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Reshaping European Energy Relations across the Mediterranean

The Case of Green Hydrogen

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Summary

Geographical proximity, climate and meteorological conditions favourable to the production of renewable energies as well as a plethora of existing energy infrastructure and trade relationships represent a huge potential for both sides of the Mediterranean basin to develop a future market for green hydrogen together. This study aims to take stock of the current state of national hydrogen markets in the MENA region, looks at their potential for future use and production of green hydrogen and presents policy recommendations for each specific context that may help raise this potential for domestic use and export to other markets.

For each of the countries, the specific context determines how a path towards the development of a national hydrogen market may look like. On the other hand, like everywhere else, they share the challenge of the substantial infrastructure investment necessary to ramp up production as well as consumption of green hydrogen. The need to develop coherent yet flexible green hydrogen strategies to integrate the different aspects of industrial policy that are necessary during the market ramp-up is also shared by all as is the regulatory and technological uncertainty surrounding the modes of transport and methods of transformation.

This paper represents a starting point for the discussion about a new future energy relationship between Europe and MENA but also between the countries that are part of the MENA region. We hope it will lead to a better mutual understanding of the economic, political, geopolitical, regulatory and other challenges that will determine how green hydrogen will reshape the energy relationships around and across the Mediterranean basin in the decades to come.

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By Rim Berahab & Afaf Zarkik
The Policy Center for the New South

From Part of the Problem to Part of the Solution – Changing Hydrogen from Grey to Green

In 2021, around 70% of the world's energy requirements for dedicated hydrogen[1] production were met by methane (CH^4) as feedstock. This 'grey hydrogen' is produced using the Steam-Methane Reforming (SMR) method to separate hydrogen atoms from carbon atoms in methane. However, this is a highly endothermic reaction, which releases carbon dioxide (CO^2) into the atmosphere.

The remaining 30% of hydrogen production was met with coal (brown hydrogen). Electrolysis (i.e., the process of using electricity to split water (H^2O) into dihydrogen (H^2) and oxygen (O^2)) and biomass gasification barely met 0.2% of the total energy demand for hydrogen production. Less than 1% of the hydrogen produced with fossil fuels was from facilities equipped with carbon capture, utilization, and storage (CCUS) (blue hydrogen) (IEA, 2022).

The production cost of hydrogen from natural gas is influenced by a range of technical and economic factors, with gas prices and capital expenditures being the two most important. Fuel costs are the largest cost component, accounting for between 45% and 75% of production costs. Therefore, the production of hydrogen is emission intensive. It is responsible for around 830 million tons of CO^2 per year, equivalent to the CO^2 emissions of the United Kingdom and Indonesia combined.

Supplying hydrogen to industrial users is now a major business around the world. Demand for hydrogen, which has grown more than threefold since 1975, continues to rise – almost entirely supplied by fossil fuels, with 6% of global natural gas and 2% of global coal going to hydrogen production (IEA, 2019). With growing climate change awareness and governments net zero ambitions, demand for zero carbon hydrogen or green hydrogen (Green H2) is expected to grow exponentially in the future, reaching 20.000 TWh in 2050 (WEC, 2018).

Green H2 is commonly produced by electrolysis from renewable energy sources. As the cost of renewables continues to plummet and electrolysis technologies are expected to become more mature and competitive with conventional unabated fossil-based technologies, green H2 has the potential to take over the proportion of grey, brown, and blue production for chemical and industrial processes; (2) can reduce dependence on fossil fuels for deep decarbonization of the economy for hard-to-electrify sectors either by acting as a fuel burned in combustion engines or by producing electricity from hydrogen in a device known as hydrogen-powered fuel cells; and (3) is also seen as an enabling technology - enabling renewables through long-duration energy storage and offering flexibility through Power-to-X applications.

Ambitious Strategies and Investment in Renewables Provide Early-Adopter Advantages for Morocco in Green Hydrogen

Since 2009, the Kingdom of Morocco has adopted an ambitious energy strategy, which drove its energy transition by focusing primarily on developing renewable energy in the electricity sector. In 2020, nearly 20% of electricity is generated from renewable energy, and the share of the latter in the installed capacity is close to 37% (Ministry of Energy Transition and Sustainable Development, 2022).

Recently, Morocco has initiated a new process aimed at creating an economic and industrial sector around green molecules- namely hydrogen, ammonia, and methanol- to strengthen its transition in sectors that are difficult to decarbonize. Today, the world market for hydrogen is essentially industrial. It is mainly used in petroleum and chemical industry processes, notably for the desulfurization of petroleum fuels and the synthesis of ammonia for fertilizers.

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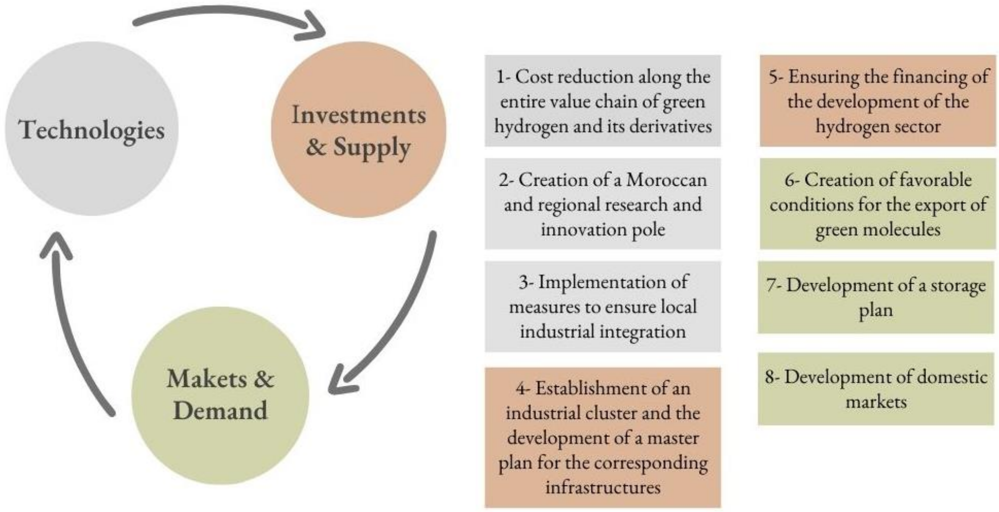
[1] Hydrogen (H) consists of a single proton and its atom has only one electron. The molecule of dihydrogen (H2) is made up of two hydrogen atoms joined by a single bond. Commonly, the term hydrogen is actually used to refer to dihydrogen.

A series of initiatives and studies have been initiated by Morocco since 2018 to understand this technology, the demand, and the potential market size. These initiatives have culminated in the development of a national "*Green Hydrogen Roadmap*" that was unveiled in 2021. This roadmap is based on three strategic areas: (i) technologies, (ii) investment and supply, and (iii) markets and demand, and is translated into a sequenced action plan for 2050 (Figure 1).

Figure 1: Strategic areas of Morocco's Green Hydrogen Roadmap



According to the roadmap, Morocco intends to produce green H2 through electrolysis technology using green electricity. Hydrogen can also exist in its natural form in underground deposits. Studies have shown the availability of this potential in many countries, including Mali and the United States. In the case of Morocco, the National Office of Hydrocarbons (ONHYM) is currently studying the national potential in this field. An initial study has identified 8 areas of interest, including 2 areas with significant concentrations of surface infiltration of natural hydrogen. ONHYM plans to map, model, drill, and experimentally monitor the identified sites.

Hitting the right note: combining public investment and market forces in pilot programmes

As green H2 is at the crossroads of several sectors, many institutions and public companies could be involved at different levels in its market development. These institutions include the Ministry of Energy Transition and Sustainable Development, the Ministry of Economy and Finance, the Ministry of Industry, Investment, Trade, and Digital Economy, the Institute for Research on Solar and New Energies (IRESEN), the Moroccan Agency for Sustainable Energy (MASEN), the National Office of Water and Electricity (ONEE), the National Electricity Regulatory Authority (ANRE), and the National Office of Hydrocarbons and Mines.

Institutional and regulatory landscape

Morocco created new institutions dedicated explicitly to green H2. For instance, the National Hydrogen Commission aims to reinforce Morocco's strategy in renewable energy development, ensure its energy independence, and reduce greenhouse gases. It will also be responsible for guiding and monitoring the implementation of studies in the field of hydrogen, as well as examining the implementation of the roadmap to produce hydrogen and its derivatives.

