HYDROGEN IN MARITIME: OPPORTUNITIES AND CHALLENGES

Exploring how hydrogen and hydrogen hubs at ports can advance the global transition from fossil fuels to clean energy

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Sections in this article:

Hydrogen offers vast potential to advance the decarbonization of the maritime sector and support the broad shift to clean-energy alternatives worldwide. Ports can lead efforts in maritime to foster an integrated approach that drives this shift away from fossil fuels—one that considers how to increase the use of clean energy in port operations and vessel propulsion and how to establish production and distribution capabilities to develop the hydrogen supply chain.

All of these factors must be addressed to support the uptake of hydrogen in this decade of action,[1] which calls for accelerating solutions to deal with climate change and other major global challenges. COP26 (the 2021 United Nations Climate Change Conference) also underscores the need for stronger national plans and collective action as global leaders continue to develop their decarbonization strategies toward net zero.

This article explores opportunities for ports—to develop production and distribution capabilities through hydrogen hubs while advancing the potential applications of hydrogen; it also presents the challenges involved in transporting hydrogen and powering vessels with this alternative fuel.

HYDROGEN HUBS

MARITIME SECTOR OVERVIEW

Approximately 80 percent of global trade by volume and over 70 percent of global trade by value are carried by sea and are handled by ports worldwide.[2] The central role of ports in international trade and thus the global economy points to their importance in decarbonization efforts around the world—both as potential cornerstones for the adoption of hydrogen technologies and as backbone infrastructure for hydrogen transport and trade.[3]

The maritime sector is responsible for only 2.9 percent of global greenhouse gas emissions and moves freight with some of the lowest carbon emissions per tonne.kilometre (t.km) of any transport sector. However, maritime emissions are expected to increase as global trade continues to grow; in addition, maritime shipping is needed to support low-carbon transitions of other industries—for example, by moving wind turbine blades and lithium-ion batteries for electric vehicles. This central supply-chain role—relative to global trade and the net-zero goals of other industries—requires maritime to make headway to decarbonize in a number of areas: port construction, production and distribution of lower-carbon fuels, and vessels themselves.

IMPORT – EXPORT HYDROGEN MARKET TRENDS

As global leaders develop their climate strategy following the recent COP26, importing and exporting hydrogen is forming an essential part of their decarbonization plans. According to the World Energy Council, the number of hydrogen partnerships around the world is increasing and expected to continue to

[1] United Nations, Sustainable Development Goals, Decade of Action: The Decade of Action calls for accelerating sustainable solutions to all the world's biggest challenges—ranging from poverty and gender to climate change, inequality and closing the finance gap.
[2] UNCTAD (The United Nations Conference on Trade and Development), Review of Maritime Transport 2018.
[3] Global Ports Hydrogen Coalition, World Ports Sustainability Program.

grow; global trade in hydrogen is likely to follow current traditional fossil fuels trades. Regions and countries such as the Middle East, Africa, the United States, South America and Australia have the greatest potential to become the largest exporters, mostly due to access to ample renewable energy or access to large oil and natural gas reserves. Hydrogen needs to be decarbonized, and this will require the full capacity of our worldwide renewable energy production. Developing countries could respond to this need by exporting green hydrogen produced by the wind and solar energy they possess in abundance. Northeast Asia, including Japan and South Korea and Europe, will likely be the biggest importers of hydrogen to support their decarbonization strategies. Figure 1 represents the potential hydrogen import-export market.

The maritime sector is playing an important part to make international hydrogen trade possible, but for hydrogen to be a viable alternative that advances the transition to clean energy it is essential to develop supply chains logistics, supporting infrastructure and new ports. Globally, hydrogen import and export hubs are likely to develop where they can support the decarbonization strategies of countries and where they can build on existing trade links with port terminals.

