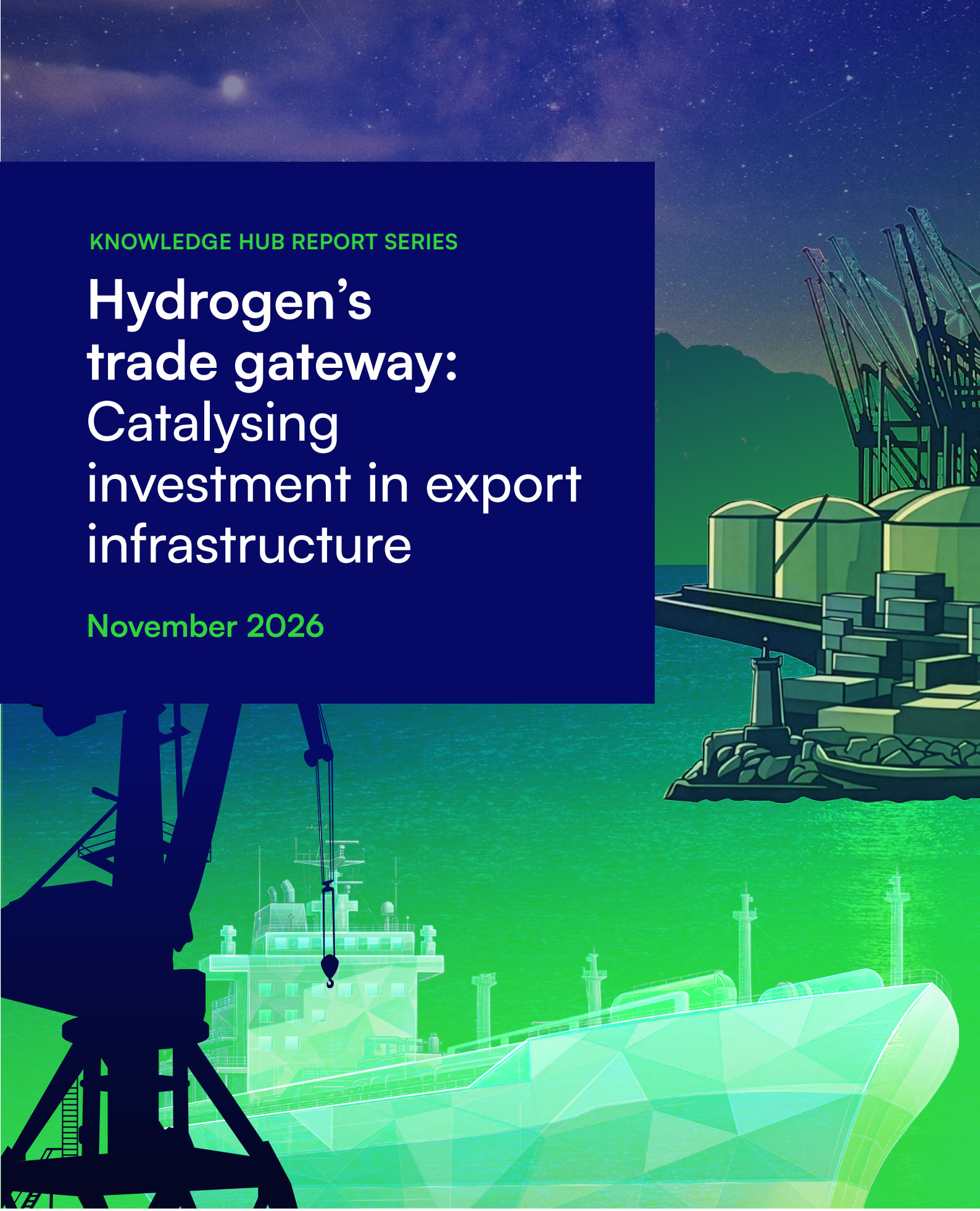
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Hydrogen's trade gateway: Catalysing investment in export infrastructure

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H2Global Foundation

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Glossary

Term	Definition
BHC	Baltic Sea Hydrogen Collector
CAPEX	Capital expenditure
CCUS	Carbon capture, utilisation and storage
CEF	Connecting Europe Facility
CHE	Clean Hydrogen to Europe
CIF	Climate Investment Funds
COD	Commercial operation date
CRF	Capital recovery factor
CUI	Common-user infrastructure
DFI	Development finance institution
EHB	European Hydrogen Backbone
ENNOH	European Network of Network Operators for Hydrogen
ENTSOG	European Network of Transmission System Operators for Gas
e-SAF	Sustainable aviation fuel, produced from renewable hydrogen
EU	European Union
FEED	Front-end engineering design
FID	Final investment decision
FSRU	Floating storage and regasification unit
FSU	Floating storage unit
GH2	Gaseous hydrogen
IBRD	International Bank for Reconstruction and Development
ICA	Intertemporal cost allocation

Term	Definition
IEA	International Energy Agency
IPF	Investment project financing
ktpa	Thousand tonnes per annum
LCOH	Levelised cost of hydrogen
LH2	Liquid hydrogen
LNG	Liquefied natural gas
LOHC	Liquid organic hydrogen carrier
LPG	Liquefied petroleum gas
MDB	Multilateral development bank
MeOH	Methanol
Mtpa	Million tonnes per annum
NBHC	Nordic-Baltic Hydrogen Corridor
NH3	Ammonia
OMIFCO	Oman India Fertiliser Company
PCI	Project of Common Interest
PMI	Project of Mutual Interest
SCZONE	Suez Canal Economic Zone
SNG	Synthetic natural gas
SPM	Single-point mooring
SPV	Special purpose vehicle
TEN-E	Trans-European Networks for Energy
TNPA	Transnet National Ports Authority
TRL	Technology readiness level
TSO	Transmission system operator

Foreword

2026 has been a year of progress for clean hydrogen projects after almost two years of bad news. This year, companies focused on fewer projects that have better chances of succeeding. Major projects in China, Latin America, and Europe went online or started construction. H2Global also delivered on its second round of tenders with new winning projects across regional lots, mobilising significant volumes for imports to Europe. H2Global's unique double-sided auction mechanism thus contributes to the creation of hydrogen markets alongside H2Global's global engagement with governments, industry leaders, and in-depth research. H2Global's work is increasingly gaining trust as demonstrated by the funds committed to the double-sided auctions designed and conducted by its intermediary Hintco, which are worth up to EUR 9bn in total at this point.

In 2024 and 2025, H2Global published the first two rounds of research reports as part of the H2Global Knowledge Hub Programme, which is financially supported by a research fund issued by the German Federal Ministry of Research, Technology and Space. H2Global is proud to continue this series in 2026 by tackling three of the biggest challenges facing the clean hydrogen economy: catalysing investment in export infrastructure, enabling value chains to bridge the green premium, and activating lead markets for clean hydrogen. These reports were created with the valuable insights of 77 private sector supporters.

Countries interested in developing export-oriented clean energy supplies can only succeed if they are able to set up the corresponding infrastructure. The 2024 and 2025 reports, "Bridging the gap: Mobilizing investments in hydrogen infrastructure", and "From ports to offtakers: Scaling last-mile hydrogen infrastructure", already considered support instruments and the infrastructure in importing countries — now our research team explores the "Hydrogen's trade gateway: Catalysing investment in export infrastructure", asking: what infrastructure needs and development models are currently deployed in net-exporting countries around the world?

Clean hydrogen and its derivatives will depart from their countries of origin by ships and — when within reach — pipelines. Particularly in regions with strong renewable resources but limited existing infrastructure suitable for hydrogen exports, the availability and timely development of export infrastructure may become an important constraint.

Yet, infrastructure planning hinges on predicting future utilisation correctly, which in turn depends on the progress of developing the projects aiming to export and their demand-side counterparts in net-importing markets. How this can be achieved via thoughtful planning is the core interest of this report.

Developments on the demand side are also the subject of H2Global's second report "Hydrogen's missing link: Enabling value chains to bridge the green premium", as primary hydrogen users need to find a way to pass on the higher cost of clean production. In the third report, "Activating lead markets: Pathways to scale for clean hydrogen", H2Global further explores how governments can effectively leverage clean hydrogen development through a mix of instruments.

"Export infrastructure is crucial to link hydrogen producers and users across continents. It is a very timely exercise to gauge how such infrastructure can be developed in different contexts and with different approaches across Latin America, Southern Africa, Gulf States, and Europe."

Matthias Janssen
Executive Director
Frontier Economics

The three reports in 2026 are the latest additions to H2Global's growing, internationally recognised knowledge base and conclude the current cycle of Knowledge Hub reports. By providing clear solutions to the challenges of the clean hydrogen economy, the series aims to improve shared understanding of global clean fuels markets. H2Global's research remains dedicated to decarbonising energy markets and creating a more resilient energy system globally.

Executive summary

Clean hydrogen exports can only scale if production sites are connected to international markets by reliable, appropriately sized infrastructure. Yet investment in pipelines, ports, storage, and loading facilities must often precede certainty over future export volumes and timelines. This creates a coordination problem: hydrogen producers need infrastructure to reach final investment decisions (FIDs), while infrastructure investors need credible production and offtake commitments. This report examines the technological and economic requirements for export infrastructure, assesses existing and planned capacity, and identifies development approaches emerging across Brazil, Oman, Namibia, and South Africa for sea-bound exports, as well as European hydrogen pipeline corridors.

The central challenge is not whether export infrastructure can be built, but how investment can be sequenced and risks shared while hydrogen markets mature.

The analysis points to five key findings:

— **Existing assets provide a head start, but gaps remain substantial.** Most infrastructure technologies for ammonia, methanol, and other established hydrogen derivatives are commercially mature, and existing port and liquid-bulk facilities can often be adapted or expanded. However, these assets are unevenly distributed, may already be used for conventional trade, and do not necessarily coincide with emerging production hubs. Liquid-hydrogen terminals and offshore ammonia systems also face remaining technology-readiness gaps.

— **Export ambitions are outpacing committed infrastructure.** Nearly 12 million metric tonnes per annum (Mtpa) of hydrogen-equivalent production capacity announced for 2030 is export-oriented, but less than 8% of these volumes are linked to projects that are operational, under construction, or at FID. Ammonia accounts for around three-quarters of announced exports. Of 70 announced ammonia export and bunkering terminal projects, only 20 have reached front-end engineering design (FEED), FID, or construction. In 11 assessed countries, even all announced ammonia terminal capacity combined would fall short of planned exports.

— **Scale and utilisation are decisive for export costs.** For an illustrative 0.1 Mtpa hydrogen-equivalent project, dedicated greenfield port and terminal infrastructure adds around EUR 0.22—1.17 per kg of hydrogen equivalent to levelised costs, depending on site conditions. A modelled 20-inch pipeline of 500—2,000 km, assuming 60% repurposed gas infrastructure, adds approximately EUR 0.50—2.00 per kg. Shared infrastructure can significantly reduce unit costs through higher utilisation, but it is harder to finance while prospective users are still at early project stages.

— **Four complementary development approaches are emerging.** Anchor-led development aligns infrastructure with a large project's requirements; port-led hubs coordinate several prospective users; government-supported common-user infrastructure (CUI) helps make shared assets investable through public risk-sharing; and government-led master planning coordinates projects and enabling systems at a wider scale. Brazil's Pecém and Açu illustrate port-led development, Oman combines master planning with CUI; Namibia and South Africa employ port- and anchor-led models, and European pipeline corridors illustrate publicly de-risked CUI.

— **Common-user infrastructure is valuable, but not always the first step.** Shared assets can avoid duplication and support larger hydrogen clusters, yet capacity must often be planned before users can make binding commitments. Dedicated facilities may provide a faster route to market for credible first movers, provided later expansion or third-party access remains possible. For large-scale pipelines, coordinated multi-user planning and measures such as capacity reservations, guarantees, and intertemporal cost allocation can be particularly important.

Five priorities follow for governments, ports and infrastructure investors: make better use of existing assets; plan shared infrastructure early but expand it in phases; balance first-mover needs with the option of future shared access; tailor financial risk-sharing to fiscal and institutional capacity, including international development finance where needed; and strengthen cooperation with importing markets to translate announced supply into credible demand.

Ultimately, export infrastructure can become a gateway to global hydrogen trade only when its development is aligned with bankable production projects and functioning markets (see Table 1).

Table 1: Key recommendations

Key area	Recommendation
Making use of existing infrastructure	• Prioritise opportunities to reuse or expand existing port, storage, and loading infrastructure • Facilitate access to existing infrastructure through transparent processes for allocating land and infrastructure capacity • Coordinate port-level infrastructure development to avoid unnecessary duplication • Reserve sufficient land for hydrogen derivatives through appropriate planning • Enable gradual infrastructure expansion where possible
Master planning infrastructure early	• Identify shared infrastructure requirements early • Define responsibilities and interfaces between infrastructure and production • Develop commercial models alongside technical infrastructure concepts • Establish how to de-risk early-stage utilisation • Regularly update infrastructure plans
Balancing first-mover needs and common-user infrastructure	• Do not make CUI a prerequisite where it would delay viable first-mover projects • Preserve the option for dedicated infrastructure to accommodate additional users from the outset • Plan large-scale hydrogen pipeline infrastructure as CUI from the outset where feasible
Matching de-risking to fiscal and institutional capacity	**Governments with sufficient fiscal and institutional capacity:** • Use public balance sheets selectively to bridge the infrastructure ramp-up period • Use public or state-owned infrastructure companies with appropriate capabilities • Design support to decline as infrastructure utilisation increases **Governments with constrained domestic public capital:** • Mobilise financing from multilateral development banks (MDBs) and development finance institutions (DFIs) • Engage future importing markets in export infrastructure development • Use international partnerships to support project preparation and construction
Reducing uncertainty over future needs	• Support viable production projects in reaching FIDs • Cooperate with importing countries • Coordinate cross-border hydrogen pipeline development between exporting, transit and importing countries



IMAGE CREDIT: ADOBE STOCK / MICHAELJUNG



IMAGE CREDIT: ADOBE STOCK / DARUNRAT



1

The importance of export infrastructure for global hydrogen trade

Around the world, numerous large-scale clean hydrogen projects have been announced with export ambitions towards prospective importing regions such as Europe, Japan, and South Korea. Realising these ambitions will require competitive clean hydrogen production and credible demand, supported by infrastructure capable of connecting production locations with international markets. Particularly in regions with strong renewable resources but limited existing infrastructure suitable for hydrogen exports, the availability and timely development of export infrastructure may become an important constraint.[1]

Developing international clean hydrogen trade requires progress across three interdependent areas: competitive clean hydrogen production, credible demand supported by long-term offtake, and enabling infrastructure connecting production and demand centres.

Export infrastructure poses a particular coordination challenge because major assets can have long development lead times and significant economies of scale.

Export infrastructure poses a particular coordination challenge because major assets can have long development lead times and significant economies of scale. Infrastructure may therefore need to be planned before future production volumes and demand are fully certain, creating uncertainty over its timing, sizing and utilisation. This challenge can be particularly pronounced in emerging production regions with limited existing infrastructure. Over the last two years, H2Global has examined key elements of hydrogen infrastructure, including financial support mechanisms for midstream infrastructure and a gap analysis of hydrogen import infrastructure.[2]

This report builds on that work by shifting the focus upstream to export infrastructure, examining infrastructure requirements, case studies, and development archetypes needed to connect hydrogen production regions with international markets. Figure 1 illustrates the role of export infrastructure within the hydrogen value chain.

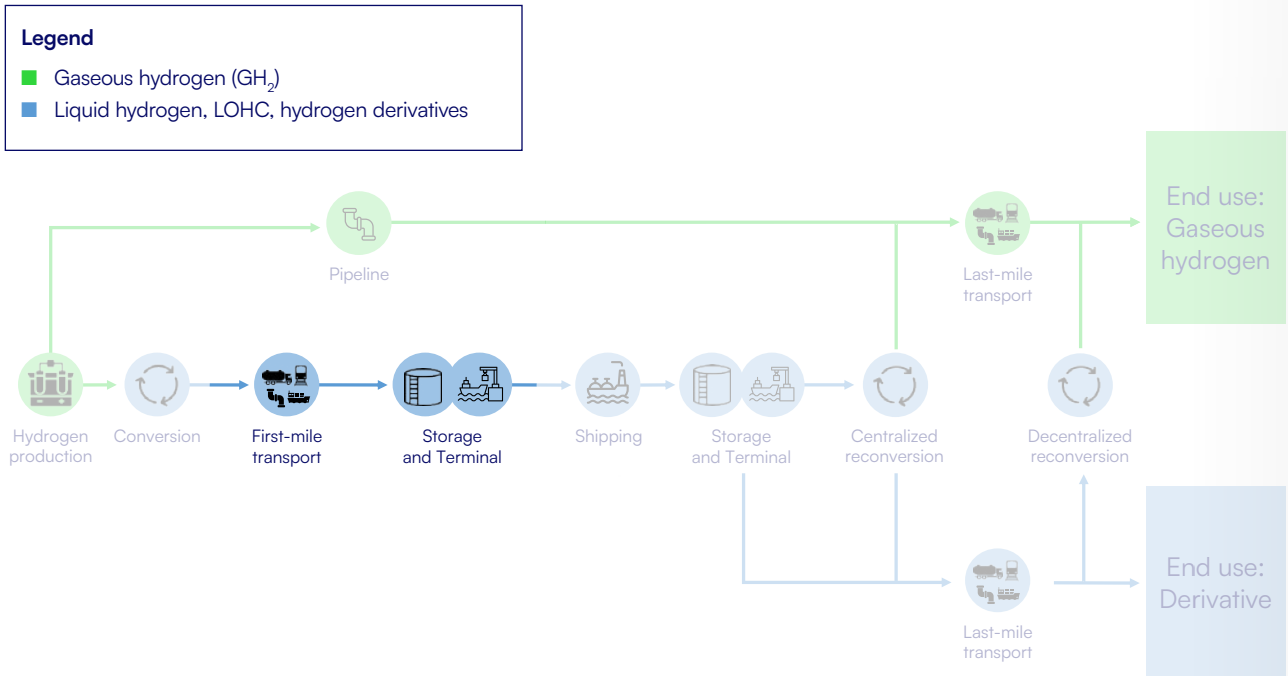
Depending on the export pathway, export infrastructure may include transport connections between production sites and export facilities, storage and terminal infrastructure for ship-based exports, or dedicated pipeline systems for the direct transport of gaseous hydrogen. The nature and magnitude of export infrastructure gaps differ significantly across potential exporting regions.

For **seaborne exports**, three categories can be distinguished:

- Regions with **established infrastructure for liquefied gases**
- Regions with **established infrastructure for liquid-bulk commodities**
- Regions with **limited or no suitable port infrastructure** serving prospective clean hydrogen production sites

The first category includes ports with infrastructure for handling liquefied gases, including ammonia, liquified natural gas (LNG), and liquified petroleum gas (LPG).

Figure 1: Export infrastructure within the hydrogen value chain



Existing ammonia terminals provide the most direct basis for future clean ammonia exports, subject to available capacity and the scale of future export volumes. Ports handling other liquefied gases such as LNG or LPG may also offer advantages, including deep-water maritime access and experience in handling refrigerated or pressurised products.

However, substantial product-specific investments may still be required, for example in dedicated storage, loading, and handling systems.

Ports with established infrastructure for liquid-bulk commodities, including methanol, crude oil, and other liquid fuels constitute the second category. Existing methanol infrastructure can provide a direct basis for clean methanol exports where sufficient capacity is available. Other liquid-bulk ports may provide relevant enabling infrastructure and experience, such as maritime access, jetties, tank-farm areas, and established logistics systems, although dedicated or adapted facilities will generally be required for the respective hydrogen derivative.

The third category includes shallow-draft ports, ports with limited bulk-handling infrastructure, or locations without suitable existing port infrastructure. In these cases, substantial investment may be required to develop new or substantially expand existing export facilities, potentially including deep-water access, breakwaters, jetties, storage facilities and associated logistics infrastructure. Where basic port infrastructure already exists, however, existing maritime access, roads, breakwaters, and other supporting infrastructure may still reduce development requirements compared with a fully greenfield port.

In contrast, dedicated **large-scale hydrogen pipelines for international trade are not yet available in any region**. Consequently, pipeline-based hydrogen trade faces a more universal infrastructure challenge, as entirely new transport corridors would need to be planned, financed, and constructed.

Despite these differing starting points, most new hydrogen export infrastructure projects remain at an early stage of development. Numerous export terminals, storage facilities, and pipeline concepts have been announced, but only a limited number have progressed to advanced development stages. This partly reflects the limited maturity of the production projects expected to use them: infrastructure providers face difficulty committing capital where future throughput and timelines remain uncertain. At the same time, production projects require confidence that adequate infrastructure can be available when operations begin. Export infrastructure development therefore needs to be coordinated closely with the maturation of production projects and associated demand.