In addition, Green H2 Morocco was created by the Ministry of Energy Transition and Sustainable Development in 2021. Its objective is to contribute to the emergence of a competitive green H2 sector, to strengthen the capacities of local actors in the production, use, and development of the green molecule and to stimulate collaborative innovation. Besides, the Moroccan Association for Hydrogen and Sustainable Development (AMHYD) brings together hydrogen and fuel cell actors, companies, laboratories, research institutes, competitiveness clusters, local authorities, and regional associations.

Pilots to test technology and markets

The green H2 industry is still in its infancy in Morocco. As such, there isn't a fully operational market for it yet. However, numerous pilot projects have sprung up as a first step in implementing the national "Green Hydrogen Roadmap," by acting as Proof of Concept, thus capitalizing on Morocco's renewable energy ecosystem- including research platforms, public agencies, energy service companies, clusters, and industry associations.

One example is the Power-to-X project, which is the first large-scale green H2 industrial project in Morocco, in collaboration between MASEN and the German government. It consists of building a 100 MW renewable energy plant to produce green H2 through electrolysis and is scheduled to be commissioned in 2025. Another example is the Hevo Ammonia Morocco Project, which aims to produce green ammonia and hydrogen with a Portuguese company, Fusion Fuel Green, and a global provider of engineering solutions, Consolidated Contractors (CCC). The project was expected to start in 2022 after the completion of the feasibility study.

In addition, a small-scale green ammonia production project is also being developed in partnership with the OCP Group (Morocco's state-owned enterprise producing phosphate and fertilizers), IRESEN, Mohammed VI Polytechnic University, and the Fraunhofer IMWS & IGB centers. This pilot project will have a capacity of 4 tons of green ammonia per day and will be equipped with an electrolysis capacity of 4MW.

More recently, the Moroccan company GAIA Energy signed an agreement with the Israeli company H2PRO on the sidelines of the COP 27 to implement a pilot project in Morocco to produce a large capacity of hydrogen and green ammonia, using H2PRO's electrolyzer technology, starting with a capacity of 10-20 megawatts.

The global hydrogen market – an incentive or a threat to competitiveness?

Morocco is thus multiplying agreements with partner countries on joint projects to develop value chains and R&D around green H2. However, many of these same countries- particularly in Europe- have also shown interest in other countries of the Mediterranean region as well, suggesting that Morocco should carefully consider the potential drawbacks of developing its green H2 industry in the coming years.

In doing so, the country risks being exposed to the high risk and volatility of the international market, which will require continued assurance of national competitiveness in many areas: cost, sustainable transportation, certificates of origin, etc. As far as public opinion is concerned, green H2 is seen as the future low-carbon technology that will revolutionize the energy transition, both for its environmental benefits and for strengthening the competitiveness of Morocco's industrial sector.
However, many experts are cautioning against this enthusiasm as the green H2 industry is still emerging and faces several technical limitations that must be overcome to achieve its potential. For instance, the cost of producing green H2 currently remains higher than that of grey hydrogen. In addition, the hydrogen molecule is particularly unstable, which raises the issue of its transportation and storage. Addressing these limitations will be critical to the pace of the development of the green H2 industry.

Future Potential for Green Hydrogen in Morocco

In its "Green Hydrogen Roadmap," Morocco assessed potential domestic demand and international market that it can capture and rolled out two scenarios: (1) The reference scenario, where national energy efficiency targets are achieved, but with less than 52% installed capacity of renewable energy sources by 2030; (2) The optimistic scenario, where Morocco achieves targets of 52% installed capacity of renewable energy sources (which includes rapid deployment of renewables), but without meeting energy efficiency targets.

For its domestic market, Moroccan-produced green H2 has three applications:
(1) As an input in industrial processes: the roadmap primarily sets on capitalizing on Power-to-X applications to improve the fertilizer industry integration rate; and may possibly use green H2 in the refinery industry, whereby green H2 can aid the desulfurization of crude oil without the output of CO_2 into the atmosphere.
(2) To a much lesser extent, as an alternative fuel in the transportation sector either in the form of green H2 or synthetic fuel and to a lesser extent in the residential sector to replace imported Liquefied Petroleum Gas (LPG) commonly used in Morocco for cooking and heating.
(3) As a storage and flexibility solution, which constitutes a real asset in mitigating the intermittency of renewable energy sources and safeguarding the national network.

Domestic Applications: Leveraging Green Hydrogen Competitiveness to Explore Wider Applications

Green H2 to produce ammonia locally

Morocco is one of the world's most competitive fertilizer producers. It currently holds 72% of the world's phosphate reserves (estimated at 50,000,000 metric tons). It is also the second-largest phosphates producer worldwide (37,000 metric tons in 2020), after China (90,000 metric tons) and followed by the USA (24,000 metric tons). The OCP Group (OCP), Morocco's state-owned phosphate rock miner, phosphoric acid manufacturer, and phosphate fertilizer producer, therefore, has significant ammonia (NH_3) needs.

In fact, Morocco is the world's fifth-largest importer of ammonia, importing 1.59 million tons (Mt) and 1.44 Mt in 2019 and 2018, respectively, corresponding to OCP's needs. Morocco's leading supplier of ammonia is Russia, which has, on average, a carbon footprint of 2.4 tons of CO2 per ton of ammonia produced [2] (Berahab et al., 2021).

One way to produce green ammonia locally is by using green H2 and nitrogen. These are then fed into the Haber-Bosch process that artificially fixates molecular nitrogen (N_2) to dihydrogen (H_2) in order to convert it to ammonia (NH3). In the 'Green Hydrogen roadmap,' instead of remaining a net importer of ammonia, Morocco plans to produce upwards of 3.7 Mt of green ammonia annually by 2050.

Recently, OCP Group launched a 13-billion-dollar strategic program for 2023-2027, called its Green Investment Strategy devoted to raising fertilizer production, but also investing in new green fertilizers, renewable energy, and desalination units, thus marking a big leap from ambition and reality. The Group aims to produce 1 million tons (Mt) of green ammonia by 2027 and 3 Mt by 2032, 5 gigawatts (GW) of clean energy by 2027 and no less than 13GW by 2032 and a seawater desalination a capacity of 560 million m^3 (Mm^3) in 2026, of which 110 Mm3 should already be achieved in 2023 due to the commissioning of several new desalination stations (OCP, 2022). Through this large-scale project, OCP can improve its competitiveness by becoming a net exporter of green ammonia.

Green H2 as input for the refining industry

For the refining sector, a demand for hydrogen has been calculated in Morocco's 'Green Hydrogen roadmap' based on refineries that may emerge in Morocco. This demand should start at 5 Mt initially and reach 10 Mt in the long term. It is assumed that Green H_2 will cover 25% of its total demand for this fuel by 2030 and may reach 40% in 2050. It is worth mentioning that the only refinery in the country 'Société Anonyme Marocaine de l'Industrie du Raffinage '(SAMIR), initially a joint venture between the Moroccan state and the Italian giant ENI then privatized in 1997, closed in 2015 due to severe financial difficulties and management failure.

SAMIR was put into judicial liquidation in 2016 following a decision by the Casablanca Commercial Court. In January 2023, the Commercial Court of Casablanca rendered a judgment authorizing the continuation of the activity of Samir. The Court announced that the potential buyer will not be bound by the company's accumulated debts, which amount to more than 40 billion dirhams; the court will receive offers to purchase production units consisting of the company's assets and all its affiliated assets, without its liabilities.

Green H2 as an alternative fuel for domestic transportation and residential sectors

Green hydrogen can accompany the decarbonization of hard-to-electrify sectors, such as transportation. While battery technology is adapted for urban cars, long-range trucks, vans, heavy-duty vehicles, return-to-base fleets, and aviation are moving towards hydrogen either as a fuel burned in hydrogen combustion engines or by producing electricity from hydrogen-powered fuel cells. Battery packs supported by hydrogen fuel cells are also an option.

The aviation sector presents significant potential for hydrogen fuel cells, but also for future fuels such as cryogenic hydrogen. The emergence of Power-to-X can also be beneficial for producing high-valued synthetic fuels such as gasoline, diesel, methane, or even kerosene through renewables-powered electrolytic routes and even partially substituting LPG used in cooking and heating. The production of synthetic fuels could replace some volumes of imported conventional fuels.

[2] Ammonia is commonly produced following these three steps: 1) SMR method to produce H2; 2) Separation of nitrogen of the air mostly via fractional distillation of air, a highly energy intensive method; 3) In addition to the Haber-Bosch process.

