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Shared Infrastructure for Clean Hydrogen

The bottom line. Studies of the development of clean hydrogen have often focused on the production side. Infrastructure built and used for storage and transportation warrants more attention. Among the topics that should be assessed are system design, operation, integration, and ownership; market design and governance; and planning. This Live Wire examines case studies and literature on the infrastructure for hydrogen hubs, with an emphasis on the benefits of shared infrastructure. Given the breadth of hydrogen production and infrastructure, the focus is on renewable hydrogen production for domestic use and for export after conversion to ammonia.

Global investment related to hydrogen infrastructure could amount to between $1.5 and $5 trillion between now and 2050 (Hydrogen Council 2022; Palladino 2023; ESMAP et al. 2024).

For that reason, the World Bank is receiving a growing number of requests related to hydrogen infrastructure and hydrogen hubs. This includes expansion or development of ports or port terminals for exporting hydrogen or hydrogen derivatives such as ammonia, and related infrastructure in Brazil, India, Mauritania, Namibia, Panama, and South Africa. Activities range from assessment of legal and regulatory frameworks to techno-economic studies and financing of infrastructure investments.

The overall investment requirements for hydrogen out to 2050 are highly uncertain, given that their size and timing depend on many factors. These factors include how fast the capital cost of electrolysis plants, PV and wind projects, storage and transportation infrastructure, and end-use assets fall with deployment and scale; how and where global production and demand grow over time; and the split between different applications—all of which carry significant uncertainty.

This Live Wire uses the terms “renewable hydrogen” and “low-carbon hydrogen” for what are sometimes called “green” and “blue” hydrogen. Renewable hydrogen is produced from renewable power sources. Low-carbon hydrogen is produced from fossil fuels, combined with carbon capture and storage (CCS). “Clean hydrogen” is used to designate both.

Authorship

This Live Wire was prepared by the Energy Sector Management Assistance Program at the World Bank in support of the Hydrogen for Development Partnership. H4D consists of nearly 50 partner organizations around the world. It assists countries that have included low-emissions hydrogen in their long-term decarbonization strategies.

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Why does infrastructure matter?

Infrastructure planning is key to the growth of renewable hydrogen and ammonia

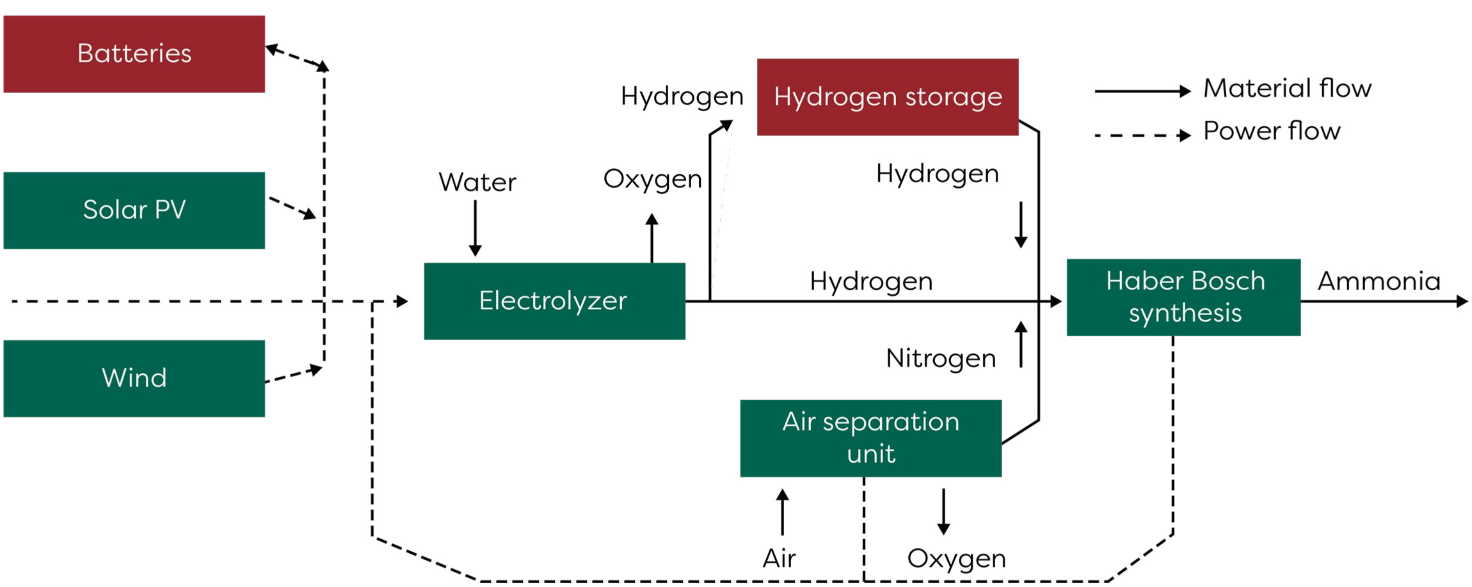
Renewable hydrogen projects for conversion of hydrogen to ammonia often consist of the elements illustrated in figure 1. The key components for the production and export of renewable hydrogen and ammonia include these components, as well as transportation- and port-related infrastructure. These facilities consist of the power generation site; electrolysis plant where electricity is used to split water into hydrogen and oxygen; hydrogen storage facilities used to balance variable hydrogen production and thereby provide a consistent supply to the ammonia plant (figure 1); a desalination plant and water pipelines for locations that lack access to clean water; the ammonia plant, including refrigerated liquid ammonia storage tanks (assuming hydrogen is converted to ammonia); and port facilities.

The specific configuration and relative sizing and location of these hydrogen production facilities and associated infrastructure will vary by project and region, as determined by a least-cost system optimization that takes future expansion into account (Armijo and Philibert 2020; Campion et al. 2024).

To cite just one example, decisions must be made whether to situate the electrolysis plant near the port and connect it to a renewable generation site via electrical transmission, or to produce hydrogen near the variable renewable energy (VRE) source and then build and use a hydrogen pipeline to transport the hydrogen gas to an ammonia plant close to the port. Figure 2 shows a range of possible configurations.

