The Potential of Hydrogen Transition for Ports in the Sultanate of Oman

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MESSAGE FROM ASYAD GROUP CEO

Abdulrahman Al Hatmi
Chief Executive Officer
Asyad Group

As a responsible global citizen and trusted logistics provider, Asyad Group presents to you Oman's first outlook on hydrogen transition for ports in Oman, where we identify the key hydrogen enablers in the near future and explore the prospects of a long journey towards clean energy and a decarbonized logistics sector.

We, at Asyad Group, recognize our duty as Oman's national hydrogen logistics provider to continuously develop our potential in this emerging industry and utilize our world-class logistics ecosystem to provide the optimal support for the up-and-coming hydrogen industry in the Sultanate.

We work proactively to better our position in all futuristic markets and sectors, especially ones that have the potential to support Oman Vision 2040 and its renewable energy objectives. That is why we continue to explore our hydrogen potentials through such studies, reports and outlooks that can better shape our development plans.

In that spirit, we produced this outlook to identify pathways that will prepare our ecosystem to act as a lever for the new era of sustainability and green energy in the GCC and MENA. The following pages show how Asyad Group is ideally positioned to utilize its maritime muscles, superior brick-and-mortar infrastructure and innovative mindset to secure the necessary logistics competencies to support the national, regional and global drive to net-zero.

This exploratory document provides a comprehensive view of the advanced capabilities of our three deep-water ports of Duqm, Sohar and Salalah to achieve our decarbonization targets and act as forward logistical operating bases for worldwide clean energy transport. With their ideal locations, our ports are prime regional and global candidates to become vital hydrogen logistics hubs, and later fully fledged hydrogen valleys.

In Oman, this outlook is the first publication released on hydrogen transition to signal the Sultanate's readiness to kick off production initiatives and make a contribution to the world supply of renewable energy. We showcase all the advantages Oman has to offer to become a vital presence in the new market and harness its geographic location, geopolitical advantages and a recognized credibility.

We place in your hands our forward-looking publication that captures a glimpse of the role of logistics in a future guided by Oman Vision 2040 and sustainability agenda and the diligent national policies on hydrogen, the future lifeblood of industry.

EXECUTIVE SUMMARY

Energy transition is a fundamental topic in the global agenda as the world's governments work concurrently towards achieving net zero targets by 2050. Hydrogen is expected to play a key role in the future of energy, and Oman is well-placed both geographically and geopolitically to harness its potential.

Carbon emission-free resources and energy carriers will dominate the energy landscape of the future. Urgent action is needed as the current emission-intensive energy supply chain must be completely overhauled, including transport and storage infrastructure, to accommodate a more responsive demand. With 400Mt of clean global long-distance hydrogen and derivative transport expected by 2050[1], ports will play a crucial role in the ongoing transition to emission-free energy carriers, not only for logistics but also as hydrogen valleys and manufacturing hubs.

As new alternative energy sources begin to displace conventional ones, ports must accelerate efforts to optimize their energy efficiency. In the context of the emerging global energy transition and trade of e-fuels such as ammonia and methanol, this report focuses on net zero or low-emission hydrogen and the impact of its utilization at scale.

Oman has a strong competitive advantage in this new energy era, due to its strategic position, both geographically and geopolitically. The country enjoys global recognition for its political stability and neutral positioning. The Sultanate, located mid-way on the Europe-Asia route, is blessed with abundant renewable energy sources. Moreover, land availability in Oman makes it a particularly attractive energy transition hub as vast portions of land can be allocated for large-scale projects. This report examines the potential of three deep-sea ports -Port of Sohar, Port of Duqm, and Port of Salalah to strategically position the country as a leader in the clean hydrogen transition, based on the following factors:

- Availability and access to renewable energy sources.
- Geopolitical aspects.
- Industrial value chain and potential.
- Social aspects.

As Oman seeks to diversify from its dependency on oil and gas, the Sultanate has recognized the importance of early hydrogen adoption. In preparation for a post-fossil fuel era, the country is well-positioned to become a super producer in the relatively near future. The strong competitiveness of Oman in renewable energy sources must translate into a sizable production of low-emission molecules to feed the domestic market and to develop regional and global trade. In this context, Oman has the fantastic opportunity to spearhead initiatives toward developing a global market for tradable hydrogen and set the key trends in terms of regulations and certifications.

A new hydrogen-focused economy offers ports the unique opportunity to become globally significant hubs for hydrogen logistics, bolster regional development and create new business opportunities. Specifically, Omani ports are well-positioned to become a mid-way bunkering hub between Rotterdam and Singapore in the emerging hydrogen derivatives market. The importance of international partnerships and global collaboration with other ports and associations is essential when it comes to fostering alliances and creating new synergies. In addition, coordinating the ports under the Asyad Group governance will be crucial to implementing a common strategy and driving investments effectively and efficiently. As infrastructure to connect the ports will be pivotal to designing an efficient hydrogen ecosystem, it will be crucial to define whether the blueprint will be based on production close to the consumption centers or on transporting either low-emission electrons or molecules across the country. In the latter case, two options are considered: repurposing the existing pipeline infrastructure or building a dedicated hydrogen network. Both are highly dependent on economic feasibility, which will require a detailed analysis.

In any case, ports are in a favorable position to lead the adoption of hydrogen for decarbonizing their own operations and logistics. This report aims to analyze the role of hydrogen/hydrogen derivative value chains for Asyad ports and the possibility to become hydrogen valleys: fully integrated clean clusters across the ports and the industrial zones. Hydrogen hubs at port locations would also contribute to in-country value by extending the existing supply chain and attracting new energy-intensive industries. As pioneers in hydrogen applications, ports can help green existing industries, such as refineries, ammonia plants, or steel plants, and implement mobility solutions within and beyond their borders. With Carbon Capture and Storage (CCUS), ports can further support their decarbonization plans by producing low-carbon hydrogen, possibly using captured CO_2 as a feedstock for synthetic fuel production.

E-fuels represent a major opportunity to move in the direction of decarbonization for the shipping industry, which accounts for 3% of global emissions. However, economic drivers alone will not be sufficient, and the shift will need to be motivated by strategic decisions, regulations, and certifications. In this context and given exporting hydrogen, Oman should account for international rules in place – particularly looking at EU and global maritime organizations - when defining its national regulation. Asyad Group, with its sizeable fleet of more than 60 ships can drive global development in deploying and bunkering clean fuels, leveraging projects already underway in certain ports, such as e-methanol in Salalah.

Several key enablers position Oman to become one of the world's top suppliers of low-emission molecules, these include:

- The availability of world-class renewable resources; including wind and solar.
- An abundance of land available.
- A history of developing and financing renewable energy projects and IPPs in general.
- Experience in energy production and exports.
- A favorable location along global trade routes.

HIGHLIGHTS

The ongoing energy transition is shaping a new world that will be powered by emission-free energy. Oman is ideally located, both geographically and geopolitically, to lead the Middle East region in the new energy landscape. Asyad has initiated its sustainable journey and it is now ready to start positioning its ports as central, active hubs for hydrogen and e-fuels, thus becoming of global importance.
To advance in its sustainable strategy, Asyad mandated the Oman Hydrogen Center (OHC) and Dii Desert Energy, a renowned international think-thank, to deliver a report that could pave the way ahead in the energy transition.

THE MAIN HIGHLIGHTS OF THE REPORT ARE:

WIND AND SOLAR RESOURCES

In addition to a unique geographical and geopolitical positioning, Oman has outstanding wind and solar resources, showing the potential to become a key production and trading hub for net zero emission energy.

BOLD STRATEGY

A bold strategy can help to make the country a super producer of zero and low-emission molecules, dwarfing today's entire power sector, and helping to execute on central pillars of Oman's Vision 2040 and its 2050 net zero commitment.

HYDROGEN ECONOMY

Developing a hydrogen economy in the country will create a significant number of jobs and resolve strategic challenges on lowest cost energy sourcing, energy security, and preserving export revenues.

TRADED GLOBAL MARKET

Oman can spearhead initiatives to create a traded global market for low-emission hydrogen and derivatives based on (traded) certifications on the way toward net zero.

HYDROGEN INFRASTRUCTURE

A new dedicated hydrogen infrastructure could be developed in Oman to transport zero-emission energy from where it is produced to the demand centers in the country and ports for export.

LOCAL CONSUMPTION

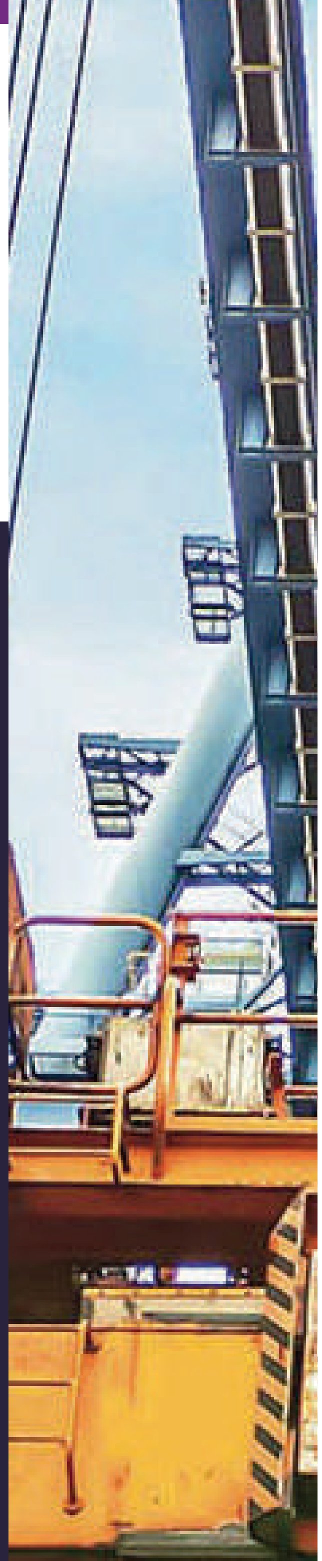
Local consumption will play a key role to develop a hydrogen economy and free up more gas for export.

HYDROGEN VALLEYS

The three deep-sea ports managed by Asyad can all aspire in becoming hydrogen valleys: central hubs for hydrogen production and utilization that would also unlock new potential job opportunities.

HYDROGEN LOGISTICS

Ports can become central hubs for hydrogen logistics to boost regional development, creating new business opportunities for a new hydrogen-based economy.



DECARBONIZATION

Adopting hydrogen for ports operation and logistics will accelerate the already initiated decarbonization process of Oman's three ports.

EMERGING GLOBAL MARKET

Omani ports can have the ambition to play a prominent role in the emerging global market for traded ammonia and to become a mid-way bunkering hub between Rotterdam and Singapore for low-emission molecules.

COMMON STRATEGY

Asyad can have a coordinating role to ensure that a common strategy results in strategic investments.

NEW SYNERGIES

Global collaboration with Asyad's international partners, other ports, and associations is also strongly encouraged to foster alliances and create new synergies.

GREEN SHIPPING

Zero or low-emission ammonia, methanol, synthetic methane, and synthetic gas are expected to play a key role as future fuels for shipping and Oman can play an important role as one of the centers on green shipping corridors.

DECARBONIZATION

While the first wave is driven by strategic reasons, regulations and certifications will ultimately be crucial to enable the decarbonization of the shipping sector.

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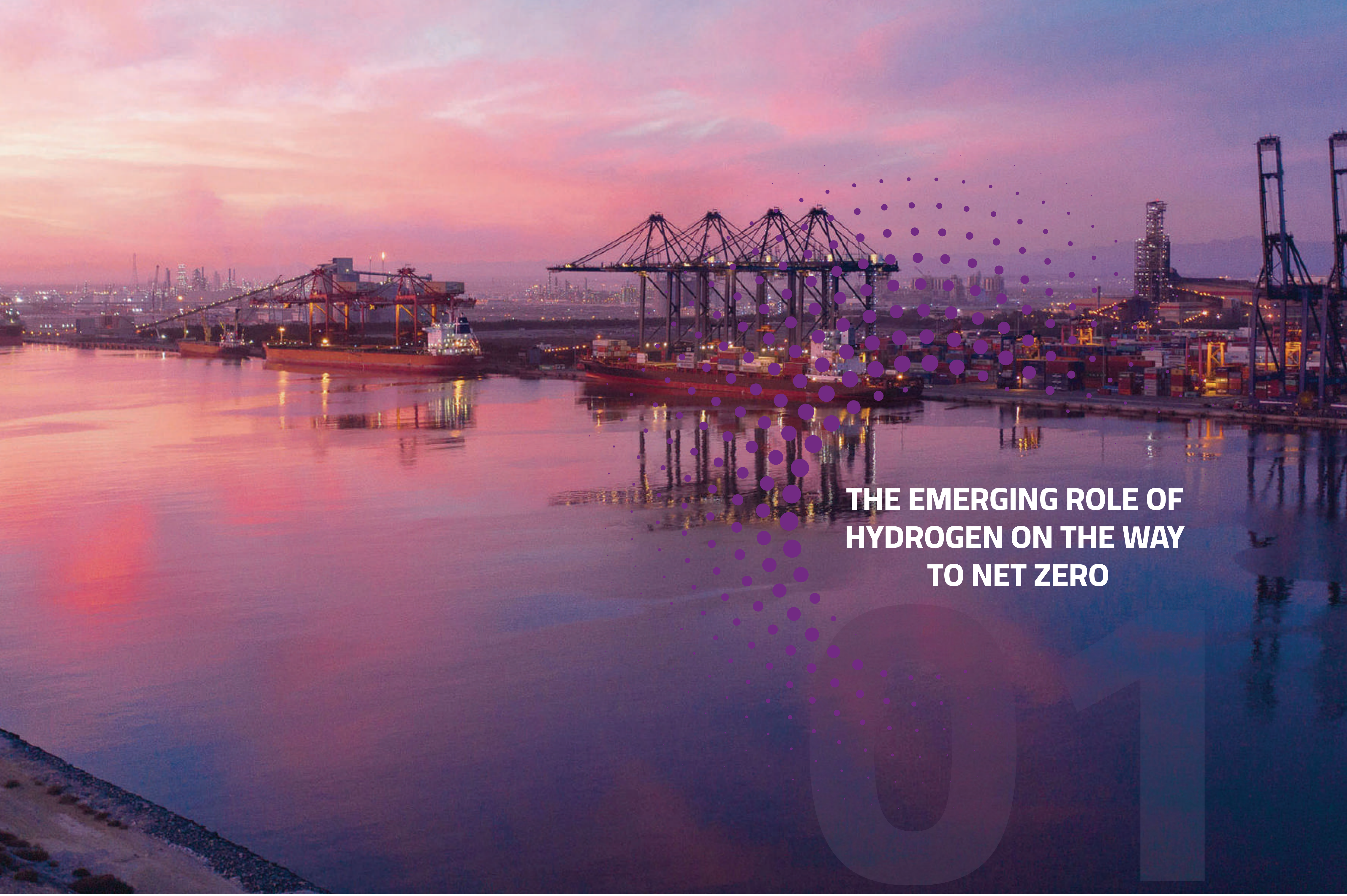


THE EMERGING ROLE OF HYDROGEN ON THE WAY TO NET ZERO

01

THE EMERGING ROLE OF HYDROGEN ON THE WAY TO NET ZERO

For decades the energy markets worldwide have been dominated by fossil fuels, e.g., as a feedstock for the industry, as a (thermal) energy provider and to produce electricity. Fossil fuels have led to an unparalleled growth of wealth of an expanding world population and satisfied expanding energy needs. At the same time, carbon emissions caused by burning fossil fuels are not without major environmental impacts. Based on the UNFCC 2015 Paris Agreement, there has been a political worldwide commitment to reduce carbon emissions. Governments have, thus, been developing and implementing national and local programs to cope with these challenges. The energy transition towards net zero emissions is becoming a matter of urgently migrating existing infrastructures to ensure sustainable low-cost, secure, and (near) emission-free energy supply to all. The energy systems of the future will utilize carbon emission-free sources and/or carbon capture or recycling to prevent further increase of carbon in the atmosphere.