Storage Solutions for Green Hydrogen

Green hydrogen can serve as a medium to store green energy or used as a 'balancing load', but itself is hard to store and transport, owing to energy-intensive processes of compression or liquefaction and boil-off losses during transportation. Therefore, it represents a solution as an energy vector, but may require storage solutions in the form of hydrogen carriers.

For instance, in addition to the role of 'chemical commodity,' green ammonia can also be a flexible energy carrier since it is easier to store and transport than hydrogen or also used as a 'balancing load.' Synthetic methane can also potentially be a part of this circular hydrogen economy, acting as a source of hydrogen that can be transported over long distances for various applications.

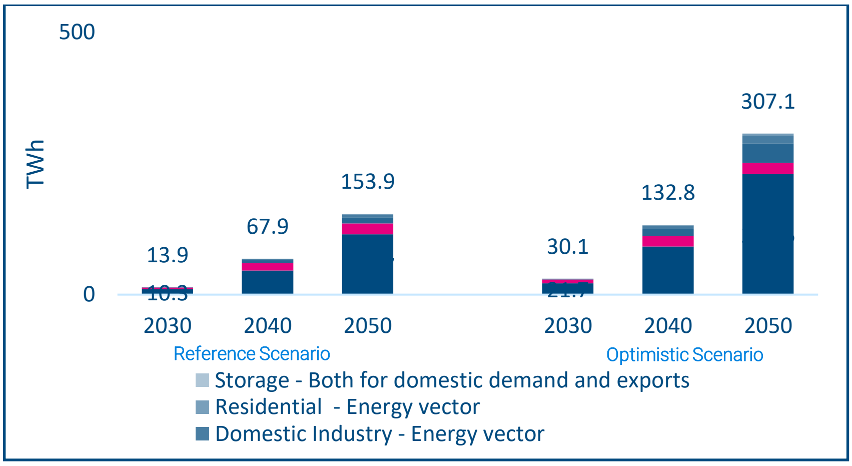
International market: Morocco's green hydrogen roadmap, an export-oriented strategy

Morocco's share of the international market is estimated using a World Energy Council study called "international aspects of a power-to-x roadmap," which projected the global market for Green H2 at 20.000 TWh by 2050 (WEC, 2018). The Moroccan "Green Hydrogen roadmap" assumes that this global market will represent 600 TWh in 2030. A study published by the Fraunhofer Society titled "Study of the opportunities of Power-to-X in Morocco" has shown that the country may capture up to 4% of this global demand in 2030 and that the participation of Morocco in the world market would decrease to about 1% by 2050 when other countries accelerate the pace of development of this industry.

In Morocco's "Green Hydrogen roadmap," it is assumed that 75% of exports will correspond to hydrogen exported in the form of ammonia and 25% to synthetic liquid fuels. The production of synthetic fuels could replace imported conventional fuels to be used by local industries or to be transported by pipeline to Europe or West Africa [3], in case of proven economic profitability.

In this regard, Moroccan ports ranked at the top of Mediterranean ports and in the top 40 well-connected ports worldwide are ideal for serving as hydrogen hubs – aggregating both demands from their own operations, from maritime transport, land transport, and local industrial uses, in addition to serving as a storage production and global export asset.

Figure 2: Possible demand for green hydrogen according to Morocco's green hydrogen roadmap



Source: Morocco Green Hydrogen Roadmap, 2021

What Is Necessary for A Market for Green Hydrogen to Develop in Morocco?

From what has been laid down in the preceding lines, Morocco's green H2 strategy is mostly exports oriented as exports will account for about 70% of the overall demand for Moroccan green H2 starting 2030 for both scenarios. To be a leader in the international market requires Morocco to continuously ensure national competitiveness in many areas: regulatory, technical, managerial, and financial [4], to name a few.

[3] Planned Morocco-Nigeria pipeline.

[4] Capital and operational expenditures, and soft costs such as financing, permitting, project management etc.)

Fundamentally, Morocco's green H2 ambitions highlight the need for additional (1) renewable capacities, (2) industrial electrolyzers; (3) desalination plants given water scarcity in the country; (4) processing plant capacities – PtL; and finally (5) Haber Bosch processing plants capacities – PtA. These are all accounted for in the roadmap with projections about capacity requirements along with the CAPEX necessary for their development. Morocco plans a cumulative investment of 90 billion Moroccan Dirhams (MAD) by 2030 and 760 (MAD) by 2050 in the reference scenario (Tables 4 and 5 in the annex).

One of the main challenges for green H2 production anywhere is its cost, which is currently two to three times higher than that of grey hydrogen. This is owing more to the high cost of electrolyzers than to the cost of green energy. Indeed, the weighted average cost of energy (LCOE) of renewable energies has decreased considerably in recent years on a global scale.

And while Morocco is currently lagging behind other countries, especially in solar energy, the country continues to reduce renewable energy production costs. For example, the sales contract signed between Nareva and ONEE in 2012 for the Tarfaya wind plant was Dh0.64/kWh, whereas the 850 MW wind power project signed between the two operators in 2015 was Dh0.30/kWh (CESE, 2020). In any case, Morocco possesses substantial experience and potential economies of scale in this area. Therefore, it is the cost of electrolyzers that must be addressed as it should drop by 80% in the long term to be competitive with grey hydrogen (Res4Africa, 2021). Incentives will thus be needed in the near term.

Additionally, considering water scarcity in Morocco, green H2 is dependent on desalination [5]. The required plants would have to produce an amount of water in the range of 50 to 70 Mm3 water, depending on the scenario [6]. This will not interfere with municipal water needs [7] (Bozier P. et al., 2022). However, it will generate constraints regarding the location of the green H2 production, which will therefore need to be close to the seaside.

This is advantageous to Morocco given the country's shorelines that span 3500 km, its proximity to end markets (Europe), and its significant maritime export experience: 34 ports, including 13 open to foreign trade, and its maritime transport infrastructure places the country at the top of the Mediterranean ports. In 2019, Morocco was ranked in the top 40 well-connected ports worldwide. The country's maritime infrastructure could also be a real asset for storage at ports and global exports while respecting safety measures, as green H2 is highly flammable, odorless, and colorless. Therefore, proper ventilation and leak detection are essential elements in the design of safe hydrogen systems.

In terms of export outlets, Morocco has two alternatives. It could either (i) export green H2 to the whole world, at the risk of losing part of the strategic advantage in terms of flexibility/reliability of supply to other competing countries (Middle East, Australia), or (ii) export to Europe, given the proximity to Morocco. It seems that this second option is the preferred one.
For Morocco to ship its green H2, it needs to invest in new sites in the south where the best sites for high-capacity factor for hydrogen production are located and then reload the green H2 produced by trucks to be shipped through the available ports. However, costly long-haul transportation may require additional investment in new infrastructure that must be secured and made available in time to meet the National Roadmap.

Therefore, developing a common market for green H2 between Morocco and Europe will require coordination in order to build or adapt the necessary infrastructure on both sides of the Mediterranean and investment in storage facilities for green H2 and derivatives in the form of salt caverns. In this sense, Morocco could leverage and adapt its gas and port infrastructure, which is well connected to the Atlantic and the Mediterranean.

In addition, given that transportation of green H2- either via trucks or by ship to destination markets- should become environmentally sustainable, it is essential for Morocco to ensure the traceability of the green H2 value chain, from production to final disposal, a process that involves different types of rules of origin. Hence the need to implement certifications or guarantees of origin that comply with the regulations and standards of exporting countries, in this case, Europe, and allow hydrogen to be labeled as "green" to ensure consumer transparency. For instance, the European Union is already working towards standardizing the hydrogen sector through a common low-carbon standard for hydrogen production based on lifecycle performance. It has come up with solutions like the CertifHy project, which is a Guarantee of origin scheme for green and low-carbon hydrogen (RES4Africa, 2021).

Morocco's vision for producing and exporting green H2 cannot be fulfilled without laying the foundation for a clear and transparent institutional and regulatory framework to send the right signals to investors and customers. In a rapidly

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[5] The draft National Water Plan 2020-2050, which constitutes a roadmap to face future challenges in the water sector, foresees the construction of seawater desalination plants to produce nearly 515 million cubic meters per year in 2030.

[6] For reference, in 2020, ONEE produced 1.25 bcm of water, representing about 85% of the country's water production.