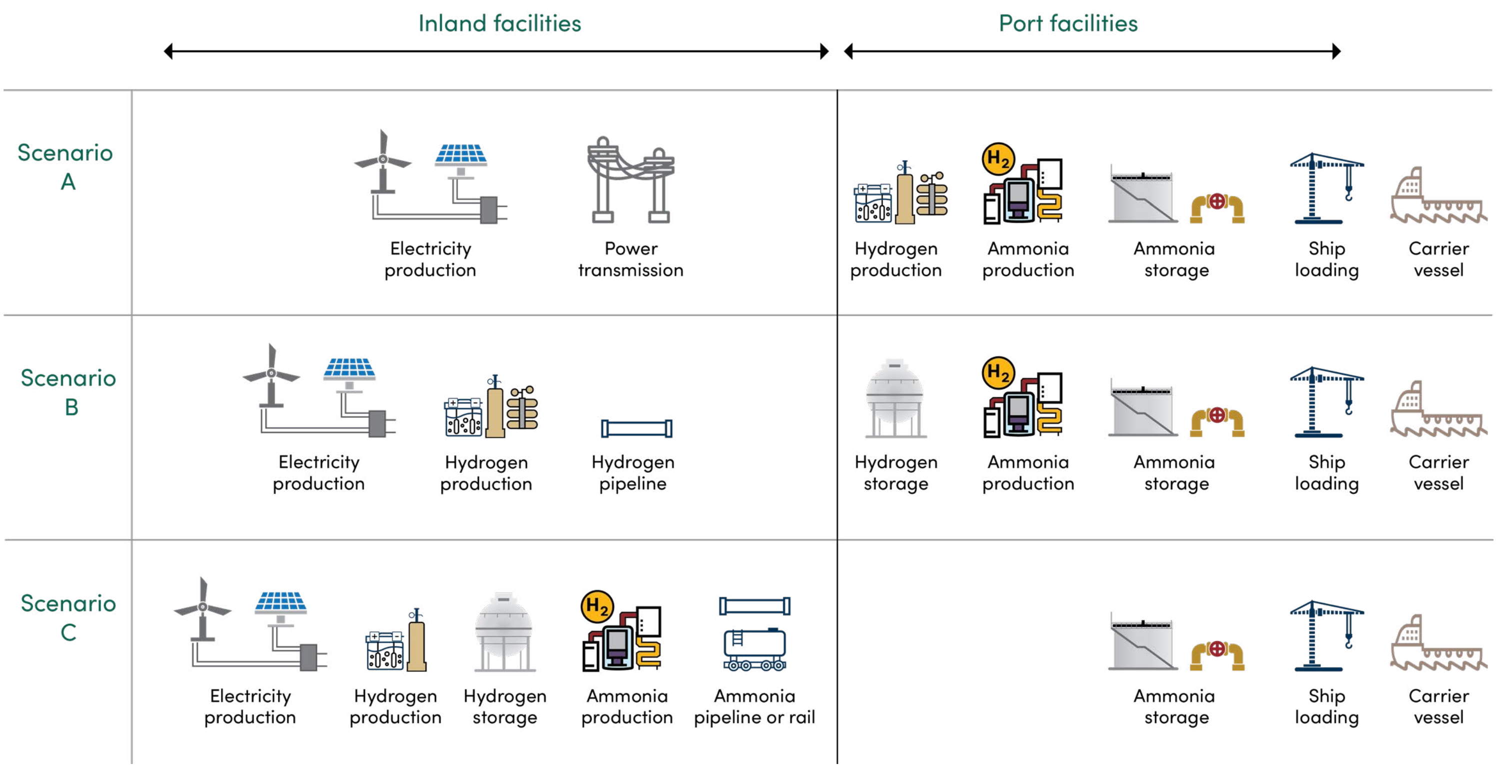
Scenario A shows remote PV and wind projects that transmit electricity to nearby port facilities to produce hydrogen and ammonia, whereas in scenario B, the hydrogen is produced near the VRE generation site and then transferred as a compressed gas by pipeline to the port. Scenario B also may require on-site storage to balance supply and demand, as well as water pipes to transfer water from a desalination plant near the coast. In scenario C, hydrogen is converted to ammonia near the VRE generation site; the ammonia is then transferred in liquid form via pipeline or rail. Variants of these scenarios may involve access to the grid to supplement PV and wind; grid access may also be available at or near the port. In some cases where salt caverns or other underground storage are available, scenarios might be modified to include seasonal hydrogen storage (Nayak-Luke 2020; DNV 2022).

Figure 1. The use of renewable electricity for the production of hydrogen and ammonia



Note: Energy storage and hydrogen storage are shown in red. These are required in the absence of a grid connection or access to so-called baseload renewables—consistent, reliable energy sources like geothermal or hydropower—to be able run the ammonia plant at a high capacity factor.
PV = photovoltaic.

Figure 2. Three possible renewable hydrogen and ammonia production and transportation routes



Source: Figure adapted from DNV 2022 and Chen et al. 2023.

For renewable hydrogen projects that are not grid connected, the combined nameplate capacity (MW) of the PV and wind project may often be oversized relative to the capacity of the electrolysis plant. The purpose of oversizing VRE relative to the electrolysis plant capacity is to lower the delivered cost of hydrogen by increasing the capacity factor of the electrolysis plant. The trade-off is curtailment, unless surplus electricity is stored. The extent of oversizing will depend on location and resources, with a range of x1.2 to x2.0 being quite common (Armijo and Philibert 2020; LBST 2022).

At port facilities, liquid ammonia (at −33°C) can be transferred to the loading arm on the jetty or berth or to a single mooring point offshore connected to the shore by underwater pipelines. Terminals with solid jetties or piers are more expensive but can provide flexibility by being designed for both the import and export of a range of goods. Greater utilization can also lower the levelized cost for loading, as the fixed costs for the berth and other port facilities are split over a larger volume and mass of cargo (Salmon, Bañares-Alcántara, and Nayak-Luke 2021).

For an illustrative port terminal exporting 1.2 million metric tons of liquid ammonia per year (equivalent to 210,000 metric tons H_2/year), refrigerated liquid ammonia storage tanks may be sized at 15 to 30 days storage and able to hold approximately twice the size of the carrier vessel (DNV 2022; Elishav et al. 2021; Goff 2020). In this case, 15 days of storage—based on average daily production—would need one or more tanks sized overall at about 80,000 m^3 (about 55,000 metric tons of liquid ammonia). Such an export terminal might be served by carrier vessels sized at 40,000 m^3 arriving once a week, or by larger vessels of about 80,000 m^3 arriving once every two weeks (Goff 2020).[1]

1. The illustrative example follows an approach similar to that in Goff (2020) but for a plant and port with smaller annual hydrogen production and ammonia exports.

Figure 3. PECEM port and port infrastructure

Source: PECEM 2023 and PECEM complex (https://www.complexodopecem.com.br/informacoes).
TMUT = multi-utility terminal.

Shall we take a closer look?

