Ministry of Energy and Mineral Resources
The Hashemite Kingdom Of Jordan

DRAFT NATIONAL GREEN HYDROGEN STRATEGY FOR JORDAN

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CONTENTS

Acronyms

Acronym	Definition
AGP	Arab Gas Pipeline
ASEZA	Aqaba Special Economic Zone Authority
BESS	Battery energy storage system
BEV	Battery electric vehicle
BF-BOF	Blast furnace-basic oxygen furnace
BRT	Bus rapid transit
CCGT	Combined cycle gas turbine
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP 27	The 27th UN Conference of Parties
EMRC	Energy and Minerals Regulatory Commission
EU	European Union
EV	Electric vehicle
FCEV	Fuel-cell electric vehicle
GDP	Gross domestic product
GHG	Greenhouse gas
GIZ	Gesellschaft für Internationale Zusammenarbeit (Society for International Cooperation, German development agency)
GW	Gigawatt (1000 MW)
HEFA	Hydrotreated esters and fatty acids
HV	High voltage
IEA	International Energy Agency
IFC	International Finance Corporation
IMF	International Monetary Fund
JPMC	Jordan Phosphate Mines Company
JPRC	Jordan Petroleum Refinery Company
Kg	Kilogram
Km	Kilometer
kWh	Kilowatt-hour
kWh/kWp	Kilowatt hours per kilowatt peak, a measure of solar capacity factor
LCOH	Levelized cost of hydrogen
LTNS	Long-Term National Transport Strategy

Acronym	Definition
LULUCF	Land Use, Land Use Change, and Forestry
MCM	Million cubic meters
MEMR	Ministry of Energy and Mineral Resources
MENA	Middle East and North Africa
MT	Metric tonnes
MMT	Million metric tonnes
MtH2eq	Metric tonnes hydrogen equivalent
Mtpa	Million tonnes per annum
MoENV	Ministry of Environment
MoPIC	Ministry of Planning and International Cooperation
MW	Megawatt
NDC	Nationally determined contribution
NEPCO	National Electric Power Company (Jordan)
NZE	Net Zero Emissions
OHL	Overhead lines
PHS	Pumped hydro storage
PPA	Power purchase agreement
PtX	Power-to-X
PV	Photovoltaic
R&D	Research and development
RE	Renewable energy
SAF	Synthetic aviation fuel
SMR	Steam methane reformer/reformation
T&D	Transmission and distribution
Tpa	Tonnes per annum
UAE	United Arab Emirates
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USD	US dollars
VRE	Variable renewable energy

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EXECUTIVE SUMMARY

Decarbonization is increasingly becoming a global imperative as nations around the world commit to reducing greenhouse gas (GHG) emissions in line with the Paris Climate Accord and their own Nationally Determined Contributions (NDCs). Green hydrogen—or hydrogen produced entirely from renewable sources—is gaining traction as a potentially transformative solution to combat the climate crisis while also strengthening energy security and resilience. Through the ability to convert renewable energy to chemical energy, green hydrogen, and its derivative products (called "Power-to-X" or "PtX" for short)[i] present an opportunity for countries with strong solar and wind resources, such as Jordan, to meet increasing global demand for clean energy. The Hashemite Kingdom of Jordan has taken major strides in reducing emissions and promoting the growth of clean energy solutions over the past two decades. Building on this success and significant renewable energy potential, Jordan can play an important role in the emerging global hydrogen economy.

This draft report establishes the **National Green Hydrogen Strategy** for Jordan (hereafter, the "Draft Strategy"), as well as an Action Plan for guiding the growth of the sector. It provides an overview of the potential for low-cost production of green hydrogen in Jordan and the opportunity to serve anticipated demand across sectors, including for export. It sets a *Mission* for **Jordan as a regional epicenter for green hydrogen and PtX products**, supported by a *Vision* to create a green hydrogen economy in Jordan that **supports robust exports and a domestic supply that is affordable, clean, and part of an overall transition to a more prosperous, equitable, and sustainable economy**. To achieve this *Vision* and *Mission*, this draft Strategy lays out five strategic priorities to support the development of the sector:

- **Strengthen Measures to Support Hydrogen Investments.** Concentrating green hydrogen production near the port of Aqaba can help Jordan realize significant economies of scale. Proximity to many of the main end-users, including existing fertilizer production and export infrastructure, will reduce the cost of transportation, encourage innovation and ecosystem collaboration, and enhance competitiveness.
- **Stimulate market demand.** Targeting strategic, priority applications for support in the short-term while laying the groundwork for expansion can spur market demand. Jordan should leverage positions of competitive advantage, government support, and relatively mature technologies to kickstart demand locally for green hydrogen offtake in applications such as municipal bus transportation, hydrogen blending in natural gas for power generation, and some select heavy-duty trucking routes. The Draft Strategy plans to start small to scale big, with initial pilot projects in industrial applications that can enable orders of magnitude expansion over time.
- **Facilitate low-cost supply.** As a nascent sector, green hydrogen will require strategic support to reach price predictability and cost-competitiveness with incumbent fuels and feedstocks. While private sector investment is expected to drive green hydrogen production in Jordan, government support is needed to accelerate the development of the sector and resolve remaining barriers, particularly around regulation, land and water availability, and

[i] PtX refers to any of several processes by which renewable power and chemical feedstocks, such as electrolytic hydrogen or captured carbon, are converted into other products or fuels. Examples include Power-to-gas, to produce synthetic methane; or Power-to-liquid, to produce liquid fuels like kerosene.

infrastructure. Incentives developed in accordance with Jordan's Investment Environment Law can help drive financing and support the sector in the short-term.

- **Leverage existing leadership in renewable energy.** Jordan has historically been a regional leader in renewable energy deployment, although technical hurdles challenge further rapid integration of renewable resources onto the grid. Fostering continued growth of renewable power generation will also support green hydrogen production at scale in Jordan, and green hydrogen production will help support the integration of higher shares of renewable power on the grid through balancing and storage.
- **Strengthen the enabling environment.** As a nascent industry, green hydrogen in Jordan will require updated (or, in some cases, new) regulations and health and safety standards in line with evolving international standards. A strong governance structure and skilled workforce capable of building, operating, and maintaining new infrastructure will also be crucial. Conducting education and public campaigns on the benefits of hydrogen throughout Jordan must also be implemented to raise awareness of the new industry. Ensuring the safe operation and regulation of green hydrogen and PtX products and infrastructure can enable social license to operate and accelerate foreign direct investment to rapidly scale the industry.

Executing these priorities is expected to drive the initial uptake of green hydrogen for targeted domestic use and modest export in the short-term in Jordan, with orders of magnitude expansion over time. However, a variety of factors can influence the timing or feasibility of uptake or supply for different sectors, leading to different outcomes or scenarios for the future. Three possible scenarios were assessed (Conservative, Base, and Optimistic), resulting in distinct outlooks (more information on these scenarios can be found in Appendix A). However, the potential for green hydrogen in Jordan remained compelling across all three scenarios, underscoring the importance of supporting the sector. The Base Scenario, which is informed by economics and reasonable technical assumptions, provides the basis for this Draft Strategy.

In the Base Scenario, early action towards export and domestic use, even on a small scale, will likely pay significant future dividends in the form of demonstrated demand and commercial relationships. Pathways to reducing demand in key domestic sectors, while also supplying demand for green hydrogen and "Power-to-X" (PtX) products internationally, present a potential opportunity for **591,000 metric tonnes (MT) per year of green hydrogen production by 2030, 1.5 million metric tonnes (MMT) by 2040, and 3.4 MMT by 2050**, including up to 2.3 MMT of exports in the form of green ammonia in the Base Scenario (Figure 1). While the investment required is significant— at least $175 billion in capital expenditure (CAPEX)—the benefits to Jordan's economy are manifold, including the creation of over **65,000 jobs** and the possibility of avoiding up to **8.2 MMT per year** of CO_2e by 2050. Satisfying a growing portion of energy demand with domestically produced green hydrogen can also reduce costly energy imports, improve energy security, and enhance export competitiveness in meeting the increasing global demand for low-carbon products.

Figure 1: Export potential and domestic hydrogen uptake by sector under the base scenario

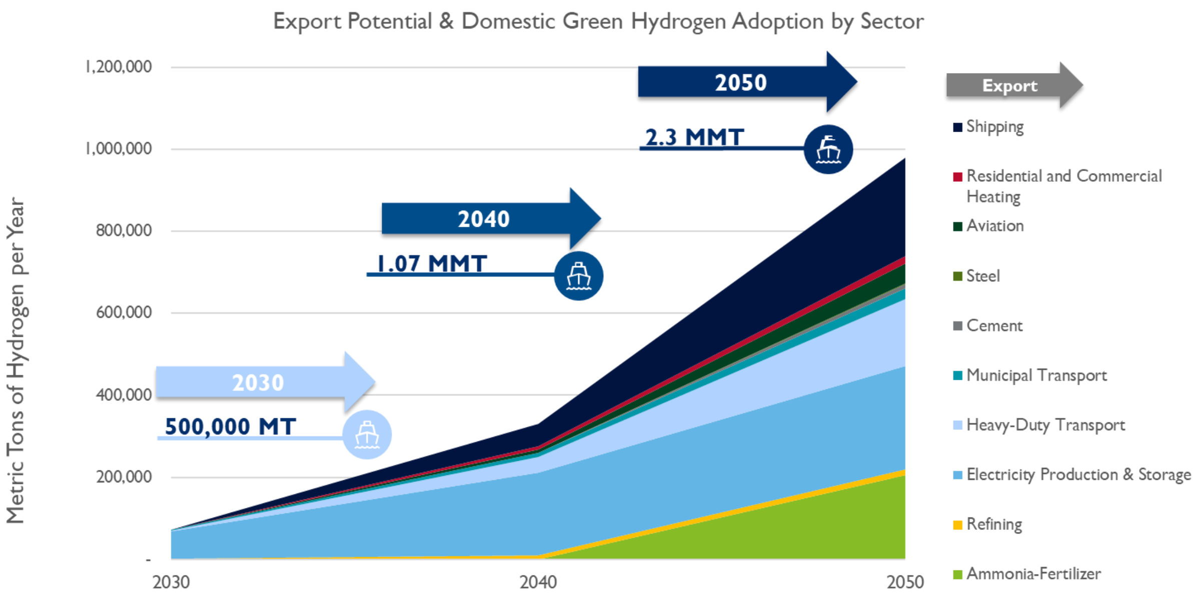
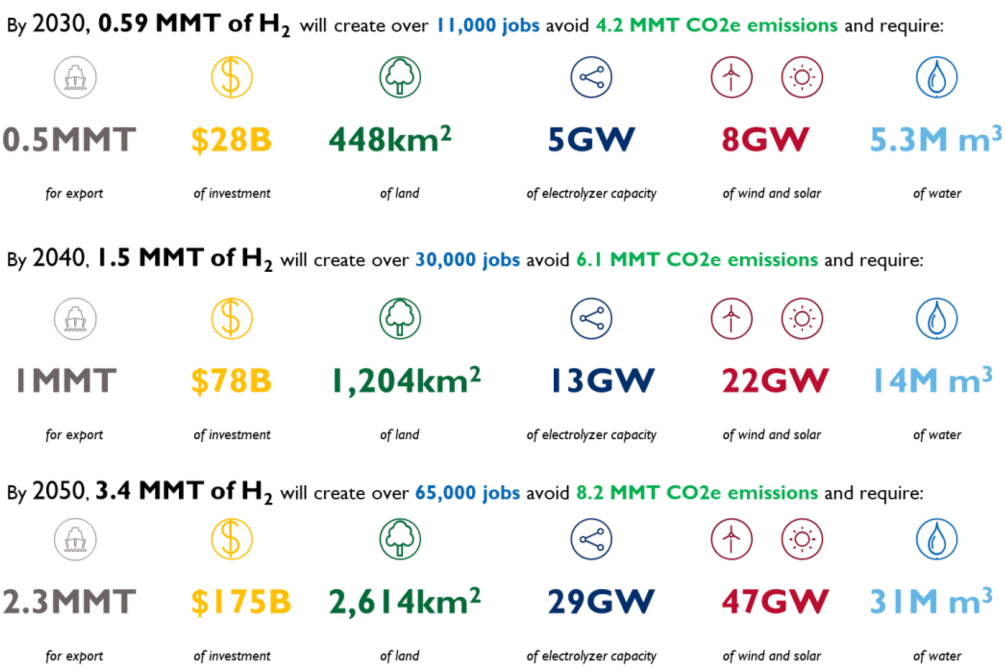


Figure 2: Jordan's green hydrogen potential, requirements, and benefits under the base scenario



While other forms of "clean" hydrogen (such as the application of carbon capture technology to today's primarily natural gas-derived hydrogen production, producing "blue hydrogen") are expected to play a role in the global hydrogen market, this Strategy focuses specifically on green hydrogen. Green hydrogen is produced through electrolysis, a process that splits water into hydrogen and oxygen using electricity powered by renewable sources. As a net importer of fossil fuel resources, fossil-based hydrogen with carbon capture is unlikely to be economical for Jordan in large quantities. On the other hand, Jordan's significant low-cost renewable energy potential makes it an attractive location for green hydrogen production.

Developed with the support of the United States Agency for International Development (USAID) Jordan Energy Sector Strengthening Activity (hereafter, "USAID Jordan ESSA"), this Draft Strategy builds on analysis performed in three previous studies conducted for the Ministry of Energy and Mineral Resources of Jordan (MEMR) with support from Gesellschaft für Internationale Zusammenarbeit (GIZ) that set a foundation for understanding green hydrogen's potential for the Kingdom. Those studies are:

- "Study on energy system impacts and business potential of hydrogen production in Jordan," Tractebel Engineering GmbH, Engie Impact GmbH (April 2022)
- "Report WP II: Needs assessment policy and strategic framework in Jordan," GFA Consulting Group (October 2022)
- "Report WP III: Regulatory policy roadmap," GFA Consulting Group (October 2022)

The Draft Strategy includes feedback from public and private stakeholders who were consulted at various points throughout the process, including through individual interviews and multiple workshops. However, continued engagement, feedback, and refinement of the Strategy will be required moving forward as market dynamics shift, policies are implemented, and feasibility studies are conducted that may influence the conclusions reached in this document. Based on the final recommendations of the Green Hydrogen Strategy, some of the integral parts of Jordan's National Energy Sector Strategy will need to be adjusted by MEMR. Among others, these may include renewable energy targets and enablers, in addition to other cross-sectoral factors.

This document begins with an overview of the benefits of green hydrogen and the role that the Kingdom of Jordan can play in the global hydrogen economy. It then identifies current and future uses of hydrogen within Jordan, focusing in particular on the specific applications for which hydrogen is most suitable, including for export. It then assesses the current supply landscape and the best approach to generating sufficient supply to cover the economically valuable use cases, considering the barriers to development that the Kingdom faces. These considerations inform concrete strategic, operational, and tactical plans and visions for a sustainable, robust, and value-driven hydrogen economy in Jordan.

Finally, this document concludes a set of recommendations on opportunities for continued collaboration and coordination to facilitate these actions, as well as immediate next steps following the finalization of this Strategy, including:

- Incorporate the recommendations presented in the Draft Green Hydrogen Strategy into Jordan's updated National Energy Sector Strategy
- Incorporate the Strategy's action plan into Jordan's Economic Vision, with special focus on the latter's short-term initiatives for the energy sector
- Update the National Green Hydrogen Strategy's key findings on a regular basis as domestic and international market conditions and technologies evolve
- Establish a senior cross-ministerial steering committee for green hydrogen in Jordan, to be chaired by MEMR
- Work with EMRC to identify and address regulatory requirements based on the findings of the Strategy
- MEMR to lead efforts to designate Aqaba as a Green Hydrogen Hub and help ADC and ASEZA establish necessary conditions for development
- Create a unit within MEMR responsible for guiding green hydrogen initiatives, leading investor engagements, developing and maintaining critical data, identifying capacity-building areas, and conducting further studies, etc.

- MEMR to sign Memoranda of Understanding (MOUs) with interested investors to support pre-feasibility studies and exploration to vet potential projects
- MEMR to maintain a pipeline of hydrogen investments by screening and prioritizing potential projects, with the prospect of carrying out that process jointly with the Ministry of Investments and other members of the senior steering committee. The value of the pipeline should be based on the strategy goals, and the selection process should refer to "to-be established" criteria (CBA, minimum capital thresholds, etc.) to assess feasibility. Proceeding to framework and/or investment agreements should hinge on meeting the criteria and should also be done in line with the MoU process.
- Work with USAID to channel donor support towards follow-up activities to complement the strategy and/ or implement the action plan

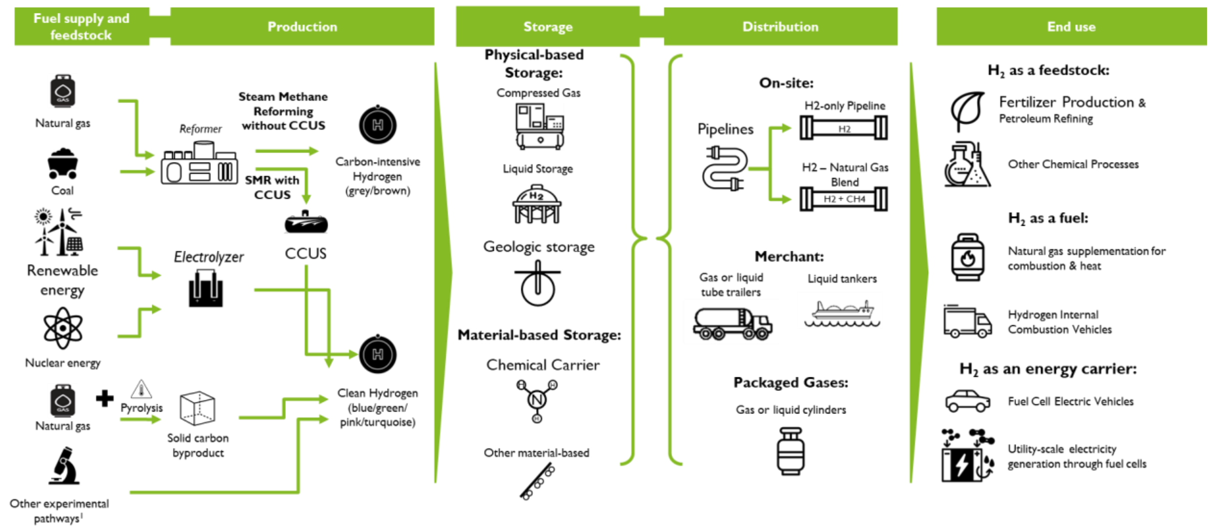
This is the first step in the establishment of a new industry for Jordan. By building on and continuously improving the planned course laid out by this Draft Strategy, Jordan has an opportunity to develop an internationally competitive and sustainable green hydrogen economy that supports the Kingdom's economic and environmental goals and strengthens its position as a regional clean energy hub. The production, utilization, and export of green hydrogen build on Jordan's existing resource endowment, stock of intangible capital, and geographic position to drive lasting benefits for the Jordanian people.

INTRODUCTION: HYDROGEN'S ROLE IN THE GLOBAL ENERGY TRANSITION. JORDAN'S DECARBONIZATION GOALS AND THE ROLE HYDROGEN CAN PLAY

Globally, hydrogen has received growing attention as a valuable tool in broad decarbonization efforts, especially for tackling hard-to-abate sectors such as chemicals, steel, and heavy transport. Leaders have named hydrogen a specific priority and acknowledged the central role of policy and regulation in speeding the development of a clean hydrogen economy.[1]

Today, hydrogen is typically produced from hydrocarbons, which results in roughly 11 kilograms of CO_2 emissions per kilogram of hydrogen produced.[2] Alternatively, there are several ways to produce clean hydrogen (also referred to as "low-carbon" or "zero-emissions" hydrogen). However, it is made, the use of hydrogen does not produce additional emissions, only water vapor and a small amount of nitrogen oxides. The different hydrogen production technologies, often distinguished by different "colors" of hydrogen, are outlined in Figure 3.