[7] A 1 GW electrolysis plant would use less than 10 million litres per day of water, which is low by the standards of seawater desalination plants.

advancing world with countries issuing laws and regulations in record time, being among the first to develop a regulatory and policy framework could become a strong competitive advantage.

To successfully create a green H2 market, one of the challenges is bringing academic and industrial skills, opening up internationally, organizing a technological watch, and patenting the results and findings. It is also important to integrate green H2 targets systematically into energy, climate, and economic policies to leverage synergies and avoid contradictory strategies. In addition to setting targets within the development of the green H2 sector, it is also important to finance the routes to market to these targets. In the case of green H2, evidence shows that massive investments along the value chain are needed. In addition, the sector's governance must be brought to the highest level of importance (highest state level) and promote the emergence of an ecosystem capable of carrying out the desired ambition for the sector and the market.

Conclusion

Morocco is committed to participating in global climate efforts. The country is pursuing ambitious CO2 emission reduction targets and actively participating in international climate negotiations. It has also embarked on an energy transition focused primarily on deploying renewable energy. Morocco has now added another ambitious goal to its energy policy agenda: to position itself in the global market for green H2 through exports. The prospects for this vision are promising: the production of green H2 in Morocco would promote its economic growth, contribute to the decarbonization of its industry and strengthen the security of its energy and non-energy input supply. It would also strengthen its position as a strategic partner for the European Union.

Achieving such a vision requires addressing several technical, financial and institutional limitations (high cost of the electrolysis process, need to increase the production of green electricity, important water requirements, substantial financing, the necessity of regulation etc.). Besides the production of green ammonia for domestic use, the green H2 strategy is mainly oriented towards exports to Europe.

In this scenario, it is important to consider the impact of this export orientation on Morocco's energy transition and on the country's own population. To date, Morocco's ambition has been strongly demand-driven to supply EU member states seeking to secure access to the "oil of the future." However, the focus on exports must not be at the expense of the local population. Morocco must ensure that its own population can benefit from the hydrogen boom as well.

Furthermore, what is needed now for Morocco is to complete the national hydrogen roadmap by setting ambitious but achievable quantified targets for the entire green hydrogen value chain from production and electrolysis capacity to desalination plants, necessary transportation infrastructure, operating costs, R&D, etc. Short- and medium-term targets should be set to facilitate monitoring and evaluation.

Morocco should also define the country's priority in terms of green H2 and its place in the energy strategy relative to other energy sources (oil, RES, natural gas, etc.) and infrastructure. For example, lack of clarity on the priorities and objectives of the natural gas and infrastructure sector and other fossil fuels could result in duplication of costs and investments and may not be financially sustainable, especially in the long term.
Finally, given that the relationship with the natural gas sector is particularly tight, the relationship between the natural gas strategy and the national green hydrogen roadmap needs to be carefully assessed.

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Green Hydrogen in Jordan

By Eng. Hamza Alnawafah

The Current Hydrogen Market in Jordan - Renewables as a Way to Decrease Energy Dependence in Hydrocarbons

Jordan has limited access to natural resources and energy; up to 92% of its primary energy requirements are covered by imports. Jordan consumed 9712 thousand toe (the equivalent of one ton of oil) as its primary energy in 2019.It uses coal, crude oil, pet coke, and natural gas as sources for its primary energy. These sources represent 92% of the total energy resources. However, the average sunny hours in Jordan are considered high; ~13 % of its energy is generated from renewable resources, mainly sun, and wind.

Because Jordan is not an oil country, it depends entirely on oil and gas imports. Therefore, Jordan's economic and foreign currency resources have been depleted Trade deficit and increase in public debt resulting in the need to use and enhance own resources from renewable energy, especially wind and photovoltaic, which is one of the high comparative advantages due to continuous solar radiation and a large number of sunny days per year. In fact, the annual average daily sunlight in Jordan is within the range of 5-7 kilowatt-hours / m2, one of the world's highest figures. Also, the wind speed in Jordan is within the range of 7-9 m/s.

Jordan is considered an excellent example for other countries in the MENA region as it faces the numerous challenges in the power production sector, which still an obstacle for government and an impediment to the country's economic and social development. These challenges have encouraged the government to search for alternative energy sources, review its energy strategy, and take a significant legislative change to increase the use of renewable energy.

Despite all the benefits of renewable energy, the integrating of renewable energy resources as part of the distribution system is very challenging. First, the main problem is that most of our power distribution systems are designed for one-way power flow, such as equipment like voltage regulators, transformers, and protection equipment. Integrating these renewable resources at high levels can result in a bidirectional power flow that can mislead some of the existing power system controllers.

Second, renewable energy resources such as wind and photovoltaics are not reliable, because they depend on the weather conditions; it is challenging to identify when clouds come through to block sunlight or high wind speeds.
Therefore, the integration of renewable energy requires new planning and operation procedures for high-voltage grids as well as distribution grids. For that reason, we need to increase the energy mix and integrate new technology to use extra energy from renewable resources to produce hydrogen (Alnawafah & Harb, 2021).

Hydrogen market

As a clean, eco-friendly energy carrier and storage solution, hydrogen is a resource that can be utilised. Along with renewable energy, it is one of the primary factors considered to reduce greenhouse gas emissions. On Earth, hydrogen is a widely exploited chemical element that is also abundant, however it is primarily found in compounds. These chemicals, some of which are or are contained in water, biomass, wastes, fossil fuels (hydrocarbons), and many other substances, require processing in order to yield hydrogen.

The concern with hydrogen occurs when it comes to its production rather than consumption; some of the processes used to manufacture hydrogen are considered to be unsustainable and harmful to the environment. Due to the range of environmentally friendly hydrogen production techniques, the produced hydrogen has been divided into three categories based on the type of energy source that was used to produce it, which is directly related to the amount of CO_2 emitted from the method.

The three colours are blue, grey, and green. Blue hydrogen is produced from fossil fuels, but by using Carbon Capture Use and Storage (CCUS), which involves capturing the hydrogen and isolating or "sequestering" it, the CO_2 emissions are decreased. Grey hydrogen is the term for hydrogen produced from fossil fuels in a variety of methods where CO_2 is produced as a byproduct and released into the atmosphere. It is also currently a cheapest of the hydrogen production methods.

Green hydrogen is defined as hydrogen that was produced using renewable energy sources without the use of carbon capture and storage systems (CCUS). Because the technologies required to produce green hydrogen have not yet developed to their maximum potential, they are more costly. The cost of producing green hydrogen will undoubtedly reduce as long as renewable energy production continues to fall.

Rapid global growth of Green Hydrogen

The market for hydrogen generation is anticipated to grow at a CAGR of 5% in the global hydrogen industry. is anticipated that the increased use of hydrogen will cause major change. The market's expansion can be ascribed to the increasing worldwide need for long-term power storage as well as the rising demand to balance supply and demand in the power sector and the demand for renewable energy resources. Along with this, rising greenhouse gas emissions are expected to drive market expansion in the upcoming years.

According to the International Energy Agency (IEA), in 2020, the global demand for hydrogen amounted to 90 Mt. A percentage of 79% of the demand was met through fossil fuel-powered hydrogen plants, 59% of which wa
s natural gas-powered hydrogen plants with no use of CCUS; completely grey hydrogen, 0.7% was also powered from natural gas but with the use of CCUS, 19% was produced through coal, 0.6% through oil. Finally, the remaining 21% of the hydrogen was produced as a by-product in facilities that are designed to produce other products.

In order to replace natural gas, coal, and oil in hard-to-decarbonize industries and transportation sectors, the European Union (EU) is establishing a target of 10 million tonnes of domestic renewable hydrogen production and 10 million tonnes of imports by 2030. However, enhanced sub-targets for some sectors would need to be approved by the co-legislators in order to accelerate the hydrogen market. In order to guarantee that production proceeds in net decarbonization, they simultaneously released two delegated Acts on the definition and production of renewable hydrogen.

Green Hydrogen in Jordan: From ideation to early-stage projects

The hydrogen market in Jordan is still in the first phase (Implementing strategy phase). The Jordanian Energy Ministry is currently developing a strategy to establish technical and regulatory requirements for producing green hydrogen using wind and solar power. But the main goal for the Ministry is to use green hydrogen production to reduce the nation's dependence on the importation of fossil fuels and encourage the development of locally sourced renewable energy. Additionally, one of the main goals of the strategy is to increase energy efficiency through the implementation of plans and the improvement of national energy efficiency regulation.