This coordination challenge is particularly pronounced for infrastructure with strong economies of scale, where developing capacity for several prospective users may be more efficient than building project-specific assets but requires earlier coordination across projects. Regulatory requirements, ownership structures, and the allocation of investment and utilisation risks further shape which actors can develop individual infrastructure components. Together, these factors create the well-known "chicken-and-egg" problem: infrastructure investors require sufficient confidence that production projects will materialise before committing capital, while production projects need sufficient confidence that export infrastructure will be available when required. Long-term capacity commitments and other contractual arrangements can help reduce these risks but may themselves be difficult to secure while production projects and associated offtake remain immature. This coordination and financing challenge has been consistently highlighted by major bodies; for instance, the International Energy Agency (IEA) and the World Bank have strongly emphasised the criticality of closing the infrastructure gap to realise international hydrogen trade.[3]

Ensuring that appropriate export infrastructure develops in coordination with production and demand will be critical to enabling competitive and resilient international clean hydrogen trade.

Against this backdrop, this report assesses the current status of hydrogen export infrastructure in four analytical chapters. It first takes a techno-economic view, assessing the technological readiness of relevant infrastructure technologies and the costs associated with their development. It then provides a global overview of existing, planned, and required export infrastructure. Building on this assessment, the report examines ownership models and the role of common-user infrastructure before introducing different development archetypes for hydrogen export infrastructure. Finally, case studies covering Brazil, Oman, Namibia and South Africa, as well as the planned European cross-border hydrogen pipeline corridors, illustrate how these different approaches to infrastructure development are emerging in practice.

Ultimately, ensuring that appropriate export infrastructure develops in coordination with production and demand will be critical to enabling competitive and resilient international clean hydrogen trade.



IMAGE CREDIT: ADOBE STOCK / KALYAKAN



2

Technology readiness and costs

The infrastructure required to export hydrogen and its derivatives differs substantially across transport carriers in terms of technological maturity, complexity, and cost. While established commodities such as ammonia and methanol can largely rely on commercially proven infrastructure, emerging hydrogen carriers require new or adapted solutions. This chapter assesses the technological readiness and suitability of the main export infrastructure options and examines the additional costs associated with developing dedicated greenfield infrastructure.

Technology overview and readiness

The analysis of technological sub-systems focuses on four integral parts: (1) conversion of gaseous hydrogen to different export products, (2) onshore export terminals, (3) offshore terminals, including floating storage units, and single-point mooring systems, and (4) pipelines for export. Table 2 provides an overview of the technology-readiness levels (TRLs) across these sub-systems and hydrogen products being analysed based on the TRL database of the International Energy Agency (IEA). TRLs range from 1 (initial idea reported) to 9 (technically ready for sale or licensing).[4]

Overall, most technologies required for hydrogen export infrastructure build on commercially mature technologies already used for conventional energy and chemical commodities. However, their application to clean hydrogen trade may require different operating conditions and scales. Important technology-readiness gaps remain, particularly for liquid hydrogen terminals, offshore ammonia terminals, and offshore gaseous hydrogen pipelines.

Conversion

Conversion infrastructure processes gaseous hydrogen (GH_2) into derivatives suitable for ship-based export. Hydrogen liquefaction is an established technology, with commercial applications dating back several decades.

More recently, in 2024, SK E&S commenced operations of its liquefaction facility in Incheon, South Korea — currently the world's largest hydrogen liquefaction plant. In addition, established industry players such as Air Liquide, Linde, and Air Products have developed their own liquefaction technologies.[5]

Overall, most technologies required for hydrogen export infrastructure build on commercially mature technologies already used for conventional energy and chemical commodities.

The conversion of hydrogen into liquid organic hydrogen carriers (LOHC) through hydrogenation is also an established industrial process. For example, the toluene/ methylcyclohexane route builds on established hydrogenation technologies, while companies such as Chiyoda and Hydrogenious are advancing their application to large-scale hydrogen supply chains.

Table 2: Technology-readiness levels of technological sub-systems for hydrogen-export infrastructure

	Conversion	Onshore export terminal	Offshore terminals**	Pipeline
Gaseous hydrogen				Onshore: 9 (new), 8 (repurposed) Offshore: 6
Liquid hydrogen	9	7		
LOHC	9	9	9	9
Ammonia	9	9	7	9
Methanol	9	9	9	9
SNG*	9	9	9	9
e-fuels	9	9	9	9

* SNG reconversion without carbon capture and storage (CCUS). ** Include floating storage units and single-point mooring systems.

Similarly, the conversion of gaseous hydrogen into ammonia (via the Haber-Bosch process), methanol, synthetic natural gas (SNG), and e-fuels (via Fischer-Tropsch synthesis) builds largely on established industrial processes. However, newer approaches, including more flexible operation and alternative production routes, are still being developed. The large-scale deployment of clean methanol, SNG, and e-fuels also depends on the availability of sustainable carbon feedstock, a constraint that is largely independent of the export infrastructure considerations discussed here.[6]

Onshore and offshore export terminals

Terminal infrastructure is required to enable ship-based exports of hydrogen-based products. It provides temporary storage and facilitates the loading of vessels. Traditionally, such terminals are developed onshore within dedicated port areas, where large storage tanks and loading facilities can support high export volumes. However, offshore solutions, such as floating storage units (FSUs) and single-point mooring (SPM) systems, offer an alternative where dedicated port infrastructure is unavailable or uneconomical.

These systems combine storage and loading functions in offshore facilities connected directly to export vessels, reducing the need for extensive onshore infrastructure and associated high upfront capital investments. Due to their modular nature and comparatively lower capacity, offshore solutions are particularly suited to individual projects, early-stage export developments, or locations with limited port infrastructure. Their applicability may, however, be constrained as export volumes increase or multiple users require infrastructure, as well as in locations with adverse weather and sea conditions that can increase operational downtime.

For most hydrogen-based products, including methanol, SNG (via LNG infrastructure), e-fuels, and LOHC, onshore and offshore export terminal solutions are already available. Ammonia-specific offshore terminal solutions are currently being developed but have yet to reach commercial maturity. Liquid hydrogen constitutes another exception: here, a Japanese-Australian consortium is currently advancing the "Liquefied Hydrogen Supply Chain Commercialization Demonstration" project, which aims to validate the commercial viability of liquid hydrogen exports, including the associated export infrastructure in Australia.[7]

Pipeline

Cross-border hydrogen pipelines represent an important alternative to ship-based transport of hydrogen and its derivatives, particularly in cases where supply and demand regions are geographically relatively close. Pipeline transport is considered more cost-effective over distances of up to around 2,000 km, especially where existing natural gas infrastructure can be repurposed for hydrogen use. Pipeline economics are strongly influenced by the transported volumes and utilisation, as substantial economies of scale can be achieved at higher throughput.[8]



IMAGE CREDIT: ADOBE STOCK / MIKE MAREEN

Pipeline transport is considered more cost-effective over distances of up to around 2,000 km, especially where existing natural gas infrastructure can be repurposed for hydrogen use.

Pipelines for hydrogen-based products such as ammonia, methanol, e-fuels, synthetic natural gas, and LOHC (leveraging existing oil infrastructure) are already widely used at commercial scale. Examples of commercial pipelines with third-party access exist for all the above-mentioned products, except for methanol, to the authors' knowledge. Dedicated pipelines for gaseous hydrogen also have a long history of industrial use, particularly within chemical and refining clusters. For large-scale hydrogen transmission, new onshore pipelines and the repurposing of existing natural gas pipelines are considered technologically mature or close to commercial maturity. Offshore hydrogen transmission is less mature, with dedicated offshore hydrogen pipelines yet to be demonstrated at commercial scale.

In Europe, several cross-border hydrogen pipeline corridors have received Project of Common Interest (PCI) or Project of Mutual Interest (PMI) status and are progressing through different stages of development. Notable examples include the H2Med corridor, connecting Portugal and Spain with France and subsequently Germany, and the SoutH2 Corridor, connecting North Africa via Italy and Austria with Germany. Further PCI projects are being developed in the Baltic Sea region, including the Nordic-Baltic Hydrogen Corridor and the Baltic Sea Hydrogen Collector. Beyond the European context, an example of a planned cross-border export pipeline is the corridor linking the envisioned hydrogen hub in Lüderitz, Namibia, with South Africa's ports of Boegoebaai and Saldanha Bay.[9]

Techno-economic analysis of greenfield export configurations

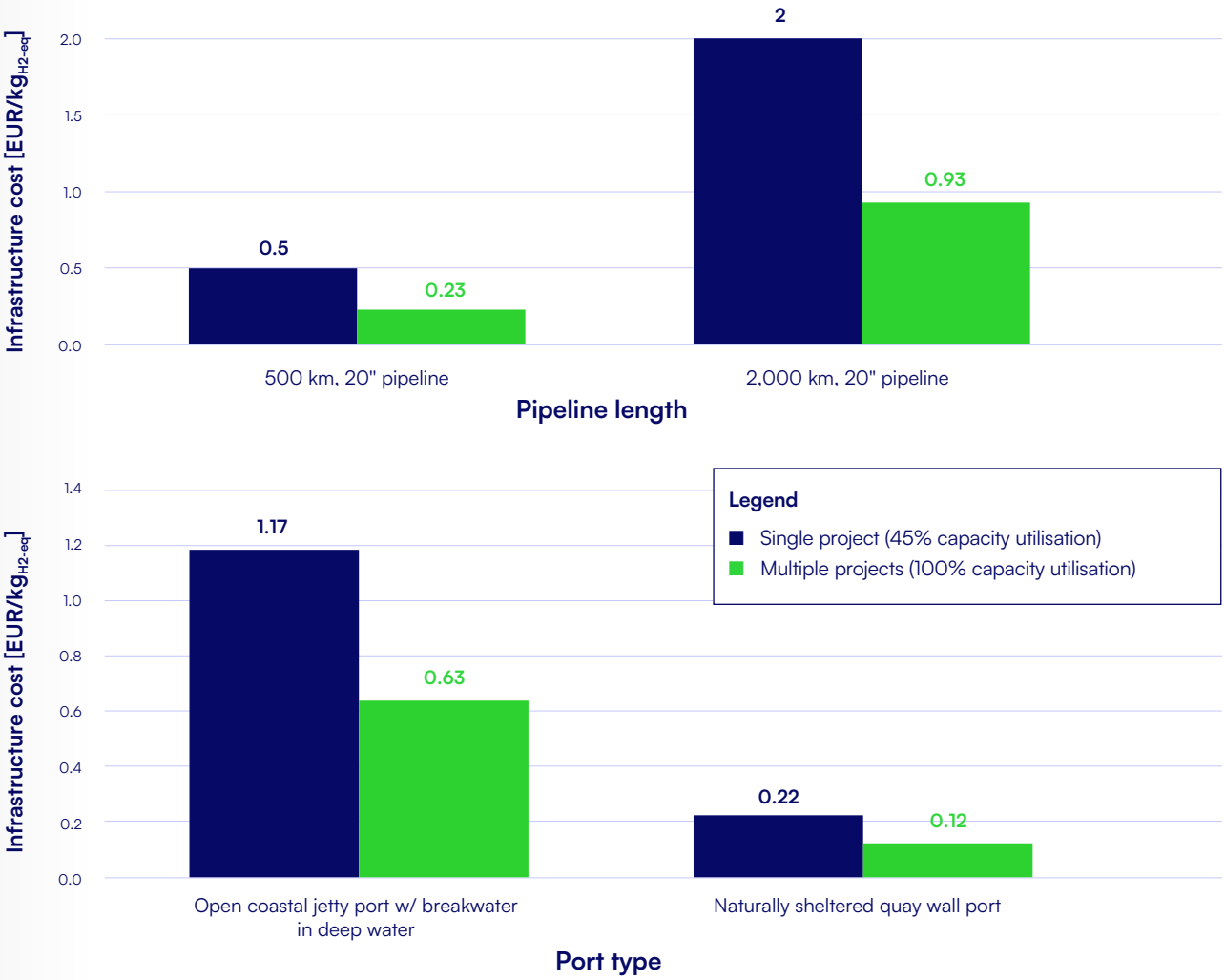
According to the IEA, hydrogen production projects linked to around 70% of the capacity announced for commissioning by 2030 have chosen a location within 500 km of a major port.[10] This underlines that these projects value the strategic importance of access to export infrastructure for project viability, as the development of dedicated infrastructure, whether for ship-based transport or pipelines, can significantly increase overall project costs.

Figure 2 illustrates an internal analysis of the additional levelised cost of hydrogen (LCOH) associated with building dedicated pipeline or port infrastructure to export hydrogen or hydrogen derivatives. The analysis considers different scales and configurations, including 20-inch pipelines over 500 km and 2,000 km and four port infrastructure configurations reflecting different environmental pre-conditions. Two infrastructure utilisation scenarios are compared. In the "single project" scenario, the infrastructure serves one archetypal project with an annual output of 0.1 $Mtpa_{H2\text{-}eq}$. In the "multi-project" scenario, several projects share the infrastructure, increasing utilisation to its theoretical maximum capacity. This illustrates the potential cost benefits of common-user infrastructure. The underlying techno-economic assumptions and additional sensitivity calculations are provided in Annex I.



IMAGE CREDIT: ADOBE STOCK / NATARAJ

Figure 2: Additional LCOH component of dedicated pipeline and port infrastructure for exporting hydrogen and its derivatives



For a representative hydrogen project with an annual production capacity of 0.1 Mtpa$_{H2-eq}$ and no access to existing export infrastructure, the results show that dedicated pipeline infrastructure can add between EUR 0.5 and 2.00 per kg$_{H2-eq}$, depending on the pipeline length. Developing dedicated port infrastructure adds between EUR 0.22 and 1.17 per kg$_{H2-eq}$, depending on the site conditions and required infrastructure. Only under the most favourable conditions does the additional cost fall to around EUR 0.23 per kg$_{H2-eq}$; under less favourable configurations, dedicated infrastructure adds substantially more to overall hydrogen costs.

In the absence of existing infrastructure, improving economic viability therefore depends on the shared use of export infrastructure among multiple, co-located hydrogen projects. As shown in the calculations above, increasing the utilisation rate of the newly built infrastructure proportionally affects the additional levelised cost of hydrogen. This creates a trade-off between developing infrastructure tailored to the needs of an individual project and sizing infrastructure to accommodate additional users and future volumes.

Developing dedicated port infrastructure adds between EUR 0.23 and 1.17 per kg$_{H2-eq}$, depending on the site conditions and required infrastructure.

These results underline the importance of existing infrastructure, infrastructure scale, and utilisation for the economics of hydrogen exports. The following chapter therefore assesses where suitable export infrastructure already exists and where additional infrastructure may be required to accommodate announced hydrogen export projects.



IMAGE CREDIT: ADOBE STOCK / RAHMAT



3

Existing, planned, and required hydrogen export infrastructure

Existing infrastructure provides an important starting point for developing hydrogen export supply chains, but its availability and suitability vary considerably across countries and hydrogen carriers. At the same time, the scale and geographic distribution of announced clean hydrogen projects could create substantial additional infrastructure requirements, particularly for ammonia exports. This chapter assesses the existing infrastructure base, examines the pipeline of planned terminal developments, and identifies where gaps may emerge between announced export ambitions and available infrastructure.

Existing infrastructure

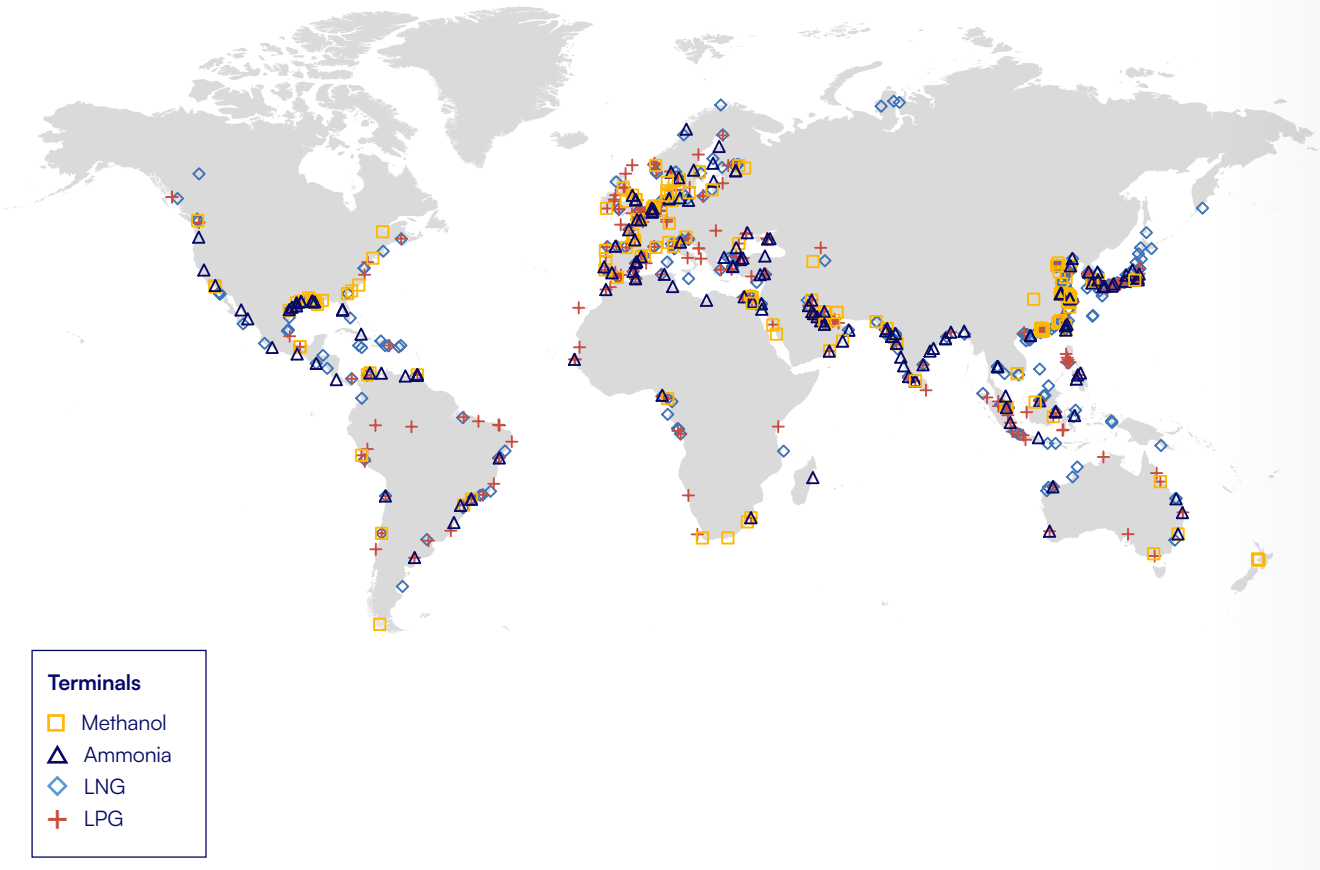
The development of international hydrogen trade will not start from a blank slate. Existing infrastructure for bulk chemicals and energy commodities already provides an important foundation for handling hydrogen carriers and derivatives. As shown in Figure 3, ports around the world currently operate terminals for fossil-based ammonia, methanol, LNG, and LPG. These existing facilities may reduce the need for additional infrastructure to support future clean hydrogen exports and hold valuable experience in the storage, handling, and transport of hazardous gases and liquid commodities, facilitating potential infrastructure expansion.

To assess the readiness of ports for future hydrogen trade, the International Energy Agency (IEA) developed the "Chemical-handling Infrastructure Score" based on existing infrastructure and operational capabilities for ammonia, methanol, LPG, and LNG. Nearly 80 ports worldwide achieve a score above five out of ten, indicating that they already possess infrastructure and expertise that could facilitate the uptake of hydrogen-based commodities.[11] The highest concentrations of well-prepared ports are found in Europe, East Asia, North America, and parts of the Middle East, reflecting their existing role in global energy and chemical trade.

Nearly 80 ports worldwide achieve a score above five out of ten, indicating that they already possess infrastructure and expertise that could facilitate the uptake of hydrogen-based commodities.

Existing assets provide an important starting point for the development of hydrogen export infrastructure. In many locations, existing terminals, storage facilities and loading systems for ammonia, methanol, LNG, or LPG could be adapted or expanded to accommodate clean hydrogen derivatives, while their established operations provide valuable handling capabilities, operational experience, and regulatory frameworks that can facilitate such developments. Similarly, existing oil terminals could be adapted or expanded to handle LOHCs. However, much of this infrastructure is currently used for fossil-based commodity trade and may not be fully available for future clean hydrogen exports, nor located close to prospective production sites.

