction targets and increasing energy self-sufficiency in Finland but also support Finland in exporting/sharing technological expertise with other countries.	• Kick-start the Finnish P2X efforts through supportive regulatory frameworks and supportive mechanisms • Issue Green Certificates for green/low-carbon hydrogen produced from renewables, other low-carbon sources, and P2L fuels to demonstrate that energy is sustainable and emission-free.
2	**Green Ammonia**	Finland has solid technological expertise in icebreakers and ice-going vessels, cruise ships, offshore solutions, and port technology. The Finnish maritime industry is taking a collaborative approach to innovating and developing clean fuel solutions to decarbonize its maritime sector, which is possible by using green ammonia as fuel.	• Establish a regional partnership with other Nordic countries to provide investments to build infrastructure for producing green ammonia and utilize it as a maritime fuel creating fossil-free regional shipping routes. The funding must cover investment in conversion or new vessels, necessary infrastructure, and operating subsidies for green ammonia.
3	**Synthetic Fuels**	The technology needed to make synthetic fuels exists and is already on the Finnish market. Finland can produce synthetic fuels on a large scale by combining CO2 emissions from pulp mill smokestacks and green hydrogen from its RES, which would replace petrol and diesel. Finland has the potential to export synthetic fuels.	• Kick-start pilot & demonstration projects on production and utilization of synthetic fuels • Issue Green Certificates for synthetic fuels produced from green hydrogen and incentives to produce and purchase synthetic fuels.
4	**Electrolysers + Renewables As Standard**	Finland has a robust electric grid and the potential to build new renewable wind power offshore and onshore. Offshore wind projects in Finland are in an early stage of development. They will play a key role in increasing the share of renewable energy in the Finnish energy mix and contribute significantly to producing green hydrogen and decarbonizing its chemicals industry.	• Secure investments and define regulatory procedures for offshore wind energy development in Finland. • Engage with stakeholders in the offshore wind value chain and electrolyzers and support adopting digital technologies to bring down the cost economics of offshore wind farms and electrolyzer plants.

Source: Frost & Sullivan

KEY BUSINESS OPPORTUNITIES – FIT FOR FINLAND

No.	Growth Opportunity	What is in it for Finland?	Recommendations for Finland
5	**Utilisation Of Recovered Carbon Black**	The Finnish tire manufacturers are exploring opportunities to cut down carbon emissions and release volatile organic compounds (VOCs) from their production sites. A combination of recovered carbon black and pure carbon black produced through methane pyrolysis of natural gas would enable Finland to reduce harmful emissions from its tire and other chemicals industries.	• Engage with the industry to understand the infrastructure requirements for producing recovered carbon black. • Scale up the production of hydrogen and carbon black through methane pyrolysis to reduce the cost associated with production and utilization. • Investigate possible ways to encourage industries to utilize both forms of carbon
6	**Advanced Material Supply**	Finland has strong technical expertise in the R&D of advanced and functional materials, chemical synthesis, and energy storage. The country's research institutes, businesses, and government organizations can partner/collaborate to leverage their technical expertise to develop/synthesize advanced hydrogen production, storage, and transportation materials.	• Deepen engagement with R&D institutes, government organizations, industries, and universities to understand the requirements for research on advanced materials. • Secure public & private investments to support R&D with respect to materials involved in hydrogen production, storage, and transport.
7	**Water Treatment Systems/Water-as-a-service**	The water supply system in Finland is robust, reliable, and cost-effective and consistently ranks high in international comparisons.	• Support the Finnish water industry so it can play a central role in the development of a centralised water treatment infrastructure for electrolyzer plants.
8	**Blending Into The Gas Grid**	Blending green hydrogen with natural gas can generate heat and power with lower emissions than using natural gas alone. In the short- and mid-term, Finland could leverage its offshore potential to produce green hydrogen that could be blended with natural gas and significantly reduce its carbon emissions from industrial processes that use heat.	• Coordinate internally with the gas network operator to do a feasibility check on the health of the current gas transmission network and the percentage of hydrogen that can be blended with the network.