Figure 3: Hydrogen color spectrum and value chain

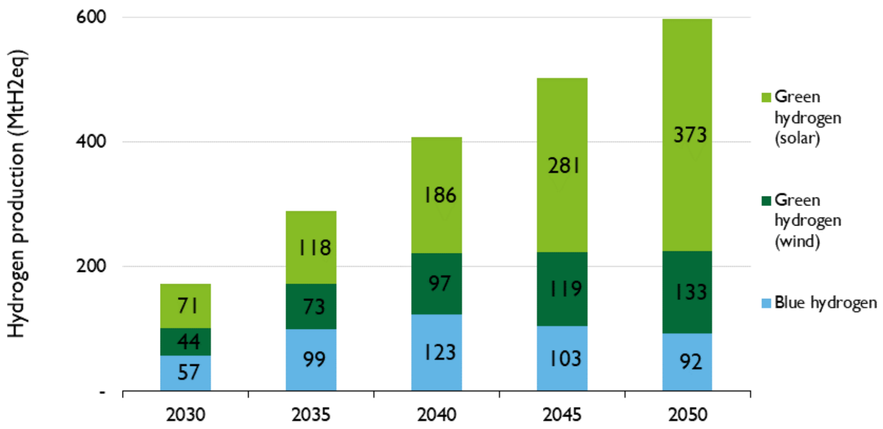


Notes: 1. Other experimental pathways include chemical water splitting, microbial metabolism, high temperature electrolysis

Global hydrogen supply in 2021 stood at approximately 90 MMT, of which approximately 99 percent is grey. Current uses of hydrogen encompass ammonia and methanol production within the chemical sector (37 percent and 15 percent of global hydrogen use, respectively) and as a reactive hydrogenation agent in refining (42 percent). The remainder (approximately 6 percent) is used as a hydrogenating agent for food and pharmaceutical production and as a chemical feedstock or reactive catalyst for other industrial processes.[3]

The future market for clean hydrogen is expected to continue growing as production costs fall, a result of investments, planned projects, increased government support, geopolitical energy concerns, and technology advancements. Including derivatives, demand for hydrogen is forecasted to increase from around 90 MMT today to around 600 MMT by 2050 for the world to be on track to reach net-zero emissions by 2050, as shown in Figure 4.[4] Clean hydrogen production currently accounts for less than 1 percent of hydrogen production globally but is projected to make up a significant share in the future (>99 percent in a Net Zero Emissions Scenario).[5]

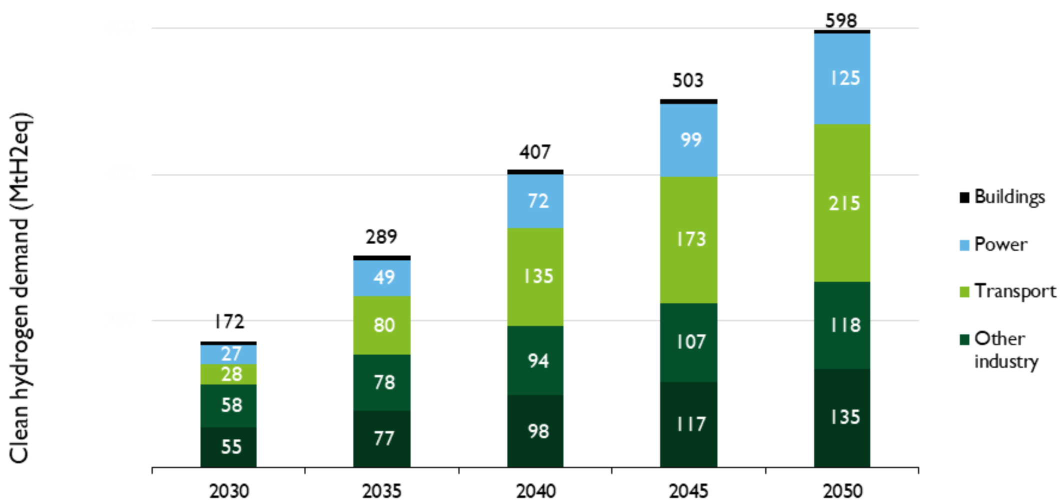
Figure 4: Hydrogen demand forecast under IEA's net zero emissions by 2050 scenario (NZE) [6]



In recent years, investment in clean hydrogen has accelerated rapidly. As of August 2022, an estimated 600 clean hydrogen projects had been announced worldwide, totaling 53 metric tonnes per annum (mtpa) of production capacity, including nearly 44 mtpa of green hydrogen.[7] This includes approximately 89 projects accounting for at least 4.6 mtpa of green hydrogen in the MENA region. Recently, announced project capacity in the MENA region has exceeded 5.3 mtpa (more than 15 percent growth in just a few months)[8], with the first project reaching final investment decision (FID) and beginning construction in NEOM, Saudi Arabia.[9]

As clean hydrogen production scales, its use is expected to expand to include new and additional applications in downstream industries, displacing incumbent fossil fuel or feedstock use in sectors that are difficult to decarbonize through electrification or other approaches (see Figure 5). As a result, sectors including steel, cement, chemicals, heavy-duty transportation, power generation, and synthetic fuel production are expected to become priority markets for clean hydrogen worldwide in the coming decades. Through use in these and other applications, hydrogen is projected to make up about 10 percent of total energy consumption by 2050.[10, 11]

Figure 5: Global clean hydrogen demand forecast by sector



Green hydrogen is expected to drive emissions reductions in these sectors in Jordan as well, by serving as a sustainable fuel or feedstock substitute to help reach national decarbonization goals.

Climate action in the Hashemite Kingdom of Jordan: How hydrogen fits in

Jordan's GHG emissions are estimated at 31.06 million tonnes of CO_2 equivalent, according to the 2016 GHG National Inventory.[12] The energy sector (including transportation) is by far the largest contributor to emissions, accounting for about 76 percent of total emissions, driven primarily by the combustion of fossil fuels.[13] Industrial process emissions, which result from manufacturing, conversion, and mining activities, produced 10 percent of the total (3.18 MMT CO_2e). Jordan's transition plans are expected to improve this figure, for instance, by reducing dependence on imported fossil resources.[14]

At 2.3 tonnes of CO_2 per capita, Jordan ranks 133rd in the world in CO_2 emissions per capita. Although this only accounts for an estimated 0.06 percent of global emissions, the Kingdom has nevertheless pledged to cut its greenhouse gas (GHG) emissions by 31 percent (including 1.5 percent unconditionally, with an additional 12.5 percent reduction dependent upon availability of international financial assistance) by 2030 in line with its updated NDC, submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in October 2021.[15]

Jordan's NDC Action Plan sets objectives to transition to a low-carbon and climate-resilient economy by increasing the share of renewable energy (RE) in its grid and upscaling energy efficiency measures, strengthening resilience and adaptation to climate change in the water and agricultural sectors, and mainstreaming climate change in local and regional development planning.

Additionally, Jordan's National Energy Sector Strategy 2020–2030 is largely aimed at reducing import reliance and increasing self-sufficiency through the use of domestic natural and renewable resources. Currently under revision to reflect heightened sustainability goals, the 2030 target for RE as a share of electricity generation is expected to rise from 29 percent to 50 percent.[16] Strategic priorities for energy sector planning are also expected to include:

- Electricity: Moving towards a greener power sector through increased penetration of renewable sources, demand-side management, and energy efficiency
- E-mobility: Promoting the use of electric vehicles. This can include both battery electric vehicles (BEV) and fuel-cell electric vehicles (FCEV)
- Hydrocarbons: Verifying and exploring new reserves and downstream industry opportunities while shifting toward clean energy (green hydrogen, biofuels)
- Energy Efficiency: Enabling incentives for efficient energy consumption
- Natural Gas: Establishing a gas network to supply industrial clusters with their needs
- Upgrade energy infrastructure: Developing infrastructure, including:
  - Smart power grid and metering
  - Storage technologies
  - Inter-regional electrical transmission connectivity to efficiently serve Jordan's needs and initiate exports to the region
  - Pipelines for transmission and distribution of natural gas

This Green Hydrogen Strategy is aligned with national policies and strategies, particularly the National Climate Change Policy, NDC Action Plan, and the National Green Growth Plan for Jordan, which focus on mitigation, adaptation, and cross-cutting sectors. Hydrogen has a key role to play in climate mitigation, therefore integrating hydrogen into existing strategic plans will be crucial to realizing its environmental and economic benefits.

In particular, green hydrogen has the potential to avoid a cumulative total of up to 8.2 mtpa of CO_2e emissions by 2050 across the main sectors where hydrogen is expected to be utilized in Jordan, namely ammonia for fertilizer production, transport (heavy duty and municipal transport), power generation, refining, cement and steel production, aviation, shipping, and residential and commercial heating. Figure 6 illustrates the indicative use of hydrogen in each sector and the resulting estimated emissions reductions.

Figure 6: Summary of domestic hydrogen applications and expected CO_2 emissions avoided

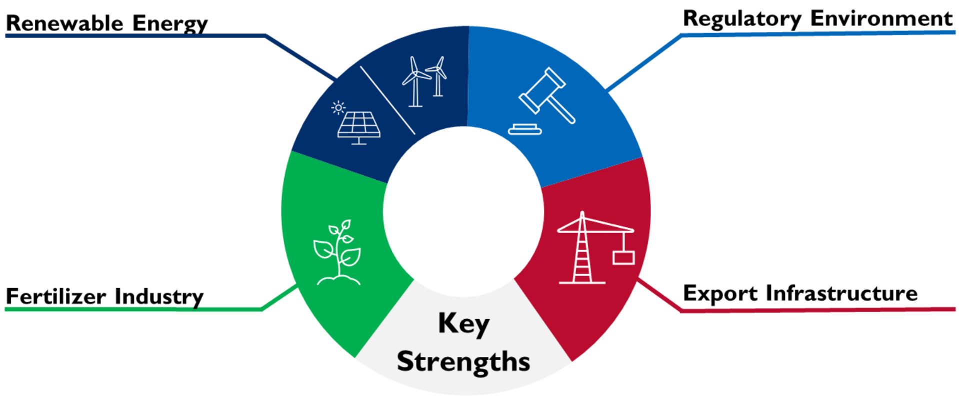
	Avoidable Emissions (MT CO2e)		
	2030	***2040***	***2050***
Ammonia for Fertilizer	N/A	N/A	N/A
Transport (Heavy Duty & Municipal)	43,195	431,388	1.6M
Power Generation	4.1M	4.1M	1.6M
Refining	10,874	81,020	123,662
Cement & Steel	N/A	1,977	163,736
Aviation	N/A	1,073	7,450
Shipping	69,277	967,165	2.2M
Residential/ Commercial Heating	69,277	967,165	2.3M
Total	4.2M	6.1M	8.2M

The substitution of hydrogen will drive other environmental benefits as well, for example, by reducing particulate matter and other emissions (beyond carbon) resulting from the burning of fossil fuels, improving air quality, particularly in densely populated areas and near industrial facilities. Green hydrogen is therefore an important solution that supports Jordan's environmental and economic goals and is closely tied to other strategies guiding the Kingdom's decarbonization efforts.

Green hydrogen production: Building on Jordan's strengths

Jordan has many advantages that underpin the Kingdom's vision to become a regional epicenter for green hydrogen as shown in Figure 7. The maturity of the renewable energy (RE) market, along with Jordan's existing fertilizer manufacturing industry, also provides a strong basis for the expansion of the PtX value chain for green hydrogen and ammonia production, while legacy infrastructure and a supportive regulatory environment can support the growth of the sector.

Figure 7: Jordan's key strengths for green hydrogen



Renewable Energy

Green hydrogen production potential is closely linked to renewable energy potential. Up to 40 percent of the cost of green hydrogen production can be for electricity alone. Similar to other countries in the MENA region, Jordan has strong onshore wind and solar resources, including some of the highest solar irradiation levels in the world. The abundance of low-cost wind and solar resources can drive lower green hydrogen production costs relative to other countries with more limited potential. At an estimated $3.20/kg by 2030, Jordan's levelized cost of hydrogen (LCOH) is much lower than forecasted costs in key export markets, for example, in Central Europe, where green hydrogen is expected to cost $5-6/kg to produce.

Over the past decade, Jordan has made significant progress in promoting the increased utilization of its domestic renewable energy potential, becoming an early leader in the region for wind and solar as a share of power generation.[17] Starting at less than 1 percent in 2014,[18] renewable energy accounted for 29 percent of electricity generation in 2022, causing the Kingdom to elevate its target of from 30 percent to 50 shares of renewables by 2050.[19, 20] This strong track record has laid the groundwork for robust production of green hydrogen, for which green electrons are a crucial input.

Fertilizer Production

Jordan's existing production and export of nitrogen-based fertilizers represents another strength within the PtX value chain. Ammonia (NH_3) is a primary input in fertilizers and is synthesized using hydrogen. Currently, Jordan imports all ammonia for this purpose, which is produced using GHG-emitting grey hydrogen. Despite relying on imported feedstock, Jordan's value chain for finished, soil-ready fertilizer products is a point of strength. Through domestically produced green ammonia, green hydrogen could allow Jordan to expand on existing valuable industries while decarbonizing the agricultural sector by switching to domestically produced green ammonia. This could simultaneously increase energy and food security, as well as open up the possibility for valuable green ammonia exports.

Export Capabilities

The Port of Aqaba, with access to the Red Sea, hosts Jordan's main ammonia terminal for international trade. As the Middle East's only certified "Eco Port," the Port of Aqaba has a strong track record as a trusted and safe handler of liquid fuels and chemicals. Although some retrofitting and expansion will be required to prepare the port for export, existing infrastructure presents a potential pathway to lower capital expenditure and faster time to market for potential investors looking to export green ammonia to key demand markets in Europe and Asia. This advantage, coupled with the proximity to local demand sources for hydrogen (e.g., for the fertilizer industry, heavy-duty transport, port logistics vehicles, municipal transport, and some power generation), provide varied sources of demand, reinforcing supply stability and further building the case for producing green hydrogen in Aqaba.

Regulatory

Additionally, Jordan's political, regulatory, and investment environment are conducive to attracting and supporting foreign investment in the green hydrogen industry. Clear decarbonization targets and goals from the highest levels of government, coupled with a track record of stability, generate confidence from investors and reduce the cost of capital. Supportive policy incentives tied to Jordan's Investment Environment Law and regulations further support market stability. The conditions that helped to enable the rapid build-out of the renewable energy sector demonstrates the promise that Jordan could bring together key stakeholders to implement similar measures for green hydrogen development.

With these advantages, Jordan is well-positioned to incorporate hydrogen as a part of its energy transition efforts and support a new source of economic value. The coming sections will discuss in more detail how hydrogen can be produced and utilized in the Kingdom to unlock these wide-reaching benefits.

GREEN HYDROGEN USE CASES IN JORDAN

While green hydrogen can play an important role in Jordan's overall decarbonization ambitions for 2050, the initial drivers of green hydrogen development in the country will be oriented around more competitive export opportunities (discussed in the next section). However, to better understand drivers of domestic demand, each sector's current hydrogen use, future demand, and potential for substituting green hydrogen are important to consider.

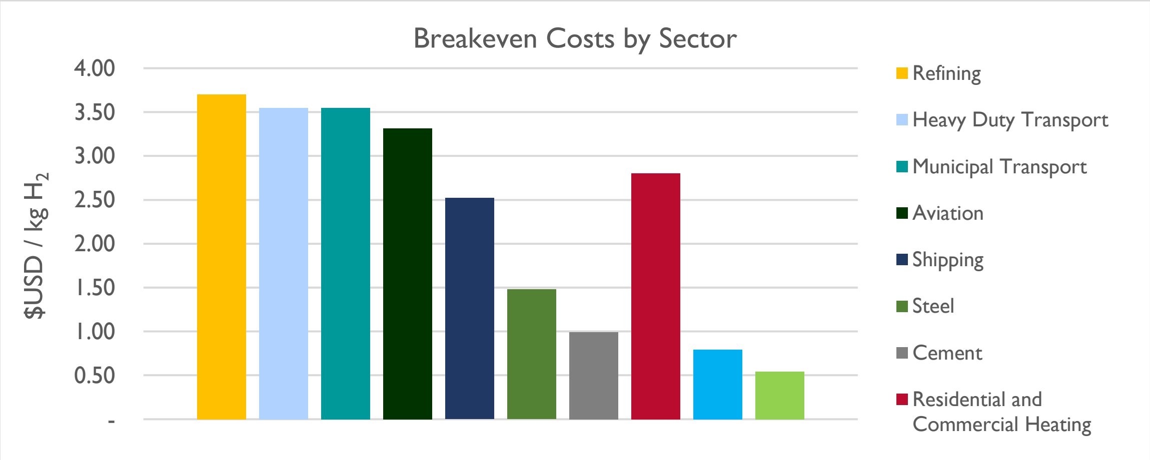
Short-term drivers of domestic demand are expected to originate from the refining sector (assuming business-as-usual operations in the Base Scenario), with additional strategic pilot projects driving initial uptake in limited heavy-duty trucking routes, municipal urban bus networks, port-logistics vehicles, and hydrogen blending in natural gas for power generation. These initial drivers could later be followed by industrial sector applications that can enable orders of magnitude expansion over time as well as for ammonia-fertilizer production domestically, as the cost of production decreases and becomes competitive with incumbent fuels / feedstocks.

Volumes were determined based on demand forecasting in the Base Scenario – for more information on other possible scenarios, see the Appendix.

Sector breakeven points inform timeline for uptake

Domestic uptake of green hydrogen is expected to be driven primarily by economics and companies' willingness to decarbonize. Absent a price on carbon, uptake for domestic use is expected to occur when the cost of green hydrogen production reaches a comparable point to today's delivered price of the incumbent fuel or feedstock that it would be replacing. Assessing the different "breakeven points" (as shown in Figure 8) for when it will become cost-effective for domestic sectors to transition to green hydrogen illustrates when uptake is likely to occur in the short-, medium-, and long-term.

Figure 8: Breakeven costs based on current prices influence anticipated green hydrogen demand



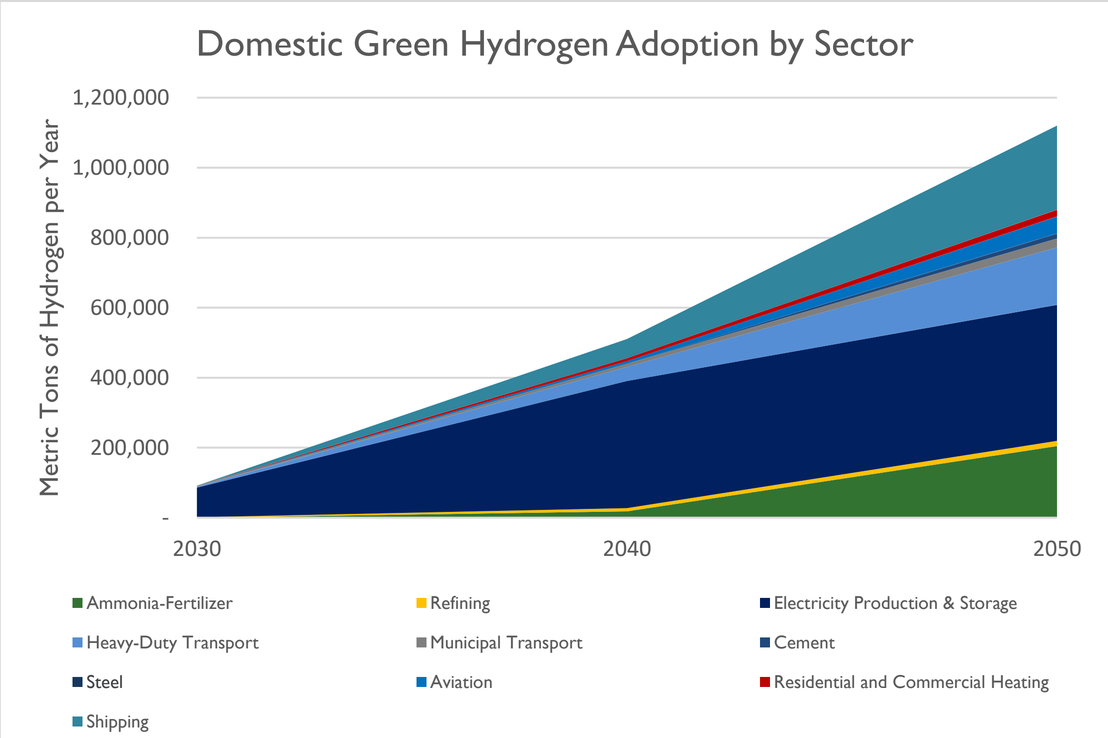
Jordan's refining sector is positioned to first see cost-effective use of green hydrogen due to the one-to-one replacement for grey hydrogen, which is currently costly to produce. The "drop-in" potential for green hydrogen in refining means that little to no switching costs are required. Given the relatively high price of fuel in Jordan, the transport sector (heavy-duty trucking and municipal transport) is expected to break even next at roughly $3.50/kg of green hydrogen, which is very close to today's expected LCOH. Switching costs, which include the cost of new vehicle fleets, fueling stations, and infrastructure, are not considered within this breakeven price but add additional costs that will delay uptake in this sector.