Figure 3: Existing infrastructure for handling hydrogen derivatives at ports worldwide[12]



The extent to which existing assets can support hydrogen exports will therefore depend on their location and availability, the pace of the transition from conventional to clean commodities, and expansion plans within ports.

Future infrastructure needs

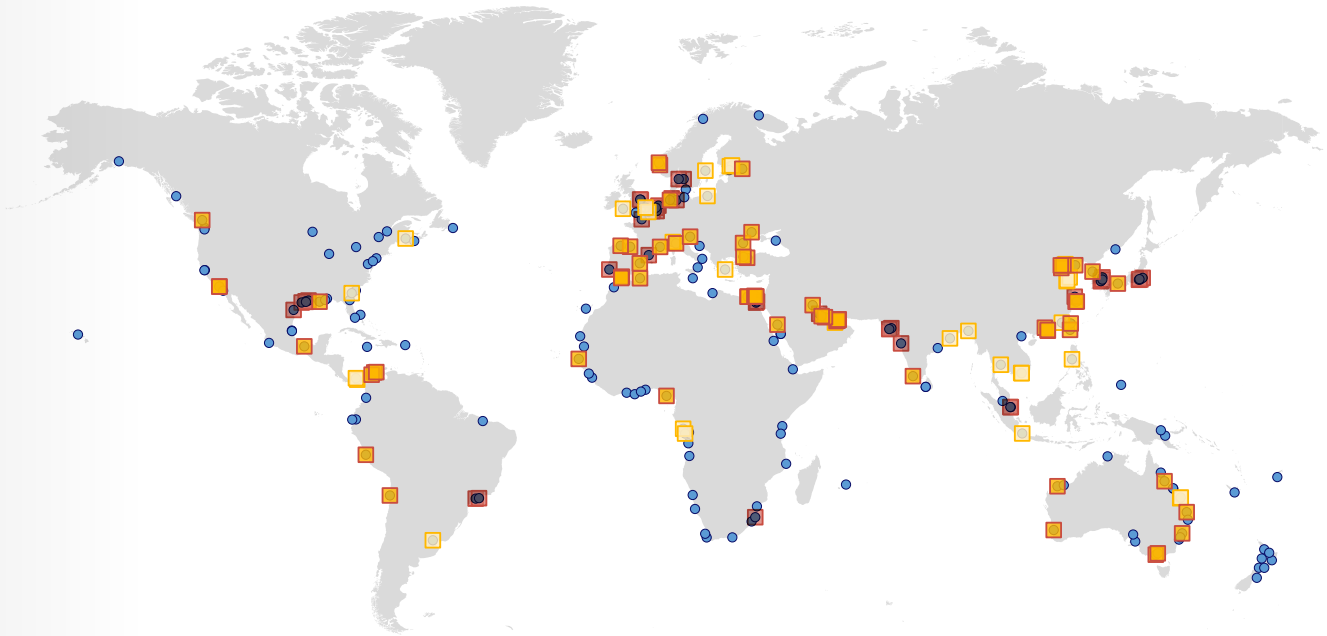
Hydrogen trade is expected to become an important component of the emerging global hydrogen economy. According to the IEA, export-oriented projects represent almost 12 $Mtpa_{H2\text{-}eq}$ by 2030, corresponding to more than 40% of all announced low-emissions hydrogen production projects worldwide. However, progress remains limited. Less than 8% of the announced trade volume originates from projects that are operational, under construction, or have reached FID, indicating that export-oriented projects are advancing more slowly than the rest of the global project pipeline.[13]

The vast majority of announced exports are expected to take the form of hydrogen derivatives rather than gaseous or liquid hydrogen. Around three-quarters of announced export volumes are planned as ammonia, equivalent to around 50 Mtpa of ammonia trade. By comparison, current global ammonia trade amounts to less than 20 Mtpa. If all announced projects materialise, global ammonia trade volumes could therefore more than double, creating substantial demand for new storage, terminal, and shipping infrastructure. In addition, the emergence of a more geographically diverse group of potential exporting countries compared with today's ammonia market would require the development of new export routes and supporting infrastructure.[14]

Less than 8% of the announced trade volume originates from projects that are operational, under construction, or have reached a final investment decision (FID).

Infrastructure requirements for other hydrogen carriers and derivatives differ. E-fuels and SNG can largely build on widely available infrastructure for conventional fuels, although existing facilities may need to be adapted or expanded to accommodate clean alternatives. Liquid hydrogen, by contrast, requires dedicated storage, loading, and shipping infrastructure that is not yet available at commercial scale.

Figure 4: IEA's "Chemical-handling Infrastructure Score" of global ports[15]



Legend

- Main ports with limited chemical-handling infrastructure

Chemical-handling Infrastructure Score at ports

- 8-10
- 6-8
- 4-6

LOHCs can build on existing chemical or liquid-bulk handling infrastructure, depending on the carrier, but their infrastructure needs form part of an integrated supply chain that requires hydrogenation, transport, and dehydrogenation, as well as the return transport of the carrier material. Liquid hydrogen and LOHC infrastructure is therefore generally planned as part of dedicated supply chains rather than as standalone export terminals, and only a limited number of projects involving either carrier are currently under development.

While 70 ammonia terminal projects for export and bunkering have been announced globally, almost three-quarters remain at the concept or feasibility stage.

Against this broader picture, ammonia and methanol account for the largest pipeline of announced new terminal projects. Figure 5 illustrates the current development status of announced ammonia and methanol terminal projects for export and bunkering. While 70 ammonia terminal projects for export and bunkering have been announced globally, almost three-quarters remain at the concept or feasibility stage. Only 20 projects have progressed to FEED, FID, or construction. The pipeline of announced methanol terminals is considerably smaller, reflecting the lower number of announced methanol export projects, but a substantially larger share has progressed to advanced development stages. This may partly reflect the comparatively simpler storage and handling requirements for methanol, while demand for methanol bunkering provides an additional driver for terminal investment: 12 of the 22 identified methanol projects focus on bunkering. Overall, the comparison highlights that the large number of announced ammonia terminals has not yet translated into a similarly large number of committed infrastructure investments.[16]

The importance of port infrastructure is further highlighted by the relative location of announced hydrogen production projects. More than 50% of announced low-emissions hydrogen projects are located within 250 km of a major port, increasing to almost 70% within 500 km.[17] This strong spatial alignment suggests that ports will play a central role not only as export gateways, but also as industrial hubs integrating production, storage, bunkering, and international trade.

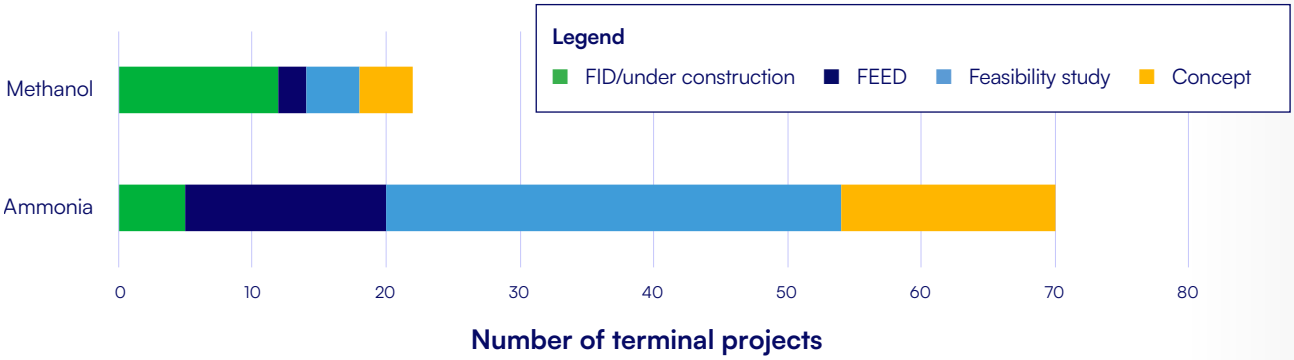
Despite the concentration of many announced clean hydrogen projects near existing ports, investment in export infrastructure remains limited relative to the scale of announced hydrogen projects. In many cases, terminal developments are closely linked to individual hydrogen projects and therefore face similar commercial and financing uncertainties. As a result, delays in hydrogen project development may also slow the deployment of infrastructure required to support future trade.

Ammonia infrastructure readiness

Given ammonia's dominant role in announced export projects and its more specialised storage and handling requirements compared with liquid derivatives, the following analysis focuses specifically on ammonia infrastructure readiness. Today, more than 170 ammonia terminals operate across nearly 60 countries, providing a global storage capacity of approximately 6.5 Mt of ammonia.

At the same time, new ammonia terminal projects have been announced in around 30 countries, many of which currently lack ammonia export infrastructure.[18]

Figure 5: Development status of announced ammonia and methanol export and bunkering terminal projects worldwide[19]



This report assesses ammonia infrastructure readiness in countries with announced clean hydrogen export projects by comparing the production capacity of announced ammonia export projects with the handling capacity of existing and planned ammonia infrastructure in each country based on two IEA databases.[20] Planned infrastructure is differentiated by development stage to account for the greater uncertainty associated with projects at the concept and feasibility stages. Figure 6 illustrates the four categories that can be distinguished.

Category 1 comprises countries where existing ammonia infrastructure appears sufficient to accommodate announced ammonia production volumes. Twelve countries fall into this category, reflecting the advantage of established ammonia production, storage, and export networks.

Countries in Category 2 have insufficient existing ammonia infrastructure to accommodate announced production projects. However, infrastructure that has already reached advanced development stages — including operational facilities, projects under construction, projects with an FID, and projects in FEED — appears sufficient to meet future infrastructure requirements. Four countries fall into this category, suggesting that the infrastructure needed to support announced export ambitions is already progressing beyond the early planning stage.

Category 3 includes countries where existing infrastructure is insufficient and where advanced infrastructure projects alone would not provide sufficient capacity.

However, when all announced terminal projects are considered — including projects at the concept and feasibility stage — planned infrastructure appears sufficient to accommodate announced ammonia production ambitions. Five countries fall into this category, indicating a stronger dependence on infrastructure projects that remain at an early stage of development.

Category 4 consists of countries where existing infrastructure and all currently announced terminal projects combined would still fall short of announced ammonia production volumes. Eleven countries fall into this category, highlighting substantial infrastructure gaps that will require terminal developments beyond those currently planned.

Overall, the analysis suggests that infrastructure readiness is becoming an important differentiator among prospective clean hydrogen exporters. While clean hydrogen production potential is widely distributed, the ability to export at scale depends on the availability of adequate storage, terminal, and loading infrastructure, as well as on the maturity of associated infrastructure investments. Countries with established ammonia export infrastructure or well-developed expansion plans may therefore be better positioned from an infrastructure perspective during the early phases of international clean hydrogen market development. Conversely, many emerging exporters will need to develop entirely new export infrastructure systems before large-scale clean hydrogen trade can materialise, potentially affecting their near-term competitiveness and the pace at which export projects can be developed.

Figure 6: Ammonia infrastructure readiness across countries with announced ammonia export projects

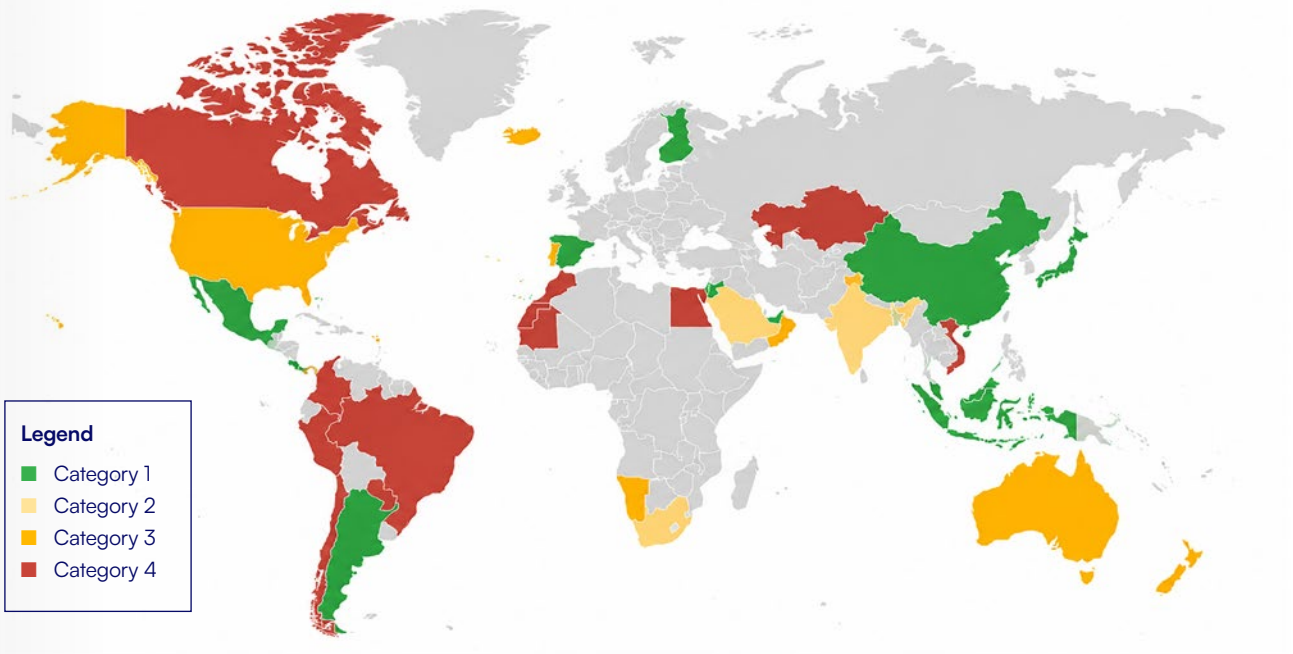




IMAGE CREDIT: ADOBE STOCK / KELVN



4

Ownership models and development archetypes for hydrogen export infrastructure

Addressing clean hydrogen export infrastructure gaps is not only a question of what needs to be built, but also who develops, owns, and finances it — and who bears the associated investment risks. While infrastructure investment in established markets can generally rely on predictable utilisation and revenues, these conditions are often absent in nascent clean hydrogen markets.

Few clean hydrogen projects have reached FID, future demand volumes and development timelines remain uncertain, and infrastructure may need to be developed before sufficient users can make firm capacity commitments. This creates significant coordination and utilisation risks for infrastructure investment.

Against this background, different approaches to developing hydrogen export infrastructure are emerging. This chapter first introduces established ownership structures and the concept of common-user infrastructure (CUI), which can enable facilities to serve multiple clean hydrogen projects. It then draws on the infrastructure initiatives analysed for this report to identify four development archetypes through which different actors are coordinating, anchoring, or enabling infrastructure investment in the nascent clean hydrogen market.

Ownership models and common-user infrastructure

Export infrastructure can be developed under different ownership structures, depending on the relationship between the hydrogen project and the infrastructure owner. Figure 7 distinguishes four stylised models. Under the integrated model, export infrastructure forms part of the clean hydrogen project and is developed and owned by the same project consortium. The separated model retains ownership by the project consortium but places export infrastructure in a separate special purpose vehicle (SPV).

Alternatively, infrastructure can be developed and owned by an independent infrastructure operator under a third-party model, providing infrastructure services to one or more hydrogen projects. Finally, under the shared infrastructure model, two or more clean hydrogen projects jointly own the infrastructure.

The choice of ownership structure involves a trade-off between project control and infrastructure sharing.

The choice of ownership structure involves a trade-off between project control and infrastructure sharing. Project-owned facilities give developers greater control over infrastructure design, development timelines, capacity, and future expansion, and can facilitate close alignment between production and export infrastructure. However, the project also bears the associated capital requirements and utilisation risks. Separating infrastructure ownership

Figure 7: Four ownership models for infrastructure projects

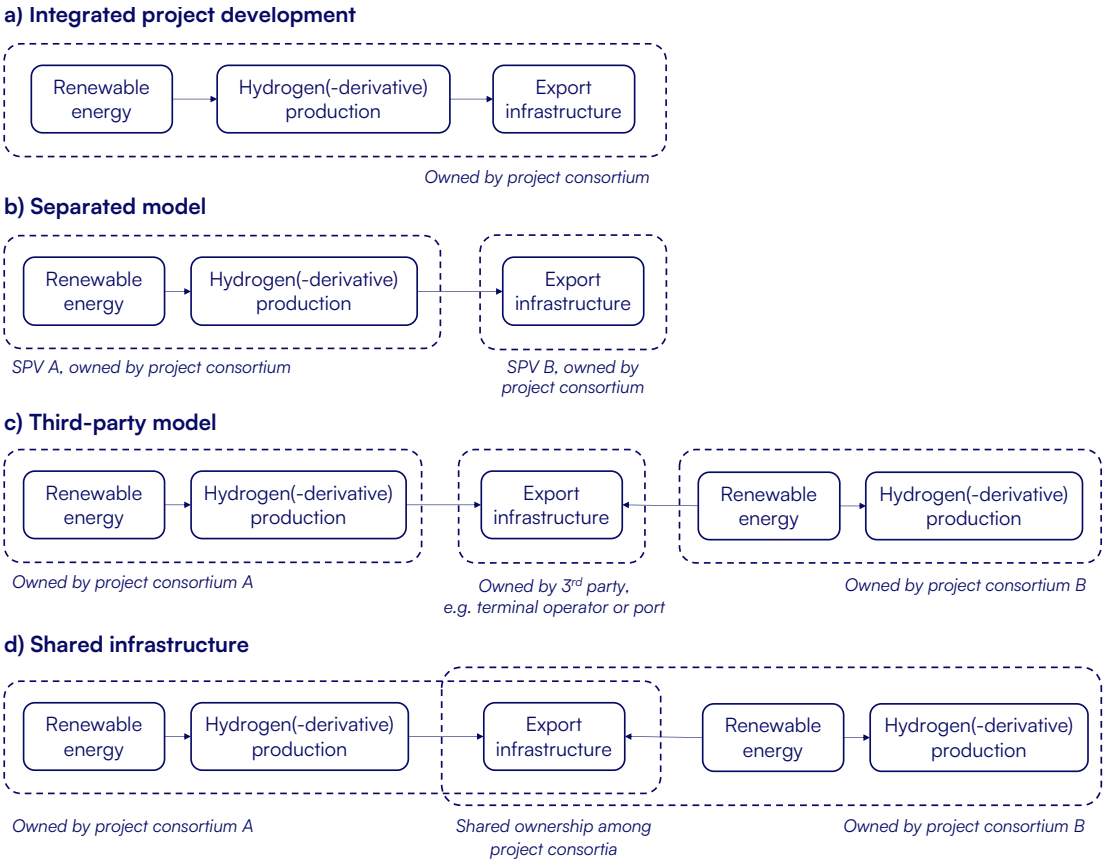




IMAGE CREDIT: ADOBE STOCK / NASOS ZOVOILIS

from the production project can reduce these investment requirements and enable specialised infrastructure operators to serve multiple projects, while joint ownership can allow several projects to share infrastructure costs. Both approaches, however, introduce additional interfaces and dependencies between infrastructure users and owners and require coordination of development timelines and capacity requirements.

Common-user infrastructure (CUI) adds another dimension to these ownership structures: access. CUI provides access to multiple users rather than serving a single project exclusively, and should therefore not be understood as a distinct ownership model. It may, for example, be developed by a specialised third-party infrastructure operator or owned jointly by several users. Depending on the regulatory and institutional setting, public entities may also own or support CUI.

CUI is particularly relevant for emerging clean hydrogen hubs because several projects may require similar infrastructure, including hydrogen pipelines, storage facilities, port connections, and loading infrastructure. Sharing such assets avoids duplication, increases utilisation, and enables economies of scale, while reducing the infrastructure investment required from individual projects. It may also enable smaller projects to access facilities that would be difficult to justify on a standalone basis and, where access terms are clear, offer greater certainty over availability.

At the same time, these benefits come with coordination and investment challenges. Infrastructure capacity may need to be planned before the number, scale, and timing of future users are known. Projects may reach FID at different times, creating uncertainty over initial utilisation and raising questions about who bears the cost of spare capacity during ramp-up.

CUI may be beneficial from a wider system perspective without necessarily being the preferred solution for an individual project developer.

CUI also creates dependencies between projects and infrastructure providers regarding timelines, access, tariffs, and future capacity expansion. CUI may therefore be beneficial from a wider system perspective without necessarily being the preferred solution for an individual project developer.