Figure 1 – Potential Hydrogen Import-Export Market

PORTS: A CATALYST FOR THE DEVELOPMENT OF HYDROGEN HUBS

There are multiple ways to use hydrogen power in shipping and the port industry. Ports can catalyze the development of hydrogen hubs by becoming international centers for hydrogen production, application, import and transport to other countries. Hydrogen hubs can be defined as an area where various users of hydrogen across industrial, transport and energy markets are co-located. Hubs help to minimize the cost of infrastructure and support economies of scale in producing and delivering hydrogen to customers as well as facilitating cross-sector opportunities for innovation and collaboration. The development of hydrogen hubs is gaining momentum worldwide, as indicated by recent collaborative efforts:

- In Europe, the Port of Rotterdam plans to use hydrogen imported from places around the globe, such as Latin America, the Middle East, North Africa and Australia, to supply hydrogen to Europe. The Port of Rotterdam Authority and many port-based companies are preparing to build the infrastructure required for a complete system of local and international supply and demand, developing Rotterdam as one of Europe's hydrogen hubs. In neighbouring Belgium, the ports of Antwerp and Zeebrugge signed a Memorandum of Understanding (MoU) with the government of Chile to set up a corridor to speed up green hydrogen flows between South America and Western Europe. Other European ports, such as Hamburg and Valencia, are also forming alliances to promote the use of hydrogen in collaboration and with the support of the European Union.
- In North America, Apex Clean Energy, Ares, EPIC Midstream, and PCCA (Port of Corpus Christi) will explore the development of green hydrogen production, including a new pipeline and a green fuels hub at the US Port of Corpus Christi in the state of Texas.
- In Australia, the Port of Newcastle is partnering with Macquarie Group's Green Investment Group and the Commonwealth Government's Australian Renewable Energy Agency (ARENA) to support the development of a green hydrogen hub at the port.
- In Japan, the Port of Kobe is exploring the potential of using hydrogen and ammonia under a government strategy to establish itself as a carbon-neutral port by 2050. The port is looking to develop hydrogen import, storage and supply infrastructure for a targeted 2030 start-up as part of efforts to assist the proposed fuel shift inside the port and adjacent areas. Kobe is already accommodating Japan's first hydrogen import terminal with the first international import of liquefied hydrogen occurring in 2021, with hydrogen from Australia being shipped to Kobe LH2 terminal.

POTENTIAL HYDROGEN APPLICATIONS

The potential applications for hydrogen are widespread—relevant across transport sectors and industries. Application will depend on the given country's hydrogen strategy. The European Union (EU) and several countries around the world—Canada, Chile, Australia, South Korea and Japan—have detailed strategies, and the list is growing. As presented in Figure 2, hydrogen can act as a new energy vector, and the maritime sector has a major role to play.

Potential applications of hydrogen through hydrogen hubs:

- Import and export of hydrogen and derivatives such as ammonia
- Storage and distribution through multimodal transport for delivery to customers (road, rail, pipeline, inland waterways, etc.)
- Hydrogen / ammonia fuelling for ships – Hydrogen can be used directly as a fuel on board ships, but this requires specialized engines, and ship classification society certification is in its infancy stages. Hydrogen then needs to be stored in a liquid organic hydrogen carrier (LOHC) or cryogenically. Ammonia, converted from hydrogen, can be used in large engines directly as fuel.
- Use green hydrogen to power a powerplant and produce green electricity. Apply the electricity to electrified port terminals and battery-operated equipment.

– Hydrogen fuel cell for port vehicles and equipment. Fuel cells operate as an electrolyzer system. Electrical power is generated by the fuel cell—the reverse process of producing hydrogen with electrical power. This also requires port equipment and/or ships to be electrified.

– Hydrogen refuelling station for local transport, such as cars, trucks and buses.

– Application to support various industries by generating heat, electricity or chemical feedstock.