Five case studies highlight the importance of infrastructure in renewable hydrogen hubs

More than 90 hydrogen hubs are under development in 36 countries (Mission Innovation 2024). Given that design details for these projects are varied and rapidly evolving, the case studies offered here—from Brazil, South Africa, Egypt, Mauritania, northern Chile, and southern Chile—are not comprehensive, though they are illuminating.[2]

Case study 1: PECEM hydrogen hub, northeast Brazil

The PECEM industrial and port complex (Complexo Industrial e Portuário do Pecém) comprises an industrial area, deep-water port, and export processing zone (figure 3).[3] The complex, covering 190 km2 (19,000 hectares), is a joint venture owned by the Brazilian state of Ceará (70 percent) and the Port of Rotterdam (30 percent). Its commercial advantages include proximity to global shipping lanes with deep drafts to handle large ships; existing port infrastructure; space for expansion; connections to rail; and a local industrial base, including existing cement, steel, iron, and ceramic plants, and connection to the national electricity grid (PECEM 2021, 2023). Expansion plans include new berths at Pier 2 for ammonia export and at a multi-utility terminal to be used to import project equipment, such as electrolyzers and equipment for PV and wind projects.

The shared use of common infrastructure promises important benefits. At PECEM, this is reflected in plans for the shared use of the following: storage for hydrogen and derivatives; loading and offloading facilities; pipelines and water (wastewater reuse, desalination and raw water); and a 500 kilovolt power substation that provides a 3 GW connection to the grid.

2. The information in these case studies and in the review of the literature represent a snapshot of a dynamic field.

3. This case study mainly summarizes information presented by Fabio Grandchamp, COO, PECEM Complex, Brazil, at the 2nd Hydrogen for Development (H4D) Partnership meeting in Santiago, Chile on October 24, 2023; https://www.complexodopecem.com.br/institucional/.

PECEM's ambition is to become the main renewable hydrogen hub in Brazil and the main exporter to Europe via Rotterdam. The port complex has signed memoranda of understanding with national and international clean hydrogen developers to invest in the industrial zone, as well as several pre-contracts for land leases in the zone that could unlock up to US$10 billion in private capital for investments in the production of clean hydrogen and derivatives over the next decade. The first projects expected are to reach financial closure in 2026 and commissioning in 2029.

A World Bank loan provides financing for the two new dedicated berths at Pier 2 and the multi-utility terminal, and a utility corridor and pipeline connecting ammonia production in the export processing zone to Pier 2 at the port (a distance of about 12 km).

Key determinants of PECEM's success include:

- ✓ Availability of renewable energy and access to the grid[4]
- ✓ Availability of land on which to develop electricity generation and infrastructure for hydrogen production, storage, and transportation
- ✓ Tax policies and incentives, including an export processing zone
- ✓ A pre-approved environmental license
- ✓ Skilled labor

Local market opportunities including the use of renewable hydrogen for ammonia, methanol, sustainable aviation fuel, fuels, steel, chemicals, fertilizer, and soy.

Case study 2: Freeport Saldanha, South Africa

The Freeport Saldanha industrial development zone is the first South African special economic zone to include space in a commercial port, as opposed to being adjacent to a port..[5] The port is the largest and deepest natural port in the southern hemisphere, able to accommodate and service a wide range of vessels. It is located about 60 nautical miles north of Cape Town. The region has easy logistical access by sea, land, rail, and air. Freeport Saldhanha is jointly supported and funded by the National Department of Trade Industry and Competition and the Western Cape Government (Freeport Saldanha 2023, 2024).

Key advantages of the zone include:

- ✓ Very good solar and wind resources and significant available land
- ✓ A marine and energy services and engineering center
- ✓ Well-established and potentially highly suitable port infrastructure to support the export of hydrogen and hydrogen derivatives and to serve as a bunker fuel location for shipping
- ✓ Saldanha Bay Municipality's permit to build and operate a seawater reserve osmosis desalination plant processing 25,000 metric tons per day or 8.7 million metric tons per year, within 10 km of the port
- ✓ Local inland and export demand potential
- ✓ Potential off-takers of its hydrogen production—including ArcelorMittal South Africa, MyCity Bus, port equipment, and ground vehicles
- ✓ Access to a skilled workforce.

Saldanha presents first-mover advantages similar to PECEM's. It is an excellent location, with transformative value potential (in the center of a manufacturing cluster), with multiple markets and a supportive public sector ecosystem.

Prefeasibility studies will focus on catalytic investors, shared infrastructure solutions for public sector readiness, and coordination of private and public sector developments (Freeport Saldanha 2023).

Case study 3: Suez Canal Economic Zone (SCZONE), Egypt

Strategically located on the Suez Canal, SCZONE encompasses four industrial zones and six seaports.[6] The Sokhna Renewable H_2 Cluster is on the west side of the Red Sea,

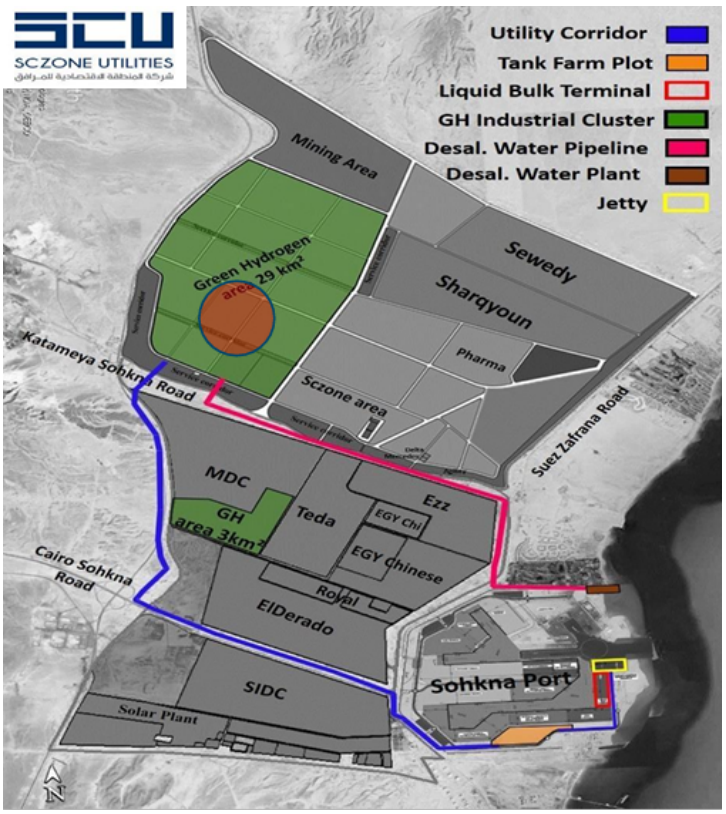
4. In recent months all hydrogen projects in northeast Brazil have been denied grid access owing to lack of grid capacity. Assessments are ongoing on what investments are needed to increase capacity. This example showcases the importance of infrastructure planning and investment for the timely roll-out of hydrogen.