Oil, natural gas, coal, lignite, etc. that have dominated the energy markets to date, shall gradually be phased out unless their emissions can be kept away from the atmosphere. The energy supply chain will, consequently, become more dependent on fluctuating energy from natural sources, such as solar, wind, and hydro. Furthermore, storage, international energy transport infrastructure, and more flexible demand will become pivotal elements to enable alignment with the dynamics of natural energy sources. As such, global energy trading will migrate from the oil, gas, and interconnected power markets that we know today to a market with guarantees of 'green' origin (GO's) and/or proof of captured carbon. In fact, trading seems to develop towards separated physical markets (electrons and molecules) on the one hand and green certificates (GOs, ECS, etc.) and/or emission certificates on the other hand. Ports are natural nodes in the energy value chains and may become active hubs in the emerging migration from fossil fuels to emission-free energy carriers, in particular hydrogen and e-fuels.

Arab countries are blessed with quasi-unlimited amounts of solar and wind energy. Only a tiny fraction of their over 14 million km2 desert areas would allow low-cost energy harvesting for serving their citizens and industries. Most MENA countries would also be well positioned to, eventually, export substantial amounts of emission-free energy to large remote demand centers, such as Europe, Japan, and other industrialized regions. These regions are 'notorious' energy importers, facing increased energy security issues and volatile energy prices while moving away from fossil fuels. Countries like Germany, Netherlands, and Belgium, or Japan and South Korea from Asia, are the first movers in the transition towards a low-emission hydrogen economy. The European Commission (EC) has already adopted in 2020 the recommendation of Dii Desert Energy's MENA Hydrogen Alliance to facilitate 40 GW Electrolysers in the EU and 40 GW in neighboring North Africa. With the EU Hydrogen Accelerator, these numbers have already been increased to more than 2 x 200GW in March 2022, required to produce the increased 20 million tonnes target. In the meantime, several global countries have adopted ambitious hydrogen strategies.

In this context, the entire MENA region is exceptionally well-placed to become the world's largest 'green Powerhouse', not only for serving its citizens and industries but on top of that serving remote regions worldwide.Oman has expressed high ambitions to become a significant player in this emerging market with preliminary studies indicating a potential for low-emission hydrogen up to 30-60 GW by 2040 in terms of electrolyzer capacity. Oman, with its natural energy sources, its visionary energy strategy, its strong track record of stability and reliability, and its transport and port capabilities, is ideally positioned. That includes becoming a master of low-emission hydrogen production, the smart substitution of local fossil energy demand by green energy use, and the development of export channels for low-emission hydrogen and e-fuels. Oman's seaports and airports are, thus, crucial enablers for Oman's emerging low-emission hydrogen economy and value chains.

THE ROLE OF LOW-EMISSION HYDROGEN IN THE GLOBAL ENERGY TRANSITION AND NET ZERO TARGETS

Future energy outlooks are regularly published by several organizations, e.g., IRENA and Hydrogen Council. For this report, we utilize the IEA Net Zero by 2050 scenario report to paint a global picture for the role of hydrogen and its derivatives. In summary, the hydrogen demand is forecast as follows (Figure 1):

- Hydrogen and its derivatives should meet 13% of final energy use in 2050.
- 2020 demand is around 90 Mt per annum.
- 2050 demand forecast is around 528 Mt per annum.
- The majority of future demand is heavy transport, hydrogen derivative fuel for shipping and aviation, and flexible power generation.
- H_2, NH_3, and methanol could meet 60% of energy demand in shipping.
- Synthetic fuels could meet a third of energy demand in aviation.

FIGURE 1. GLOBAL HYDROGEN AND HYDROGEN-BASED FUEL USE IN THE NZE

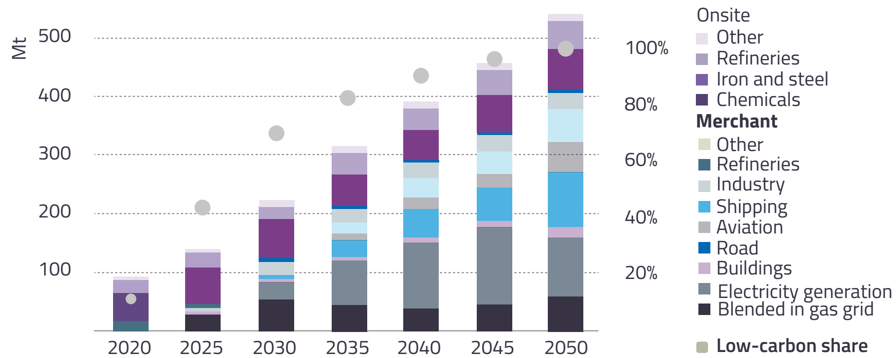
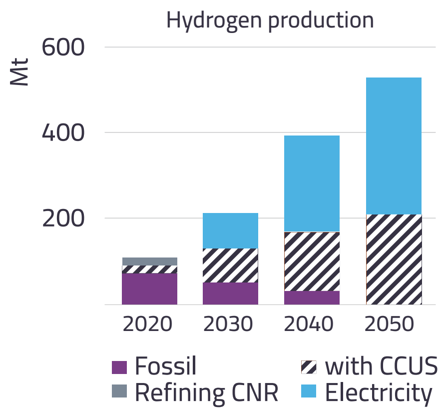


Figure 1: The initial focus for hydrogen is to convert existing uses to low-carbon hydrogen; hydrogen and hydrogen-based fuels then expand across all end-uses.

As for the hydrogen supply, the IEA forecasted (Figure 2):Decarbonizing fossil-based hydrogen is vital.

- Low carbon-based hydrogen supply will increase from today till 2050.
- Electricity-based hydrogen represents 62% of the supply by 2050.
- Electrolysis capacity could reach 850 GW by 2030.
- Electrolysis capacity could reach 3000 GW by 2045.
- Scaling up and innovation are critical for electrolysis cost reduction.

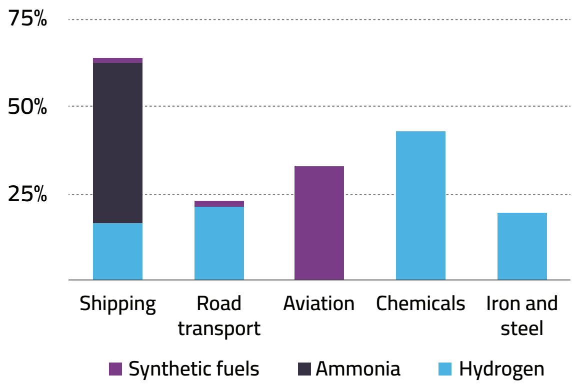
FIGURE 2. HYDROGEN PRODUCTION FORECASTED BY 2050.



Source IEA.

Once the forecasted hydrogen demand vs. supply is balanced, then it is essential to evaluate the next level of analysis for the share of hydrogen-based fuels by sector (Figure 3) along with its phased deployment approach (Figure 4).

FIGURE 3.SHARE OF HYDROGEN FUELS BY SECTOR IN 2050



Source IEA.

FIGURE 4. KEY DEPLOYMENT MILESTONES FOR HYDROGEN AND HYDROGEN-BASED FUELS

Sector		
Total production hydrogen-based fuels (Mt)	87	212
Low-carbon hydrogen production	9	150
shore of fossil-based with CCUS	95%	46%
share of electrolysis-based	5%	54%
Merchant production	15	127
Orsite production	73	85
Total consumption hydrogen-based fuels (Mt)	87	212
Electricity	0	52
of which hydrogen	0	43
of which ammonia	0	8
Refineries	36	25
Buildiings and agriculture	0	17
Transport	0	25
of which hydrogen	0	11
of which ammonia	0	5
of which synthetic fuels	0	8
Industry	51	93

Figure 4: The initial focus for hydrogen is to convert existing uses to low-carbon hydrogen; hydrogen and hydrogen-based fuels then expand across all end-uses.

It is worth mentioning that the global hydrogen theme is not set in stone but rather a dynamic one that will evolve as the market develops and eventually matures in the next decade or so. Nonetheless, the set theme entails a significant potential demand. Countries like Oman can have a slice of this new global hydrogen economy, provided that global policies, legislation, and regulations on regional and individual countries' levels follow through in creating sustainable and stable bankable markets.

TRADED GLOBAL MARKET

Like Oman has taken a leading role in introducing the first electricity spot market in the MENA region, the country could take advantage of pioneering standards and spearhead initiatives towards developing a global market for tradable physical molecules and tradable emission and/or green properties. There has been much discussion at a global level on how to roll-out cross border hydrogen trade. The collective view is that the most important policy decisions will be on the certification of hydrogen's environmental attributes and the creation of demand for zero or low-emissions hydrogen. The practical implementation of this principle is still not well-defined, let alone harmonized. As all signs point towards a green and/or zero emission premium of most industrial products and commodities, Oman could lead the way in setting standards, e.g., for green or emission-free steel as well. Ideally, the market should be regulated based solely on CO_2 emission certificates, directly or indirectly expressing intensity (measured in g CO_2/kWh). However, the fact that energy originates from renewable sources could help to give this energy greater market value.

In the end, energy markets should lead to the lowest costs, high security of supply, and no (or limited) emissions. This could principally be structured in the following way (Figure 5):

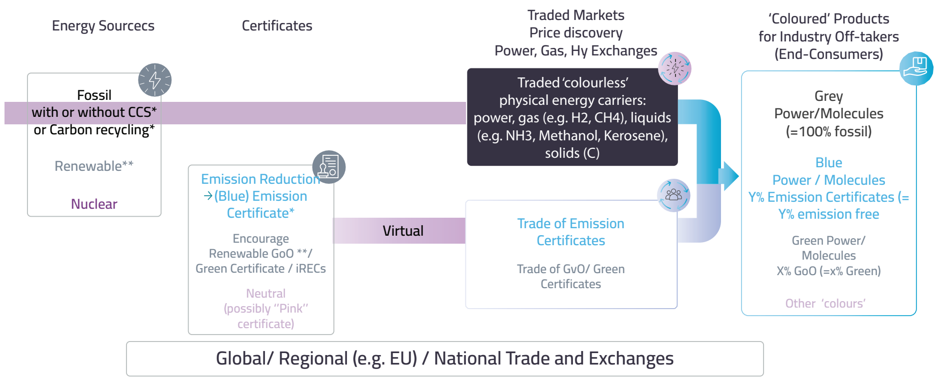


Figure 5: Schematics representing how a common physical infrastructure and separated certificate trade can help achieve the lowest costs and high security.

CERTIFICATION

A growing number of countries have developed tagging or tracking systems for certifying renewable energy. Examples include Renewable Energy Guarantees of Origin (REGOs; Europe), Renewable Energy Certificates (RECs; North America), and International Renewable Energy Certificates (I-RECs; managed by non-state, non-profit organization I-REC Standard). These "book and claim" schemes enable producers to register origin, production, and date information about their energy so end-users can claim certificates to prove their consumption of renewable energy. The alternative model is "mass balancing", which requires a physical link between the production and end-use of low-emission energy, sometimes to the extent that consignments must be in physical contact to prove physical traceability.

Currently, consultations to introduce certification measures EU-wide are ongoing as part of Repower EU, launched in May 2022. The package aims to create a standardized EU certification framework that distinguishes between 'green' hydrogen (as the benchmark) and 'blue' hydrogen (which is not perfect but remains necessary to produce in the medium term). Some other EU proposals include hydrogen having an 'additionality' requirement, i.e., it will not be certified 'green' if its production diverts renewable energy away from existing applications (instead of having its own purpose-built source). The rationale is that simply diverting existing renewable production circumvents the core purpose of reform to incentivize a greener energy mix overall. Following Dii's joint proposal to relax these rules, in September 2022 the old rigid version of the delegated act is currently being revised in favor of a new and more pragmatic version to come out in 2023.

Singapore announced its National Hydrogen Strategy at the end of October 2022, and recently signed an agreement with New Zealand concerning low-carbon hydrogen and fostering closer cooperation on matters such as certification. I-REC Standard is in the process of developing an international Hydrogen Product Code with Avance Labs but these discussions are also still in their infancy. Such examples offer little practical insight at present beyond being something to be mindful of going forward.

Oman could adopt a similar color-based system to that of the EU or one based on a sliding carbon emissions scale, i.e., the higher the carbon emissions in producing the hydrogen, the less encouragement to use that hydrogen. Whatever approach is adopted by Oman, the successful emergence of a global low-emission hydrogen market will depend greatly on increased international cooperation. Some degree of harmonization with various international standards will therefore be essential if Oman is to capitalize effectively on the opportunities presented by this emerging market.