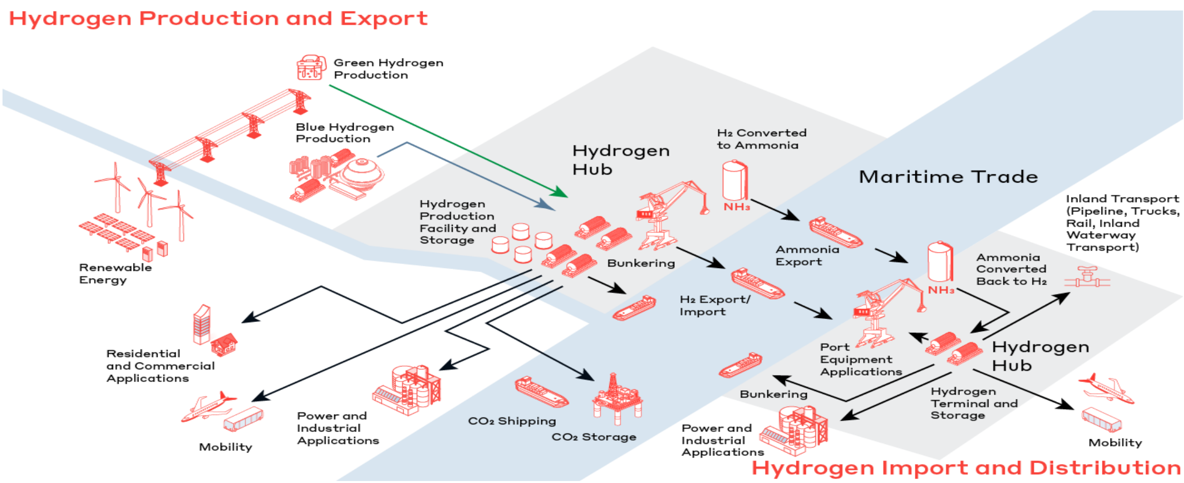

Figure 2 – The Role of Ports in the Hydrogen Supply Chain

Ports that serve as international hubs for hydrogen production, import/export, use and transportation across countries and regions will inherently have large capacity to service the needs of the port itself and support hydrogen production for trade.

Ports with hyperlocal, smaller-scale production capacity and small-real-estate footprint hydrogen hubs can support the needs of the port itself, the port's operators and its neighboring jurisdictions. These hydrogen hubs would support on-site production and delivery of hydrogen in the vicinity. In the United States, there is momentum toward hydrogen hubs[4] because of the relatively low capital expenditure, minimization of hydrogen transportation risks associated with urban ports, and the large influx of private and public capital to support creation of these hubs.

ROLE OF STRATEGIC PARTNERSHIPS

There is a need for strong public-private partnerships to advance the adoption of hydrogen. The tail winds are right with strong government policy and funding incentives, which encourage both innovation and deployment of innovative solutions.

[4] Fact Sheet: Biden-Harris Administration Advances Cleaner Industrial Sector to Reduce Emissions and Reinvigorate American Manufacturing, The White House, February 15, 2022.

In addition to traditional public-private partnerships, strategic partnerships can catalyze deployment and scaling of effective technologies, such as the partnership between WSP and BayoTech[5], an onsite hydrogen production, delivery and transportation company based in the southwest of the United States and currently developing hydrogen production hubs in the United States and the United Kingdom.

Subject matter experts and innovators bring the technology, usually in the form of a pilot. In order to deploy production, hydrogen hubs and facilities require multidisciplinary engagement beyond the technology itself—i.e. siting, permitting, design, operations and maintenance. WSP serves as subject-matter experts for deployment of technologies in compliance with local regulations, which can vary dramatically across jurisdictions and countries.

In the United Kingdom, plans are in place to explore the potential for a hydrogen super-hub in the Port of Southampton. WSP was commissioned in 2020 by the gas network operator SGN and Macquarie's Green Investment Group to prepare a feasibility study investigating the potential to decarbonize the Southampton Water industrial cluster with a focus on hydrogen and carbon capture, utilization and storage (CCUS) technologies.[6] WSP mapped the largest point emitters in the area across power and industry. These fed into mapping of the hydrogen demand across multiple sectors: industry, power generation, transport, maritime and domestic heating. Stakeholder engagement involved 27 organizations to build a picture of hydrogen demand, help with the economic vision and understand local support for the project. Our feasibility study included the design for the new scheme, inclusive of a low-carbon hydrogen production facility, CO_2 export facility and the network infrastructure required to facilitate a transition of the gas network to hydrogen. The study was concluded by setting out a phased roadmap to make it happen. Following WSP's feasibility study, SGN and Green Investment Group signed a memorandum of understanding with ExxonMobil to explore the use of hydrogen and carbon capture to reduce greenhouse gas emissions in the Southampton industrial cluster.

CENTRAL CHALLENGES

Appreciating why it is important to focus on green hydrogen requires understanding the different types of hydrogen that can be produced:

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[5] WSP USA, Emerging Growth Partnership Program, January 27, 2022.

[6] "Port of Southampton targeted for a flag-ship UK hydrogen hub," Macquarie|Green Investment Group, December 14, 2020.