Source: Frost & Sullivan

KEY BUSINESS OPPORTUNITIES – FIT FOR FINLAND

No.	Growth Opportunity	What is in it for Finland?	Recommendations for Finland
9	**Nuclear Produced Hydrogen**	Hydrogen produced from Finnish nuclear power plants can play a crucial role in decarbonizing the country's carbon-intensive industrial sectors, including refineries, the metals industry, and chemical plants. The VTT Technical Research Centre of Finland is studying the potential use of small modular reactors (SMRs) for district heating, electricity generation, and hydrogen production.	• Foster collaboration between nuclear power plants and electrolyzer companies for pilot and demonstration projects highlighting the potential of nuclear power plants in hydrogen production.
10	**Hydrogen Production From Waste Heat**	The metal industry is an important industrial sector in the Finnish national economy. Finnish metal industries could leverage their massive waste heat potential with SOEC Technology to produce low-carbon hydrogen at lower costs. The low-carbon hydrogen produced this way can be used as a feedstock to supply heat to Finnish metal industries and reduce carbon emissions.	• Foster collaboration between industries and electrolyzer companies for pilot and demonstration projects highlighting the potential of waste heat in hydrogen production.
11	**Energy Hubs & Green Hydrogen Production**	In its National Recovery Plan, the Finnish government acknowledges the crucial role offshore wind energy and P2X Technology could play in aiding the country achieve its decarbonization goals.	• Engage with other countries bordering the Baltic Sea to develop a plan to assign areas for constructing new offshore wind capacity and energy hubs and decide on the split between electricity and hydrogen produced and the re-usability of offshore gas infrastructure.
12	**Circular Economy**	Finland was the first country in the world to prepare a national road map to a circular economy in 2016. The Finnish government supports entrepreneurship in creative reuse, or upcycling, and seeks to reduce waste going to landfills drastically.	• Build an attractive business climate for circular economy with different stakeholders in the hydrogen value chain.