Shipping and aviation fuels are also relatively expensive in Jordan today (at $22 and $29 per mmbtu, respectively), resulting in a higher breakeven price for green hydrogen at between $2.50 and $3.25 per kilogram. However, conversion costs to turn green hydrogen into usable fuels (e.g., SAF or methanol) plus additional switching costs are likely to delay uptake in these sectors. Similarly, residential, and commercial heating fuels, are also relatively expensive in Jordan. Natural gas use is expected to expand in this sector, but limitations in Jordan's gas distribution network prompt the use of liquid petroleum gas (LPG) in most cases, which is distributed and stored in tanks. Despite the relatively high breakeven price, hydrogen is unlikely to be used for heating purposes outside of industrial high-heat applications until after 2040.

Industrial sectors like cement, steel, and thermal power generation have lower breakeven prices given the use of relatively cheap and abundant fuels (e.g., natural gas, coke) at high volumes. This is especially true for the cement sector, which can use a significant amount of waste product in its fuel mix. Though a source of current hydrogen demand today, ammonia for fertilizer production has the lowest breakeven price among the sectors assessed. Today, Jordan imports grey ammonia for fertilizer production at a very low-cost ($4.69/mmbtu), produces nitrogen-based fertilizers, and then exports those fertilizers abroad (primarily to India). For this use case, ammonia for fertilizer production and export is treated separately from the export use case for domestically produced green ammonia, which is aimed at export to markets in Europe and Asia where demand for green products is expected to drive a much higher breakeven price. For domestic ammonia production to be cost-effective as an input to the current fertilizer export industry, Jordan's green hydrogen production will need to reach a low enough cost to compete with today's import of grey ammonia, which includes the cost to convert green hydrogen (roughly 18% of ammonia by mass) to ammonia.

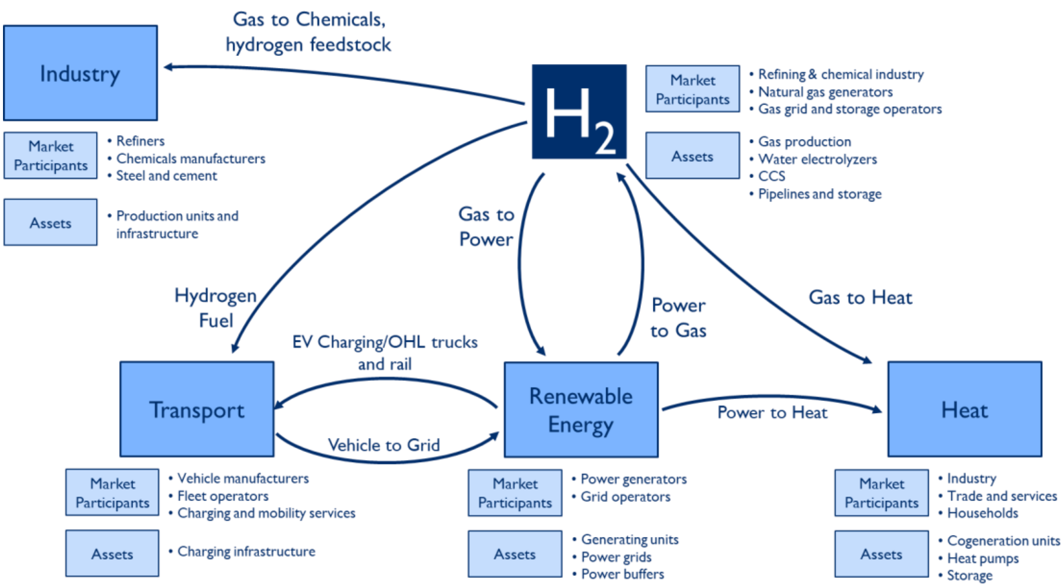
Domestic applications for hydrogen can represent a significant source of demand for green hydrogen in Jordan in the short-, medium-, and long-term. This demand breakdown by sector is shown in Figure 9, starting in 2030 with projections up to 2050. In total, Jordan's domestic green hydrogen demand is expected to surpass 91,000 tpa by 2030, reach 510,000 tpa by 2040, and exceed 1.1 mtpa by 2050 in the Base Scenario.

Figure 9: Domestic green hydrogen adoption by sector in the Base Scenario



Focusing on some of these initial sectors in the short-term could help spearhead a fully developed hydrogen ecosystem in Jordan. This will enable connections between several important economic sectors, including industry, transportation, and power generation, as shown in Figure 10. Further, it could provide the opportunity for the uptake of green hydrogen within more sectors in the medium- and long-term, such as shipping, aviation, steel, cement, and ammonia-fertilizer.

Figure 10: Potential of green hydrogen to converge ecosystems



For each of these sectors, current technology and market factors will likely influence uptake and total demand potential over time. The factors contributing to this forecast are described for each use case below.

Refining

Oil refining is the process of separating and chemically modifying crude oil to produce more useful products, including fuels and other chemicals. Hydrogen is used in several refining processes, including desulfurization, which reduces harmful emissions of produced fuels.

Jordan's only refinery, operated in Zarqa by Jordan Petroleum Refinery Company (JPRC), refines around 36,000 barrels per day, which requires about 14,600 MT of hydrogen per year (24 percent of current hydrogen demand in Jordan).[21] JPRC's current refining processes produce hydrogen from naphtha. This hydrogen is then used for hydrocracking heavy-fuel oil or for desulfurization of naphtha for other refining processes.

As demand for cleaner products grows, the refinery at Zarqa could represent a consistent, centralized source of demand for green hydrogen in the near-term. Refining demand may also form the basis of a broader demand cluster in areas like heavy-duty transport or power generation in the Zarqa / Amman area. In the interim, if investments in enabling infrastructure are made and government action is taken, green hydrogen demand for refining could begin as early as 2029 and reach up to 14,600 tpa at current refining levels. Current plans call for the potential expansion of the Zarqa refinery, resulting in double the capacity and requiring up to 29,200 tpa of hydrogen. However, the refinery faces increased competition from refined products imported from abroad, putting the future of the plant into question. As a result of this uncertainty, this Strategy focuses on the refinery use case assuming that operations continue under a business-as-usual scenario.

Heavy-duty Transport

Hydrogen can also be used as a fuel for a variety of vehicles, either combusted directly in an internal combustion engine (ICE) or within a fuel cell. The electrochemical process required produces only water vapor as exhaust. Many models of fuel cell electric vehicles (FCEVs) of various sizes are currently available and competing with battery electric vehicles (BEVs) in certain applications. Many heavy-duty vehicles often have to travel long distances, which requires larger batteries and poses obstacles related to weight and longer charging times, supporting the use of FCEVs as a potential solution. Heavy-duty vehicles, for example trucks or logistics vehicles, often make predictable stops at centralized locations, such as warehouses and truck depots. This means that large numbers of vehicles can be fueled with relatively little infrastructure. Refueling an FCEV takes roughly the same amount of time as fueling traditional vehicles, avoiding long down times needed to charge BEVs. Together, these considerations make the business case for heavy-duty FCEVs, particularly within the heavy-duty trucking sector, more promising.

One potential pilot use case for Jordan involves the large truck fleets used in transporting phosphate from mining locations to the Port of Aqaba for processing and export. Routes are between 200km and 370km, and available models of heavy FCEVs have a range of 400km. With this, refueling stations would be needed at the port, which is already identified as an area for hydrogen production and use, as well as at mining sites (which would require developing and siting on-site RE generation assets, electrolyzers, and storage). If this use route, estimated at roughly 350 tpa, proves effective, other routes and use cases can be identified, developed, and scaled in Jordan.[22]

Additionally, container-handling vehicles in ports, as well as forklifts, can be effectively transitioned to run on hydrogen. In fact, the use of hydrogen-powered forklifts (particularly in enclosed warehouse spaces, where the lack of particulate emissions is a clear health and safety benefit) are already widely used and economical in many places around the world. In a similar way to municipal transport applications, these types of vehicles involve long-duty cycles in a small geographic area, reducing the need for fueling infrastructure. Hydrogen fueling also lends itself to a better combination of space usage and refueling times compared to BEV solutions. Material handling vehicles, including reach stackers, empty container handlers, and terminal trucks in use at the Port of Aqaba, may be an easier case for hydrogen power, especially if Aqaba is developed as a hydrogen hub and could provide fueling sources close by.[23] This technology is relatively mature internationally, and pilots are already underway for some of these more heavy-duty transport use cases. Overall, heavy-duty road transport could see green hydrogen demand as early as 2029 and is expected to account for nearly 3,000 tpa of demand by 2030, nearly 40,000 tpa by 2040, and over 164,000 tpa by 2050.

Municipal Transport

Municipal transport systems, like heavy-duty road transportation, employ centralized depots from which many vehicles (in this case, buses) are serviced and fueled, reducing overall infrastructure burdens. FCEV buses are currently available and operating in several municipal transport systems, making this sector a more promising option for hydrogen in the short-term.

Jordan's Long-Term National Transport Strategy (LTNS) already involves plans to implement bus rapid-transit (BRT) systems as part of a push to increase the use of public transit. Incorporating hydrogen strategies into existing plans can leverage the work already done to realize quick wins, especially in cases such as hydrogen-powered buses, that have been demonstrated in other countries.[24]

Pilot projects (of small hydrogen-powered bus fleets) systems could take place in Amman and Zarqa or Aqaba, at as little as 300 tpa of hydrogen from dedicated or centralized electrolysis production facilities to fuel an initial fleet of 50 buses. Opportunities to provide hydrogen to multiple end users can help expand use and reduce costs.[25] Given this context, green hydrogen uptake for municipal transport could begin as early as 2028, exceeding 2,000 tpa of demand by 2030, approximately 9,500 tpa by 2040, and over 25,500 tpa by 2050.

Power generation and energy storage

Hydrogen can be used as an energy carrier to generate power and also utilized to chemically store energy for long periods of time. Hydrogen can be burned in turbines similar to those used in present-day natural gas plants. Though pure hydrogen turbines have already been developed and tested internationally, capacity may be limited while supply chains ramp up. Hydrogen can also be used in fuel cells (in electrochemical rather than combustion reactions), which may soon be available at industrial scales.

Certain amounts of hydrogen may be blended into the natural gas supply to existing thermal power plants, depending on the specifications of each plant. Currently, around half of Jordan's generation capacity is from combined cycle gas turbines (CCGTs), which may be suitable for retrofitting to accept hydrogen, either as part of a natural gas blend or as pure hydrogen.[26] Blending rates vary by turbine model and age, necessitating individual assessment of each legacy generation assets to determine the maximum amount of hydrogen that can be feasibly co-combusted.[27, 28]

Jordan's updated National Energy Sector Strategy 2020-2030 ("Increased Sustainability" scenario) envisions a total of approximately 5.1GW of RE generation by 2030, roughly 56 percent of total power plant capacity, which would drive further emissions reduction in the power sector. However, this would require an anticipated 841 MW of installed storage capacity to handle increased intermittency and power balancing.[29] This is anticipated to be provided primarily by batteries, as hydrogen is comparatively less efficient in providing on-demand or short-term energy storage due to round-trip efficiency losses from converting and reconverting hydrogen from electricity.

Instead, hydrogen is more effective at storing energy over long periods of time, making it an attractive option for providing long-duration storage (i.e., longer than a few days). Such storage can be used to offset seasonal variability in demand: peak loads are highest in winter and summer; additionally, summer off-peak loads are higher than in any other season.[30] It is expected that seasonal energy storage will be needed after the level of variable renewable energy generation reaches 60 percent of total generation capacity.[31] After this point, up to 0.18GW of seasonal energy storage is expected to be required per GW of RE (18 percent).[32] A build-out of 19.4GW of RE by 2050 in Jordan would therefore require approximately 3.5GW of long-duration energy storage. Minus the planned 400MW pumped hydropower storage project, Jordan will need about 3GW of additional long-duration storage, which could be met by about 176,000 metric tonnes of hydrogen. In this way, hydrogen could be produced with excess variable renewable energy (VRE) generation in the spring and autumn months for storage, stored in purpose-built tanks or in geologic storage formations, and then used to generate electricity later in the summer and winter when electricity demand is higher.[33]

Exploiting the synergies between VRE and green hydrogen production could help leverage high-quality resources and significantly increase VRE deployment rates in Jordan. In addition to providing energy storage, electrolyzers can act as demand response units, dialing up or down in response to changes elsewhere in the grid (though the value of demand response must be weighed against the diminished electrolyzer capacity factor). Crucially, these valuable services depend not just on the presence of hydrogen production equipment but also on grids, storage solutions, and regulatory infrastructure to support the dynamic power balancing activities required. Overall, power generation and storage have the potential to drive strong demand for green hydrogen, beginning as early as

2028 and reaching nearly 85,000 MT of hydrogen demand per year by 2030, over 363,000 tpa by 2040, and nearly 390,000 tpa by 2050.

Residential and commercial heating

Hydrogen can be used for heating applications: when combusted, it produces a high-temperature flame and emits only water vapor. Hydrogen-capable boilers and heating equipment are already available or expected to be on the market soon. Driving wide uptake of hydrogen for residential and commercial heating applications may, however, be challenging, as the existing gas distribution grid in Jordan (e.g., for natural gas) is limited or absent in the residential and commercial sectors in Jordan.[34]

However, retrofitting gas grids, or blending hydrogen as an intermediate step, is often much cheaper than building large-scale net-new distribution systems. In the absence of existing infrastructure, solar heating, heat pumps, and other electro-technology may be more cost-effective at delivering the relatively low-temperature needs of most nonindustrial customers. In fact, Jordan's updated Nationally Determined Contributions plan for the UN calls for the installation of solar heating systems in 90,000 homes.[35] However, the feasibility of hydrogen for heating could increase based on higher penetration of natural gas (and potentially even dedicated hydrogen furnaces), resulting in potential demand for residential and commercial heating at around 550 tpa of hydrogen by 2030, nearly 8,000 tpa by 2040, and over 19,000 by 2050.

Shipping

Most maritime vessels themselves are too large to be directly electrified. However, it's possible to design specialized marine engines to run on liquid hydrogen or PtX fuels such as ammonia or methanol, which, if produced from green sources, could help to decarbonize maritime transport. This would require substantial expansion of clean fuel production and storage near Aqaba to service fleets entering and exiting the port.

According to the Jordan Shipping Association, an average of 1,892 ships per year have docked at the Aqaba industrial port from 2018-2022, including periods of relatively lower usage during the 2020-2022 COVID-19 pandemic.[36] This translates to an estimated 1.1 billion gallons of shipping fuel needed in 2022, currently supplied by bunkering facilities in the Red Sea region outside of Jordan. While some ships have traditionally bunkered in Aqaba in the past, several factors have influenced ships to switch to offshore bunkering facilities outside of Jordan, primarily arising from new restrictions on the sulfur content of fuels. The production of new, sustainable fuels and PtX derivatives for shipping fuel in Jordan may once again make bunkering possible in Aqaba for visiting fleets. Assuming that 20% of ships refuel in Jordan, and that at least half of global fleets transition to sustainable fuels like methanol and ammonia by 2050 as required to reach net zero, this could result in over 240,568 tpa of green hydrogen demand by 2050.

Due to infrastructure demands, retrofitting costs, and a relatively low breakeven price with traditional fossil-based shipping fuels, sustainable maritime fuel is likely to become viable in the medium- to long-term. Beginning in 2031, when the cost of green ammonia is expected to become competitive with traditional fuels (primarily diesel and/or fuel oil), demand for green hydrogen for sustainable shipping fuels could reach 55,000 tpa in 2040 and scale to 240,568 tpa by 2050.

Aviation

Jordan, a regional logistics hub with three main airports, has published a comprehensive Long-Term National Transport Strategy that establishes carbon reduction goals for the sector. As the majority of emissions in the aviation sector are a result of fuel use, this will require significant shifts to new, clean fuels such as sustainable aviation fuel (SAF) or, in some potential cases, liquid hydrogen fuels. While burning SAF does release carbon, it is carbon that is captured from the natural environment (e.g., not extracted in the form of fossil fuels), which is ultimately carbon neutral.

Similar to its application in shipping, hydrogen's low energy density by volume complicates its use as a pure gas in aviation applications. These require ample amounts of power with strictly limited space and weight requirements; tanks of the strength needed to contain highly compressed hydrogen are often both large and heavy. While this limits hydrogen's use as a gas or liquified fuel for long-haul flights, some shorter regional flights are possible, however, they are in very early stages of development.[37]

Perhaps more promisingly, hydrogen is an important feedstock to produce net-zero sustainable aviation fuel (SAF). SAF is chemically nearly identical to traditional aviation fuels but is manufactured instead of extracted from existing fossil fuels. A variety of methods exist, all requiring hydrogen to some degree. Hydro-processed esters and fatty acids (HEFA) fuels require hydrogen as a hydrogenating agent and use vegetable or animal fat as a feedstock. Another process, known as Power-to-Liquids, uses hydrogen combined with carbon captured from the atmosphere or point sources (such as industrial waste streams). These are combined to form kerosene and other hydrocarbons, which can be used by current aircraft powertrains without modification.

Global SAF production is currently very limited; specific locations, sectors, and routes that are most amenable to transition remain to be studied. However, SAF could be produced and utilized in Jordan, provided sufficient volumes of bio-based renewable feedstock and a steady supply of green hydrogen. SAF, being chemically identical to traditional aviation fuel, can be transported and stored in the same way, allowing it to take advantage of existing infrastructure.

One promising route is to produce SAF at a hydrogen hub at or near the Port of Aqaba and distribute it to domestic airports or export it to markets, for example, Europe, which has implemented SAF quotas.[38] Domestic green hydrogen usage for aviation is expected to become economical no earlier than 2035 and could potentially reach nearly 7,000 tpa by 2040, scaling to 48,000 tpa by 2050.

Ammonia for fertilizers

Hydrogen is an essential feedstock for the production of ammonia (NH_3), a key ingredient in chemical fertilizers. Hydrogen is combined with atmospheric nitrogen in the Haber-Bosch process. Most ammonia plants today currently also produce hydrogen with closely integrated SMR modules, presenting a challenge to incorporating green hydrogen into plant processes. These can be decarbonized with the addition of carbon capture units to produce blue hydrogen that reduces the emissions footprint of the ammonia and final fertilizer product. However, it is expected that green ammonia, sourced from green hydrogen, will become the more desirable and sustainable solution in global markets.

Jordan currently has a sizeable fertilizer production sector, producing 748,000 metric tonnes in 2019, mostly for export.[39] In fact, 76 percent of the total annual demand for grey hydrogen in Jordan today is for the fertilizer industry. This strong position in nitrogen-based fertilizer products can pave a potential path for the uptake of green hydrogen within the Kingdom.[40] These nitrogen-based fertilizers require a significant supply of ammonia each year, almost all of which is currently imported.[41] In 2022 alone, Jordan imported 248,145 tonnes of ammonia as a feedstock for fertilizer production.

Displacement of these imports with the domestic production of green ammonia would serve to increase supply security, improve the balance of payments, and create new jobs and sources of economic value for Jordan. However, the economics of producing green ammonia in Jordan from domestic green hydrogen depends on the delivered cost of green hydrogen (and therefore the production cost of green ammonia) versus existing grey ammonia. With ammonia not currently produced in Jordan today, the CAPEX required to construct new green ammonia plants will account for a sizeable share of the levelized cost of green ammonia production.

At today's prices, this results in a breakeven cost of $0.54/tonne of green hydrogen for ammonia production, which is well below current production costs. As costs fall over time, it is expected that domestic green hydrogen production could become cost-competitive with grey ammonia imports (irrespective of a carbon price or other incentive mechanism) by 2040. Notably, this use case is distinct from the production of green ammonia for export purposes (discussed separately in the next section), which already presents a compelling business case in the near-term given high demand and willingness to pay for green ammonia in key import markets such as Europe, Japan, and Korea.

Several factors could influence the timing of green ammonia uptake in the fertilizer industry, including the imposition of a carbon tax or price, an increase in demand for clean products that contributes to a price premium for green ammonia, and/or sharp increases in grey ammonia prices (tied to natural gas prices) as occurred in the wake of the Russian invasion of Ukraine. As demand for low-emissions fertilizers rises, a price premium for green products may develop that can outpace could help cover the additional CAPEX cost of new green ammonia facilities. Import market appetite to pay a green premium on fertilizers (or equivalent measures like carbon border adjustments) will be crucial in determining the economic competitiveness of domestic green ammonia production and export.

The production of green ammonia for use in maritime fuel (discussed above) or for export (discussed in the next section below) provide synergies that are expected to help accelerate the transition to green ammonia for fertilizer production and drive increased cost savings through economies of scale via large, GW-scale electrolyzer facilities.[42, 43] However, given the lower breakeven point and lack of existing domestic ammonia production, demand for green hydrogen for the purpose of producing green ammonia for the fertilizer industry is not expected to materialize until 2040, after which point demand would be expected to scale quickly to at least 204,000 tpa by 2050.