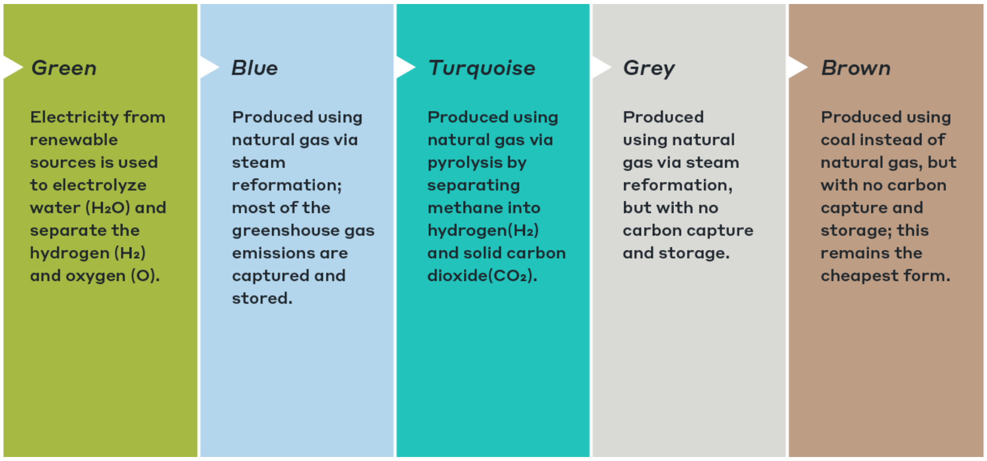

Figure 3 – Five Shades of Hydrogen – Source: Control Risks[7]

Green hydrogen produced from fresh water with renewable energy is the lowest-emission hydrogen. Blue hydrogen requires the carbon captured from the gas to be stored underground to avoid creating greenhouse gas emissions (GHG) emissions; turquoise hydrogen requires the CO_2 to be stored; grey and brown (from gas and coal without carbon capture) are counterintuitive to the idea itself. The color of hydrogen can be shifted through purchase of renewal gas credits, a trend that is emerging in the United States.

Hydrogen can also be produced from seawater, but it then needs to be desalinated first, which also requires considerable quantities of water. Using large quantities of water for hydrogen may seem counter productive with the rising need for fresh water for human needs (water scarcity), but hydrogen production plants will only be economically feasible next to ample water sources where there is no competition between water needed for human needs and for hydrogen production. In fact, research[8] has shown that using hydrogen as a method to reach a renewable energy society will lead to drastic water savings, not expenditures, by using less water for the hydrocarbon production industry. Moreover, green hydrogen production would consume 1.5 parts per million (ppm) of Earth's freshwater or 30 parts per billion (ppb) of saltwater each year, an amount smaller than what is currently consumed by fossil-fuel-based energy production and power generation. If desalination by reverse osmosis is utilized, the additional energy requirement would be less than 0.2 percent of the minimum energy required to produce the hydrogen by electrolysis, and the energy cost would add approximately $0.01 to the price of hydrogen per kilogram.

COST OF GREEN HYDROGEN

The first challenge in making the transition to clean energy via green hydrogen is that green hydrogen is not economically available in the required quantities and in the right locations for transport usage.

Green hydrogen needs to be cost effective to be used for shipping compared against the present marine gas oil or liquid natural gas (LNG). This is only possible if it is produced on a large scale in countries

[7] Joseph Smith, Oksana Antonenko, Jacob Larsen, "Hydrogen – green superhero cleared for take-off?", April 16, 2021.

[8] Rebecca R. Beswick, Alexandra M. Oliveira, and Yushan Yan, "Does the Green Hydrogen Economy Have a Water Problem?", August 17, 2021, American Chemical Society (ACS) Publications.

where ample amounts of cheap renewable green electricity and clean water are available. Significant amounts of energy are required to convert clean water into hydrogen; the energy needs to be available in excess to what is needed to feed to local energy grid.

In some cases only seawater is available, and then even more green energy is required to feed large-scale desalination plants to produce fresh water. Such excess power can come from countries where hydropower from dams is readily available or additional large-scale solar farms or windfarms can be built. There are only several countries—Canada, Argentina, Chile, Democratic Republic of Congo, Ethiopia, Norway, Sahel countries—where such power can be available in the right amount and/or where capacity can be built fast by a developer over and beyond what is needed for the country's own energy requirements. This geographical concentration would then result in green hydrogen being available a great distance from areas where it is needed for use, including as a fuel for shipping (cabotage, oceangoing long-distance carriers, river navigation, port equipment, tugs).