According to Jordan 2020–2030 Energy Strategy, renewable energy will contribute for 14% of the total energy mix in 2030 compared to its current 11% share in 2021. The strategy also aims for a 52% decrease in natural gas-based electricity output by 2030 and a 30% rise in renewable energy. Only 84% of the total electricity is produced by this, leaving 16% open to the potential of new sources.

As an energy source, hydrogen is still in its infancy and won't likely have a sizable market share for another 2 to 5 years. Although many improvements and new discoveries are still feasible and required, hydrogen production, storage, and conversion technologies have achieved a technical stage that already makes its use as an energy carrier highly interesting. On the other hand, a number of challenges need to be addressed before hydrogen can play a significant role in the energy market from a commercial standpoint. In addition, it is probable that the technology will change significantly as a result of the increased use of hydrogen.

Hydrogen Technologies

Instead of being an energy source, hydrogen generally used as a method of energy storage, especially form renewable energy sources when all of their production can't be utilized. In order to power hybrid vehicle or autonomous energy production systems, it can also be used to produce energy. The heat generated during the hydrogen production process can also be used on-site, for example, to heat buildings.

Cost and CO2-footprint distinguish the different production techniques
There are several techniques to generate hydrogen in general:

1. The widely utilized process of reforming natural gas using superheated steam.

2. In the gasification process, a reactor burns charcoal. The released gases form at extremely high temperatures, releasing hydrogen and carbon monoxide.

3. Using electrolysis to separate water into oxygen and hydrogen. This method is attractive because it makes it simple to produce pure hydrogen and, more importantly, since it is the only one that is completely carbon-free when the electricity is generated using renewable energy sources like wind and solar.

The process of Steam Methane Reforming (SMR), which uses natural gas as a feedstock, is currently the most widely-used way to produce hydrogen. the SMR method of producing hydrogen, where depending on the presence of a CCUS system, both blue and grey hydrogen can be created. Other techniques for producing hydrogen from fossil fuels include partial methane oxidation, coal gasification, and partial oil product oxidation.

Water splitting, which can be performed through either water electrolysis or water thermolysis, is another way to produce hydrogen. In order to successfully separate water into H2 and O2, water must be heated to temperatures above 4000°C, which is very difficult and expensive to achieve. As a result, additional steps are added to lower the temperature requirements, resulting in successful decomposition at temperatures between 500°C and 1000°C. Water thermolysis also produces green hydrogen, but it is challenging to use it as a large-scale hydrogen production plant.

Solid polymer electrolyte membrane (PEM) water electrolysis is a method of analysis that can operate at higher pressures and current densities than liquid electrolyte-containing cells because of the volume decrease. The usual operating temperature range is 200 to 400 °C. The architecture of this membrane electrolysis is simpler, and it offers a longer lifespan and more efficiency.
Electricity consumption will be decreased to levels of 4 kWh/Nm3 of H2. Small-scale units (8–260 Nm3/h) have somewhat lower efficiency but nevertheless accomplish high-pressure systems with pressures of 3 MPa in the lower power range. The main drawback is the continued high cost of manufacturing membranes.

Production of hydrogen can be divided into large-scale, small-scale, centralized, and decentralized production.
All principal hydrogen production technologies can be used to produce the majority of hydrogen locally, in industrial, large-scale SMR units devoted to addressing the demands of the chemical and petrochemical sectors. Production that is done locally means that there are either no or very few transportation costs. On the other hand, the alternative is a large-scale system characterized by a hydrogen delivery/distribution network that supplies H2 to the consumption site by pipeline or truck in a gaseous or liquid state. With centralization, a reliable supply is feasible. The goal of centralizing large facilities is frequently to reduce specific production costs by increasing unit size (economy of scale).

Future Potential for Green Hydrogen in Jordan

Green hydrogen production technologies are gaining popularity. This is due to the fact that hydrogen's possible applications are expanding across a wide range of industries, including power generation, manufacturing processes in industries such as steelmaking and cement production, fuel cells for electric vehicles, heavy transport such as shipping, green ammonia production for fertilizers, and electricity power grid stabilization.

<u>Possible applications in a variety of industrial sectors in Jordan</u>

In Jordan green hydrogen will have great potential for different sectors, such as the energy sector, transportation sector, and water sector.

Jordan's primary challenges are: providing energy, given the country's scarcity of natural resources, as well as regional insecurity and increasing demand for electricity in Jordan due to the high growth in population, in addition to hosting a high number of refugees from neighbouring countries that lead to increasing energy consumption, and rising public awareness of the need for environmental protection and governmental incentives for renewable integration.
These challenges have encouraged the government to search for alternative energy sources, review its energy strategy, and take a significant legislative change to increase the use of renewable energy.

Electrical power systems in Jordan consist of three main stages: power generation, transmission, and distribution. The power plants generate power using fossil fuel (natural gas), and these plants transfer the power to distribution units by long, high-voltage transmission lines. Finally, distribution units are connected to end-users by low-voltage distribution lines. So, green hydrogen will be one of the leading solutions for storing renewable energy in power generation, and hydrogen can be utilized in gas turbines to increase power system flexibility.

<u>Green Hydrogen to improve the energy mix and reduce energy generation costs</u>

Green hydrogen may be used to store and deliver green energy for a variety of sectors in Jordan, including transportation. It has the potential to significantly minimize air pollution from vehicles, buses, and planes emitting greenhouse gases. Greenhouse gases trap heat and contribute to climate change, with transportation accounting for 14% of these emissions.

EVs in Jordan - from battery to fuel-cell powered?

The public transport system in Jordan is not very developed and is described as being inefficient, unreliable, and reform-resistant. Several projects have been implemented over the last decade to address the problems associated with the current transportation system, such as the Amman Bus Rapid Transit Project (BRT). However, when it comes to electric vehicle mobility, Jordan is regarded as a pioneer. Jordan has more than 18,000 electric vehicles (EVs) on the road, which is mostly due to the lower cost of EVs compared to conventional fuel combustion and the waivers from customs charges and licensing costs. But this will create a new challenge for the government to upgrade the current infrastructure to handle the new demand.

Fuel cell electric vehicles (FCEVs) powered by green hydrogen will play an essential role in decarbonizing the transport sector. FCEVs will increase by up to 35% in 2050. It is expected that Germany, Japan, California, and South Korea will lead the global markets in FCEV adaptation.

Water scarcity and social and environmental impact

In water sector in Jordan the water scarcity exacerbates already-existing systemic difficulties, such as poverty and public health crises. As of November 2021, the Kingdom had an extraordinary youth employment rate of 48.1% and was struggling to meet pandemic-induced public health demands. Jordanians may progressively feel the effects of water scarcity in Jordan during the next decade as the effects of environmental changes continue to emerge. According to Jim Yoon's March 2021 research paper, more than "90% of Jordan's low-income people" will face acute water insecurity by 2030.

Because of Jordan's water scarcity, impoverished households will receive less than forty liters of water per capita per day. Also, more than 80% of Jordan's land area is desert and receives less than 100 mm of rain per year; only 4% receive more than 300 mm per year. Jordan receives water from international rivers such as the Yarmouk River in addition to precipitation. Water demand by other riparian countries implies that Jordan has only a limited supply. Climate change exacerbates the problem by reducing Jordan's accessible water supply. As a result, Jordan is facing significant water scarcity. It would be possible to source water for a green hydrogen facility in Jordan through water desalination from the Red Sea through Aqaba, taking Jordan’s water security into account (Abdelsalam et al., 2021; Alkasrawi et al., 2021).In addition, we must do different feasibility studies to validate this approach.

Outlook for a Green Hydrogen Market in Jordan

Geographically, the market is divided into five regions: Europe, North America, Latin America, the Middle East, and Africa ,and Asia Pacific. The Asia Pacific market is expected to develop at the fastest compound annual growth rate (CAGR) during the forecast period, owing to the region's increasing energy demand and the increasing use of green energy to meet government targets for lowering greenhouse gas emissions, especially in India and China.

Furthermore, North America is expected to have the greatest market share during the forecast timeline due to increased investment in Research and development (R&D) and the government's support for hydrogen generation through innovation funding, required targets, and public-private partnerships. The United States hydrogen production is expected to account for 14%–16% of worldwide hydrogen production in 2023.

Similarly, the European market is expected to hold a major proportion of the hydrogen generation industry due to the region's increasing adoption of electric vehicles.