5. https://www.thedtic.gov.za/sectors-and-services-2/industrial-development/special-economic-zones/. This case study summarizes information presented by Patrick Lakabane at the second H4D Partnership meeting in Santiago, Chile, on October 24, 2023.

6. This case study draws heavily on a presentation given by Ahmed Saad of the Suez Canal Economic Zone at the 2nd Hydrogen for Development (H4D) Partnership meeting in Santiago, Chile on October 24, 2023 (SCZONE 2023).

Figure 4. SCZONE at Sokhna, Egypt

Potential layout for hydrogen production cluster and port showing potential shared facilities, including use of central substation



Source: SCZONE 2023.

south of the entrance to the Suez Canal. Planned shared facilities with the SCZONE industrial complex at Sokhna may include (figure 4):

- ✓ Water desalination plant with phase 1 capacity of 250,000 m^3/day by 2026, with plans to expand fourfold
- ✓ Common area for electrolysis plants
- ✓ Utility corridor, with an operational model that considers three scenarios, based on developers' preferences and feasibility
- ✓ Liquid bulk terminal and jetty
- ✓ Tank farm, with similar ownership and operational model as the utility corridor
- ✓ Single expandable substation based on initial demand or multiple smaller substations
- ✓ Gas network, with Air Liquide ready to provide shared gas solutions, focusing on nitrogen production and integration for ammonia production.

Case study 4: Mauritania hydrogen hub

Access to the Atlantic Ocean, excellent solar and wind potential, and proximity to major markets in Europe place Mauritania in a strong position to develop large-scale renewable energy and hydrogen projects. Exploiting that potential could diversify the country's economy, create jobs, and make Mauritania a relevant player in renewable hydrogen and sustainable energy.

The country plans to develop renewable hydrogen projects to produce hydrogen and ammonia for export and domestic use (ESMAP/JESA 2025). Four projects reportedly in development call for electrolysis plant capacity of nearly 10 GW, with renewable resource capacity and electrolysis plant in an approximately 2:1 ratio, yielding expected output of nearly 6 million metric tons of ammonia per year.

Building and operating projects on this scale will require the development of extensive infrastructure. The shared use of much of that infrastructure is implied by the need for close collaboration between the government, private investors, and international stakeholders. As a recent study (ESMAP/JESA 2025) put it:

> *The infrastructure required for Mauritania's green hydrogen strategy forms the backbone of its ambitious energy transition. Ports like Nouakchott and Nouadhibou need significant upgrades to accommodate large-scale hydrogen exports, while road and rail networks must evolve to efficiently connect production zones to export hubs. Critical utilities such as desalination plants for water supply and expanded energy grids for renewable energy integration are essential to meet the industrial-scale demands of hydrogen production.*

Key activities required to support hydrogen and ammonia production at this scale include (1) extending the length of quays and deepening the draft of berths and/or access channels for the ports of Nouakchott and Nouadhibou; (2) strengthening, widening, and extending the road network to permit trucks to transport key components of renewable hydrogen plants; (3) expanding the rail network to connect hydrogen production facilities to export ports; (4) upgrading grid capacity and scaling up the integration of renewable energy to meet the demands of hydrogen production; and (5) building desalination facilities to ensure a reliable water supply (ESMAP/JESA 2025).

A milestone-driven approach will prioritize near-term investments to upgrade road and port infrastructure, construction projects tied to ammonia exports, and public-private partnerships to leverage investment and reduce financial risk. The approach will stress the importance of eco-friendly construction and community engagement (ESMAP/JESA 2025).

Case study 5: Renewable hydrogen hubs in northern and southern Chile

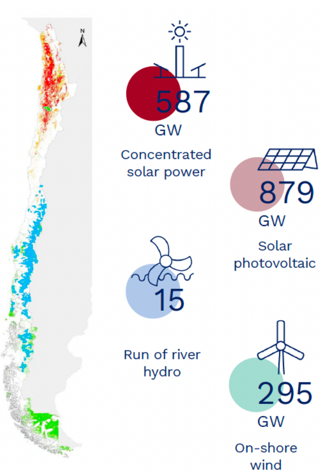
Chile's exceptional solar and wind resources have led to significant interest in the development of hydrogen hubs. The hubs would enable Chile to become a low-cost exporter of renewable hyrogen and hydrogen derivatives, and to produce and use hydrogen to provide low-carbon energy sources in certain sectors, such as for producing renewable hydrogen and ammonia for fertilizers, ammonium nitrate for explosives for the mining industry, and blending with natural gas, as well as transportation applications (Chilean Ministry of Energy 2020; LBST 2022).

Chile's National Strategy for Green Hydrogen aims to create at least two hydrogen valleys with 25 GW of electrolysis capacity deployed by 2030 (Chilean Ministry of Energy 2020). A recent study (LBST 2022) highlighted that the selection of H_2 hub locations should be based on existing infrastructure (such as ports), proximity to domestic demand, synergies with existing industry, and local capacities (availability of skilled workers), among other factors. It identified two key regions for hub development: the Antofagasta region in the north, for its exceptional solar potential, and the Magallanes region to the south, which has significant onshore wind potential.

Figure 5 shows the solar and wind resource potential (in GW) in the northern Antofagasta region and southern Magallanes region, and the location and size of renewable hydrogen projects under development in Chile (Chilean Ministry of Energy 2020; Corfo Green Hydrogen Committee 2025).