Steel and Cement

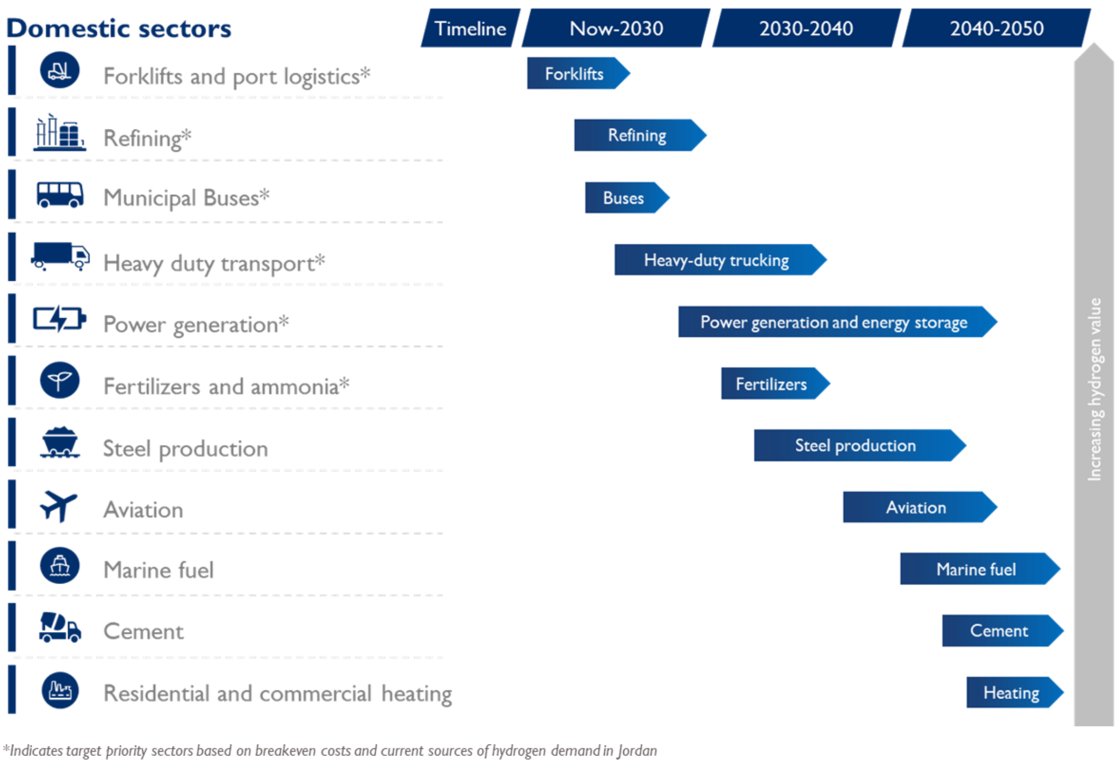
Hydrogen has been identified as a key solution for decarbonizing the steel and cement sectors, with stakeholders globally exploring fuel switching, recycled materials, and low-carbon power sources. Jordan's steel manufacturing predominately uses blast furnace-basic oxygen furnace (BF-BOF) as the dominant technology to produce scrap steel in relatively small amounts.[44] Globally, scrap steel accounts for about 3 percent of CO_2 emissions, with the Middle East comprising about 3 percent of production. As a more circular solution that emits significantly less CO_2 compared to steel production from iron ore, growth in demand for scrap steel is expected to accelerate globally.[45,46] Blending and/or switching to hydrogen as a substitute for coke and natural gas fueling the high heat needed for production can serve to further reduce emissions in this sector. Given limited production volumes in Jordan today and a relatively low breakeven price vs incumbent fuels, hydrogen demand for steel production is not expected to materialize until nearly 2040, reaching limited demand by 2050 of around 1,000 tpa.

In the cement industry, hydrogen has the potential to act as a source of high-temperature industrial heat. Modern cement plants require very high temperatures (more than 1200°C) in rotary kilns (where raw minerals are sintered into cement clinker) and relatively lower temperatures (more than 600°C) in precalciner equipment. These temperatures are out of reach for many other forms of low-carbon heat, such as heat pumps, but within the range of hydrogen, which burns at 2100°C. Physical and chemical differences between hydrogen and substitute flames will put a ceiling on uptake for cement; therefore, the scale of hydrogen integration into Jordan's domestic cement value chain is dependent on several factors and requires further study. Based on the current state, Jordan's cement sector could expect to see hydrogen demand closer to 2050, reaching nearly 14,000 tpa.

In sum: Domestic demand for green hydrogen in Jordan

Despite the varying domestic demand potential for green hydrogen within certain sectors in Jordan, green hydrogen is a key piece of the overall portfolio of clean energy technologies that can support Jordan's climate ambitions. By leveraging Jordan's current strengths, the Kingdom has the opportunity to develop a green hydrogen industry that can help reduce emissions from domestic industries while also strengthening energy security, creating more skilled jobs, and opening up opportunities for increased export and new sustainable products. The long-term scope for hydrogen usage is broad, and a fully developed economic and technological environment could support hydrogen utilization across various sectors over time, as shown in Figure 11.

Figure 11: Potential domestic uses for hydrogen over time



GREEN HYDROGEN FOR EXPORT

The global interest in clean hydrogen presents a major opportunity for Jordan to meet rapidly increasing demand for PtX products outside its borders. Limited domestic supply capability in key demand centers globally present an opportunity for countries with abundant, low-cost renewable energy resources to develop clean hydrogen supply infrastructure that can help to meet growing global demand. Key import markets in Europe and Asia, in particular, are expected to account for the majority of global hydrogen demand in the near-term. The EU expects its aggregate hydrogen demand to reach 20 MMT per year by 2030, of which it expects to import half from outside of the EU.[47] Additionally, Japan has set a target as part of its national hydrogen strategy to import 3 MMT of hydrogen per year by 2030, and Korea aims to consume 5.3 MMT by 2040.[48,49] Overall, hydrogen trade (in its various forms) is expected to account for 36 percent of global supply by 2050, or over 180 mtpa.[50]

These import volumes can be met by countries, like Jordan, with incumbent natural resource advantages (e.g., strong renewable energy potential) that enable a comparatively low-cost of production for hydrogen and who are able to rapidly scale infrastructure to supply green hydrogen and its derivatives. Proximity to these key markets (e.g., Europe and Asia), will help reduce the delivered cost of hydrogen, which includes transportation and conversion costs, to end customers to a point where imports may be competitive with other hydrogen supplied either domestically or by other exporters. Geography, existing trade infrastructure (both seaborne and via pipeline), and well-established diplomatic and trade relations are therefore also important advantages for Jordan to play a role in facilitating trade for hydrogen and PtX products.

When it comes to exporting green hydrogen, there are two potential use cases for Jordan:

1. Synthesizing green ammonia to transport via ship from the Port of Aqaba in the short-term *(included in the Strategy)*
2. Transporting hydrogen as a gas via pipeline in the medium- to long-term *(currently excluded from the Strategy)*

Several key challenges in transporting and storing hydrogen point to the use of PtX derivatives, like ammonia, as the leading export solution, especially in the near-term, and have resulted in pipeline export being excluded from the Base Scenario and, therefore, from this draft of the Strategy.

As a very small molecule, hydrogen gas has a high tendency to leak through valves, seals, and other equipment. These leaks are riskier due to hydrogen's relatively low ignition temperature compared to natural gas and its low-visibility flames. Additionally, hydrogen has a relatively low volumetric energy density, meaning more space will be required to store the same amount of energy in hydrogen form. This disadvantage is compounded by hydrogen's very low boiling point (–253°C[51] vs. –162°C[52]), making higher-density liquid storage costly and technologically complex. Transport of hydrogen gas, either by tank or pipeline, is similarly difficult given its lower volumetric energy density and need for cooling. Hydrogen also has the potential to cause embrittlement and, in some cases, lead to the failure of pipelines and storage tanks, depending on the material and age. This can be dangerous at high pressure.

Due to these challenges, hydrogen trade via pipeline or truck is unlikely to occur outside of regional markets, while over 90 percent of interregional trade will be through PtX derivatives.[53] Alternatives to pure hydrogen transport, such as the use of ammonia or other carriers, are therefore expected to be the focus for hydrogen export opportunities in Jordan.

Maritime Transport

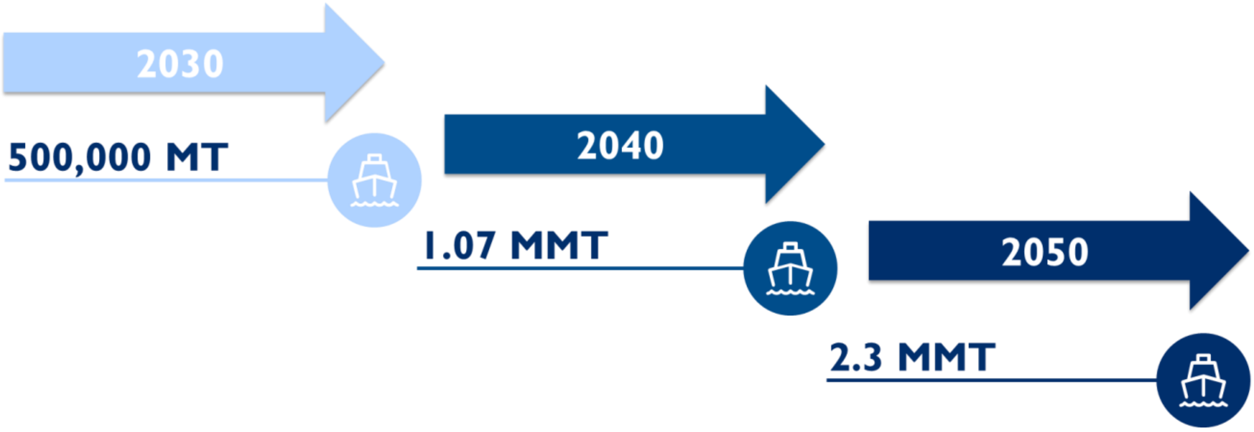
In the maritime context, ammonia is a cost-effective alternative to shipping hydrogen, given its higher energy density by volume and already well-established global trade infrastructure. However, the process of reconverting ammonia to hydrogen (catalytic cracking) is energy intensive. It requires temperatures exceeding 900°C, and so reduces the net energy accessible in each tonne of hydrogen.[54] Other maritime transport solutions, such as transporting liquid organic hydrogen carriers (LOHCs), may become prevalent in the long-term, however, technological constraints make this approach uneconomical in the short-term.

Jordan's Port of Aqaba has strategic access to the waterways of the Red Sea and is a primary transport gateway for moving cargo between countries within the region. The port is known for importing and exporting fertilizers, salt, sulfur, chemicals, and potash and could be leveraged for its infrastructure to export green hydrogen in the form of green ammonia. The Middle East's only European-certified "Eco Port," the Port of Aqaba, has a strong track record as a trusted and safe handler of liquid fuels and chemicals and currently maintains three fully serviced berths up to 100,000 deadweight tonnage (DWT). The industrial terminal currently facilitates ammonia imports and can accommodate ships up to 30,000 DWT, with potential for expansion.[55]

To position the port for export of green ammonia, limited retrofits to the current infrastructure will be required, including new storage tanks (the current tanks have an operational capacity of up to 34,000 tonnes, but are nearing the end of their operational lifespan), a new export pipeline to the jetty, and more.[56] Although the industrial jetty could be transitioned fully for export in the long-term, the port has adequate capacity to support both continued imports of grey ammonia for existing customers in Jordan's fertilizer industry, while also simultaneously exporting green ammonia to key demand markets. Operating the existing jetty at this capacity would enable export-oriented producers in Jordan to quickly access markets in parts of Central Europe (e.g., Germany, Netherlands, Belgium) as well as Asia (e.g., South Korea and Japan) where growing demand for green hydrogen products and limited domestic supply potential contribute to higher expected prices.

Route distance is an important factor when Jordan's export competitiveness vis-à-vis other expected suppliers of PtX products in the MENA region and beyond. Given the longer distance required to get to South-East Asia, Jordan is expected to encounter low-cost supply competition from Australia, Indonesia, and others in the region. However, as technology advances and capacity expands, Jordan may be able to scale exports to Asia if demand increases. Proximity to Europe (both land and sea routes) positions Jordan to become an important supplier to key demand centers, particularly in central and northern Europe. When taking into account expected supply from neighboring MENA countries with strong production potential, Jordan is expected to account for around 500,000 MT of green hydrogen supply (in the form of ammonia) to Europe by 2030, with the ability to reach over 1 MMT by 2040 and 2.4 MMT by 2050 in the Base Scenario (Figure 12).

Figure 12: Targets for maritime export of green hydrogen (as green NH_3)



In the Optimistic Scenario, Jordan could reach up to **5 MMT** of exports by 2050. For more on the Scenarios, see the Appendix.

Pipeline Transport

Hydrogen can be transported via pipeline by blending into current natural gas networks, retrofitting current pipelines to accommodate hydrogen, or by building new dedicated hydrogen pipeline networks. Dedicated pipelines are often most effective for high-volume, long-distance transportation over land, but the investment can be significant for building new pipeline networks: capital costs can often exceed $1.2M per kilometer.[57] While blending is already occurring in some pipelines around the world, the maximum blending percentage that is technologically feasible without leading to these failures is highly dependent on the specific qualities of each pipeline and the requirements of end users, requiring testing for each pipeline prior to blending. Current blending rates generally do not exceed 20 percent (equivalent to less than 10 percent of energy content), though many systems can only accommodate significantly less hydrogen, at under 5 percent.[58] Blending potential must therefore be determined on a case-by-case basis.[59]

Following the initial focus on seaborne trade of green hydrogen derivatives, opportunities for pipeline export may arise in the medium- to long-term, given these technological challenges and the cost of retrofitting or building new pipelines. Blending into the 1,200km-long transnational Arab Gas Pipeline (AGP), as past studies have suggested, is likely not feasible. Beyond the technical challenges outlined above, it is expected that any potential for hydrogen blending (likely minimal) will be met by upstream suppliers (e.g., Egypt) with little capacity for Jordan to add additional hydrogen volumes midstream.

However, in the medium- to long-term, Jordan may consider developing new dedicated hydrogen infrastructure along existing pipeline routes, such as the AGP, that connect Syria-Turkey-Greece-Italy and Israel-Cyprus-Greece-Italy, enabling pipeline export to key consumers under a more optimistic export scenario.[60] A new pipeline via Syria-Turkey-Greece-Italy with an assumed capacity of 10.3 billion cubic meters of natural gas and a diameter of 36 inches could provide Jordan with an additional transport capacity between 1.3 mtpa to 2.1 mtpa at full utilization.[61] Realizing this level of export would require significant infrastructure investment and further studies as market conditions evolve. As such, this use case was excluded from the Base Scenario underpinning this Strategy but may be revisited in future updates.

OVERVIEW OF GREEN HYDROGEN PRODUCTION POTENTIAL IN JORDAN

To understand the potential for a domestic green hydrogen economy, it is important to consider the supply landscape for meeting the resource needs, key inputs, and capital requirements of green hydrogen production. Together, these factors determine the levelized cost of hydrogen (LCOH), which will impact the economic potential for both domestic use and export of green hydrogen in Jordan.

Produced through the electrolysis of purified water, green hydrogen depends on two key inputs: green electricity (renewables) and purified water. Benchmarking Jordan's RE potential and water resources and allocating appropriate shares of both to green hydrogen production will be an essential step for setting Jordan's National Green Hydrogen Strategy in motion.

Jordan's main sources of renewable energy are solar PV and onshore wind. Jordan has over 30 renewable energy companies, with over 40 projects (a mix of wind, solar, biomass, and some hydropower) currently in operation.[62] Within the country, the Energy and Minerals Regulatory Commission (EMRC) runs and regulates the energy sector, allowing renewable companies to supply electricity to the National Electric Power Company (NEPCO), the single buyer of energy in Jordan. As previously mentioned, the Kingdom currently produces approximately 29 percent of electricity with renewable energy annually (around 2.5 GW of capacity), with the goal of producing 50 percent by 2030.[63,64] The quality of Jordan's solar and wind resources underpins these plans for future growth, as well as the potential for green hydrogen production.

Solar potential

The productivity of solar generation, and therefore the cost of green hydrogen produced by solar, exhibits some variation across Jordan, generally increasing in irradiation levels (increasing the capacity factor and therefore decreasing the cost) when moving from north to south. While land constraints may affect the overall scale of solar generation, Jordan scores remarkably well on measures of average solar potential (expressed as kWh/kWp/day). Aspects including insolation, temperature, terrain, type and degree of land cover, and many other factors contribute to an average of 5.32 kWh/kWp/day in Jordan, which ranks third in the world behind Namibia and Chile.[65]

Green hydrogen production potential from PV systems can be expressed in terms of tonnes per annum per square kilometer, or tpa/km^2. The highest production potential from solar PV is in the southern part of Jordan at more than 4,700 tpa/km^2.[66] For pure PV-to-hydrogen systems, nearly half of the production potential could be produced at or below $5/kg, placing Jordan among the lowest cost PV-to-hydrogen producers in the world.

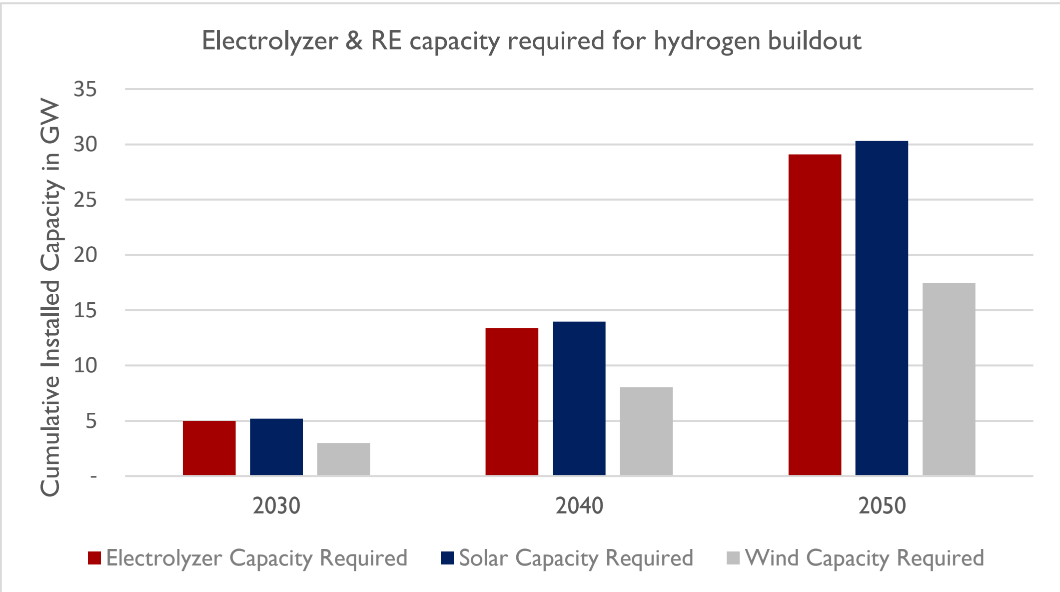
Wind potential

As with solar, wind potential varies geographically, with the most promising wind resources in the southern parts of the country (in the Aqaba region) and in the northeast between the Syrian border and Amman. Southeastern production potential, in some cases, exceeds 800 tpa/km^2. Here, costs per kg of hydrogen from wind-to-hydrogen systems could be lower than $4/kg. Outside of the south, wind potential varies significantly, resulting in a nationwide average of just 380 tpa/km^2.[67]

Wind-powered hydrogen production is more land intensive than PV-to-hydrogen systems but may exhibit different intermittency patterns. Often, these supply patterns can be complementary to one another. Providing electrolyzers with power from both wind and solar resources allow electrolyzers to maintain a higher capacity factor and operate more efficiently, improving project economics.[68] With combined PV and wind systems, Jordan's potential LCOH drops below $4/kg on average. At Jordan's current $3.89/kg LCOH, hydrogen produced is well within the range of production costs of other countries in the MENA region and proves cost-competitive for export. In the long-term, Jordan's production costs could fall to $1.8 – 2.2/kg, according to the IEA analysis on global hydrogen production costs.[69]

Realizing this potential, while also achieving targets related to expanding RE for power generation, will require a significant build-out of wind and solar resources as well as electrolyzer capacity. This will in turn necessitate measures to mitigate the variability from increased intermittency: investment in domestic energy storage, upgraded grid infrastructure, improved wheeling capabilities, and cross-border power transmission. Achieving the supply target of over 500,000 tpa by 2030 will require around 8GW of renewables by 2030 (5GW of solar and 3GW of wind) and 5 GW of electrolyzer capacity by 2030. By 2050, around 29GW of electrolyzer capacity will be required, powered by over 30GW of solar PV and 17GW of wind, to produce 3.4 mtpa of green hydrogen (Figure 13).

