Egypt's National Low Carbon Hydrogen Strategy – FULL Version

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The intent of this document is to provide draft, high-level strategy for the future of low carbon hydrogen within Egypt, complete with the main technical details and analysis that has helped form this strategy.

A **SHORT** version of this document has been issued - which contains the key messages but without the technical details. Both documents lay out the short-term and long-term vision of the role that low carbon hydrogen can play in Egypt including the following key areas:

- International context and export market potential
- Overview of hydrogen value chain and priority end users within Egypt
- The action plan and mechanisms required to turn the vision into reality

The strategy is the start of the journey for low carbon hydrogen and will require review and updating as this emerging market matures and develops.

The intent of this full document is that it is for internal use only at the relevant ministries.

Executive Summary

Egypt will play a leading role in the supply of hydrogen and its derivatives for the developing low carbon hydrogen economy. Egypt will take advantage of its competitiveness to fulfil its ambitious plans for the hydrogen sector, targeting up to 8% (5.6 MTPA) of the tradable market by 2040 and requiring around 60 USD billion of investment.

Exploiting current experience in both grey and electrolytic hydrogen production and ammonia production and export will enable Egypt to quickly establish itself as a major global hydrogen hub. Additionally, the excellent renewables and gas reserves, combined with Egypt's strategic location, means Egypt will be amongst the world's leaders as demand for low carbon hydrogen grows significantly over the next few decades.

Egypt will cement its position as a world leader through a phased approach:

2020s – Pilot Projects

Building on Egypt's hydrogen experience the pilot projects will lay the foundations for the developing low carbon hydrogen economy and export market. Providing close support for initial projects, and establishing a fit for purpose governance structure

2030s – Scale Up

Securing market position in the growing hydrogen economy, using the lower costs for hydrogen to support the wider decarbonisation of Egypt replacing grey hydrogen. Scaling up hydrogen production to the GW scale and beyond

2040s – Full Market Implementation

Maintain market position in the low carbon hydrogen economy

Using hydrogen across society to support decarbonisation and secure Egypt's low carbon future in industry and transport

To enable the hydrogen economy to develop quickly during the pilot phase and in preparation for scale-up, Egypt will:

- Utilise the existing, substantial industry experience and knowledge
- Enable access to the significant renewable capability and capacity
- Provide support to develop at strategic locations with geographical proximity to Europe and access to global maritime traffic through the Suez Canal. Building on existing experience and infrastructure with ports and export facilities
- Establish the governance structure/legislation to minimise the barriers, including:
  - Enabling access to the necessary land infrastructure and utilities
  - Setting a clear governance structure, which simplifies decision-making to set hydrogen projects faster in motion, encouraging investments, and envisages a regular Strategy monitoring, review and update
  - Prioritise legislative and regulatory framework reviews that focus on reducing potential barriers and administrative burdens, providing both sufficient certainty and flexibility to investors and project developers
- Work with investors to consider a mix of financing mechanisms to de-risk and improve the profitability of low carbon hydrogen and stimulate its market uptake in the country

- Build on the track record of attracting overseas investment in renewables and use hydrogen diplomacy to secure international assistance for launching low carbon hydrogen projects and accelerating hydrogen technologies deployment and
- Work with international bodies to ensure transparency that hydrogen produced complies with low carbon standards with the "guarantee of origin".

The benefits to Egypt in achieving the vision:

Economic Benefit – The low carbon hydrogen economy is expected to be at least double the current demand, with some predicting it will increase almost seven times, with much of this hydrogen being expected to be traded on the international market. Obtaining a significant proportion of the market will provide a major boost to Egypt's GDP in the order of **10-18 billion USD**[1] by 2040. At the same time, Egypt should target greater amounts of the value chain, such as completing a greater proportion of the assembly within Egypt. Additionally, Egypt's expertise in DRI could also enable a quicker move to low-carbon steel, opening further lucrative markets.

Jobs – It is expected that over **100,000 jobs** will be created, a high proportion being highly skilled. With the right training, the domestic workforce will take many of these. Contracts with international companies should stress the need to maxmize the domestic value chain and workforce use. It is estimated that each 1000 MW facility would require a workforce of around 750 personnel.

Energy Security – An increase in hydrogen produced locally will provide increased energy security to Egypt, with less reliance on petroleum imports.

Decarbonisation – The development of the hydrogen economy will not only help Egypt decarbonise but enable Egypt to support decarbonisation globally.

[1] Assumes that Egypt produces between 6-10 MT of hydrogen per year at a value of around 1.80 USD/kg.

Acronyms and abbreviations

Acronym/abbreviation	Definition
ATR	Auto Thermal Reformer
BCMA	Billion Cubic Metres per Annum (of gas flow)
BEV	Battery Electric Vehicle (BEV)
CBAM	Carbon Border Adjustment Mechanism
CfD	Contracts for difference
COO	EBRD's Countries of Operation
CO2e	Carbon dioxide equivalent
CCGT	Combined Cycle Gas Turbine (Power Generation)
CCS	Carbon Capture and Storage
CNG	Compressed Natural Gas
DSM	Demand Side Modelling
EGMM	European Gas Market Model
EnC	Energy Community, also referred to in the past as the Energy Community of South East Europe
EOR	Enhanced Oil Recovery
EPMM	European Power Market Model
ETC	Energy Transitions Commission
ETS	Emissions Trading Scheme
EV	Electric Vehicles
FCEV	Fuel Cell Electric Vehicle
FOB	Free On Board
GO	Guarantee of Origin
HPU	Hydrogen Production Unit
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LCOH	Levelized Cost of Hydrogen
LNG	Liquefied Natural Gas
LOHC	Liquid Organic Hydrogen Carrier

Acronym/abbreviation	Definition
LSFO	Low Sulphur Fuel Oil
MENA	Middle East, North Africa
MTOE	Million Tonnes of Oil Equivalent
NCGH	National Council for Green Hydrogen and its Derivatives
NDC	Nationally Determined Contributions
OEM	Original Equipment Manufacturer
O&M	Operating and Maintenance
PtH	Power to Hydrogen
SEMED	South and Eastern Mediterranean
SMR	Steam-Methane Reformer
RES	Renewable Energy Sources
RES-E	Renewable Electricity in Electricity
RES-H	Renewable Energy Resources in Heat
RES-T	Renewable Energy Sources in Transport
RoR	Run of River Hydropower
TPA	Tonnes Per Annum (kTPA = 1000 tonnes per annum)
TRL	Technology Readiness Level
TSO	Transmission System Operator

1 2030 and 2040 Vision

"Egypt will be one of the global leaders in the low carbon hydrogen economy, utilising world-leading expertise and innovation in hydrogen and derivatives production/export, the excellent renewable resource, gas reserves and its strategic location."

Egypt can achieve its vision to become a world leader in low carbon hydrogen production and its derivatives by utilising the following building blocks:

- Existing strong industry experience and knowledge
- Significant renewable capability and capacity
- Strategic location, geographical proximity to Europe and access to global maritime traffic through the Suez Canal
- Existing experience and infrastructure with ports and export facilities
- Ensuring the governance structure/legislation is in place to minimise the barriers to developing low carbon hydrogen and derivatives economy. This includes:
  - Enabling access to the necessary land infrastructure and utilities
  - Setting a clear governance structure, which simplifies decision-making to set hydrogen projects faster in motion, encouraging investments, and envisages a regular Strategy monitoring, review and update
  - Prioritise legislative and regulatory framework reviews that focus on reducing potential barriers and administrative burdens, providing both sufficient certainty and flexibility to investors and project developers
- Consider a mix of financing mechanisms to de-risk and improve the profitability of low carbon hydrogen and stimulate its market uptake in the country
- Build on the track record of attracting overseas investment in renewables and use hydrogen diplomacy to secure international assistance for launching low carbon hydrogen projects and accelerating hydrogen technologies deployment and
- Work with international bodies to ensure that hydrogen produced complies with low carbon standards with the transparent "guarantee of origin".

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[2] The GDP was calculated based on consumer spending on the cost of hydrogen production if Egypt were to achieve the ambition (6-10MTPA at 1.8USD/kg) as set out in the hydrogen strategy, it did not include any additional taxes or assume a market price or foreign investment for the hydrogen as this is uncertain at this time. This and the wider economic benefits of developing a hydrogen economy should be regularly reviewed to ensure it lines up with Egyptian Growth plans.

should target greater amounts of the value chain, such as completing a greater proportion of the assembly within Egypt and manufacturing hydrogen derived products.

Jobs – It is expected that over **100,000 jobs** will be created, a high proportion being highly skilled. With the right training, the domestic workforce will take many of these. Contracts with international companies should stress the need to maximise the domestic value chain and workforce use.

Energy Security – An increase in hydrogen produced locally will provide increased energy security to Egypt, with less reliance on petroleum imports. To achieve this, it will be essential to ensure the renewable electricity used to produce hydrogen is additional (and not resulting in increased gas demand for electricity production), and a proportion of the hydrogen produced is made available to be used in Egypt's domestic market to directly replace fossil alternatives.

Decarbonisation – The development of the hydrogen economy will not only help Egypt decarbonise but enable Egypt to support decarbonisation globally.

2 Low Carbon Hydrogen Context

2.1 International Context

In May 2022, the EU unveiled its REPowerEU Plan in response to the hardships and global energy market disruption caused by the ongoing Russian-Ukrainian crisis, with the intention of ending the EU's dependency on Russian fossil fuels.

As well as increasing the ambition of the EU's renewable hydrogen production to 10 million tonnes annually by 2030, the REPowerEU Plan also sets a target of 10 million tonnes for renewable hydrogen import, also by 2030.

This represents a significant opportunity for Egypt to export hydrogen to the EU, although Egypt will not be alone in considering hydrogen exports to the region. Other MENA countries such as Morocco, Algeria, Saudi Arabia and Oman, and even as far away as Namibia, can be expected to develop projects for the supply of renewable hydrogen to the EU.

Japan is another promising large market, particularly interested in blending ammonia into their coal power stations, with an estimated demand of 500,000 tons per year into the 2040s. Ultimately Japan's hydrogen strategy suggests a demand for 20Mt of hydrogen. It is unclear how much can be met domestically.

2.1.1 Export Markets

Egypt is not alone in developing a hydrogen economy and will likely face stiff competition from countries such as Morocco, Saudi Arabia, Tunisia and Jordan that have access to high quality renewable resources. The wealth of experience operating both green and grey hydrogen stands Egypt at an advantage compared to many other countries attempting to develop a hydrogen economy. Without action on both the regulatory and investment side any advantage Egypt has will rapidly disappear as other nations develop their own low carbon hydrogen projects.

Turbulence in the energy market has resulted in countries looking to diversify their energy supply.

Power export could be maximised to neighbours such as Italy and/or Greece, in preference for domestic hydrogen production. This approach is an attractive means to balance renewables production and national electricity demand, duly considering the challenge of water scarcity. However, it does little to address energy independence and does not create value within Egypt, beyond the investment in renewables.

2.2 National Context

Being the most populous country in the region, Egypt has been facing a rapid increase in energy demand. Currently, fossil fuels (gas and oil) still account for just under 90% (88% in 20/21) of the total primary energy supply and while the country has continued expanding its renewable energy capacity, the share of renewables in total power generation accounting for 12% in 2020/2021.

In 2016 the Integrated Sustainable Energy Strategy was first issued and is currently undergoing a revision process to include an extended timeline (up to 2040), the government prioritized energy diversification strategy through the development of renewables (with an electricity generation target of 42% by 2035) as well as improvement of energy efficiency. Concerning the latter, the National Energy Efficiency Action Plan (2019-2022) focused on improving the quality of electric power transmission to decrease the losses in the electricity distribution network and on implementing energy efficiency measures - such as, e.g., renovations, rooftop PV panels and LED bulbs - in major electricity-consuming sectors, e.g., buildings.

The expansion of renewables accompanies the early initiatives to launch a hydrogen market. As of August 2023, Egypt signed 23 memorandums of understanding (MoU) for developing hydrogen production plants with partner companies, additionally during COP27 nine partnership agreements were signed with leading international developers. The agreements envisage three phases 24.63 GW of renewables to supply 9.86 GW of electrolyser capacity in the pilot phase, with an additional 57.3 GW of renewables to supply 24.55 GW of electrolyser capacity in Phase 1 and 19.35 GW of renewables and 9.4 GW of electrolysers in Phase 2. This amounts to in total 101.3 GW of additional renewables to supply 43.9 GW of electrolyser capacity. This level of ambition constitutes a core part of the hydrogen production targets proposed by this Strategy. In addition, the projects will also be considered in the updated Integrated Sustainable Energy Strategy.

Locating in clusters will provide benefits through efficiency, security of supply and cost saving (utilising shared infrastructure). Additionally, ammonia projects developed at the cluster will benefit from having access to shared pipelines and bunkering facilities at the port.

3 Strategic Role of Hydrogen

3.1 Hydrogen Production

Current annual global hydrogen demand is estimated at around 90 million tonnes, with around 70 million tonnes generated as pure hydrogen, and 20 million tonnes as carbon-containing synthesis gas where hydrogen is part of a gas mixture. This excludes hydrogen which is produced as a by-product of some industrial processes (particularly oil refining and chlor-alkali production) and then re-used as a feedstock or fuel. Egypt's hydrogen demand is estimated to be around 2.0% of global hydrogen demand.

Future production of hydrogen is expected to substantially increase as the world looks to decarbonise and improve energy security; the end users for low carbon hydrogen are discussed in Section 4.1. The rate of expansion is uncertain; there are areas where hydrogen or a derivative is essential to enable decarbonisation, and there are others where there are more cost-effective alternatives such as electrification (see Section 4.3). Therefore, there is a large range of estimates for future hydrogen demand given in the literature; we estimate that the hydrogen economy will be 60% larger by 2030 and 400% larger by 2050, with 25% of the supply traded intentionally. While the estimates may vary, the use of low carbon hydrogen as a means to achieve the 1.5C Paris Agreement climate goal is undisputed. The initial demand for low carbon hydrogen is expected to be located in the USA, Europe, South Korea and Japan, with the most significant import market being Europe.

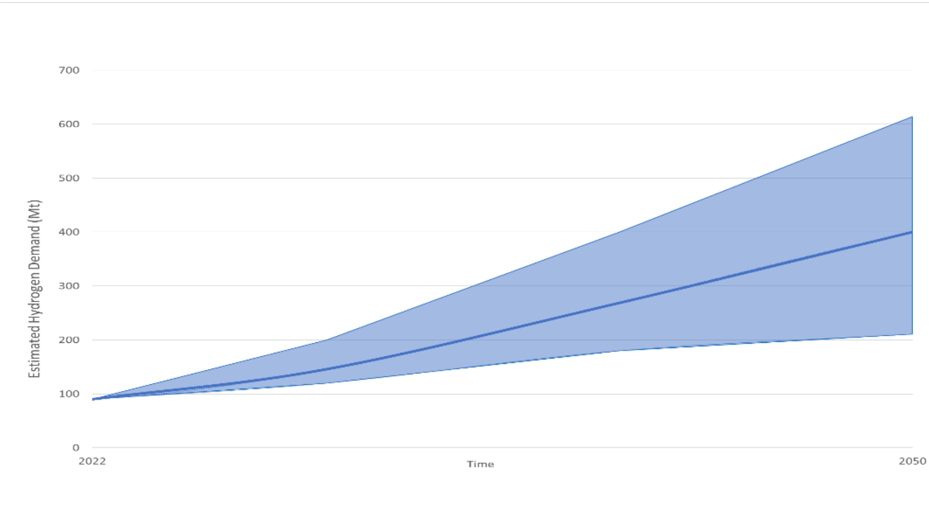


Figure 3-1 Range of estimates for future hydrogen demand

The current hydrogen demand is largely supplied by on-purpose hydrogen production plants co-located with the industrial processes or adjacent to them. These are typically owned by the company operating the refinery or chemical plant asset, or by a Third Party which is normally an industrial gas supplier. These are normally described as "captive" hydrogen plants, as they provide large amounts of hydrogen to a single facility, or at most to a local industrial cluster. In some parts of the world, such as the Gulf Coast of the USA, Canada, and Northern Europe, there are networks of hydrogen pipelines between third-party producers and industrial plants, but this is relatively unusual. Industrial gas suppliers also transport hydrogen in cylinders by truck and rail to a variety of customers, but these amounts are very small in comparison to the bulk industrial users that consume hydrogen for oil refining, fertiliser production (via ammonia) and methanol production.

The current global demand is almost entirely met through the use of fossil fuels (natural gas and coal), in so-called grey hydrogen production. This accounts for 95% of all production. Within Egypt, domestic hydrogen production is through the steam-methane reforming (SMR) of natural gas. SMR can be considered a mature technology and is widely used across the refining and petrochemical industries. Egypt has around 15 single on-purpose grey hydrogen production units for the production of ammonia as feedstock for fertiliser production. In addition, there are currently 6 refineries utilising on-purpose grey hydrogen production at their respective sites, with at least two more planned. There is little or no hydrogen infrastructure for transporting hydrogen over significant distances at scale within Egypt, as all bulk hydrogen demand is met via dedicated, captive hydrogen production plants. Industrial gas supplies do supply very small volumes of hydrogen to specialist users by truck, but these amounts are tiny in comparison to captive production plants supplying large industrial facilities.

Hydrogen production using fossil fuels as feedstock is a carbon intensive process, with 8.5 to 10 kg of CO2-e being produced per kg of hydrogen when made from natural gas, and with higher value still when using coal. As a means to decarbonise hydrogen production, new technologies have been developed based on renewable power as the feedstock for hydrogen production, as opposed to fossil fuels. This is known as green hydrogen production.

Egypt has a long history of producing and using both green and grey hydrogen. Constructed in 1960 (when natural gas was not available locally), KIMA Fertilizers Company in Aswan Governate for a time operated the world's largest green hydrogen plant at 150 MW using hydroelectric power from the Aswan Dam. The original electrolysers were replaced in 1977 and operated until 2019 when the plant was replaced with a natural gas-based grey hydrogen plant. The facility used green hydrogen to manufacture ammonia, nitric acid and ammonium nitrate. Natural gas-based technology became the dominant technology in the 60s/70s when the steam-methane reformer (SMR) technology took off. More recently Auto-Thermal Reforming (ATR) is being deployed as the preferred technology due to its improved efficiency.

Low carbon hydrogen can also be produced from fossil fuels, as long as most of the CO_2 produced in the production process is captured and then either re-used or stored. So-called blue hydrogen production is based on the same processes as grey hydrogen however with the addition of carbon capture and storage (CCS). Carbon capture could be retrofitted to an existing hydrogen production asset (in ammonia or methanol production) or incorporated as an integral part of a new purpose-built hydrogen production facility. How carbon intensive blue hydrogen depends on how much CO_2 can be captured from the reformer (the capture rate from an SMR is generally considered to be around 90% whereas from an ATR it is expected to be >95%) and the upstream fugitive emissions.

Blue Hydrogen also is reliant on CO_2 storage, there are currently several projects ongoing assessing the potential for CCS across the country

3.1.1 Grey Hydrogen

Grey Hydrogen

- Produced by steam methane reforming of natural gas or coal
- 95% of all current H_2 production
- 8.5-10 kg of CO_2 /kg of H_2

Currently, 95% of the world's hydrogen production is derived from the reforming of natural gas or other hydrocarbons, gasified coal or gasified heavy oil residues. The most widely applied technology is steam methane reforming (SMR), although auto-thermal reforming (ATR) is increasingly being applied for large-scale hydrogen production. SMR can be considered a mature technology and is widely used across the refining and petrochemical industries. Improvements in recent years have included higher performing materials, improved heat recovery, lower pressure drop and higher conversion catalysts, the efficiency of the process ranges from around 45-60 kWh of natural gas per kg of hydrogen. Integration of SMR technology into the Haber-Bosch process for ammonia synthesis is a mature technology with huge commercial competition driving continuous technology evolution. In comparison, numerous ATRs are less commercially mature the major difference between an ATR and SMR is that generally, ATR uses pure oxygen from an air separation unit, additionally, the heat is supplied directly in the process eliminating the need for a furnace. Cost effectiveness and energy consumption of these reforming technologies vary considerably with scale. Generally, these plants are increasingly being considered at a larger scale. Current evidence suggests that the majority of new plants in development today are ATR in part owing to the higher efficiency. The carbon intensity resulting from modern methane reformation plants ranges from 8.5 to 10 kg CO_2e / kg H_2, this does not include upstream fugitive emissions which could substantially increase the carbon intensity.

Grey hydrogen is considered to be high carbon and therefore is only considered in the Hydrogen Strategy to be able to compare costs.

3.1.2 Blue Hydrogen

Blue Hydrogen

- Produced by coupling SMR with Carbon capture and storage
- Not yet practiced but significant attention lately
- 0.8-4.4 kg of CO2 /kg of H2

Blue hydrogen production is based on the same processes as grey hydrogen however with the addition of carbon capture and storage (CCS). Carbon capture could be retrofitted to an existing hydrogen production asset (in ammonia or methanol production) or incorporated as an integral part of a new purpose-built hydrogen production facility.

As with grey hydrogen, two main potential technologies are Steam Methane Reforming (SMR) and Auto-Thermal Reforming (ATR). The ATR process is well established with several OEMs providing designs and is now considered to be the preferred technology, due to improved efficiency and capture rates (considered to be >95% this compares to capture rates from SMR at around 90%), for blue (and increasingly grey) hydrogen at large scale.

Blue Hydrogen also is reliant on CO_2 storage, there are currently several projects ongoing assessing the potential for CCS across Egypt. These include assessing the shallow offshore CO_2 storage opportunities, competitive advantages for Egypt and the use of CCS to decarbonize the refining and chemicals sectors.

The time required to develop plans for CCS in Egypt and subsequently develop a blue hydrogen project will likely result in the earliest blue hydrogen production facilities coming online by the late 2020s/ the early 2030s.

Depending on the process selected blue hydrogen can have a carbon intensity of between 0.8 – 4.4 kg CO_2/kg H_2, however increasingly international standards include upstream emissions in the standard (see low carbon hydrogen standards). Recent papers have been critical of the low carbon credentials of blue hydrogen owing mainly to upstream fugitive methane emissions, scrutiny will likely increase on these emissions. Even if utilizing an ATR with high capture rates blue hydrogen produced in Egypt may not meet future low carbon hydrogen standards. Therefore, Egypt should carry out a review of fugitive methane emissions and undertake suitable methane mitigation, this will result in both carbon savings and maximised use of a valuable resource.