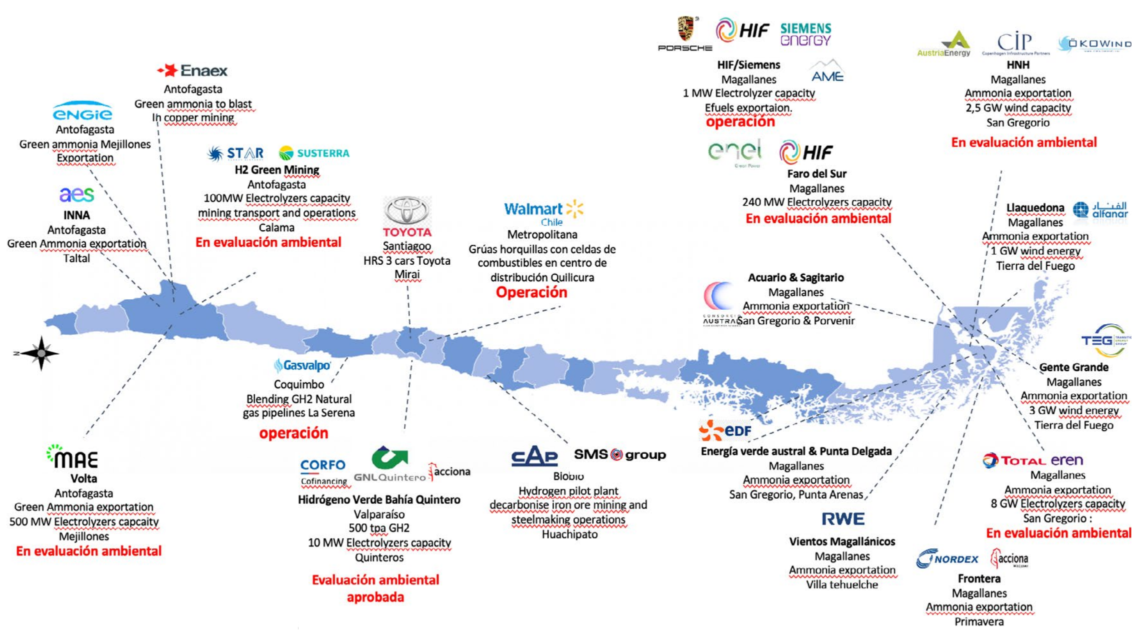
Figure 5. Renewable energy potential in Chile and location of renewable hydrogen projects in development as of 2025

a. Renewable energy potential as of 2022 (GW)



Source: Adapted from LBST (2022) and Chilean Ministry of Energy (2020).

b. Renewable energy projects in development as of 2025



Source: Corfo Green Hydrogen Committee.

The LBST study noted that if hydrogen and ammonia production were to develop as expected, existing infrastructure would have to expand substantially. The electrical grid, in particular, would need to grow to transmit needed renewable electricity to the hubs.

Antofagasta region (northern Chile)

The LBST 2022 study identified the port city of Mejillones in the Antofagasta region as the best potential port location for a hydrogen hub based on its existing infrastructure (port facilities, rail connections, proximity to solar and wind resources, grid capacity), as well as other factors (domestic demand, a skilled workforce, and the location and size of proposed renewable hydrogen projects). Noting that Mejillones met all major criteria, the study also emphasized that it was only a preliminary assessment and not the "detailed and thorough assessment" that was still required.

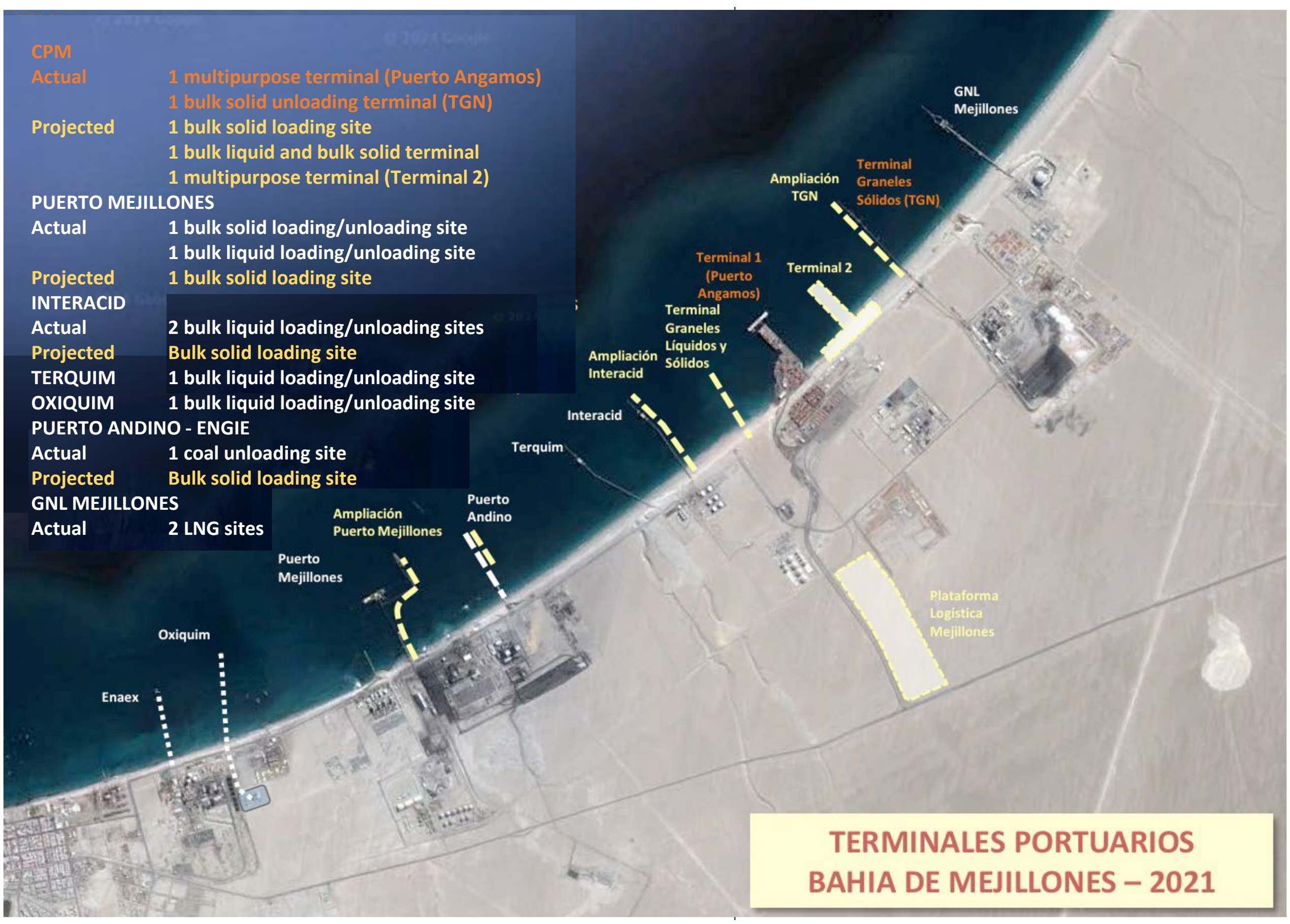
Figure 6 offers an aerial view of the privately and publicly owned terminals on Mejillones Bay.

In 2024, the multipurpose terminal at Angamos port unloaded 1,260 components of Colbún´s Horizonte wind park. Chile's largest wind park (at 860 MW) is located in Taltal province of the Antofagasta region.[7]

All of Chile's imported ammonia presently moves through ENAEX terminal, but additional port capacity will become

7. https://www.colbun.cl/en/corporate/press-room/news-and-press-releases/2024/06/03/puerto-angamos-culmina-la-descarga-del-parque-eolico-horizonte-de-colbun-un-hito-para-la-energia-renovable-en-chile-y-latinoamerica

Figure 6. Port terminals in the Bay of Mejillones, 2021



Source: Adapted from Google Earth by Arroyo (2021).

available as thermal plants are decommissioned under the national electricity decarbonization plan.