The global hydrogen generation market is divided into different segments as in the table 1:

Table 1 global hydrogen generation market segments

Source	Technology	Application
Blue Hydrogen	Steam Methane Reforming (SMR)	Petroleum Refinery
Green Hydrogen	Electrolysis	Ammonia Production
Grey Hydrogen	Coal Gasification	Methanol Production
	Partial Oxidation (POX)	Power Generation
		Transportation
		Water desalination

Priority and focus – key to Green Hydrogen success in Jordan

To facilitate and ensure the easy entry of the green hydrogen market in Jordan, it is important to prioritize the areas where green hydrogen can be successful in lowering the country's CO2 emissions. In addition, setting target sectors can attract investors and direct funding to essential economic activities, by allowing green hydrogen to enter the market through these activities.

First step to enter the green hydrogen market is Green hydrogen must be included in Jordan's 2020- 2030 Energy Strategy to serve as a framework for the implementation of other programs, as well as to attract foreign investments and development collaboration.

Second, Upgrading the current grid in Jordan to the smart grid. A smart grid provides a host of solutions to many of the issues faced by the current electric grid by taking advantage of next-generation technologies such as distributed generation, energy management systems, distribution automation, renewable energy generation technologies, and plug-in hybrid electric vehicles. In the smart grid, the renewable energy source will be solar or wind, which can only provide electricity through generators. This indicates that the electrolyzers will operate gradually. If these electrolyzers are powered by energy from the national grid at a given price, they will function as on-demand load controllers with extremely high consumption capabilities. Electrolyzers can help the operator of a hydrogen facility by producing non-green hydrogen at a low cost for export or local usage. So, the smart grid will improve the energy mix in the Jordanian power grid and power the green hydrogen facility.

Third, there is the need for a water desalination plant in the south of Jordan, supplied by renewable energy, and using it to produce green hydrogen, whether for export or local use(Abdelsalam et al., 2021).

Fourth, designing and equipping a research facility in Jordan with all the needed tools to help these facilities conduct research to increase electrolysis system efficiency and simplify the design of large-scale electrolysis systems is needed. Such studies could lead to technological advancements and reduce hydrogen costs for end users. Additionally, it will tackle problems related to green hydrogen technology. The research facility could be extremely important in promoting and disseminating information.

Finally, the green hydrogen economy in Jordan will not only boost economic growth, but it'll also provide opportunities for new job creation in this sector.

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Building a Sustainable Hydrogen Economy for Tunisia Quick Wins and Long-Term Benefits

By Chokri Aslouj

The Tunisian Energy Deficit and its Related Problems

Since the year 2010, the energy balance in Tunisia has been marked by a steady decline in the national primary energy resources of about 7% and an increase in the demand of more than 2% per annum, which led ultimately to a tenfold rise of the energy deficit during the last decade. Therefore, Tunisia is compelled to resort massively to imports in order to cover almost half of its energy needs, a situation which undermines markedly its energy security.

In addition, Tunisia's electricity mix is strongly dependent on natural gas, which currently represents around 97% of the electricity sector's consumption. This situation poses also a serious problem for securing the electricity production given that the Tunisian natural gas resources cover no more than 1/3 of the national needs and the rest is imported from Algeria. In Tunisia, energy subsidies represent 58% of development expenditure, 13% of the state budget or 3.7% of GDP. The surge in prices following the Ukrainian crisis has aggravated the situation of the already precarious public finances, by increasing the budgetary burden of the subsidy from 2885 to 5920 MTND. Despite this alarming situation and regardless of its considerable potential, the actual contribution of renewable energies - RE in the energy mix is still marginal and does not exceed 3% currently.

The yearly Greenhouse gas GHG emissions in Tunisia amount to 30 million tons of CO2. According to its drawn up Nationally Determined Contribution in the year 2015, Tunisia proposed to cut its cross-sectoral GHG emissions, by reducing its carbon intensity by up to 41% until 2030 compared to the base year 2010. In 2021, Tunisia even raised its target reduction to 45%. The mitigation effort will come mostly from the energy sector, which alone will account for 75% of the reductions in emissions. The implementation of the Tunisian contribution in terms of mitigation requires the mobilization of significant financial resources, estimated at around US$ 14 to 18 billion. The amount of 2.2 billion could be self-funded by Tunisia; the rest has to come from international partners.

Current Situation and Developments in the Hydrogen Market in Tunisia

In Tunisia, grey hydrogen, which is supplied in its pure and gaseous form by the Tunisian subsidiary of the company “Air Liquide” is mainly, used as a coolant for the generators’ gas turbines in company Société Tunisienne d’Électricité et de Gaz (STEG) power plants. It is also produced as a by-product of the oil refining process and used as a recycle gas in the catalytic reforming (platforming) process of the STIR refinery.

The Tunisian Solar Plan (TSP), which was devised in 2012 according to the country's strategic orientations and updated in 2015 and 2022, stipulates the increase of renewable energy integration rate to reach 35 % of the national electricity mix by the year 2030. To achieve this goal, the development of solar and wind energy capacities (additional 4300MW) and the decrease of the national primary energy consumption by 30% through the acceleration of energy efficiency actions, have to be driven forward.

Most experts agree today that green hydrogen is the best-suited energy carrier, which will facilitate the storage and transport of renewable energy and thus allow to overcome their fluctuating supply. It will also make the decarbonization of the so-called hard to abate sectors (heavy-duty terrestrial and maritime transport, aviation, heavy industry, etc.) possible, which is an indispensable condition to achieve the carbon neutrality by the year 2050.

Germany leads the field in Tunisia’s international cooperation initiatives on green hydrogen

In a far-sighted move and in order to strengthen their long-standing cooperation, Germany and Tunisia concluded in December 2020, the Tunisian-German Alliance for green hydrogen. Pursuant to this agreement, Germany has granted 31 million € to help Tunisia kick-start a green hydrogen market by implementing a pilot production unit KfW, conducting studies, performing capacity building activities and establishing an institutional and regulatory framework GIZ. After conducting three rounds of the high-level Tunisian-German dialog on green hydrogen and organizing three introductory workshops, the project "Green hydrogen for sustainable growth and a low-carbon economy in Tunisia (H2Vert.TUN) was formally launched, in June 2022.

On behalf of (BMZ), the Wuppertal Institute has issued in April 2021 a study, which highlighted the high potential and the very competitive production costs of PtX in Tunisia. Furthermore the Bavarian Ministry for European and International Affairs launched a Tunisian-Bavarian technology and innovation program for green hydrogen was announced on September 7th, 2022 with a financial support of the federal Land of Bavaria amounting to 820,000 €.

Other countries did not take long to express their interest to develop a close energy partnership with Tunisia. The Italians, with a long tradition in the hydrocarbons sector in Tunisia, were also quick to come forward and dispatched two high-level delegations in May and June 2021, representing the giants of the energy sector SNAM and ENI, to convey to the head of government, their willingness to invest heavily in the green hydrogen sector in Tunisia.

Four (MoU)'s between Tunisia and Japan were also announced at the business forum, organized as part of the Tokyo International Conference on African Development TICAD 8, which was held in August, 2022 in Tunis, two of which at least are directly linked to the production of green hydrogen, namely the water desalination and the production of renewable energy. Business France, the French agency in charge of the internationalization of the French economy, and the French Agency for the Environment and Energy Management (ADEME), organized in September 2022, in Tunis, the first Africa-France Forum for ecological and energy transition. Representatives from eight countries (Tunisia, Algeria, Ivory Coast, Cameroon, Senegal, Egypt, Libya and France) presented the issues and solutions for the environment, energy transition and sustainable cities including those related to the development of green hydrohen.

Within the framework of the working visit of Lord Tarek Mahmoud Ahmed, the British Minister of State for South and Central Asia and North Africa, Tunisia and the UK have signed in June 2022 an MoU to reaffirm the commitment of the British government to further support Tunisia in various sectors, especially those related to its energy transition, by creating a financing line worth 2.5 million pounds for purchases and services originating from UK that will be included in the establishment of clean energies and green hydrogen projects in Tunisia. This seems to pander particularly to the interests of Tunur, a subsidy of the British company Nur energy, which has a successful tender track record in RE projects in Tunisia and which has developed a long-term green hydrogen strategy in Tunisia, based on developing a series of projects for the production of green hydrogen and its derivatives beginning with an ammonia producing pilot project in Gabes.