OMAN: A LAND OF OPPORTUNITIES FOR HYDROGEN INVESTMENTS

Looking towards the upcoming hydrogen era, the Sultanate of Oman can develop a strong competitive advantage, thanks to its strategic position both geographically and geopolitically. It is located mid-way on the route Europe-Asia and blessed with abundant renewable energy sources, with the possibility to allocate vast areas of land available for energy projects. Furthermore, Oman has built political stability over the years and it is globally recognized for its neutral positioning, to the extent that the country is commonly nicknamed 'the Switzerland of the Arabian Peninsula'. The roadmap to attract new industries in these countries builds on five key factors: access to new demand markets (green economy); cost structure; access to skills and capabilities; access to logistics; and support of the government with the allocation of land and infrastructure. Companies willing to invest in Oman can count on top-notch logistics and infrastructure in terms of utility connections, road and rail, and ports and aviation.

Oman's economy has historically been largely dependent on the oil and gas industry, following its fluctuation both upwards and downwards, with the national economy benefitting from the recent surge in oil and gas prices.

Nevertheless, low-emission hydrogen is a high-priority item in the national agenda and one of the key pillars (with the others being CCUS, Energy Efficiency, and Renewable Energy) of the policy framework currently under development at the Ministry of Energy and Minerals. Furthermore, it is a key enabler in meeting the objectives set out in the Oman 2040 Vision concerning the use of renewable and diversified energy sources.

Future outlooks indicate that: as fossil fuel reserves will start declining in the coming decade, it is likely that from the early 2030s, there will be a conflict between gas available for domestic needs and that required to meet export demand. As such, this represents a great opportunity for hydrogen to replace gas in the energy mix.

With high gas prices making export more commercially attractive, local demand in Oman will play a much larger role in developing a hydrogen economy than many market players anticipate. It could indeed be the key driver, with hydrogen valleys developing around the country's main ports. Catering for domestic use would enable Oman to ensure energy security, develop a value chain in new future industries, and attract entirely new industries running on record low-cost low-emission energy while achieving decarbonization in the region. It is also a pivotal step towards becoming an exporter as some jurisdictions would not import hydrogen and derivatives from countries that are not progressing towards a net zero future, i.e., the additionality factor. However, it has to be noted that preliminary targets significantly point towards export, with only a small percentage of the forecasted hydrogen being produced to be allocated to the domestic market.

Looking just across the national borders, IRENA sees Saudi Arabia as the 6th country in terms of global demand for hydrogen in 2030 if global warming is to be limited to the goal of 1.5 C. In this context, Oman being a frontrunner in projects, and thanks also to its special diplomatic status in the Gulf region, could spearhead the opportunity to establish a regionalized market, driven by new hydrogen infrastructure.

Development of hydrogen in Oman needs a systematic approach as well as a clear view of energy security and alignment with the energy sector. His Majesty the Sultan Haitham bin Tarik has issued five Royal Directives at the beginning of 2022 to drive the hydrogen sector. Some concrete actions in this direction have been the establishment of the National Hydrogen Alliance (HyFly) in 2021 followed by Hydrom in 2022, and the restructuring of the Ministry of Energy and Minerals (MEM) to accommodate the new focus on developing and Market in Oman. The most recent announcements for green hydrogen production targets until 2050, aimed at covering both export and local demand, are: 1-1.25 Mt per annum by 2030, 3.25-3.75 Mt per annum by 2040, and 7.5-8.5 Mt per annum by 2050. For Phase A, Oman is planning two tender rounds with the aim to assign projects by the end of 2023, in order to meet the production target of one million tons per annum of green hydrogen by 2030. On the 6th of November 2022, Hydrom opened its first public bid round to award the first land blocks by March 2023. A second bid round will open in April 2023 with projects to be awarded by December 2023.

With financing having been among the key challenges for the first utility-scale solar and wind projects in Oman, the execution of an integrated strategy on low-emission molecules would be a further opportunity to attract new sources of green financing, from a variety of financier classes such as commercial lenders, export credit agencies, development finance institutions, and ESG-focused funds.

OMAN'S 2050 LEGALLY BINDING NET ZERO TARGETS

Oman's Second Nationally Determined Contribution under the Paris Agreement pledged to reduce state Green House Gas emissions by 7% by 2030. Despite environmental sustainability being a key component of the Oman Vision 2040 and given Oman's focus on energy producers, it did not originally contain a net-zero target or a purpose-built strategy for improving low-emission technology uptake by end-users.

However, on 11th October 2022, His Majesty the Sultan passed a royal decree to achieve net-zero carbon emissions by 2050. This comes as part of a new national strategy driven by cooperation between all units of the State's Administrative Apparatus. His Majesty also approved the establishment of the Oman Sustainability Centre "to supervise and follow up on plans and programs for carbon neutrality". On 24th October 2022, during the official launch of the green hydrogen sector in Oman, the Ministry of Energy and Minerals presented a comprehensive structure to drive the hydrogen economy in Oman. The Ministry of Energy and Minerals will be the policy maker and regulator, Hydrogen Oman will act as orchestrator, and infrastructure creation will be coordinated by Hydrogen Oman and the Public Authority for Special Economic Zones and Free Zones (OPAZ) for upstream and downstream respectively, OQ and international developers will be responsible for the development, and Asyad will be in charge for shipping. These developments will help Oman to foster a clearer, unified climate action framework that will encourage the necessary collaboration between its government, energy producers, and end-users to achieve this common goal.

In any case, a roadmap is in development and Oman's 2050 pledge will help drive the adoption of further policies, including but not limited to: mandates, quotas, carbon tax, production tax credits, tradable renewable energy low-emission electrons and low-emission molecules certificates, contracts for difference, project technology de-risking guarantees, project finance support, standardized guarantees of origin, standardized and bankable offtake agreements, standardized and bankable plant performance guarantees, long-term partnerships with large demand centers countries for low-emission hydrogen and derivatives like in the Far East and the EU. This is fundamental amid concerns following COP26 that current international plans combined still fall short of global sustainability targets. There is much detail still to be disclosed regarding the plan and interim timelines, so there is scope for further developments for Oman's net zero pledge in the near future. The pledge could also be instrumental in attracting sustainability-minded foreign investors and creating a regulatory regime that complements Oman's ambitions for a functional hydrogen industry in the coming years.

FOCUS AREAS OF ASYAD AND HYDROGEN VALUE CHAIN

02

FOCUS AREAS OF ASYAD AND HYDROGEN VALUE CHAIN

ASYAD DEEP-SEA PORTS

For the purpose of this study, the focus will be on the three deep-sea ports managed by Asyad (Figure 6): Port of Sohar (50% owned by Port of Rotterdam), Port of Salalah (operated by APM/Maersk, owning 30%), and Port of Duqm (50% owned by Port of Antwerp). These are all distributed along the coast of Oman and have distinctive features, for example, in terms of renewable energy access and vicinity to existing business centers.

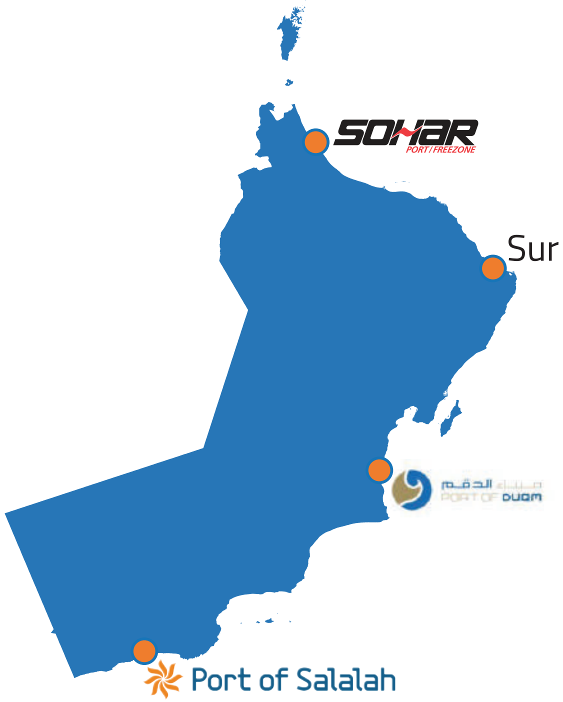


Figure 6: The localization of the three deep-sea ports and Sur.

Port of Sohar has been in operation since 2004 and is managed by a joint venture (50% Asyad, 50% Port of Rotterdam). It is located North of Muscat in the Gulf of Oman, just outside and approximately 150 km south of the Strait of Hormuz and in relative proximity to the regional bunkering hub Fujairah of the UAE. Its geographical location does not present any sizable wind resources and the potential for solar is also limited due to the availability and affordability of land. As an industrial port (Figure 7) with substantial heavy industry (i.e., ammonia, steel, aluminum, refinery, and methanol), it is currently the largest domestic off-taker of gas (40% of Oman consumption) and is already today producing and consuming approximately 400,000 tonnes of (grey) hydrogen per year.

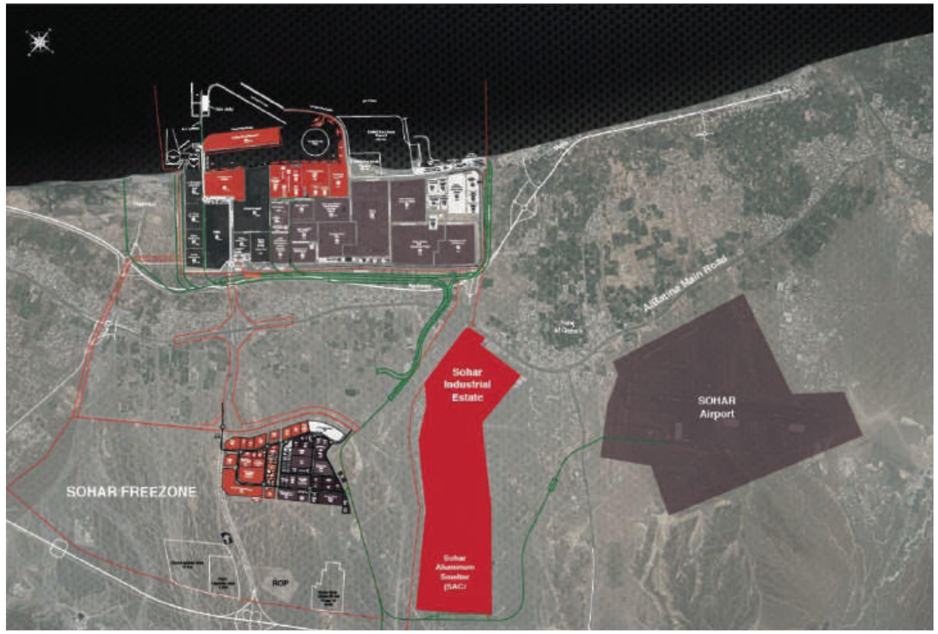


Figure 7: A map of Port of Sohar and Sohar Freezone (courtesy of Sohar FZ).

Port of Duqm (Figure 8) is located midway on the South-Eastern coast of Oman and is the newest among the three deep-sea ports, only being operational since 2012. The port is managed by a joint venture between Asyad and Port of Antwerp/DEME. Its location is ideal in terms of the abundance of renewable energy sources, having both solar and wind. Weather conditions are much more favorable than in Salalah, with little rain, and it is the only port (of the three) with abundant land available around the port. A refinery is currently under construction. With its 230,000 barrels per day, it will be the largest in the country and is expected to become operational in 2023. Mining is a key differentiator for Duqm, given the presence of substantial deposits of non-metallic minerals, limestone, and dolomite in the region. In fact, this could present an opportunity to establish the first ammonium nitrate production line in the Middle East for which dolomite is essential to mitigate the risk of explosion in ammonium nitrate fertilizers. For example, Calcium Ammonia Nitrate (the main fertilizer in Europe) contains a large percentage of dolomite to dilute the 35% of nitrogen content in ammonium nitrate to 33%, 27%, and 20% to make it more tradeable.

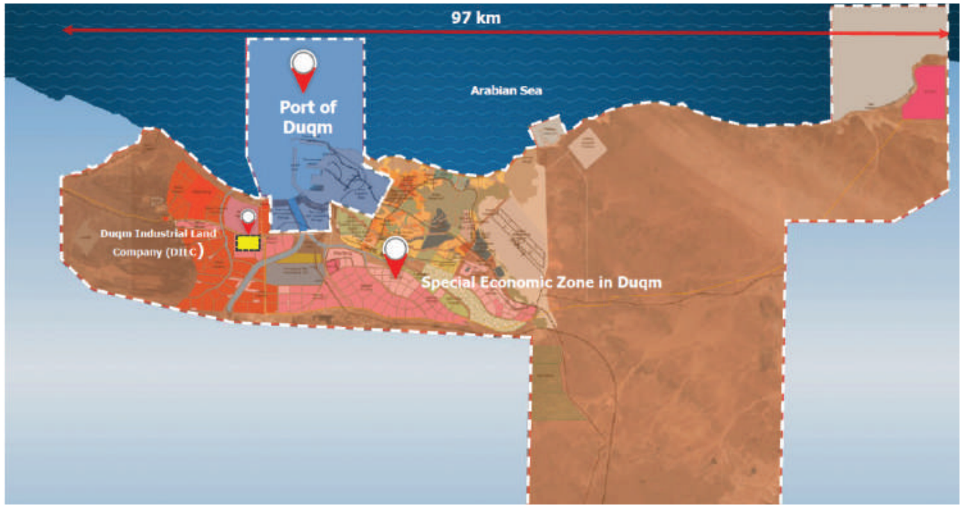


Figure 8: A map of Port of Duqm and the Special Economic Zone (courtesy of Port of Duqm).

Port of Salalah is the oldest deep-sea port in Oman, having been operational since 1998. It is in the Southern region of the country, in an area with high solar and wind potential. Salalah has an overall very good connectivity and is a natural stop for shipping going to the Red Sea. This trans-shipment port (Figure 9) is operated by APM/Maersk, who are firmly committed to achieving net zero. As such, the focus is currently on green methanol, strongly influenced by Maersk's plan to utilize it to decarbonize its fleet.

Figure 9: A map of Port of Salalah (courtesy of Port of Salalah).