In April 2025, Terminal Graneles del Norte (TGN) and Complejo Portuario Mejillones (CPM) inaugurated a new terminal for the export of copper concentrates, with an investment of $130 million. The project added shipping capacity to the original terminal—in operation since 2011—and will allow the transfer of up to four million tons of copper concentrates annually, marking a milestone of innovation and sustainability in the port industry. Its combination of technologies makes it unique in the world.[8]

One plan under consideration is to develop shared infrastructure located in the Parque Industrial H_2 Mejillones, where the idea is for a common port and hydrogen and ammonia production plants connected to PV plants of different owners.

The potential location for a new hydrogen and ammonia industrial park, a terminal jetty, and a liquid ammonia pipeline is being analyzed (GIZ 2024). It remains to be seen whether a single port will be sufficient for the Antofagasta region, as some projects are far from Mejillones.

Either way, collaboration among stakeholders will be essential to support scale-up, innovation, and the satisfaction of future demand (Chile TNO 2024).

Complejo Portuario Mejillones (CPM) appears committed to providing the infrastructure needed for the storage and export of renewable ammonia. CPM is currently updating its master plan and exploring options to build a new liquid bulk terminal and adapt existing infrastructure. Moreover, it is seeking to collaborate with developers to build efficient export channels. Finally, CPM will likely offer logistical support for the $2.5 billion Volta project (Chile TNO 2024).

Magallanes region (southern Chile)

The Magallanes region in southern Chile has significant onshore wind resources and a substantial number of renewable hydrogen projects under development. The region's ports are connected to the Pacific and Atlantic oceans by the Magallanes Strait. There is less existing infrastructure in the Magallanes region than in the Antofagasta region. In particular, the region has limited desalination, port, and electrical infrastructure (LBST 2022).[9]

Mardones (Punta Arenas) and Laredo (Cabo Negro) could be the first port facilities to unload components for renewable hydrogen projects in the region. Both ports have had initial experience unloading wind turbines. In July 2025, Mardones unloaded two wind turbines (4.5 MW) for Total Energies' Rio Cullen wind farm project in Tierra del Fuego Province, Argentina.[10] Laredo has unloaded three wind turbines for the Pecket wind park (2.5 MW) and three for the Cabo Negro park (3.45 MW). Hosting would require adaptation or expansion of terminals to allow for importation of electrolysis equipment and large wind turbine blades (BN Americas 2024) and to enable construction to move forward on the most advanced projects, examples of which are discussed below in more detail.

- ✓ The largest planned project is the H_2 Magallanes project (Total Eren). Located near San Gregorio, the project is planned to have 10 GW of wind capacity, 8 GW of electrolyzers, a desalination plant, an ammonia plant, and a port terminal for the export of renewable hydrogen. The expected annual output capacity of 47,000 GWh of electricity is expected to produce 800,000 metric tons of hydrogen each year for conversion to 4.4 million metric tons of ammonia for export, with hydrogen production starting in 2027 (Atchison 2021).
- ✓ Total port specifications in the environmental impact study indicate that the project will have three berthing sites in San Gregorio Bay.[11] Two of them will be equipped to handle cargo imports, the transfer of ocean-going vessels to shallow-draft barges, and the future export of ammonia. The landward side of the platform will be used exclusively for unloading. Once importation of materials and supplies is complete, the berthing sites will be reconditioned for ammonia exports.

8. https://mejillones.com/es/cpm/inauguran-nuevo-terminal-portuario-para-embarcar-concentrados-de-cobre-con-una-inversion-de-us-130-millones/

9. https://www.acades.cl/wp-content/uploads/2025/04/Catastro_ACADES_09-04-25.pdf

10. https://www.epaustral.cl/iniciamos-inedito-movimiento-de-aerogeneradores-desde-terminal-mardones-a-tres-puentes-en-punta-arenas/

11. https://www.sea.gob.cl/portal-de-participacion-ciudadana-y-consulta-indigena/proyecto/proyecto-de-produccion-de-hidrogeno

- ✓ The Haru Oni e-fuels plant (HIF) uses wind energy and electrolysis to produce renewable hydrogen. The plant uses CO_2 from a biogenic source and combines it with hydrogen to produce e-fuels, including synthetic gasoline and liquefied gas. These e-fuels will enable existing infrastructure to become low carbon by continuously reusing and recycling CO_2 (HIF 2024a). The pilot plant, with a 3.4 MW wind turbine and a 1.2 MW electrolysis plant, began exporting e-gasoline in late 2023. The commercial-scale Cabo Negro facility is planned to have an annual production capacity of 173,000 metric tons of e-methanol and 70,000 tons of e-gasoline (HIF 2024b).

- ✓ The HNH Energy project plans to produce and export renewable ammonia from a terminal near San Gregorio. Construction is set to begin in 2027, with commercial operation commencing in 2030. The first phase includes a seawater desalination plant; onshore wind farms producing 1.4 GW from 194 turbines; plants for the production of hydrogen and ammonia; an ammonia storage facility; and a multi-purpose port with a sea terminal available to other market participants. Each year, the estimated production of 270,000 tons of hydrogen will be converted into approximately 1.3 million tons of ammonia (EQS 2024).

"The importance of public-private partnerships in the development of shared hydrogen port terminals and other infrastructure to facilitate the production and export of ammonia is illustrated by several recent agreements."

The importance of public-private partnerships in the development of shared hydrogen port terminals and other infrastructure to facilitate the production and export of ammonia (while making the best use of existing infrastructure) is illustrated by several recent agreements between the National Petroleum Company (ENAP) and several international energy companies.

In April 2023, ENAP signed an agreement with Total Eren, HIF Chile, and HNH Energy that aims to transform the Laredo maritime terminal infrastructure into a hydrogen industrial hub to enable imports of equipment. The estimated investment cost of the project is $60–70 million (ENAP 2024).

In July 2023, ENAP signed a separate agreement with six international energy companies—FreePower Group, EDF, HIF Chile, HNH Energy, RWE, and Total Eren Chile—to turn the Gregorio Maritime Terminal into the largest industrial complex in the Magallanes region and to facilitate the production and export of ammonia and other hydrogen derivatives. The estimated investment is between $700 and $900 million, including storage (ENAP 2024).