Figure 13: Electrolyzer and renewable capacity required for hydrogen buildout



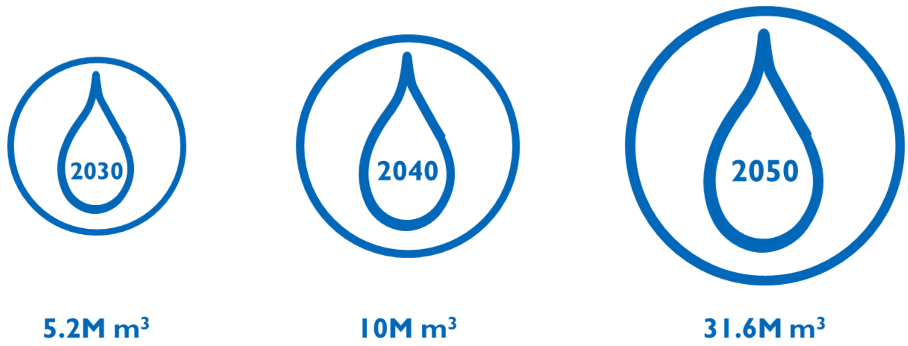
Water Supply

Purified water is another crucial input for green hydrogen, and another important factor in assessing Jordan's green hydrogen production potential. Jordan's current annual water availability is approximately 1,054 million cubic meters (MCM), with a majority coming from groundwater (20 percent of which is considered a nonrenewable resource). Surface water is another major source; however, supply is becoming less dependable due to over pumping, upstream diversion, and climate-related concerns.[70]

As demand for fresh water increases for domestic and agricultural purposes, Jordan's renewable groundwater is being used far faster than it can be replaced. As a result, seawater desalination will be required to meet the increased water demands of green hydrogen. Current plans for the National Water Desalination and Conveyance Project call for the supply of 300 million cubic meters of fresh water from a large desalination facility in the Port of Aqaba to supply numerous off-takers, primarily agricultural and civilian as well as industrial, in Aqaba and Amman. In the future, when this project is finalized, green hydrogen producers may be able to secure fresh-water offtake to supply electrolyzer facilities located in the Port of Aqaba. However, due to current uncertainty around the timing and volume of available supply from the National Conveyance Project, and to avoid competing directly for fresh water with other sectors, a dedicated desalination facility for green hydrogen production is envisioned for the Port of Aqaba to meet supply needs through 2040.

Depending on the electrolyzer technology, approximately 9 kg of water is required to produce 1 kg of hydrogen.[71] To meet anticipated supply volumes for 2030 and 2040 will require 5.4 million m^3 of water in 2030, rising to 14.4M m^3 in 2040 and 31.6M m^3 in 2050 as shown in Figure 14. While initially, these volumes would account for a relatively small share of the planned National Conveyance Project capacity relative to other industrial water demands in Jordan, as production scales over time to 2050, water demand becomes significant. As supply from the National Conveyance Project is uncertain, a dedicated desalination facility with sufficient capacity to meet green hydrogen demand over time is planned for the Port of Aqaba. To ensure that the hydrogen produced is truly "green," the desalination process must also be powered by renewable energy, requiring an additional 14 MW of RE capacity by 2030, rising to 36 MW in 2040 and 79 MW by 2050.

Figure 14: Water required green hydrogen buildout over time



Land requirements

The expansion of hydrogen production facilities and necessary infrastructure will necessitate that sufficient land be made available to developers along the value chain. At this time, the Aqaba Development Corporation has made approximately 4.5km^2 of land available within the industrial port for green hydrogen production. As space is limited in the port, the fact that these plots (three in total) have been made available specifically for green hydrogen is a testament to Jordan's commitment to developing the sector. Proximity to the port's existing infrastructure, export facilities, and to potential end-users in the area make these attractive locations to site electrolyzer facilities, supplied by high-voltage power lines from RE sites nearby. While this land can help kickstart project construction in Jordan, in order to reach future export and domestic targets, Jordan will require a total land area of around 448 km^2 by 2030, 1,205 km^2 by 2040, and 2,613 km^2 by 2050, as shown in Figure 15. The majority of land required is for wind, which has a much lower power density than solar. In addition to the 4.5km^2 already made available in Aqaba for electrolyzers, an additional 2.5km^2 will be required by 2030 to meet 2030 production targets, with an additional 18

km^2 needed by 2040 and 38 km^2 by 2050, moving farther and farther away from the priority land near the industrial port and export terminal over time.

Figure 15: Land required for green hydrogen buildout

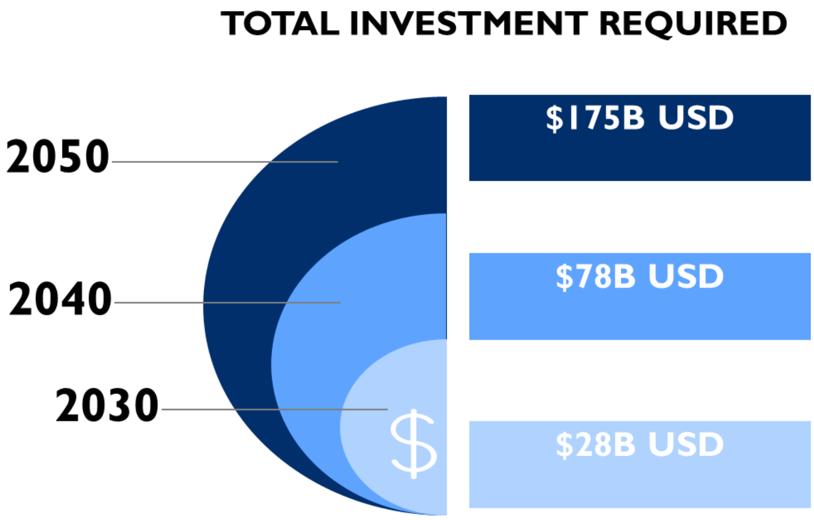
Capital Investment Needed

Green hydrogen is a capital-intensive industry. For example, overall capital expenditure typically accounts for 45 to 50 percent of levelized production cost, with up to 40 percent for the purchase of solar or wind renewables for electricity and up to 20 percent for electrolyzers. Operational expenditures can also account for up to an additional 30 percent of the levelized costs.[72,73] Electrolyzer modules currently range from $7.20/MW for large (100 MW) installations to up to $10/MW for smaller, 5 MW models. This highlights the benefits of scaling for larger production facilities to meet Jordan's low-cost supply needs. These costs are expected to come down significantly over time as global electrolyzer manufacturing capacity expands, though near-term supply could be constrained, keeping prices elevated.[63]

Jordan will need to work with the private and public sectors, especially in the short-term, to raise debt and equity required to build green hydrogen infrastructure. These financing costs could put additional pressure on hydrogen's levelized costs, which could account for an additional 30 percent. Existing investments, for instance in desalination infrastructure, will need to be complemented by funding electrolyzers, end-use equipment (such as ammonia plants), and distribution infrastructure for power, water, and hydrogen.

The production targets laid out in this Strategy will require significant investment across the green hydrogen value chain. Total CAPEX requirements for production infrastructure alone (including desalination) are estimated at $28.5B USD by 2030, $78.7B USD by 2040, and $175B USD by 2050 (Figure 16). Additional investments in transportation infrastructure, T&D infrastructure, storage, demand-side retrofitting costs, and other expenditures will also be required over time. The cost of this capital could put additional pressure on expected LCOH, underscoring the need for Jordan to attract capital from a variety of sources, including through access to concessionary financing.

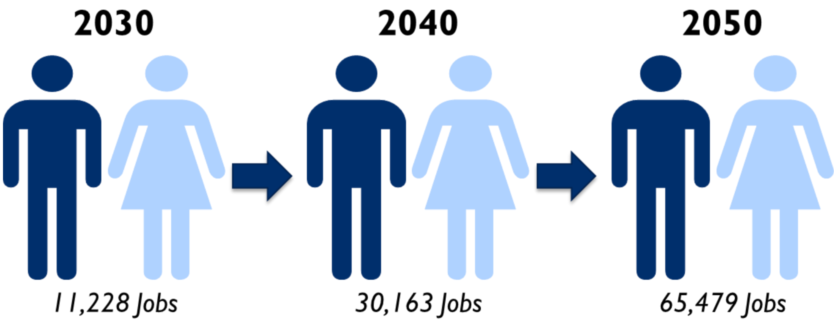
Figure 16: Total investment required for green hydrogen buildout



Expected economic and environmental benefits for Jordan

Despite the significant resources and investment required, reaching 2030, 2040, and 2050 targets for domestic green hydrogen consumption and export will yield significant economic and environmental benefits for Jordan. Ramping up the infrastructure needed to supply green hydrogen is expected to create over 11,000 new jobs by 2030, more than 30,000 by 2040, and over 65,000 by 2050, as shown in Figure 17. These comprise both direct and indirect job creation within the new green hydrogen sector and supporting industries, driving demand for skilled labor in construction, manufacturing, renewable energy, plant and port operations, and more. Job creation is a significant contributor to GDP growth, though further studies are needed to determine the expected GDP growth associated with green hydrogen development.

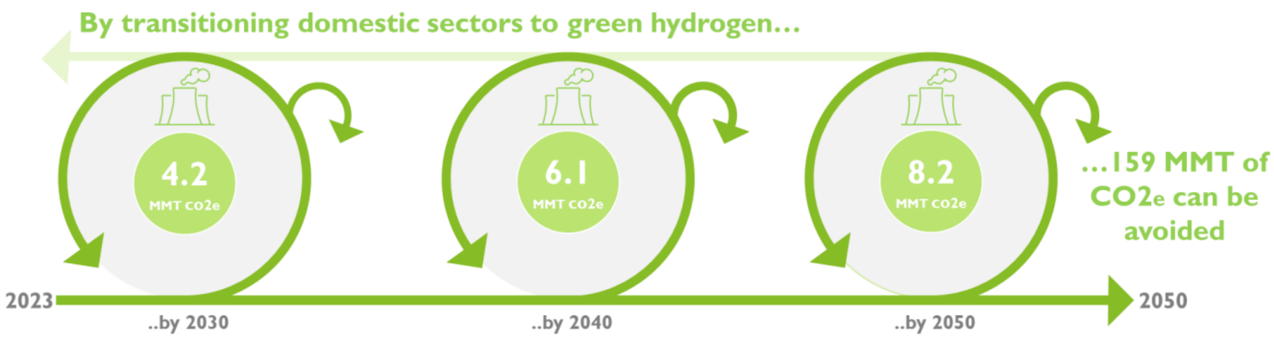
Figure 17: Job creation from green hydrogen over time



In addition to new jobs and economic opportunities for Jordan, domestic utilization of hydrogen will lead to significant environmental benefits in-line with the country's decarbonization goals. By utilizing green hydrogen at the rate envisioned in this Draft Strategy, Jordan will be able to displace current CO_2e emissions from incumbent fuels across various sectors. In total, this is expected to avoid up to 8.2 mtpa of CO_2e emissions by 2050 (Figure 18). Emissions avoided from transitioning to green hydrogen will be a key step to helping Jordan achieve its NDCs and overall goals for climate neutrality by 2050.

The substitution of hydrogen will drive other environmental benefits as well, for example, by reducing particulate matter and other emissions (beyond carbon) resulting from the burning of fossil fuels, improving air quality, particularly in densely populated areas and near industrial facilities. However, land and water use and the ecological impacts of wind, solar, and particularly water desalination must be carefully managed and continuously assessed to minimize potentially adverse environmental effects.

Figure 18: CO_2e emissions avoided through domestic green hydrogen uptake



In summary: Requirements and benefits of green hydrogen

The previous section assesses applications for hydrogen across various sector use cases and export. Modeling shows that each of these varies in terms of potential for substituting green hydrogen in the short-, medium-, and long-term. For Jordan to reach its domestic green hydrogen potential of 91 kt by 2030, 510 kt by 2040, and 1.12 MMT by 2050 and its export potential of 500 kt by 2030, 1.08 MMT by 2040, and 2.33 MMT by 2050, the Kingdom will require significant capital investment, land, water and renewable and electrolyzer capacity. However, through the introduction of green hydrogen, Jordan could reap the benefits of over 65,000 new jobs by 2050 and avoid up to 8.2 mtpa of CO_2e emissions by 2050, as shown in Figure 19.

Figure 19: Requirements to reach Jordan's green hydrogen potential

By 2030, **0.59 mtpa of H_2** will create over **11,000 jobs** avoid **4.2 mtpa CO2e emissions** and require:

0.5mtpa	$28B	448km^2	5GW	8GW	5.3M m^3
for export	*of investment*	*of land*	*of electrolyzer capacity*	*of wind and solar*	*of water*

By 2040, **1.5 mtpa of H_2** will create over **30,000 jobs** avoid **6.1 mtpa CO2e emissions** and require:

1mtpa	$78B	1,204km^2	13GW	22GW	14M m^3
for export	*of investment*	*of land*	*of electrolyzer capacity*	*of wind and solar*	*of water*

By 2050, **3.4 mtpa of H_2** will create over **65,000 jobs** avoid **8.2 mtpa CO2e emissions** and require:

2.3mtpa	$175B	2,614km^2	29GW	47GW	31M m^3
for export	*of investment*	*of land*	*of electrolyzer capacity*	*of wind and solar*	*of water*

MAIN CHALLENGES AND RISKS TO ADDRESS IN SCALING GREEN HYDROGEN IN JORDAN

While the case for hydrogen production in Jordan is strong, regulatory and policy gaps remain that must be bridged in order to unlock the full economic potential of the green hydrogen economy. To close these gaps, mitigating risks across multiple fronts and coordinated efforts between the public and private sector will likely be required. These challenges fall under four main categories, including:

1. Institutional and Regulatory
2. Human and Intellectual Capital
3. Infrastructure and Resource Constraints
4. Economic Competitiveness

Monitoring risks within these categories and acting to reduce them (as illustrated in Figure 20) can help minimize challenges associated with scaling green hydrogen in Jordan.

Figure 20: Risks and mitigation measures to reduce green hydrogen challenges

Risk Type	Examples	Mitigation Measures
Institutional & Regulatory	• Nascency of hydrogen economy and need for collaboration among closely regulated industries • Reclassification of hydrogen gas • Lack of end use case clarity from the top, and identification of clean H_2 benefits • Public concern related to safety and H_2 benefits	• *Work with institutional bodies within Jordan and international groups to facilitate buy-in and develop consistent standards* • *Clearly define H_2 gas and specify blending percentages* • *Facilitate public and private cooperation and action* • *Clearly define benefits and set priorities at government level* • *Develop education campaigns to increase social license to operate*
Human & Intellectual Capital	• Large workforce needed for planning and constructing infrastructure necessary for entire H_2 value chain • Insufficient research and development (R&D) for H_2 and PtX technology to scale	• *Develop education and skills training programs* • *Partner with academia and key sectors to identify priority R&D efforts and invest in focused pilots and feasibility studies* • *Track investment and R&D progress to ensure efficient fund allocation*
Infrastructure & Resources	• Land constraints for greater RE and electrolyzer capacity, especially near clustered end users (e.g., Port of Aqaba) • Grid management to scale electrolysis • Access to fresh water and high cost of desalination • Regulatory limit on wheeling and high fees • Challenges and costs related to production, transport and storage	• *Clearly designate land for GH_2 infrastructure and conduct feasibility studies for additional land plots* • *Reassess grid management framework (e.g., NEPCO single buyer)* • *Define common-use land and water infrastructure models* • *Revisit legislation related to wheeling* • *Introduce incentives* to reduce costs, and identify targeted R&D, pilots, and investments for technologies and processes across value chain*
Economic & Market	• Availability of financial capital • Costs of using H_2, encompassing switching costs, high levelized cost of H_2, and potential decreases in efficiency from new equipment • Regional supply constraints from rapid H_2 expansion • Lengthy contracting procedures • Offtake uncertainty	• *Consider risk sharing frameworks* • *Identify market mechanisms including tax credits and incentives* to reduce costs of capital to attract sufficient investment, access to FDI, and encourage switching* • *Encourage simultaneous commitments, including agreements from various participants across value chain to coordinate supply and demand* • *Streamline contracting process to reduce barriers*

*Incentives to be aligned to the Investment Law

Institutional and Regulatory

Institutional

Hydrogen production, transportation, and end-use involve several closely regulated industries. The nascent status of the hydrogen economy entails a low level of current hydrogen utilization. Therefore, Jordan will need to collaborate with other countries to further develop regulatory frameworks for the safe integration of hydrogen into these processes.

As a broad-based economic transformation, the incorporation of hydrogen into Jordan's industrial systems will also likely require concerted buy-in from institutional bodies, including the Ministry of

Planning and International Cooperation, Ministry of Industry and Trade, Ministry of Environment, Jordan Standards and Metrology Organization, NEPCO, Customs Bodies, and Distribution System Operators, among others. One key gap is a need for more education and familiarity with hydrogen-specific issues and benefits among key personnel at these organizations. Ultimately, a fully developed hydrogen economy will require these institutions to stand up dedicated hydrogen units responsible for planning, analysis, and implementing regulation.

Regulatory: Capital constraints

Current hydrogen regulations, or lack thereof, could impact the availability of financial capital for green hydrogen development. Regulators, tax authorities, and other bodies within the Ministry of Finance and the Central Bank of Jordan may need to act to reduce costs of capital to attract sufficient investment, support the construction of new hydrogen projects, and incentivize domestic sectors to transition to green hydrogen. Political and macroeconomic stability, along with legal and regulatory environments, are especially important in attracting foreign capital. Developing a clear, stable policy and regulatory environment for hydrogen should thus be a major consideration for the Kingdom.[74]

Additionally, Jordan will require significant capital to build necessary infrastructure to develop a green hydrogen economy. This additional infrastructure will take the form of electrolyzer stacks, desalination plants, renewable generation, hydrogen transport, and storage systems (including compressors, tanks, and possibly pipelines), ammonia synthesis plants (in the longer-term), and likely expanded grid infrastructure to accommodate changes in power usage. Existing supply chains for some of these assets (particularly electrolyzers) are constrained. Though growth is expected in the short-term, the rapid expansion of the hydrogen economy in many regions may cause a supply crunch. Supply chains for crucial equipment, including electrolyzers, pipes, compressors, storage systems, and hydrogen-capable end-use equipment, will likely need to be created or significantly expanded to meet planned and future demand. Helping de-risk the market through potential tax credits and incentives in alignment with the present Investment Environment Law (as is being done in other countries) could support increased financing to assist with the ramp-up of green hydrogen for priority sectors and use cases in Jordan.

Regulatory: Hydrogen classification & blending rates

Another regulatory challenge exists around the classification of hydrogen gas. Current regulations in Jordan do not specify the nature or allowable percentages of blending into natural gas streams. Though varying case-by-case, blending rates for hydrogen in natural gas turbines globally ranging from 5 percent to up to 39 percent by volume have proven feasible without generating unacceptable risk or requiring extensive retrofit.[75] The specific percentage of blending that will make sense for Jordan still requires further study. Close analysis of current infrastructure, including physical pipes, valves, sensors, and end-use equipment, is needed to determine what level of hydrogen can be safely incorporated into natural gas streams to avoid risks of leaks or material embrittlement. Additionally, hydrogen is presently regulated as an industrial gas rather than an energy carrier, which has some adverse tax and regulatory implications. This may be reclassified to better align with international regulatory schemes and key export markets.

Further regulatory evolution, especially around hydrogen production, storage, and transport codes in and around the Port of Aqaba, will also be required. Many of these regulatory changes can be made unilaterally and rapidly by the Energy and Minerals Regulatory Commission (under Petroleum

Products Law No. 11 of 2018) but should still be aligned with those of other relevant agencies where necessary.

Human and Intellectual Capital

Human Capital

Another cluster of existing gaps focuses on the human capital needed to build, expand, and maintain the hydrogen economy. Planning and constructing infrastructure necessary for hydrogen production, transport, and storage will require many skilled workers, including some with experience in new and evolving fields, like large-scale hydrogen transport. While skills and capabilities exist within the country from other industries and projects, effective hydrogen-specific training is essential for the successful application to these new markets.

The need for hydrogen-related skills and training fits well with the broader necessity of raising awareness for the particular government entities and current sectors operating within Jordan. If the Kingdom plans to realize its green hydrogen potential, this new economy could introduce over 65,000 jobs, ranging broadly in skill level.[76] Making sure that employees in existing sectors have the support necessary to participate in the green hydrogen economy will be crucial to ensure inclusivity is at the core of this transition in Jordan.

Intellectual Capital

In addition to the broad-based efforts needed to train a sufficient workforce, Jordan faces gaps relating to research and development (R&D) for hydrogen and PtX technology. R&D is needed for its specific hydrogen use cases, for example, electrolyzer manufacturing, desalination, or the direct electrolysis of seawater. Current R&D efforts, whether public or private, may require more coordination from MEMR to ensure that there are no gaps or redundancies in the research agenda. Tracking progress where investments have been made and reassessing research priorities each year will also be critical to ensure funds are being allocated appropriately.