Outside the direct scope of this report, but with a potential role in future hydrogen development, Port of Sur is located 150 km southeast of Muscat. It hosts Oman LNG (the only LNG export terminal in the country to date) and OMIFCO, a company producing both ammonia and urea. Sur does not have an industrial port and relies on offshore jetties to load ships directly from the producing plants. An expansion of LNG export capacities is planned, but this could also be deployed in Sohar or Duqm.

RENEWABLE ENERGY SOURCES' AVAILABILITY

Oman is blessed with a great abundance of renewable energy sources, notably wind and solar, that show significant geographical variability (Figure 10). Together with Morocco, Egypt, and Saudi Arabia, Oman ranks top in terms of wind resources globally, with capacity factors in excess of 50%. Wind resources are more important than solar for the low-cost production of low-emission molecules, but even seasonally and daily, we can observe a good complementarity with solar resources in the country. At a macro level, the southern and eastern regions of the country, where the Ports of Duqm and Port of Salalah are located, have a significantly higher production potential of renewable energy, specifically wind. Indeed, Sohar does not have any substantial wind resources and solar is also limited due to the availability of land. It should be noted that both Duqm and Salalah are exposed to natural risk hazards that are known and accounted for from a risk management perspective, with Salalah having specific challenges in summer during the monsoon season.

Oman has only recently embarked on a program to develop solar and wind projects in the country, with a comprehensive 2030 plan, but this plan lacks ambition. However, the recent launch of the green hydrogen sector in the Sultanate of Oman on 24th October 2022 added significant targets in terms of renewable capacity for green hydrogen projects, namely: 16-20 GW by 2030; 65-75 GW by 2040; and 175-185 GW by 2050.

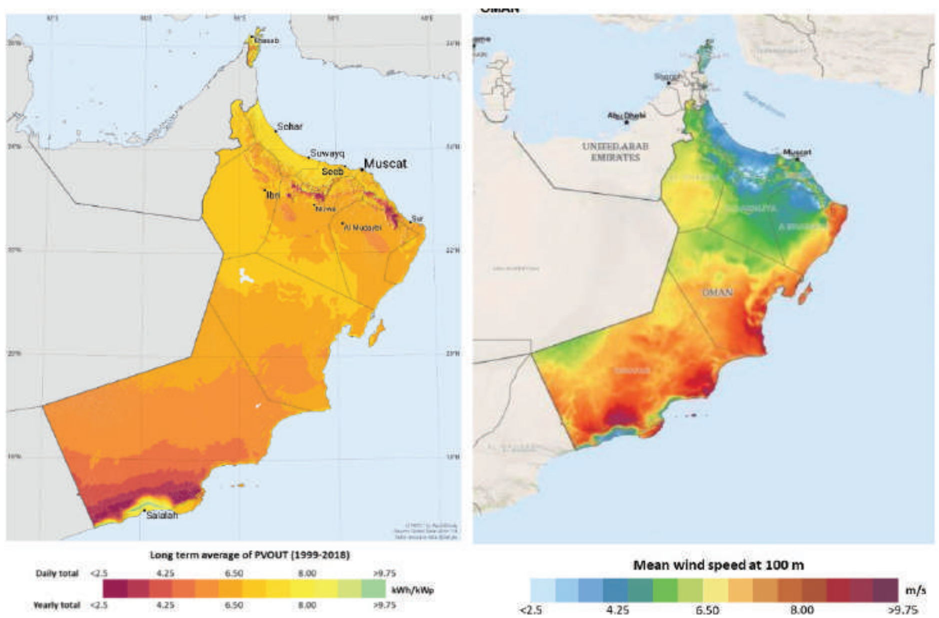


Figure 10: Left: Photovoltaic Electricity Potential in Oman © 2020 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis. Right: Mean Wind Speed Map @ DTU, Source: Global Wind Atlas 3.0

The solar and wind potential increases as you move towards the South of the country, with Duqm and Salalah being better positioned than Sohar. Note that the first utility-scale solar project in the country, commissioned in 2020 by a Marubeni-led developer consortium (with PDO as a sole off-taker), is located in the Al Wusta Governorate midway between Duqm and Salalah. Although Sohar has a favorable level of solar irradiation, the availability and cost of the land limit the development of projects at scale. Nevertheless, Port of Sohar is today the more advanced in terms of existing facilities, hosting already a 25 MW PV plant (Sohar Solar Qabas, built by Shell to operate a ferrochrome production facility). Presented in the tables below is an overview of existing projects and future developments in the ports regions (Table 1 and Table 2):

TABLE 1: OPERATIONAL AND ANNOUNCED SOLAR ENERGY PROJECTS IN THE REGIONS OF THE THREE DEEP-SEA PORTS.

NAME	LOCATION	DVELOPERS	CAPACITY	STATUS
Amin Solar PV	Al Wusta Gov. (between Duqm and Salalah)	Marubeni, OQ, Nebras, Bahwa	125 MW	Operational since 2020
Ibri II PV	Al Dhahirah Gov. (180 km from Sohar)	ACWA Power	500 MW	Operational since 2021
Sohar Sohar Qabas PV	Sohar FZ	Shell	25 MW	Operational since 2021
Manah I Solar PV	Al Dakhiliyah Gov. (250 km from Sohar)	Tendered by OPWP	500 MW	Operational since 2024
Manah II Solar PV	Al Dakhiliyah Gov. (250 km from Sohar)	Tendered by OPWP	500 MW	Operational since 2024
Sohar Industrial City (SIC)	Sohar FZ	SIC	100 MW	Under Development

NAME	LOCATION	DVELOPERS	CAPACITY	STATUS
Dhofar I Wind Farm	Dofar Region (Salalah)	Masdar, Tanweer	49.4 MW	Operational since 2019
Dhofar II Wind Farm	Dofar Region (Salalah)	Tendered by OPWP	100 MW	Announced for 2026
Sohar Sohar Qabas PV	Duqm SEZ	Tendered by OPWP	200 MW	Announced for 2025
Duqm II Wind Farm	Duqm SEZ	Tendered by OPWP	160 MW	Announced for 2027
Jalal Bani bu Ali	Sur Region	Tendered by OPWP	100 MW	Announced for 2025

Water supply is another key factor to be considered for the implementation of hydrogen projects, especially in a dry climate country such as Oman. In fact, a reliable stream of pure water is necessary to ensure the functioning of electrolyzers and sourcing water needs must be accounted for in terms of facilities and costs. It is likely that, to avoid any competition with water available for the population and agriculture, water will be supplied through desalination of seawater, thus additional facilities will be required.

GEOPOLITICAL AND SOCIAL ASPECTS

Geopolitical considerations should be considered when planning future developments. Port of Sohar is located in the Gulf of Oman only 150 km South of the Strait of Hormuz, a choke point to the Arabian Gulf that posed several maritime security issues in the past and requires enhanced levels of attention. The proximity to Iran could be a disadvantage for the Port of Sohar in the event of a future conflict in the Gulf. Port of Duqm and Port of Salalah being farther from the Arabian Gulf and the Strait of Hormuz carry a lower risk in this respect. Although Salalah is close to Yemen, the port city is a major regional tourist destination along with an industrial hub and there has not been any disruption caused by the ongoing war with Yemen. Hence, geopolitical risk at this stage can be considered as low to moderate.

Hydrogen can be a growth enabler for the country. As such, opportunities are likely to be evaluated not only from an economic viewpoint but also using social indicators. Projects that can cater to the growing job demand will have more chance of being supported. In this context, being closer to Muscat, Sohar has a high job demand, but it lacks empty spaces to develop new projects and the land is expensive. Duqm, on the contrary, has lower land costs but also has a limited local job demand. A rotational working scheme, as already in place for the oil and gas industry, would need to be envisaged for future projects, thus limiting the potential for new residential centers around the Port (at least in the short term). A long-term vision for Duqm could be the development of a new fully-fledged commercial city with access to the port. Salalah is the third largest city in the country and the main population center of the Dhofar region in the South, but it is far behind Muscat (165,000 vs 800,000 from a demographic point of view). The Port of Salalah is the biggest employer in the region, providing jobs to 2,600 people.

HYDROGEN VALUE CHAIN

The hydrogen value chain (Figure 11) describes the full hydrogen life cycle from production to the end-users. Typically, the main components are production, storage, transport, and consumption. For low-emissions hydrogen, production starts with the generation of renewable energy to provide electricity down the chain. Due to renewable energy's intermittency, a reliable storage system for both electricity and water is needed.

The hydrogen produced must then be stored before it can be transported. Transporting large quantities of hydrogen over long distances may require complex infrastructure, consisting of a combination of transport methods such as pipelines, ships, or trucks, as well as storage facilities in tanks at each transshipment point as a minimum. Hydrogen can be: (i) transported in gaseous form in pipelines; or (ii) transported in liquid form, e.g., on ships or liquid hydrogen semi-trailers and ISO containers for local consumption; or alternatively (iii) converted into other low-emission molecules including ammonia, e-methanol, or other e-fuels.

Hydrogen has many uses and applications as shown by this study, given that the consumers of hydrogen come from a wide spectrum of industries such as the maritime, industrial, and mobility industries. Depending on the needs of the end-users, hydrogen can be used in various pure forms or converted into other derivatives such as ammonia and methanol. Ports and their surrounding industrial zones can be primary local off-takers and use hydrogen for powering refineries and industrial plants. Furthermore, ports play a pivotal role in the export of hydrogen (independently of the carrier) due to the need for storage and cargo handling via terminals/jetties in the port areas. Hydrogen-based fuels (e-fuels) can gradually replace fossil fuels for shipping and mobility services within and outside the ports area. Furthermore, Asyad could extend this opportunity to its postal service and bus fleet.

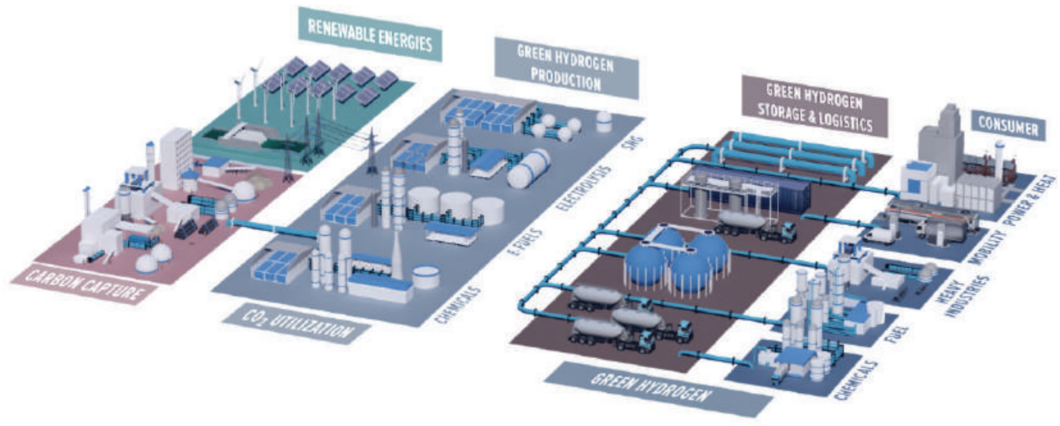


Figure 11: Hydrogen value chain from the producer of electricity & water, nitrogen, or carbon, down to the consumer. Source ILF.

HYDROGEN VALLEYS AND THE POTENTIAL FOR NEW JOBS

Hydrogen valleys combine elements of the value chain (i.e., zero/low-emission hydrogen production, storage, distribution, and final use in one geographical area), thereby forming an integrated ecosystem (Figure 12). Key benefits are lower hydrogen costs, heightened investment attraction, increased adjacent industry localization, and the promotion of low-emission hydrogen. It will be important for Oman moving forward to develop projects that can cover the value chain, leverage local assets, and address local needs.

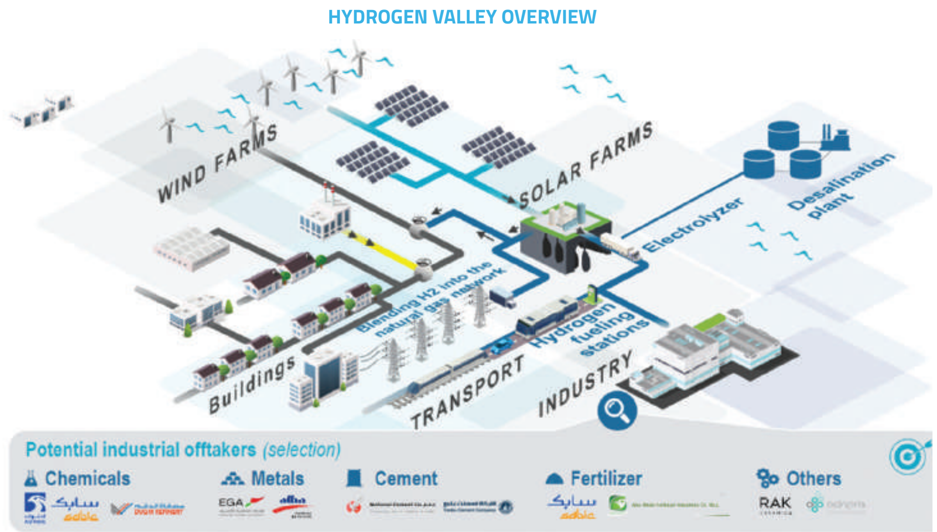


Figure 12: Hydrogen value chain from the producer of electricity & water, nitrogen, or carbon, down to the consumer. Source ILF.

In a recent study, the MENA Hydrogen Alliance and Roland Berger looked at the potential to localize the hydrogen value chain and learn from hydrogen valleys in Europe to deploy the first ones in the region. The first hydrogen valleys are currently at the early stage of implementation, it is worth noting that some are planned around ports (e.g., Port of Rotterdam) and even connecting multiple ports (e.g., Ports of Flanders, including Port of Antwerp-Bruges, North Sea Port, and Port Oostende). Learning from these cross-sectorial collaborations on how to integrate ports and their surrounding activities could certainly help develop Omani ports.

The overall effect of creating an entire hydrogen economy, starting with hydrogen valleys, will be the creation of many future-proof jobs in Oman. The Ministry of Energy and Minerals during the presentation of Oman's green hydrogen strategy envisaged the creation of 70,000 jobs that would be directly related to hydrogen developments. Recent studies indicate that the localization of the hydrogen value chain activities in the Gulf region could result in 400,000-900,000 new indirect jobs depending on the hydrogen economy scenario (Figure 13), with Oman expected to account for 20% of the job demand, i.e., 80,000-180,000 jobs. Almost half of the new jobs created would be in the renewable generation space, followed by electrolysis, storage, and distribution. Across the value chain, multiple skills will be required, creating diversified opportunities for high-skilled workers, technicians, and unskilled workers. It is expected that the oil and gas industry could provide a highly qualified workforce to the hydrogen industry, which would also balance the future decline of job opportunities in that sector.