These challenges are particularly pronounced in the nascent hydrogen market, where few projects can provide firm, long-term capacity commitments. While specialised operators can develop multi-user infrastructure commercially when future utilisation and revenues are sufficiently predictable, alternative approaches are required to coordinate infrastructure development and allocate early-stage investment risks. The following section examines four development archetypes emerging across planned clean hydrogen infrastructure initiatives.

Emerging infrastructure development archetypes

The ownership models and common-user infrastructure concepts discussed above provide different options for structuring export infrastructure. However, the development of such infrastructure ultimately depends on whether sufficient demand and revenue certainty exist to mobilise investment. In established infrastructure markets, specialised infrastructure operators can develop assets based on predictable utilisation and revenues from infrastructure users. In the nascent clean hydrogen market, these conditions are often not yet present. Few clean hydrogen projects have reached FID, future infrastructure demand remains uncertain, and projects within the same region may progress at different speeds. This creates a particular challenge for infrastructure that needs to be developed ahead of, or in parallel with, clean hydrogen production projects.

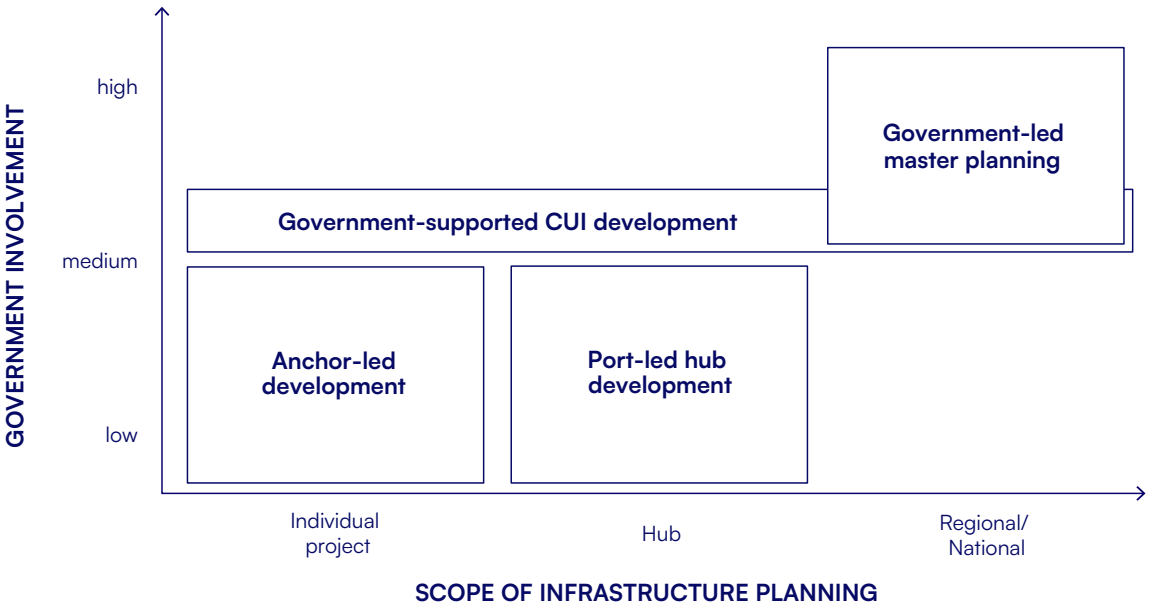
In established infrastructure markets, specialised infrastructure operators can develop assets based on predictable utilisation and revenues from infrastructure users. In the nascent clean hydrogen market, these conditions are often not yet present.

Against this background, different approaches are emerging to overcome the coordination and investment challenges associated with clean hydrogen export infrastructure.

Based on the analysis of planned and ongoing infrastructure initiatives across potential clean hydrogen-exporting regions, four broad development archetypes can be identified: **anchor-led development, port-led hub development, government-supported common-user infrastructure development, and government-led master planning**. These archetypes differ primarily in the actor or mechanism that takes a leading role in bringing infrastructure development forward, as well as in the geographic scope of infrastructure planning and the degree of government involvement. Figure 8 positions them along the latter two dimensions: infrastructure planning scope ranges from an individual project to a regional or national system, while government involvement increases from bottom to top. This involvement can range from enabling measures, such as regulation or land allocation, to active planning, equity participation, or direct infrastructure development.

The four archetypes are stylised approaches rather than mutually exclusive models. Different approaches may coexist within the same country, region, or hydrogen hub, and may apply to different infrastructure components. For example, government-led master planning can provide the overarching framework for infrastructure development, while individual assets are developed through government-supported CUI or by individual anchor projects. The approaches may also evolve as projects mature and future infrastructure utilisation becomes more certain.

Figure 8: Development archetypes for clean hydrogen infrastructure



Anchor-led development

Under the anchor-led development archetype, export infrastructure is developed primarily to meet the requirements of a single large clean hydrogen project. The anchor project provides the scale and demand certainty required to justify infrastructure investment, allowing production and export infrastructure to be developed in parallel and closely aligned in terms of capacity and timelines. Infrastructure may be developed as part of the production project itself or through a separate infrastructure SPV controlled by the project consortium.

This approach reduces the need to coordinate infrastructure development with other clean hydrogen projects and gives the anchor project a high degree of control over infrastructure design, timing, and capacity. However, the project also bears the associated investment and utilisation risks. Infrastructure may be designed with the possibility of accommodating additional users in the future, but expansion into common-user infrastructure is not an inherent feature of the archetype.

The extent of public-sector involvement can vary within this archetype. Anchor-led development does not imply that export infrastructure and the production project are necessarily developed without government support. Public actors may participate through, for example, financial support or equity investment and land allocation, while the requirements and timeline of the anchor project remain the principal drivers of infrastructure development. For example, both the NEOM Green Hydrogen Project in Saudi Arabia and the Hyphen project in Namibia involve direct state participation in the project companies, whereas AM Green's Kakinada project in India is primarily commercially financed and developed.

The scale of new export infrastructure required also differs substantially between projects. Large greenfield developments such as NEOM and Hyphen require extensive new infrastructure to connect new production sites to export markets. By contrast, anchor projects located within established industrial and port environments may build on existing infrastructure and invest only in the additional assets required for their export volumes. AM Green's Kakinada project illustrates this latter pathway. The project plans to export ammonia through the existing Kakinada Deep Water Port, which already handles liquid ammonia. Rather than developing an entirely new port, AM Green will construct project-specific infrastructure, including an ammonia product pipeline connecting the production site to the port, and loading equipment at an existing berth.[21]

Port-led hub development

Under the port-led hub development archetype, a port authority, port operator, or special economic zone coordinates the development of clean hydrogen export infrastructure for multiple projects within a defined industrial or port hub. Rather than infrastructure development being driven primarily by the requirements of a single clean hydrogen project, the port takes a broader perspective on the infrastructure needs of the emerging hub. Its role can include long-term spatial and infrastructure planning, stakeholder engagement, and matchmaking between project developers, infrastructure providers, and potential offtakers, as well as the allocation of land for clean hydrogen production and infrastructure development.

Table 3: Applicability and key challenges of anchor-led development

Applicability	Key challenges
• Existing infrastructure is insufficient, requiring project-specific investment. • Opportunities for sharing infrastructure with other projects are limited or uncertain. • One sufficiently large and advanced project can justify dedicated infrastructure. • The project requires strong control over infrastructure capacity and development timelines.	• High upfront capital requirements for the anchor project. • Strong dependency on the anchor project reaching FID and proceeding on schedule. • Underutilisation risk if production is below expected levels. • Project-specific design can make later access by additional users difficult. • Oversizing for potential future users shifts additional utilisation risk to the anchor project.

This approach is closely related to the landlord-port model under which the port authority typically manages and develops port land and common infrastructure, while terminal facilities and specialised infrastructure are developed and operated by private companies.

This approach is closely related to the landlord-port model under which the port authority typically manages and develops port land and common infrastructure, while terminal facilities and specialised infrastructure are developed and operated by private companies. Applied to clean hydrogen, the port can therefore provide the spatial and organisational framework for hub development and invest in general enabling infrastructure. Clean hydrogen-specific production and export infrastructure, on the other hand, is primarily financed, developed, and operated by private-sector project developers and specialised infrastructure operators. This allows different ownership structures to emerge within the same hub and can facilitate the development of shared infrastructure where a commercial case exists.

The level and form of public-sector involvement can vary considerably within this archetype, reflecting different port governance structures. Ports may be governed by public port authorities or state-owned entities, or operated by private companies under concession or private-port models. Consequently, port-led development can range from predominantly private-sector coordination and investment to models in which public authorities play a significant planning and enabling role. Port authorities may also invest in general infrastructure serving the wider port or industrial hub without directly financing the clean hydrogen projects or their dedicated export facilities.

Examples include the ports and industrial hubs of Pecém and Açu in Brazil, Namport's development of Walvis Bay in Namibia, and the Suez Canal Economic Zone (SCZONE) in Egypt. While their governance structures and geographic scope differ, these entities follow a similar development approach: they use instruments such as spatial planning, land allocation, and engagement with project developers and infrastructure providers to facilitate the development of hydrogen hubs, while clean hydrogen-specific infrastructure can be developed by private project developers and specialised infrastructure operators. SCZONE represents a broader application of this approach, as the authority coordinates several industrial areas and ports, including the emerging clean hydrogen hub around Sokhna.

Table 4: Applicability and key challenges of port-led hub development

Applicability	Key challenges
• Several clean hydrogen projects are concentrated within or around an existing or planned port or industrial hub. • A port authority, operator, or special economic zone has the mandate and capacity to coordinate industrial development and allocate land. • Existing port, industrial, or liquid-bulk infrastructure can support clean hydrogen and derivative exports. • Opportunities exist to share infrastructure or coordinate connections between several projects and infrastructure operators. • Clean hydrogen derivatives can serve both as export commodities and shipping fuels, creating opportunities to aggregate demand through bunkering and the development of green shipping corridors.	• Clean hydrogen projects may progress towards FID at different speeds, making the timing and sizing of shared infrastructure uncertain. • Land and infrastructure capacity may need to be reserved before future demand is certain, creating a risk of over- or under-dimensioning. • Terminal and infrastructure operators may be reluctant to invest without sufficiently firm long-term volume or capacity commitments. • Coordination and commercial arrangements are required between multiple project developers, infrastructure operators, and other port users, including rules for capacity allocation, tariffs, and future expansion. • Port-level development needs to be aligned with wider regional and national infrastructure planning.

Government-supported CUI development

Under the government-supported common-user infrastructure (CUI) development archetype, public intervention enables shared infrastructure serving multiple users where commercial investment would otherwise be constrained by insufficient demand or revenue certainty. Infrastructure may be developed, owned, and operated by public, private, or mixed-ownership infrastructure or network operators, while governments address early-stage investment and utilisation risks through instruments such as grants, guarantees, concessional financing, regulated tariff mechanisms or, in some cases, direct public investment.

Government-supported CUI can be applied at different scales, from individual clean hydrogen hubs to regional, national, or cross-border infrastructure networks.

The rationale for public intervention is particularly strong where infrastructure has high upfront investment requirements and significant economies of scale, making the development of separate assets for individual projects inefficient. In the nascent clean hydrogen market, however, private infrastructure operators may be unwilling to invest in appropriately sized shared infrastructure before a sufficient number of users have reached FID or made firm capacity commitments. Public support can help bridge this ramp-up period until utilisation and associated infrastructure revenues increase.

Government-supported CUI can be applied at different scales, from individual clean hydrogen hubs to regional, national, or cross-border infrastructure networks. It can also form part of a broader government-led master planning approach. The distinction between the two archetypes lies primarily in the nature of public intervention: government-led master planning focuses on coordinating where and how infrastructure should develop, while government-supported CUI uses public support to help make specific shared infrastructure investments viable. The two approaches are therefore complementary rather than mutually exclusive.

The form of government support can vary considerably. Germany's clean hydrogen core network uses a regulated amortisation mechanism and state-backed interim financing to address low utilisation during market ramp-up, while the network itself is financed and developed by transmission system operators. At European Union (EU) level, clean hydrogen infrastructure can receive grants for studies and construction through the Connecting Europe Facility (CEF), while financing models for emerging cross-border hydrogen corridors are still being developed.

Table 5: Applicability and key challenges of government-supported CUI development

Applicability	Key challenges
• Several potential users could benefit from shared infrastructure, and clarity on its availability could support their FIDs. • Infrastructure has strong economies of scale and duplication would be inefficient. • Expected long-term utilisation is credible, but insufficiently certain to support commercial investment during ramp-up. • Governments have the financial and institutional capacity to provide appropriate support or risk-sharing mechanisms. • A capable infrastructure or network operator and an appropriate regulatory framework exist or can be established.	• Infrastructure may need to be sized before the number, scale, and timing of future users are certain. • Where shared capacity is built ahead of firm user commitments, ramp-up and stranded-asset risks need to be allocated between governments, operators, and users. • Tariffs, capacity allocation, and non-discriminatory access arrangements must be established. • Public support needs to be sufficiently reliable and predictable, while lengthy public approval and procurement processes can delay infrastructure development. • Cross-border infrastructure introduces additional regulatory and institutional coordination challenges.

Australia provides direct public funding for common-user infrastructure within clean hydrogen hubs, including pipelines and port infrastructure. In Oman, a different approach is emerging, with Hydrom coordinating CUI and designated national utility companies taking responsibility for clean hydrogen pipelines, electricity transmission, and water infrastructure.

Under the government-led master planning archetype, a government or designated public entity takes a leading role in coordinating and steering the development of a clean hydrogen ecosystem at a regional or national scale.



IMAGE CREDIT: ADOBE STOCK / ARDAN FUESSMANN

Government-led master planning

Under the government-led master planning archetype, a government or designated public entity takes a leading role in coordinating and steering the development of a clean hydrogen ecosystem at a regional or national scale. Beyond strategic planning, this can involve identifying priority development areas, allocating land, selecting projects, coordinating infrastructure requirements across multiple projects and parts of the value chain, and establishing dedicated regulatory, permitting, or fiscal incentives. Together, these measures provide an overarching framework to attract clean hydrogen projects and steer their development in line with wider infrastructure and spatial planning objectives. Government leadership does not, however, imply public ownership or financing of the resulting infrastructure, which can subsequently be developed by private project consortia, by infrastructure operators, or through common-user arrangements.

Table 6: Applicability and key challenges of government-led master planning

Applicability	Key challenges
• Multiple large projects and infrastructure systems must be coordinated across a region or country. • Significant greenfield development requires early land and infrastructure planning. • Scarce resources or infrastructure bottlenecks, such as suitable land, coastline, water, grid capacity, or transport corridors, must be managed strategically. • Governments have sufficient institutional capacity and authority to coordinate development across sectors and stakeholders. • Countries' governance structures allow for effective central or regional coordination of infrastructure development.	• Planning ahead of firm project commitments risks creating infrastructure plans that exceed realised demand. • Planning alone may be insufficient to mobilise investment where demand and revenues remain uncertain. • Government processes can slow project development or conflict with commercial timelines. • Effective implementation depends on institutional capacity, credibility, and consistent government policy. • Authorities need to distinguish between infrastructure requiring central coordination and assets that can be developed commercially.

Government-led master planning can provide the wider framework within which the other development archetypes operate.

Government-led master planning can therefore provide the wider framework within which the other development archetypes operate. Anchor-led projects and port-led hubs can develop within the areas and infrastructure frameworks established through master planning, while government-supported CUI can be used where additional public support is required to make specific shared infrastructure investments viable. The distinction is that master planning primarily coordinates and steers the development of the wider ecosystem, rather than directly addressing the investment case of individual infrastructure assets.

The extent and instruments of government-led master planning vary across countries. Oman represents a comprehensive approach, with Hydrom identifying dedicated development areas, allocating land through competitive auctions, coordinating project development and common infrastructure, and providing fiscal incentives, while CUI development is led by national entities. Morocco's Green Hydrogen Offer similarly combines the allocation of public land and competitive project selection with investment incentives and integrated planning of the electricity, port, and desalination infrastructure required by emerging clean hydrogen projects. Mauritania follows a more developer-led approach, with its Green Hydrogen Code and green hydrogen cadastre providing a dedicated regulatory, fiscal, and land-allocation framework, complemented by assessments of future infrastructure needs, while clean hydrogen infrastructure investment is expected primarily to be undertaken by private developers. While the degree of central coordination differs, all three approaches go beyond strategic target-setting by actively using land allocation, regulatory frameworks, incentives, and infrastructure coordination to steer an emerging clean hydrogen ecosystem.



IMAGE CREDIT: ADOBE STOCK / CORLAFFRA



IMAGE CREDIT: LARA JAMESON



5

Case studies: Development archetypes in practice

There is no single model for developing clean hydrogen export infrastructure. The approach depends on local market and institutional conditions, existing infrastructure, and the scale and type of new infrastructure required. This chapter examines how different development archetypes are applied in practice across four case studies: Brazil, Oman, Namibia and South Africa, and cross-border clean hydrogen pipeline development in Europe.

Each case study follows a common structure. It first establishes the infrastructure starting point and development challenge, including the extent to which existing infrastructure can be used and where new investment is required. It then examines the approach to infrastructure development, focusing on the actors coordinating and investing in infrastructure and the application or combination of the development archetypes identified in Chapter 4. Finally, each case study derives key lessons for clean hydrogen export infrastructure development. As the archetypes are not mutually exclusive, individual case studies may combine several approaches or apply different archetypes to different infrastructure components.

Brazil: Port-led development of hydrogen export hubs

Brazil is emerging as a major location for clean hydrogen and hydrogen-derivative projects. A distinctive feature of the country's portfolio of proposed projects is its concentration around existing ports and industrial areas, where projects can potentially draw on established maritime access, industrial land, and infrastructure. This case study focuses on the ports of Pecém and Açu, which host two of the largest concentrations of announced clean hydrogen projects in Brazil. Both illustrate the port-led hub development archetype, although they differ in their governance structures, infrastructure starting points, and the degree of public involvement. Their comparison therefore provides insights into how port ecosystems can coordinate the development of clean hydrogen export hubs while specialised infrastructure investment remains largely with project developers and infrastructure providers.

Infrastructure starting point and development challenge

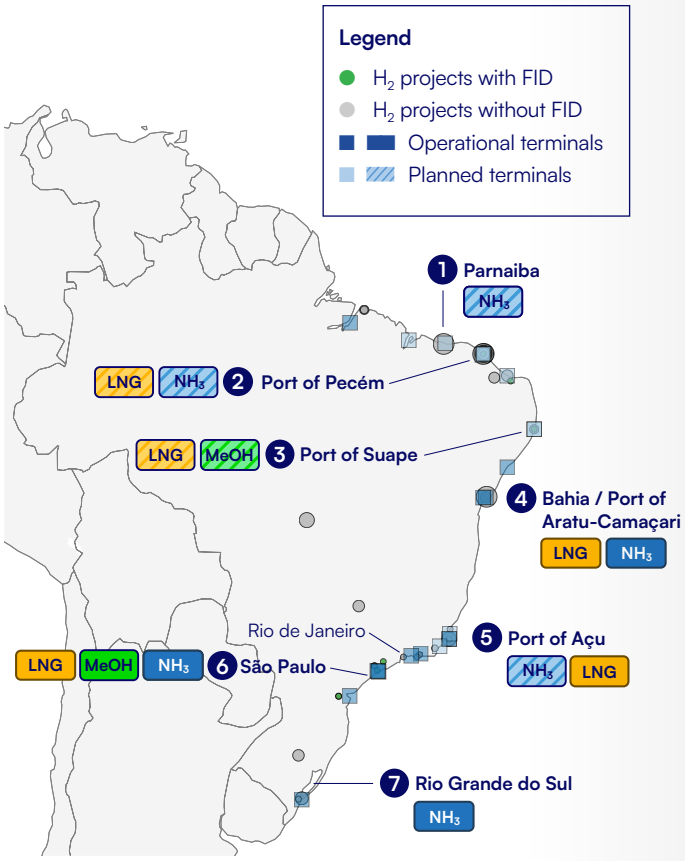
Brazil has a substantial portfolio of announced clean hydrogen projects, but most remain at an early stage of development. According to the IEA Hydrogen Projects Database, 75 clean hydrogen projects are currently being tracked in the country. Of these, six projects have already reached a final investment decision (FID) or are operational, while 10 projects are classified as dormant, on hold, or cancelled. The remaining projects are at earlier stages of development. All six projects that have reached FID or are operational are small-scale pilot projects. In total, the announced projects represent a production capacity of approximately 10.8 $Mtpa_{H2\text{-}eq}$.[22]

Most announced clean hydrogen projects are strategically located near ports to use existing infrastructure and facilitate exports (see Figure 9). This provides an important advantage compared with entirely greenfield export locations, as projects can potentially build on existing port access, industrial areas, electricity connections, and liquid-bulk infrastructure. At the same time, existing facilities were not designed for the volumes and products envisaged by the emerging clean hydrogen industry. Additional investment in electricity and water supply, pipelines, storage, and loading infrastructure will therefore be required to enable large-scale exports of clean hydrogen derivatives.