Beyond ramping up skilled workers and researchers to scale green hydrogen, there is also the need for the broader population to endorse and engage with this new industry. Public opinions may include fears related to hydrogen safety, concerns over losing current employment, and objections to the diversion of often scarce land, power, and water resources towards hydrogen production. The need to generate foundational support and social license to operate is another constraint that must be addressed and will require collaboration between government officials, the private, and public sector (i.e., NGOs, academia).

Infrastructure and Resource Constraints (Land, Power, Water)

Gaps tied to resource requirements, including land, power, and water, must also be addressed to enable a green hydrogen economy in Jordan.

Land Availability

Renewable power generation, needed for green H_2 production, requires large areas of land (especially onshore wind) to supply electrolyzers at a sufficiently high-capacity factor. Suitable land to house electrolyzers and the generation to power them is also in short supply, though the role of government in resolving this issue may be limited to managing tradeoffs with other uses of scarce land. In conditions of water scarcity, this issue is compounded. Desalination plants, the only feasible way of expanding Jordan's water supply without cutting use, require additional amounts of renewable energy and land.

When considering land, the highest-potential area for solar and wind production is in the south, around the Port of Aqaba. The Port is also home to significant hydrogen end uses, including heavy-duty transport applications and ammonia production. Further, the Port is Jordan's main export terminal, and its only connection to a large body of water suitable for desalination. The area in and around Aqaba is therefore in high demand as a hydrogen hub for several reasons. Given the area around the Port has limited land due to prior commitments and other constraints, using the available land intentionally for hydrogen and considering additional plots will be key for rapid buildout of green hydrogen.[77]

Addressing this constraint may require transporting water, electricity, or hydrogen across large distances to connect land available for generation to electrolyzer or desalination facilities. The optimal configuration of these systems will need to be further assessed by individual developers.

Water

Water is another limited resource requires the attention of policymakers. Jordan is one of the most water-scarce countries in the world, with the current supply meeting only two-thirds of the population's water needs.[78] Concerns have been raised over future water scarcity and green hydrogen's impact on the water supply. Producing 1 kilogram of green hydrogen via electrolysis requires a theoretical minimum of 9 liters of water, but actual production processes may lose water to evaporation or purification.[79] Water for industrial processes in most regions can be easily sourced from groundwater or municipalities; however, this is not an option for Jordan.

Large-scale desalination is likely the only way to resolve water shortages and would be desirable even if the hydrogen economy were not a priority for Jordan. The Aqaba Special Economic Zone Authority (ASEZA) currently maintains strict Zero Discharge rules that may include the concentrated brine effluent from desalination plants. Amending this rule or granting an exception for desalination represents an important step in enabling green hydrogen production.

Grid Capacity

Green hydrogen requires a significant amount of electricity (approximately 50 kWh per kg of hydrogen, depending on the electrolyzer technology used). Some aspects of the current institutional framework governing grid management may hamper the ability to scale electrolysis over time. NEPCO is, by law, the single buyer of electricity in Jordan, meaning green hydrogen producers cannot purchase renewable energy directly from generators. Further, the legislated limit on wheeling (transportation of electrical power through the grid for self-use) is 1MW, which, coupled with high wheeling fees, limits supply choice for electrolyzer facilities. Grid transmission infrastructure may, in some areas, be insufficient to accommodate electrolyzer load, and also requires expansion. The use of hydrogen to store renewable energy also faces constraints due to the absence of safety and technical standards.

As Jordan executes its National Energy Strategy, increasing shares of renewable generation may present a challenge for grid operators. Grid systems may require increasingly high levels of curtailment to mitigate the effects of excess supply. When renewable power generation exceeds grid demand, green hydrogen production can be an attractive use for excess electricity.

Lastly, the intermittency of wind and solar generation may reduce the realized capacity factor of electrolyzers. Oversupply of renewables or connection of multiple generating assets in different parts of the country may be necessary to produce green hydrogen effectively and continuously at scale. If, however, sufficient renewable, electrolyzer, and supportive grid infrastructure can be installed, green hydrogen can be used to shift energy supply. This can occur on an intraday scale, by season, or geographically, turning Jordan's strong renewable energy potential into valuable commodities for export.[80]

Economic Competitiveness

The potential domestic use cases for hydrogen require a transition in fuel or feedstock from existing ones. Given this, hydrogen will always be competing with an incumbent solution, such as natural gas, diesel fuel, or coal. These fuels are often typically selected to minimize costs and used in processes that have been extensively optimized. The costs of using hydrogen, encompassing switching costs, high levelized cost of hydrogen, and possible decreases in efficiency from new equipment, will likely be a significant barrier to transition.

Government support through investment, practical regulation, incentivization, and investment in R&D will likely be crucial to adopt green hydrogen. Economically calibrated measures will be especially helpful, for instance, a carbon tax, which would correct market distortions caused by fossil fuel externalities.

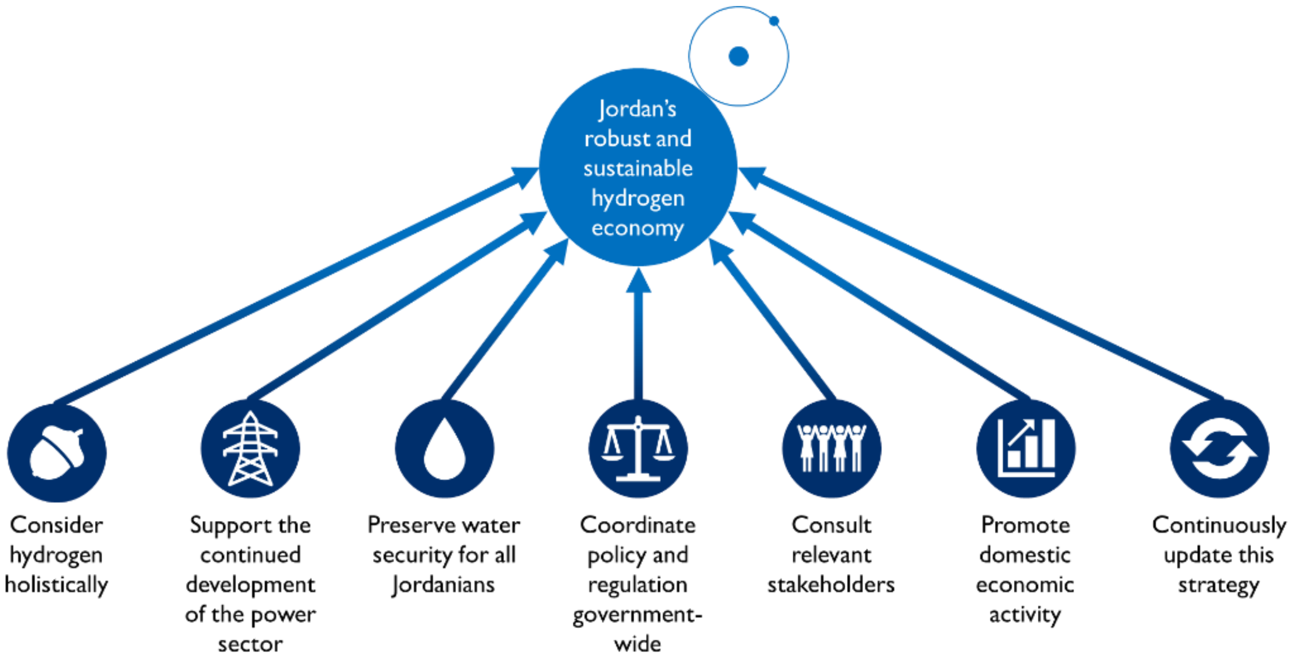
STRATEGIC VISION AND ACTION PLAN FOR JORDAN

With this Draft Strategy, Jordan joins other nations around the world in conceptualizing the important role that green hydrogen will play in the transition to a more sustainable future and articulating how Jordan can benefit from developing a robust green hydrogen economy. The prospect for hydrogen in Jordan is twofold: as a solution to help decarbonize domestic industries in line with national sustainability goals, and as a valuable commodity for export. Both opportunities can ultimately help drive sustainable economic growth, attract foreign direct investment, create jobs, reduce emissions, and further strengthen Jordan's position as a green tech leader in the MENA region.

Focusing on Jordan's strengths, this Strategy establishes an ambitious vision for hydrogen in Jordan that recognizes its full potential, while also identifying the barriers and challenges that remain. The Government of Jordan understands the need to be bold in ambition, while also balanced in approach. This Strategy is the first step in a journey to assess, test, and refine plans for supporting and developing a new green hydrogen economy in Jordan. The rapidly evolving nature of the nascent global clean hydrogen economy, the maturation of different technologies, and the evolution of the energy, water, transportation, and other interconnected systems will necessitate that this Strategy be regularly updated, and additional feasibility studies conducted to test and refine assumptions on hydrogen's potential for different applications.

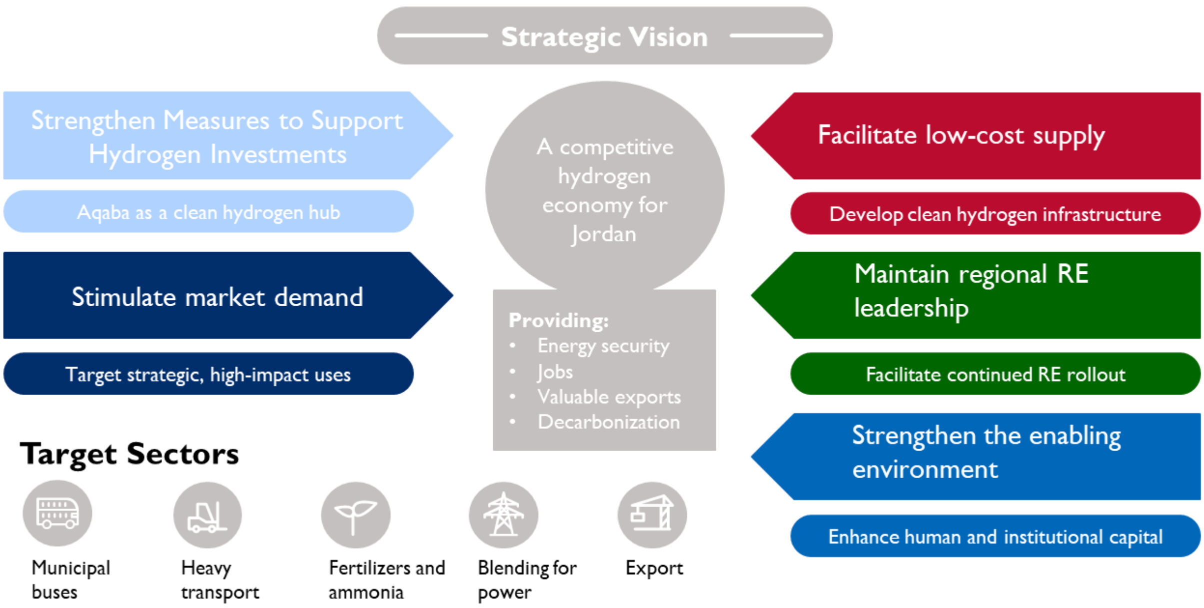
Nevertheless, hydrogen will have a role in the energy system of the future and in Jordan's economy. This Strategy sets the foundation for **a future hydrogen economy in Jordan that supports robust exports and a domestic supply that is affordable, clean, and part of an overall transition to a more prosperous, equitable, and sustainable economy.** To realize this vision, seven principles must be followed to guide the development of the sector (See Figure 21).

Figure 21: Guiding principles



Adhering to these principles and strategic vision, this document establishes five **strategic priorities** that together can help develop and scale clean hydrogen for domestic use and for export as shown in Figure 22. An Action Plan has been developed for each, to guide the development of the sector in the near-term (to 2030), medium-term (to 2040), and long-term (to 2050). These actions are presented under each of the respective strategic priorities below, followed by a list of immediate next steps (2023-2025) that need to be taken to begin executing on this Strategy.

Figure 22: Jordan's strategic vision and five strategic priorities



1. Strengthen measures to support Hydrogen investments

A main priority for Jordan will be on strengthening measures to support hydrogen investments to scale up hydrogen production and end-use in close proximity. Green hydrogen is likely to see accelerated adoption in areas where value-chain collaboration is encouraged. Infrastructure and transportation requirements remain key barriers to green hydrogen, driving up costs and decreasing attractiveness compared to traditional energy sources. The hub concept and locating key stakeholders near one another is meant to accelerate the deployment of hydrogen and infrastructure build.

The Port of Aqaba has already been identified as a priority locus for developing a green hydrogen/PtX hub in Jordan. Analysis shows that the port is already home to significant hydrogen uses, including heavy-duty transport applications and ammonia production, meaning existing infrastructure could be leveraged with the introduction of green hydrogen. Additionally, the highest-potential land for solar and wind production is in the south, which could help reduce energy transport if RE plants were installed in close proximity. Given the port is Jordan's main export terminal and its only connection to a large body of water suitable for desalination, the area in and around it is well positioned for a hydrogen hub.

To support hydrogen investments and enable Priority 1, Jordan should consider key actions, outlined in Figure 23, from now until 2030, 2030-2040, and 2040-2050 to scale up hydrogen production and end-use in the Port of Aqaba.

Figure 23: Priority 1 Strengthen measures to support hydrogen investments

	Timeframe	Actions	Stakeholders Involved
Priority 1: **Strengthen Measures to Support Hydrogen Investments**	**Now-2030**	• Work with the National Green Hydrogen Committee on a number of issues that impact the Green Hydrogen Strategy implementation and overall development of the Hydrogen market in Jordan. Among others, priorities include: – Develop a common use model for infrastructure in Aqaba, and assess land allocation options based on different investment scenarios. – Facilitate common access to developers and off-takers in ASEZ and consider provision of incentives in line with the Investment Environment Law (No. 21 of 2022). – Align private sector's role in developing Aqaba as a GH2 hub, and assign ASEZA, MEMR, and MoINV to supervise and lead efforts to engage the private sector.	**Primary stakeholders**: MEMR & MoINV **Secondary stakeholders**: ADC, ASEZA MoENV, MoPIC, MWI, MoIST, EMRC
		• Develop proper standards and memorandums of understanding (MoUs) to qualify private sector investors and classify sector developers, signing MoUs with them, and setting clear investment time frames.	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoINV, ADC, ASEZA, Private Developers,
		• Develop a dedicated "green grid" supplying green projects in ASEZA (e.g., GH2, desalination, etc.), with electricity from renewable energy sources, to be implemented either through NEPCO or by partnering with the private sector, considering available financing alternatives and compliance with relevant laws and regulations.	**Primary stakeholders**: MEMR, ASEZA, NEPCO **Secondary stakeholders**: ADC, MoIN, Power Companies, EDCO, Power Plants, Private Developers, Financial Institutions

		• Collaborate with MWI to explore potential alternatives for implementing desalination projects (in and outside of Aqaba) to meet water demand for GH2 projects. Also, assess the feasibility of securing projects with the needed desalinated water through NCP, based on the NCP implementation timeline.	**Primary stakeholders**: MEMR & MWI **Secondary stakeholders**: ADC, ASEZA MoENV, MoPIC, MWI, Private Developers, Financial Institutions
		• Retrofit Port of Aqaba for export—based on assessing the current versus future Aqaba port capacity.	**Primary stakeholder**: ASEZA **Secondary stakeholders**: MEMR, ADC
	2030-2040	• Re-assess the key priorities and projections in the Hydrogen Strategy, including expansion of common infrastructure (e.g., new liquids export terminal and/or existing terminal expansion), and current capacity to meet any potential increase in demand (RE, electricity transmission lines, desalinated water, etc.)	**Primary stakeholder**: MEMR **Secondary stakeholders**: ADC, ASEZA MoENV, MoPIC, MWI, NEPCO, JVA, JSMO, EDCO, FAJR, MoIN, Power Companies, Power Plants, Private Developers, Financial Institutions
	2040-2050	• Further assess jetty capacity and retrofit/convert part of the terminal for export of PtX products.	**Primary stakeholders**: MEMR, ASEZA **Secondary stakeholders**: ADC, Private Developers, Financial Institutions
		• Connect Aqaba Hub to other GH2- consuming centers.	**Primary stakeholders**: MEMR, ASEZA **Secondary stakeholders**: ADC, MoENV, MoPIC, MWI, NEPCO, JVA, JSMO, EDCO, EMRC, FAJR, MoIN, Power Companies, Power Plants, Private Developers, Financial Institutions

2. Stimulate market demand

Second, while hydrogen can be used across a number of use cases, many are not economically viable at this time. The strong early business case for export is expected to drive initial development of the green hydrogen sector in Jordan, though domestic demand will be important to reduce project risk for developers, provide additional offtake, and deliver economic benefits. Government support will be needed initially to drive demand certainty in key domestic applications for hydrogen until favorable economics can drive organic market demand.

To also facilitate maritime export in the short-term, the Jordanian government will need to work to promote green ammonia export opportunities internationally within target markets, for example, by facilitating trade agreements and by signing memoranda of understanding with key partners. This would involve fostering a market environment that enables contracting between producers of green ammonia and off-takers.

Focusing initially on sectors where the Government of Jordan can drive early uptake for pilot projects to kickstart demand, MEMR can help facilitate demand uptake across use cases over time, for example by establishing pilots, and/or exploring carbon pricing mechanisms to stimulate demand. Four key initial applications are expected to be early drivers in addition to export: municipal bus transport, heavy-duty trucking, port logistics vehicles, and pilot-scale blending for power generation. Over time, additional support will be needed to facilitate green hydrogen adoption in the aviation, shipping, steel, power generation and storage, and cement sectors that are sources of more medium- to long-term demand.

To stimulate demand and enable Priority 2, Jordan should consider key actions, outlined in Figure 24, from now until 2030, 2030-2040, and 2040-2050 to facilitate export and scale hydrogen uptake domestically.

Figure 24: Priority 2 Stimulate market demand

	Timeframe	Actions	Stakeholders Involved
		• Identify a number of specific use-cases that can help kickstart domestic demand for green hydrogen and collaborate with the World Bank, ESSA, and other donors to expedite that process. • Examples include municipal buses, heavy duty trucking (i.e., phosphate transport, oil containers), port logistics, and blending for power generation to help create greater demand certainty.	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoINV, Private Companies, Private Developers, Financial Institutions, JPRC, Power Plants, MoENV, Jordan Chamber of Industry

Priority 2: Stimulate Market Demand	**Now-2030**	• Channel the private sector interest in Hydrogen towards feasibility studies and market analysis to identify industrial demand potential for green hydrogen.	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoINV Private Companies, Private Developers, Financial Institutions,
		• Enter into agreements with the private sector which is expected to play a major role in identifying priority export markets.	**Primary stakeholder**: MoINV **Secondary stakeholders**: MEMR, MOIST, Power Companies, Power Plants, Private Developers, Financial Institutions, World Bank
	2030-2040	• Scale up demand from 2030 use-cases and prioritize new areas of interest focused on industrial demand potential in net-new sectors (i.e., methanol). Scaling up should be driven by the success stories achieved in the previously selected cases based on a number of factors. These mainly include ROI, environmental benefits, successful transition to green hydrogen, and expanded financing for potential domestic demand areas to further aid green hydrogen uptake.	**Primary stakeholders**: MEMR, MoINV **Secondary stakeholders**: Private Companies, Private Developers, Financial Institutions, JPRC, Power Plants, MoENV, MoPIC, Jordan Chamber of Industry
		• Consider expanding to other sectors such as aviation (SAF), residential / commercial heating, shipping, and fertilizers.	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoINV, Private Developers, Financial Institutions, JPRC, Power Plants, MoENV, Jordan Chamber of Industry, Civil Aviation Regulatory Commission
		• Expand heavy-duty trucking use to additional routes. In addition to phosphates/ fertilizers, the GOJ should consider other industries where economies of scale	**Primary stakeholder**: MoT

		and cross-sectoral benefits may justify the CBA, such as oil products and cargo-based local shipping.	**Secondary stakeholders**: MEMR ASEZA, ADC, Oil Marketing Companies (OMCs), JOPM
		• Assess the need to sign power purchase agreements (PPAs) or other contractual forms to formalize any GH_2-driven power generation agreements at a larger scale. This is crucial to meet renewable power needs and certify hydrogen as "green" if Jordan is unable to supply full RE amounts.	**Primary stakeholders**: MEMR, NEPCO **Secondary stakeholders**: MoINV, Private Developers, Financial Institutions, World Bank, Power Plants,
		• Work with international bodies, starting with regulators, to establish low-carbon fuel regulations to certify low-carbon hydrogen and/or carbon pricing per international standards. The objectives are to limit green hydrogen impacts, enable emissions reduction, and ensure impacts are measured consistently so products can be traded and used across borders.	**Primary stakeholders**: MEMR, EMRC **Secondary stakeholders**: Private Developers, MoINV, MoENV, World Bank, International regulators
		• Continue to scale up projects that were prioritized in the previous phase. For example, expand funding or target amounts for successful model projects or work on full transition plans for certain sectors based on success rate and calculated/ estimated return on investments.	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoINV, Private Developers, Financial Institutions, JPRC, Power Plants, MoENV, Jordan Chamber of Industry

3. Facilitate low-cost supply

Given existing barriers to scaling green hydrogen, the Jordanian government should play an active role in policy and program development to create a positive environment for the production, transport, and trade of green hydrogen. A crucial first step to scaling green hydrogen will require setting general regulations for this new market. In Jordan, green hydrogen is currently classified as an industrial gas and therefore falls under all regulations related to the production, handling, and use of such products. By classifying green hydrogen under the appropriate categorization, government incentives and policies can be developed within the country to provide greater market certainty and de-risk investments necessary to scale green hydrogen.