FIGURE 13. FORECASTED JOB CREATION IN THE GCC REGION BY VALUE CHAIN ACTIVITY

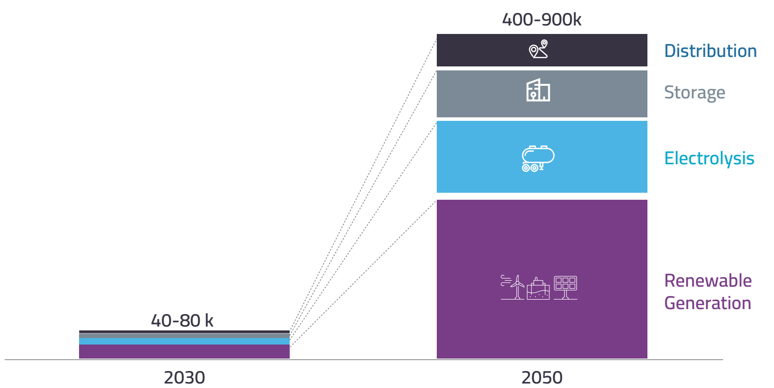


Figure 13: Forecasted job creation in the GCC region by value chain activity. Source: Roland Berger.

POWERING THE PORTS WITH RENEWABLE ENERGY AND ENABLING HYDROGEN TRANSPORT

Renewable energy availability differs significantly amongst Oman's three ports, and as things currently stand, the main hub of consumption (Port of Sohar) is located far from the hubs of production. Going forward on the design of a hydrogen ecosystem, this poses the first strategic question of whether it will be cheaper to transport hydrogen, or will it be better to focus the operations closer to where renewable energy is produced (i.e., in the Southern regions where Duqm and Salalah are located).

The discussion below provides an overview of the current options for repurposing the existing transport pipeline infrastructure. Given a future decline in gas supply, repurposing could help to avoid stranded assets, i.e., plants that are solely powered by gas. As the switch from gas to hydrogen will not be immediate and the cost for repurposing will be substantial (studies for the European Hydrogen Backbone indicate that repurposed pipelines would amount to 33% of the cost of newly built pipelines), there could be a business case to develop a new hydrogen pipeline network that is separate from existing pipeline infrastructure.

POTENTIAL APPLICATIONS OF HYDROGEN IN PORTS

The key factor in building hydrogen infrastructure is the demand for clean hydrogen. In processes where hydrogen is already in use today, clean hydrogen must offer advantages over conventional hydrogen, for example, having lower CO_2 emissions. As such, a cost analysis will ultimately drive demand for clean hydrogen to be adopted more readily if it is cheaper than conventional hydrogen with respect to CO_2 emissions, for example, in the context of an ETS scheme.

SHIP REFUELING

Ports are a classic trans-shipment point for ammonia. Ammonia production plants are often located near ports.

SOHAR, DUQM, SALALAH

The hydrogen required for ammonia production has historically largely been obtained from natural gas, via steam methane reforming. Depending on economics, this can be gradually replaced by low-emission hydrogen. Most of the ammonia produced by industry is currently produced for fertilizers. Like ammonia, these are traded and transported internationally. An important development is anticipated in the fuel market for ocean-going vessels and ammonia, which apart from its role as a transport vector, will be traded as a possible fuel, together with e-methanol, and used for co-firing gas turbines to reduce emissions in electricity generation. Here, in particular, ports could offer the possibility of refueling ships with low-emission ammonia or e-methanol during unloading or loading.

HEAVY INDUSTRY

Various types of heavy industry, such as the production of ammonia or methanol, already require large quantities of hydrogen. This hydrogen produced by fossil fuel sources could be gradually replaced by low-emission hydrogen in the short to medium term.

SOHAR

In the medium to long term, steel production could transition to Direct Reduced Iron (DRI) technology, whereby coking coal is replaced completely by hydrogen. Today, sponge iron is produced in blast furnaces based on coal, which causes large amounts of CO_2 emissions. This direct reduction process, already in use in different countries globally (where gas is cheapest and largely available), uses hydrogen as a reducing agent instead. Most steel producers in Europe, such as ThyssenKrupp or Salzgitter, already have programs for such conversion. In India, Jindal Stainless recently announced plans for investing in green stainless-steel production.

Another heavy industry responsible for significant amounts of CO_2 emissions is the cement industry. With an energy mix supply heavily dependent on coal and liquid, hydrogen and derivatives could be used as fuel to decarbonize the cement manufacturing process. Pilots are already underway, for example, CEMEX is fueling all its European factories with hydrogen and looking at expanding this to all its global operations. Hanson UK (a subsidiary of Heidelberg Cement) has been operating using a mix of 100M climate-neutral fuels including hydrogen.

REFINERIES

Refineries are massive producers and consumers of hydrogen, e.g., to support the desulfurization of crude oil. Electrolysis using renewable energies can therefore replace steam methane reforming.

SOHAR, DUQM

Hydrogen-based fuels (e-fuels) can be blended with conventional fuels. These clean fuels will command a premium price and help towards reaching quotas, e.g., in aviation, a minimum quota of sustainable fuels is expected to spread from Europe globally. In the long term, many refineries are already thinking about applying a circular carbon approach, with fossil feedstocks being used less and less and biological or waste materials increasingly replacing their role. Hydrogen is an important chemical element in this process.

In a changing and expanding business model, refineries see themselves as enablers for mobility. They do not necessarily remain conventional fuel suppliers. Big oil and gas groups already operate renewable energy plants and supply refueling stations with electricity. Shell even expanded their network with chargers for electric cars and started deploying hydrogen mobility projects. They are now increasingly producing and supplying hydrogen for the mobility sector, for example in Germany, with already around 100 hydrogen filling stations, Austria, Greece, Romania, and Poland. The distribution points are either in their own refueling stations on or at the company premises or by trailer delivery to refueling stations in the vicinity. In this way, refineries are using their classic marketing business on non-fossil energy sources.

It has also to be noted that when the energy transition to e-fuels succeeds, refineries will cease to exist and will have to be converted to e-fuel producing sites, where oil imports would stop, and hydrogen consumption will further increase.

MINING

Traditional mining activities require the consumption of substantial water and diesel. In the stationary sector, conventional power plants are supplemented with solar energy generation systems and batteries to reduce diesel consumption.

SOHAR, DUQM, SALALAH

The first projects for alternative propulsion of mining vehicles (which are usually in mobile operation 24/7) are being tested on a hydrogen basis, e.g., by Anglo-American in South Africa. Other projects are in development, such as that by Fortescue Future Industries (FFI) in Australia. Likewise, Austrian engineering consultancy ILF has developed a study to produce hydrogen in the vicinity of mines and to consume it locally.

REPURPOSING THE EXISTING PIPELINE INFRASTRUCTURE

Oman has an extensive natural gas network, totaling approximately 4,000 km of pipelines that connect key points in Oman such as the ports of Salalah, Sohar, and Sur, through the compressor stations and gas fields hub at Fahud in central Oman (Figure 14). A new pipeline connection from Fahud to Duqm stretching approximately 200 km, is planned to deliver gas supplies for the new refinery. Oman LNG, near Sur, is the only operational export terminal today. Marsa LNG (80% Total, 20% OQ) is planning a new LNG terminal in Sohar powered by solar electricity. OQ gas networks (a subsidiary of OQ), owner and monopoly operator of the country's vast gas pipeline system, intends to upgrade or repurpose the existing infrastructure to enable hydrogen transportation and is already undertaking feasibility studies to this end. Leveraging existing pipeline networks and capitalizing on such developments will reduce the construction requirements for new, specially built construction hydrogen transport infrastructure, and significantly reduce hydrogen transportation costs. A review of options based on current technologies is provided below.

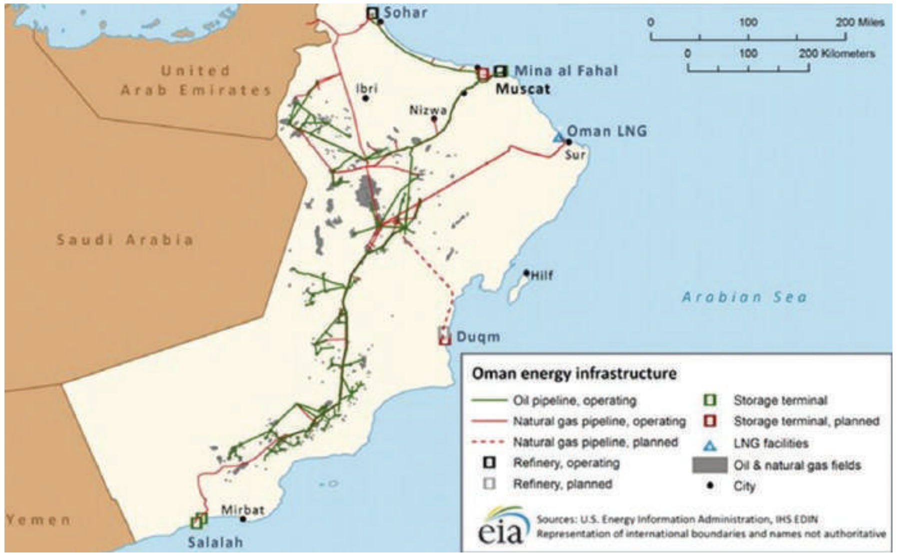


Figure 14: Oman Oil & Gas infrastructure. Source: U.S. Energy Information Administration, HIS EDIN.

Hydrogen can be fed into natural gas pipelines in gaseous form (blending), where a 5% hydrogen is generally considered technically feasible and safe without network modifications. The main challenge is that some end-users might not be able to use blended mixtures due to asset limitations, thus requiring separation. However, separation is not economically viable with today's technology and such low blending ratios would have minimal emissions-saving benefits. Hence, this option does not seem to be a viable solution, and some studies support this assertion.
Conversion of existing natural gas pipelines for the transport of hydrogen would be technically possible, however, it would require a case-based suitability assessment with respect to corrosion and pipeline coating. Yet, following conversion, no more natural gas can be transported, so the timing of conversion must be planned carefully so long as natural gas plays an important role in the country's energy supply.

If the low-emission hydrogen is converted to synthetic fuels, these can be transported in existing product pipelines. There is a product pipeline between Muscat and Sohar that transports kerosene from the refinery to Oman's main aviation hub. In this context, it should be technically feasible to transport e-kerosene through the same pipeline and in a mix, creating immediate synergies.

DEVELOPMENT OF A DEDICATED HYDROGEN TRANSPORT AND STORAGE INFRASTRUCTURE

Liquid and gaseous semi-trailers are currently widely used to transport hydrogen on roads to cater to industrial customers or filling stations. This option is very flexible and good for smaller quantities, but logistically not suitable and too expensive for hundreds of MW or even GW of electrolysis capacity.
For overland transport, especially the transmission from the wind-rich south to the high-demand north of Oman, the construction of a dedicated hydrogen pipeline is an option. Even the supply lines from different hydrogen plants, which are located near large renewable energy plants, or which receive energy from different locations to a collection point (for example near a port), could be carried out with so-called feeder lines. The same applies to spur lines and branches, e.g., to smaller ports along the route.

Hydrogen distribution networks in the low-digit diameter range already exist in some regions of Europe or the USA. They link producers with consumers at chemical sites. However, these networks are minimalist concerning pipeline diameter. In Oman, it is expected that large pipeline systems, as was already the case for natural gas, will have to be ahead of their demand and manage cost-effective transport over long distances. The bigger the pipeline, the cheaper, but larger pipelines must also push through higher gas quantities. This presupposes good and long-term predictability of supply and demand, as a quasi-market ramp-up with resilient capacities and quantities, since investments in new infrastructure have to be paid off over long periods such as 20 years, so that transport tariffs are not disproportionately high.

A 40-42" pipeline of 1,000 km length from south to north Oman may be designed considering peak production and flow rate of 2 million Nm^3/h without storage. With a load factor of 30% of the electrolysis plant, which is equivalent to about 2,600 full load hours per year, it can transport about 500,000 t H2/a, which is equivalent to 16.5 TWh of low heat value. Such pipeline is calculated with the maximum production of the electrolysis plant, which draws volatile electricity directly from solar and wind power. The pipeline is, first and foremost, a transport system optimized via the flow rate. That said, it could be also considered as a storage system itself and further optimized as a buffer storage tank.

Oman's total electricity consumption, which is mainly generated by CO_2-intensive gas-fired thermal power plants, is about 33 TWh, which we assume is largely generated in the northern regions of Oman. Assuming a further efficiency of about 50%, regardless of whether hydrogen is burnt in gas-fired power plants or fuel cells, the pipeline would help replace 25% of grey power generation with low-emission power. Considering the "additionality", which means that new renewable energy is used (i.e., primarily meeting electricity demand with renewables) and only secondarily than generating hydrogen, the required installed renewable energy capacity must be much higher. As an example, for an expected power supply of the electrolysis of 10 GW, there must be at least 10 GW of renewable energy projects in the pipeline beyond the current plans.

The figures might be credible, even if the numbers are still quite challenging, especially looking at the world markets (i.e., capacity and supply shortages for solar modules and electrolyzers) as well as increasing demand from other countries. If the energy supply reaches the levels while the demand is still high or even increasing, there is a possibility to build a second pipeline. The investment costs for the pipelines described above would amount to about USD 3 billion, depending on the routing, landscape and elevation profile, compression, and the material to be used such as green steel.