3.1.3 Electrolytic (Green) Hydrogen

Green Hydrogen

- Produced by electrolysis of water
- Solid oxide technology has significant efficiency advantage
- Direct solar variants in development
- Minimal GHG footprint

Using electrolysers for water splitting is a technology that uses an electrical charge to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). This is often termed green hydrogen since the key inputs to this process (renewable electricity and demineralized water) can be produced sustainably.

Fundamentally, the electrolysis process converts electrical energy into chemical energy stored in hydrogen, according to the reversible reaction:

$$2\ H_2O_{(l)} \rightarrow 2\ H_{2(g)} + O_{2(g)}$$

Theoretically, the minimum energy required to drive this reaction is equivalent to hydrogen's higher heating value (HHV) when combusted in air, which is 39 kWh/kg of hydrogen.

Until 2019 Egypt operated the world's largest electrolyser, and China currently holds that record with a 100 MW. The recently announced Shell project in Rotterdam at 200 MW is likely to take that crown when it comes online

In regions of water scarcity like certain regions of Egypt, it is best to avoid creating any additional burden on freshwater usage, especially in areas where drinking water is difficult to attain. Therefore, while renewable resources might exist in different regions it is important to balance that with the water resource at each site. Green hydrogen requires substantial volumes of high purity water (13 kg/kg of hydrogen, see Section 4.7) this likely will mean that major electrolyser developments in Egypt will be located on the coast and use seawater desalination. This is also where the initial hydrogen demand is expected. Alternative sources of water such as brackish or wastewater could provide a non-freshwater source away from the coastal region, however, there may be limitations to extraction/production rates, and each site would require an environmental assessment.

Electrolytic hydrogen can be produced via several technological pathways. In the nearer term only Alkaline Electrolysis (AE) and Proton Exchange Membrane (PEM) technologies are considered to be mature, other promising technologies being developed include solid oxide electrolyser (SOE) and anion exchange membrane (AEM). R&D is happening around all technologies, which will lower the costs whilst increasing performance.

- Alkaline electrolysis (AE) – is an electrochemical cell and a well-established technology that benefits from lower capital costs and process improvements than Proton exchange membrane (PEM) technology. However, is often associated with poor current density, less dynamic operational capabilities and oxygen impurities in the hydrogen product.
- Proton exchange membrane (PEM) – splits water catalytically into protons to eventually bond with hydrogen atoms to create hydrogen gas. This technology currently suffers from higher capital costs however offers greater flexibility and dynamic response, higher current density and purity of hydrogen.

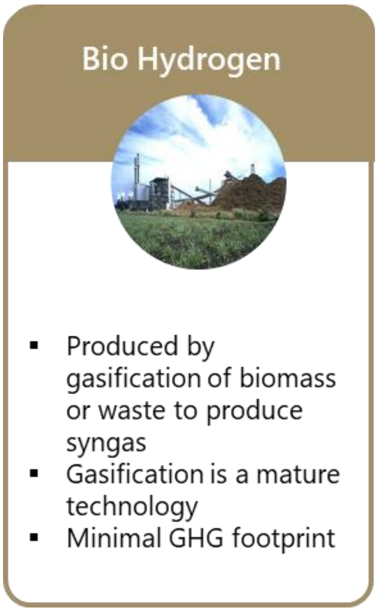
Electrolytic hydrogen is only as low carbon as the electricity used to produce it, green hydrogen requires renewable electricity to enable it to be zero carbon (excluding emissions in the supply chain). However, this also depends on whether renewable electricity is additional. The production of electrolytic hydrogen should not come at the expense of creating limitations in access to renewable electricity elsewhere across the country.

A further challenge is that production will be inconsistent, owing to the intermittency of renewable production, this will have to be accounted for in the design of the system, both in sizing the renewables adding storage (electrical and/or hydrogen), or taking grid electricity to supplement renewable production, as the amount of renewables increases this may become increasingly challenging.

The main constraint today in developing green hydrogen projects is the availability of the electrolyser stack but also the skills to develop such projects, especially if at a large scale.

3.1.4 Bio-hydrogen Production

There are currently two methods to produce bio-hydrogen:



Gasification of biomass or waste Gasification technology allows for the transformation and upgrade of solid fuel into a mixture known as syngas. This syngas can be separated and purified to produce high-purity CO_2 and hydrogen streams.

Gasification is a mature technology and traditionally comprises a gasifier fed with coal, producing syngas which is then converted to an end product via the Fischer-Tropsch process.

Recently companies have been looking to develop waste/biomass gasification to create low carbon hydrogen. Bio feedstock gasifiers are currently still mainly in the R&D phase however some technologies are in an early stage of commercialisation. The feedstocks can range from biomass (including agriculture residue) to RDF (sorted municipal waste). The gasification process has been mainly developed to produce a range of products including methanol, renewable diesel and sustainable aviation fuel, with few considering hydrogen as a product owing to the large quantities of biological CO_2 produced which has a value.

If used for biomass/waste is used for hydrogen production between 65-80 kg of hydrogen can be produced from a ton of oven-dried waste. The cost of the hydrogen produced is highly sensitive to the source of biomass and waste and the scale of operation. A review of waste carried out in 2014 estimated that Egypt produces over 50 million tons per year of municipal and agricultural waste. Approximately 20% of this waste would be non-biogenic resulting in just under 20 million tons of dried biogenic waste which if gasified to hydrogen could produce up to 1.3 MTPA of hydrogen.

A further potential option would be to produce hydrogen from Anaerobic digestion followed by reformation. Anaerobic digestion is currently being carried out at Egypt's largest sewage treatment works. Currently, the gas produced is burned in a turbine to produce electricity.

3.1.5 Pink Hydrogen

Pink Hydrogen

- Generated from nuclear power via electrolysis
- Solid oxide technology well suited with high temperature, utilising High temperature steam
- Minimal GHG footprint

Pink hydrogen is generated from nuclear power; in its simplest form, it uses the electricity from the nuclear power station to produce hydrogen via electrolysis using electricity. However, the high temperature heat produced from the nuclear island will likely work well with solid oxide electrolysers, which use high temperature steam to produce hydrogen, enabling greater efficiency for hydrogen production, and lowering the costs of the hydrogen. As an alternative to electrolysis thermochemical processes such as the iodine-sulphur process are being explored, with plans to run a demonstration in 2026.

3.1.6 Turquoise Hydrogen

Turquoise Hydrogen

- Feedstock of electricity and natural gas
- Hydrogen and solid carbon produced
- Early technology but promising for remote areas with limited electricity and water
- Minimal GHG footprint

As a hybrid between blue and green hydrogen, turquoise hydrogen uses both electricity and natural gas. Methane is pyrolyzed using electricity to produce either microwaves or plasma, resulting in hydrogen and solid carbon. This has the advantage over blue hydrogen of not requiring CCS, and green hydrogen of requiring comparatively less electricity and little water, additionally, the carbon produced has a value and is used to produce carbon fibre, carbon black or even be used as a soil enhancer. However, this technology is at an earlier stage of development with the market for the produced carbon being uncertain. It is currently unclear whether turquoise hydrogen could be considered as a major route for hydrogen production although it is likely a good option for more remote regions which have a gas supply but limited electrical and water supply.

3.2 Location Considerations for New Hydrogen Production Supply Chains

The establishment of cost-effective hydrogen supply lines from points of generation to locations of consumption is a critical component of developing a viable hydrogen market

The hydrogen production supply chain for the existing major grey hydrogen facilities within Egypt is relatively simple. Hydrogen is generated from natural gas at the point of use for hydrogen, primarily as a feedstock for refining, or ammonia or methanol production. These industrial facilities have been invariably located next to major natural gas pipelines, so feedstock supply is via short connection to these pipelines.

Currently, only very small volumes of hydrogen are transported in Egypt, and this is by truck in cylinders. However, trucking hydrogen is not practical for the scale of future production use as a hydrogen economy develops outside of captive grey hydrogen production.

For both green and blue hydrogen production, the hydrogen supply chain is much more complicated, both in terms of feedstock supply, hydrogen product distribution and (for blue hydrogen) storing/utilisation of CO_2.

The supply chain pathway for green hydrogen production comprises two main components, renewable power production, and the use of this power to drive the electrolysis process that produces hydrogen. Ideally, these would take place at the same location, adjacent to the point of hydrogen use. This would avoid the need for the transportation of power and hydrogen over a long distance. However, in reality, the optimum locations for renewable power and hydrogen use are likely to be some distance apart, and there is a choice of where to locate the hydrogen production facility. Close to the location of power production, or close to the point of hydrogen use. This is sometimes referred to as a choice of moving electrons (electricity) or molecules (hydrogen).

Given that an electrolyser might use multiple sources of renewable power (multiple solar and wind assets), it may not even be feasible to avoid power transmission over a substantial distance.

The optimum location of electrolysers compared to renewables and demand will likely only be found on a project by project basis, as well as minimising costs projects would also need to explore wider social and environmental impacts such as effluent from the hydrogen and desalination plants, additional dredging, and distance to the local population. Initially clustering the demand such as along the Suez Canal will provide opportunities to share infrastructure and utilities allowing for economies of scale for the export market, however, the impacts do need exploring.

Other Hydrogen colours

For other "colours" of hydrogen, there is less to consider. For example, blue hydrogen production requires a CCS infrastructure and therefore will, most likely be located at a CCS cluster with an existing hydrogen demand such as refineries. Pink hydrogen will be located next to the nuclear plant, enabling the use of heat from the nuclear island. Biohydrogen will normally be located near the source of biomass, especially if considering waste, to limit the costs associated with transporting the low value waste.

3.3 Hydrogen Transportation

For merchant hydrogen supply within Egypt, the options for distribution are predominantly through three methods:

- Pipeline
- High-pressure tube trailers and
- Liquefied hydrogen tankers.

Transport by road or rail is not suitable for the large volumes of hydrogen required by industrial users such as refineries and ammonia production facilities.

100% pipelines have been operated in Europe and North America for many years, and this can be considered a mature technology if the pipelines are specifically designed for hydrogen transport. The hydrogen is consumed by industrial users (chemicals, refining, and metals) as feedstock. It is estimated that there are around 1500 km of dedicated hydrogen pipelines in Northern Europe and 2600 km in the USA (particularly in Texas).

As an alternative to constructing new hydrogen pipelines, various options are being explored to make maximum use of existing pipeline assets. These include:

- Blending hydrogen with natural gas in an existing natural gas pipeline, and then using the blended gas at the destination without separation of the natural gas and hydrogen. This would typically mean using the blended gas as a fuel.
- Blending hydrogen with natural gas in an existing natural gas pipeline, and then separating the hydrogen from the natural gas at the destination. This is necessary if hydrogen is required as a pure product.
- Transporting near pure hydrogen through an existing natural gas pipeline, re-purposed just to use hydrogen.

All three of these options require evaluation of the existing pipeline to assess whether it is suitable for either blended hydrogen or near pure hydrogen use. Transportation of nearly pure hydrogen is much more onerous in terms of both pipeline and compressor constraints.

Many countries have been evaluating the potential to re-purpose existing natural gas pipelines use, both to transport 100% hydrogen and hydrogen blended into natural gas.

3.3.1 Repurposing existing natural gas networks – blended gas

Hydrogen has historically been treated as a contaminant of natural gas, with many countries and regions having specified a maximum volumetric concentration of hydrogen in natural gas. This can be as low as 0.1 vol% (UK, Japan, California). However other countries have a more relaxed standard, with France allowing 6 vol% and Germany allowing 10% hydrogen blending into natural gas in some circumstances. There has never been much pressure to relax these standards until recently because hydrogen does not occur naturally in significant amounts in natural gas production.

As natural gas is routinely transferred across national borders, it has been recognised in the EU that to facilitate hydrogen injection into major natural gas transmission networks, standards relating to the maximum hydrogen content of natural gas must be harmonised across Europe. Within the EU, there is now a strong push to establish and regulate the hydrogen backbone with a transition period until 2030. The Hydrogen and Decarbonised Gas Market Package is a proposed revision to the existing Gas Directive and Regulation. This contains several provisions for the hydrogen midstream sector to facilitate the deployment of the low carbon gas market. As one such provision, an EU-wide blending threshold is proposed to be set at 5% as of 1 October 2025. These regulations also have importance for countries exporting natural gas into the UK such as Algeria and Azerbaijan, with pipeline connections via Morocco, Tunisia and Turkey. Import of blended hydrogen into the European natural gas transmission network requires harmonisation of regulations and standards across Europe.

Whilst regulation and standardisation are barriers to re-purposing natural gas networks, there are also technical and commercial barriers to overcome. From the technical perspective, there are many trials underway relating to hydrogen blending, looking at both transmission and distribution and end-use. As one example, Turkey has been active in the testing of hydrogen blending into natural gas systems. The GAZBIR-GAZMER Clean Energy Technology Center is conducting studies and tests for blending natural gas with hydrogen and biogas which is aimed to be used in household appliances. Over the last two years, several demonstration projects aimed at hydrogen blending have been implemented, including in the Izmir and Konya regions. Another example is the HyDeploy program in the UK.

A consensus is emerging that up to 20 vol% hydrogen injection is possible with minimal investment requirements for upgrading the existing national gas pipelines, associated compressor stations, and end user appliances Above this level, required investment for upgrading compressor equipment becomes extensive, although will vary on a case-by-case basis.

The operating pressure of the natural gas pipeline at the point of hydrogen injection is likely to be higher than the available pressure of hydrogen from green or blue production, and hence a new hydrogen compressor is likely to be required. In certain cases, it might be feasible to inject hydrogen on the suction side of an existing natural gas compression station, if hydrogen and natural gas production are co-located.

3.3.2 Repurposing existing natural gas networks – pure hydrogen

Whilst the physical hydrogen readiness of a natural gas pipeline needs to be assessed at all hydrogen concentration levels, it becomes more critical as hydrogen concentrations increase above 20%

The physical hydrogen readiness of a national natural gas pipeline system essentially depends on the possible influence of hydrogen on the materials of construction used. A reduction in material toughness can be measured under the influence of hydrogen (hydrogen embrittlement). Depending on the steel grade and the operating conditions of the pipeline, this reduction in material toughness can lead to the growth of existing crack-like defects, leading to a reduction of the service life in the pipeline.

The following hydrogen damage mechanisms need to be considered when re-purposing natural gas pipelines for hydrogen use.

3.3.2.1 Hydrogen Embrittlement

Hydrogen damage is a form of environmentally-assisted failure that results most often from the combined action of hydrogen and residual or applied tensile stress. The failure modes include cracking, blistering, hydride formation and loss in tensile ductility, and the mechanism is generally called hydrogen embrittlement. Hydrogen damage is affected by:

- Hydrogen pressure
- Purity of hydrogen (quantity and type of impurities)
- Temperature

- Stress level
- Strain rate
- Material microstructure (and presence of non-metallic inclusions)
- Strength
- Condition of internal pipeline wall (inspection and maintenance history)

Molecular hydrogen is twice the size of atomic hydrogen and does not tend to cause embrittlement. However, di-hydrogen (molecular H2) can dissociate into protons H+ (atomic hydrogen), which can diffuse into and permeate through the pipeline wall; the atomic hydrogen then interacts with the inner features of the microstructure and becomes trapped at non-metallic inclusions, causing hydrogen embrittlement. Trace amounts of oxygen reduce the dissociation of H_2 into protons H+. The oxygen effectively acts as an inhibitor of hydrogen embrittlement. On the other hand, H_2S acts as a promoter of H_2 dissociation and is effectively a promoter of hydrogen embrittlement.

3.3.2.2 Hydrogen Assisted Fatigue

Carbon and low alloy steels show accelerated fatigue crack growth and degradation in fatigue endurance limits when exposed to hydrogen even at relatively low pressures. The accelerated fatigue crack growth is more pronounced at ambient temperatures and becomes less severe at elevated temperatures.

The presence of hydrogen reduces the threshold cyclic stress factor as well as fatigue life, thus fatigue cracking will be a concern if the pipeline experiences pressure fluctuations.

3.3.2.3 Material Durability for Hydrogen Service

The durability of carbon steel pipelines can degrade when they are exposed to hydrogen over long periods, particularly with hydrogen in high concentrations and at high pressures. The effect is highly dependent on the type of steel and must be assessed on a case-by-case basis.

Metallic pipes made from low strength steel, typically API 5L A, B, X42, and X46, are generally not susceptible to hydrogen induced embrittlement under normal operating conditions. There is also no major concern about hydrogen ageing effects on polyethylene (PE) or polyvinylchloride (PVC) pipe materials. Most of the elastomeric materials used in distribution systems are also compatible with hydrogen.

Hydrogen is more mobile than methane. The permeation coefficient of hydrogen is higher through most elastomeric sealing materials than through plastic pipe materials. However, pipes have much larger surface areas than seals, so leaks through plastic pipe walls would account for the majority of gas losses. Permeation rates for hydrogen are about 4 to 5 times faster than for methane in typical polymer pipes. Leakage in steel systems mainly occurs through threaded or mechanical joints.

3.3.2.4 Elastomeric Materials

Elastomers have been used as mechanical coupling seals and gaskets, meter and regulator diaphragms, boots, O-rings, flange seals, valve seats, etc. Failure of elastomers could result in leaks. The majority of failure of elastomers comes from the chemical reaction between the elastomers and the chemicals or adsorption/permeation of the chemicals by the elastomers. This attack results in swelling and softening with a reduction of their tensile strength.

3.3.3 Repurposing Existing Natural Gas Networks – Commercial Considerations

There are also substantial commercial issues to be addressed concerning hydrogen blending. Supply commitments under gas contracts are typically long term and do not include any provisions for hydrogen supply. Many pipelines operate close to maximum capacity, and hence blending of hydrogen would require less natural gas flow to be transferred. Such a reduction may not be allowable commercially. An example of a long-distance pipeline being evaluated for transportation of blended hydrogen is the Southern Gas Corridor system from Azerbaijan to Italy, which comprises the South Caucasus Pipeline (SCP), the Trans-Anatolian Natural Gas Pipeline (TANAP) and the Trans Adriatic Pipeline (TAP). The commercial issues associated with the gas supply contracts are potentially at least as challenging as the technical issues, with regards to hydrogen blending.

Other international examples are the Maghreb-Europe Gas (MEG) pipeline between Morocco and Spain, and the Trans-Mediterranean Pipeline (TransMed), which transports natural gas from Algeria to Sicily and then to mainland Italy

In 2020, eleven gas infrastructure companies published a vision of a European Hydrogen Backbone (EHB), a dedicated hydrogen pipeline transport network spanning ten European countries. This report was updated in 2021, now involving 23 Transmission System Operators (TSOs) from 21 countries. The authors envisage a pan-European dedicated hydrogen transport infrastructure with a total length (by 2040) of around 39,700 kilometres, consisting of 69% repurposed existing infrastructure and 31% of new hydrogen pipelines. This includes hydrogen pipeline connections with Morocco, Algeria and Tunisia in North Africa, as well as Turkey, the Western Balkans and Ukraine. The anticipated investment cost (medium scenario) is estimated at $56 billion.

Transporting hydrogen over 1,000 km along an average stretch of the hydrogen backbone, as presented in this report, would cost 0.11-0.21 USD per kg of hydrogen transported with 0.16 USD per kg in the central case. The capital cost of re-purposing existing natural gas pipelines is estimated at 20% of the cost of building new hydrogen pipelines.

3.3.4 Blending/deblending

If hydrogen is required in near pure after transportation by pipeline, there are three options:

- Transportation as a blended gas, followed by separation of the hydrogen and natural gas
- Transportation in a re-purposed pipeline
- Transportation in a new pipeline

Separation of hydrogen from blended gas after transportation can potentially be an attractive option where:

- The routing of an existing pipeline flows the preferred route of required hydrogen transportation
- The existing pipeline cannot be re-purposed to pure hydrogen due to material constraints and/or compressor constraints.
- A substantial level of flow of natural gas has to be maintained through the existing pipeline, but there is “space” for hydrogen addition.
- The cost of a new hydrogen pipeline is prohibitively expensive or challenging for technical, commercial or environmental (permitting) reasons.

A schematic of a transportation system with both blending and deblending of hydrogen and natural gas is shown below:

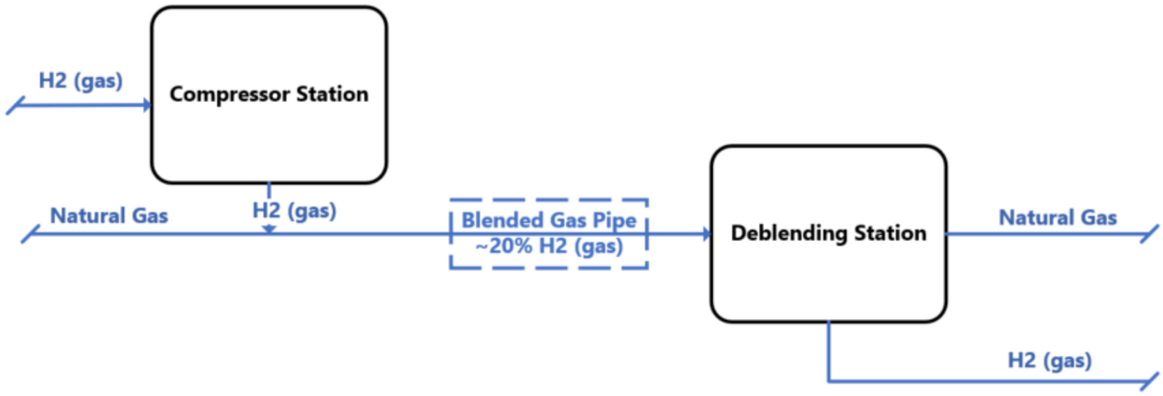


Figure 3-2 Simplified Schematic of a Transportation System

In terms of deblending technology development, Linde Engineering started the operation of the world's first-ever full-scale pilot plant in January 2022 to showcase its HISELECT® powered by Evonik membrane technology to separate hydrogen from natural gas streams flowing through pipelines. According to Linde Engineering, the blended gas can comprise 5-60% hydrogen extracted from the natural gas streams using membrane technology at the consumption point, resulting in about 90% pure hydrogen, the lower the concentration and pressure of the hydrogen the lower the efficiency of the process. This impure hydrogen is then processed using Linde Engineering's pressure swing adsorption (PSA) technology to achieve a purity of 99.99%.