Most announced clean hydrogen projects are strategically located near ports to use existing infrastructure and facilitate exports.

The concentration of projects is particularly pronounced at the Port of Pecém and the Port of Açu. Of the 65 active projects tracked in the IEA database, 29 are located in the industrial areas around these two ports. The following analysis therefore examines how the two port-industrial ecosystems are preparing for clean hydrogen exports and addressing infrastructure requirements while most prospective users remain at pre-FID stages.

Figure 9: Overview of Brazil's planned hydrogen projects and existing and planned port infrastructure



Port of Pecém: Large project cluster requiring new derivative infrastructure

Located on the north-eastern coast of Brazil, the Port of Pecém already provides substantial industrial and logistics infrastructure, including one dry-bulk terminal and one liquid-bulk terminal. Until 2023, the port also hosted an LNG regasification terminal based on a floating storage and regasification unit (FSRU), and a new FSRU-based terminal is currently planned. In 2025, the port handled approximately 21 mn tonnes of cargo. However, dedicated ammonia storage and handling infrastructure does not yet exist and would need to be developed to enable large-scale clean ammonia exports.[23]

A particularly large clean hydrogen project cluster is emerging in the nearby Ceará industrial and special economic zone, located approximately 6 km from the port. Eighteen projects have been announced, including eight at the concept stage, nine in the feasibility stage, and one operational project. Together, these projects represent a planned production capacity of approximately 4.1 $Mtpa_{H2\text{-}eq}$, consisting of clean ammonia (1.8 Mtpa) and clean hydrogen (2.3 Mtpa).[24]

Pecém therefore combines an established port and industrial environment with a portfolio of prospective clean hydrogen projects that substantially exceeds the infrastructure currently available for clean hydrogen derivatives. Beyond expanding ammonia storage and loading capacity at the port, the emerging production cluster will require new connections for electricity, water, and ammonia transport between the industrial area and the port. The central challenge is to develop these systems at a sufficient scale and in time for future production projects while the timing and volumes of most prospective infrastructure users remain uncertain.

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IMAGE CREDIT: ADOBE STOCK / MASTERSKUZ55

Port of Açu: Using an established liquid-bulk and energy hub

Açu provides a different infrastructure starting point. Located on the southern half of Brazil's Atlantic coast, approximately 250 km north of Rio de Janeiro, the port is the largest private deep-water port in Latin America and hosts eleven private terminals. Its existing industrial activities include large-scale iron ore and oil exports as well as LNG imports, providing an established liquid-bulk, energy, and logistics ecosystem that can potentially be used for clean hydrogen derivatives.[25]

Ten clean hydrogen-related projects have been announced at the port, representing approximately 0.7 $Mtpa_{H2\text{-}eq}$ of planned production capacity. All remain at concept or feasibility stage. Compared with Pecém, the emerging clean hydrogen project cluster is therefore considerably smaller, while Açu's existing port and industrial infrastructure is more extensive. However, as with Pecém, dedicated ammonia storage and handling infrastructure does not yet exist and would need to be developed to enable large-scale clean ammonia exports. The infrastructure challenge is consequently less about establishing a new export location and more about preparing and expanding the existing industrial-port environment to accommodate new clean hydrogen derivatives and future production volumes.

Infrastructure development approach: Variations of port-led hub development

Despite these different physical starting points, Pecém and Açu are pursuing broadly similar approaches to clean hydrogen hub development. In both cases, the port ecosystem goes beyond providing maritime access by allocating or preparing industrial land, coordinating infrastructure requirements, and connecting clean hydrogen project developers with infrastructure providers. The ports thereby seek to reduce development risks for individual projects while enabling infrastructure to serve multiple prospective users. However, the instruments used and the degree of public involvement differ between the two hubs.

The ports seek to reduce development risks for individual projects while enabling infrastructure to serve multiple prospective users.

Port of Pecém: Coordinating shared infrastructure across a large project cluster

The port's business model is based on a land-lease model under which project developers can initially select land on a non-binding basis before committing through the payment of a reservation fee. To date, seven projects have secured land reservations. Of these, two projects have finalised the FEED stage, while one project is currently advancing towards FID with a targeted commercial operation date before 2029. This staged approach allows land to be allocated to prospective projects while providing flexibility during the comparatively long development period of clean hydrogen projects.[26]

The wider industrial zone provides dedicated land for clean hydrogen projects and facilitates environmental permitting within designated industrial areas. More importantly for export infrastructure development, Pecém is pursuing a common-user infrastructure (CUI) approach intended to connect the emerging production cluster with the utilities and export facilities required by multiple projects. The concept is built around three main infrastructure systems: a dedicated electricity connection and substation within the production cluster; a water supply system using treated wastewater from the nearby metropolitan area; and an ammonia pipeline connecting the production cluster with storage and new ship-loading facilities at the port's existing liquid-bulk terminal. Strategic partners have already been selected to develop and invest in this shared infrastructure rather than requiring each clean hydrogen producer to establish a separate infrastructure chain.[27]

The CUI approach responds directly to the scale and maturity challenges identified above. Aggregating infrastructure requirements across several projects can reduce duplication and enable infrastructure to be developed at a greater scale. At the same time, the limited number of projects approaching FID creates uncertainty over when capacity will be required and how quickly infrastructure utilisation will ramp up. The development of shared infrastructure therefore requires coordination not only between prospective users, but also between production-project and infrastructure-investment timelines.



IMAGE CREDIT: ADOBE STOCK / CACIO MURILO

Pecém is pursuing a common-user infrastructure (CUI) approach intended to connect the emerging production cluster with the utilities and export facilities required by multiple projects.

Pecém's clean hydrogen hub also benefits from substantial public and international involvement. The port itself is jointly owned by the State of Ceará and the Port of Rotterdam, with the latter holding a 30% stake. In addition, the World Bank is supporting the project through an Investment Project Financing (IPF) instrument with total financing of USD 134 mn. This package includes a USD 90 mn IBRD loan, a USD 9 mn grant from the IBRD Surplus-Funded Livable Planet Fund, while the Climate Investment Funds (CIF) provides a USD 33.5 mn loan under the Renewable Energy Integration Program and an additional USD 1.5 mn grant.[28]

Pecém therefore primarily reflects port-led hub development, but with important elements of government-supported CUI development. The port ecosystem coordinates land, projects, and infrastructure providers, while public and development-finance support contributes to creating the wider conditions for shared infrastructure investment before demand from clean hydrogen projects is fully established.

Port of Açu: Preparing an integrated industrial hub for hydrogen projects

The port pursues a land-lease business model similar to that of Pecém, under which project developers and infrastructure providers can lease dedicated industrial areas within the port complex. In addition to land provision, the port facilitates access to existing and shared infrastructure and services, including electricity grid connections for clean hydrogen production, water supply, and liquid-bulk terminal infrastructure, which is expected to support the future handling of clean hydrogen derivatives such as ammonia. A water-reuse project at the port has the potential to supply up to 1,000 m^3/h of treated industrial wastewater, subject to any further treatment required for clean hydrogen production. The Prumo Group, the holding company responsible for developing the Port of Açu, may draw on its links to the port's water-services provider and liquid-bulk terminal operator to coordinate infrastructure across clean hydrogen projects.[29]



IMAGE CREDIT: ADOBE STOCK / ANTONIO SALAVERRY

Alongside its coordination of infrastructure, the port of Açu handles the advance preparation and environmental licensing of industrial land. Approximately 100 hectares have already been environmentally licensed for clean hydrogen-related activities, corresponding to an estimated electrolysis capacity of around 3.7 GW. Additional land is being prepared for hydrogen derivatives and other low-carbon fuels, including ammonia, methanol, biofuels, and e-fuels. By undertaking environmental licensing at the hub level before individual projects reach FID, Açu can reduce permitting risks and development timelines for prospective investors. In parallel, the Caruara Reserve dedicates approximately one-third of the port's land to conservation and provides opportunities for companies to support ecosystem restoration.[30]

Açu's approach therefore builds on the combination of an established industrial-port ecosystem and the advance preparation of land for new hydrogen projects. Rather than planning a predefined package of new clean hydrogen-specific CUI comparable to that of Pecém, the port facilitates the integration of individual projects with existing and future infrastructure and specialised infrastructure providers. This can reduce the amount of infrastructure that needs to be developed by individual clean hydrogen projects, while allowing additional infrastructure capacity to be developed as project requirements become more certain.

Açu therefore primarily reflects port-led hub development. The port creates and coordinates the wider development environment through land provision, environmental licensing and integration with port infrastructure, while investment in specialised clean hydrogen and export infrastructure remains largely a private-sector responsibility.

Açu's approach therefore builds on the combination of an established industrial-port ecosystem and the advance preparation of land for new hydrogen projects.

Two variations of the same archetype

Pecém and Açu demonstrate that port-led hub development can emerge under substantially different governance and infrastructure conditions. Pecém combines port coordination with a stronger public-sector and development-finance role, and is pursuing a defined package of new shared infrastructure across a comparatively large portfolio of prospective users. Açu, by contrast, builds more strongly on an established industrial-port ecosystem and the advance preparation and environmental licensing of land, while specialised infrastructure investment remains largely a private-sector responsibility.

In both cases, however, the port ecosystem performs the same underlying function: reducing the coordination burden faced by individual clean hydrogen projects. Instead of each developer independently securing land, permits, and infrastructure connections, and developing a complete export chain, the port prepares a common development environment and coordinates infrastructure provision across multiple prospective users. Pecém further illustrates how government-supported CUI can complement this model where uncertainty over future utilisation makes investment in shared infrastructure difficult.

Lessons for export infrastructure development

— **Ports can play a central coordinating role in clean hydrogen hub development without necessarily investing in hydrogen-specific infrastructure themselves.** Pecém and Açu show how ports can bring together project developers and infrastructure providers, allocate and prepare industrial land, facilitate permitting, and coordinate infrastructure requirements, while specialised infrastructure can be developed and operated by other actors.

— **The appropriate role of the port depends on the existing infrastructure and emerging project portfolio.** Where substantial new infrastructure is required across a large number of prospective users, as in Pecém, port-led development can extend to the coordination of dedicated CUI.



IMAGE CREDIT: ADOBE STOCK / MASTERSKUZ55

Where an extensive industrial and logistics ecosystem already exists, as in Açu, the port can focus more strongly on preparing land and facilitating the integration of new projects with existing and future infrastructure.

— **Developing shared infrastructure ahead of clean hydrogen projects creates a trade-off between de-risking projects and taking utilisation risk.** Providing infrastructure at the hub level can reduce duplication and project-level development risks, but determining its timing and capacity is difficult while most prospective users remain pre-FID. Pecém illustrates how public and development-finance support can complement port-led development where this uncertainty constrains investment in shared infrastructure.

— **Port-led hub development is not dependent on a particular ownership or governance model.** The cases of publicly anchored Pecém and privately operated Açu demonstrate that the defining feature is the port ecosystem's coordinating role rather than its ownership. However, governance and access to public support can influence how far the port can go in facilitating shared infrastructure development.

Oman: Government-led development of an integrated hydrogen ecosystem

Oman is emerging as a potential large-scale exporter of clean hydrogen and its derivatives, supported by favourable solar and wind resources and direct access to international shipping routes. Clean hydrogen development is concentrated in several coastal industrial regions, with particularly large production clusters emerging around Duqm and Salalah. However, these regions differ considerably in their existing industrial and export infrastructure, creating different requirements for the development of future clean hydrogen export chains.

A distinctive feature of Oman is the strong coordination of clean hydrogen production and enabling infrastructure development through Hydrom, the government-owned entity responsible for orchestrating the country's clean hydrogen sector.

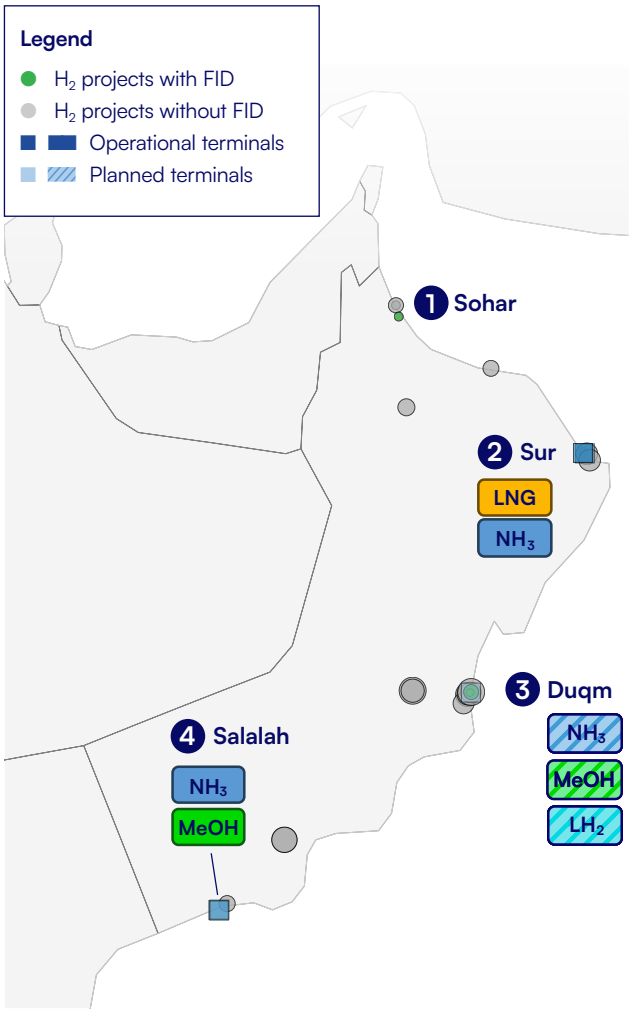
A distinctive feature of Oman is the strong coordination of clean hydrogen production and enabling infrastructure development through Hydrom, the government-owned entity responsible for orchestrating the country's clean hydrogen sector. Oman therefore provides an example of how government-led master planning can be combined with government-supported common-user infrastructure (CUI), while individual export infrastructure assets can follow separate development models. The case study focuses particularly on Duqm and Salalah, and examines how this coordinated approach responds to their different infrastructure starting points.[31]

Infrastructure starting point and development challenge

Oman's existing energy and industrial infrastructure is concentrated around four main coastal regions: Sohar, Sur, Duqm, and Salalah (Figure 10). Sohar and Sur already host substantial energy-intensive industries and export infrastructure. Sohar is Oman's most developed industrial cluster, with refining, steel, ammonia, methanol, and petrochemical production alongside an established deep-water port. Sur hosts the country's LNG export terminal as well as the Oman India Fertiliser Company (OMIFCO), which produces ammonia and urea for international markets. However, neither location has become the principal focus of Oman's emerging large-scale clean renewable hydrogen production. Sohar faces comparatively less favourable renewable-energy and land conditions, while clean hydrogen developments around Sur remain relatively small.[32]

Recent large-scale clean hydrogen development has instead concentrated on Duqm and Salalah, where Hydrom's competitive land-allocation rounds have awarded large development areas to clean hydrogen projects. Both regions combine favourable renewable resources with access to maritime export infrastructure, but their infrastructure starting points differ considerably. Duqm represents the development of a new clean hydrogen and derivative export cluster around an existing port with limited liquid-bulk infrastructure, whereas Salalah can build on a more established chemical and liquid-bulk export ecosystem.[33]

Figure 10: Overview of Oman's planned hydrogen projects and existing and planned port infrastructure



Duqm: Large greenfield production cluster with significant new export infrastructure requirements

Duqm has emerged as the largest concentration of planned clean hydrogen production in Oman. Located on the country's central coast, the region combines strong solar and wind resources, large areas of available land and direct access to an existing deep-water port and special economic zone. Unlike a fully greenfield export location, hydrogen projects can therefore build on existing maritime access and basic transport and industrial infrastructure. However, the port currently lacks the liquid-bulk handling and supporting infrastructure required for clean hydrogen derivatives at the scale envisaged by the emerging production cluster.[34]

Nine clean hydrogen and ammonia production projects have been announced in the region, three of which foresee phased expansions. Two of these projects have since been cancelled. Together, the remaining projects represent approximately 4.0 $Mtpa_{H2\text{-}eq}$ of planned production capacity. Accommodating these volumes would require substantial new infrastructure across the production and export chain, including electricity transmission, water supply, clean hydrogen transport, and ammonia storage and loading facilities.[35]

Significant export infrastructure is already being planned in response. Four ammonia terminal projects, one methanol terminal, and one liquid clean hydrogen terminal project have been announced, representing approximately 3.2 $Mtpa_{H2\text{-}eq}$ of potential export capacity. On paper, this is comparable in scale to the announced production volumes.

Neither production nor terminal capacity alone determines infrastructure readiness: the infrastructure and production projects remain at different stages of development, and their timelines are not necessarily aligned.

However, neither production nor terminal capacity alone determines infrastructure readiness: the infrastructure and production projects remain at different stages of development, and their timelines are not necessarily aligned. Export infrastructure could therefore still become a bottleneck if storage and loading capacity is not available when individual production projects are ready to proceed.[36]

Salalah: Using a more established chemical export location

Salalah provides a different infrastructure starting point. Located in southern Oman, the region combines favourable solar and wind resources with an established industrial and logistics ecosystem. The Port of Salalah is one of the region's major transhipment ports, while the adjacent Salalah Free Zone hosts existing chemical industries and infrastructure for ammonia and methanol production and exports.



IMAGE CREDIT: ADOBE STOCK / STOCKFOTOS

Compared with Duqm, future clean hydrogen projects can therefore build on a more developed liquid-bulk and chemical-export environment.[37]

Five large-scale clean hydrogen projects have been announced in the Salalah region, while two have since been cancelled. Together, the remaining projects represent approximately 0.90 $Mtpa_{H2\text{-}eq}$ of planned production capacity, although none has yet reached FID. Existing ammonia export infrastructure, by contrast, can accommodate only around 0.06 $Mtpa_{H2\text{-}eq}$, while the currently announced expansion identified in the analysis would add approximately 0.06 $Mtpa_{H2\text{-}eq}$. Existing infrastructure can therefore provide a starting point for renewable clean ammonia exports, but its capacity is far below the scale of the announced project portfolio.[38]

Salalah consequently faces a different infrastructure challenge from Duqm. Rather than establishing clean hydrogen exports around a port with limited existing liquid-bulk infrastructure, development can build on existing chemical handling and export capabilities. Nevertheless, substantial expansion would still be required if the announced renewable clean ammonia projects materialise. The case therefore illustrates that the presence of existing ammonia infrastructure does not necessarily eliminate an infrastructure gap when future production ambitions are several times larger than existing handling capacity.

Infrastructure development approach: Combining master planning and government-supported CUI

Despite their different infrastructure starting points, Duqm and Salalah are being developed within the same nationally coordinated framework for clean hydrogen development. In both regions, infrastructure needs to be planned alongside a large portfolio of production projects that have not yet reached FID, creating uncertainty over the timing and scale of future infrastructure demand. Rather than leaving individual project developers to independently secure land and develop all required enabling infrastructure, Oman has established a coordinated approach that aligns project development, land allocation, and infrastructure planning across emerging clean hydrogen clusters. This approach combines government-led master planning with government-supported CUI development, while export terminals and other project-specific infrastructure can follow separate development models.

Hydrom: Coordinating clean hydrogen development through government-led master planning

The government-owned entity Hydrom has added another layer of coordination since its establishment in 2022. Hydrom acts as a central interface between project developers, infrastructure providers, and government stakeholders. Its responsibilities include identifying suitable development areas, allocating land through competitive auctions, and coordinating the infrastructure requirements of emerging clean hydrogen clusters. To date, its land-allocation rounds have focused particularly on Duqm and Salalah.[39]

Rather than leaving individual project developers to independently secure land and develop all required enabling infrastructure, Oman has established a coordinated approach that aligns project development, land allocation, and infrastructure planning across emerging clean hydrogen clusters.