Source: Frost & Sullivan

KEY BUSINESS OPPORTUNITIES – FIT FOR FINLAND

<table>
<tr><th>No.</th><th>Growth Opportunity</th><th>What is in it for Finland?</th><th>Recommendations for Finland</th></tr>
<tr><td>13</td><td>Digital Twin</td><td rowspan="2">Digital technologies can improve the economics of renewable power and hydrogen produced from electrolyzer plants. Finland tops the Digital Economy and Society Index (DESI) in the latest EU annual digital performance and digitalization progress evaluation. The country Finland ranks first in the integration of digital technology in businesses and e-commerce. Finnish companies continue to embrace advanced digital technologies, including cloud solutions and AI technology, in their operations.</td><td rowspan="2">• Work with companies offering digital solutions to determine how best to leverage these technologies to enable Finland to transition smoothly toward a hydrogen economy.</td></tr>
<tr><td>14</td><td>Digitalization of Hydrogen Industry</td></tr>
<tr><td>15</td><td>Aviation & Maritime Fuels</td><td>Synthetic aviation fuels (SAF)(Biofuels and P2L Fuels) contribute to sustainable air transport by reducing aviation's climate-relevant emissions. Finland wants to achieve a "zero-emission" status in domestic aviation by 2045, and SAF will help the country achieve its goals. The Finnish market for synthetic fuels will grow considerably in the coming years with increased green hydrogen production.</td><td>• Engage with industry to understand the infrastructure requirements (including CO2 infrastructure) for developing synthetic fuels production capacity. Also, engage with neighbouring countries to understand their appetite for synthetic fuels, cost considerations, and time horizons for export.</td></tr>
<tr><td>16</td><td>Industrial Decarbonization</td><td>Finland acknowledges the role green hydrogen could play in decarbonizing its energy-intensive industries. The country wants to be a forerunner in enabling decarbonization solutions across its industrial sector, and 14 Finnish industries have already presented their low-carbon industry roadmaps. The industries include steel & metal, pulp &paper, food & beverage, and chemical and textile industries.</td><td>• Support the use of green hydrogen as a decarbonizing tool in industrial processes and study the impact of replacing fossil fuels with equivalents produced with green hydrogen to understand the effects of future cost and market developments for the Finnish industry and determine how to ensure the sector's competitiveness in a rapidly changing international operating environment.</td></tr>
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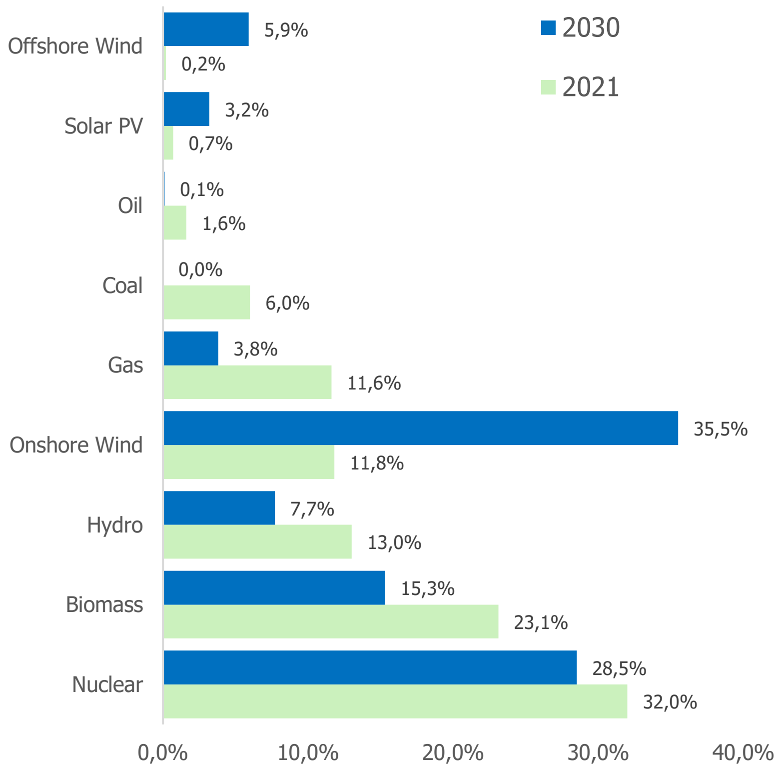
Source: Frost & Sullivan

Appendix

FINLAND'S EXCESS OF RENEWABLES

Finland's strengths include highly advanced decarbonization of electricity generation, robust transmission networks, and significant potential for constructing low-carbon electricity production

Electricity Mix (2021 & 2030)



% Share of Electricity Generated

Share of renewables in the final energy mix to increase

Finland has one of Europe's lowest carbon intensity systems, with 40% of its electricity coming from renewable sources and 72% from non-GHG-emitting sources. According to Finland's National Energy and Climate Strategy, the goal is to increase the use of renewable energy so that its share of final energy consumption will exceed 50% by the end of 2030. The country has made good progress, mainly in power generation, thanks to large shares of nuclear, hydro, and bioenergy. Fossil fuel use has significantly decreased in the past years.

The green Hydrogen market is in its early stages

Although the technology readiness for green hydrogen is high, grey hydrogen continues to dominate Finnish markets. Green hydrogen plants are still only in the pilot phase, as their production technologies have not been sufficiently cost-efficient to compete with other existing production technologies. However, green hydrogen will assume increasing capacities by 2030, and reductions in renewable power costs will drive higher adoption of green hydrogen.