A more detailed schematic of the deblending separation scheme adapted from Linde Engineering is shown below:

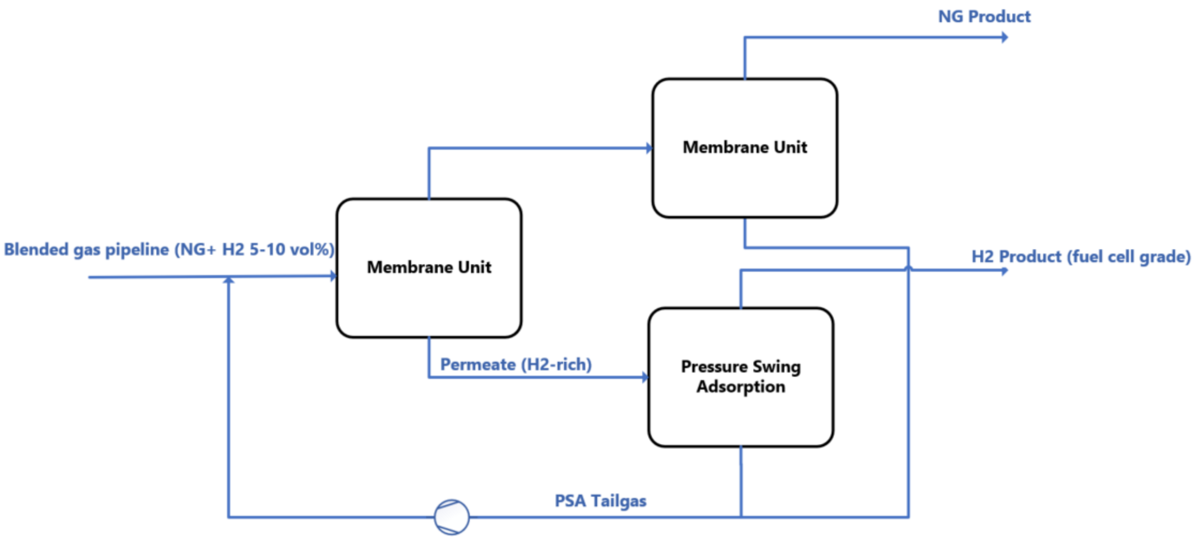


Figure 3-3 Simplified Schematic of a Deblending Separation Scheme

The process flowsheet can be optimised to use a one or two stage membrane system. The PSA tail gas flows to a compressor, which has a substantial power requirement.

It is estimated that deblending hydrogen would approximately add 1 USD/kg on top of the cost of producing and transporting the hydrogen.

3.3.5 Transport via Road Trailers

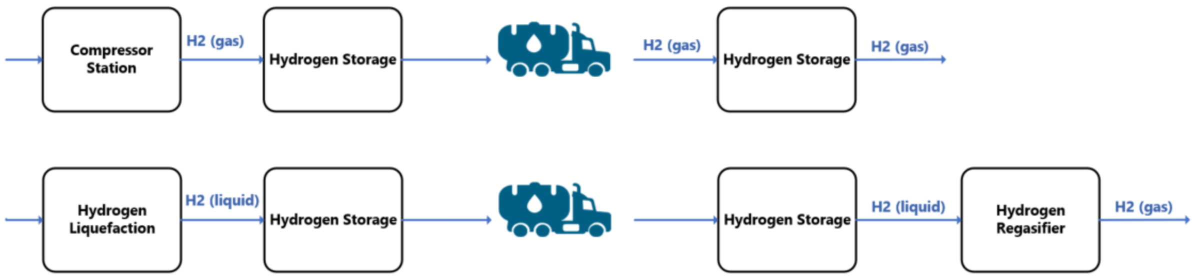


Figure 3-4 Overview of Transport via Road Trailers

The trucking of hydrogen has been utilized in several industries such as space exploration and is considered to be at a high level of technology readiness. Hydrogen can be transported using gaseous tube trucks and cryogenic liquid trailers. This option is generally advised for applications that are small /pilot scale stage of application.

Gaseous hydrogen is typically transported in tube trailers where before loading, the hydrogen is compressed to pressures of 180- 500 bar and stored in long cylinders stacked on a trailer. The truck's carrying capacity is dependent on the storage pressure within the tube trailer, with capacity currently ranging from 0.4 to 0.9 tonnes in capacity. Owing to this small capacity, it is generally considered that this transport method is mainly used for small scale operations. Currently, Linde is working to develop a truck capable of holding 1.1 tonnes of gaseous hydrogen at 500 bar, with the vehicle undergoing trials for its deployment.

Liquid hydrogen (LH_2) hauliers are generally considered more economical than gaseous hydrogen hauliers over long distances owing to the higher density of hydrogen than in its gaseous state. Tanker capacities for LH_2 can range from 3.5 – 7 tonnes in a single truck meaning fewer trucks are required to transport specified supply volumes. However, this benefit is offset against losses due to significant liquefaction investment and energy requirements and boil-off, increasing the levelised costs of transport. LH_2 tanker trucking is an established practice that has been long utilised in countries across the world.

3.3.6 Alternatives for transportation

Other options for hydrogen transportation include the use of hydrogen carriers, in which hydrogen is chemically reacted to produce another chemical before transportation, and then converted back to pure hydrogen (if required) after arrival at the destination. These are more commonly considered for shipping over long distances where pipeline transfer is not possible, although potentially could be used over shorter distances.

Conversion of hydrogen to ammonia or methanol is most attractive when these products are used directly or as low carbon transportation fuel, without the need for conversion back to hydrogen. Ammonia is a feedstock to the fertiliser industry as well as other industries, whilst methanol is also a chemical building block for many products. Both ammonia and methanol (when produced from sustainable sources) are being considered for use as shipping fuels.

Transportation of hydrogen using a liquid organic hydrogen carrier (LOHC) is also under development. Hydrogen is chemically bonded to an organic compound before transportation using the process of hydrogeneration and then released at its destination through the process of dehydrogenation. The toluene-based LOHC system hydrogenates toluene to methylcyclohexane (MCH), which is then transported to the destination point. The MCH is then dehydrogenated back to toluene and hydrogen, and the toluene is transported back to the point of departure in a circular loop. Other compounds are also being evaluated to minimise the overall cost of transportation. The de-hydrogenation process is energy-intensive, which is challenging both in terms of energy costs and associated GHG emissions.

3.3.7 Export of Hydrogen to EU

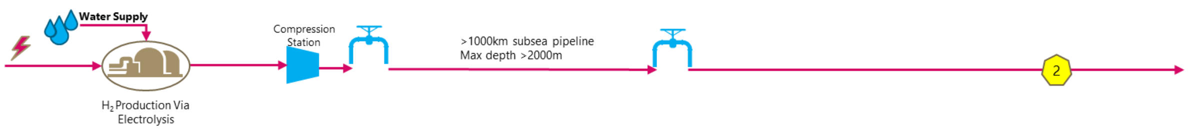
Hydrogen produced for export either as hydrogen or its derivates is expected to account for the vast majority of new production in Egypt in the short to medium term. Therefore, understanding the options for export to the key markets is essential in assessing the competitiveness of Egyptian low carbon hydrogen in these markets. With an ambition to import 10 MTPA by 2030, which accounts for >95% of the tradable low carbon hydrogen market announced to date, Europe is expected to be by far the largest market for Egypt

Currently, Egypt does not have any hydrogen infrastructure connecting to Europe, therefore it is vital to identify the most appropriate route. There are five options to transport hydrogen to Europe, each with its challenges as shown in Figure *3-5*.

1 - HVDC Subsea Cable

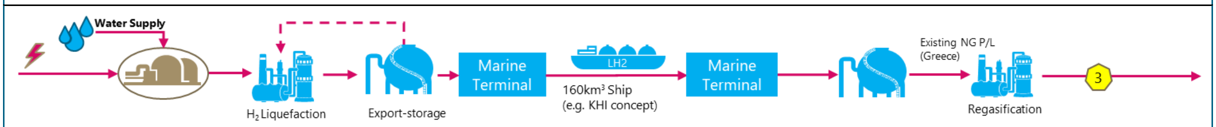
Drivers	Challenges
Established and proven technology **Minimal emissions required from supply operations** **Minimal OPEX requirements (after power generation)** **High efficiency of energy transmission along the full supply chain**	Subsea HVDC cables have high-cost requirements, especially when operating in deep water Possible need for conversion from DC to AC at destination Pathway experiences transmission losses Transmission capacity is limited to ~1 – 1.2 GW per HVDC monopole

2 - Pure Hydrogen Pipeline



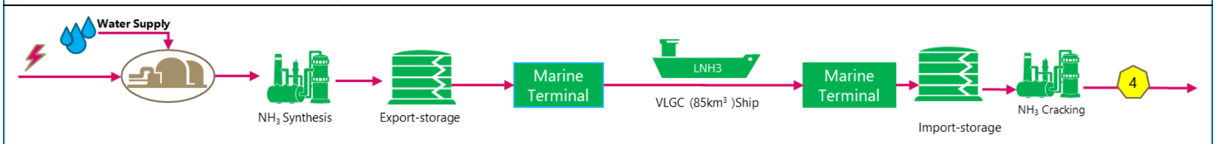
Drivers	Challenges
Offers the highest energy transportation capacity of all options **Technology is established and proven** **Additional benefits as hydrogen storage/firming asset** **Hydrogen does not undergo a phase change or chemical conversion**	High initial CAPEX requirements Requires high compression power requirements Pipelines susceptible to hydrogen embrittlement Water depth/pressure in the Mediterranean limits pipeline diameter to 30 inches

3 - Liquefied Hydrogen Shipping



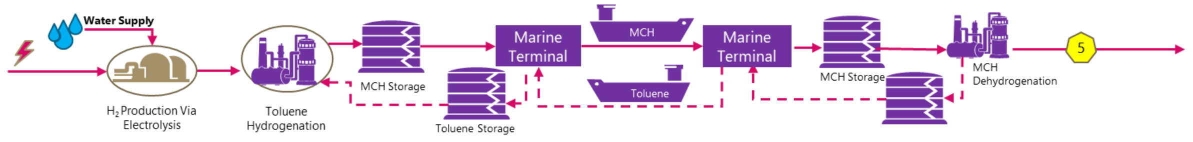
Drivers	Challenges
Able to provide high purity levels of hydrogen **Technology for liquefaction is proven (but only at a small scale)** **Limited downstream energy requirements (where utility price is higher)** **Carbon-free carrier**	LH2 carrier ships are currently only starting to be trialled. Low thermodynamic efficiencies (30% to 35%) The liquefaction process is energy-intensive, leading to low overall thermodynamic efficiencies A high boil-off rate in shipping necessitates re-liquefaction over long distances

4 - Green Ammonia Shipping



Drivers	Challenges
High hydrogen and volumetric density **Ammonia is easily liquefied** **Well-developed global transport/trade network** **Supply chain technologies well established for large-scale production**	Ammonia cracking is an immature and energy intensive technology Shipping engines require further development before being capable of burning ammonia Chemicals classed as toxic and corrosive Boil off requires reliquefication or flaring of ammonia product during storage

5 - Liquid Organic Hydrogen Carriers (LOHC) Shipping



Drivers	Challenges
Chemicals are stable under ambient conditions	Toluene/hydrocarbons must be purchased and replenished
Amenable to existing hydrocarbon infrastructure	Low wt.% capacity of hydrogen and requires the continuous transiting of organic chemicals between supply and destination
The process is derived from existing hydrogenation technologies	Dehydrogenation is energy-intensive, ongoing development of process catalysts
Process stages require comparatively low capital costs compared to other carrier shipping options	The toxicity of carriers necessitates specialised chemical tankers

Figure 3-5 Summary of Export Options to EU

3.3.8 Hydrogen Storage

As the production of hydrogen increases in Egypt, there will be a greater need for storage. This is especially the case with the increasing production of green hydrogen which relies on variable renewable energy, meaning to ensure the security of supply a large amount of storage is likely to be required. How much storage is required will depend upon the demand profile, it is expected that early adopters of green hydrogen such as ammonia and methanol require relatively consistent flows, therefore the size of storage will have to account for the variation in electricity production.

Hydrogen is relatively expensive to store, as a gas it has comparatively low energy density (1/3 of natural gas). Alternatively, hydrogen can also be stored as a liquid, as ammonia or integrated with a carrier (LOHC), however, these options have significant roundtrip energy penalties. However, the advantage of these alternatives is they are more readily transportable and can be potentially moved to more isolated pockets of hydrogen demand.

Depending on the scale of storage required there are several options for compressed hydrogen storage.

The likely storage solution for relatively small-scale hydrogen production (<200 MW) would be 500 Bar storage tanks, which cost around 2 MUSD/tonne of hydrogen stored. On a larger scale buried pipeline will likely be more economical which can store hydrogen at around 100-150 Bar and cost around 1-1.5 MUSD/ tonne of hydrogen stored. Ultimately the amount of storage required will vary from project to project based on the project's specific needs. Large amounts of storage will significantly increase the cost of a project, for example the equivalent of a days could increase the LCOH by over 30%, therefore projects often will look to minimise the hydrogen storage requirements.

The increasing penetration of renewables will require increasing amounts of energy storage to balance the electricity grid for example. One option is to balance the electricity grid by converting the electricity to hydrogen at the point where the grid is congested. Subsequently, the hydrogen could be used as hydrogen or converted back to electricity (via a turbine or fuel cell) when it is required. This can be achieved at a range of scales but is most likely more economic at a large scale in something regularly referred to as "longer duration storage". At a smaller scale batteries is a more credible option. Geological storage will be required for this scale of storage. To date, geological hydrogen storage has been limited to salt caverns and is a proven technology that has been deployed in countries such as the UK and USA.

Salt caverns are man-made underground holes created by washing salt out of large geological structures made of almost pure salt.

However, work is ongoing to establish the potential to repurpose depleted gas fields and aquifers. Hydrogen storage in depleted gas fields is being considered, although there are concerns regarding the contamination of nearly pure hydrogen with hydrocarbons.

Hydrogen storage in a cryogenic lined rock cavern (LRC) is another storage technology under development, particularly in Scandinavia. Vattenfall, SSAB and LKAB are constructing a rock cavern storage facility in northern Sweden. The 100 m^3 facility is being constructed 30 meters below ground and will begin storing green hydrogen next year. The walls of the cavern will be covered with a selected material as a sealing layer, to prevent hydrogen losses and also contamination. The rock caverns and connecting tunnels are being constructed specifically for this project. Compared to depleted oil and gas reservoirs, salt caverns offer the benefits of the large sealing capacity of rock salt and the inert nature of salt structures.

3.4 Low Carbon Standards

Various hydrogen sustainability standards are under development globally with little consensus on approach. In some regions, a "technology agnostic" approach has been taken with low carbon definitions that apply equally to green and blue hydrogen, whilst in other geographies, specific standards have been developed for green hydrogen and for hydrogen produced via non-renewable pathways. A summary of some of these standards is shown below in terms of maximum GHG intensity. The value in red represents the actual standard value, as opposed to the conversion to different units of measurement.

Table 3-1 Summary of Low Carbon Hydrogen Standards

Hydrogen Standard	Region	Threshold GHG Intensity for H2		
		gCO2e/MJ LHV	gCO2e/MWh LHV	kgCO2e/kgH2
Low Carbon Hydrogen	UK	20	72	2.40
CertifHy	EU	36.4	131	4.37
2020 Taxonomy Regulation	EU	25.0	90	3.00
RED-II planned (RFNBO)	EU	28.2	102	3.38
Gas and Hydrogen Directive	EU	28.2	102	3.38
GH2 Green Hydrogen Standard	Global	8.3	30	1.00
Low Carbon	China	121.0	435	14.51
Clean/Renewable Hydrogen	China	40.8	147	4.90
IRA Clean Hydrogen - Low	USA	33.3	120	4.00
IRA Clean Hydrogen High	USA	3.8	14	0.45

Rather confusingly, the term "low carbon" hydrogen does not have a unique definition. Generally, it is a term applied to cover all forms of hydrogen production that meet the maximum threshold GHG intensity, so covers both green and hydrogen production. However, the EU legislation separates renewable hydrogen production (wind, solar, hydro) from low carbon production, which is hydrogen production from non-renewable resources such as nuclear and natural gas with CCS. The CertifHy standard also follows this separation. Nuclear power is not considered a renewable source. Despite biomass being included in the CertifHy definition of green hydrogen, the EU does not wish to incentivise the use of biomass for hydrogen production. Hence within the EU's RED-II legislation and the definition of a renewable fuel of non-biological origin (RFNBO), this relates specifically to water electrolysis with the renewable power obtained from primarily hydro, wind and solar resources. Hence hydrogen generated from biomass cannot access the financial incentives available for RFNBOs.

One of the first standards developed is the CertifHy standard. The maximum threshold for GHG intensity is set at a 60% reduction relative to an unabated steam-methane reformer (SMR) with natural gas feedstock. This standard should be achievable for an existing SMR retrofitted with carbon capture.

The UK has adopted a Low Carbon Standard that would be achievable for an SMR or ATR with a high level of carbon capture of 90% or over and with relatively low additional supply chain fugitive GHG emissions.

The European Union has adopted separate approaches for renewable (green) hydrogen and low carbon (blue or other non-renewable pathways) hydrogen. Currently, the GHG intensity thresholds for renewable and low carbon hydrogen are the same, set at a 70% GHG reduction relative to the fossil fuel comparator. However, the EU sees blue hydrogen very much as a short-term energy transition fuel and has already stated that a more stringent GHG threshold will be implemented for plans beginning operations after January 1st 2031. The EU wishes to encourage the decarbonisation of existing grey hydrogen production through the use of carbon capture, but not the building of new blue hydrogen plants.

Both the GHG emission intensity and sustainability standards for green hydrogen production are covered under the recast of the Renewable Energy Directive (RED-II), whereas standards for low carbon from non-renewable production are covered under the new Gas and Hydrogen Directive.

China has two standards for hydrogen production. The standard for low carbon production is set so loosely that it can be achieved in an unabated coal gasification process. The standard for Clean/Renewable hydrogen is still relatively lax compared to other global standards.

In the US, the Inflation Reduction Act of 2022 (IRA) aims to promote investment into domestic energy production whilst promoting clean energy. The minimum threshold for GHG intensity of low carbon production to qualify for financial incentives is set low enough to encourage blue hydrogen production, but realistically the higher financial incentives available could only be achieved by green hydrogen production.

The UK, EU and USA standards above cover emissions across the whole supply chain, not just the point of hydrogen production. Hence for blue hydrogen production, this would include GHG emissions arising from gas production and transportation and includes fugitive emissions along the supply chain.

The Green Hydrogen Standard has the most aggressive maximum threshold for GHG intensity, which would be evaluated over a 12 month period. It was launched by the Green Hydrogen Organization, or GH2, which has a target to produce 100 million metric tonnes of green hydrogen by 2030. Green hydrogen projects that meet the Green Hydrogen Standard will be licensed to use the label "GH2 Green Hydrogen" and will be eligible to obtain and trade GH2 certificates of origin for green hydrogen and derivatives such as green ammonia. GH2 is a not for profit foundation under Swiss law. In addition to its office in Geneva, it is present in London, Perth, and Sydney It remains to be seen to what extent this standard will be adopted globally.

Maximum GHG intensity is just one metric with which to assess the sustainability of hydrogen production. Under the RED-II legislation, there are other sustainability criteria to be met for renewable hydrogen to be eligible for benefits as a Renewable Fuel of Non-Biological Origin (RFNBO). The details of these criteria were recently published in a draft delegated act, which sets out the rules by which economic operators are to comply with the requirements.

One very important concept concerning sustainable green hydrogen production is the concept of "Additionality". The EU is very keen to ensure that renewable power production used to decarbonise national grids (by displacing fossil fuel-based power production) is not diverted to green hydrogen production. Hence there will be clear rules for new green projects to ensure that the renewable power generation on which this production relies is "additional" to the existing national power generation capacity. This principle is likely to be applied to hydrogen imports. For example, Germany's National Hydrogen Strategy states that trade in gas should not "impede the supply of renewable energy, which is inadequate in many cases, in the developing countries"

There are other sustainable criteria still under development relating to "geographical correlation" and "temporal correlation". The details around these criteria are complex and hard to understand, especially when translated from potential projects within the EU. However, they do have substantial importance to those countries looking to export hydrogen and its derivatives into the EU to qualify under RED-II incentives.

The trading of certificates in renewable power production is a much more established practice globally compared to the trading of renewable or low carbon hydrogen certificates, which is still at an early stage of evolution. Energy Attribute Certificates (EAC) are used to trace renewable power and are the preferred way to document and report renewable energy consumption. Each EAC represents unique ownership of 1 MWh of renewable energy that has been produced and injected into the grid.

In Europe, the Association of Issuing Bodies (AIB) develops, uses and promotes a European, harmonised and standardised system of energy certification for all energy carriers. This is known as the European Energy Certificate System (EECS). Under this, Guarantees of Origin (GOs) have the purpose of showing to a final customer that a given share or quantity of energy was produced from renewable sources. Member States in the EU can issue GOs for electricity, gas (including hydrogen) and heating and cooling. GOs are a purely voluntary system used by businesses, public institutions, and households in Europe.

In North America, Renewable Energy Certificates are used as a market-based instrument that represents the property rights to the environmental, social, and other non-power attributes of renewable electricity generation. Similar to Europe, RECs play an important role in accounting, tracking, and assigning ownership to renewable electricity generation and use. On a shared grid, RECs are the instrument that electricity consumers must use to substantiate renewable electricity use claims.

Outside of North America and Europe, International Renewable Energy Certificates (I-REC) are being traded, primarily for renewable electricity. The issuer of I-REC in Egypt is the Green Certificate Company (GCC). As an example, I-RECs have been delivered to Scatec Solar for a wind project in Egypt.

Whilst these standards can potentially be extended for certification of hydrogen supply chains, GO schemes specifically for hydrogen are under development. The most advanced of these is the CertifHy scheme. CertifHy GOs are intended to allow end-users to consume Green and Low Carbon Hydrogen across the EU, regardless of their location. The CertifHy Guarantee of Origin scheme is considered essential for labelling the origin of the product providing transparency to consumers and creating market pull for green and low carbon hydrogen. A pilot was launched involving Air Liquide and Air Products, speciality chemicals company Nouryon, retailer Colruyt Group and the energy utility Uniper. The CertifHy scheme is compliant with AIB's EECS (European Energy Certificate System).