This approach goes beyond defining national clean hydrogen targets or providing a general regulatory framework. By determining where large-scale clean hydrogen projects are developed and coordinating land allocation with infrastructure planning, Hydrom considers the requirements of multiple projects at the cluster level rather than leaving infrastructure development to individual projects. Oman therefore provides a clear example of the government-led master planning archetype introduced in Chapter 4. Importantly, this does not mean that the government develops or owns all infrastructure itself; its central role lies in coordinating the wider development framework within which production projects and infrastructure providers invest.[40]

Common-user infrastructure: Coordinating shared clean hydrogen, electricity, and water systems

A central component of this master-planned approach is the development of CUI. Rather than requiring each production project to independently develop its own clean hydrogen transport, electricity transmission, and water infrastructure, Hydrom coordinates shared systems intended to serve multiple projects within a cluster. The current CUI concept includes clean hydrogen pipelines, electricity transmission infrastructure, and desalination and water transport systems. In Duqm, for example, current plans include approximately 200 km of clean hydrogen pipelines alongside new electricity and water infrastructure.[41]

Hydrom coordinates the planning and commercial structuring of these systems, while their development and ownership are expected to involve specialised state-owned entities, including OQ Gas Networks and Nama Group entities, as well as potentially private investors. Technical planning has already progressed through pre-FEED for parts of the infrastructure and into subsequent development stages. However, important aspects of the future commercial model, including ownership structures, cost-recovery mechanisms, tariffs, and risk allocation, remain under development or have not yet been publicly disclosed.[42]

The CUI approach seeks to capture economies of scale and avoid the duplication of large infrastructure systems across neighbouring clean hydrogen projects.

The CUI approach seeks to capture economies of scale and avoid the duplication of large infrastructure systems across neighbouring clean hydrogen projects. At the same time, it creates a coordination challenge characteristic of emerging clean hydrogen hubs: shared infrastructure must be sized and developed while prospective users are at different stages of project development and future utilisation remains uncertain. Infrastructure providers may therefore need to commit investment before all future demand is secured. Oman consequently also illustrates the government-supported CUI archetype, in which public coordination and the involvement of state-owned infrastructure companies can help bring forward shared infrastructure that may be difficult to develop solely on the basis of firm near-term demand.

Export terminal infrastructure: Different development models outside the CUI framework

An important feature of the Omani approach is that the centrally coordinated CUI framework does not currently extend to export infrastructure at the port level. Storage tanks, loading systems, and export terminals for clean hydrogen and its derivatives are largely expected to be developed separately from the shared clean hydrogen, electricity, and water systems. This creates a clear division within the infrastructure chain: enabling infrastructure between production sites and the wider energy and water systems is centrally coordinated, while the infrastructure required to transfer products onto ships can follow different ownership and development models.[43]

Duqm illustrates the implications of this distinction particularly clearly. Several independent terminal developments are being planned that could potentially provide storage and loading services to multiple clean hydrogen projects. Such facilities could evolve towards third-party or common-user infrastructure if they serve several producers, allowing infrastructure costs to be shared and reducing asset duplication. However, their development still depends on sufficient certainty regarding future throughput and on the coordination of terminal investment with the timelines of production projects.[44]

At the same time, individual clean hydrogen projects may choose to develop dedicated export solutions rather than depend on future shared terminal capacity. The ACME green ammonia project, for example, is planning an offshore ammonia-loading solution together with Bluewater based on a single-point mooring system. Integrating export infrastructure directly into the project can give the developer greater control over infrastructure availability and timing, but it also increases project-specific investment and reduces opportunities for infrastructure sharing.[45]



IMAGE CREDIT: ADOBE STOCK / CLEMENS

Box: Beyond the development archetypes — coordinating an emerging LH_2 corridor[46]

Oman's proposed liquid clean hydrogen corridor to Europe illustrates an infrastructure development challenge that extends beyond the four archetypes identified in Chapter 4. In April 2025, eleven companies and organisations from Oman, the Netherlands, and Germany signed a Joint Development Agreement to assess an integrated liquid hydrogen (LH_2) supply chain connecting clean hydrogen production and liquefaction in Oman with maritime transport, import through Amsterdam, and onward distribution towards Germany.

Unlike ammonia, LH_2 currently lacks an established large-scale international transport and terminal infrastructure network. Developing such a corridor therefore requires coordination across multiple parts of the supply chain, including liquefaction, specialised shipping, export and import terminals, and onward transport infrastructure. The initiative illustrates a broader challenge for emerging clean hydrogen export pathways: where established infrastructure and logistics chains do not yet exist, infrastructure development may require coordination between actors across both exporting and importing countries rather than within the export hub alone.



IMAGE CREDIT: ADOBE STOCK / MAGANN

The coexistence of shared and project-specific export solutions demonstrates that different development archetypes and ownership arrangements can operate within the same nationally coordinated clean hydrogen ecosystem. Government-led master planning and government-supported CUI can provide the overarching framework and shared enabling infrastructure, while individual export assets may be developed by terminal operators or anchor projects according to their respective commercial requirements.

Lessons for export infrastructure development

- **Government-led master planning can align project and infrastructure development.** A central coordinator can combine land allocation with infrastructure planning across multiple projects.
- **CUI can reduce duplication but introduces coordination and utilisation risks.** Shared infrastructure must be sized and financed while future demand and project timelines remain uncertain.
- **Different infrastructure components can follow different development models.** In Oman, clean hydrogen, electricity, and water are planned as CUI, while export terminals may be developed by independent operators or individual anchor projects.
- **Less mature export pathways require coordination beyond the export hub.** The Oman—Europe LH_2 corridor illustrates how production, export infrastructure, shipping, and import infrastructure may need to develop in parallel.

Namibia and South Africa: Emerging export hubs under uncertain infrastructure demand

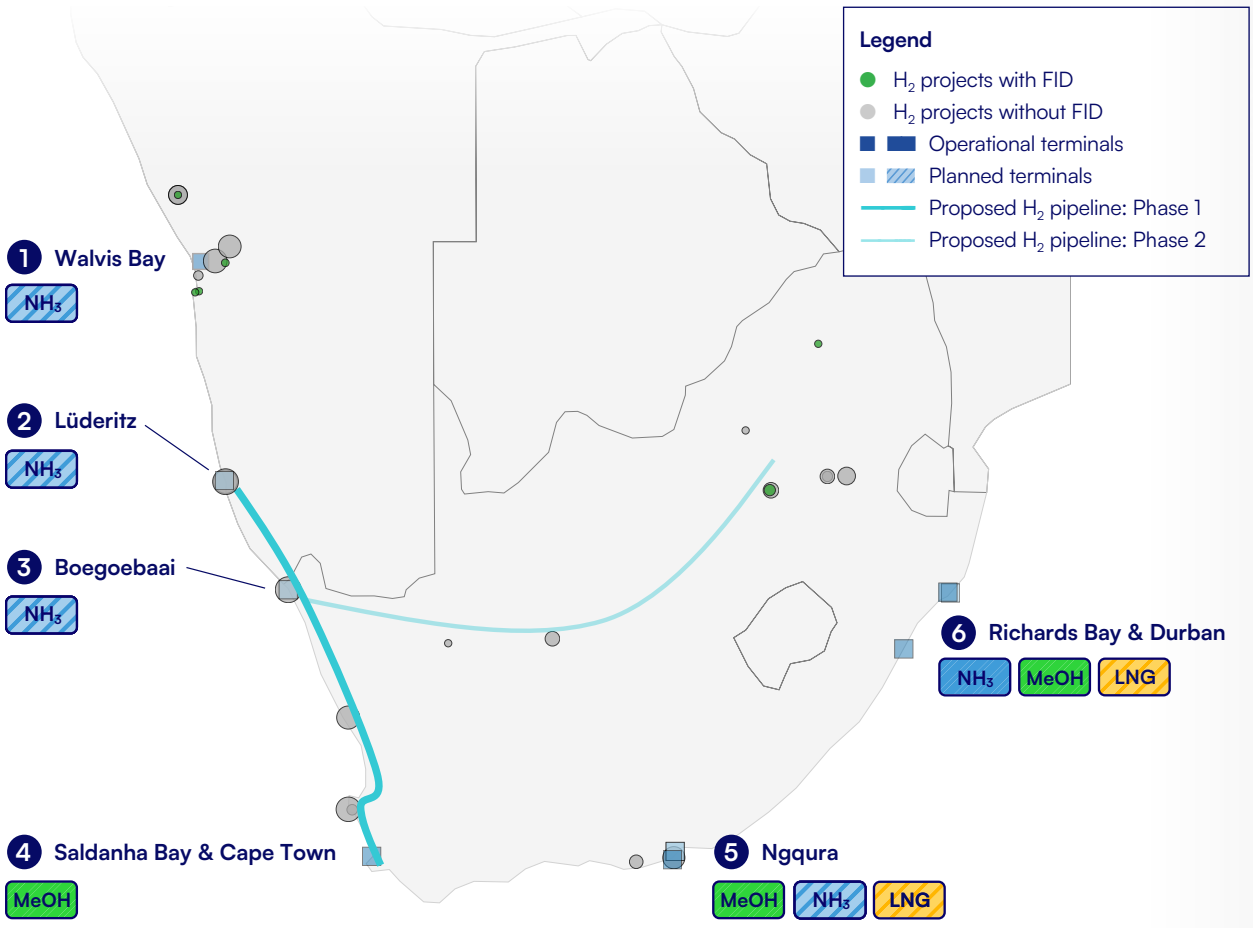
Namibia and South Africa are among the most prominent emerging clean hydrogen producers in sub-Saharan Africa, benefiting from favourable renewable-energy resources and direct access to international shipping routes. However, the infrastructure starting points across the two countries differ considerably. While some prospective clean hydrogen hubs can leverage existing ports, liquid-bulk infrastructure, and industrial ecosystems, others would require largely new export infrastructure. At the same time, few hydrogen projects have reached FID, creating considerable uncertainty over where, when, and at what scale future infrastructure will be required.[47]

Consequently, the two countries are pursuing several infrastructure development approaches simultaneously. Port authorities are preparing existing ports for prospective clean hydrogen projects, large anchor projects are driving infrastructure planning at greenfield locations, and longer-term common-user infrastructure concepts seek to connect multiple production and demand centres. The case study therefore illustrates a combination of port-led and anchor-led development, alongside emerging concepts for government-supported CUI at a regional scale.

Infrastructure starting point and development challenge

Figure 11 provides an overview of emerging clean hydrogen production and export hubs across Namibia and South Africa. Namibia currently hosts ten clean hydrogen projects under development, alongside three pilot-scale projects that have reached FID or are already operational. South Africa has 13 announced clean hydrogen projects and two small operational projects. In September 2026, the Hopefield e-SAF project became the first major clean hydrogen project in the country to reach FID. Despite this progress, large-scale clean hydrogen export infrastructure remains at an early stage of development.[48]

Figure 11: Overview of planned hydrogen projects and existing and planned infrastructure in Namibia and South Africa



Three broad infrastructure starting points can be distinguished across the two countries. First, Richards Bay already possesses ammonia-handling infrastructure, including storage and rail connections to inland industrial demand. Second, locations such as Walvis Bay, Saldanha Bay, and Ngqura can make use of existing port, liquid-bulk, and industrial infrastructure, although substantial adaptation and new clean hydrogen-specific infrastructure would still be required. Third, Lüderitz/Angra Point and Boegoebaai represent largely greenfield developments where new port and export infrastructure would need to be developed alongside clean hydrogen production.[49]

Namibia: Existing Walvis Bay versus greenfield Angra Point

Namibia's two principal prospective export locations illustrate substantially different infrastructure starting points. Walvis Bay provides an established commercial port with existing liquid-bulk infrastructure. Namport has designated approximately 350 hectares for clean hydrogen-related activities, with part of this area already allocated, while several prospective clean ammonia projects are considering the port as an export location.

Land has also been allocated for clean ammonia storage facilities, and common-user ammonia-handling infrastructure is being considered at the existing jetty.[50]

Walvis Bay can therefore draw on existing maritime access and port infrastructure, reducing the extent of greenfield development required. However, existing liquid-bulk capacity does not in itself provide a complete clean ammonia export chain. Storage, pipelines, and loading infrastructure still need to be developed or adapted, while the appropriate capacity remains uncertain as prospective production projects are still at early development stages.

The situation around Lüderitz is fundamentally different. The existing port is relatively small and has limited potential for expansion, while the scale of the planned Hyphen project would require substantially larger export infrastructure. Namport is therefore planning a new deep-water port at nearby Angra Point. Current plans envisage dedicated clean ammonia export capacity, with the possibility of significant longer-term expansion.[51]

Table 7: Overview of emerging hydrogen export hubs in Namibia and South Africa

Hub	Existing infrastructure	Planned H_2 production projects[52]	Planned H_2 infrastructure
Walvis Bay	Existing liquid-bulk port (~10 Mtpa capacity, ~15% utilisation); 350 ha zoned for H_2-related activities, with 100 ha allocated[53]	5 projects planned; ~340 $ktpa_{H2\text{-}eq}$	Land allocated to two developers for NH_3 terminals (feasibility study); CUI for NH_3 infrastructure on existing jetty[54]
Lüderitz	Small shallow-draft port with limited expansion potential	Hyphen project; ~520 $ktpa_{H2\text{-}eq}$	Angra Point deep-water port; initial 2 Mtpa NH_3 export berth by 2028; long-term expansion to 18 Mtpa NH_3[55]
Boegoebaai	No commercial port infrastructure	1 project planned; ~400 $ktpa_{H2\text{-}eq}$	New deep-water port and rail corridor; NH_3 export facilities planned[56]
Western Cape (Saldanha Bay and Cape Town)	Existing fuel logistics and liquid-bulk infrastructure	2 projects planned; ~230 $ktpa_{H2\text{-}eq}$; 1 e-SAF project with FID	West Coast Hydrogen Master Plan: detailed technical studies underway[57]
Ngqura	Existing deep-water container and liquid-bulk port	2 projects; ~150 $ktpa_{H2\text{-}eq}$	105,000 t NH_3 storage facility planned, linked to Hive H_2 project[58]
Richards Bay and Durban	Existing ammonia import infrastructure and rail connection to Sasolburg (145 rail cars, ~500 km)[59]; pipelines for gas and liquid fuels[60]	No project in direct vicinity, 3 projects in Gauteng region; ~80 $ktpa_{H2\text{-}eq}$	LNG terminal for 2 Mtpa LNG[61]



IMAGE CREDIT: ADOBE STOCK / JEAN VAN DER MEULEN

Angra Point consequently represents a greenfield infrastructure challenge, in which port development and clean hydrogen production need to progress in parallel. Unlike Walvis Bay, where existing port infrastructure can provide the basis for gradual expansion, the viability and timing of major new infrastructure at Angra Point are closely linked to the progress of the prospective anchor project and any additional future users.

South Africa: Multiple existing ports and prospective clean hydrogen hubs

South Africa has a considerably larger existing port and industrial system, with prospective clean hydrogen developments distributed across several coastal regions. Existing infrastructure differs significantly between locations. Richards Bay already handles ammonia imports and is connected by rail to industrial users around Sasolburg, while Saldanha Bay and Cape Town possess existing fuel and liquid-bulk infrastructure. Ngqura combines a deep-water port with an established industrial development zone and existing liquid-bulk infrastructure, with new clean ammonia export facilities proposed in connection with hydrogen projects.[62]

These locations illustrate the potential to build on existing port-industrial ecosystems for future clean hydrogen exports. However, existing infrastructure was developed for different products, trade directions, and volumes, and it cannot necessarily accommodate future clean hydrogen derivatives without adaptation or expansion. The existence of established ports therefore reduces some greenfield requirements, but it does not eliminate the need for new export infrastructure.

Boegoebaai represents the opposite end of the spectrum. The proposed clean hydrogen hub on South Africa's north-western coast currently lacks commercial port infrastructure and would require the development of a new deep-water port and associated transport and clean ammonia export facilities. Sasol has been involved as a prospective anchor for clean hydrogen development in the region, although both clean hydrogen production and infrastructure development remain at an early stage.[63]

Existing infrastructure was developed for different products, trade directions, and volumes, and it cannot necessarily accommodate future clean hydrogen derivatives without adaptation or expansion.

Across South Africa, the central infrastructure challenge is therefore not simply a shortage of port capacity. It is uncertainty over which clean hydrogen hubs will materialise, when infrastructure will be required, and at what scale. This makes early investment in large clean hydrogen-specific infrastructure difficult, particularly where infrastructure providers cannot yet rely on committed throughput from production projects.

Namibia and South Africa face a similar development challenge: prospective clean hydrogen projects are advancing, but most cannot yet provide the firm long-term demand needed to underpin large-scale shared infrastructure.

Infrastructure development approach: From project-specific infrastructure to emerging shared systems

Despite their different infrastructure starting points, Namibia and South Africa face a similar development challenge: prospective clean hydrogen projects are advancing, but most cannot yet provide the firm long-term demand needed to underpin large-scale shared infrastructure. Infrastructure development is therefore currently occurring primarily around individual projects and port locations, while broader common-user concepts remain under development. Three approaches can be observed: port-led coordination at existing ports, anchor-led development at greenfield locations, and emerging regional CUI concepts.

Port authorities as facilitators of emerging clean hydrogen hubs

Namport in Namibia and the Transnet National Ports Authority (TNPA) in South Africa broadly operate under landlord-port models and focus on planning, coordination, land allocation, and other enabling activities, while private developers and infrastructure operators are expected to finance, develop, and operate much of the clean hydrogen-specific infrastructure.

In Namibia, this approach is most advanced at Walvis Bay. Namport has allocated land to prospective clean hydrogen and ammonia projects and is assessing common-user ammonia-handling infrastructure at the existing jetty.

Under the concept currently being considered, individual developers would construct their own storage facilities, while pipelines and loading infrastructure at the jetty could potentially be shared between multiple users. Namport has also established partnerships with European ports to support infrastructure planning.

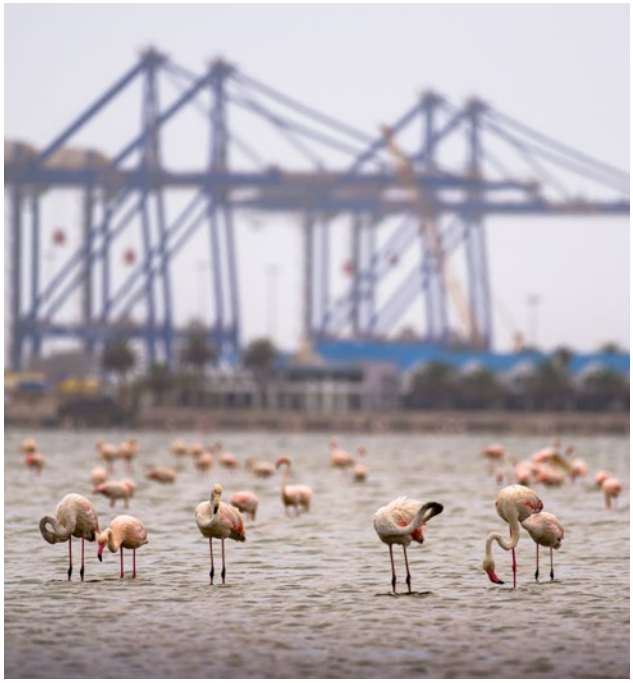


IMAGE CREDIT: ADOBE STOCK / NICK FOX

At Angra Point, the Port of Rotterdam provides technical advisory support on port planning and design, while the EU, Namport, and the Port of Rotterdam have supported environmental and technical studies.[64]

These activities illustrate the port-led hub development archetype. The port authority does not need to finance or operate all clean hydrogen infrastructure itself to play a central development role. By allocating land, preparing port development plans, coordinating infrastructure requirements, and bringing together project developers and infrastructure providers, it can reduce development barriers while leaving specialised infrastructure investment largely to private actors.

South Africa is following a similar, although currently less advanced, approach. TNPA launched a clean hydrogen-focused Request for Information in 2023 to assess market interest, preferred locations, and infrastructure requirements across its commercial ports. The process was intended as a market-sounding exercise to inform future infrastructure planning and potential concession opportunities rather than as a procurement process. In parallel, initiatives including the West Coast Green Hydrogen Master Plan and project-specific studies around Ngqura and Boegoebaai are assessing future infrastructure requirements.[65]

The experience of both countries also highlights a limitation of port-led coordination in an immature market: planning and preparing infrastructure does not by itself create an investment case. Where prospective terminal users have not reached FID or committed future throughput, private terminal and infrastructure operators still face substantial utilisation risk.