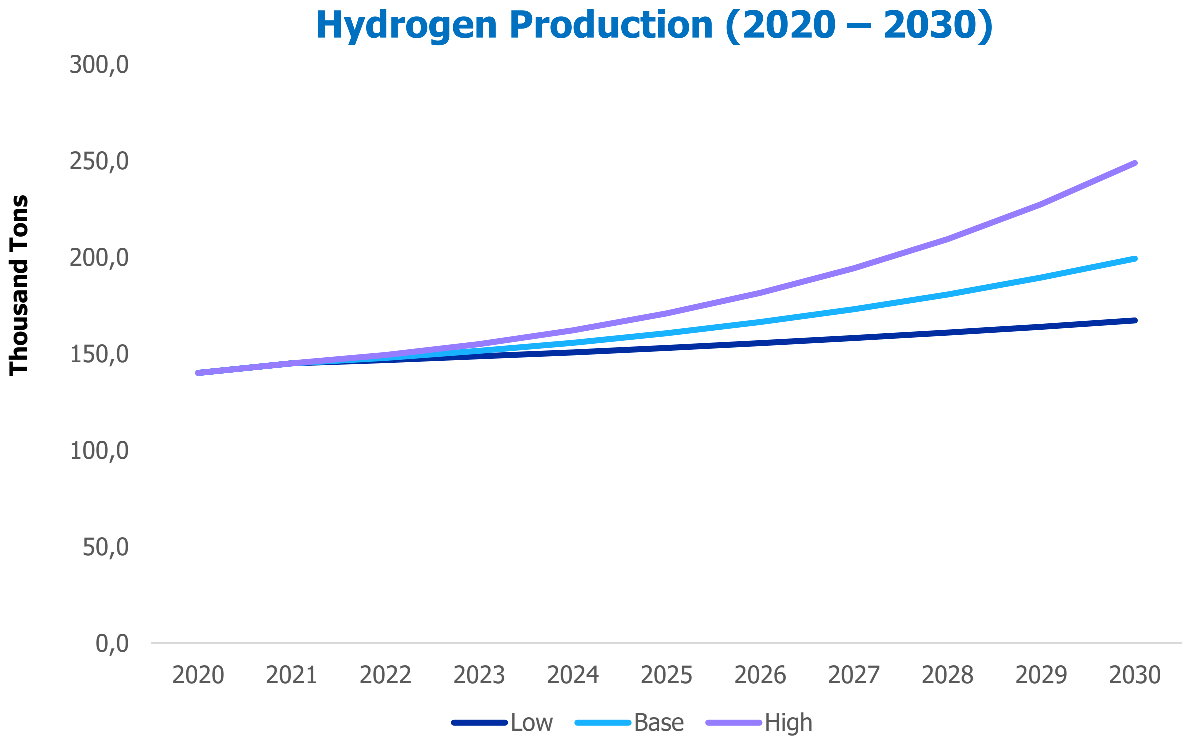
Source: Frost & Sullivan

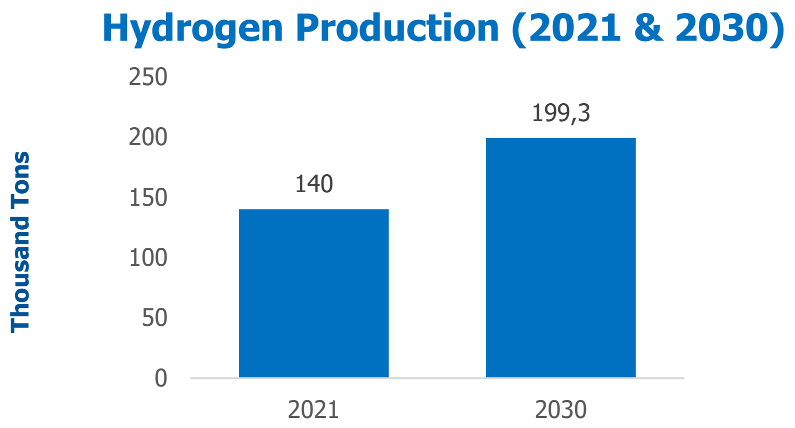
FINLAND'S HYDROGEN PRODUCTION

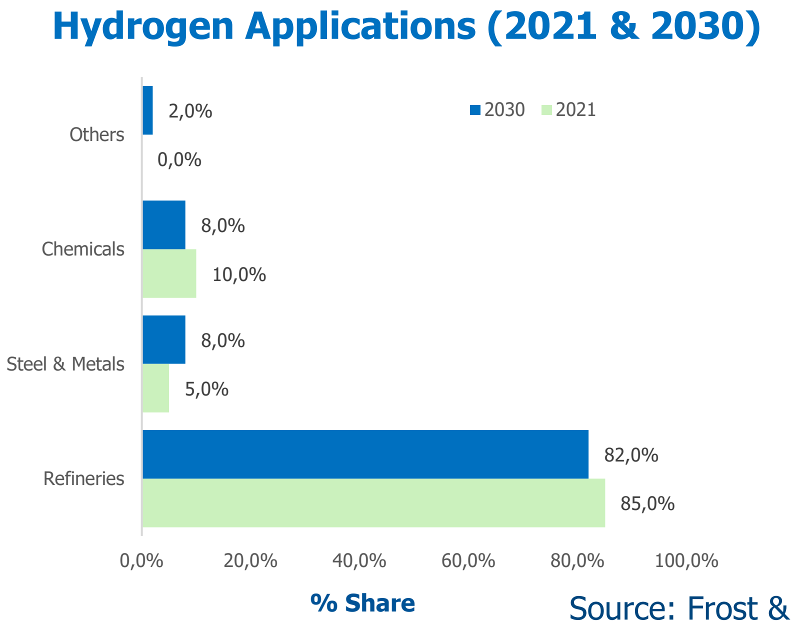
Finland already has considerable experience with the industrial use of hydrogen, particularly in oil refining and biofuel production

Refineries to drive demand for hydrogen

Refineries are the largest consumers of hydrogen followed by production of steel & metals and chemicals. With Finland keen to decarbonise heavy industries, the demand for hydrogen will gradually increase across refineries and chemical industries. Market consumption will still be dominated by refineries by 2030.