Additionally, Jordan will need to take regulatory action to reduce project barriers (e.g., licensing and permitting) as well as capital constraints throughout the value chain. Competitive incentives with respect to Jordan's Investment Environment Law will be crucial to encourage direct foreign investment (FID) and concessionary financing options, given project build and infrastructure needed will be costly (e.g., from electrolyzers, RE, to desalination facilities). However, for Jordan to attract the financing necessary for rapid build, action is needed in the short-term to begin realizing export and some domestic uses for green hydrogen by 2030.

To facilitate low-cost supply and enable Priority 3, Jordan should consider key actions, outlined in Figure 25, from now until 2030, 2030-2040, and 2040-2050.

Figure 25: Priority 3 Facilitate low-cost supply

	Timeframe	Actions	Stakeholders Involved
		• Provide competitive incentives (with some targeting the entire value chain) in alignment with the Investment Environment Law, to encourage FDI in the green hydrogen value chain, while working in parallel with the World Bank and financial institutions to develop a proper GH2 incentives package to be provided by funding agencies.	**Primary stakeholder**: MoINV **Secondary stakeholders**: MEMR, Private Developers, Financial Institutions, Power Plants, NEPCO, Power Companies, World Bank, Jordan Chamber of Industry

Priority 3: Facilitate Low-Cost Supply	**Now-2030**	• Propose to the National Green Hydrogen Committee suggested GH2 targets with a realistic timeline for domestic uptake and export to encourage supply build. • Collaborate with key stakeholders to prioritize specific actions for domestic demand uptake & exports, and set clear target dates supported by Hydrogen estimates.	**Primary stakeholder**: MEMR Input is required from almost all stakeholders through consultations
		• Begin exploring commercially viable production paths (e.g., waste to hydrogen)	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoINV, MoENV, Private Developers, Financial Institutions
	2030-2040	• Promote domestic manufacturing capacity of hydrogen production equipment. This includes mainly electrolyzers, but may also include blending, and any other equipment	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoINV, Private Developers, Financial Institutions
		• Start manufacturing of domestic electrolyzers, and initiate discussions with the private sector on sale of hydrogen byproducts.	**Primary stakeholders**: MEMR, MoINV **Secondary stakeholders**: Private Developers, Financial Institutions, Power Companies, Power Plants
	2040-2050	• Scale up domestic manufacturing and supply chains.	**Primary stakeholder**: MEMR **Secondary stakeholders**: JCI, Private Developers, various stakeholders

4. Leverage existing leadership in renewable energy

Jordan will focus on leveraging its current renewables infrastructure and further technology advancements by ramping up grid capacity and storage capabilities to aid in production efforts. A power sector characterized by transparency and certainty will help pave the way for investment and rapid growth. Improvements in the stability, capacity, and operational efficiency of Jordan's power sector will not only support the health of the sector and the greater deployment of renewable energy resources, but also benefit the scaling of green hydrogen.

While initial green hydrogen production is expected to be from behind-the-meter sources, greater interconnection will not only support the expansion of green hydrogen but also shore up imbalances in the current infrastructure through greater levels of dispatchable demand from electrolyzers and supporting infrastructure (e.g., desalination facilities). Engaging NEPCO, Jordan's single buyer of electricity, and working to expand grid transmission and facilitate one common transmission line could especially support near-term development. Collaborating with NEPCO or exploring other cost-efficient options and stakeholder partnerships where necessary to expand transmission will be key moving forward. Additionally, increased regional and cross-border interconnection will also support grid stability and further strengthen Jordan's ability to deploy renewables.

Significant current renewable generation means that synergies between RE and hydrogen can be realized sooner than areas with low shares of renewables, improving the economic case for hydrogen. The Jordanian government should focus on fostering regulatory and market changes to help both renewable power and green hydrogen production to scale rapidly and sustainably. This course of action will include short-term regulatory changes as well as longer-term investments and incentives in alignment with the current Investment Environmnet Law.

To leverage existing RE leadership and enable outcomes for Priority 4, Jordan should consider key actions, outlined in Figure 26 from now until 2030, 2030-2040, and 2040-2050.

Figure 26: Priority 4 Leverage RE leadership

	Timeframe	Actions	Stakeholders Involved
		• Establish a dedicated GH2 unit at MEMR to monitor projects, take ownership and execute the decisions and proposed actions issued by the National Green Hydrogen Committee. • The Unit should also take stock of all GH2 studies, feasibility analysis, RE inputs and requirements, Hydrogen investor criteria setting, and coordinate with EMRC on regulation and instructions as the need arises.	**Primary stakeholder**: MEMR, led by proposed GH2 Unit
		• Establish green certification for PtX products to satisfy the local market requirements in alignment with international standards with the objective of facilitating sale of new products on the market.	**Primary stakeholders**: MEMR, JSMO

Priority 4: Leverage RE Leadership	**Now-2030**		**Secondary stakeholders**: EMRC, ASEZA, ADC, MoENV, MoIST, Power Plants, World Bank, Other Regulators, Standard Setting Organizations
		• Work with stakeholders to do a deep dive study on international regulations to ensure compliance (e.g., ISOs, RED III or III, etc.) and identify what is needed in a Jordanian context. The priority is to respond to local market requirements.	**Primary stakeholder**: MEMR **Secondary stakeholders**: EMRC, ASEZA, ADC, MoENV, MoIST, Power Plants, JSMO, World Bank, Other Regulators, Standard Setting Organizations
		• Build comprehensive hydrogen health and safety standards for production, transport, and use of PtX products.	**Primary stakeholder**: MEMR **Secondary stakeholders**: EMRC, ASEZA, ADC, MoENV, MoT, MoIST, JSMO, World Bank, Other Regulators, Standard Setting Organizations
		• Fund R&D in priority areas (e.g., saltwater electrolysis, H2 blending)	**Primary stakeholder**: MoPIC **Secondary stakeholders**: MEMR, MoINV, MWI, Private Developers, Power Plants, MoENV, Jordan Chamber of Industry

	2030-2040	• Enable ancillary grid balancing services from GH_2 projects if power generation projects supplying hydrogen production units are integrated into the national power grid (e.g., helping provide network services to maintain reliability and security or acting as a demand response units) In cases when RE-power generated exceeds the base load requirements, efforts should be made to transfer the surplus power towards hydrogen projects	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoINV, Jordan Chamber of Industry, NEPCO, Power Companies, Power Plants, EDCO, Financial Institutions
	2040-2050	• Expand GH_2 seasonal storage solutions	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoIN, Jordan Chamber of Industry, NEPCO, Power Plants, EDCO, Financial Institutions, Academic Institutions

5. Strengthen the enabling environment

The Jordanian government is committed to putting enabling measures in place to help accelerate the growth of green hydrogen both within the country and the broader international market. These actions are focused on ensuring the proper policies, standards, and regulations are developed and resources available to help facilitate investment, trade, and an overall social license to operate.

Workforce development, adequate sectoral governance, health and safety standards, certification schemes, shipping and handling regulations, targeted R&D, and public outreach will all be crucial for the success of establishing a new sector.

To achieve this, the Jordanian government will need to collaborate with the private sector, as well as those from the public sector, academia, and other countries. These stakeholders will need to develop working groups, forums, and clear modes of information sharing to help advance green hydrogen at a global scale. To create an enabling environment and to advance Priority 5, Jordan should consider key actions, outlined in Figure 27, from now until 2030, 2030-2040, and 2040-2050.

Figure 27: Priority 5 Strengthen the enabling environment

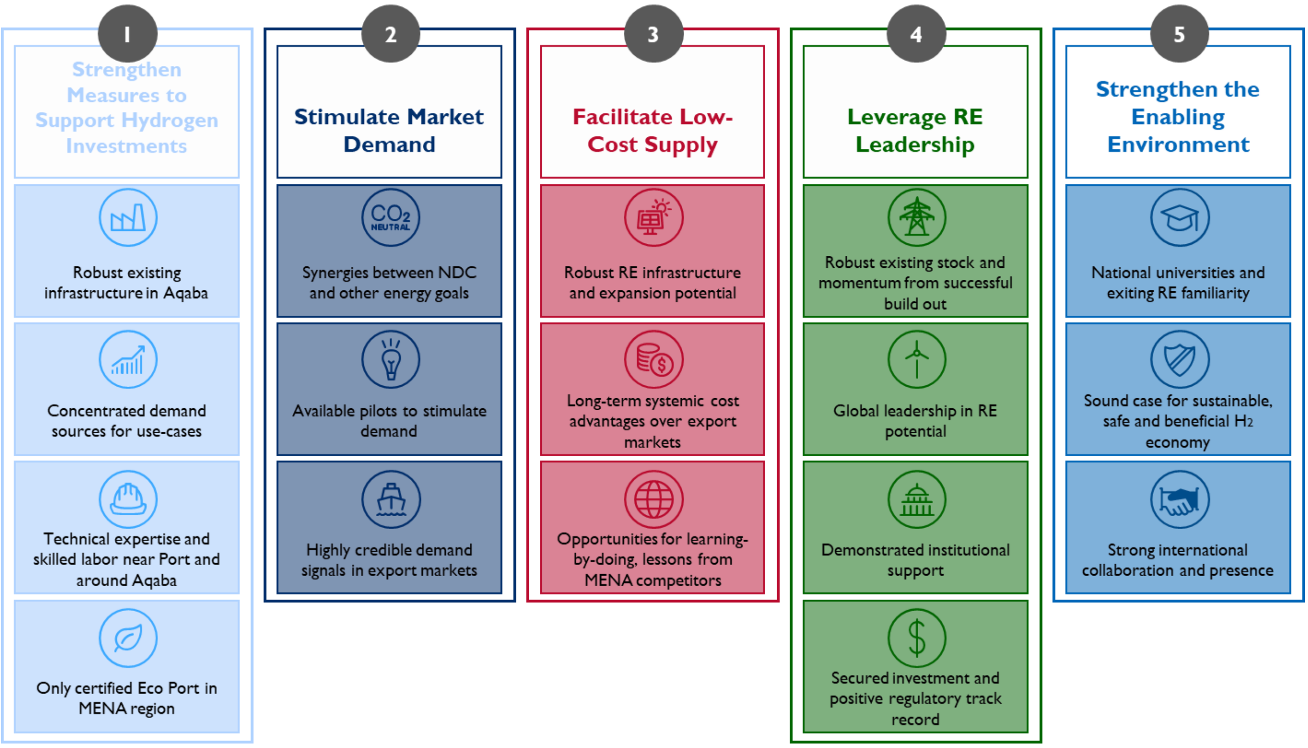
	Timeframe	Actions	Stakeholders Involved
		• Assess investments in prioritized projects to promote battery energy storage systems (BESS) and GH2 storage, (utilizing the surplus energy from RE sources for the production of green hydrogen), RE storage, and opportunities to supply grid-connected RE (e.g., curtailed power) to electrolyzes with green certification in order to help scale domestic demand and export opportunities for green hydrogen in early stages. • Collaborate with financial institutions, investors, and stakeholders like the World Bank to assess proper financing structure for pilot projects and consider which may show greatest ROI.	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoINV, EMRC, Private Companies, Private Developers, Financial Institutions, JPRC, Power Plants, MoENV, Jordan Chamber of Industry
		• Pass safety regulations and standards governing the production, transport, storage, and use of GH_2; this includes creating dedicated regulations for new hydrogen products and passing low-carbon fuel regulations per international standards.	**Primary stakeholder**: EMRC **Secondary stakeholders**: MEMR, stakeholders throughout the value chain, World Bank, Other Regulators, International Leaders, Standard Setting Organizations, Universities
		• Engage with neighboring countries to expand cross-border infrastructure to increase GH_2 potential. For example, work with MENA countries to work on potential pipeline expansion for exports or to consider shared electricity transmission lines.	**Primary stakeholder**: MEMR **Secondary stakeholders**: MoIST, NEPCO, EMRC, Power Plants, Private Developers, International Leaders
Priority 5: Strengthen the	**Now-2030**	• Review and amend existing laws to ensure GH_2 is part of regulatory frameworks	**Primary stakeholders**: MEMR, EMRC
		• Link Nationally Determined Contribution (NDC) plan and climate goals with green hydrogen priority areas	**Primary stakeholder**: MEMR

Enabling Environment			**Secondary stakeholders**: MoENV, PM Delivery Unit overseeing the EMV
		• Assess new workforce needs for project build. This also includes determining and taking measures to identify labor and education gaps, to be followed by awareness & outreach campaigns for public support. • Approach donors, international organizations, and private investors to accelerate R&D in promising areas based on market trends and potential advancements in green hydrogen.	**Primary stakeholder**: Ministry of Labor **Secondary stakeholders**: MEMR, Universities, JSMO
	2030-2040	• Collaborate with international bodies to further refine regulations, certification and safety standards as market evolves.	**Primary stakeholders**: EMRC, MEMR **Secondary stakeholders**: stakeholders throughout the value chain, World Bank, Standard Setting Organizations, Universities
		• Work with industrial and labor organizations to continuously identify workforce gaps and to develop training and curricula to address future workforce needs.	**Primary stakeholder**: MEMR **Secondary stakeholders**: stakeholders throughout the value chain, World Bank, Universities

Immediate Next Steps (between now and 2025)

For Jordan to realize its potential to reach 0.59 MMT of green hydrogen uptake for domestic sectors and 0.5 MMT of green hydrogen for export by 2030, the Ministry of Energy and Mineral Resources and its government counterparts will need to lay significant groundwork in the next few years. By leveraging current enablers (Figure 28), the Kingdom has the opportunity to begin acting on the five priority areas outlined above and can begin to set the stage for the green hydrogen economy.

Figure 28: Key enablers to drive rapid development



Additionally, given the rapid scaling needed, delaying action and collaboration with necessary stakeholders could reduce future opportunities and overall potential for leadership in this growing market. Between now and 2025, Jordan should complete the following priorities to successfully pave the way for 2030 and beyond. These include:

- Incorporate the recommendations presented in the Draft Hydrogen Strategy into Jordan's updated National Energy Sector Strategy
- Incorporate the Strategy's action plan into Jordan's Economic Vision, with special focus on the latter's short-term initiatives for the energy sector
- Update the National Green Hydrogen Strategy's key findings on a regular basis as domestic and international market conditions and technologies evolve
- Establish a senior cross-ministerial steering committee for green hydrogen in Jordan, to be chaired by MEMR
- Work with EMRC to identify and address regulatory requirements based on the findings of the Strategy
- MEMR to lead efforts to designate Aqaba as a Green Hydrogen Hub and help ADC and ASEZA establish necessary conditions for development
- Establish a unit within MEMR responsible for guiding green hydrogen initiatives, leading engagement with investors, developing and maintaining important data, identifying capacity building areas, and conducting further studies, etc.

- MEMR to sign Memoranda of Understanding (MOUs) with interested investors to support pre-feasibility studies and exploration to vet potential projects
- MEMR to maintain a pipeline of hydrogen investments by screening and prioritizing potential projects, with the prospect of carrying out that process jointly with the Ministry of Investments and other members of the senior steering committee. The value of the pipeline should be based on the strategy goals, and the selection process should refer to to-be established criteria (CBA, minimum capital thresholds, etc.) to assess feasibility. Proceeding to framework and/or investment agreements should hinge on meeting the criteria and should also be done in line with the MoU process.
- Work with USAID to channel donor support towards follow-up activities to complement the strategy and/ or implement the action plan

COLLABORATION AND COORDINATION

Collaboration and coordination are critical to successfully implementing Jordan's green hydrogen ambitions. The Ministry of Energy and Mineral Resources has been working to identify priority sectors and actions to ramp up green hydrogen in the country. As the Ministry implements this plan, it will create a clearly defined organizational structure that allows for synergies and cooperation between the different stakeholder groups, as shown in Figure 29.

Figure 29: Stakeholders of the hydrogen sector

Outside of government entities, engaging the private sector, academia, labor unions, and community organizations will be important to spur market development and social license to operate. Implementing green hydrogen into Jordan's greater economy will undoubtedly bring change, creating new jobs, while also displacing others and altering the physical environment. Working closely with communities to facilitate open dialogue and gather feedback as the green hydrogen market grows, will foster trust, and ultimately help Jordan achieve its goals in a timely manner.

Additionally, given the number of countries focused on hydrogen to support their energy and climate goals, cross-border collaboration and information sharing will be helpful in accelerating progress and making the new global clean hydrogen economy a reality. Coordinating with partner countries and developing multi-lateral and bilateral partnerships will help Jordan create more market certainty, especially as countries focus on different ways to utilize hydrogen as part of their broader decarbonization efforts. Collaborating across borders to enable information sharing and streamline regulations, frameworks, and certification schemes could also ease trade barriers and allow for quicker uptake. International coordination can foster a supportive model that contributes to the faster realization of broader climate goals.

CONCLUSION

Acting on climate change and participating in the energy transition are important priorities for Jordan as the Kingdom plans for future social, environmental, and economic resilience. Green hydrogen has an important role to play in helping Jordan achieve its Nationally Determined Contribution, energy goals, and low-carbon future.

While the emerging global clean hydrogen economy has many unknowns, hydrogen's decarbonization potential grants it a place in the clean energy system of the future. Key export markets, including Europe and parts of Asia, have set defined import targets, and have committed to clean hydrogen as a priority solution. These targets, along with further movement from countries publishing and revising national hydrogen strategies, evolving regulations and incentives, and companies reaching final investment decisions on large-scale projects, shows a promising path forward.

Collaboration, regulatory action, investment, and education in the short-term will be crucial for Jordan to scale green hydrogen for export opportunities and specific domestic sectors by 2030 and to enable scale in the future. Jordan, like its MENA peers, has significant resource advantages when it comes to producing green hydrogen, leveraging its renewable energy potential to contribute to its own climate goals as well as those of its trading partners.

The Ministry of Energy and Mineral Resources (MEMR), along with its counterparts, will play a vital role in enabling green hydrogen production and utilization in Jordan. Working together with stakeholders across the value chain, MEMR will help guide development and ensure that short-term actions within each of this Strategy's five priority focus areas are implemented in a timely manner. As the global hydrogen economy evolves and the green hydrogen sector develops in Jordan, it will become necessary to revise the targets and actions established in this draft of the National Green Hydrogen Strategy, a natural step in the evolution of an entirely new sector.

Adhering to the principles and vision established in this Strategy, and working with industry, academia, developers, and the investment community, MEMR will guide the development of the sector in a way that ensures that the significant economic and environmental benefits associated with green hydrogen accrue to the Jordanian people now and in the future.

APPENDIX A: MODELING METHODOLOGY

The quantitative predictions and recommendations in this Draft Strategy are drawn from a statistical model of the economic sectors relevant to the production, use, and export of hydrogen in and by the Kingdom of Jordan. This appendix discusses the methodology of the model. The model relies on inputs and assumptions based on prior experience and industry research to assess the possible future demand for hydrogen, determine goals for supply growth over time, and estimate the potential export market. Following an assessment of Jordan's resource endowment, the model only considers green hydrogen, which is produced via electrolysis of water powered by renewable generation.

The quantification process is split into three modules:

1. The **Demand Module** estimates the domestic demand for hydrogen based on sector-specific projections and houses estimated demand for key export markets
2. The **Supply Module** estimates the supply over time as constrained by physical and market limitations including resource availability and manufacturing capacity
3. The **Export Module** estimates the volume of demand for hydrogen and its key derivatives (e.g., ammonia and methanol) within the European Union (EU) and other relevant export markets

These modules are connected through the modeled **Levelized Cost of Hydrogen** (LCOH), an aggregative measure of cost that allows for accurate comparisons across time, sector, and jurisdiction, and determines the ability of the Jordanian hydrogen market to meet key demand and export cost thresholds. The model creates a representative 'average' LCOH for Jordan by dividing the present value of lifetime costs by the present value of hydrogen generation, as shown in Box 1.