It is important to note that the current state of affairs determines the color of hydrogen at the point of production. The sector must account for the carbon footprint associated with transportation—i.e. establish the carbon footprint of the hydrogen up until and including the point of discharge or use.

LOW ENERGY DENSITY AND RELATED SHIPPING CHALLENGES

Hydrogen has a low-energy density compared to marine gasoil or cryogenic LNG and cannot be economically shipped in a gaseous state. If gas pipeline systems are available, then those can be re-used with minimal effort to transport hydrogen from the site of hydrogen production to the final destination; however, if pipelines are not available over part or over the full supply chain distance, then other transport means need to be found.

Three methods are commonly studied to transport hydrogen, but they require the hydrogen to be converted first:

- ammonia: Hydrogen (H_2) can be converted to ammonia by adding nitrogen (NH_2). Ammonia has a higher energy density and can be transported in a cooled fashion (–33 °C). This conversion requires large amounts of energy. Ammonia can be transported in (mostly) conventional liquified petroleum gas (LPG) tankers which have compression and boil-off capabilities for LPG at –44 °C. The world fleet of LPG tankers is neither sufficient nor sufficiently available to ship these large quantities of ammonia across the globe to where it is needed.
- liquid hydrogen (LH_2): requires H2 to be cooled to –253 °C (compared to –173 °C for LNG). It is technically possible but challenging and remains very expensive. Developing new ships could take decades and require a significant investment for an uncertain market that would compete against an established ammonia shipping market. It may be possible to reuse the world's fleet of very large crude carriers and ultra large crude carriers (VLCCs and ULCCs) and repurpose existing midstream terminals for shipping of hydrogen. This brings additional challenges, but they can be overcome.
- liquid organic hydrogen carriers (LOHCs). LOHCs refer to organic chemicals that reversibly react with hydrogen to form chemicals that can be easily transported by ship. However, there are associated considerations to make this method viable, such as reshipping after conversion, use

of energy for conversion, consumption of fuel due to the weight of the LOHC, and additional cost to replace the LOHC liquid as it degrades.[9]

Ammonia can be used directly as a fuel and requires the least effort to convert existing ship engines for use, especially those that are already capable of dual fuel. However, for the same amount of energy to be stored in ammonia compared to diesel fuel or LNG, larger tanks are required on board than for conventional fuels. This would take away useful cargo space on board.

REGULATIONS

The application of hydrogen and its derivatives in the shipping industry presents challenges in terms of transportation, bunkering, storage and use. Clear guidelines, requirements and regulations are needed to minimize the risk (e.g.explosive, flammable, toxic) of handling hydrogen and ammonia to a similar risk level as that of other alternative fuel technologies.

Regulatory bodies are preparing a set of requirements for safety measures and installation requirements. Regulations and other governmental policies remain key drivers for ship and fleet decarbonization; as the regulatory agency for the global maritime sector, the International Maritime Organization (IMO) is the most influential regulator toward this goal. Draft interim guidelines[10] aimed at providing international standard provisions for ships using fuel cell power installations have been agreed upon by IMO's Sub-Committee on Carriage of Cargoes and Containers (CCC 7) in September 2021. The Sub-Committee, with the support from the Member States and international organizations has also agreed to initiate the development of guidelines for the safety of ships using hydrogen as fuel. The development of interim guidelines for the safety of ships using fuel cells is part of the work being carried out to support new fuels and propulsion systems in shipping to meet decarbonization ambitions set out in the IMO initial greenhouse gas (GHG) emissions strategy.[11] While progress is being made, more work is required to address health, safety and environment issues.

VESSELS

As presented in Figure 4, alternative fuel uptake in the world fleet is increasing— with about 12 percent of the new ships on order in 2021 running on alternative fuel such as LNG or methanol, up from 0.5 percent of the current world fleet. However, hydrogen and ammonia only represent a small portion of the ships on order. This is a consequence of the issues identified, such as cost of production, shipping challenges and technology maturity, vessel classification and regulations. LNG can reduce greenhouse gas (GHG) emissions by approximately 20 percent. Bio-methane can be carbon neutral, while hydrogen is a zero-carbon fuel. For international shipping, hydrogen might become the dominant fuel with LNG playing an important role in the interim.