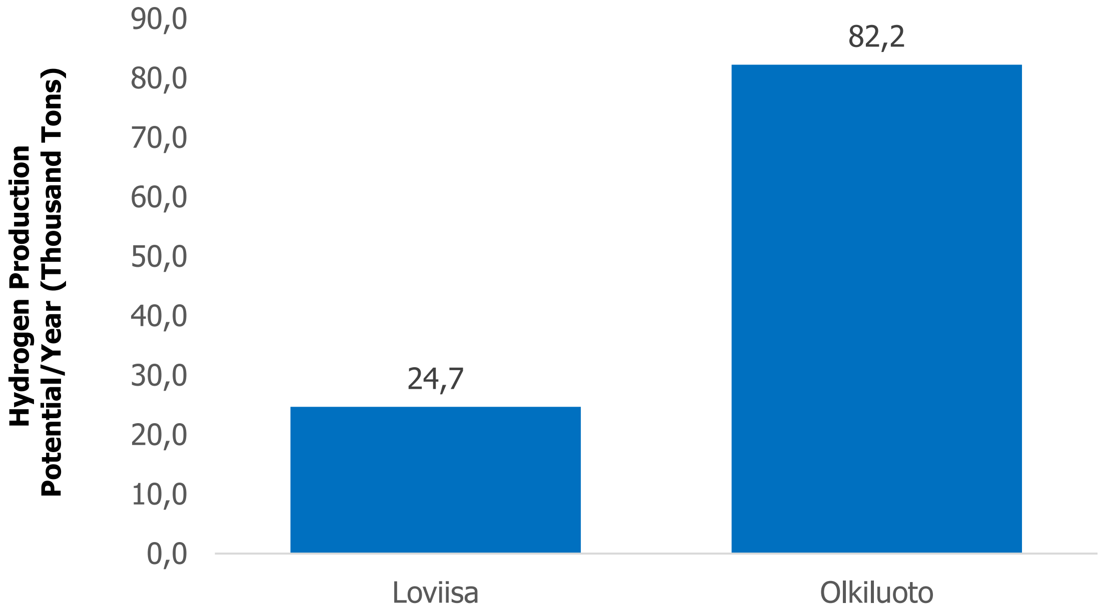


Source: Frost & Sullivan

NUCLEAR HYDROGEN

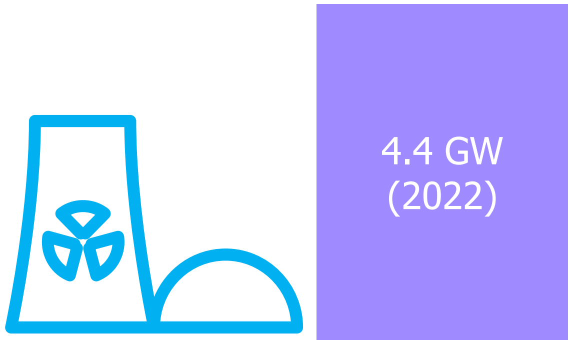
Finland is currently working on phasing out coal and increasing the share of nuclear power in energy production which will provide an opportunity for production of clean hydrogen

Hydrogen Production Potential from Nuclear Power Plant (2022)



Assumptions: SOEC electrolyser installed equivalent to installed capacity. Electrical Energy Required to Produce Hydrogen (kWh/kg): 35 kWh/kg (SOEC); Nuclear Plant production Capacity: 10%

Nuclear Capacity (2022)



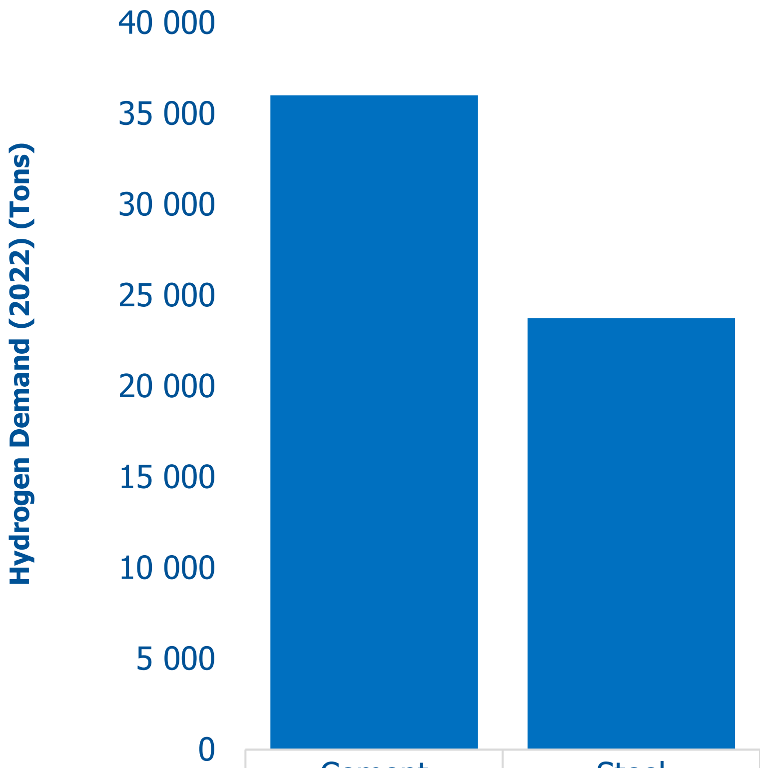
Finland has all the ingredients necessary to develop a competitive and sustainable hydrogen economy. The country's nuclear fleet and low-carbon economy present a unique opportunity to leverage Finland's expertise to build new hydrogen infrastructure assets.