In a first stage, the agreement will conduct feasibility studies for the development of a new maritime terminal for unloading equipment and new storage and export facilities for finished goods (Hydrogen Central 2023).

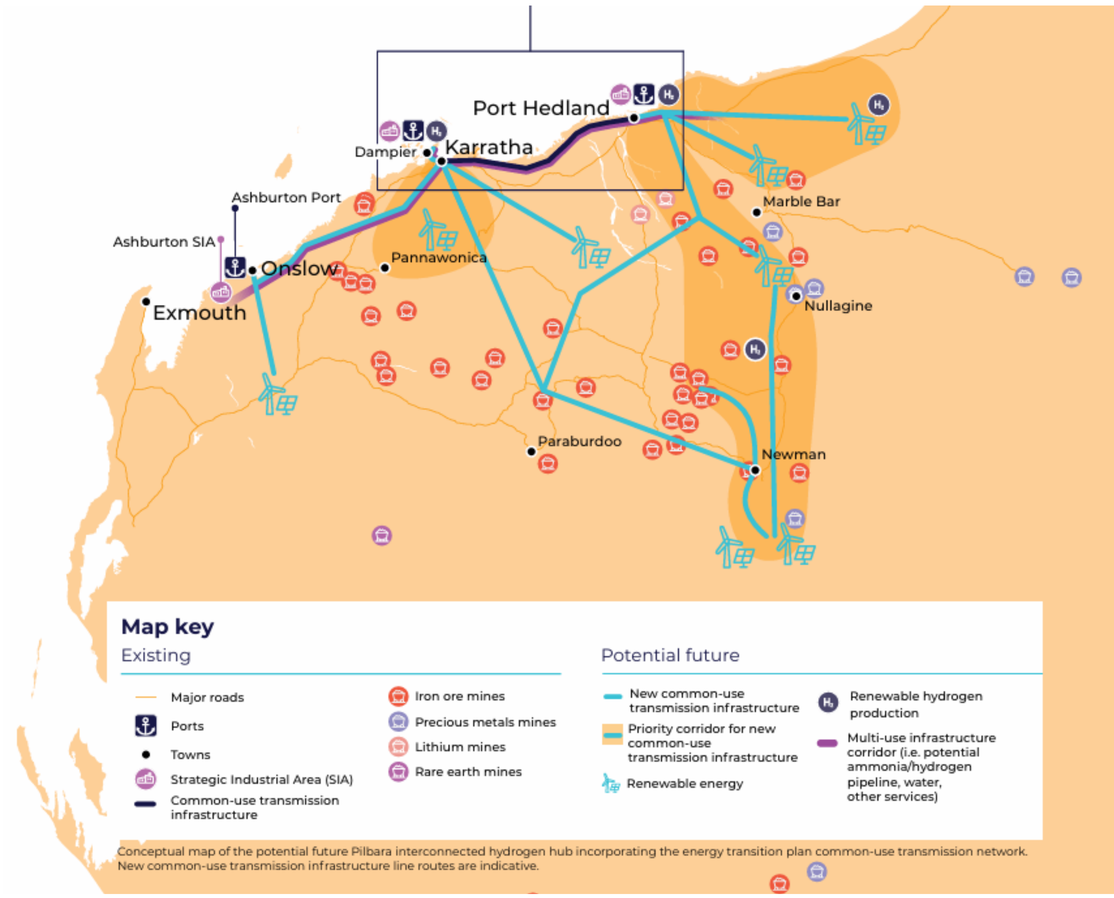
What have we learned?

Some common practices for renewable hydrogen infrastructure projects are emerging around the world

Storage and transportation assets, including port facilities, often benefit from shared use. Shared use can lower costs by increasing the utilization of assets and avoiding unnecessary duplication. Multiple smaller users can generate the demand needed to build the infrastructure in the first place. Scale matters for many types of energy infrastructure. Capital expenditures, in particular, fall rapidly with scale (Khan, Young, and Layzell 2021; DeSantis et al. 2021). In this way, high-capacity hydrogen pipelines and electrical transmission lines can be built to connect renewable hydrogen projects with end users, or a single electrical substation may be able to serve multiple electrolysis plants in an industrial park near a port (GIZ 2024). Cross-sectoral sharing of infrastructure may also be possible. For example, excess capacity of fiber optic networks owned and operated by electrical transmission providers might be used by telecom or internet service providers.[12] The shared use of infrastructure may also reduce the environmental footprint associated with the deployment of renewable hydrogen projects. For these

12. https://blogs.worldbank.org/en/ppps/infrastructure-sharing-energy-and-digital-development-takeaways-cross-sectoral-cooperation?-form=MG0AV3.

Figure 7. Conceptual map of the potential Pilbara interconnected hydrogen hub incorporating new common-use transmission infrastructure



Conceptual map of the potential future Pilbara interconnected hydrogen hub incorporating the energy transition plan common-use transmission network. New common-use transmission infrastructure line routes are indicative.

Source: Western Australia DJTSI 2024.

reasons, shared use and even open access are common business models for the use of rail, pipelines, electrical transmission, berths, and storage assets.

Hydrogen hubs are often planned as locations where “producers, users, and exporters of renewable hydrogen are co-located to improve competitiveness and attract investment through the coordination of multi-user infrastructure” (Western Australia DJTSI 2024) and to share infrastructure and expertise so as to bring the industry to scale. Benefits include lowering the cost of production, encouraging innovation, and enhancing skills and training effort (Australian DCCEEW 2024). Figure 7 provides a conceptual map of common-use infrastructure for electrical transmission and multi-user pipelines for hydrogen, ammonia, water, and other services in the Pilbara region of Western Australia (DJTSI 2024).

“Hydrogen hubs are often planned as locations where ‘producers, users, and exporters of renewable hydrogen are co-located to improve competitiveness and attract investment through the coordination of multi-user infrastructure’ (Western Australia DJTSI 2024) and to cooperate to share infrastructure and expertise so as to bring the industry to scale.”

The shared use of hydrogen infrastructure to gain economies of scale is often implicit in many modeling approaches and feasibility studies for renewable hydrogen projects. For example, a recent study into the economics of clean hydrogen export from Norway (Svendsmark, Straus, and del Granado 2024) weighed key investments in hydrogen technology and capacity expansions of wind farms and the power grid. It found that the critical factors were identifying production locations and the distance and transport methods to the market.

Ownership is another issue. Third parties may own some of the storage, transportation, conversion, and port facilities covered by shared-use arrangements. They may provide services to multiple users under fee-based tolling agreements, wherein the fee is a mix of fixed payments for capacity (to cover capital recovery) and variable payments based on actual usage. Under such arrangements the infrastructure owner does not take title to the commodity as it moves downstream, thereby avoiding commodity price risks (DNV 2022; GIZ 2024).