Historically, REC schemes have mainly focussed on counting the number of MWh generated from a renewable power source, without much consideration to the time of day and week it was generated, and the variability of the power generation over short periods. However, the variability of renewable power generation typically has an impact on its value in the context of the overall grid it is connected to. Often there are times when there is more renewable power available than the grid requires, leading to the curtailment of renewable resources. At other times there might be periods of low wind and power production, leading to more fossil fuel-based power generation to supply the grid. From the perspective of electrolyser operation, it is desirable to smooth out as much as possible the electricity supply, which is possible if there is a grid connection. However, regulators are wary of the transport of electricity from renewable sources to green hydrogen production facilities for at least two reasons. Firstly, there is the potential to take grid power at times when renewable resources are limited, and the carbon intensity of the mixed grid is high. Second, if the grid is used to balance out the power supply, there is a risk that the cost of these balancing assets is transferred to the grid operator, not the renewable power producer. As a result of these concerns, there has been a move (particularly in the EU) towards the need to demonstrate a "temporal correlation" between renewable power production and green hydrogen generation, intending that the generation and consumption take place at the same time.

The EU regulations relating to the production of green hydrogen and the need for temporal correlation are still evolving, particularly regarding the period to be used for the correlation. Periods as short as every 15 minutes have been discussed, although a minimum frequency of one hour is more likely in the final agreed regulations. The importance of this legislation to Egypt and other countries looking to export green hydrogen to the EU is that the rules for green hydrogen production within the EU are also likely to be applied to green hydrogen imports. One option to limit the impact of the need for temporal correlation is capital investment in battery storage at the point of renewable power generation, to smooth the electricity supply profile.

The EU regulations on green hydrogen (as an RFNBO) also include the concept of "geographical correlation" whereby fuels can be counted as fully renewable only when both the electricity generation and the fuel production plants are located on the same side in respect of the grid congestion. It is currently unclear how this concept could be applied to imported green hydrogen.

When developing its Hydrogen Sustainability Standards, Egypt will need to consider the following as a minimum:

- Whether to develop separate standards for renewable hydrogen and non-renewable hydrogen production or to develop a single low carbon standard that is more technology pathway agnostic.
- Whether the standard applies across the whole supply chain of hydrogen production (for example, upstream oil and gas sector emissions for blue hydrogen), or just the point of hydrogen production. For blue hydrogen production, it will almost certainly be essential to consider lifecycle emissions for upstream gas production, at least if the blue hydrogen is intended for export.
- Additional sustainability criteria that should be included in addition to minimum threshold values for GHG intensity. For example, this could include guidelines on water use, in terms of performance and water source selection.
- To what extent will Guarantee of Origin (GO) and Renewable Energy Certificate (REC) schemes be required will be required to substantiate compliance with these sustainability criteria. If exporters of hydrogen and its derivatives will be reliant on the quality of these schemes to demonstrate compliance with regulations in exporting countries, Egypt will need to ensure harmonisation with regulations in these markets. Alignment with the CertifHy scheme could be a means to easily facilitate hydrogen export to the EU.

- The extent to which the grid transmission system can be used for load smoothing and backup, to boost system availability for green hydrogen production.
- Whether the sustainability standards developed will just apply to domestic production and use or will also apply to imports and exports.
- How to ensure that growth in renewable hydrogen renewable power generation is not at the expense of decarbonisation of the Egyptian national grid.

4 Hydrogen Value Chain

4.1 End Users

Egypt already produces and uses approximately 1.5 million tonnes annually of grey hydrogen, produced from the steam-methane reforming of natural gas. Approximately two-thirds of this hydrogen is used in the production of grey ammonia, with the rest split between the use of hydrogen in refinery processing and methanol production. Whilst the Egyptian steel industry does not directly generate hydrogen as a separate product, natural gas is also reformed to syngas (containing hydrogen) as part of the direct reduction process, and there is additional scope to substitute natural gas use for green hydrogen.

Refineries produce hydrogen-rich gas as a by-product of gasoline production, and for many more simple refineries, this is sufficient to match the hydrogen demand for the hydroprocessing of products to meet fuel quality standards. For this reason, some Egyptian refineries have not required substantial quantities of on-purpose hydrogen generation. Refinery configurations that have higher levels of conversion and upgrading have much larger hydrogen demands, that cannot be met using by-product hydrogen alone. Hence new hydrogen production facilities are often a key component of new oil upgrading complexes.

The MIDOR refinery located in Alexandria is a complex refinery with substantial hydrogen production, and the new ERC residue upgrading refinery in Cairo also has a large hydrogen production plant. The Assiut Hydrocracker Complex under construction will also have a large hydrogen production plant using natural gas as feedstock. Decarbonisation of hydrogen production at Egyptian refineries could be accomplished at a major scale through the retrofit of carbon capture technology, or at a smaller scale through the incremental addition of green hydrogen. Carbon capture and transfer to storage are likely to be more challenging in central Cairo and Assiut than in Alexandria, which is likely to be more suited to an industrial cluster project around CCS. Hence the MIDOR refinery might be a priority for the preliminary screening of blue hydrogen production through the retrofit of an existing plant.

Egypt is a global producer of ammonia, and very well placed to convert at least some of its existing grey hydrogen production with green or blue hydrogen.

Full conversion of one of Egypt's direct reduced iron (DRI) plants to green hydrogen use is likely to be very capitally intensive, but there could well be scope for a pilot demonstration project that incrementally adds hydrogen to the shaft furnace.

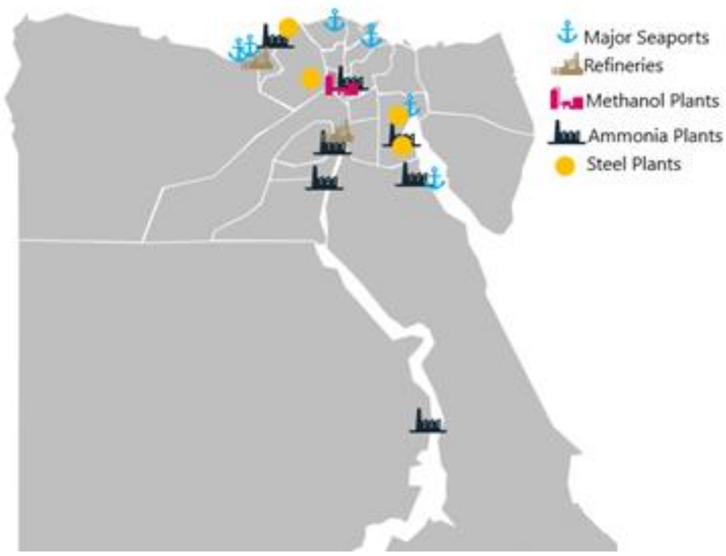


Figure 4-1 Simplified Overview of Industrial Locations

4.2 Hydrogen Applications

Industrial sectors within Egypt with potential for future hydrogen demand are: Refining, Ammonia (and processing to nitrogen-based fertilisers), Methanol production, and Steel production.

Table 4-1 Summary Overview of Hydrogen Applications

Class	Possible role of hydrogen
Feedstock for industry	Taking advantage of the specific thermo-chemical properties of hydrogen rather than just heating value.
Transport	Hydrogen can be used in fuel cells to efficiently generate electricity for an electric vehicle.
Fuel for industry	Displacing natural gas as a fuel source for industry in furnaces, boilers, and kilns.
Power and grid balancing	Similar to a battery – The generation of hydrogen with excess power and then converting back to power when there is a power shortfall.
Export	Providing a mechanism for exporting Egypt's renewable energy.

4.2.1 Ammonia

Ammonia is a compound of nitrogen and hydrogen and has historically been produced using the Haber-Bosch process. Production is energy intensive consuming around 1.8% of the global energy output, the majority of which is from hydrogen production (methane reformation or coal gasification) and as a result is responsible for 500 MT/y CO2e (1.8% of global emissions).

Egypt has a long track record with producing, storing, and transporting ammonia, and is the 9th largest global exporter, exporting 160ktPA (125 MUSD) predominately to India, Turkey, Israel, and Greece.

Figure 4-2 KIMA 1200 tpd ammonia plant in Aswan Governorate, Egypt

(https://www.stamicarbon.com/news/urea-plant-kima-egypt-successfully-operation)

Today Ammonia production in Egypt is around 6 million tonnes. The total hydrogen production capacity to support this ammonia production is around 1 million TPA.

Traditionally the primary market for ammonia was fertilisers, with the market worth around 63 USD billion, with Russia historically the main exporter with around 12% of the market. However, with trading conditions changing there is likely a substantial opportunity for Egypt to fill that market. As the world population increases demand for ammonia as a fertiliser is expected to increase. Increasingly low carbon ammonia is expected to increase its market size.

Demand for ammonia is also expected to increase from new sectors, predominantly for shipping with ammonia (along with methanol) seen to be key to helping the global shipping decarbonise. New uses also include as a method of transporting and storing hydrogen, with the ability to crack ammonia back to hydrogen (see Section 3.3.7), but also co-fired in a coal plant. Ultimately ammonia could also be used to directly produce electricity as a reductant in the steel industry. None of these applications is being used commercially today.

Based on the international gas price forecast produced for the Energy Strategy by 2030 green ammonia is likely to have a lower LCOA than grey or blue ammonia[3].

Additionally, green hydrogen will likely appear even more attractive if:

- The general ammonia market recognises a premium for green ammonia to produce fertilisers and chemicals;
- Technology advances more quickly than anticipated to create new pathways for green ammonia production, for example, high temperature electrolysis and improvements to the Haber-Bosch synthesis process;

[3] Assuming grey is produced via an SMR and blue is produced using an ATR

Egypt currently has substantial ammonia production. An estimate of the operating companies, locations and hydrogen quantities utilized in ammonia production is tabulated below.

Table 4-2 Current Hydrogen Demand for Ammonia Production in Egypt

	Company	Location	2020 Capacity (KT product)	Approx H2 Production (kTPA)
Ammonia	Abu Qir Fertilizers & Chemical Ind. -AFC (AQF) (I)	Abu Qir, Alexandria	360	66
Ammonia	Abu Qir Fertilizers & Chemical Ind. -AFC (AQF) (II)	Abu Qir, Alexandria	330	60
Ammonia	Abu Qir Fertilizers & Chemical Ind. -AFC (AQF) (III)	Abu Qir, Alexandria	400	73
Ammonia	Egyptian Fertilizer Co - (Egyfert) I	Ain Sukhna, Suez	396	73
Ammonia	Egyptian Fertilizer Co - (Egyfert) II	Ain Sukhna, Suez	396	73
Ammonia	Alexandria Fertilizers Co. - (AlexFert)	Alexandria	396	73
Ammonia	Helwan Fertilizer Co - (HFC)	Helwan	396	73
Ammonia	Misr Oil Processing Co - (MOPCO)	Damietta (III)	396	73
Ammonia	Egyptian Agrium Nitrogenic Products Co. SAE (EAgrium)	Damietta (I & II)	792	145
Ammonia	El Nasr Company for Fertilizers and Chemical Industries (SEMADCO)	Suez II	132	24
Ammonia	Al-Nasr Co. for Coke & Basic Chemicals	El-Tabbin, Helwan	33	6
Ammonia	Egyptian Basic Industries Co. (EBIC)	Ain Sukhna	660	121
Ammonia	Egyptian Chemical Industries Co. (KIMA)	Aswan	726	133
Ammonia	El Delta Company for Fertilizers and Chemical Industries (ASMEDA)	Talkha I (2 Trains)	120	22
Ammonia	El Delta Company for Fertilizers and Chemical Industries (ASMEDA)	Talkha II (1 Train)	420	77

The total hydrogen production capacity for ammonia production is around 1 million TPA. Replacing the current hydrogen demand with a low carbon alternative could result in a carbon saving of 14 MT/yr.

4.2.2 Methanol

Conventional methanol is produced by reforming natural gas and then converting the resulting syngas mixture, carbon monoxide and hydrogen, to pure methanol. Methanol is used as a feedstock to the industrial and consumer products market (~55% demand), and as an energy and fuel substitute (~45% demand). Today, the main application of methanol is the feedstock for producing formaldehyde. There has been an increase in the consumption of methanol for the production of dimethyl ether (DME) and Methyl tertiary-butyl ether (MTBE), which are a diesel alternative and gasoline additive respectively.

Renewable methanol is an ultra-low carbon chemical produced from sustainable biomass, often called bio-methanol, or from carbon dioxide and hydrogen produced from renewable electricity (referred to as e-methanol). In the latter process, the reformer unit in the conventional design is replaced with electrolytic hydrogen production and carbon neutral carbon feed. Municipal solid waste (MSW) can also be used to produce methanol, with the biogenic content of the feedstock counting as producing renewable methanol

The diagram below from the Methanol Institute shows the available feedstock for both conventional and renewable methanol production.

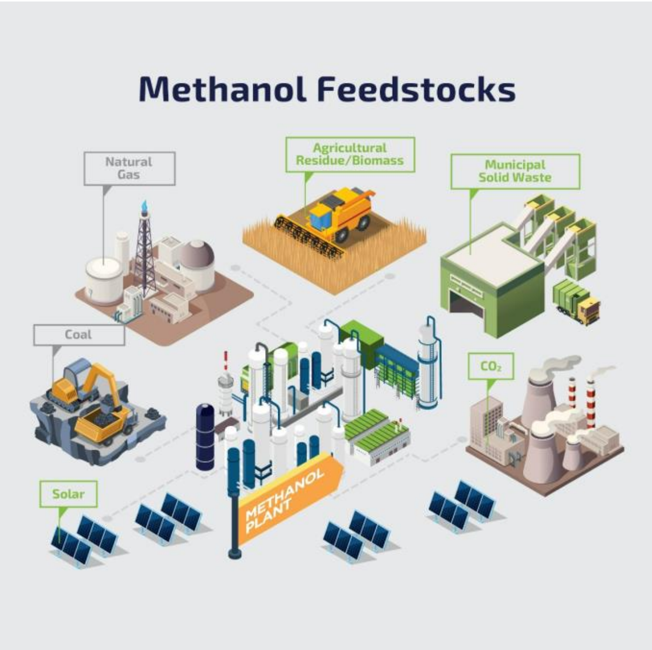


Figure 4-3 Summary Methanol Overview

When methanol is used as a fuel, such as planned for shipping, it releases CO_2 back into the atmosphere. If the source of the CO_2 is biogenic, this overall process is seen from a lifecycle as being carbon neutral, and hence also seen as an acceptable environmental solution. There is significant global debate though as to the acceptability of using fossil fuel-derived CO_2 as the feedstock for e-methanol production. Some people see this as a good thing to do, as at least the CO_2 emissions from the first combustion are re-used, halving total emissions from the combined first and second uses. Others see this as unacceptable, as there are still substantial CO_2 emissions and there is a risk that re-using fossil fuel-derived CO_2 in this way "locks in" the original use of fossil fuels. The EU's view on this is moving towards allowing financial incentives for the use of fossil fuel-derived CO_2 for e-fuel production over the next decade as a short-term energy transition measure, but only to allow financial incentives for biogenic CO_2 use in the longer term. Within the shipping industry itself, Maersk has started a clear preference for biogenic CO_2 as feedstock for e-methanol production.

If Egypt wishes to base its e-methanol production on biogenic CO_2, a key challenge for this renewable methanol production via electrolysis is sourcing significant biogenic CO_2 supply. The most attractive sources of biogenic CO_2 typically are fermentation processes, including bioethanol production. However, this is limited in Egypt. There is also potential for carbon capture of CO_2 from biomass-fired power production, but again biomass resources for this are limited.

Direct air capture (DAC) technology can be potentially used for e-methanol production, although the costs of DAC need to substantially reduce to make this attractive.

Bio-methanol could be produced in Egypt through the gasification of biomass sources, which would not require the production of hydrogen as an intermediate product. MSW could also be converted to bio-methanol via gasification in Egypt, but again this is more of a separate pathway to renewable methanol outside of hydrogen production.

Egypt can also consider e-fuel production using fossil fuel-derived CO_2, with the risk of there being no substantial export market for e-fuels produced from non-biogenic sources of CO_2. Due to the likely shortage of biogenic CO_2 in many countries, it may be that fossil fuel derived CO_2 does have a long terms future as a feedstock, just with a lower product premium.

Global conventional methanol prices have increased recently from 400 USD/ton to 600 USD/ton as a result of the ongoing energy crisis, reflecting higher feedstock costs.

There is no established global market for renewable methanol, making it difficult to assess the premium this might have over conventional (fossil fuel-derived) methanol. Conventional methanol would be of very little interest to shipping companies as a marine fuel, as it would offer no decarbonisation premium and is likely to be more expensive than other fossil-fuel derived marine fuels such as very low sulphur fuel oil and marine diesel. Hence the future growth potential for methanol as a shipping fuel is purely for renewable methanol.

Renewable methanol could become viable if the following conditions are met:

- A green market develops for methanol and methanol derived products, such as plastics.
- The shipping industry adopts renewable methanol as a low carbon fuel and is willing to pay a premium for it versus high carbon fuels.
- Methanol becomes a hydrogen vector, gaining premium value as a low emissions energy carrier.
- High natural gas prices reduce the competitiveness of natural gas in conventional methanol production, meaning that renewable methanol no longer needs to be sold at a premium to be cost-competitive.

Table 4-3 Current Hydrogen Demand for Methanol Production in Egypt

	Company	Location	2020 Capacity (KT product)	Approx H2 Production (kTPA)
Methanol	Emethanex	Damietta	1260	268
Methanol	Delta Co for Fertilizer & Chemical	Talkha	33	7

4.2.3 Oil Refining

When hydrogen demand exceeds internal by-product production, additional hydrogen is typically produced using steam methane reforming of imported natural gas or excess fuel gas. The trend towards increased hydrogen consumption in refineries is related to tightening supplies and price premiums associated with sweet/light crudes, progressive tightening of sulphur specifications on consumer fuels and marine bunkers, and a shift towards upgrading, including "bottom-of-the-barrel" processing.

Schemes such as RED II allow green hydrogen feedstock to be counted towards renewable energy requirements in fuels and this appears to be potentially cost effective compared to biofuel alternatives.

Green hydrogen is starting to be used to decarbonise refineries through projects such as REFHYNE in Germany. However, owing to the decarbonisation potential of

- Low emissions fuel standards are introduced in Australia along the lines of the European RED II scheme, creating a high value market for green hydrogen; and
- Future fuel sulphur level reduction regulations are predicated on the use of renewable hydrogen in the hydrotreating processes.

The oil refining sector is considered to have moderate dependence on hydrogen for decarbonisation. Alternatives, such as CCS, may be used on the larger processing unit such as the FCC.

Egypt has a large refining industry, which uses hydrogen as a feedstock. Some of this is provided from hydrogen-rich gas produced as a by-product of catalytic reforming, and some are provided from on-purpose hydrogen production plants.

The current on-purpose hydrogen production capacity within Egypt is summarised in Table 4-4 below. This is produced by the steam-methane reforming of natural gas.

Table 4-4 Current Egyptian on-purpose Hydrogen production for Refining

	Company	Location	Approx H2 Production (kNm³/h)	Approx H_2 Production (kTPA)
Refinery	Alexandria Petroleum Co (APC)	Alexandria	1.1	1
Refinery	Amreya Petroleum Refining Co. (APRC)	Alexandria	4.5	3.5
Refinery	Alexandria Mineral Oil Company (AMOC)	Alexandria	14	11
Refinery	Middle East Oil Refinery (MIDOR)	Alexandria	60.5	47
Refinery	Suez Oil Processing Co. (SOPC)	Suez	3.9	3
Refinery	Egyptian Refining Company (ERC)	Cairo	100	77.7

Some of these small hydrogen plants may not operate at times, depending on the overall refinery hydrogen balance. Total Egyptian refinery hydrogen demand is dominated by the two large plants at MIDOR and ERC. Total refinery hydrogen production capacity is therefore around 143 kTPA, with MIDOR and ERC accounting for over 85% of this capacity.

In addition, the Amerya National Refining and Petrochemicals Company (ANRPC) in Alexandria produces excess hydrogen-rich gas as a by-product of the catalytic reformer which is currently burned as a fuel. In future, this could potentially be supplied to other facilities in the industrial cluster such as APC.

Further planned investment in new refinery hydrogen capacity is summarized in Table 4-5. The Red Sea National Refining and Petrochemicals Company design is at an early stage, and the hydrogen production capacity has not been established yet.

Table 4-5 Planned Additional Egyptian Hydrogen Demand for Refining

	Company	Location	Approx H2 Production (kNm³/h)	Approx H_2 Production (kTPA)
Refinery	Assiut National Oil Processing Company (ANOPC)	Assiut	97	75
Refinery	Red Sea National Refining and Petrochemicals Co.	Suez	N/A	N/A

4.2.4 Iron and Steel

Primary steel in Egypt is largely produced through the Direct-Reduced Iron (DRI) process. In this process route, iron ore is reduced to sponge iron using syngas as the reductant. Natural gas is reformed into hydrogen and carbon monoxide. This is different from the blast furnace route that uses coal (converted to coke) as the main fuel. Electric arc furnaces then convert the DRI product to raw steel. The DRI route based on natural gas already offers a lower carbon pathway than the blast furnace route via coal and coke.

Whilst the DRI process uses hydrogen as a reductant, it is important to clarify that the syngas used in this process cannot be directly replaced by hydrogen with carbon monoxide playing also playing an important role as a reductant. The industry has suggested that around 20% of the syngas could be replaced with hydrogen however moving to a 100% hydrogen system would require a new shaft furnace to be installed.

The DRI plants in Egypt are summarised in Table 4-6.

Table 4-6 Current Direct Reduced Iron (DRI) Production Capacity in Egypt

Technology	Operator	Plant	Location	Capacity	Modules	Product	Start-up	Status
MIDREX	Ezz Steel	EZDK II	Alexandria	0.72	1	CDRI	1986	Operating
MIDREX	Ezz Steel	EZDK II	Alexandria	0.80	1	CDRI	1997	Operating
MIDREX	Ezz Steel	EZDK III	Alexandria	0.80	1	CDRI	2000	Operating
MIDREX		ESISCO	Sadat City	1.76	1	HDRI / CDRI	2015	Idle
HYL/ENERGIRON	Solb Misr	Suez Steel Company	Suez	1.95	1	HDRI / CDRI	2013	Operating
HYL/ENERGIRON	Ezz Steel	Al Ezz Flat Steel Co	Suez	1.90	1	CDRI	2015	Operating

Ezz Steel in Alexandria was established as the Alexandria National Iron and Steel Company (ANSDK). EZDK is the abbreviation of the Al Ezz Dekheila Steel Company.