Box 1: Formula for Calculating LCOH

$$LCOH = \sum \frac{(I_t + O_t + F_t)}{(1+r)^t} / \sum \frac{H_t}{(1+r)^t}$$

Where:

I = Investment	t = time
O = O&M expense	r = discount rate

LCOH is modeled to decline over time pursuant to Wright's Law, an observed effect common to a wide variety of industrial processes, which posits that unit costs decline as a function of production. Specifically, Wright's Law holds that each doubling of cumulative production produces a constant proportional reduction in cost, which this model assumes to be 15%. That is, per-kilogram cost of hydrogen is projected to fall by 15% for every doubling in the total amount of hydrogen produced.

For domestic demand, this model will **not factor in transportation and distribution costs**, given the relative concentration of end-use sectors will be localized in the municipalities of Amman and Aqaba. The model assessed high-impact sectors for domestic hydrogen usage: synthesis of green ammonia for use in fertilizer production, use as a reagent in oil refining, electricity production and energy storage, heavy-duty road transport, municipal transport, supply of heat for cement manufacturing, use as a reducing agent for steel production, use as an aviation fuel, residential and commercial heating, and use as a bunkering fuel for ships. Modeling of hydrogen supply for export will consider transport costs based on distances to representative import terminals in Europe and Asia and per-kilometer transportation costs.

The model generates outputs across three possible scenarios, representing different possible developments in market and policy conditions affecting the hydrogen economy. These scenarios are referred to as the **Base**, **Conservative**, and **Optimistic** scenarios, with varying assumptions and results as follows:

In the **Optimistic scenario**, the hydrogen economy faces beneficial circumstances. Early private sector investment helps hydrogen production scale more quickly, and strong global demand increases exports. Diminishing focus on legacy fuels increases hydrogen's competitiveness, speeding adoption in domestic markets. Technical barriers, such as blending in natural gas streams, are resolved, and cost-effective export by pipeline occurs earlier. Under this scenario, domestic demand could reach 128 kt by 2030, 956 kt by 2040, and 2.05 kt by 2050. Additionally, Jordan could export 700 kt by 2030, 1.82 MMT by 2040, and 4.71 MMT by 2050.

In the **Base scenario**, adoption is driven by economics, using current commodity prices and standard inflation rates. This scenario assumes neither especially advantageous nor obstructive policy and market developments. Under this scenario, domestic demand could reach 91 kt by 2030, 510 kt by 2040 and 1.12 MMT by 2050. Additionally, Jordan could export 500 kt tons by 2030, 1.08 MMT by 2040, and 2.33 MMT by 2050. Below, adoption of green hydrogen by domestic sector, jobs created, and emissions avoided are outline in Table I. This is ultimately the scenario that underpins the Draft Strategy.

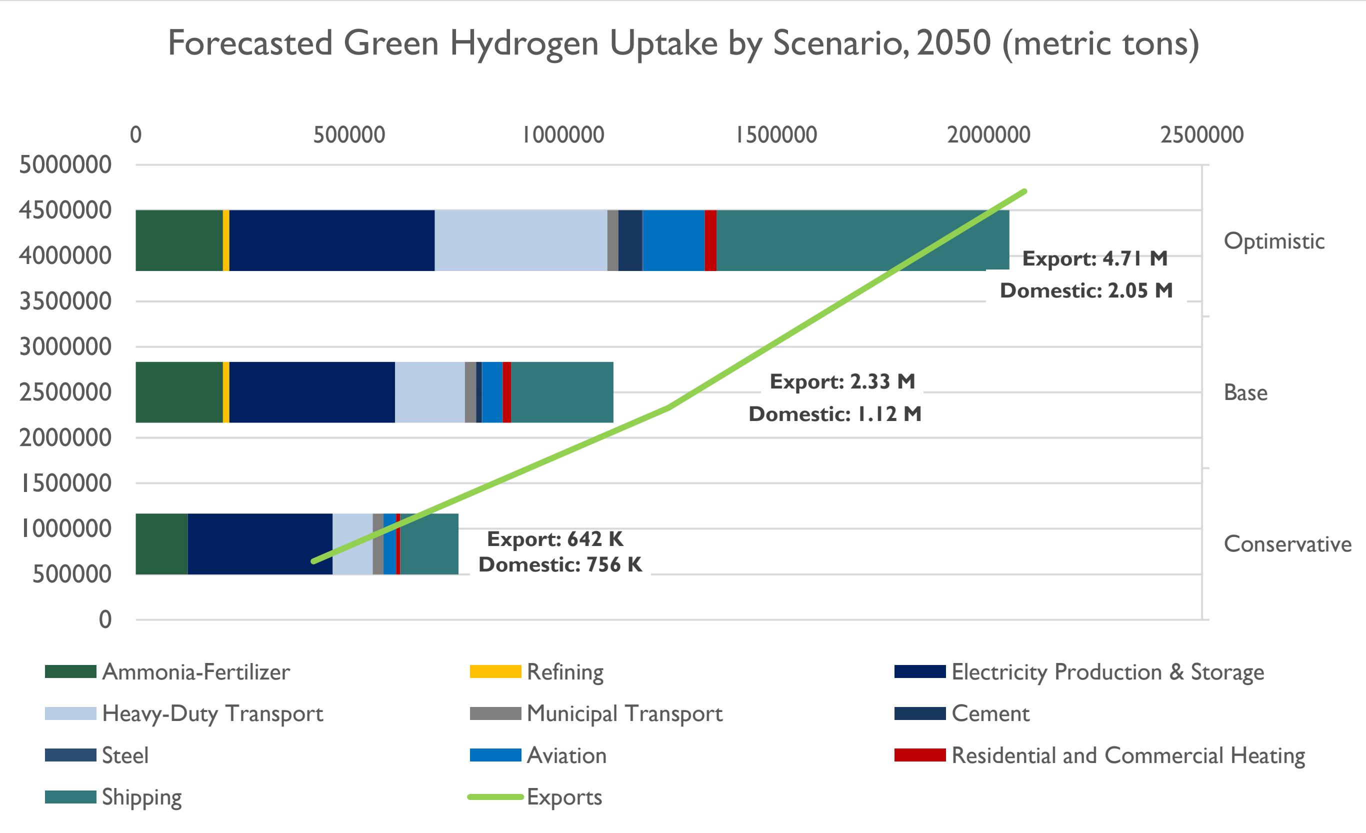
Table 1: Base scenario potential and requirements

	H2 potential (MT)		CAPEX ($/Bn)		Land (km2)		Jobs (jobs/MT)		Water (m3)		RE & Electrolyzer Capacity (GW)		Avoidable Emissions (MT CO2e)	
	2030	*2050*	*2030*	*2050*	*2030*	*2050*	*2030*	*2050*	*2030*	*2050*	*2030*	*2050*	*2030*	*2050*
Ammonia for Fertilizer	N/A	204,446	N/A	10.4	N/A	155	N/A	3,879	N/A	1.8M			N/A	N/A
Transport (Heavy Duty & Municipal)	5,119	189,610	0.2	9.6	4	144	97	3,598	46,505	1.7M			43,195	1.6M
Power Generation	84,742	388,965	4.1	19.7	64	295	1,608	7,381	769,876	3.5M			4.1M	1.6M
Refining	1,284	14,600	0.1	0.7	1	11	24	277	11,663	132,641			10,874	123,662
Cement & Steel	N/A	14,767	N/A	0.8	N/A	11	N/A	280	N/A	134,153			N/A	163,736
Aviation	N/A	48,148	N/A	2.6	N/A	36	N/A	914	N/A	437,402			N/A	7,450
Shipping	N/A	240,568	N/A	12.2	N/A	182	N/A	4,565	N/A	2.1M			69,277	2.2M
Residential/ Commercial Heating	558	19,206	N/A	1.1	N/A	15	11	364	5,071	174,484			69,277	2.3M
Total	91,702	1.12M	4.4	56.8	848	497	1,740	21,258	833,115	10.17M	5GW Electrolyzer 8GW RE	29 GW Electrolyzer 47 GW RE	4.2M	8.2M

In the **Conservative scenario**, the hydrogen economy faces stiff headwinds. Technical barriers and supply chain issues persist and hamper the unit economics of hydrogen production. Global adoption of hydrogen is slower, leading to weaker exports, and domestic adoption takes longer. Private investment is lacking, leading to later production starts and poor price competitiveness of hydrogen against incumbent fuels. Additionally, in this scenario, the refinery at Zarqa, an important early source of demand, shuts down production. Under this scenario, significant production of hydrogen does not pick up until 2032. Domestic demand is projected to reach 104 kt by 2032, 352 kt by 2040, and 756 kt by 2050. Additionally, Jordan could export 166 kt by 2032, 478 kt by 2040, and 642 kt by 2050.

The effects of the different scenarios on domestic consumption and export rates are shown in Figure 30.

Figure 30: Green hydrogen potential for domestic demand & export by 2050, based on scenario



Further assumptions of the model can be found in Table 2, below.

Table 22: Modeling assumptions

Category	Assumptions
Demand	• A recycled Haber-Bosch process, with roughly 99% efficiency, would be utilized to produce ammonia for fertilizer production • Oil refining production is not expected to grow from current rates • For any processes requiring a blending of hydrogen (blending with natural gas for power production, heating, etc.) utilizes a maximum blend rate of 15% hydrogen with natural gas • Grid composition was changed from the GIZ grid projections to account for increased renewable energy targets, affecting overall production from gas turbines over time. See Grid for grid composition calculations • Hydrogen-based storage for electricity production is assumed to not be economically viable until the % of renewables on the grid reaches 60% per GIZ • Hydrogen-based storage demand does not include capacity reserved from other use cases. All other use cases are assumed to be behind-meter and not connected to the grid for the purpose of balancing services • Heavy-duty transport fuel utilization per year assumes a Class 8 truck, and total mileage is based on US DOT analysis of shipping • Energy demand from cement production is based on global average energy utilization • Maximum blending of hydrogen in the cement sector is 39%. This is the current maximum blend rate of facilities that currently utilize hydrogen globally. Hydrogen utilization beyond this blending threshold decreases cement plant productivity. The model assumes no improvement in blending capacity over time. • Steel demand for hydrogen assumes a shift to electric arc furnacing over time for the melting of scrap steel, as this is the most energy efficient and environmentally friendly steel production process. Only 27% of energy can be utilized for iron reduction in this production pathway • Model assumes liquid hydrogen utilization in commercial flights will be viable in 2035 • Model takes an average of hydrogen composition for E-SAF and Bio-SAF for SAF hydrogen requirements, as the dominant, long-term method of production in Jordan is currently unknown • Model assumes Jordan will produce all SAF domestically • Model assumes ships will bunker fuel up to 90% of their fuel capacity. Ships do not typically fill up to 100% of their fuel tank in port • Model assumes 20% of ships will bunker in Aqaba port • Model assumes fuel capacity of a 15,000 TEU ship for bunkering
Supply	• Model assumes a maximum of 5% YoY conversion to hydrogen for existing sectors that do not have a manual supply build • Model assumes Jordan will be able to mandate blending of hydrogen in power production • Model assumes a $.55 per kg premium to convert H2 to ammonia • Model assumes a 15% learning rate for cost estimation for Wright's Law
Export	• Competitor country production assumptions are based on their published supply goals • Model assumes competitor countries will prefer to export over production for domestic utilization of hydrogen • Model assumes Jordan's exports will not grow faster than 8% YoY on average • Model assumes shipping of hydrogen as ammonia for all exports • Model assumes export shipping distance from competitor country to Hamburg, Germany for exports to Europe and to Osaka, Japan for exports to Asia. See SM for distance estimations • Asian demand comprised of Japanese and Korean demand only • Model assumes domestic hydrogen production in Japan and Korea will be minimal • Model assumes exports to Europe are preferred over exports to Asia
LCOH	• LCOH assumes behind-the-meter renewable energy production to feed electrolyzers • Model assumes 80% electrolyzer utilization

	• Model assumes ~1.6:1 ratio of renewable energy to electrolyzer capacity ratio • Model assumes utilization of PEM electrolyzers due to PEM's relatively smaller size and long-term projections for PEM to surpass Alkaline from a cost perspective
Output and other misc.	• Jobs created is based on a European study and only refers to jobs in the hydrogen sector. It does not factor any spillover effect into downstream sectors. It is also not specific to permanent vs temporary jobs (e.g., construction jobs) •
Emissions	• 3 emissions (upstream transport, downstream transport, grid losses) are out of scope for emissions calculations • Ammonia is out of scope for emissions. Emissions related to the manufacturing of ammonia currently occurs abroad • All hydrogen is green hydrogen, and all green hydrogen has an emissions factor of 0 • Power storage does not have any emissions and does not contribute to emissions savings over time • Emissions are only measured by the CO_2 Output • Phosphate Transportation is not considered

APPENDIX B: MOU GUIDANCE: ESSENTIAL FEATURES & CONSIDERATIONS

Essential features of the MOU[2]

- Clearly define outcomes expected from the feasibility study to help ensure that MEMR gains high quality insights and results from prospective investors.
- Define high level investor/developer criteria and requirements to help with company selection process and better ensure companies engaging in feasibility studies are serious about investment/project development in Jordan. For example, MEMR should consider:
  - Setting minimum criteria for investors/developers interested in conducting a feasibility study (i.e., minimum paid capital, previous successful implementation of projects similar in size (but not exclusive to green hydrogen), successful financial closings for previous projects, minimum turnover, profit, etc.)
  - Including a "catch-all" provision to ensure an investor responds to all information requests in a timely manner in order to facilitate relevant decisions related to the study to allow MEMR to adequately perform due diligence.
    - *For example: If MEMR or other members of the Steering Committee need to obtain information related to financing capabilities, and reputation, etc. to better inform future partnership*
  - Setting clear requirements within the feasibility study to demonstrate how a project will contribute to Jordan's plan in achieving its Nationally Determined Contribution tied to the Paris Agreement as well as its social, and economic goals.
    - *For example: Specifying that feasibility studies take into consideration environmental impact, particularly with regard to saltwater intake and brine discharge in the Port of Aqaba. MEMR can also consider adding a social impact assessment or estimated jobs created be included in the feasibility study*
- Add language to clearly state that MEMR can/will be entering into multiple MOUs to ensure transparency upfront and to protect from confidentiality concerns at later stages.
- Do not designate specific plots of land at the MOU stage.
  - *For example: Developers may be interested in studying more than one location and it is in the Government of Jordan's best interests to allow multiple developers to study the same areas in order to facilitate a competitive bidding process and select the best overall vendor when it is time to sign a Framework Agreement*
- Clearly define entities & personnel that will be part of the Steering Committee and/ or Working Groups to ensure necessary stakeholders are involved to evaluate MOUs and feasibility study results
  - *For example: Include all necessary stakeholders to ensure data requests and reviews happen in a timely manner. For example, consider participation from MEMR, Ministry of*

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Finance, Ministry of Investments, Government Tenders Department, Ministry of Public Works and Housing, NEPCO, EMRC, ASEZA, ADC, Ministry of Water and Irrigation

Guidance on Contracting Approaches based on Best Practices[3]

- Projects should be competitively "funneled" through increasingly competitive and evaluative stages (see the graphic below).
- The MOU stage is typically the starting point for negotiations and should set broad outlines of an agreement.
- A "Framework Agreement" is typically binding and establishes conditions and a path forward towards an "Investment Agreement".
- MEMR can choose to skip the MOU stage and proceed with Framework Agreements as with FFI, but it is recommended to hold a competitive process for awarding these agreements, and investors should reach a relatively advanced stage in project planning in order to sign

	Key Attributes	Requirements
All Interested Parties	• MEMR hydrogen unit should act as POC for all interested parties	• N/A
1 *Memorandum of Understanding*	**Manageable # (~10 suggested)** • Nonbinding statement of intent • Can include an NDA • Land not specified • Initiates broad-based studies + cooperation	• Relatively simple / easy requirements • Includes basic outlines of the project • Has a set length / period + conditions for when the MOU could be terminated
Should be done together 2 *Request for Information, Competitive Tender*	• Multiple rounds suggested for different tranches of projects (public auction) • Land specified • No more than 2-3 tenders at a time	• Must have signed NDA • Feasibility studies should be completed / advanced stage • Evaluation criteria clearly defined
3 *Framework Agreement*	**2-3 parties per round** • Binding agreement • Land leased for a fee • Regular performance reviews / stage gates	• Sets a deadline to move forward or terminate • Sets specific terms • Exclusive rights to that land if conditions are met
Project FID / Investment Agreement	**2-3 projects per round (ideally)** • Defined investment contributions / sources • Defined project roadmap and milestones • Land lease agreement signed • May include potential PPA or offtake obligations	• Financing secured, project is "bankable" • Framework conditions are met

Basic Requirements for each of the Three Stages

- **MOU:** Generally speaking, MOUs should be nonbinding and should be worded to reflect high level goals for collaboration to develop the sector and explore potential projects. MEMR should feel comfortable signing with multiple parties at this stage.
    - Pre-contractual requirements for parties seeking to sign the MOU should be simple to promote engagement and collaboration, while also screening for best / most serious investors and helping MEMR conduct due diligence to select a manageable

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number of MOU holders. **Consider collecting investor/developer criteria, including information on:**

1. Relevant experiences/track record within Jordan (e.g., including prior investments and demonstrated projects within the country, reputation/public perception, community/environmental impact)
2. Proof of adequate and properly structured financing, such as, sources of finance for the proposed project, including audited financial statements of the investor and its affiliates or letters of credit from financing institutions or other funders
3. Details on the investor's corporate organization (i.e., annual revenue, size, reputation, track record in projects- not exclusive to hydrogen but preferred)
4. Information on recent project investment decisions, including type of project, size, and timeline to FID (e.g., especially in other MENA countries)

- **Framework Agreement:** To reach the Framework Agreement stage, MEMR should conduct a competitive solicitation (perhaps beginning with an RFI) to award specific projects (including allocating land for continued study) to the best, lowest-cost, and most prepared bidders.
    - The Framework Agreement should include clear criteria for the developer to meet within a specified timeframe in order to proceed to an Investment Agreement (this stage could also include additional scoring criteria such as larger investment, greater job creation, and higher annual output of green hydrogen.)
- **Investment Agreement:** Developers who succeed in satisfying the criteria of the Framework Agreement and who are ready to make a final investment decision (FID) can sign an Investment Agreement with MEMR and move forward with project.

APPENDIX C: GLOSSARY

Glossary

Term	Definition
Blue hydrogen	Hydrogen produced from natural gas with carbon capture.
Carbon capture	The process of isolating carbon dioxide in concentrated form for use or storage. Carbon capture and storage (CCS) involves permanent sequestration of carbon, often underground. Carbon capture and use (CCU) involves putting the isolated carbon to use, for example in oil recovery. These terms are often combined as CCUS. Carbon may be captured from a point source, such as a fossil fueled power plant, or from the atmosphere in a process known as direct air capture (DAC).
Clean hydrogen	Hydrogen produced by a number of techniques with lower carbon emissions than traditional hydrogen, including electrolysis with low-carbon power and methods using natural gas feedstock paired with carbon capture.
Electrolysis	The process of using an electrical current to split water into hydrogen and oxygen.
Electrolyzer	The device used to split water, or other components, into their respective elements through electrolysis.
Green ammonia	Ammonia produced using green hydrogen feedstock, which as a result has a much lower carbon footprint than traditional ammonia.
Green hydrogen	Hydrogen produced by water electrolysis powered by renewable generation.
Grey hydrogen	Hydrogen produced from natural gas without carbon capture.
Grid balancing	Ensuring that electrical demand and supply are matched within an electrical grid. This typically requires sources of supply or demand that are "dispatchable," meaning they can be turned on or off by grid controllers.
Haber-Bosch process	The industrial process of synthesizing ammonia using hydrogen and atmospheric nitrogen.
Oil refining	The industrial process of breaking crude oil down into more valuable products, such as kerosene, gasoline, and diesel. Hydrogen is used in many of the underlying processes, including desulfurization.
Power-to-X	Using electrical power (usually renewable energy) to make synthetic fuels, ammonia, or other end products, using electrolytic hydrogen as an intermediate product. Power-to-Gas and Power-to-Liquid are examples.

Term	Definition
Synthetic fuels	Hydrocarbons, such as methane or kerosene, made using manufactured hydrogen and captured carbon, rather than extracted from existing oil reserves. Synthetic aviation fuel (SAF) is a synthetic fuel, primarily kerosene.
Turquoise hydrogen	Hydrogen produced via methane pyrolysis, with solid carbon as a byproduct.
Wheeling	Moving electricity through an electrical grid to a source of demand outside the boundaries of the grid. The electricity may originate within the grid then leave (wheel out) or originate outside the grid and travel through the grid to a source of demand that is also outside the grid (wheel through).

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