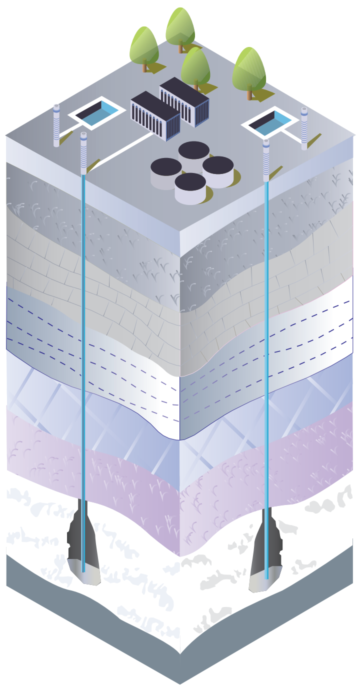


Figure 15: GSchematics of underground hydrogen storage in salt formations. (Courtesy of Geostock). (NZE). Source IEA

In addition to transport, storage will also be an important component of the hydrogen value chain and must be considered at the early stage of the consideration of a hydrogen valley. Surface facilities to store hydrogen, like spheres, cryogenic vacuum-insulated pressure vessels, ISOs, or semi-trailers are suitable for small quantities, less than 50 tons, but alternative solutions must be implemented to store larger quantities. Underground storage will be one of the best ways, with numerous advantages in terms of environment protection, safety, and above all, CAPEX and OPEX. The easiest way to store hydrogen is in a salt cavern (Figure 15). These are created by injecting fresh or sea water into a well drilled down to a geological layer of salt (Halite, NaCl). The water dissolves the salt body, saturates, and is extracted, leaving a cavern underground. Salt caverns are not lined as the salt itself acts as a sealant. An average size salt cavern can store around 4000 tons of hydrogen, at a pressure between 80 and 200 bar.

Many occurrences of salt deposits exist in the Sultanate and notably, there are two salt basins in the north (Ghaba and Fahud salt basins) and one in the south (South Oman salt basin). Six surface-piercing salt domes are known in the Ghaba Salt Basin (North Oman) at about 150 km from the coast. The South Oman Basin is made of a relatively thin bedded layer (around 300 m) and at a depth of around 1500 m. It is very probable that geologically suitable sites for the construction of salt-leached caverns will be found in Oman, with more favorable conditions in the North, on the Ghaba basin, but also possibly in the South. Additional onsite investigations are required to confirm this potential.

As Omani ports are not located close to the salt basin areas, storage in lined rock caverns could also be considered to store large quantities of hydrogen closer to the ports. Rock caverns are galleries excavated at around 150 m below ground (Figure 16). To store hydrogen as compressed gas, the galleries need to be lined to contain the high pressure. The capacity of lined caverns ranges from 50 tons to 1000 tons of hydrogen and even more. CAPEX for this kind of storage is higher than for salt caverns but is still very competitive when compared to above-ground storage options. Furthermore, lined caverns have numerous advantages over salt caverns, which are no risk of product contamination, low cushion gas, and fewer constraints in terms of geology. Lined rock caverns can also be used to store other products like ammonia or CO_2.

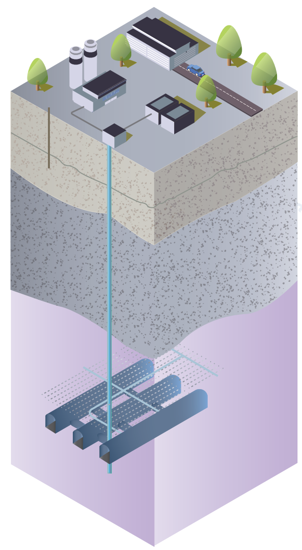


Figure 16: Schematics of underground hydrogen storage in rock caverns. (Courtesy of Geostock)(NZE). Source IEA

Oman offers good potential for the development of mined caverns with two major ophiolitic complexes. However, these favorable areas are not located in the immediate vicinity of the proposed sites:

- Sohar Port area is located over recent post-obduction sediments and is therefore not suitable for mined cavern construction. The nearest possible locations (Semail Ophiolite complex) are located about 35 km inland.
- Duqm Port area is covered by tertiary sedimentary rocks such as silty clay, conglomerate, and sand (surrounded by limestone deposits) and is therefore not suitable for mined cavern construction. The nearest possible location is about 80 km towards the south at Ras Madrakah cape (East Oman ophiolite complex).
- Salalah Port area has the same characteristics as the Duqm area. The nearest possible location is about 70 km eastward in the Mirbat region (Crystalline Basement).

Compared to above-ground storage options, both salt and mined caverns have the following advantages: the hydrogen is stored away from the atmosphere and oxygen sources; using limited surface land and having a lesser environmental footprint; and being less vulnerable to earthquakes or surface human attacks.

Ports can play a big role in a hydrogen valley by proposing storage services to all the other actors of the Valley. Underground storage can play a big role for ports, enabling the storage of hydrogen or other feedstock and providing flexibility to the industrial system and the ships' loading/unloading operations. Storage can be mutualized under the management of the port, to utilize larger capacities at a lower cost.

PORTS AS HUBS FOR HYDROGEN LOGISTICS

It is expected that ports will prove to not only be suitable locations for production, liquefaction, storage, and bunkering, but also be hubs for the collection of hydrogen as well as further distribution. Ports are usually situated in logistically advantageous locations in any case and they serve well for intermodality, i.e., loading or unloading between different means of transport such as pipeline and ship. They are also likely to offer permitting advantages as they are often industrial special zones. Ports are often centers for major energy consumption and are already connected to high-voltage power grids or power plants.

Omani ports possess a strategic location, and the country can leverage its low profile and neutral positioning as the Switzerland of the Arabian Peninsula. In combination with free and industrial zones, Omani ports are also important tools for regional development. Massive manufacturing and industrial activities are already present today, e.g., with a steel plant, aluminum smelter, refinery, ammonia plant, etc. Another consideration is that, especially for Oman, export via pipeline is not expected to play any role for the main future off-takers, like Europe or Asia, hence ports are the only gateways for bulk export of low-emission molecules. While a race between green ammonia and methanol is expected for the decarbonization of global shipping, ammonia has a clear edge as the transport vector of choice for most projects announced through 2030. However, especially in Oman, e-methanol could play an important role in the industrial development of the country, leveraging on a current total production capacity of 2 million tons (from Salalah Methanol Company and Ferrostaal in Sohar, which account for one million tons per annum of methanol each). In this context, CO_2 capturing from the energy sector and industry of Oman will be important for the development of e-methanol production in the country. Liquid organic hydrogen carriers (LOHC) might play a role, with a Memorandum of Understanding signed in April to establish a waste-to-hydrogen facility in a coastal area in Oman, which will produce 67,000 tons of zero carbon hydrogen to be transported using LOHC technologies. A similar project is planned for Port Said (Egypt) where a 1GW LOHC hydrogen hub has received preliminary approval in February 2022, which would then allow hydrogen to be stored and transported.

The emergence of ammonia on a global tradable market itself presents significant opportunities for Omani ports, as outlined in the chapter below. In parallel, ports have ambitions in bunkering and can position themselves to play a significant role internationally as midway hubs between Singapore and Rotterdam. A more comprehensive analysis is provided in the following chapters.

BOOSTING THE AMMONIA MARKET

An interesting opportunity for Oman might be to take a leading role in boosting the global market for ammonia. As of 2021, only slightly more than 10% of the global ammonia market was traded (and the rest was produced and consumed on site), a percentage that will grow with increasing levels and different places of production and new use cases. Latest insights indicate that Ammonia production could globally increase three-to-six-fold (from 185 Mt in 2020 to 540-1,140 Mt by 2050), driven by the emergence of ammonia as a transport vector of low-emission hydrogen. A dynamic development is therefore expected in Oman, amplified by a trend towards using green fertilizers as well as the usage of ammonia as a fuel for shipping and also a source for the power industry (e.g., with co-firing into coal plants (Figure 17)). Green fertilizers are expected to enter the market in the next few years, with four projects publicly announced globally: two by Grupo Fertiberia in Spain and Sweden; one in Norway led by Yara; and one by Nutrien in the USA.

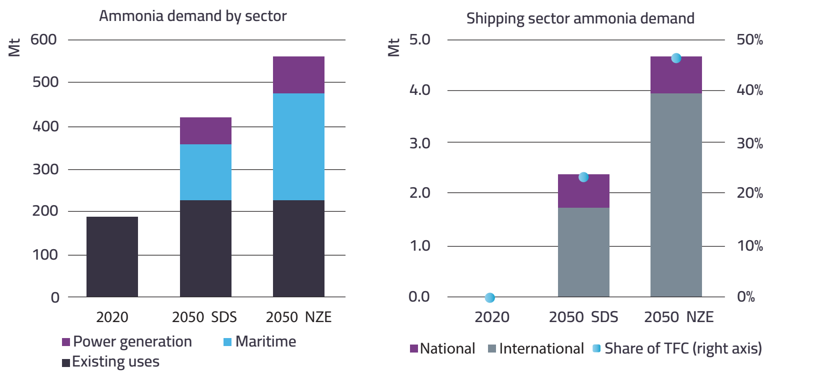
There are several projects where ammonia is identified as the transport vector of choice already under development in Oman and more have been recently announced (Table 3)..

TABLE 3: AN OVERVIEW OF AMMONIA PROJECTS UNDER DEVELOPMENT IN OMAN.

NAME	LOCATION	DVELOPERS	ELECTROLYZER CAPACITY	PRODUCTION CAPACITY
Green Energy Oman	Al Wusta Governorate	OQ, Intercontinental Energy, Enertech	Phase 1: 4,7 GW Phase 2: 14 GW	H_2 1,8 Mt per annum NH_3 10 Mt per annum
HYPORT Duqm Green	Duqm SEZ	DEME, OQ, Uniper	Phase 1: 500 MW Long-term: 1.5GW	Phase 1: NH_3 0,33 Mt per annum Long-term: NH_3 1 Mt per annum
Oman Green H_2 Project	Duqm SEZ	ACME Group, Scatec ASA, KBR (technology partner), Tatweer	Phase 1: 300 MW	Phase 1: NH_3 0,1 Mt per annum Long-term: NH_3 1 ,1 Mt per annum
SalalaH2	Salalah FZ	OQ, Marubeni, Linde, Dutco	400 MW	NH_3 0,365 Mt per annum
Green Hydrogen Hub	Port of Sohar	Port of Sohar, Port of Rotterdam, Hydrogen Rise, Shell, Jindal Shadeed	Phase 1: 35 MW Phase 2: 350 MW	
H2Oman	Salalah FZ	ACWA Power, OQ, AirProducts	Phase 1: 500 MW	NH_3 0,330 Mt per annum
POSCO	Duqm SE	POSCO		H_2 0,23Mt per annum NH_3 1,2 Mt per annum

The ACME and Scatec consortium has signed an offtake agreement with Norway's Yara International for the offtake of the entire Phase I green ammonia production of 0.1 Mt per annum. The green ammonia offtake shall be used by Yara as emission-free fuel for deep-sea shipping, power production, and global fertilizer production.

AMMONIA USE AS AN ENERGY CARRIER IN THE SUSTAINABLE DEVELOPMENT SCENARIO AND THE NET ZERO EMISSIONS BY 2050 SCENARIO

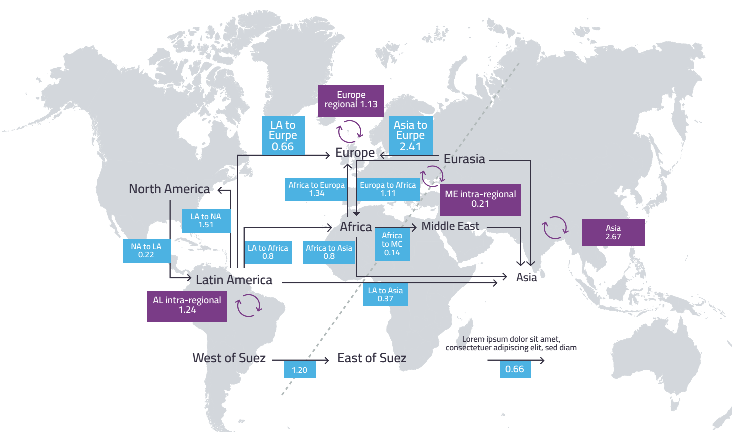


NOTES: SDS = SUSTAINABLE DEVELOPMENT SCENARIO: NZE = NET ZERO EMISSIONS BY 2050 SCENARIO: TFC = TOTAL FINAL ENERGY CONSUMPTION IN THE MARITIME SHIPPING SECTOR. ''EXISTING USES'' REFERS TO CURRENT AGRICULTURAL AND INDUSTRIAL USES, COINCIDING WITH THE CORE ANALYTICAL SCOPE FOR THIS TECHNOLOGY ROADMAP.

Figure 17: Ammonia use as an energy carrier in the SDS and the NZE by 2050 Scenario. Source: International Energy Agency (IEA), 2021. Ammonia Technology Roadmap CC BY-NC 3.0 IGO.

Out of the 10% of global ammonia production which is traded, the main flows are from Belarus/ Russia/Ukraine to the Black Sea and Northern Europe, inside Asia and from US/Trinidad to Houston in the Gulf of Mexico. Smaller flows are from Australia to Asia and GCC to India (Figure 18). Regarding the main future off-takers, Europe will be the obvious partner, complemented by interesting international opportunities in Asia. Japan, for example, is expected to be a major importer of low-emission ammonia, whilst Singapore has significant ambitions in expanding its role as a global LNG bunkering hub to also becoming a bunkering hub for ammonia. As Singapore cannot have any ambitions to become a producer of low-emission molecules, and due to a similar political positioning as the Switzerland of Asia, the opportunity to establish a partnership with Oman seems compelling.

GLOBAL TRADE FLOWS OF AMMONIA IN 2050 (MT)



Disclaimer: This map is provided for illustratiom purposes only. Boundaries and names shown on this map do not imply the expression any opionion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities conerning the delimitation of frontiers or boundaries. Source: (Topsoe 2020) NoteL LA: Latin America, NA: North America, ME: Middle East.

Figure 18: Global trade flows of ammonia in 2019 (Mt). Source: IRENA (2022), Global hydrogen trade to meet the 1.5°C climate goal: Part II – Technology review of hydrogen carriers, International Renewable Energy Agency, Abu Dhab

A BUNKERING SPOT BETWEEN SINGAPORE AND ROTTERDAM

Oman has a strategic position being midway between the two existing LNG bunkering ports, Singapore and Rotterdam (Figure 19). New bunkering patterns will emerge as the market evolves (i.e., when ammonia volumes and trade flows will increase). It could be therefore a good opportunity for Omani ports to start planning now for future developments and to position themselves as mid-way bunkering locations for a range of products. Taking the initiative now, to spearhead such international alliances, could be an important factor in securing a place as a key bunkering hub for the future.