It is understood that the ESISCO (Beshay Steel) plant at Sadat City is currently Idle. Hence current Egyptian production capacity is around 6 million TPA.

The Egyptian Iron and Steel Company is the only company in Egypt that uses blast furnaces to convert iron ore to sponge iron. It received coke from the Nasr Coke Company.

The two main process licensors for DRI production are MIDREX and DANIELI/TENOVA (owners of the HYL/ENERGIRON technology). An estimate of the potential for hydrogen consumption in DRI production can be made based on a MIDREX estimate of the incremental hydrogen that can be fed to an existing DRI process without major equipment replacement. This is 30 kNm^3/h per 1 million tonnes per annum of DRI production. Hence 6 million TPA DRI capacity equates to 180 kNm^3/h of hydrogen demand, which equates to 140 kTPA of hydrogen.

This would displace around one-third of current natural gas use. 100% displacement of natural gas by hydrogen is technically feasible (according to MIDREX) but would require complete replacement of the shaft reformer section. Decarbonisation of steel production in this way is likely to offer substantial competitiveness advantages as future global demand for low carbon steel ramps up. The EU's proposed Carbon Border Adjustment Mechanism (CBAM) will favour low carbon steel imports into the EU.

4.2.5 Transport

Marine shipping

The marine shipping industry consumes 300 million tonnes per year of oil fuel - around 10% of global transportation fuel demand (Agarwal, 2019) and is a significant contributor to global GHG emissions. Heavy fuel oil (HFO) is the most widely used fuel today (Allied Market Research) followed by Marine Gasoil (MGO), while natural gas is only used by around 2% of the global fleet. In the near term it is expected that MGO and very-low sulphur fuel oil (VLSO) will be the predominant marine fuels (Repsol, 2019) provided that they can comply with IMO sulphur emissions restrictions.

The use of alternative fuels such as green methanol and green ammonia offers some of the most cost-effective mechanisms for complying with GHG emissions reduction regulations.

- Green methanol - When used as a marine engine fuel, conventional methanol has 90-95% lower SOx, 30-50% lower NOx, 5% lower CO_2 and 90% lower PM than a Tier II compliant HFO engine (Man Energy Solutions.). When running with green methanol the SOx and PM emissions would be negligible, and CO_2 emissions would have been offset by the CO_2 capture required during production.
- Green ammonia - Ammonia has the key qualities of a low carbon economy fuel – higher energy density than hydrogen and zero carbon and sulphur free emissions when combusted. There are currently no commercial ships running on ammonia. The ammonia storage and transport infrastructure are well developed globally with significant international trade. Ammonia's shipping routes are well established and there is a comprehensive network of ports globally able to handle ammonia shipments at a large scale.

Land Transport

Following the discovery of oil in the 1860s, crude oil based liquid fuels have dominated the transportation industry. These fuels have a high energy density, are cheap and abundant and can be handled safely and easily. The energy in these fuels is harnessed into movement with internal combustion engine (ICE) technology. In the last decade, powering vehicles using electric motors and batteries (BEV) has become increasingly popular, not only do BEVs produce no NOx, but they also have lower lifecycle GHG emissions and increasingly lower lifecycle cost. Hydrogen can provide an alternative to BEV, using a fuel cell to produce electricity, which then powers an electrical motor.

Hydrogen vehicles (FCEV) have several strengths and weaknesses when compared to BEV

- Strengths – the main strengths of FCEVs are the range of the vehicles and the refuelling time. In addition, in regions with poor existing electrical infrastructure hydrogen can be transported to the region and stored.
- Weaknesses - the energy efficiency is roughly a third of BEV, this is due to the efficiency of the electrolyser (currently around 70%) and fuel cell (<50%), ultimately meaning it costs more to run an FCEV. The comparative cost of vehicles is also higher. Availability of hydrogen, generally electricity is widely available.

Due to the generally poorer cost competitive nature of FCEVs compared to BEVs, they are only expected to be deployed where BEVs are not suitable or there is poor availability of electricity. These likely include heavy-duty vehicles/buses which are required to drive long distances, high-demand vehicles, where the charging time makes BEV unsuitable, mining vehicles (especially where flexibility is a key requirement), and long-distance trains (where demand makes it uncompetitive to electrify).

Aviation

The aviation sector is considered a sector that is difficult to decarbonise, as it is not suited to electrification, at least beyond short-haul flights.

Hydrogen is seen as an option for decarbonising the sector either through being used as a building block in sustainable aviation fuel (SAF) or directly as hydrogen.

The most likely decarbonisation pathway for aviation is the widespread adoption of SAF, especially as it makes use of the existing infrastructure in terms of the aeroplanes themselves and airport refuelling logistics. Hence SAF is considered a drop-in replacement.

There are many potential process pathways to produce SAF, only some of which involve the use of hydrogen. The most promising pathways are shown schematically below:

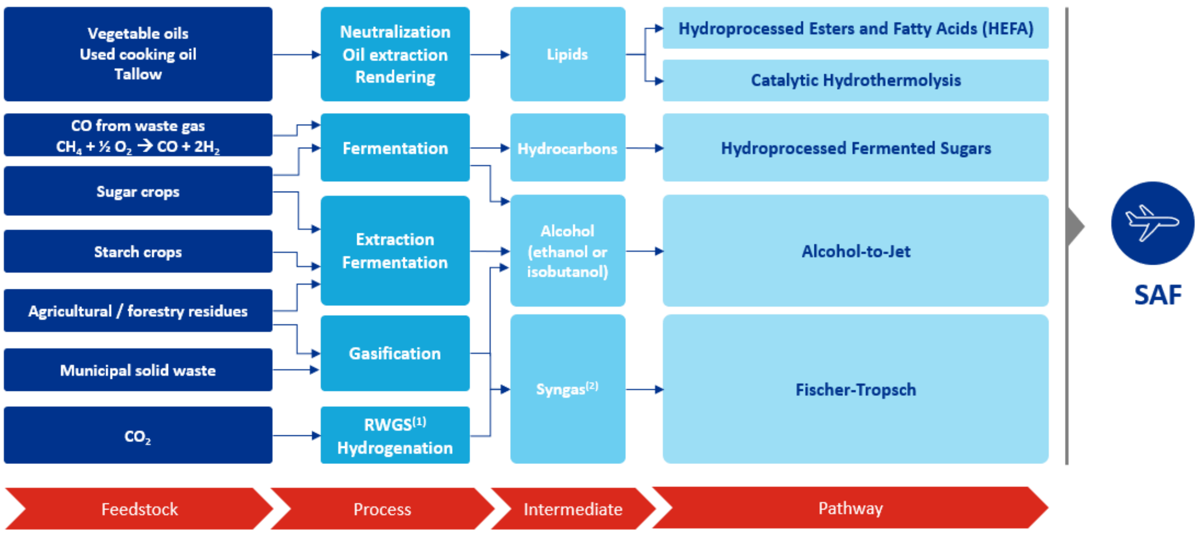


Figure 4-4 Overview of the SAF process

From a technology deployment perspective, the most advanced technology for producing SAF is the so-called HEFA route, using vegetable oils. Hydrogen is used as a feedstock in the hydroprocessing of vegetable oils and this is one potential application of green hydrogen, but these opportunities are relatively small.

In a similar way to e-methanol production for shipping, e-fuels that use green hydrogen and CO_2 as feedstock are seen as a potential long-term solution to produce SAF. Similar arguments can also be expected around the use of biogenic and non-biogenic CO_2 as feedstock. When producing SAF, there are several potential pathways for e-fuels. The syngas mixture of CO and hydrogen can be converted using the Fischer Tropsch process to produce synthetic aviation fuel. Alternatively, the gas mixture can first be converted to e-methanol or another e-alcohol, and then subsequently converted to SAF.

SAF production is also seen as a premium product to be derived from MSW gasification, again without the need for intermediate hydrogen production.

The EU, under its ReFuelEU Aviation component of the "Fit for 55" package, is introducing mandates for SAF production. The exact target numbers have yet to be finalised, but the 2050 target is likely to be that SAF should comprise 63% of all aviation fuel in the EU, and this could be as high as 85%. Intermediate targets are planned for 2025, 2030 and 2040, The EU is also planning to introduce sub-mandates for e-fuel in aviation, to encourage their development and deployment. This could be as high as 0.7% in 2030, 8% by 2040, and 28% by 2050. The very low sub-target for e-fuels before 2040 reflects the speed at which the EU expects e-fuels for aviation to become cost-competitive versus the other SAF pathways.

It is unlikely that there will be a substantial export market for e-fuels used as a SAF alternative before 2040, as other process routes are likely to be more cost-competitive. Egypt could consider setting its mandates for SAF production, specifically encouraging e-fuels as a pathway, and a means to establish an industry. Otherwise, e-methanol production for shipping is likely to be a more attractive proposition.

4.2.6 Heat

A major use of natural gas is for the production of heat. Hydrogen can provide an alternative and be blended into the gas network or replacing natural gas entirely

Generally, blends of hydrogen at 10-20% are not expected to require significant investment in new burners. There are still some concerns if CNG is used widely in vehicles with limits closer to 2-5% owing to the impact of the higher pressures involved. Although this is only an issue if hydrogen is blended into the grid which is not unlikely to be the case until well beyond the operational life of the CNG vehicle. These blends are not expected to cause problems for turbines although variability in the composition may cause instability.

Moving to higher concentrations is summarised in Table 4-7 below:

Table 4-7 Summary of heating end users versus H2 concentration

End user	Response to <10%-20% hydrogen	Response to >10-20% hydrogen
Residential applications (e.g. water heating, cooking appliances)	No significant impact.	Replacement burners or new appliances required
Vehicle refuelling systems	Hydrogen can cause embrittlement in high pressure compressed natural gas (CNG) tanks Countries limit hydrogen content to 2-5% by volume if CNG refuelling is possible	Not suitable for high pressure tanks used in CNG applications Beyond current CNG limits
Gas turbines	Low blends are unlikely to affect turbines but variability in composition can cause instability	New combustors are required but variability in the composition may cause instability
Industrial – Heat	No impact	Replacement burners or new equipment are required. Potential downstream impacts for products such as urea that rely on captured CO_2

For lower temperature heat, such as for residential and some industrial applications electrification, via the use of heat pumps, will be the most economic option.

4.3 Priority Ladder

The analysis of the current and future hydrogen supply and demand, together with the assessment of the national and international socio-economic contexts has identified the following priority actions required to maximise the impact of the marginal hydrogen produced.

Table 4-8 Applications for hydrogen

Application	Incumbent	Dependence on Hydrogen for decarbonisation	Economic Gap	Ready by 2030
Ammonia	Reformed methane, then Haber Bosch	High, alternative electrochemical synthesis at low TRL	Low, especially for the export market	
Methanol	Reformed methane then reacts with the catalyst	High, although limited by the availability of biogenic CO2	Med, biogenic CO2 would have to be acquired	
Oil refining	Reforming methane or light ends	Med, reliant on CCS for the majority of emissions savings	Low, Green hydrogen is competitive with grey in the 2030s	

Application	Incumbent	Dependence on Hydrogen for decarbonisation	Economic Gap	Ready by 2030
Iron and Steel	Reformed methane to DRI	Med, CCS is an option and full electrification (although low TRL)	Med, new major plant items required	Expected to be available around 2030
Transport - Cars	Petrol/Diesel	Low, likely higher costs compared to electrification	Expected to be higher than diesel/electrification	
Transport - Buses	Diesel	Low, likely higher costs compared to electrification	Expected to be higher than diesel/electrification	
Transport - HGV	Diesel	Med, competitive with electrification at longer distances	Expected to be higher than diesel	
Transport - Mining	Diesel	Med, competitive with electrification	Expected to be higher than diesel	
Transport - Rail	Diesel	Med, competitive with electrification at longer distances	Expected to be high than diesel and potentially electrification	
Transport - Aviation	Jet Fuel	High, although electrification may be possible on some routes	High but the only low carbon alternative for longer routes	SAF will be available by 2030
Heat – Low Temp	Natural gas	Low, likely higher costs compared to electrification	Higher cost than natural gas to 2040 and electrification	Safety trials planning for 2025
Heat – High Temp	Natural gas	Med, technologies more developed than electrification	Higher cost than natural gas to 2040 and electrification	Some applications will be available
Power – Longer duration storage	n/a	Alternatives such as CAES and pumped storage	Uncertainty surrounding the cost of utilizing geological storage	Beyond salt caverns, geological storage is still to be tested

Table 4-9 Summary of Hydrogen End Users

Hydrogen Use	Fossil Fuel Competition	Additional Low Carbon Options
Feedstock for ammonia production	Natural gas-based ammonia production	
Use of ammonia and methanol as marine fuels	Diesel, LSFO, LNG	Renewable LNG, biofuels, electric
Transportation fuel for buses and HGV	Crude-derived diesel, CNG	Renewable diesel, CNG, EV
Aviation fuel derived from e-methanol and other e-pathways	Crude-derived jet fuel	Sustainable aviation fuel (SAF) derived from biogenic sources
Fuel for power generation	HFO, natural gas	Renewables
Fuel for industrial and commercial heating	Fuel oil, natural gas	Bioenergy, Electric-driven heat pumps
Fuel for domestic heating, including district heating	Fuel oil, natural gas, butane	Electric-driven heat pumps, energy efficiency

4.4 Current Hydrogen Production in Egypt

Egypt has a long history of producing and using both green and grey hydrogen. Constructed in 1960 (when natural gas was not available locally), KIMA Fertilizers Company in Aswan Governate for a time operated the world's largest green hydrogen plant at 150 MW[4], using hydroelectric power from the Aswan Dam. The original electrolysers were replaced in 1977 and operated until 2019 when it was replaced with a natural gas-based grey hydrogen plant[5]. The main driver of this switch was to free up power generation capacity. The facility used green hydrogen to manufacture ammonia, nitric acid, and ammonium nitrate. Natural gas-based technology became the dominant technology in the 60s/70s when the steam-methane reformer (SMR) technology took off. The scale of green hydrogen production at the Aswan facility has only been matched worldwide in late 2021 by a new 150 MW electrolyser plant in China's Ningxia Autonomous Region[6].

The majority of the hydrogen demand is detailed in Section 4.2, however, hydrogen is also produced as a by-product of several petrochemical and chemical processes, such as ethylene cracking, chlor-alkali (CA), propane dehydrogenation (PDH), and dehydrogenation of ethylbenzene to styrene. Sometimes this hydrogen is sold in pure form as an industrial gas, sometimes burned as a fuel (typically saving natural gas use), or in some cases vented. In Egypt, by-product hydrogen is expected to be produced at the plants listed in Table 4-10.

[4] https://www.nrel.gov/docs/fy10osti/46676.pdf
[5] http://41.222.168.85/ProjectDetails.aspx?id=10
[6] https://fuelcellsworks.com/news/the-worlds-largest-green-hydrogen-project-with-a-150mw-electrolyser-comes-online-in-china-el-periodico-de-la-energia/

Table 4-10 Estimated Current Locations of By-Product Hydrogen Production in Egypt

	Company	Location	Capacity Basis	2020 Capacity (KT product)
Chlor-Alkali	Trust Chemical Industries (Sanmar)	Port Said	NaOH	265
Chlor-Alkali	Egyptian Petrochemicals Company (EPC)	Alexandria	NaOH	228 (T/Day)
Ethylene	Sid Kerir Petrochemicals Company (SIDPEC)	Alexandria	Ethylene	375
Ethylene	Egyptian Ethylene & Derivatives Co (Ethydco)	Alexandria	Ethylene	460
PDH	Egyptian Propylene and Polypropylene Company (EPPC)	Port Said	PDH	300
Styrene	Egyptian Styrene and Polystyrene Production Company (ESTYRENICS)	Alexandria	Styrene	Shutdown

Estimates have been made of current global hydrogen demand, with a census for total on-purpose hydrogen production (excluding by-product production) of around 90 MTPA. Hence current Egypt's hydrogen demand is estimated to be around 2.0% of global hydrogen demand or 13% of current gas demand.

Considering the above, the status of the current hydrogen production, demand and associated infrastructure in Egypt can be summarised as follows:

- 15 single on-purpose grey hydrogen production units to produce ammonia as feedstock for fertiliser production.
- There are currently six refineries utilising on-purpose grey hydrogen production at their respective sites, with at least two more planned.
- No green hydrogen production, after the decommissioning of the KIMA Fertilizer electrolysers in 2019.
- No merchant hydrogen supply market beyond very small volumes.
- No hydrogen pipelines, or transportation of hydrogen at any scale.
- No hydrogen storage facilities.
- No known use of hydrogen for heating purposes.
- No known hydrogen use in mobility applications.

4.5 Opportunities for Developing a Hydrogen Economy

Based on the current estimates for blue and green hydrogen:

- Blue hydrogen is not expected to be available in Egypt until around 2030 (it is estimated that it will take at least 5 years to develop projects) and therefore unlikely to be economic unless gas prices fall below the current forecasts and there are other mechanisms, such as a carbon price to drive investment.

- There is a credible cross-over point around 2030 where green hydrogen becomes lower cost than grey. This is expected to encourage replacing current Egyptian grey hydrogen production with increasing blends of green hydrogen, this will likely be limited by the local grid capacity and water availability, and potentially delayed if significant wheeling charges are applied pushing up the cost of hydrogen. Conversely, other mechanisms such as CBAM will accelerate the use of green hydrogen.
- After 2040 it is expected there will be increasing volumes of green hydrogen directly replacing natural gas, with the price of green hydrogen likely to be competitive with natural gas by the mid-2040s. This is likely to happen initially through blending into the gas grid. This would be accelerated if Egypt had a carbon price, or other mechanisms to promote decarbonisation

Egypt has a long history of producing and using both green and grey hydrogen and is estimated to currently produce around 2% (1,418 kTPA) of global hydrogen demand, and until 2019 they operated the world's largest alkaline electrolyser at 150MW

Short-term: 2020–2030

For the next ten years, we expect to see a substantial increase in ambition initially at pilot scale increasing in size, as renewables capacity and international demand for low carbon hydrogen (driven through policies such as REPowerEU, Fit for 55 and CBAM), and derivatives increases. It is recommended that Egypt should focus on:

- Rapid expansion of infrastructure required to support a fast-growing hydrogen economy including renewables capacity and associated infrastructure, development of desalination capacity, and bunkering facilities at key locations
- Use of low carbon hydrogen as raw material in industry; predominantly for the production of ammonia for both fertilisers and shipping, with slowly increasing volumes in the steel sector
- Futureproofing of natural gas assets, such as pipelines and power stations to be hydrogen-ready.
- Investigations into the potential of CO_2 storage, and upstream gas emissions to support the development of future industrial decarbonisation/blue hydrogen projects.

The development of the nascent hydrogen industry in this phase would be initially based on smaller scale projects, supported by national authorities and international financial institutions.

Mid-term: 2030–2040

In the medium-term increased infrastructure, favourable legislation, and increased technical know-how is expected to reduce the cost of low carbon hydrogen production and its derivatives. This in turn could see the first economically viable projects coming online. During these years it is recommended that Egypt focuses on:

- Maximising export of green hydrogen and its derivatives
- Production and consumption of low carbon hydrogen for the domestic market with increased demand mainly from ammonia, methanol, refining and steel sectors.
- Domestic use of low carbon hydrogen in the power sector as a carrier for energy storage to reduce grid congestion and improve the flexibility of the national electricity system.
- Hydrogen blended into the gas grid at key locations to enable the transport of hydrogen to industry.
- Domestic use of green hydrogen as a transitional fuel in transport, e.g., rail freight, HGV, and buses.

Long-term: 2040–2050

In the long term, the global demand for low carbon hydrogen and derivatives such as ammonia, hydrogen and synthetic fuels is expected to greatly increase as countries look for further options to achieve net-zero, carbon prices make low carbon alternatives competitive. Alternatives beyond decarbonising the electricity grid will also push Egypt to utilise hydrogen to decarbonise other sectors domestically. It is recommended that Egypt focus on:

- Hydrogen to fully decarbonise large parts of the steel manufacturing
- Domestic use of green hydrogen in the industrial sectors
- Domestic use of green hydrogen in air transport.
- Hydrogen for longer duration storage and electricity peaking plants.

Whilst Egypt's current hydrogen demand is expected to remain, how quickly it moves over to a low carbon alternative is uncertain and is dependent on market forces which will be impacted by local and international policy decisions

It is expected that there will be additional demand for hydrogen both domestically and internationally in the future. Due to the cost differential with the counterfactual and how costs can be socialised any increased domestic demand is expected predominately in industry with some in transport, and potentially power, but less likely in the short to medium-term in the domestic heating sector. Internationally Egypt is well placed to meet an increase in demand, however with other countries racing to fulfil any future demand, how much of it is built in Egypt depends on Government ambition.

Further uncertainty is added owing to numerous alternative opportunities for decarbonisation, such as electrification, which may be more cost optimal/efficient in many scenarios, but not all. Generally, when directly comparing electrification and hydrogen, the electrification route, where possible, is likely the optimal alternative to fossil fuels. However, this doesn't account for all the local circumstances, such as local climate, condition of infrastructure and speed of transition. If there is a choice between electrification and low carbon hydrogen to support decarbonisation this should be done on a case-by-case basis.

Using this information two scenarios (Central and Green) have been used to estimate Egypt's future hydrogen demand for 2030, and 2040. By 2030 demand is expected to be led by demand for low carbon hydrogen and ammonia for export and shipping. A major jump in hydrogen demand is expected through the 2040s with demand increasing significantly across all end users.

The key characteristics that drive the variation in our production/demand forecast are as follows:

- Egypt has experience in electrolytic hydrogen production however the plant was built in the 1960s – it is, therefore, necessary to have a coordinated ramp-up of the supply chain and upskill the workforce. This will enable the costs and risks associated with potential GW scale hydrogen projects to be reduced. Added to this, there is at least a one-year lead time for electrolysers; the increase in demand for electrolysers will only start to be met once the "gigafactories" become fully operational.
- For the EU's proposed Carbon Border Adjustment Mechanism (CBAM), even if it goes ahead on schedule, the reporting phase is from 2023 to 2026, with free allowances phased out over 10 years from 2026. Hence it is expected only to start to have a substantial impact financially from around 2030. CBAM will drive investment in low carbon hydrogen in Egypt mainly in the production of steel and ammonia. Therefore, a delay in the implementation period would reduce the low carbon

hydrogen demand in those sectors. Other international policy drivers will be from REPowerEU, Fit for 55, which is looking for 10Mt of hydrogen to be imported.