Source: Frost & Sullivan

FINNISH DECARBONISATION

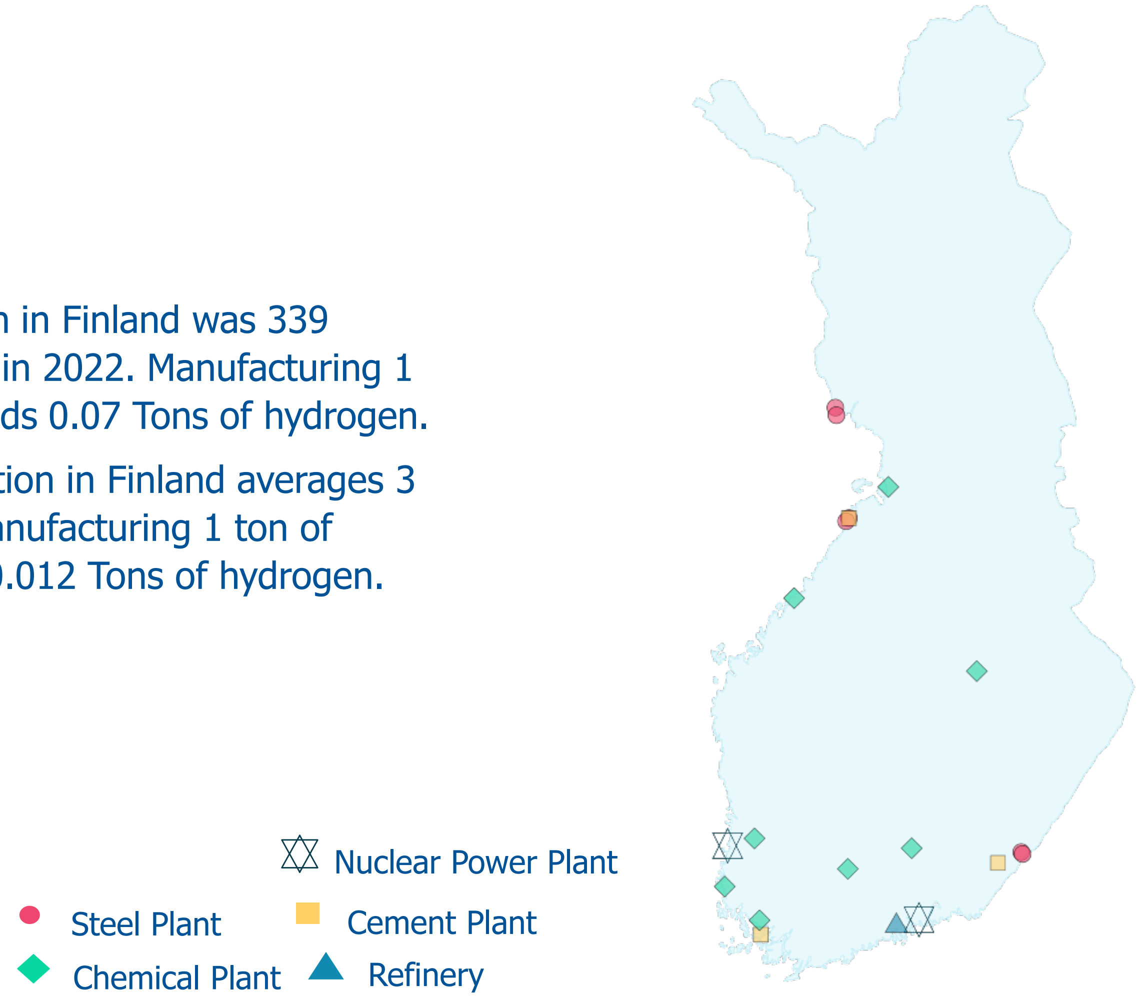
Hydrogen produced from Finnish nuclear power plants can play a crucial role in decarbonizing the country's carbon-intensive industrial sectors, including refineries, the metals industry, and chemical plants.

Hydrogen Demand Across Key-Hard to Abate Industries (Tons)



	Cement	Steel
Hydrogen demand	36000	23730

- Steel Production in Finland was 339 Thousand Tons in 2022. Manufacturing 1 ton of steel needs 0.07 Tons of hydrogen.
- Cement Production in Finland averages 3 Million Tons. Manufacturing 1 ton of cement needs 0.012 Tons of hydrogen.



Source: Frost & Sullivan

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