All relevant financial institutions for Tunisia, such as the German bank of reconstruction – KfW, The European Investment Bank EBI, the European Bank for Reconstruction and Development – EBRD, the African Development Bank – ADB, the International Finance Corporation – IFC (World Bank Group), etc., have assured the Tunisian government of their support for the Tunisian energy transition in general and the development of the GH sector in particular.

Existing legislation on renewable energies to be complemented by specific rules applying for green hydrogen

We may consider that the existing legislative framework relating to hydrocarbons and renewable energies covers the production and use of green hydrogen quite well and requires therefore little or even no further adjustments at all. In general terms, new laws would be needed for:

- Electrolysis (Hydrogen production and storage) and Hydrogen injection in gas networks (Gas sector)
- Manufacturing and use of synthetic fuel from hydrogen (Oil sector)
- Use of hydrogen for transportation (Road and rail transport sector)

Future Potential for Green Hydrogen in Tunisia

Early Mover advantage - Export as a driver for economic growth and hydrogen development in Tunisia

In the elaboration of the Tunisian national green hydrogen strategy, which was recently launched by GIZ, the future development of the green hydrogen market in Tunisia should necessarily take into consideration the development of two sectors, one oriented towards the local use of this resource and the other towards its export, especially to Germany/Europe. However and given that the storage and distribution infrastructure as well as the industrial hydrogen consuming applications are more developed in Europe than in Tunisia, this sector should be the first to be considered since it's easier, cheaper and faster to implement because it only requires the build-up of production capacities. To offset the large deficit in the foreign trade balance and create a source of hard currency to finance its development and overcome its precarious financial situation, Tunisia is well advised to work diligently in order to position itself well in advance, among the major green hydrogen exporting countries.

In May 2022, the European Commission presented the REPowerEU Plan, which pledges to end the European Union's dependency on Russian fossil fuels and to tackle more rapidly the climate crisis, which manifested itself clearly during this last summer throughout Europe. The objective to be met by the year 2030, according to this plan is to attain 10 million tons of green hydrogen from domestic production and 10 million tons from imports, in order to replace natural gas, coal and oil in hard-to-decarbonize industrial and transport sectors, the implementation of which requires at least € 84 billion in investments over the next 7 years. This constitutes a unique opportunity for Tunisia to get its share of the pie.

Open Questions – export of renewable energy or green hydrogen?

Electricity from renewable sources and produced in Tunisia could be exported in the form of electricity or already transformed into gaseous green hydrogen. Currently two projects are planned to interconnect Tunisia with Europe. The Elmed project consists of a new interconnection between Tunisia and Sicily to be carried out through a 500MW High Voltage Direct Current – HVDC transmission submarine cable aiming at increasing the interconnection capacity of the Euro-Mediterranean. As for the TuNur project, a 2,000 MW HVDC transmission system will provide 13 TWh/year of low-cost controllable solar energy to European consumers under long-term (CPPAs).

Compressed gaseous hydrogen could also be exported mixed with natural gas at a proportion of 15 to 20% and transported via the existing Transmed gas pipeline to Italy or in pure form via a dedicated pipeline to be built in the future. Liquefied green hydrogen or other liquid derivatives (methanol, ammonia, eFuels, …) could furthermore be transported by sea with special tanker ships.

Building the green hydrogen economy - the case for local use in industry, power generation and transport

Industry

Hydrogen is used currently in several industrial sectors mainly as a feedstock rather than an energy carrier. The possible use of green hydrogen or derivatives in the future is specific for each industrial segment and could range from the simple substitution of the already used fossil based hydrogen to changing entirely the production processes:

Refining: In the national reform plan of the energy sector in Tunisia "TUNEREP" and more specifically in the activity No. 8 relating to the feasibility study for the development of the STIR oil refinery, it is stipulated the establishment of a natural gas based hydrogen production unit with a capacity of 2.4T/h for supplying hydrogen consuming chemical processes (hydro-cracking, desulphurization, etc.). A pilot project for the production of green hydrogen could constitute an appropriate substitution alternative allowing the reduction of the refinery's carbon footprint and pave the way for a future partial or total reconversion towards the production of green Fuels.

Cement: Tunisia has nine cement factories, which are responsible of 3000 kt CO2/a. green hydrogen could replace the extreme polluting petroleum coke, used currently for high temperature heat generation in the Tunisian cement industry. Furthermore, cement factories could serve as abundant CO2 sources, needed for the production of green methanol (H2 + CO2).

Fertilizer: Apart from the production difficulties linked to the political and social instability in recent years, Tunisia occupied the third (2010) and the 5th place (2015) in the worldwide ranking of the phosphate producing countries. The CPG, a state owned company, is carrying out all mining activities in the south of Tunisia. The GCT uses most of the extracted phosphate to produce fertilizers, a state owned company and TIFERT, a Tunisian-Indian joint-venture. Ammonia, the second most produced synthetic chemical in the world, is a chemical compound formed by nitrogen (N) and hydrogen (H) atoms, which is necessary for the production of fertilizers.

Tunisia could avoid its ammonia imports, currently ranging from 250 – 400 Kt/a, and even become an exporting country by developing a green ammonia industry.

Other industries: Methanol (CH3OH) is the second largest produced synthetic chemical after ammonia; it is an important feedstock for the chemical, pharmaceutical and building materials industries. Methanol can also be used as an energy carrier for RE or as a fuel either directly mixed with other hydrocarbons or further converted to MTBE or DME.

Power Generation

By increasing the share of intermittent renewable energy in the electricity mix, it becomes more and more challenging to balance the temporal and spatial mismatch between the demand and the supply. To meet the peak demand, renewable energy must be stored as electricity or PtX and the grid must become smarter to allow operation flexibility. Besides pumped storage, batteries, grid expansion and cross-border trading, and because many gas turbines in the Tunisian power plants are 'hydrogen ready', green hydrogen as a fuel could become an option to offset the mismatches, by managing the surplus electricity generated from non-dispatchable and fluctuating RE sources and thus partially replace the 4000 Ktep consumed to generate electricity.

Furthermore, green hydrogen could replace fossil-based hydrogen used currently for gas turbines' cooling. Green hydrogen could also be injected into existing natural gas pipeline networks either directly or after being converted into syngas. It is assumed that the share of green hydrogen could go as high as 20% without the need of any costly retrofitting measures for the existing transport and distribution gas infrastructure.

Transport

The transport sector accounts for about 26% of Tunisia's CO2 emissions and 31 % of its national energy consumption. Powering the different transportation modes with green hydrogen could contribute significantly to decarbonize this sector.

<u>Railway</u>: Only circa 4% of the railway network in Tunisia is electrified, the rest is operated with diesel locomotives. For this reason, the SNCFT is looking for sustainable alternatives and has launched in 2021, with the financial and technical support of the EIB, a call for tenders for a feasibility study on the deployment of alternative propulsion solutions in the Tunisian railways. Given the high investment costs for overhead electrification infrastructures and the successful experience with H2 trains in the German Lower Saxony and elsewhere, locally produced gaseous green hydrogen could become the ideal solution for retrofitted existing diesel locomotives in replacement of the imported diesel.

<u>Shipping</u>: In the Mediterranean Sea circulates more than 20% of world trade, one of the busiest Mediterranean maritime routes passes just alongside the Tunisian coastal city of Bizerte, which is located in the northernmost point of the African continent. In the course of cutting at least 50% of (GHG) emissions by the year 2050, as decided by the IMO in 2018 and following the deployment of large-scale industrial hydrogen production, Bizerte could become a main "gas station" in the Mediterranean, where ships passing by will make a stop to refuel with green hydrogen or derivates (green ammonia).

<u>Road</u>: While Battery Electric Vehicle are better suited for light duty vehicles such as passenger cars and vans, Fuel Cell Electric Vehicle running on hydrogen should be prioritized for heavy duty and long-haul transport as well as for long distance buses. The state owned bus service company SNTRI operating 121 buses from Tunis to nearly all significant towns in the country could be an ideal candidate to introduce H2 powered buses for longer distances.

<u>Aviation</u>: IATA has set the target of 50% reduction of aviation CO2 emissions by 2050. Since both of the Tunisian airliners are members of IATA, this is going to be binding for Tunisia as well, which will have to substitute wholly or partly its 300K tons kerosene imports, with locally produced green fuel.