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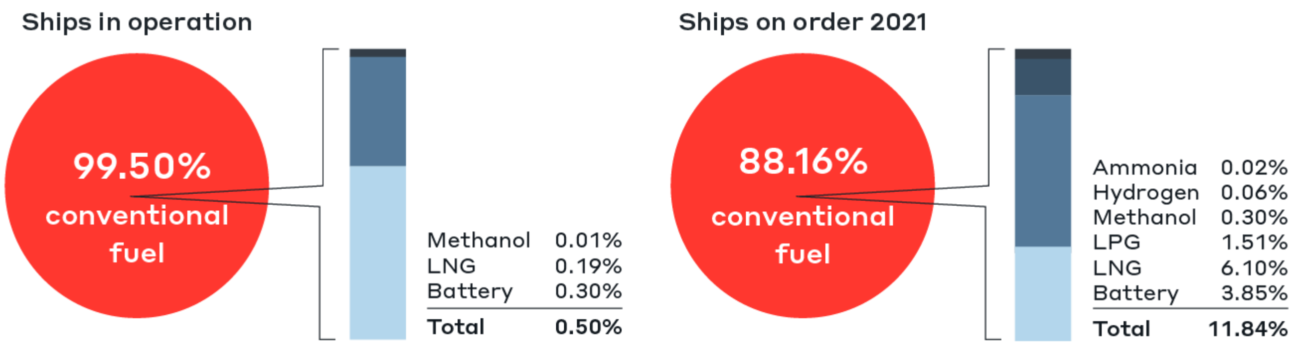
[9] Source: Anthony Wang et al., *European Hydrogen Backbone - Analysing Future Demand, Supply, and Transport of Hydrogen*, June 2021, accessed at Hydrogen Central

[10] IMO, Draft interim guidelines for ships using fuel cells agreed by Sub-Committee.

[11] "UN Body adopts climate change strategy for shipping," April 13, 2018, International Maritime Organization (IMO)

Alternative fuel uptake (percentage of ships)



Key: LNG – liquefied natural gas | LPG – liquefied petroleum gas

Figure 4 – Uptake of alternative fuels for the world fleet as of June 2021 including ships in operations and on order
Sources: IHSMarkit (ihsmarkit.com) and DNV's Alternative Fuels Insights for the shipping industry – AFI platform (afi.dnv.com)

CONCLUSIONS AND TAKEAWAYS

Creating a successful transition from fossil fuels to hydrogen in maritime requires simultaneous attention to production, distribution, vessels and regulatory factors. Integrating clean technologies across business sectors and around the world is critical to generating positive impact to achieve net zero. As industry adopts clean technologies, ports will be called upon to transport materials around the world to support clean transportation and commerce. This envisioned trend underlines the need for ports and vessels to apply clean technologies to port operations and vessels.

Partnerships are essential to support the development of hydrogen and to harmonize international standards for shipping hydrogen and derivatives and using hydrogen as fuel. Cooperation between all stakeholders—including governments, maritime organizations, policymakers, classification societies, port authorities, port operators, shipping companies, industry/energy companies and investors—will eliminate the last barriers and ensure the effective kickstart of clean hydrogen adoption at scale from production to transport and usage.

Takeaways

- Green hydrogen is one of the most promising and mature technologies that can be implemented at a sufficient scale globally and in a timely fashion to move society away from fossil fuels. The largest obstacle to implementation is not having the ability to transport green hydrogen from where it is produced to the end user at the required scale. Today, there is no ready-made solution to ship green hydrogen in the required quantities to where it is needed.
- Hydrogen needs to be decarbonized, and this will require the full capacity of our worldwide renewable energy production. Developing countries could respond to this need by exporting

green hydrogen produced by the wind and solar energy they possess in abundance. Worldwide maritime trade relationships between net exporters and net importers will need to be established to support this process. The development of supply chain logistics, supporting infrastructure and new ports will be an essential link to support hydrogen trade. Ports have the opportunity to become the catalyst for the development of hydrogen hubs at both ends—export and import.

– Potential applications of hydrogen through hydrogen hubs extend across the transport, industrial and energy sectors. Applications could include import and export of hydrogen and derivatives; storage and distribution through multimodal transport for delivery to customers; production of green hydrogen; hydrogen / ammonia bunkering for ships; implementation of hydrogen fuel cell technology for port vehicles and equipment; hydrogen refuelling stations for local transport, such as cars, trucks and buses; and support for various industries by generating heat, electricity or chemical feedstock.

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