- The location of Egypt on major shipping routes provides an opportunity to be a major hub for low carbon fuels, both ammonia and methanol. The availability of sustainable biogenic CO2 is expected to be a limiting factor for methanol production.
- For Egypt to export green hydrogen will initially require a hydrogen carrier either LOHC or ammonia, this will add substantial costs to the LCOH which will limit the potential opportunity. Additionally, some countries in Europe are likely to subsidise their internal hydrogen production (mainly to establish the hydrogen economy but partly in a race to bring large parts of the industry into their country). These subsidies will likely end in the mid to late 2030s once the carbon price is sufficiently high. Therefore, substantial volumes of hydrogen are not expected to be exported to Europe via carriers until the 2030s. Furthermore, Egypt is exploring both gas and electricity interconnectors, which may negate the use of hydrogen carriers.
- Other uses of hydrogen such as for wider industry and surface transport are expected to pick up after the production of hydrogen has become well established, and if alternatives (such as electrification) aren't appropriate. The hydrogen is expected to be transported to industry through the existing gas network via blending in the gas grid and deblending at the industrial site. For use in the power sector, it is dependent on new CCGTs and OCGTs being compatible with a high hydrogen blend (preferably 100% hydrogen).

Central Scenario

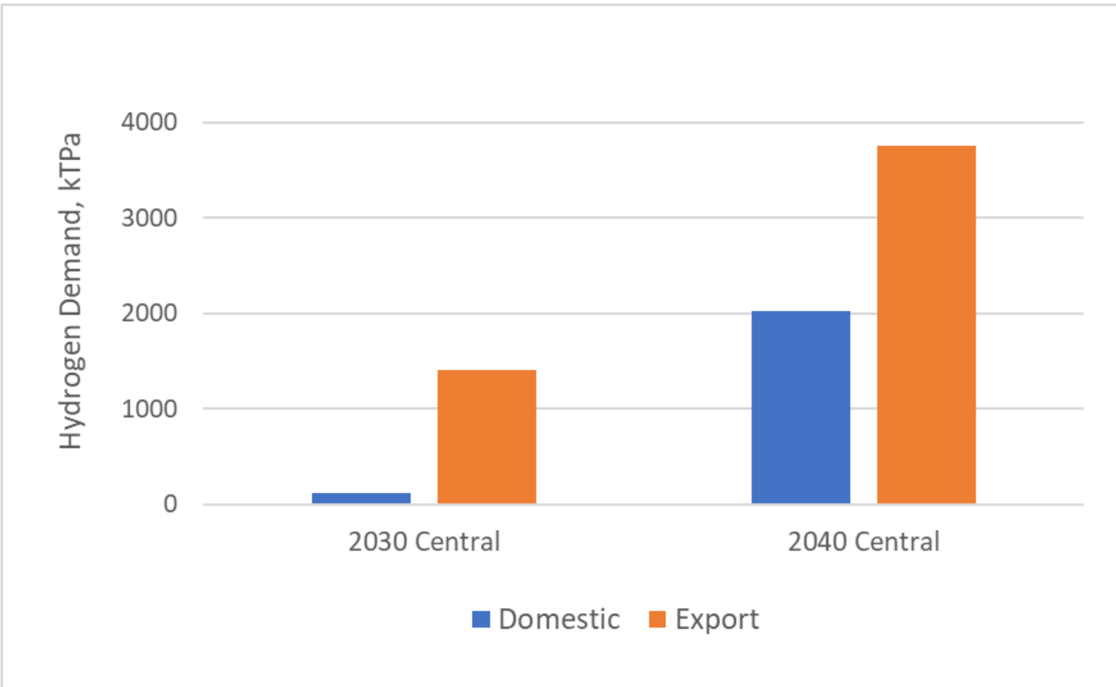


Figure 4-5 Central Scenario - Domestic and Export Hydrogen Demand produced in Egypt

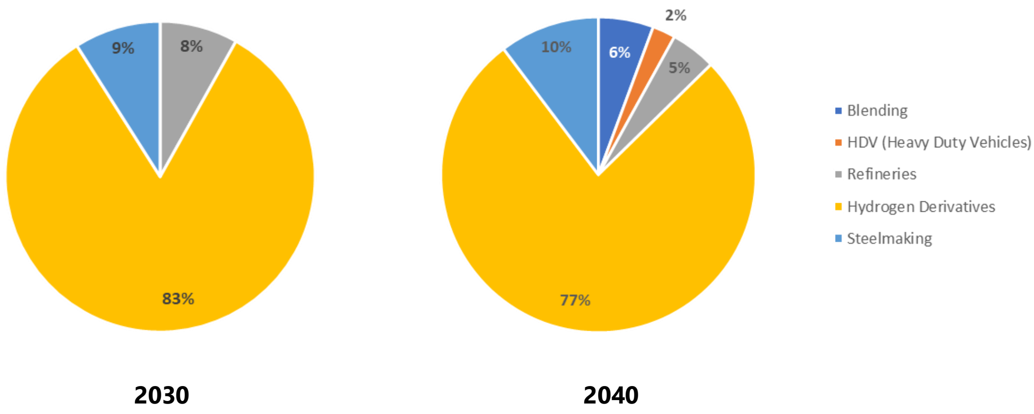


Figure 4-6 Central Scenario - Domestic Hydrogen Demand Sectoral Split

Only a small proportion of low carbon hydrogen is expected to be produced to meet local demand in 2030, this will be predominantly from the production of hydrogen derivatives. Demand for derivatives and steel is expected to increase in line with population growth. By 2040 demand for hydrogen is expected to be blended into the gas grid to supply hydrogen to industries not located in the coastal regions (where green hydrogen will be produced owing to water scarcity), hydrogen is also expected to be used in the heavy goods transport sector.

Table 4-11 Central Scenario – Key metrics

	2030		2040	
Hydrogen production (annual)	0.1 Mt Domestic	1.4 Mt Export	2 Mt Domestic	3.75 Mt Export
Electrolyser Capacity	13 GW		48 GW	
Additional RES requirement	19 GW		72 GW	
Electrolyser Investment required	10 USD Bn		24 USD Bn	

Green Scenario

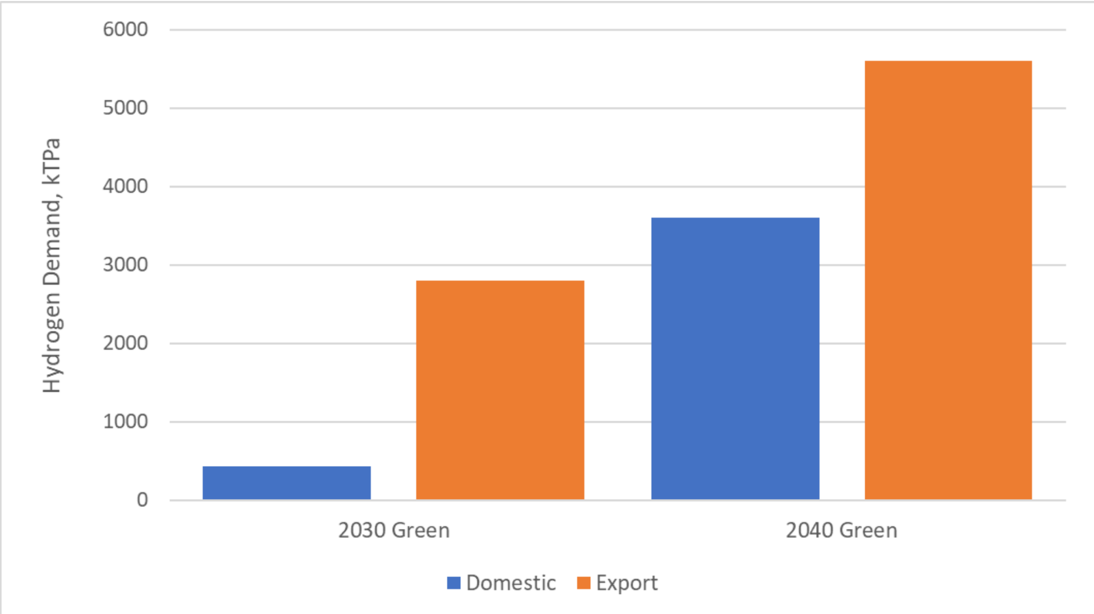


Figure 4-7 Green Scenario - Domestic and Export Hydrogen Demand produced in Egypt

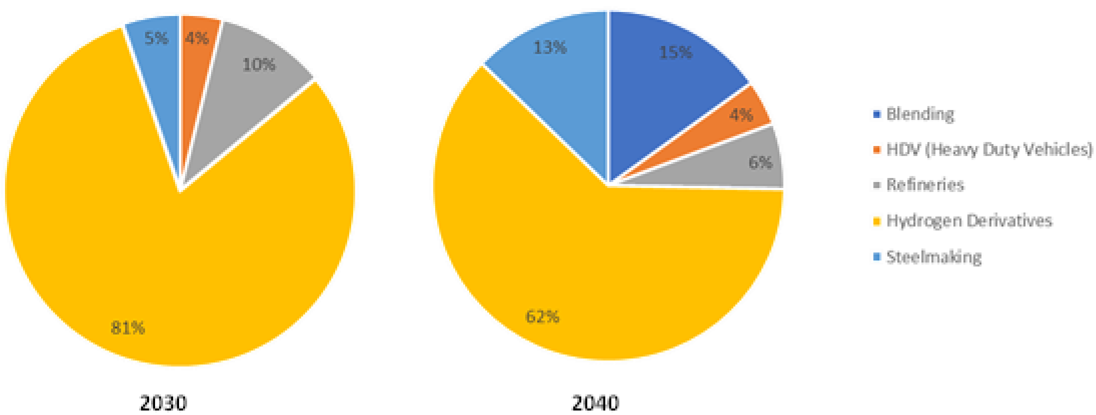


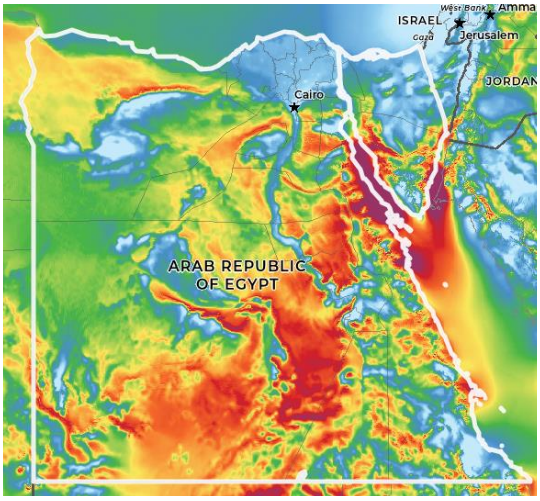
Figure 4-8 Green Scenario - Domestic Hydrogen Demand Sectoral Split

Similarly, to the central scenario, however, a greater switch away from the high carbon alternative is expected. Additionally, an increase in low carbon steel production (for both domestic and export markets) is expected as is the replacement of grey hydrogen with low carbon hydrogen.

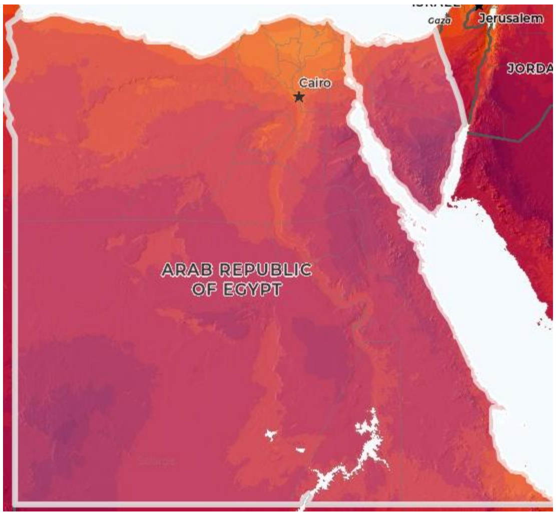
Table 4-12 Green Scenario – Key Metrics

	2030		2040	
Hydrogen production (annual)	0.4 Mt Domestic	2.8 Mt Export	3.6 Mt Domestic	5.6 Mt Export
Electrolyser Capacity	27 GW		76 GW	
Additional RES requirement	41 GW		114 GW	
Electrolyser Investment required	22 USD Bn		34 USD Bn	

4.6 Impact on Renewable Energy



Egypt has around 2850 MW of existing hydropower capacity, which supplies approximately 7.2% of the total Egyptian power generation. The excellent wind resources are in the Gulf of Suez and, for solar, particularly around the South West and Benban. Solar and wind renewable electricity only account for around 5% of total generation capacity with an ambitious target to increase the renewable energy share to 42% by 2035[7]. The excellent renewable resources combined with an ambitious renewables target (along with a reliable electricity grid) should allow for significant green hydrogen production within Egypt.



In recent years, Egypt has been expanding its solar and wind energy capacity, recording an over four-fold increase (from about 690 MW in 2014/2015 to 3,016 MW in 2019/2020). Such growth was possible thanks to establishing a favourable policy, legislative and institutional framework, including investment law with incentives such as tax reductions for new and existing projects, net metering (with the recently increased capacity from 5 MW up to 20 MW), feed-in tariffs (accompanied by currency guarantees and international arbitration terms), and competitive bidding based on independent power producers' model.

It should be noted that the above renewable energy targets have been set to decarbonise the country's fossil fuel-based electricity generation. In this context, expanding green hydrogen production should be conducted bearing in mind that objective and the actual availability of dedicated renewable energy supplies to run electrolysers, so as not to slow down this process and, inadvertently, promote increased fossil fuel consumption for electricity generation. In the EU, the risk of diverting renewable power towards electrolysis at the expense of decarbonised power generation is also recognised. To address

[7] This ambition is expected to be brought forward to 2030

this, the requirement for "additionality" for renewable hydrogen projects has been introduced in policy, such that the power requirement for electrolysis must be supplied for new, or at least recent, renewable power investments.

Egypt has high wind energy potential, especially in Gulf of Suez area with a stable wind speed of around 8-10 m/s. Recently, a new potential area has been untapped in the east and west of the Nile River, in the Beni Suef Governorates and El Kharga Oasis. These areas have wind speeds between 5 m/s and 8 m/s, which is suitable for electricity generation.

The requirement for further new renewables to support the expanding low carbon hydrogen sector is high, the central scenario predicts a demand of 19 GW by 2030 increasing to 72 GW by 2040, and these increase to 41 GW and 114 GW in the green scenario.

4.7 Impact on Water

The United Nations predicts that Egypt could be water scarce by 2025. Supplying a share agreed by international treaties at 55.5 billion cubic meters (BCM) per year, the Nile River is the main source of fresh water for Egypt. The remaining freshwater resources available provide an additional 20 BCM and include groundwater aquifers, reuse of agricultural drainage and treated wastewater, rain and floods, and desalination.

With population and economic growth, there has been a sharp decline in the annual freshwater resources available per capita, pushing the country closer to the severe water scarcity threshold (500 cubic meters per capita per year). Climate change impacts, water pollution, and geopolitical factors (such as the Grand Ethiopian Renaissance Dam) are expected to exacerbate water stress in Egypt. Egypt is in the process of implementing a substantial investment program towards the efficient use, reuse, and generation of new water sources as a national priority.

Green hydrogen requires significant quantities of high purity water, currently, systems use 13 kg water/kg hydrogen (as electrolysers are improved the water demand is expected to be reduced to around 9kg/kg). Whilst R&D is ongoing on the use of brackish water and seawater directly[8], it is not expected that this technology will be available in the near future therefore significant water treatment is required. Blue hydrogen is likely to require comparatively smaller volumes, especially if air cooling is employed, however, water is still likely to be a constraint and requires consideration in the development of blue hydrogen projects. Therefore, it is necessary that as the low carbon hydrogen market increases in Egypt it does so with minimal impact on freshwater supply, therefore alternative water sources need to be used.

[8] https://www.pnas.org/doi/full/10.1073/pnas.2024855118#sec-3

Water from desalination is expected to be the main source of water for low carbon hydrogen, as transporting water for hydrogen production is unlikely economic, the majority of hydrogen production will be in the coastal region, which also happens to be where the majority of the demand will be.

The disposal of the resulting brine may increase costs significantly. Historically brine was disposed of through a single outfall, the resulting highly concentrated brine was found to suffocate the seabed with a plume extending for several kilometres. Modern discharge practices, which conform to IFC Performance Standards, look to maximise the dispersion of the brine and have been found to mitigate the impact, however, brine disposal should be limited near sensitive or productive habitats. Ultimately if brine cannot be discharged back to sea, it will require to be discharged to an evaporation pond.

Water reuse – Fresh water scarcity means that it is unlikely that green hydrogen will be produced at scale inland. However, it is possible to treat wastewater from a sewage treatment works, sufficiently so that it could be used for hydrogen production. The processes required range from settling, activated sludge, activated carbon, filtration, UV processes, and finally reverse osmosis. This range of processes has been proven in Namibia[9]. The added advantage of collocating hydrogen production is that the oxygen could be used to improve the efficiency of the wastewater treatment process. However, this would have to be examined on a case-by-case basis as the water may also be fit for human consumption.

4.8 Impact on Natural Gas Market

Egypt has natural gas reserves. The majority of the gas produced, is to meet Egypt's demand (mainly for power and industry), one of the largest in the MENA region, the remainder is exported, normally by LNG.

New pipelines can easily be designed for 100% hydrogen service, but the conversion of existing pipelines designed for natural gas service to carry hydrogen blends needs investigation on a case-by-case basis. It is generally accepted that in most cases, a blend of hydrogen in natural gas of up to 20% is technically feasible with minimal capital investment in the pipeline and associated compressor system. Operation above this level may well be feasible from a pipeline perspective, but the capital investment for compression modification starts to become substantial.

Based on the latest research, it is credible that hydrogen could be blended into the gas network up to 20% by volume without impacting downstream users, which equates to 11 million tonnes of hydrogen per year. This blending rate is unlikely to be achieved but gives an idea of the potential scale of demand from blending.

Assuming CO_2 storage is technically and economically feasible, the gas reserves should enable Egypt to produce blue hydrogen competitively. However, replacing natural gas with blue hydrogen will increase gas demand; this may impact the volume of gas available for export.

Egypt has extensive gas resources and an extensive natural gas system. The Arab Gas Pipeline (AGP) allows gas export to Jordan and potentially to Syria and Lebanon. Gas is imported into Egypt from Israeli offshore gas fields, and gas is exported in the form of LNG. The near-term intention is to make Egypt the East Mediterranean gas hub for all regional gas finds. We, therefore, expect it to have a long-term surplus of gas feedstock and continued major investment in gas export infrastructure.

Egypt has also produced plans planning to expand Egypt's natural gas supply network into households by 950 km by the end of 2023. This would bring the length of the network to 8750 km.

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[9] https://journals.openedition.org/factsreports/6341

4.9 CCS Requirements

The potential for large-scale CO_2 storage is a pre-requisite for blue hydrogen production unless CO_2 can be exported in large volumes by pipeline or ship.

According to the World Bank study for Jordan, six oil fields in the Red Sea Basin of Egypt may be technically feasible locations for CO_2.

The six Egyptian oil fields are sufficiently deep for the application of miscible CO_2, with depths averaging 8,630 feet (2,610 m); the actual range of depths is from 5,750 feet (1, 400 m) to 12,050 feet (3,650 m).

The estimated primary/secondary (P/S) oil recovery for these six oil fields is 0.8 billion barrels. Assuming 40% P/S oil recovery efficiency, the original oil in place (OOIP) in these six oil fields is estimated at 12 billion barrels. With a +15% recovery of OOIP, the CO_2-EOR target is nearly 2 billion barrels.

The implementation of carbon storage projects can be a lengthy process, and typically takes up to 10 years from conception to reality. Given the earlier stage of investigation into storage facilities in Egypt, the realistic time frame for blue hydrogen is 2030 onwards.

5 Opportunities for Egypt

As mentioned in the Vision, Egypt is in a strong position to play an important role in the nascent low carbon hydrogen economy., benefitting from current knowledge in hydrogen production, both grey and electrolytic, and ammonia production and export. As discussed in Section 4, the excellent renewables, and gas reserves, combined with the strategic location of Egypt, along one of the main shipping routes close to key import markets means Egypt will be amongst the world's leaders as demand for low carbon hydrogen grows significantly over the next few decades.

The table below summarises the key advantages of Egypt but also threats and possible mitigations.