IMAGE CREDIT: ADOBE STOCK / EDER

Anchor projects driving greenfield infrastructure development

At greenfield locations, infrastructure development is more closely linked to individual anchor projects. This is particularly visible around Lüderitz and Angra Point, where the Hyphen project represents the principal prospective source of initial clean hydrogen and ammonia volumes. Namport intends to lease land to Hyphen for the development of a dedicated clean ammonia export terminal, while retaining its role as the port authority. The terminal is not currently envisaged as common-user infrastructure (CUI), reflecting the absence of multiple mature clean hydrogen projects in the region.[66]

This illustrates the anchor-led development archetype. Where there are not yet enough committed users to underpin shared infrastructure investment, a large project can provide the initial demand required to bring infrastructure forward. Dedicated infrastructure can also reduce the anchor project's dependence on the timing and investment decisions of other prospective users.

However, anchor-led development does not automatically evolve into CUI. Infrastructure designed around the requirements and timeline of one project may remain dedicated even if additional projects emerge. Alternatively, selected assets could later be expanded or opened to additional users where technically and commercially feasible. The potential transition from dedicated to shared infrastructure therefore depends on the emergence of credible additional demand rather than representing an inevitable development pathway.

A similar concept has been proposed around Boegoebaai in South Africa, where the development of a new deep-water port and clean hydrogen hub has been closely associated with Sasol as a prospective anchor project. However, both the clean hydrogen project and supporting infrastructure remain at an early stage, illustrating the interdependence between anchor-project maturity and major greenfield infrastructure investment.[67]

Beyond individual port hubs, Namibia and South Africa are exploring a substantially larger common-user infrastructure concept through the proposed cross-border clean hydrogen pipeline.

Regional CUI: The proposed Namibia—South Africa clean hydrogen corridor

Beyond individual port hubs, Namibia and South Africa are exploring a substantially larger common-user infrastructure concept through the proposed cross-border clean hydrogen pipeline. The initiative aims to connect emerging clean hydrogen production hubs and export locations in the two countries, while also linking production with industrial clean hydrogen demand in South Africa.[68]

The concept was formalised through a memorandum of understanding signed in 2024 between stakeholders including the Namibia Green Hydrogen Programme, Wesgro, the Northern Cape Economic Development Agency, Gasunie, and Climate Fund Managers. The proposed development is structured in phases. Initial development would focus on the clean hydrogen hubs around Lüderitz, Boegoebaai, and Saldanha Bay, followed by an approximately 800 km cross-border

connection between the hubs. A later extension of around 1,300 km could connect the network to Gauteng, South Africa's main industrial and economic region, which includes Johannesburg.[69]

The pipeline is envisaged as open-access infrastructure capable of serving multiple clean hydrogen producers and users. Unlike project-specific export infrastructure, it could aggregate production and demand across several regions and provide connections both to export gateways and to domestic industrial users. The initiative therefore represents an emerging example of regional CUI, extending infrastructure planning beyond individual projects and port hubs.

At the same time, the corridor magnifies the investment challenge associated with CUI in an immature market. A large cross-border pipeline requires substantial up-front investment while the timing, location, and scale of future clean hydrogen supply and demand remain uncertain. Developing the pipeline in phases could limit the initial investment commitment and align construction with emerging supply and demand.

Financing, ownership, and tariff design would nevertheless need to be resolved for each section, alongside cross-border governance arrangements. The corridor illustrates the potential value of government-supported CUI development, but it also demonstrates why such infrastructure is particularly difficult to develop before enough producers and users have reached advanced project stages.

From dedicated infrastructure towards CUI?

Although CUI features prominently in clean hydrogen infrastructure planning in both countries, most near-term developments remain project-specific. At Lüderitz, the proposed terminal is currently linked to Hyphen; at Walvis Bay, individual storage facilities are expected to serve single developers even if selected jetty infrastructure could ultimately be shared. This reflects the limited number of projects that have reached advanced development stages and the resulting uncertainty over future infrastructure utilisation.

The case therefore highlights the importance of time and market maturity for infrastructure development. Dedicated or anchor-led infrastructure may be easier to finance during the early stages of clean hydrogen market development because demand and infrastructure requirements can be tied to a specific project. As additional projects mature, opportunities for sharing selected assets may increase, and larger common-user systems may become commercially viable.

Dedicated or anchor-led infrastructure may be easier to finance during the early stages of clean hydrogen market development because demand and infrastructure requirements can be tied to a specific project. As additional projects mature, opportunities for sharing selected assets may increase, and larger common-user systems may become commercially viable.

This should not, however, be understood as an inevitable progression from dedicated to shared infrastructure: the appropriate model will continue to depend on the number and maturity of users, infrastructure economics, and the characteristics of individual assets.

Lessons for export infrastructure development

— **Existing ports provide a starting point but do not eliminate clean hydrogen-specific infrastructure needs.** Namibia and South Africa combine established ports with greenfield locations requiring substantially different levels of new investment.

— **Ports can facilitate infrastructure development without becoming the principal investors.** Land allocation, planning, and coordination can help enable investment by project developers and specialised infrastructure operators.

— **Anchor projects can bring infrastructure forward where multiple committed users are absent.** Infrastructure may initially be developed for a single project, while later expansion to shared use remains possible rather than guaranteed.

— **CUI ambitions may precede the market conditions required to finance them.** With few projects at FID, project-specific infrastructure may emerge first, while shared infrastructure becomes more feasible as additional users mature.

— **Regional CUI can connect export infrastructure with domestic demand.** The proposed Namibia—South Africa corridor illustrates the potential for shared infrastructure to connect multiple production hubs, industrial users, and export gateways.

European cross-border clean hydrogen corridors: Developing CUI ahead of market demand

Cross-border clean hydrogen pipelines are expected to play an important role in connecting prospective clean hydrogen production regions with industrial demand centres across Europe. While clean hydrogen production is expected to develop particularly in regions with favourable renewable resources, including Southern Europe, the Nordic and Baltic regions, and potentially neighbouring countries, major demand centres are concentrated in Central Europe. This geographical mismatch has led to the development of several large-scale clean hydrogen corridor initiatives connecting production, import, and demand regions across national borders.[70]

Unlike the port-based infrastructure examined in the previous case studies, these pipelines are conceived from the outset as common-user infrastructure serving multiple producers and consumers across large geographical areas. Their development is primarily led by specialised transmission system operators (TSOs), closely resembling the infrastructure-operator model found in mature gas markets. However, the clean hydrogen market that would underpin these investments does not yet exist at a comparable scale. The European corridor case study therefore illustrates the government-supported CUI development archetype, in which public intervention is required to enable large, shared infrastructure to develop ahead of sufficiently certain market demand.[71]

Infrastructure starting point and development challenge

Europe already possesses an extensive natural-gas transmission network connecting production and import locations with industrial and residential demand centres. Parts of this infrastructure could be repurposed for clean hydrogen, while other sections of the future clean hydrogen network will require new dedicated pipelines. Several corridor initiatives therefore combine existing national gas infrastructure, planned clean hydrogen backbones, and new cross-border or offshore connections to create an interconnected European clean hydrogen network. For example, around 65% of the SoutH2 Corridor is expected to consist of repurposed natural-gas pipelines, while projects such as H2Med and AquaDuctus include substantial new offshore infrastructure.[72]

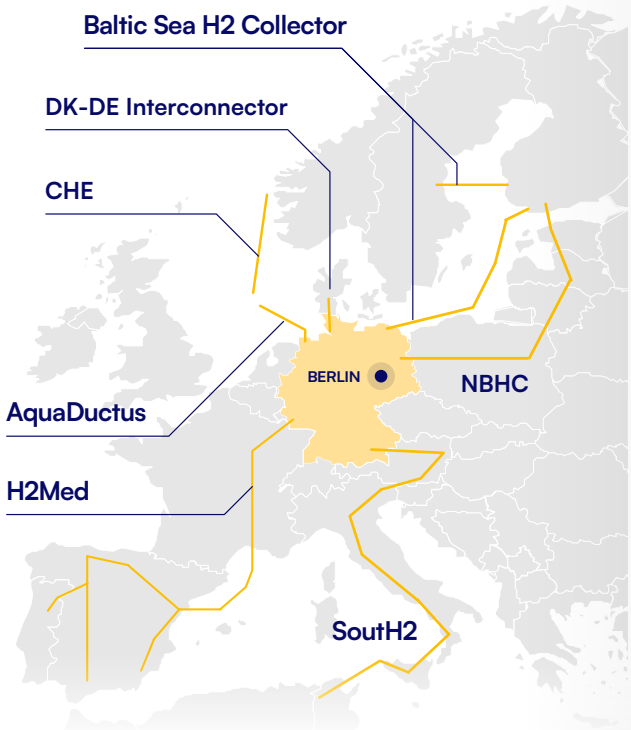
Existing gas infrastructure therefore provides Europe with a substantial physical and institutional starting point for clean hydrogen transport. Nevertheless, retrofittable assets alone do not create a functioning clean hydrogen network.

New connections are required between emerging production regions and future demand centres, while infrastructure across different countries needs to be developed and commissioned in a coordinated manner. The development challenge is consequently not only to construct individual pipelines, but also to establish an interconnected network before clean hydrogen supply and demand have reached sufficient scale.[73]

A portfolio of planned cross-border corridors

Several major cross-border clean hydrogen corridor initiatives have been proposed or are currently under development. These include H2Med between the Iberian Peninsula, France, and Germany; the SoutH2 Corridor connecting North Africa through Italy and Austria with Germany; the Nordic—Baltic Hydrogen Corridor connecting Finland through the Baltic states and Poland with Germany; the Baltic Sea Hydrogen Collector; the Denmark—Germany Hydrogen Interconnector; AquaDuctus in the North Sea; and the "Clean Hydrogen to Europe" (CHE) pipeline between Norway and Germany, which is currently on hold. Most of these projects have received project of common interest (PCI) or project of mutual interest (PMI) status under the EU Trans-European Networks for Energy (TEN-E) framework, reflecting their strategic relevance for cross-border energy infrastructure. PCI/PMI designation can also facilitate permitting and access to EU support through the Connecting Europe Facility.[74]

Figure 12: European hydrogen corridors with PCI or PMI status[75]



Own visualisation based on information from project website

Table 8: Overview of European cross-border hydrogen pipeline projects

Corridor	Route	Planned capacity	PCI/PMI status	Development status	Public support/ development mechanism
H2Med[76]	Portugal—Spain—France—Germany; New cross-border sections: CelZa ~270 km and BarMar ~400 km offshore, connected to national H_2 grids	Up to 2 Mtpa	PCI	BarMar entered FEED in July 2026; CelZa engineering, environmental studies, and permitting ongoing. Corridor COD targeted for 2032.	Call for Interest (2024/25) to assess future supply/ demand; >EUR 35mn CEF funding for preparatory studies.
SoutH2[77]	North Africa—Italy—Austria—Germany; ~3,300 km. >65% repurposed natural-gas infrastructure	>4 Mtpa import potential	PCI & PMI	Planning and permitting phase; operation targeted for the early 2030s.	Cross-border TSO cooperation and political coordination.
Nordic—Baltic Hydrogen Corridor (NBHC)[78]	Finland—Baltics—Poland—Germany; ~2,500 km, primarily new dedicated H_2 pipelines	Up to 2.7 Mtpa by 2040	PCI	Pre-feasibility done in 2024; feasibility phase ongoing, to be completed in 2027; COD planned for 2033+.	EUR 6.8m CEF funding for feasibility studies; call for interest conducted in 2026.
Baltic Sea Hydrogen Collector (BHC)[79]	Sweden/Finland—Germany across Baltic Sea; ~1,250 km, new offshore H_2 pipeline system	Not yet specified	PCI	Pre-feasibility completed; pre-FEED / preparatory studies underway; COD planned for early-to-mid 2030s.	EUR 15.3mn CEF grant for pre-FEED and technical, regulatory, and environmental studies.
AquaDuctus[80]	North Sea—Germany/ Netherlands; ~400 km offshore + ~100 km onshore, new dedicated H_2 infrastructure.	Up to 20 GW (~1.5—1.7 Mtpa)	PCI	Feasibility study done in 2024; detailed planning ongoing; COD planned for 2030, with subsequent expansion.	EUR 200mn German federal funding; integration into German H_2 core network; capacity reservation process launched March 2026.
CHE pipeline[81]	Norway—Germany; 3 concepts under assessment: 360 km new + ~600 km repurposed; 937 km new offshore pipeline; or ~600 km new connection to AquaDuctus.	Up to 4 Mtpa	PMI	On hold; three transport concepts previously assessed, but no final concept selected.	German—Norwegian bilateral cooperation and joint feasibility work; potential integration with AquaDuctus assessed.
Denmark—Germany Hydrogen Interconnector[82]	Denmark—Germany; 450 km new + 90 km repurposed, connected to national H_2 grids	3-4 GW	PCI	Capacity marketing/ reservation underway; Energinet and Gasunie signed the Joint Development Agreement in March 2026; operational readiness targeted by end of 2030.	Cross-border TSO coordination; coordinated capacity marketing/ reservation.

IMAGE CREDIT: ADOBE STOCK / UWE



The central development challenge: Infrastructure ahead of demand

Despite differences in route, scale, and technical configuration, the proposed corridors face a common commercial challenge. Clean hydrogen pipelines require high upfront investment and are characterised by strong economies of scale and long asset lifetimes. Developing sufficient capacity from the outset can reduce long-term transport costs and avoid repeated network expansion, but it also means that infrastructure may initially be substantially underutilised while clean hydrogen production and demand gradually develop.[83]

The H2Med Call for Interest illustrates this timing mismatch. The exercise identified substantial prospective clean hydrogen supply and demand along the corridor, but also significant differences in their expected ramp-up. Surveyed export volumes at the French—German interconnection reached around 1.9 Mtpa for 2030, while indicated demand amounted to only around 0.21 Mtpa in France and 0.44 Mtpa in Germany. By 2050, surveyed supply and demand were substantially more closely aligned.[84]

This creates a fundamental challenge for CUI development. If early users were required to recover the full cost of initially underutilised infrastructure, tariffs could become prohibitively high; if infrastructure operators instead were required to bear the utilisation risk, expected revenues might be insufficient to justify FID. At the same time, developing only the capacity supported by current firm demand risks creating infrastructure bottlenecks as the market grows. Clean hydrogen corridors therefore face a ramp-up gap between the point at which infrastructure needs to be built and the point at which sufficient users exist to support it commercially.

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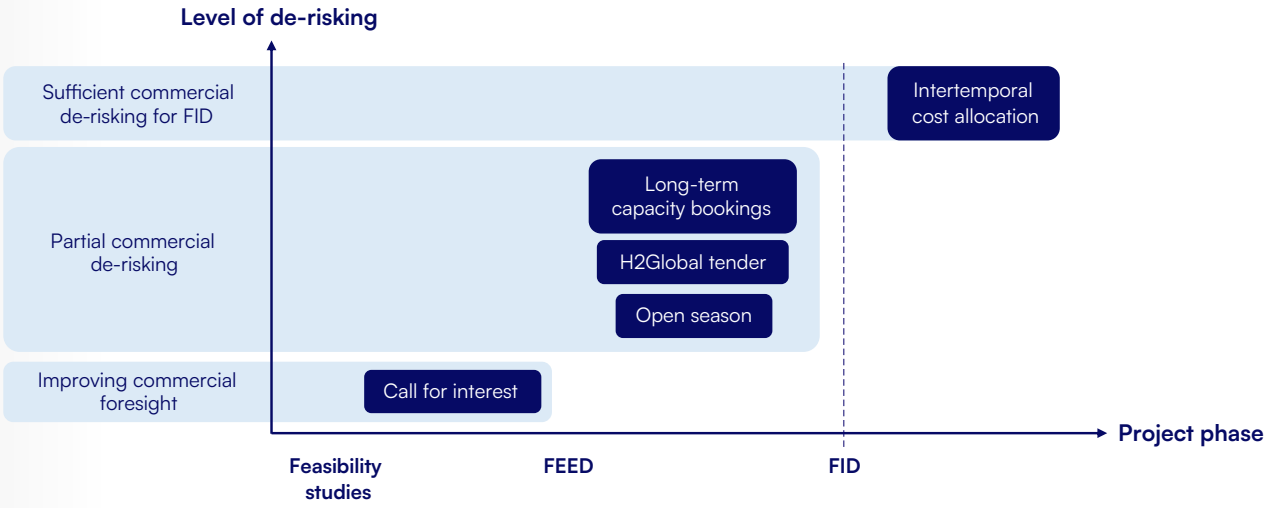
Infrastructure development approach: Publicly de-risking common-user networks

Specialised infrastructure operators are the predominant developers of the European clean hydrogen corridors. H2Med, SoutH2, the Nordic—Baltic Hydrogen Corridor, and the Denmark—Germany Hydrogen Interconnector, for example, are being developed through cooperation between national TSOs. TSOs therefore provide the technical and institutional capacity to plan, construct, and operate infrastructure serving multiple users across national borders.[85]

This brings the European corridor model comparatively close to the infrastructure-operator model found in established energy markets: infrastructure development does not depend on a production project or port authority taking responsibility for the transport asset. However, the existence of specialised infrastructure operators does not eliminate the early-market utilisation risk identified above. The central development question therefore shifts from who can develop the infrastructure to how sufficient revenue certainty can be created while the clean hydrogen market ramps up.

Several instruments are already being implemented or are under discussion to address different parts of this challenge. These range from non-binding market-sounding exercises and binding capacity allocation processes to financial mechanisms that redistribute utilisation and revenue risk, as well as market-support instruments that can help generate actual clean hydrogen flows.[86]

Figure 13: Classification of support instruments to de-risk clean hydrogen pipeline projects in different project phases



Building demand visibility and capacity commitments

Calls for interest are an established market-sounding instrument used to assess prospective infrastructure demand before binding capacity commitments are available. Clean hydrogen producers and potential consumers can indicate expected volumes, locations, and project timelines, allowing infrastructure developers to validate initial capacity assumptions and better understand how future utilisation may develop. H2Med conducted such a process in 2025, while a similar approach has been used for the Nordic—Baltic Hydrogen Corridor.[87]

Calls for interest can therefore reduce information uncertainty and help avoid infrastructure being planned without reference to prospective users. However, because the indications are non-binding, they provide limited revenue certainty and are generally insufficient on their own to support an infrastructure FID. They help answer who might use the infrastructure and how much capacity may eventually be required, rather than guaranteeing that this demand will materialise.

Open seasons move one step further by seeking capacity commitments from prospective infrastructure users. In contrast to non-binding calls for interest, they can result in binding capacity reservations and therefore provide a stronger indication of future infrastructure utilisation. Such an approach is being applied within the German Hydrogen Core Network and AquaDuctus to obtain firmer commitments from future users.[88]

Binding reservations can improve infrastructure bankability by converting prospective demand into contracted capacity. However, they do not necessarily eliminate the ramp-up problem. Particularly during the early years of network operation, committed private demand may still cover only part of the capacity required for an efficient long-term network. Market commitments can therefore reduce utilisation risk without necessarily making large-scale CUI fully commercially viable.

Where private capacity commitments remain insufficient to support investment, additional mechanisms are required to bridge the gap between the revenues available during market ramp-up and those required by infrastructure operators.

Bridging the remaining ramp-up and utilisation gap

Where private capacity commitments remain insufficient to support investment, additional mechanisms are required to bridge the gap between the revenues available during market ramp-up and those required by infrastructure operators. Different approaches are currently being implemented or discussed in Europe. They share a common objective despite design differences: allowing infrastructure to be developed ahead of full utilisation without placing the entire cost and risk on either early users or infrastructure operators.[89]



IMAGE CREDIT: ADOBE STOCK / UWE

Intertemporal cost allocation (ICA) addresses the ramp-up gap by spreading infrastructure cost recovery across different generations of network users. Rather than requiring the relatively small number of early users to cover the full cost of an initially underutilised network, temporary revenue shortfalls can be financed and recovered later as network utilisation increases.

Temporary revenue shortfalls can be financed and recovered later as network utilisation increases.

This principle underpins the financing mechanism adopted for Germany's Hydrogen Core Network and has also been proposed at European level in combination with public guarantees.[90]

Under the European approach discussed by the European Network of Network Operators for Hydrogen (ENNOH) and the European Network of Transmission System Operators for Gas (ENTSOG), the mechanism would provide infrastructure investors with a sufficiently predictable return while a public guarantee covers the risk that future network revenues are insufficient to recover the initial financing gap. A clawback mechanism could allow public support costs to be recovered if future revenues exceed the level required to remunerate investors. The approach therefore primarily addresses the timing mismatch between infrastructure costs and future tariff revenues, rather than requiring the state to permanently subsidise infrastructure utilisation.[91]

An alternative approach is to provide infrastructure operators with minimum revenue certainty through **long-term capacity bookings** backed by a public or publicly supported entity. The ENNOH and ENTSOG analysis discusses a European special-purpose vehicle that could secure a minimum level of pipeline capacity over a longer period, thereby reducing the volume risk faced by infrastructure operators.[92]

The distinction from intertemporal cost allocation is important. ICA primarily shifts cost recovery over time, anticipating that a larger future user base will ultimately finance the infrastructure. Public capacity bookings instead transfer part of the utilisation risk to a public actor, which provides revenue certainty where private users are not yet willing or able to make sufficiently large long-term commitments. Both approaches can enable investment ahead of market maturity, but they allocate the associated risks and potential public costs differently.[93]

Supporting actual clean hydrogen flows

Infrastructure-side de-risking alone does not guarantee that clean hydrogen will ultimately flow through the pipelines. Intertemporal cost allocation, guarantees, or public capacity bookings can improve the investment case for infrastructure, but they do not directly address the economic gap that may prevent clean hydrogen production projects and offtakers from contracting actual supply.