Ports should develop an infrastructure for export and bunkering but at the same time, support the local demand in the country. In this context, bunkering will be critical to enable additional activities at the ports in a cost-attractive way. Port of Sohar recently launched bunkering services by leveraging on being the main export center for petroleum products in Oman. In fact, two refineries are in Muscat and one in Sohar, with an additional refinery under construction in Duqm. Salalah, which has the highest container traffic in the country, has also ambitions to become a bunkering hub by focusing on methanol. In planning for the future, a flexible approach should be kept in mind to position the country as a low-carbon bunkering spot, differentiating the bunkering opportunities between Oman's three ports. One direction could be a product differentiation with, for example, Duqm focusing on ammonia, Salalah on methanol, and Sohar on LNG. Another lead could be for Port of Sohar to focus on domestic and regional markets but for Duqm and Salalah to use their optimal geographic position to concentrate on exports.

Moreover, the presence of large salt basins in Oman (Fahud Salt Basin, Ghaba Salt Basin, and the South Oman Salt Basin) could potentially open up opportunities for the underground storage of very large quantities of hydrogen (TW hour range) and natural gas, but will also bridge the seasonal gap of a much higher power requirement in summer, due to the increased use of air conditioners. We recommend that this should be investigated further. As outlined in previous chapters, storage in lined rock caverns could also be investigated to establish the best storage locations closer to the port areas, so that products like hydrogen, LOHC, ammonia, and CO_2 can be stored.

Figure 19: The Asian-Europe container route. Source: The Next Wave Green Corridors, Getting to Zero Coalition 2021

HOW OMANI PORTS CAN SUPPORT THE HYDROGEN VALUE CHAIN LOCALLY AND GLOBALLY

03

HOW OMANI PORTS CAN SUPPORT THE HYDROGEN VALUE CHAIN LOCALLY AND GLOBALLY

PORTS IN THE HYDROGEN OMAN PLANS

The strategic development of hydrogen hubs at Port locations is an early opportunity for Oman to create a hydrogen-based economy. While some competition elements may emerge in the beginning, it is expected that all those involved will realize that no single organization or company can provide all the products, services, and resources required to make such hydrogen hubs a success. Resources that are located inland away from ports will need to be connected via pipeline or the grid and therefore, the entire supply chain from upstream to downstream will need to be involved. To date, all preliminary studies have been focused on Port of Duqm, Port of Salalah, and Port of Sohar.

Port of Sohar is fairly advanced in its strategy and plans for decarbonization, aiming at becoming a low-emission industrial center. Considering the challenges in producing renewable energy in Sohar and the amount needed to fully decarbonize the port in the long term (up to 12/13 GW renewable energy equivalent), an integrated strategy with the other two Omani ports will be crucial. Specifically, Sohar Port and Freezone intends to develop a low-cost hydrogen hub by producing its own low-emission hydrogen and developing its own 3.5 GW solar power capacity. This includes the development of storage facilities for different forms of low-emission molecules and increasing bunkering capacities. It must be noted that the availability of affordable energy sources in huge quantities is a major challenge for future expansion of Sohar Port and Freezone, in which feasibility studies with Port of Rotterdam (50% owner in Sohar port) and Germany's Hydrogen Rise are ongoing. Moving forward, with a pilot project already underway, Sohar could position itself as a producer of green steel leveraging on the already existing DRI plant. This could cater to both the domestic market as well as involving export opportunities globally (especially with a green premium for steel being expected to develop and Europe introducing a carbon border tax). Another opportunity is represented by e-fuels, specifically synthetic kerosene which requires a CO_2 source for production (Sohar is a high emitter of CO_2). Green kerosene could be blended with the grey one and sent to Muscat airport via the existing pipeline.

Port of Duqm is committed to working on low-emission initiatives, following a decarbonization strategy initiated by the Port of Antwerp/DEME consortium, which cascaded to its subsidiaries. The Hyport Duqm project (an OQ/DEME partnership), targeting large-scale production of low-emission hydrogen, is the first step in this direction. Duqm port is expected to be Oman's leading hub for handling and exporting low-emission molecules due to its proximity within areas of the Al Wusta Governorate earmarked for large-scale renewables and electrolyzer-capacity development. The presence of the Port of Antwerp as a shareholder is expected to result in access to the Port of Antwerp in Belgium, which is a market for low-emission hydrogen as well as a key import entry point into Europe. Duqm port has a liquid terminal suited for storage and handling of low-emission fuels and it is currently advancing in negotiations with steel manufacturers interested in powering their plants with low-emission hydrogen.

Duqm has the opportunity to establish a full-value chain around the port area for the mining sector (already active in the region) and also solar and wind, thanks to its easy accessibility and raw materials availability. Duqm is the only of the three ports with vast areas of additional land available adjacent to the port.

With bold objectives and by virtue of its shareholder APM, Port of Salalah is now in the early stage of planning and executing its way ahead towards a net zero future. The mid-term strategy for the next 3 to 5 years will be built around two main areas, which are the port business itself and e-fuels (starting with e-methanol). The own port operations consume alone approximately 1 million liters of diesel per year and tackling this will be crucial in the decarbonization journey of Salalah. Maersk, which is both a shareholder and a customer, focused on e-methanol early on, therefore Salalah can leverage this to supply the 25 lines currently operated, and at the same time, develop a bunkering hub. A drawback in the decarbonization plans of Salalah could be represented by the difficulty of transport logistics outside the port area and accessibility of the Thumrait plateau where wind and solar projects are operated and planned. For example, the wind blades and masts for the Dhofar I project were imported and transported via Duqm, although much more distant.

	PORT OF SOHAR	PORT OF DUQM	PORT OF SALALAH
OPPORTUNITNITIES	Well-developed infrastructure Well-developed industrial zone Diversified group of offtakers Ahead in decarbonization strategy & execution Proximity to industrial and residential centers Higher job demand in the area	Abundance of solar and wind resources Availability of land for renewable energy and hydrogen production Availability of space (at the port and within the SEZ) for further expansion Mining sector active in the region Largest distance from potential conflict zones Ideal location mid-way on the EU-Asia route	Abundance of solar and wind resources Availability of space within the FZ for further expansion Largest transshipment port and biggest container hub Ahead on planning the adoption of e-fuels (e-methanol) Best connectivity, as ideal location mid-way on the EU-Asia route Distance from the Arabian Gulf
CHALLENGES	Lack of wind resources and land for solar Availability of sufficient energy and land for further expansion Proximity to Fujairah as the leading bunkering hub in the region Proximity to potential conflict zones	Distance from residential and industrial centers Workers will be required to work on rotations, at least initially Lack of infrastructure	Limited space at the port for further expansion Difficulty of transport logistics outside the ports area Difficulty to access the Thumrait plateau where RE is produced Furthest from big residential and industrial centers Limited job demand, with Port of Salalah already being the first employer in the area

POSSIBILITIES FOR PORTS AND BROADER LOGISTICS TO DECARBONIZE THEIR OWN OPERATIONS WITH HYDROGEN APPLICATIONS

Ports can be early adopters of hydrogen and start to decarbonize their own operations as well as logistics. Ports do not only take on the role of loading or unloading goods, liquids, or gases. In some cases, they also serve for further processing. For example, a chemical complex is connected to the port of Antwerp-Bruges to further process products. The chemical industry needs hydrogen, which it has so far largely produced from natural gas. This can be replaced by low-emission hydrogen or cracked ammonia. Instead of processing products at unloading ports, products can already be refined at the port of loading. There are already projects for this in Oman such as the production of sponge iron by means of direct reduction based on low-emission hydrogen.
Ports are also only one stop in supply chains. Further transport from or to the interior of the country is managed by lorries, railways, and pipelines. Provided that road transport is guaranteed along frequented routes, the trucks can be supplied in the future via hydrogen refueling stations. Comparable projects for the construction of high-capacity refueling stations can be found in the motorway network in Germany, to and from the port of Rotterdam, and in Australia on the Hume Freeway between Sydney and Melbourne.

The refueling stations themselves can be supplied with hydrogen by decentralized electrolysis on site. Alternatively, centralized production of hydrogen is conceivable with delivery to the filling stations. The demand for trucks is immensely greater than for cars. A pipeline supply is therefore conceivable in contrast to the expensive and quickly reaching the limit trailer supply. Although comparable infrastructure exists for the supply of conventional fuels, comparable pipelines for hydrogen are still unusual, as the quantities of hydrogen refueled at hydrogen refueling stations are still so small, which means that only trailer supply is worthwhile.

In Bavaria, an electrolysis plant is currently being built that will exclusively supply refueling stations in the area for filling buses, trucks, and cars. The trucks' original equipment manufacturers are clearly starting to signal their preference for LH2 as opposed to gaseous because of space, weight, cost, and the extra capacities achieved with liquid. In fact, as with any gas, storing and transporting it as liquid takes less space than storing it as a gas at normal temperature and pressure. As a consequence, when space is at a premium (on trucks and busses for instance) four times more products can be stored in the same amount of space allowing four times more range and capacity of the vehicle. The corresponding impact on cost per kg for the Gas Supply Chain vs Liquid Supply Chain is shown in the graph below (Figure 20):

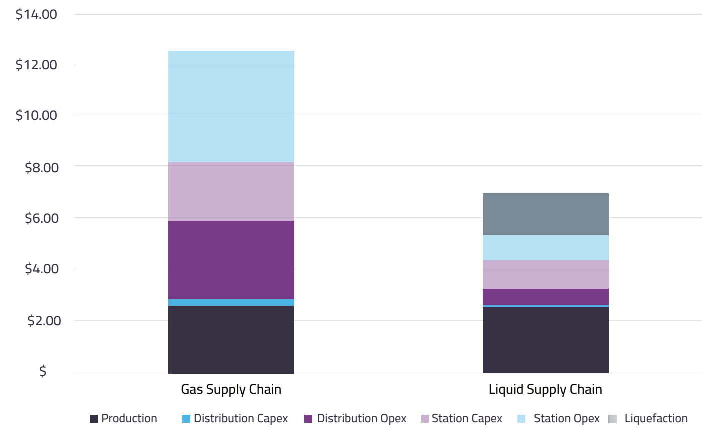


Figure 20: Difference in cost per kg for the Gas Supply Chain vs Liquid Supply Chain.

HYDROGEN TO ATTRACT LOCAL VALUE-CREATION AND ENERGY-INTENSIVE INDUSTRIES

Oman has a strong competitive advantage in natural renewable energy sources, being one of the top countries in the entire MENA region for combined wind/solar generation potential. There is a relatively good seasonal and daily complementarity as well, allowing high combined load hours. With abundant land and ambitious national targets, the country has the potential to become a sizable global producer of low-emission molecules, as well as a trading hub, while also developing a local hydrogen economy due to the presence of sizable offtakers. Low-emission electricity could be a low-cost basis for the production of hydrogen, giving a strong edge to Omani ports with respect to nearby ports like Port of Fujairah, which would face higher production costs.

Another opportunity, with a direct impact on the local economy, could be the extension of part of the existing supply chain into the hydrogen space (e.g., dry docks and welding capabilities). Examples from Germany (e.g., Leuna) show that e-fuels (in this particular case, green methanol) could act as an economic developer for industry hubs in the chemical space.

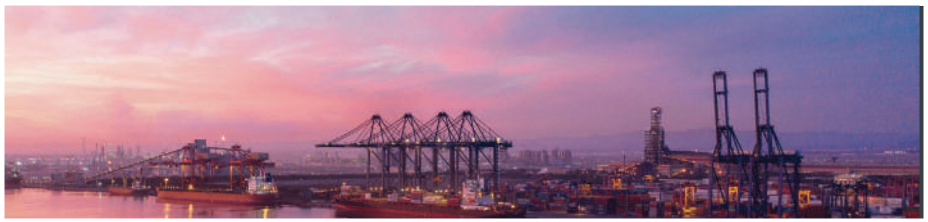
Similar to countries like Morocco, Oman has the potential to attract entirely new energy-intensive industries with the cheapest low-emission electrons and molecules. Also, due to existing infrastructure and the strategic location of the country at the crossroads of global trading routes, this could be an exciting future development. Such new developments could be new steel plants like those under discussion in Duqm, or different applications adjacent to an emerging mining industry. The recently founded Minerals Development Oman (MDO) has ambitions to develop this sector which has been undervalued for many years due to the success of the oil and gas industry. The relaunch of the copper value chain as well as promising exploration findings for quartz could contribute to the localization of the solar and wind industries (e.g., for the production of copper cables and wires). As the Middle East does not have a sizeable manufacturing industry for solar and wind yet, this could provide a significant competitive advantage to the country.

MOBILITY WITHIN AND OUT OF THE PORTS

From the offtake side, there is much attention being paid to exploring ways to reduce their CO_2 footprint. Ports can focus on improving transport in and out of the port, with solutions already available for trucks and facilities. A Green Hydrogen for Mobility project has been recently promoted by Shell and Oman Airports, in which a similar application could easily be foreseen for internal mobility within the ports. Hydrogen enables especially larger vehicles to achieve greater ranges that would not be possible with battery-powered vehicles. Asyad could also extend the deployment of hydrogen-powered vehicles as the operator of the Omani Post and Asyad Express postal services, as well as extend it to the circa 500 buses used for public services. Even mining companies that need to transport their passengers over long distances, such as in Chile, are exploring hydrogen-based bus operations. However, a sizable market for fueling stations must be developed in the first instance and it must be considered that the establishment of nationwide hydrogen refueling infrastructure is costly. Therefore, the refueling of fleets that return to the depot on a daily basis could be a suitable solution. There are good examples not only for local public transport in Europe but also for fleet operators who are interested in this solution, such as MPREIS in Austria for supplying their supermarkets.

Fuel cell technology is a more convenient option than EV for high energy-consuming systems, i.e., refrigerator trucks. As such, it represents an opportunity for Omani ports to be the first movers in developing low-carbon cold chain logistics. Fuel cell technology is also applied to sea products, especially in Europe/Korea/US with few applications in the Middle East. Current technology allows push-boats and barges to have fuel cells as secondary propulsion for boosting (in the case of small ships it can act as primary combustion).