Table 5-1 Summary of Egypt's Key Advantages

Area	Sector	Egypt Advantage	Threats	Mitigation
NATURAL RESOURCES	Renewables	Excellent wind resource in the Gulf of Suez, and solar, particularly in the south and around Benban.	Wind and solar currently only represent 12% of electrical energy. A large expansion in renewable energy and further strengthening of the grid is required to develop green hydrogen at scale.	There are plans to greatly increase renewable generation. Alongside a plan to strengthen the grid to cope with expansion in hydrogen production
	Gas Reserves / CO2 Storage	The natural gas fields provide a source of natural gas for blue hydrogen production.	Upstream emissions may result in blue hydrogen not being compliant with international low carbon standards. Quantification of carbon storage capacity is still at a very early stage, so storage potential unproven. Given the current high gas prices, there is currently an opportunity cost with maximising exports of natural gas in comparison to blue hydrogen	Egypt is working to establish the best opportunities for developing CCS in Egypt. Egypt will work with international bodies to ensure our blue hydrogen complies with standards
	Location	Egypt is very well placed geographically as a major shipping hub, with easy access to the Mediterranean Sea and Suez Canal., which could accommodate more than 20% of international shipping	Egypt faces competition from other countries in the region, for example, Morocco, Tunisia, and Jordan.	Egypt will work with producers to provide an equitable level of support for hydrogen production, which could include low rents, access to shared infrastructure, low wheeling charges,

Area	Sector	Egypt Advantage	Threats	Mitigation
				access the cheap finance or grants
	Water	Egypt has a wealth of experience in desalination and is expected to soon produce 1.4 million m3/d	This water is for domestic use	Egypt will work with producers to ensure that water used for hydrogen production does not impinge on domestic supply or impact the local environment.
ASSETS AND INFRASTRUCTURE	Domestic Gas Demand	Egypt has one of the highest domestic gas demands across the MENA region, with gas predominantly used in the power and industry sectors. Hydrogen could initially be blended into the gas network before it is upgraded to a 100% hydrogen grid.	Current energy subsidies may discourage the switch to hydrogen use. Suitability of pipelines for re-purposing to blended hydrogen at an early stage of evaluation.	Egypt is assessing appropriate levels of subsidy and will ensure this does not act as a barrier to the use of competitive low carbon energy
	Ammonia/ Methanol Industry	Egypt's ammonia and methanol industries provide a focal point for green and blue production. There are also emerging markets for both as shipping fuels.	The market for low carbon ammonia and methanol is yet to be established	Egypt will work with international organisations to ensure Egypt can support the transition to low carbon fuels
	Steel Industry	Egypt's steel industry (apart from one blast furnace) uses the direct reduced iron (DRI) process route, in which iron ore is converted to sponge iron. In this process, hydrogen is produced by the reforming of natural gas and acts as the reducing agent. There are options for incremental hydrogen injection to displace the natural gas route.	Full replacement of natural gas use by hydrogen still requires major capital investment, and whilst promising the technology development is still at the pilot stage.	Egypt will monitor developments in the technology and work with industry to draw up plans for hydrogen in the steel sector

Area	Sector	Egypt Advantage	Threats	Mitigation
FINANCIAL	Overseas Investment	Egypt has successfully attracted agreements with major players such as Siemens, Scatec, Eni, Masdar, AMEA Power, Maersk and ACWA for both renewables and hydrogen investments.	The supply cost of green hydrogen will still need to be competitive.	New agreements are already in the pipeline; Egypt can count on concessional finance (donors and multilateral development banks)
	CBAM	The introduction of the EU CBAM can help to economically justify low carbon hydrogen projects and facilitate launching the energy transition.	The impact of CBAM might shift Egypt's exports in covered sectors (chemicals, iron, and steel) away from the EU.	Engaging in hydrogen diplomacy with the EU and planning assessment of carbon price introduction in Egypt

The main options for future hydrogen demand in Egypt are as follows:

- Use of low carbon hydrogen in the production of ammonia creating low carbon fertiliser products.
- Use of hydrogen in the production of methanol and ammonia for use as marine fuels, or for export as energy carriers.
- Use of hydrogen in further power-to-X applications, such as sustainable jet fuel production.
- Use of hydrogen for other mobility applications, such as buses, trains (passenger and freight), heavy goods vehicles (HGV) and mining operations, where electrification is not possible.
- Use of hydrogen as a fuel for power generation, for long term energy storage, to balance the grid and to replace natural gas consumption.
- Use of hydrogen as an industrial fuel to displace fuel oil or natural gas in more energy-intensive industries such as steel production.

Although Egypt has an excellent location to produce low carbon hydrogen, the key challenges and barriers to a hydrogen economy are as follows:

- Freshwater scarcity – estimates place Egypt's current water resources closer to the absolute scarcity threshold of 500m^3/person/year,
- Location disparity between renewable energy and the credible location of water desalination plants,

Egypt will also need to ensure compliance with emerging international certification standards relating to renewable hydrogen production and the production of low carbon hydrogen products such as green ammonia. A Guarantee of Origin (GO) scheme will be required, and it will need to be in line with global/EU standards, especially when the power is being wheeled on the system from different locations. This is challenging as the speed of change in global policy implementation is very high, particularly regarding EU regulations. Egypt should endeavour to work with their international counterparts to ensure this is clearly defined and that Egyptian low carbon hydrogen is compliant.

In each of these options listed above, there will be different economic drivers, with a primary consideration being the increased costs compared to the use of the “incumbent” fuel that is displaced (normally natural gas and diesel).

6 Action Plan

Following the analysis of the current situation regarding the hydrogen market, both in Egypt and globally, as well as based on international best practices in enabling low carbon hydrogen expansion according to different market maturity stages, the Consultant suggests a phased approach to hydrogen economy development in the country. This includes (see Figure 6-1): the pilot phase (in the 2020s), the scaleup phase (2030s), and the full implementation phase (2040).

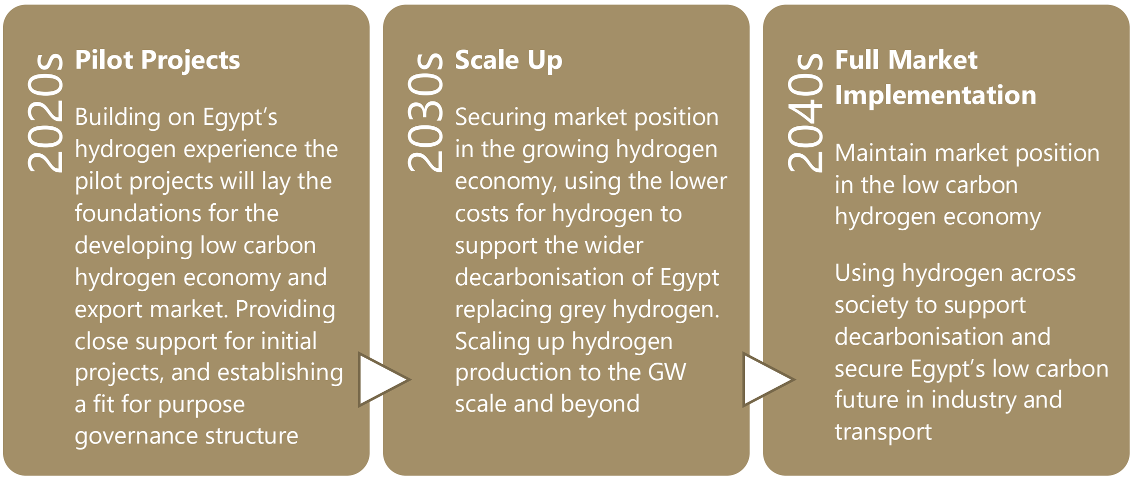

Figure 6-1 Summary Action Plan

Further, we describe the specific actions per phase:

Pilot phase:

Immediate actions – governance framework

- Creation of thematic working groups within the technical secretariat which will include a focus on developing future frameworks for MOUs which set out how to maximize the economic benefit to Egypt;
- Organisation of stakeholder roundtables in Egypt (hydrogen market actors) and hydrogen diplomacy (active participation in international initiatives).

Short-term actions (next one to two years) – market development incentives

- New pilot projects identification, preparation and delivery (know-how and knowledge transfer, hydrogen production and export); incorporation of lessons learned from the ongoing MoUs and conclusion of new agreements);
- Conducting studies, reviews and assessments (National Hydrogen Council working groups on: enabling laws and regulations; existing infrastructure; low carbon hydrogen definition; carbon pricing/tax implementation; financial assistance for first hydrogen projects; a roadmap for R&D and capacity building/skills development; public awareness campaign, benchmarking incentives against international best practice, and maximising benefits to Egypt).

Mid-term actions (next three to five years) – continued support for hydrogen technologies deployment and expansion – in particular through:

- Preparing and issuing the needed regulations for paving the way for investors and providing the enabling environment for the low carbon hydrogen industry.
- Development of a national strategy for short-term and longer-term public support to be applied across the whole hydrogen value chain (to ensure short-term competitiveness while establishing the hydrogen economy and planning long-term revenue generation for Egypt);
- Roll out of sustainable development laws and regulations to incentivise the production of low carbon hydrogen;
- Review of future-proofing natural gas infrastructure investment for the transition to hydrogen, and other natural gas pipeline extensions to industrial users; conducting a technical feasibility study of blending up to 100% hydrogen to future proof the industry and power generation; setting guidelines to increase hydrogen blending into the current gas grid for industrial areas;
- Development of a strategy for low carbon hydrogen integration and gradual phase-out of the grey hydrogen production plants, but also how hydrogen can be blended into the existing steel plants;
- Increase the scope of decarbonisation within the country by considering new hydrogen uses, e.g., local transport, ports and terminals, and low carbon ammonia/methanol production;
- Establish the likely costs of carbon capture and CO_2 transfer to storage sites. Prepare a strategy to develop CCS hubs around key industrial areas such as, e.g., Alexandria and Ain Sokhna.

Long Term Actions (next five to ten years) – considering the uncertainty related with long term planning, these actions should focus on reassessing the hydrogen market (at the international and national scale) and natural gas price and adjusting Egypt's approach to further development of hydrogen economy in the country.

6.1 Governance

An analysis of the hydrogen economy governance models in different countries (see Table 6-1), permits to draw some conclusions on common approaches towards setting an enabling institutional framework for market development, including:

- Typically, the national hydrogen strategy implementation is entrusted to an existing ministry that oversees the entire energy sector (sometimes also beyond, e.g. industry, development etc.), including energy production from conventional and new sources, corresponding infrastructure, energy policy and regulation, as well as security and affordability of supply. Alternatively, a new, dedicated government agency/body covering a wide range of relevant fields is created. Such an approach simplifies the decision-making process (e.g., regarding land allocation, licensing, financing, and incentives) and allows to set hydrogen projects faster in motion as the organisation responsible has easier access to different competencies and broad direct decision-making power over pertinent energy sector aspects. It also helps in overcoming administrative barriers, stimulates investments by providing a sense of stability and security for project developers, and in the longer term contributes to technology cost reductions
- In addition, a multistakeholder and multidisciplinary advisory body is created to support the designated executive body in the strategy implementation by providing regular monitoring, reviews, and updates, as well as on-demand, targeted expert advice through thematic working groups or task forces.

Table 6-1 Overview of the Institutional Framework for Hydrogen in Different Countries

Country	Governance body	Role in hydrogen economy development	Composition
Chile	Ministry of Energy, Division for Fuels and New Energy Carriers	Monitors the Strategy, coordinates implementation of the action plan, and carries out an update process	N/A
	Interministerial Committee for the Development of the Green Hydrogen Industry	Supports the Ministry of Energy in the Strategy Implementation; proposes hydrogen industry development initiatives; oversees technology and knowledge transfer; capacity building and training; establishes thematic technical task forces	Ministries of Energy, Economy, Finance, Science, Public Works, National Assets, Environment and Social Development, Foreign Affairs, Agriculture and Transport, Corporation for the Promotion of Production (Corfo)
Morocco	Ministry of Energy Transition and Sustainable Development	Policy making and Strategy implementation	N/A
	National Commission for Green Hydrogen	Hydrogen Strategy elaboration	Ministerial Departments (Energy, Finance, Transport, Higher Education, Industry), National Office for Electricity (ONEE), Moroccan Agency for Sustainable Energy (MASEN), Research Institute on Solar Energy and Renewables (IRESEN), Confederation of Moroccan Enterprises (CGEM) and the Energy Federation
	Green H2 Moroc (hydrogen cluster)	Development of hydrogen/PTX industry through collaborative innovation, industrial integration, capacity building, knowledge transfer and market growth. Working Groups on R&D&I, Industry-Renewable Energy, Industry-Chemical, Project development, International Partnership, Transport of Energy	Ministry of Energy, Mining and Environment; Ministry of Industry, Trade, and Green and Digital Economy; National Fuel and Mines Administration (ONHYM); Moroccan Agency for Sustainable Energy (MASEN); Moroccan Agency for Energy Efficiency (AMEE); National Office for Drinking Water and Electricity (ONEE); Research Institute for Solar Energy and Renewable Energy (IRESEN); Mohammed VI Polytechnique University (UM6P). Other founding members also include public and private Moroccan universities, companies and associations working in the energy sector.
Germany	State Secretaries' Committee for Hydrogen	Provides strategic management, including decisions on targets, objectives, and action plan.	Interministerial committee composed of the Federal Ministries of Environment, Nature Conservation, Nuclear

Country	Governance body	Role in hydrogen economy development	Composition
			Safety and Consumer Protection (BMUV), Economic Affairs and Climate Action (BMWK), Education and Research (BMBF), Economic Cooperation and Development (BMZ), Digital and Transport (BMDV)
	National Hydrogen Council	Assists and advises the Committee in the development and implementation of the Strategy	Independent, non-partisan advisory board bringing 25 high-ranking experts representing business, academia and civil society and specialised in the fields of production, research and innovation, industrial decarbonisation, transportation and buildings/heating, infrastructure, international partnerships as well as climate and sustainability. The board is organised in thematic work groups.
	Hydrogen Coordination Office	Supports the Ministries and the Council in the Strategy implementation, providing project management structure and drafting annual monitoring reports	The Office is coordinated by five governmental agencies: Future-Environment-Society (ZUG), German Energy Agency (DENA), National Organisation for Hydrogen and Fuel Cell Technology (NOW), Project Management Juelich (PtJ) and German Development Agency (GIZ)
UK	Department for Business, Energy and Industrial Strategy	Leads UK hydrogen policy, providing strategic direction, policy development and funding for hydrogen	N/A
	Hydrogen Advisory Council	Identifies and promotes concrete actions to enable the supply of low carbon hydrogen at scale for use across the energy system	Government and industry
	Hydrogen Champion	Facilitates industry and government cooperation on hydrogen	One person position

Considering the governance models existing internationally, Egypt's specific energy sector context, the following Governance structure will apply to hydrogen in Egypt.

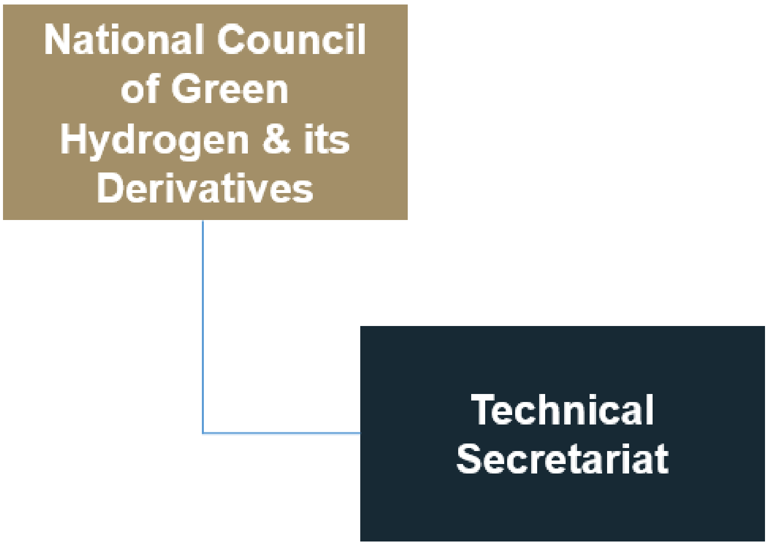

Figure 6-2 Hydrogen Governance Structure in Egypt

The National Council for Green Hydrogen and its Derivatives (NCGH) aims to unify the state's efforts to stimulate investment in the field of green hydrogen and its derivatives, in line with the requirements of sustainable development and the state's plans for economic and social development, and to ensure its competitiveness at the international and regional levels. The main responsibilities of the NCGH include

- Following up on the implementation of the national strategy for green hydrogen,
- Proposing the update of the strategy in light of the international and national developments,
- Approves policies, plans and mechanisms necessary to implement and update the strategy,
- Coordinating between ministries and concerned authorities, and proposing the necessary solutions to overcome investment obstacles in the field of green hydrogen and its derivatives,
- Reviewing the legislation, regulations and rules regulating the field of green hydrogen and its derivatives, and proposing necessary updates.

To enable smooth coordination of actions across Egyptian government institutions also to create a strong sense of inclusion and ownership over the process and address the need to develop competency in and awareness of the hydrogen economy across Egyptian public administration, the NCGH will bring together leadership representing other relevant institutional stakeholders including:

- **Prime Minister (Chairman)**
- Minister of Electricity and Renewable Energy
- Minister of Petroleum and Mineral Resources
- Minister of Justice
- Minister of Planning and Economic Development

- Minister of International Cooperation
- Minister of Finance
- Minister of Environment
- Minister of Housing Utilities, and Urban Communities
- Minister of Transport
- Minister of State for Military Production
- Minister of Water Resources and Irrigation
- Minister of Public Business Sector
- Minister of Trade and Industry
- Chairman and Managing Director of Suez Canal Authority
- Chairman of Suez Canal Economic Zone (SCEZone)
- First Assistant to the Prime minister (Rapporteur)
- Executive Director of The General Authority for Free Zones and Investment (GAFI)
- Chief Executive Officer of The Sovereign Fund of Egypt for Development and Investment
- Representative of Ministry of Defense

The responsibilities of the Technical Secretariat shall be addressed by the Cabinet. The members shall include:

- First Assistant to the Prime minister (Chairman)
- Chairman of Cabinet's Advisory Board
- Chairman of Information and Decision Support Center (IDSC)
- Representatives from all National Council of Green Hydrogen members.

The private sector is essential to enable the development of the hydrogen economy in Egypt. The private sector will be invited to participate in council or technical secretariat meetings as required. Moreover, discussions with the hydrogen developers will continue to take place in various roundtable meetings.

6.2 Targets

The 2030 and 2040 vision, introduced in Section 1, and the hydrogen market scenarios presented in Section 4, set the direction and overall ambition for the hydrogen economy development in Egypt outlining key elements of the strategic framework, such as the creation of a leading international export hub for hydrogen and its derivatives, and achieving energy security in the country.

Accordingly, the expected strategic outcomes by 2040 include:

- Production of 5.6 million tons of low carbon hydrogen
- Reaching 8% of the global hydrogen market

- Setting up and localising the electrolyser manufacturing industry
- Contribution to decarbonisation efforts of Egyptian flagship industrial sectors
- Contribution to the growth of the country's economy by boosting GDP (USD 10-18 billion), providing upwards of 100,000 thousand new jobs

6.3 Legislative and Regulatory Aspects

The legislative and regulatory framework relating to hydrogen requires a broad range of rules and regulations spanning from the environment and safety, through markets, competition, and planning to different end uses (industry, transport, energy, households). Considering the early stages of the first hydrogen projects, most countries still lack specific, hydrogen-related legislation and have no dedicated regulations regarding the development, implementation, and licensing of hydrogen facilities. The focus of the initial steps in this area is to provide both sufficient certainty and flexibility to investors and project developers by simplifying the existing frameworks and reducing potential barriers and administrative burden. Operating within the existing regulatory regimes, first-of-a-kind real applications of industrial-scale low carbon hydrogen systems play a crucial role in facilitating the understanding of how current regulations to support (or impede) project development and delivery. These pathfinder initiatives permit the identification of potential solutions to address the existing challenges and to send the right signals and incentives to the industry, unlocking future investment and technologies deployed across the hydrogen value chain.

In this light, it will be important to create a **hydrogen projects platform** that gathers information and facilitates the exchange of lessons learned about the preparation and implementation of pilot hydrogen projects in Egypt. The initiative could be coordinated by the earlier mentioned National Hydrogen Council. Based on the input from pilot projects and in consultation with hydrogen value chain stakeholders, the Council will suggest simplification of environmental, industrial, and municipal **licensing procedures** for hydrogen projects. Further, it will propose the conclusion of **strategic commitments** and **new agreements** with hydrogen project developers and investors (hydrogen production, technologies development, know-how transfer, capacity building, and institutional collaboration).

In addition, bearing in mind the recent **progress achieved** by Egypt in renewables capacity expansion, the Government should also build on experience from this process; in particular, concerning its four pillars, namely:

- Development of state-owned projects with competitive bidding for engineering, procurement, and construction (EPC) contracts
- Introduction of competitive bidding for build-own-operate (BOO) contracts
- Implementation of feed-in tariffs
- Introduction of a scheme where independent power producers can enter into bilateral contracts to sell power directly to consumers using the national grid against wheeling and grid-access charges payable to the grid operator.

Advancing the hydrogen market and achieving cost-competitiveness over the course of the 2020s and beyond will require setting **new rules and regulations**. The Egyptian Government should bear this objective in mind and start as soon as possible (i.e. within the next one to two years) a review and subsequent update of the country's key laws and regulations that are relevant from the perspective of the hydrogen industry and supply chain development. Considering the existing best practice in hydrogen policy and regulatory framework development, this could include such topics as: land use (and associated permitting processes), gas market (which classifies hydrogen as a gas) and power market (to enable hydrogen's role in energy, capacity, and ancillary services) but also projects' environmental impact assessment (classification list, principles, and procedures guidelines)[10]. The review process should be carried out by a dedicated working group (within the National Hydrogen Council), composed of technical and regulatory experts representing a broad range of sector stakeholders.

It is envisaged that the revisions and updates will concern especially the Renewable Energy Law 203/2014, Electricity Law 87/2015, and Investment Law 72/2017. Further, the development of an **overarching Hydrogen Law** should also be considered to lay the legal basis to establish safety standards, complete the definition of the roles and responsibilities of participating public institutions and formalise incentives for hydrogen projects (financial and administrative simplification mechanisms e.g. grants, preferential loans, contracts for difference, priority grid connectivity, land availability, permits and guarantees exemption etc.), prepare hydrogen related statistics, mandate hydrogen-ready installations and appliances, allow hydrogen use as a fuel and in gas networks (with standardisation of admissible hydrogen concentrations), develop education and capacity building programmes etc.

Along with a gradual market expansion, it will be important to ensure that the role of hydrogen is considered in broader reviews of energy system rules, regulations, and institutional arrangements, including system operation and energy code governance (interlinkages with gas; electricity; CO2 transport, storage, and planning).

6.4 Standards, Guarantees of Origin and Certification

Expansion of low carbon and renewable hydrogen production and uses call for developing internationally a common language and shared rules that will enable actual cross-border trade and provide more certainty to project proponents and investors. This harmonisation can be achieved through the design and implementation of standards, guarantees of origin (GOs) and the corresponding certification that will:

- Provide adequate signals on the price of low carbon and renewable hydrogen and its derivatives
- Facilitate the need for market actors to meet regulatory requirements
- Give the confidence to end users that low carbon hydrogen is a good alternative to fossil fuels and, in general, inform consumers about the origin of hydrogen and its environmental attributes.

For now, the approaches to and priorities for standardisation and certification vary widely among countries, making harmonisation internationally a challenging, medium-term perspective task. In the case of standardisation, safety aspects of hydrogen production and handling are frequently seen among top priorities (see Section 6.5). Apart from that, countries investigate topics, e.g.: low carbon hydrogen definition; technical standards for hydrogen use in gas installations, boilers, and heating systems as well as fuel cell modules; hydrogen concentration in gas networks etc.