One potential complementary approach considered in previous H2Global work is an H2Global tender targeted at clean hydrogen projects connected to European pipeline corridors. By supporting transactions between clean hydrogen producers and buyers, such an instrument could help projects commit actual volumes to the infrastructure and thereby contribute to pipeline utilisation.

An important distinction between de-risking infrastructure investment and creating the market that uses the infrastructure: Infrastructure-side mechanisms can enable pipeline FID despite initially uncertain utilisation, while clean hydrogen-market support can help turn prospective supply and demand into actual transactions and capacity bookings.

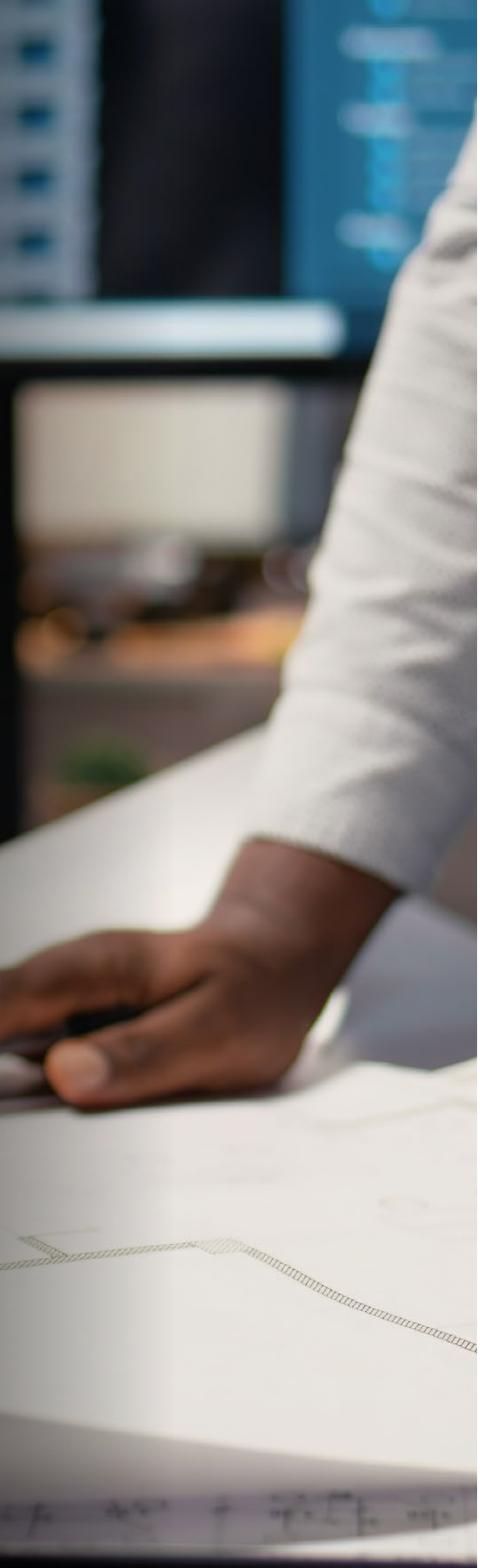
This highlights an important distinction between de-risking infrastructure investment and creating the market that uses the infrastructure. Infrastructure-side mechanisms can enable pipeline FID despite initially uncertain utilisation, while clean hydrogen-market support can help turn prospective supply and demand into actual transactions and capacity bookings. The two types of intervention are therefore complementary: one addresses the infrastructure investment gap, while the other can contribute to closing the utilisation gap.

Lessons for export infrastructure development

- **Large-scale CUI may need to be developed ahead of firm demand.** Clean hydrogen corridors illustrate the challenge of investing before a sufficient number of infrastructure users have reached maturity.
- **Specialised infrastructure operators do not eliminate early-market risk.** TSOs can develop and operate open-access networks, but uncertain initial utilisation can still prevent FID.
- **Market-sounding and capacity-allocation mechanisms progressively improve demand certainty.** Calls for interest identify prospective users, while open seasons can translate interest into firmer capacity commitments.
- **Public support can bridge the remaining ramp-up gap.** Intertemporal cost allocation, guarantees, and public capacity bookings can redistribute early utilisation and revenue risks.
- **Infrastructure and market support address different but complementary risks.** De-risking pipelines can enable infrastructure investment, while instruments supporting clean hydrogen transactions can help generate actual utilisation.



IMAGE CREDIT: ADOBE STOCK / DC STUDIO



6

Recommendations

This report examines existing and planned infrastructure, future infrastructure needs, ownership and business models, and different approaches to infrastructure development. It shows that the success of infrastructure development approaches depends on factors including existing infrastructure, the number and maturity of prospective projects, institutional arrangements, and access to capital.

Substantial infrastructure for clean hydrogen exports already exists. Established ammonia, methanol, and other liquid-bulk supply chains provide infrastructure that can in some cases be reused or expanded for clean hydrogen derivatives. However, existing infrastructure is unevenly distributed and does not necessarily coincide with the locations and capacities of announced clean hydrogen production projects. Additional export infrastructure will therefore be required in many emerging production regions, ranging from incremental expansions of existing ports to dedicated greenfield infrastructure.

Export infrastructure will therefore be required in many emerging production regions, ranging from incremental expansions of existing ports to dedicated greenfield infrastructure.

At the same time, the scale and timing of these infrastructure requirements remain highly uncertain. Announced clean hydrogen production volumes considerably exceed the capacity of projects that have reached advanced development stages, while long-term offtake remains uncertain for many projects. Infrastructure requirements based on the full announced project pipeline therefore risk overstating near-term needs.

Conversely, waiting for production projects to reach FID before developing infrastructure can create a coordination problem, as credible infrastructure solutions may themselves be required for projects to advance. Managing this timing and utilisation risk is therefore one of the central challenges for export infrastructure development.

The case studies further demonstrate that there is no single model for addressing this challenge. The four development archetypes identified in this report — government-led master planning, government-supported CUI development, port-led hub development, and anchor-led development — are reflected in different combinations across the case studies:

Oman illustrates how government-led master planning can coordinate infrastructure requirements across multiple projects, while the European hydrogen corridors demonstrate the role of public support and cross-border coordination in developing large-scale common-user pipeline infrastructure. The **Brazilian** ports of Pecém and Açu highlight the role port authorities can play in facilitating infrastructure development within emerging clean hydrogen hubs, while **Namibia and South Africa** illustrate how existing infrastructure, anchor projects, and longer-term shared infrastructure development can coexist as an export market develops.

The derived archetypes are neither mutually exclusive nor sequential: different approaches can coexist within the same country or hub and may evolve as markets develop.



IMAGE CREDIT: ADOBE STOCK / EKATERINA ELAGINA

The challenge is less whether export infrastructure can technically be developed than how infrastructure investment can be sequenced with an uncertain and evolving project pipeline, and how the associated risks should be allocated among project developers, infrastructure operators, and the public sector.

A particular trade-off arises around CUI. Shared infrastructure can reduce duplication, capture economies of scale, and facilitate the development of larger hydrogen clusters. However, developing common-user infrastructure ahead of firm demand also increases coordination requirements and exposes infrastructure providers to utilisation risk.

For early anchor projects, dedicated infrastructure may therefore provide a faster and more controllable route to market. The challenge is to enable such first movers without foreclosing opportunities for infrastructure to accommodate additional users as the market develops. Large-scale clean hydrogen pipelines present a distinct case, as their network characteristics and economies of scale strengthen the rationale for coordinated, multi-user development from an early stage.

Overall, the challenge is therefore less whether export infrastructure can technically be developed than how infrastructure investment can be sequenced with an uncertain and evolving project pipeline, and how the associated risks should be allocated among project developers, infrastructure operators, and the public sector. The case studies demonstrate different ways of addressing this challenge: building on existing port infrastructure, planning shared infrastructure before all users are confirmed, allowing anchor projects to advance with dedicated infrastructure, and involving public or international partners in infrastructure development and project preparation. The appropriate combination will depend on local circumstances and is likely to change as production projects and clean hydrogen trade mature.

The following part outlines five key areas for accelerating export infrastructure development.

Making use of existing infrastructure before developing greenfield assets

Existing port and liquid-bulk infrastructure can reduce investment requirements, shorten development timelines, and lower first-mover risks. Port authorities can support this by identifying opportunities to reuse or expand existing assets and ensuring that port development today preserves sufficient space and capacity for emerging clean hydrogen exports.

Recommendations for port authorities and operators:

— Assess opportunities to reuse or expand existing port, storage, and loading infrastructure before developing dedicated greenfield facilities.

— Facilitate access to existing infrastructure by coordinating relevant stakeholders and establishing transparent processes for allocating land and infrastructure capacity.

— Coordinate port-level infrastructure development to avoid unnecessary duplication, including jetties, berths, utility corridors, and other space-constrained assets that can potentially accommodate multiple projects.

— Reserve sufficient land for clean hydrogen derivatives through land allocation, zoning, and long-term port master planning.

— Enable incremental infrastructure expansion where possible, for example through modular storage, additional loading arms or berths, and phased terminal development.

Master planning infrastructure early and allocating ramp-up risks

Where several production projects are expected to develop within the same region or cluster, infrastructure requirements should be assessed before individual projects develop their own solutions. Master planning can identify opportunities for shared infrastructure and clarify responsibilities, interfaces, and commercial arrangements. However, planning for long-term infrastructure needs should not imply building immediately for the full announced project pipeline; infrastructure development should be phased as production projects mature.

Recommendations for governments:

— Identify shared infrastructure requirements before individual production projects reach advanced development stages, including requirements for electricity, water, clean hydrogen pipelines, and port connections.

— Early on, define responsibilities for planning, financing, developing, and operating individual and shared infrastructure, including clear interfaces between production projects and infrastructure providers.

— Develop commercial models alongside technical infrastructure concepts, including ownership, access conditions, tariffs, and the allocation of utilisation and ramp-up risks.

— Identify how early-stage utilisation risk will be allocated and de-risked before infrastructure becomes a bottleneck to production-project FID.

— Regularly update infrastructure plans as the production project pipeline matures and phase infrastructure development where possible, rather than building against the full volume of announced projects.

Balancing first-mover needs with the benefits of common-user infrastructure

CUI can reduce duplication, capture economies of scale, and facilitate the development of clean hydrogen clusters. However, requiring shared infrastructure from the outset can increase coordination requirements and expose first movers to delays or risks created by less mature projects. Dedicated assets may therefore be more appropriate for credible anchor projects in port settings, provided that opportunities for later expansion and third-party access are preserved. Large-scale clean hydrogen pipelines, on the other hand, benefit from coordinated, multi-user development from the outset due to network characteristics and economies of scale.

Recommendations for governments:

— Do not make CUI a prerequisite where it would delay viable first-mover projects, particularly where a credible anchor project can develop dedicated infrastructure independently.

— Preserve the option for dedicated infrastructure to accommodate additional users from the outset, for example by reserving space for future expansion, considering scalability in infrastructure design, and attaching appropriate third-party access provisions to public support or preferential land allocation.

— Plan large-scale clean hydrogen pipeline infrastructure as CUI from the beginning where feasible, using coordinated assessments of prospective supply and demand to determine routes and capacity.

Matching de-risking approaches to countries' fiscal and institutional capacity

Infrastructure that needs to be developed ahead of firm utilisation may require temporary risk-sharing. Yet governments have different capacities to absorb these risks through public balance sheets or state-owned infrastructure companies. De-risking approaches should therefore reflect domestic fiscal and institutional capacity. Countries with constrained public capital may rely more heavily on international finance and strategic partnerships.

Recommendations for governments with sufficient fiscal and institutional capacity:

— Use public balance sheets selectively to bridge the infrastructure ramp-up period, for example through guarantees, concessional financing, or revenue-stabilisation mechanisms.

— Deploy public or state-owned infrastructure companies with appropriate capabilities, and provide them with a clear mandate to develop strategic enabling infrastructure.

— Design support to decline as infrastructure utilisation increases, progressively transferring utilisation risk to infrastructure users as the market matures.

Recommendations for governments with constrained domestic public capital:

— Mobilise financing from multilateral development banks (MDBs) and development finance institutions (DFIs) for strategic shared infrastructure, including concessional loans, guarantees, and blended-finance structures.

— Engage future importing markets in export infrastructure development, including importing ports, infrastructure operators, and other strategic partners through equity participation, joint development arrangements, or long-term cooperation agreements.

— Use international partnerships to support project preparation as well as construction, including feasibility studies, master planning, engineering, environmental assessments, and commercial structuring to bring infrastructure projects towards bankability before major capital commitments are required.



IMAGE CREDIT: ADOBE STOCK / CHAOSAMRAN_STUDIO

Reducing uncertainty over future export infrastructure needs

Despite the concrete infrastructure opportunities identified in this report, the scale and timing of future export infrastructure requirements remain highly uncertain because only a limited share of announced clean hydrogen production projects has reached an advanced stage and secured long-term offtake. Infrastructure-specific measures may reduce the resulting investment risks, but cannot fully resolve them. Governments can reduce uncertainty over future infrastructure utilisation by helping production projects advance towards FID and strengthening cooperation with prospective importing markets.

Recommendations for governments:

— Use targeted support instruments to help viable production projects reach FID, turning announced production volumes into credible infrastructure demand.

— Work with importing countries to support clean hydrogen trade corridors, for example through bilateral cooperation, coordinated support programmes, or joint H2Global auction mechanisms that connect export production with credible demand in importing markets.

— Coordinate cross-border clean hydrogen pipeline development between prospective exporting, transit, and importing countries, aligning infrastructure planning and timelines with credible production and demand developments along the corridor.

Ultimately, accelerating clean hydrogen export infrastructure development will require coordinated action across governments, port authorities, infrastructure operators, and project developers. There is no one-size-fits-all approach: infrastructure development must reflect local conditions, existing assets, project maturity, and the ability of different actors to bear early-stage risks. By using existing infrastructure, planning future needs early, preserving opportunities for shared use, and deploying appropriate de-risking approaches, countries can enable first projects to move forward while retaining the flexibility to expand infrastructure as clean hydrogen trade develops. Close cooperation between exporting and importing markets will be essential to turn planned production and infrastructure into functioning clean hydrogen trade corridors.

Annex: Techno-economic assumptions for infrastructure cost calculations

Section 2 of the report presents a calculation of the levelised cost per $kg_{H2\text{-}eq}$, that is added to the costs of a hydrogen project through the construction of a dedicated export infrastructure, i.e., a clean hydrogen pipeline or an export terminal for ship-based exports. This annex lays out the techno-economic assumptions (Table 9) and provides additional sensitivity tables (Table 10 and Table 11) for the presented calculations.

Table 9: Techno-economic assumptions for the calculation of additional levelised cost of hydrogen for the construction of dedicated export infrastructure, i.e., hydrogen pipelines or export terminals

Model input	Assumption	Source
Assumptions for pipelines		
Capital expenditure (CAPEX), new 20" pipeline	EUR 1.8 mn per km	European Hydrogen Backbone (2024): "EHB Implementation Roadmap: Public support as catalyst for hydrogen infrastructure" [94]
CAPEX, repurposed 20" pipeline	EUR 0.54 mn per km	
CAPEX, pipeline compressor 20"	EUR 0.026 mn per km	
CAPEX, new 36" pipeline	EUR 3.2 mn per km	
CAPEX, repurposed 36" pipeline	EUR 0.64 mn per km	
CAPEX, pipeline new compressor 36"	EUR 0.093 mn per km	
CAPEX, pipeline repurposed compressor 36"	EUR 0.04 mn per km	
Capacity, 20" pipeline	1.2 GW-H2 (Lower heating value)	European Hydrogen Backbone (2021): "Extending the European Hydrogen Backbone" [95]
Capacity, 36" pipeline	3.6 GW-H2 (Lower heating value)	
Assumptions for export terminals		
CAPEX, ammonia storage tank w/ capacity of 60,000 tonnes	EUR 150 mn	Internal model
# of tank turnovers per year	20	Expert interview
CAPEX, port and superstructure, Type A	EUR 1,100 mn	IEA (2025): "Global Hydrogen Review 2025" [96]
CAPEX, port and superstructure, Type B	EUR 190 mn	
CAPEX, port and superstructure, Type C	EUR 180 mn	
CAPEX, port and superstructure, Type D	EUR 90 mn	
Economic assumptions		
Weighted average cost of capital	8%	Internal assumption
Project lifetime	25 years	Internal assumption
Capital recovery factor (CRF)	9.368%	Internal calculation based on economic assumptions

Table 10 shows the calculated pipeline costs across assumed lengths of 500 km, 1,000 km, and 2,000 km and diameters of 20" and 36". These diameters correspond directly to maximum transport capacities of 0.22 Mtpa H_2 for 20" and 0.65 $Mtpa_{H2}$ for 36" pipelines. In all scenarios, a share of 60% repurposed natural gas pipelines is assumed. The table also compares pipeline infrastructure serving a single mid-scale project (annual production capacity of 0.1 $Mtpa_{H2}$) with a scenario where multiple clean hydrogen projects share access to achieve full pipeline capacity utilisation. The additional LCOH is inversely correlated with capacity utilisation. This confirms the cost-saving potential of shared clean hydrogen export infrastructure and the sizing challenge that arises during the design phase.

Table 10: Sensitivity analysis for the calculated additional levelised cost of hydrogen for the construction of pipelines for hydrogen export

Pipeline length [km]	500	1,000	2,000
20" pipeline, 60% repurposed			
Additional LCOH for **single project** w/ capacity utilisation of 45% or 0.1 $Mtpa_{H2-eq}$ **[EUR/kg_{H2-eq}]**	0.50	1.00	2.00
Additional LCOH for **multiple projects** w/ capacity utilisation of 100% or 0.22 $Mtpa_{H2-eq}$ **[EUR/kg_{H2-eq}]**	0.23	0.46	0.93
Capex pipeline [EUR million]	535	1,070	2.140
36" pipeline, 60% repurposed			
Additional LCOH for **single project** w/ capacity utilisation of 15% or 0.1 $Mtpa_{H2-eq}$ **[EUR/kg_{H2-eq}]**	0.81	1.62	3.23
Additional LCOH for **multiple projects** w/ capacity utilisation of 100% or 0.65 $Mtpa_{H2-eq}$ **[EUR/kg_{H2-eq}]**	0.12	0.25	0.50
Capex pipeline [EUR million]	863	1,725	3,450

Table 11 shows the calculated additional levelised cost of clean hydrogen for greenfield construction of an export terminal and associated port infrastructure. The table presents four scenarios of environmental preconditions that affect construction of a new port and export terminal either positively or negatively. It also includes additional costs if the terminal and port were constructed for a single mid-scale project with an annual production capacity of 0.1 $Mtpa_{H2-eq}$, and for a scenario where multiple projects co-locate to maximise export infrastructure utilisation to 100% (=0.187 $Mtpa_{H2-eq}$). As with pipeline infrastructure, this comparison highlights the potential cost savings of shared export infrastructure in boosting utilisation rates.

Table 11: Sensitivity analysis for the calculated additional levelised cost of hydrogen for the construction of greenfield terminal and associated port infrastructure for hydrogen export.

A: Open coastal jetty port w/ breakwater in deep water
B: Open coastal jetty port w/ breakwater in shallow water
C: Naturally sheltered jetty port
D: Naturally sheltered quay wall port

Port type	A	B	C	D
Additional LCOH for **single project** w/ capacity utilisation of 53% or 0.1 $Mtpa_{H2\text{-}eq}$ **[EUR/ $kg_{H2\text{-}eq}$]**	1.17	0.32	0.31	0.22
Additional LCOH for **multiple projects** w/ capacity utilisation of 100% or 0.187 $Mtpa_{H2\text{-}eq}$ **[EUR/ $kg_{H2\text{-}eq}$]**	0.63	0.17	0.17	0.12



IMAGE CREDIT: ADOBE STOCK / TIKHOMIROVSERGEY

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