Under the fully integrated model, by contrast, the infrastructure for generation, electrolysis, transportation, conversion, storage, and port handling may all be owned and operated by a single joint venture. The chief advantage of integrated models is that lower revenue risk can allow for greater debt levels and a lower cost of capital (DNV 2022). For some large renewable hydrogen projects, the ownership of generation assets may be integrated with hydrogen production, ammonia conversion, and some port facilities.

Between these extremes lies a range of semi-integrated models (with a variety of contract structures), where ownership of electricity, hydrogen production, transportation, ammonia production, and storage and port facilities can be divided in various ways, including cases where a single owner may still use a tolling arrangement for some infrastructure assets to better allocate costs. Contract structures will depend on the ownership structure along the value chain, which may vary significantly for hubs in different countries and regions.

As hydrogen hubs and partnerships evolve, plans may change. For example, while some early plans for the Australian Renewable Energy Hub suggested that hydrogen and ammonia might be produced near the PV and wind site and then exported using a dedicated mooring point close to the generation site, more recent information suggests a phased approach involving the wider use of shared infrastructure, including: (1) using a new 330 kV electrical transmission line connecting the PV and wind generation site to the existing Pilbara network and to Port Hedland (approximately 270 km east); and (2) later producing hydrogen near the generation site and moving it by pipeline to Port Hedland to be used locally or converted to ammonia for export. This phased approach provides flexibility, allowing the output to be a mix of electricity and hydrogen in the early years, when demand for hydrogen may be relatively low, while also offering the potential, in later years, of connecting the hydrogen electrolysis plant to the grid to improve utilization.[13]

Some further highlights of emerging practices in the development of renewable hydrogen projects and hubs from the preceding case studies and related literature are presented in box 1.

Not all the suggestions highlighted in this section would be applicable to all renewable hydrogen or infrastructure projects. For example, a key project and infrastructure decision is whether the electrolysis plants should be located at or near the ammonia plant or the port, or close to the renewable energy resources. Some studies for specific projects recommend locating the electrolysis plant close to ammonia facilities adjacent to the port (GIZ 2024), whereas others suggest that hydrogen may be produced close to the energy source and transported to the conversion facility and port by pipeline (Rouwenhorst 2023; ENGIE-YARA 2020; ENAEX-ENGIE 2023), where the latter may be motivated by the low cost of transporting hydrogen by pipeline over long distances at a large scale (DeSantis et al. 2021). The right answer is case specific and depends on many factors, including location, the status of existing infrastructure (including nearby ports), and any decisions made about shared infrastructure by planners, regulators, or investors. Other relevant factors include near-term and longer-term scale and strategic objectives (as mentioned in relation to the Australian Renewable Energy Hub).

13. BP recently announced its intention to leave the AREH project. However, according to Laity (2025) the other partners are working with the government of Western Australia to drive the next phase of development.

Box 1. Some key features of emerging practices in the development of renewable hydrogen projects and hubs

- *Availability of strong renewable energy resources and land.* Ideally the location is relatively near a multi-purpose port or a potential site for a new port terminal.
- *Access to large amounts of fresh water*, or the ability to develop desalination plants and pipelines where needed.
- *Access to or potential to develop multi-purpose ports and storage* that can handle imports needed to build renewable hydrogen projects and to export ammonia and other hydrogen derivatives.
- *Access to or willingness to build conversion facilities and related storage facilities* to export ammonia or other hydrogen derivatives.
- *Local demand opportunities to complement the development of renewable hydrogen and hydrogen derivatives for export*, such as industrial users for the production of ammonia, methanol, steel, and mining explosives.
- *Shared use of infrastructure assets to serve clusters of industrial users and so improve asset utilization, reduce risk, and lower infrastructure costs.* Such assets may include water, pipelines, desalination plants, storage facilities, shipping berths, loading and offloading facilities, rail networks, and transmission lines.
- *Shared use of infrastructure assets to lower the risk and enhance financial viability of private investments to produce renewable hydrogen and derivatives.* Shared infrastructure may lower capital requirements, reduce operational and financial risks, and make projects more attractive for private financing.
- *Public and private sector collaboration among multiple partners for shared development and use of infrastructure.* Partners include government, industry, research institutions, and international organizations. Such collaboration typically brings economic benefits to the government, such as job creation and revenue.
- *Leveraging of and building on existing infrastructure, such as terminals, storage, electric transmission, conversion facilities, and rail and road links.* This may be particularly valuable at early stages, when hydrogen volumes are low but growing.
- *Access to a skilled workforce.*
- *Funding studies to establish feasibility and analyze alternative development pathways and models*—including (1) flexibility in the face of uncertainty about the scale, location, and growth of supply and demand over time; and (2) ownership and business model alternatives, including for the shared use of infrastructure.
- *Regulatory conditions, incentives, and other government activities that support the development of large renewable hydrogen and infrastructure projects.* Considerations may include (1) the use of special economic zones and similar entities; (2) the streamlining of permitting processes; (3) clear and uniform safety and environmental standards; (4) subsidies for pilot projects to gain knowledge and experience and accelerate the deployment of commercial projects; and (5) detailed studies of renewable hub infrastructure design. Clarity of regulations reduces risk and uncertainty and lowers barriers to investments.
- *Access to underground hydrogen storage such as salt caverns for seasonal storage—where available.* Owing to the variability of PV and wind power, storage can help match supply with demand and increase the capacity factors for hydrogen production, ammonia conversion, and the use of port facilities and other infrastructure assets.
- *Access to the electrical grid at the port to power electrolysis when wind and photovoltaic generation is insufficient.* While this could increase the capacity factor, there would be trade-offs to consider—for example, grid power may be more expensive and may reduce incentives based on avoided greenhouse gas emissions.

Sources: Australian DCCEEW 2024; Bade and Tomomewo 2024; DNV 2022; GIZ 2024; EQS 2024; Freeport Saldanha 2023; Hydrogen Central 2023; Hydrogen Council/McKinsey 2021; LBST 2022; Notteboom and Haralambides 2023; Papadias and Ahluwalia 2021; PECEM 2023; SCZONE 2023.

More broadly, decisions about the sizing of infrastructure for storage, transportation, and conversion are interdependent, including those related to ownership and shared use. Achieving the lowest levelized cost of delivered hydrogen requires optimization of all assets, with the caveat that planning for future growth in demand and the associated need for capacity expansion must be carefully considered as part of the design process. Given this complexity, it is useful to look at recent feasibility studies, analysis, and project designs (Armijo and Philibert 2020; Campion et al. 2023).

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