In Egypt, regulation of **standards along the hydrogen value chain** will require a review of the existing laws that classify hydrogen as a gas (Gas Market Law 196/2017). In this regard, as one of the first actions, the Government of **Egypt should set up a dedicated technical working group** within the NCGH to allow hydrogen as an energy carrier and review the standards in force to facilitate the deployment of hydrogen technologies and gradual expansion of hydrogen applications. From the perspective of export

[10] Enabling Measures Roadmap for Green Hydrogen, Europe and Japan, IRENA and World Economic Forum, November 2021. Policy Toolbox for Low Carbon and Renewable Hydrogen, Hydrogen Council, November 2021

market development, the priority will be to harmonise the Egyptian framework with international standards and the national standards of key trade partners.

Concerning certification, to date, the schemes existing internationally focus mainly on the aspect of carbon emissions, although they could be expanded to other relevant environmental impacts, e.g. water consumption. Having in mind the objective of developing a hydrogen export market in Egypt, any potential **national certification scheme** should be designed considering the requirements in place on the target markets. For instance, hydrogen (and its derivatives) export to Europe will call for compliance with, e.g., the EU's Renewable Energy Directive (RED II) on renewable fuels for transport.

From this perspective, Egypt could consider the rules of the **European CertifHy** framework, an FCH JU-financed programme that uses electronic guarantee of origin (GO) documents to certify green hydrogen (i.e. made from bio, hydro, wind and/or solar energy) and low carbon hydrogen (i.e. made from (nuclear or fossil with CCS) referring to a GHG intensity benchmark of minimum 60% below the GHG intensity of hydrogen production from natural gas (www.certifhy.eu/).

Any advice on and design of prospective standards and certification schemes in Egypt should build on the existing experience of **NREA, EgyptERA, EETC and EEHC** in these fields.

6.5 Safety Measures

To date, hydrogen safety aspects in Egypt are covered by the standard on "Occupational safety and security requirements for hazardous material gases" (ES 4079-3/2008). This classification, although similar to the approach existing in other countries, puts the hydrogen sector in the context of using a legally classified hazardous product, which is dangerous to transport, store, refuel or inject into a gas network, and as such constitutes a barrier to hydrogen technologies deployment and expansion.

In this context, the Government of Egypt should establish a dedicated working group within the NCGH that identifies among the existing **standards** those, which result in constraining from the perspective of hydrogen technologies and uses deployment and expansion. In particular, this regards hydrogen production, storage, transport, and distribution, use as a feedstock and a fuel, mobility applications, hydrogen injection into the gas grid and functioning of power to gas facilities, and material handling equipment. The working group could also liaison for knowledge exchange at the international level with one of the hydrogen safety organisations, e.g. the EU co-funded non-profit International Association for Hydrogen Safety "HySafe".

6.6 Sectoral Measures

Considering the previously outlined action plan and the outcomes of the priority ladder analysis (see Table 4-8 Applications), the following sectorial measures should facilitate the adoption of hydrogen in Egypt:

- Promote the wider use of renewable hydrogen in industry. At the moment, the application of hydrogen is concentrated in oil refining, the fertiliser industry and iron and steel production. These sectors provide a reliable demand and favour greater use of hydrogen. From the cost-effectiveness perspective, renewable hydrogen use should be encouraged especially in those sectors where there is no alternative option to decarbonisation. Following the example of hydrogen front running countries, the measure could be achieved by the introduction of: (a) funding programmes for decarbonising existing hydrogen production, new merchant production, and transformation projects on hydrogen-based fuel switching (i.e., e-fuels, ammonia) and low carbon hydrogen new applications; (b) production support mechanisms for operational expenditures (e.g., ten-year tax credits per kg of hydrogen, feed-in tariff scheme with a ten-year fixed-price subsidy or contracts for difference); (c) binding targets and obligations on demand sectors (e.g. industrial consumers requiring a fixed amount/share of energy/fuels to come from hydrogen) and (d) fiscal policies such as carbon pricing, tax differentiation for goods depending on their climate impact, and tax relieves to enable a partial or total deduction of expenses incurred on green products from taxes;

- Promote and encourage the creation of hydrogen clusters (locally integrated hydrogen ecosystems for climate change mitigation and regional economic development), in the areas where hydrogen supply and demand already are or could be located nearby. The European Hydrogen Valleys, set up by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) in collaboration with European cities and regions, could serve as a good example; initially driven by public authorities or public-private partnerships, today half of the projects are led by the private sector. The valleys lean towards three main archetypes (a) local, smaller-scale and mobility-focused projects, (b) local, medium-scale and industry-focused projects, and (c) large-scale and international export-focused projects[11];
- Assess the feasibility of setting low carbon hydrogen targets for the initial market development phase (up to 2030) in those sectors, where electrification is not the most efficient option and where there is no viable sustainable alternative to it. Draft the corresponding sector decarbonisation strategies and action plans that specify emission reduction targets and milestones[12];
- Design financial and administrative support measures for R&D, demonstration, and scale-up projects, such as grants, preferential loans, tax exemptions, or simplified authorisation procedures;
- Design a system for monitoring hydrogen production and consumption (by type of hydrogen, and by consumption sector), for data collection and progress evaluation;
- Encourage the application of renewable hydrogen in the transport sector by promoting hydrogen and fuel cell technologies in local transport (including captive fleets) and ports/terminals. Draft an enabling regulatory framework for the production and consumption of synthetic fuels made from renewable hydrogen. Simplify the process of fuel cell and hydrogen vehicles and vessels approval/certification process. Support the development of a network of hydrogen refuelling stations.
- Review the technical, regulatory, and quality aspects relevant from the perspective of injection and use of hydrogen in the natural gas grid, considering the use of the existing facilities for low carbon hydrogen transport and/or storage. In addition, assess the need to adapt industrial and power-generating gas-fired devices to facilitate their safe operation with higher hydrogen concentrations.

The Government of Egypt should establish a dedicated working group within the NCGH that will assess the mechanisms required to promote hydrogen use in Egypt.

6.7 Transversal Measures

Although hydrogen has been produced and used in Egypt for many years, its future role will involve new applications and new users who often are not aware of low carbon hydrogen being a potential solution for them. Transversal measures proposed as part of this strategy aim at facilitating a wider **hydrogen and fuel cell technologies acceptance** among energy consumers, businesses, and the general public. They target information about new commercially available solutions, reliable sources of hydrogen, its cost and carbon intensity.

[11] See Hydrogen Valleys Report 2022 and best practices and lessons learned on hydrogen valleys creation section available at h2v.eu

[12] See Green Hydrogen for Industry, A guide to policy making, IRENA, March 2022

As a first step, the Egyptian Government should ensure an early and broad **stakeholder engagement** (industry, local authorities, scientific community, and non-governmental organisations), in providing feedback on the content of the National Hydrogen Strategy and, subsequently, on the implementation of the proposed actions. This could be done through regularly holding (every half a year in the pilot phase) stakeholder **roundtables**..

A dedicated **assessment study**, commissioned by the NCGH, could help in understanding the perceptions towards hydrogen and related technologies (e.g., CCS) as well as the infrastructure expansion, required behavioural changes and general awareness of safety aspects of wider hydrogen use.

6.8 Skills and Capacity Building Measures

Establishing a well-functioning hydrogen ecosystem requires access to a pool of skilled workforce that has knowledge about hydrogen and fuel cell technologies development and deployment; hydrogen production, infrastructure expansion, hydrogen transport and storage; as well as operation and maintenance of hydrogen-powered facilities and equipment; financing and promotion of hydrogen systems.

To capitalise on the potential for creating new jobs through the development of a hydrogen economy, Egypt should prioritise creating a skilled domestic workforce focusing both on hydrogen infrastructure expansion and its subsequent maintenance and the hydrogen value chain.

The task of skills development and capacity building should especially target the workforce along the whole hydrogen value chain, in the sectors of energy, industry and transport, and cover in the first place, the aspects appertaining to safety. The corresponding actions could encompass:

- Educational programmes at different levels, including universities and technical high schools, to provide a skilled workforce for the hydrogen economy (organised locally and overseas).
- Identification of required skills and definition of required profiles of workers, their subsequent education and training (initially, through work-based learning and apprenticeships while developing first-time hydrogen projects) as well as provision of support in the transitioning from carbon-intensive sectors.

As one of the first actions, the NCGH should form a dedicated working group to conduct the existing skills and knowledge gap assessment and then design tailor-made training programmes. Initially, this could be done in form of twinning projects with organisations from hydrogen frontrunning countries. .

6.9 Research and Development

For their role in accelerating market growth, research, development, and innovation (R&D&I) actions constitute an important element of any hydrogen economy plans. Their primary objective is to aid technology deployment by de-risking, improvement, cost reduction, and consideration of a broader perspective (socio-economic and environmental aspects).

Typically, R&D&I measures focus on the question of integrating hydrogen and fuel cells into current energy systems by looking at a whole range of technologies along the supply and value chain, covering production, infrastructure (delivery/storage/refuelling) and end use (in industry, transport, heat and power sectors). The corresponding actions promoting R&D&I fall under the three main categories:

- Undertaking projects aimed at products and technologies discovery, applied research, demonstration and deployment, in the framework of both national and international programmes;
- Set-up of long-term cooperation partnerships with leading R&D&I organisations to shape studying curricula; offer new courses and degree programmes; facilitate visiting scholars and student exchanges; establish scholarships and internships and best practices sharing fora; and
- Development of technical capabilities along the value chain, encouraging cross-border learning and private sector participation.

Considering the current stage of hydrogen market development in Egypt, at first, the Government should establish a working group within the NCGH that brings together the expertise from the industry, academia and research agencies. The group will assess the country's competitive advantage in the energy field, hydrogen, and identify priority R&D&I areas for action that will support the implementation of the Hydrogen Strategy and contribute to the achievement of the 2030-2040 Vision. Example technology assessment criteria include: cost reduction, increased efficiency, decarbonisation contribution and other environmental impacts, deployment barriers, socio-economic impact (e.g., gross value added and jobs creation), competitive position internationally, and a feasible implementation timeframe.

Based on the analysis and recommendations included in this document, the primary activities could concern, e.g., hydrogen in gas grids; hydrogen bulk storage options; liquid hydrogen carriers; fossil-based hydrogen replacement in the chemical and steel industry; hydrogen use in shipping, aeronautics, and road freight.

7 Financing Mechanisms

To date, governments worldwide have relied on a mix of financing mechanisms to de-risk and improve the profitability of low carbon and renewable hydrogen and stimulate its market uptake. In the following sections, we present a range of instruments that reduce risk and create certainty for investors and project developers as well as subsidise and incentivise new technologies and projects until traditional forms of financing, such as debt and equity, are not easily available. We believe that in the pilot phase of hydrogen market development, the Government of Egypt should duly consider the feasibility of introducing all types of the discussed mechanisms.

7.1 Concessional Finance

Today, most low carbon and green hydrogen projects require public funding for improved technology competitiveness and project viability. Concessional finance offers below market rate finance (in the form of low interest loans with a longer repayment period, technical assistance grants, loan guarantees and – to a lesser extent – equity investment with a less value in shares requirement) for targeted projects (e.g., having a transformative effect on a region or sector), often conditioned on achieving specific policy goals (e.g., reducing energy intensity of the economy, specific sectors' decarbonisation rates etc.). Concessional finance is provided by development banks and multilateral funds (e.g., Climate Investment Funds Clean Technology Fund) and could play an important role in accelerating hydrogen technologies deployment and expansion, especially in countries such as Egypt.

Egypt should build on its track record of attracting overseas investment in renewables and use international assistance for launching its first low carbon hydrogen projects. Among the potential donors and international financial institutions supporting the development of the hydrogen market in the country there could be:

- EU institutions with their assistance schemes targeting green transition, including climate resilience, energy, and environment, channelled within the framework of the Economic Investment Plan for the Southern Neighbours (i.e., Egypt and other countries of the south Mediterranean) under the new Neighbourhood, Development, and International Cooperation Instrument (NDICI) for the years 2021-2027. Most probably, this support will be provided in a form of grants, loan guarantees and blended finance (with loans awarded by multilateral development banks, such as EIB, EBRD, IMF and the World Bank).
- Additional funding could be mobilised regarding the planned EU and Egypt signing of an MoU on green hydrogen and ammonia production, which together with the envisaged development of the "Mediterranean Green Hydrogen Partnership" aimed at establishing hydrogen trade between Africa, Europe, and the Gulf will form a basis for investments in hydrogen economy development in Egypt and the region[13].
- EBRD's loans and assistance for the energy sector constitutes another potential source of funding for energy sector infrastructure modernisation, renewables, energy efficiency as well as alternative energy, such as hydrogen.

[13] EU strengthens climate and energy cooperation with Egypt in view of COP27, press release, European Commission, Brussels, 11 April 2022, ec.europa.eu/neighbourhood-enlargement/news/eu-strengthens-climate-and-energy-cooperation-egypt-view-cop27-2022-04-11_en

- Dedicated funds such as: Green Climate Fund (with its adaptation, mitigation, and cross-cutting theme programmes), Climate Investment Funds, Green Growth Fund, and Global Environment Facility will constitute an important source of concessional finance for green hydrogen production.
- Another potential source of assistance for hydrogen production could come through the Gulf Cooperation Council Fund following its active role in supporting renewable energy investment projects.
- Since 2008, the German government has been involved in a long-term energy sector collaboration with its Egyptian counterparts through the Joint Committee on Renewable Energy, Energy Efficiency and Environmental Protection. The cooperation encompasses utility-scale renewable energy facilities, national energy efficiency strategy, renewables and energy efficiency in utilities and industry, climate finance and capacity development. Another opportunity for hydrogen projects development in Egypt could come in relation to the recently launched (EC's approval in December 2021) H2Global funding instrument, which brings together 16 large German firms to buy green hydrogen and its derivatives abroad through long-term contracts and re-sell them in Germany via annual auctions. The difference between the purchase price of the hydrogen derivatives and the sales prices will be covered by funds from the German Federal Ministry for Economic Affairs and Energy. Egypt could also count on bilateral donor assistance from such countries as Italy, UAE, and the US.

7.2 Foreign Investment Possibilities

As previously alluded Egypt has signed 23 MOUs and nine partnership agreements with a range of low carbon hydrogen project developers and investors. It is estimated that by 2030 these first pilots should result in 24.63 GW of renewables to supply 9.46 GW of electrolyser capacity. This is planned to increase further to 101.3 GW of renewables supplying 43.9 GW of electrolyser capacity over the subsequent phases.

These initiatives are of utmost importance for launching the development of the hydrogen sector in the country. Including a gradually-phased and WTO commitments-consistent local content requirement (to derive a certain amount of the final value of a good or service from domestic firms, either by purchasing from local companies or by manufacturing or developing the good or service locally) will add value to Egypt's economy in terms of technology transfer, new local jobs creation and support in decarbonisation efforts.

The MoUs signed to date send a clear, promising signal to the market and investors, and should be continued. Hydrogen diplomacy being high up on the Government's agenda is a noteworthy element of Egypt's approach that should be supported by the introduction of a transparent set of rules and incentives facilitating hydrogen project implementation (see next section). Following the envisaged pilot phase of MoU implementation, NCGH should establish a dedicated working group that assesses the actual impact of the first hydrogen initiatives on the local economy and analyses the benefits of different business models used to deliver the agreements, e.g. BOT, BOOT, or PPP.

7.3 Support from Egyptian Government

Considering limited national funding available as opposed to huge investment needs, in the case of the first low carbon hydrogen initiatives Egypt could prioritise proposing a set of financial incentives that attract, encourage, and facilitate the development of pilot projects simultaneously adding value to the local economy in terms of technology transfer, increased production and creation of new jobs. Those include the incentives already used when supporting clean energy and hydrogen through several concluded MoUs, for instance by introducing a required percentage of local content (hiring qualified nationals, purchasing from local companies or manufacturing goods locally), exempting producers from electricity levies, offering investment cost tax deductions, lowering customs rates on machinery and equipment, and providing periodic exemptions from stamp duty and notary fees for some type of expenses.

Other tools, already used or planned in hydrogen front running countries, include:

- Lowering taxes for low carbon hydrogen fuels;
- Reducing road toll fees, ferry charges or parking fees for hydrogen-fuelled vehicles and vessels;
- Supporting low carbon steel and chemicals production through so-called contracts for difference (CfD), - see the box below.
- Grant funds paying a percentage of the CAPEX (normally up to 30%) or for developing feasibility studies.
- Warranty schemes, which will guarantee an income if the hydrogen demand fails to materialise or declines for reasons outside the producer’s control.

Concerning financial support mechanisms, the Government of Egypt should establish a dedicated working group within the NCGH that in close collaboration with the industry assesses the possibilities and potential impact of introducing pilot project incentives in the country.

Case study - Contracts for Difference

Market-based instrument to accelerate low-carbon hydrogen production and offtake

Contracts for difference (CfD) are government- or institution-backed hedging instruments that aim to reduce risk and increase certainty on the low carbon hydrogen market. These long-term arrangements close the economic gap and incentivise continued investments by supporting OPEX with a strike price guaranteed to producers over a fixed period. Providing stable and predictable terms, the mechanism stabilises revenues and enhances the business case for both hydrogen producers and users, contributing to hydrogen cost reduction in the longer run.

CFDs are increasingly recognised and adopted as part of the decarbonisation framework. Germany's H2Global initiative is a good example of the scheme's real life application to the planned import of renewable hydrogen and its derivatives. It foresees a temporary compensation for the difference between the renewable hydrogen purchase price (production plus transport cost) and the sales price (currently the market price for fossil hydrogen). The German government intends to introduce CfDs also to incentivise climate-friendly and innovative processes for use in hard-to-decarbonise industries, such as steel, cement, ammonia, chemical, ceramics, and glass sectors. A pilot scheme planned for 2023 is expected to focus on the steel and cement industries. The state-guaranteed price will include project-related additional costs for CO2 reduction as well as the realisable EU ETS price. The funding amount will be calculated as follows:

Project-related CO2 reduction additional cost (= climate protection technology - reference technology) - realisable EU ETS price + state-guaranteed contract price (subsidy amount)

The EC plans CfD introduction within its REPowerEU scheme. The pilot, probably at the EU level will support the production of low carbon and circular steel, and basic chemicals. CfD constitutes the basis of the UK government's business model for low carbon hydrogen. While designing the scheme the government used lessons learned from a similar mechanism supporting low carbon electricity generation (from off-shore wind farms) and launched stakeholder consultations in 2021.

For more information on CfD please see Policy Toolbox for Low Carbon and Renewable Hydrogen. Enabling low carbon and renewable hydrogen globally, p. 22, Hydrogen Council, November 2021.

8 Strategy Progress Tracking System

This section explains the proposed approach to monitoring and assessing the progress in Egypt's Hydrogen Strategy implementation, setting the proposed indicators and metrics that will be used to track and evaluate the outcomes.

The NCGH will be responsible for the monitoring of the Strategy implementation on a yearly basis and providing recommendations on its required reviews and updates. While monitoring the progress, the principles of flexibility, transparency and forward-thinking, bearing in mind the key drivers of hydrogen market development in Egypt, i.e. creation of a leading export market and ensuring the country's energy security should be applied.

Based on the hydrogen production and uses forecast included in the preceding analysis, the following indicators and metrics are proposed:

If having a **Central** level of ambition

By 2030

- Progress with the implementation of signed MoUs for hydrogen production
- Overall hydrogen production capacity (13 GW) and the corresponding renewable energy capacity (19 GW)
- Low carbon hydrogen use in industry (ammonia and steel production), presented in % or tons.

By 2040

- Overall hydrogen production (48 GW) and the corresponding renewable energy capacity (72 GW)
- Global leadership in the hydrogen export market (5% / 3.5 million tons/year)
- Low carbon hydrogen use in industry (ammonia, methanol and steel production, refineries, heavy-duty transport applications), presented in % or tons
- Contribution to GDP growth by an estimated USD 10-18 billion and job creation by approximately 100 thousand new posts

If having a **High (Green)** level of ambition

By 2030

- Progress with the implementation of signed MoUs for hydrogen production
- Overall hydrogen production capacity (27 GW) and the corresponding renewable energy capacity (41 GW)
- Low carbon hydrogen use in industry (ammonia and steel production), presented in % or tons.

By 2040

- Overall hydrogen production (76 GW) and the corresponding renewable energy capacity (141 GW)
- Global leadership in the hydrogen export market (8% / 5.6 million tons/year)
- Low carbon hydrogen use in industry (ammonia, methanol and steel production, refineries, heavy-duty transport applications), presented in % or tons,

- Contribution to GDP growth by an estimated USD >18 billion and job creation by over 100 thousand new posts

In addition, the proposed system will track and assess:

- Impact of delivering memorandum of understanding and other contracts concluded between Egypt and hydrogen sector developers and investors (in GW of production capacity, investment made, jobs created, export volumes and directions, domestic consumption and types of applications). Additionally, the Council should be tasked with developing a future framework for MOUs which sets out how projects should maximise the benefits to the national economy, with a range of KPIs, ensuring the renewable electricity used is additional, enabling Egypt to reduce gas demand, and a proportion of hydrogen produced is for the domestic market;
- Effectiveness of government incentives granted to first-of-a-kind hydrogen projects (trends in concluded contracts, committed production capacity, levels of investment; type of beneficiary companies);
- Impact of research and development projects, knowledge transfer and capacity building programmes as well as public awareness campaign implemented in the framework of the Strategy (number of projects implemented; the number of patents; the number of personnel trained, trends in permitting and licensing procedures eligibility and duration, the target audience of outreach campaigns, perception on hydrogen technologies deployment).

Appendix A
Useful Hydrogen Conversions

Hydrogen Flow Basis	Yearly		Daily		Hourly		Reference conditions
	UOM	Amount	UOM	Amount	UOM	Amount	
Standard Gas Flow	BCMA	**1.00**	mill Sm^3/d	2.74	k Sm^3/h	114.2	1 atm, 15°C
Standard Gas Flow			MMSCFD	96.8	MMSCFH	4.0	1 atm, 15°C
Normal Gas Flow	BCMA	0.95	mill Nm^3/d	2.60	k Nm^3/h	108.2	1 atm, 0°C
Mass Flow	kTPA	85.3	TPD	234	t/h	9.7	
Energy Flow (LHV)	GWh	2841	MWh	7784	MWh	324	
Energy Flow (HHV)	GWh	3358	MWh	9201	MWh	383	
Energy Flow (LHV)					MMBTUh	1107	
Energy Flow (HHV)					MMBTUh	1308	