European ports such as Rotterdam and Hamburg are also connected to domestic waterways and push boats are used to transport goods up and down the rivers. Pilot projects like Greenplug or Rh2ine aim to convert ships to hydrogen. Passenger ferries can also be converted to hydrogen, as port companies such as Hadag are planning. In Oman, however, the industrialization of ports and the lack of rivers mean that there are few comparable applications in this regard. However, fuel cell push boats for the transport of goods within the port could become quite interesting.



CCUS FOR ABATING EMISSIONS AND ENABLING A LOW-CARBON HYDROGEN

CCUS is an emerging sector with the potential to significantly contribute to the decarbonization plans for ports. In fact, it can help with lowering emissions for existing assets as well as enabling low-carbon hydrogen production. Ports are intrinsically high carbon emitters, with CO_2 originating from point sources, which represents an advantage for capturing. The CO_2 captured can then be either stored or utilized, perhaps as a sustainable feedstock for chemicals and e-fuels, for example.
Ports can play an important role by coordinating all the CO_2 capture initiatives in their area and by collecting and storing the CO_2 temporarily before usage, injection for sequestration locally, or by exporting it.

CCUS is at a nascent stage worldwide with most of the projects at a pilot level. Few ports are progressing towards implementation, including Port of Antwerp (Antwerp@C), the North Sea Port (Carbon Connect Delta), and Port of Rotterdam (Porthos).
Oman has already undertaken measures for development of CCUS in the country. A key step is the inclusion of CCUS as a major decarbonization solution in the National Energy Transition Masterplan, together with the intention of drafting a specific CCUS Policy as part of an overarching Energy Transition Policy. In May 2022, PDO and Shell signed an agreement to study the reinjection and storage of carbon dioxide in Oman and address key factors such as technology, cost, project timelines, and local regulatory framework for CCUS. 44.01, a company based in Oman, has already launched pilot projects for carbon capture and mineralization into peridotite rocks for permanent storage. Asyad Group has itself entered a strategic decarbonization partnership with 44.01 to explore methodologies to decarbonize its logistics assets. Furthermore, private sector developers under the IPP/IWPP model (viz. Barka IWPP, Sohar IWPP, Salalah IWPP, Sur IPP, etc.) are exploring the feasibility to incorporate CCUS technologies in large-sized gas plants for electricity generation.

INTERNATIONAL COOPERATIONS AND ALLIANCES

Collaboration among the three ports will be a key factor in minimizing costs, avoiding overlaps, and coordinating investments. Asyad can act as a facilitator for the three ports to ensure the adoption of a common strategy to position Oman as a major export player for low-emission molecules in regional and global markets, complemented by the development of a local hydrogen supply chain.

Alliances with EU and Asian ports will play a role in the future growth of the Omani ports. This can be leveraged via the existing shareholders of the three ports from Belgium, the Netherlands (with Port of Rotterdam and Antwerp being the no. 1 and 2. Ports in Europe respectively), and Maersk as a partner from Denmark. As referred to in the various chapters, we also recommend boosting relationships at the national level, with the key hydrogen-importing countries in Europe (Germany and Benelux), as well as partners from Asia such as Japan and Singapore.

To create a local hydrogen ecosystem, alliances on the technology side will also be key. This will be not only all across the hydrogen value chain but also will include wind turbine manufacturers to create local wind blade or tower production.

Establishing strong relationships with global associations would accelerate the connection to the broader value chain. As an example, the Global Maritime Forum (GMF) is leading the “Getting to Zero Coalition” a cross-sectorial initiative on Decarbonization aiming at zero emissions fuels in shipping by 2030 and Net-Zero 2050.

HOW CAN SHIPPING HELP EXPEDITE THE HYDROGEN VALUE CHAIN DEMAND

04

HOW SHIPPING CAN HELP EXPEDITE THE HYDROGEN VALUE CHAIN DEMAND

Oman's strategic geographic location presents a unique opportunity to develop bunkering capabilities, both for low-carbon ammonia and e-methanol, which are the future clean fuels for shipping. At the same time, with sizable consumers in the region like Saudi Arabia, Oman can spearhead the development of regional markets. With a sizable fleet of over 60 ships, Asyad can drive global development to gradually transition to using clean shipping fuels. However, the availability of shipyards for both the new ships and retrofitting workaround will heavily impact the timeline for the green transition.

CO_2 FOOTPRINT AND DECARBONIZATION

The global shipping industry, causing almost 3% of global CO_2 emissions, is under massive pressure to decarbonize and hence is going through a dramatic change. All major operators have developed strategies to significantly cut CO_2 (and other) emissions, with some even announcing net zero targets in the long term. While no near-term business case to apply low-emission ammonia or methanol seems to be in sight in this decade, shipping companies are moving in this direction for strategic reasons, based on ambitious decarbonization targets.

The GMF is working on Green Corridors projects to help countries prioritize certain routes in the decarbonization roadmap based on shipping traffic and operational needs. Latest insights indicate that the shipping sector alone can drive the demand for near-zero-emissions ammonia, however, it must be supported by targeted demand-side policy and regulation. The implementation of a CO_2 price could have a meaningful impact on the future of shipping to close the gap between green fuels and fossil fuels. The entire shipping industry currently utilizes 350 million tons of fossil fuels. Replacing only 1% of that with synthetic fuels requires 9 GW of electrolyzer capacity (thus making 8 million tons of CO_2 savings) or around 60TWh of electricity. The possibility to replace fossil fuels gradually with low-emission ammonia or e-methanol represents a huge potential for the maritime industry to utilize these new clean fuels.

While defining its national regulation, Oman should account also for international rules in place that have an impact on the export market. Those include, for example, the EU regulations, as the EU could be a preferred business partner, and the International Maritime Organization (IMO) requirements.

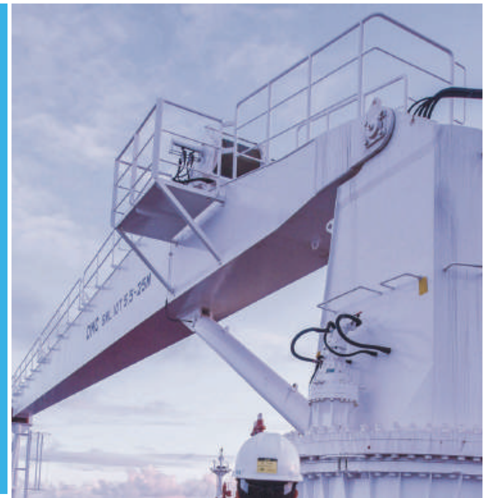
SHIPPING REGULATIONS WORLDWIDE

EU Ports have regulations in place to reduce CO_2 emissions, with such requirements on any ship that enters the EU ports. Omani ports could explore similar options in order to push for retrofitting and/or reduction of emissions in existing engines (e.g., scrapers).

Oman has extensive links with the EU through trade, bilateral cooperation, and international agreements. In addition, Oman is a party to the 1988 EU-GCC Cooperation Agreement, the EU-GCC Clean Energy Technology Network (established in 2010) and the 2020 Enhanced EU-GCC Political Dialogue, and Cooperation and Outreach project. Through these channels, EU ports and emissions regulations have significant implications for the Omani shipping industry. As an IMO member state, Oman is also subject to this system.

EXAMPLES OF CURRENT EU REGULATIONS

Regulation 2015/757 on the Monitoring, Reporting and Verification of CO_2 emissions from Maritime Transport (EU MRV Regulation). Under the EU MRV Regulation, since 1 January 2018, all ships over 5,000 gross tonnages at EU ports for commercial purposes have been required to monitor and report their CO_2 emissions, fuel consumption and other parameters such as distance traveled, time at sea and cargo carried per voyage.



EU Emissions Trading System (EU ETS) was introduced in 2005, with the aim of reducing greenhouse gas emissions in a cost-effective way and was the world's first and largest major carbon market.

Following the adoption of the EU MRV Regulation, the IMO established a similar reporting system, which has begun collecting data since 1 January 2019. The IMO data collection system required owners of ships over 5,000 gross tonnages engaged in international shipping to report information on those ships' fuel consumption to the ships' flag State. Therefore, Omani ships calling at European ports are currently required to report under both the IMO system and the EU MRV Regulation. Despite leading the way and encouraging further developments at the IMO level, the EU MRV Regulation was ultimately failing to drive sufficient reductions in shipping emissions. To account for this, the EU ETS was expanded to the shipping industry (and the transport industry) in June 2022. This means that, regardless of their flag state, all emissions from ships over 5,000 gross tonnages on voyages within the EU, 50% of emissions from voyages starting or ending outside the EU, and all emissions that occur when ships are berthed at EU ports, have become subject to the overall ETS framework. As this Carbon Border Adjustment Mechanism (CBAM) is set to apply to all ships regardless of their flag state or EU membership, Omani ship-owners will soon have to purchase and surrender ETS emission allowances for all emissions occurring within the scope of this system.

The CBAM is the first system of its kind, but many other regulators are in the consultation stages regarding similar measures, including the United States, China, and the IMO. As such, Oman's shipping industry is likely soon to be subject to similar provisions in multiple jurisdictions. The EU does plan to recognize certain international emissions reduction schemes as equivalent to the ETS. However, by introducing its own shipping emissions regulations, Oman could both generate its own emissions trading system and prevent the loss of that opportunity to other parties such as the EU. Even though IMO emissions trading initiatives are on the horizon, further measures are yet to be agreed upon.
Also, as part of REPowerEU, there are currently ongoing consultations to transform Europe's energy system in response to the Russia/Ukraine crisis. One of the main tenets is to achieve this transformation through energy savings, diversification of energy supplies, and accelerated roll-out of renewable energy. Accordingly, national and EU energy and emissions regulations will continue to be the primary sources of concern for Oman for the foreseeable future.

REPLACING HEAVY FUEL OIL WITH E-FUELS TO MEET DECARBONIZATION TARGETS

Shipping should be an early offtaker of low-emission hydrogen. In the short term (certainly up to 2030), e-methanol and ammonia are expected to play a similar role, while thereafter ammonia will likely be the carrier of choice for sea transport, and also utilized as a shipping fuel. The Alternative Fuels Insight (AFI) platform developed by DNV can be used by the shipping industry to monitor the uptake of alternative fuels.

There has been a noticeable increase in demand for dual fuel engines (heavy oil fuels/diesel and methanol) from a 20% increase in 2022 up to a 50% increase in demand in 2022, with costs in the region of 10-20% more than a normal engine. Ammonia engines are currently in development and will be released in 2024, and thereafter it is expected that their demand will compete with methanol engines. Current estimates for dual-fuel engines for newbuilds forecast a market split almost equally for LNG, e-methanol, and ammonia in 2030. Synthetic gas is also already available since it shares the same technology as natural gas. LPG is also used in certain geographical areas, and there is a trend in retrofitting LPG engines. The liquid hydrogen market is not set to reach a noticeable size due to technological constraints. LNG is expected to peak in the next 5 years and to be eventually replaced by hydrogen derivatives that are regarded as the future of fuels. Gas engines can now run with a 25% mix of hydrogen and there is a roadmap to increase their percentage share (but for marine applications, it is unlikely to reach a 100% mix).

E-fuels can find widespread application both in the maritime industry and at ports location, thus contributing to meeting the decarbonization targets. In light of Oman's ambition to become a bunkering hub, storing e-fuels at the ports would be critical to be attractive cost-wise for new business as well as an additional incentive to increase local consumption avoiding transport costs. Port of Sohar has already an ammonia plant that could potentially produce green (or blue) ammonia and a methanol plant, whereas Port of Salalah's focus is heavily directed towards methanol due to Maersk's governance. Port of Duqm as a petrochemical hub could also play a role in the production of e-ammonia and e-methanol. As such, Asyad could coordinate the local production at these three ports and promote the use the e-fuels to decarbonize operations in the first instance.

Besides the three main Omani ports, Asyad also manages Muscat International Airport which is directly connected with the Port of Sohar via a kerosene pipeline. E-kerosene, which is generated with the combination of low-emission hydrogen and CO_2, represents an additional opportunity for the Port of Sohar given that ports produce a high volume of CO_2. A CO_2 capture system along with a hydrogen production center and repurposing transport infrastructure are required to fully realize the e-kerosene potential. In this context, the presence of cement factories in the vicinity of Port of Sohar (e.g., Sohar Cement Plant and Al Tasnim Cement) could represent an opportunity for capturing CO_2 locally.

CONCLUSIONS AND RECOMMENDATIONS

Sultanate of Oman is in an excellent position, both geographically and geopolitically, to pave the path for the development of a hydrogen economy in the MENA region. With key factors in mind such as renewable energy access and geopolitical and social aspects, the main question is whether industries and people move closer to the renewable sources far away from Muscat and the main population areas, or the cheap energy is brought to the North via hydrogen pipelines, for example.

It is without doubt that all three Ports could be developed as hydrogen valleys, which could serve as catalysts to develop the entire hydrogen value chain in the country. All three Ports shall develop a specific positioning with different unique selling propositions, with a well-coordinated long-term strategy as a key pillar in the energy and development strategy of Oman Vision 2040.

The analysis presented in this study results in a series of recommendations to realize the full potential of the hydrogen transition for the Omani Ports, led by Asyad and which are:

- As a shareholder of all three ports, Asyad has a huge opportunity to develop an integrated strategy with the aim to make Oman one of the key global hubs for hydrogen;
- A hydrogen economy should be developed aiming at both export and meeting local demand, to cater to the future decline in natural gas reserves and to fully realize the national decarbonization process;
- Ports should develop as fully integrated clean industrial hubs, using and processing hydrogen directly at the ports to decarbonize or reaching net zero emissions in their own operations in the first instance;
- As repurposing the existing gas network is not likely to be achievable due to the substantial costs involved, there is the opportunity to develop a new separate hydrogen infrastructure system;
- Oman could play a strategic role in the evolving ammonia and methanol market, attracting new business and should aspire at becoming a global production and bunkering hub;
- Oman should monitor developments in the emerging global market of traded and port-relevant emission-free molecules beyond hydrogen and ammonia (i.e., e-fuels) and capture synergies based on its hydrogen basis;
- Oman has the chance to contribute to setting global standards (e.g., on traded certification) and create a competitive advantage as an early mover in an emerging market for low-emission molecules;
- Emerging hydrogen valleys around the three ports will be the key enabler for a hydrogen economy in Oman, creating significant job opportunities for the country; and
- Collaboration among the three ports, and with international ports and associations, will be a key factor going forward to provide a common strategy to position Oman as the export leader in hydrogen.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