Policy Recommendations: Building a Sustainable Hydrogen Economy for Tunisia

The development of the green hydrogen sector in Tunisia will come for sure with a host of benefits for the country. For the sake of a fast and efficient development of a green hydrogen market in Tunisia, the following recommendations are made:

Adopting regional concerted policies and collaborative approaches:

It is crucial to develop the respective national green hydrogen strategies in the Maghreb states in a prospect of clustering and a spirit of constructive cooperation and not of disruptive competition or destructive animosity.

Strengthening the role of the private sector in green hydrogen development:

Most of the activities related to green hydrogen are carried out currently within the framework of Tunisian-German bilateral cooperation in accordance with the MoU signed by the two governments and are therefore considered to be the exclusive prerogative of the administration. However, the bureaucratic approach, characterized by its cumbersome procedures, resistance to change, lack of innovation, deficiencies in terms of governance, exclusive rather than inclusive mind-set, limited delivery capacity in the concrete realization of industrial projects in accordance with the objectives set, etc., may end-up jeopardizing the chances of a swift success of the green hydrogen industry development process, as already experienced in other international cooperation projects. Thus, it is strongly recommended to explore new ways to carry out international cooperation projects on green hydrogen by involving the private sector and the civil society as equal stakeholders, alongside with public central authorities and preferably in a decentralized rather than centralized manner.

Reforming the governance infrastructure to remove roadblocks and boost production incentives:

One of the major obstacles that has hindered so far the development of renewable energies and caused a considerable delay in the Tunisian energy transition is of a structural nature. Indeed, the development of renewable energies has always been considered as a threat to the monopoly of the national electricity and gas company STEG. After having yielded, the production monopoly with the law 2015-12 relating to the production of electricity from renewable sources, the unions used (STEG's) monopoly on the national grid to prevent the new photovoltaic power plants from being connected to consumers, which deterred investors from moving forward to carry out their projects.
Within the ministry MIEM, conventional electricity and renewable energies are under the aegis of the same general directorate, which is likely to perpetuate the status quo, since this same structure is playing the role of judge and jury. This blockage causes Tunisia to lose nearly 2,500 MD of unrealized investments and 400 MD of annual forgone revenues for the State. It is therefore high time to take inspiration from Algeria and organically separate the decision-making bodies of conventional and renewable energies and to provide state guarantees for the connection of renewable energy power plants to the national electricity grid.
For the further development of renewable energy and consequently of green hydrogen in Tunisia, a lasting solution for this problem is urgently needed.

Green hydrogen as a driver for decent employment and a remedy for brain drain:

Tunisia has about 50,000 higher education graduates per year, more than 30% of whom are forced into long-term unemployment. One of the main causes is linked to the non-adequacy of the curricula and research projects, to the actual needs of the national economy. Another major cause lies in the relatively modest technological level of a large part of the Tunisian industry, which does not require a large number of highly trained personnel because of an outdated development model. With the establishment of a new, state of art green economy around renewable energy and green hydrogen and the implementation of capacity building programs that must go hand in hand with it, there is a unique opportunity for the Tunisian higher education and scientific research sector to become a catalyst for a new economic development and a driver for the creation of lucrative jobs, which could significantly reduce the worsening brain drain and illegal immigration phenomena.

Addressing the water scarcity problem in the course of developing green hydrogen:

At an early stage of the reflection and planning, the green hydrogen-water nexus has to be addressed. It is important to acknowledge in this regard, that the level of water stress in Tunisia, which is defined as the ratio of the fresh water withdrawal over the available renewable water resources, is estimated at 96%. This situation could be well considered as severe water scarcity and will constitute one of the major challenges for the Tunisian people in the years to come. The large-scale industrial development of green hydrogen production, based on the electrolysis of desalinated seawater will make it possible to increase the volume of desalinated seawater and thus to achieve an economy of scale, which will lead to a significant cost reduction of water desalination. This will benefit the production of green hydrogen and the production of potable water alike.

Preserving the Mediterranean Sea against the impacts of the large-scale development of green hydrogen:

The Mediterranean Sea will be practically the only water reservoir from which all the Mediterranean bordering and green hydrogen producing countries will draw. The enormous quantities of brine that will be discharged following the very large-scale desalination of seawater will constitute a major ecological hazard for the marine fauna and flora. In this respect, the interests of all Mediterranean basin countries must be protected; therefore, a multinational structure should be created for this purpose to protect and preserve the Mediterranean Sea from overexploitation.

Using communal waste for green hydrogen transformation:

Tunisia produces roughly 2.6 Mt/a of household waste with an annual growth rate of 3% and a biodegradable proportion of 68%. Approximately 80% of this waste is collected in urban areas and 10% in rural areas. No more than 4% of the waste is recycled, mainly plastic; the rest is buried in public landfills at a cost of 200 Dinars/t. This approach worked more or less so far, except for the fact that almost all communal landfills are currently saturated and the government lacks the time and the funds to build new ones. The solution lies in the recovery and the recycling of the municipal waste, in particular as a source of green CO_2. With green hydrogen produced with renewable-energy-based electrolysis and green carbon produced by mechanisation or gasification of biomass, it is possible to synthesize the various eFuels as well as green methanol.

Reshaping European Energy Relationships – resolving geopolitical tensions to the benefit of all:

The waged wars for black gold in the twentieth century and the ongoing conflict between Russia and Ukraine have shown that energy resources as a commodity can become a formidable economic and political weapon, which brings misery rather than wealth to the world. The same goes for the closure by Algeria of the Maghreb-Europe gas pipeline, which passes through Morocco and crosses the Mediterranean to transport Algerian gas to Spain as a form of retaliation, because of the dispute between the two countries over the Western Sahara issue.

In the same conflicting logic, two gas pipeline megaprojects are being prepared:

The first, 6000 km long, will transport Nigerian gas through Morocco to Spain via 16 West African countries, the second concerns the Galsi project with a 1450 km long gas pipeline which will link the Algerian installations of Koudiet Draouche to Piombino in Italy via Sardinia passing on the Mediterranean Sea bed in addition to its interconnection at Hasi R'mel with the 4000 km long trans-Saharan gas pipeline, thus linking Nigeria to Europe through Algeria and Niger. This will obviously make obsolete, the Trans-Mediterranean gas pipeline, transporting the Algerian gas to Italy and crossing Tunisia for a share of about 6%.

In addition to these two projects, a third proposition has been announced recently concerning a 3000 km gas pipeline linking Italy to Nigeria via Niger and Libya. Considering its immense potential in renewable energy resources, its vast unexploited desert territories, its existing and planned pipelines to Europe, the Maghreb in general and Tunisia in particular could become the main supplier of green hydrogen and derivatives to Europe in general and Germany in particular. To turn the Maghreb into a viable and durable source of green energy for Europe, increased efforts should be made to defuse the existing potential of conflicts in the region and to establish a fair win-win relationship between the two shores of the Mediterranean.

Similar to the European Coal and Steel Community Treaty of 1952, which definitively turned the page on the hostilities of the Second World War and laid the foundations of the European Union, the Maghreb Community of green hydrogen could offer a historic opportunity to revive the Arab Maghreb Union project on a solid basis of common economic interests for the benefit of the peoples in the region. Comparably to the Organization of Petroleum Exporting Countries - OPEC, Tunisia could then in the near future, become alongside its neighbours, a founding and influential member of the Organization of Hydrogen Exporting Countries - OHEC.

Abbreviations

ADEME: Agence de l'Environnement et de la Maîtrise de l'énergie, the French environment and energy management agency.
BMZ: Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung, the German ministry for economic cooperation.and developement
BEV: Battery Electric Vehicle.
CPG: Compagnie des Phosphates de Gafsa, a Tunisian state owned company for phosphate mining.
DME: Dimethyl ether
EIB: European Investment Bank.
FCEV: Fuel-Cell Electric Vehicle.
GA: Green Ammonia.
GCT: Groupe Chimique Tunisien, a Tunisian state owned company for chemical industries.
GDP: Gross Domestic Product.
GHE: Greenhouse Gas Emissions
GHG: Greenhouse Gas Emissions
GIZ: Gesellschaft für Internationale Zusammenarbeit, German agency for international cooperation.
GM: Green Methanol
HVDC : High Voltage Direct Current
IATA : International Air Transport Association
IMO: the International Maritime Organization
MIEM: Ministère de l'industrie de l'Energie et des Mines, Tunisian Ministry for Industry Energy and Mines
MTBE: Méthyl tert-butyl éther
MTND: Million of Tunisian Dinars (Tunisian currency)
MoU: Memorandum of Understanding
NDC: Nationally Determined Contribution
PtX: Power to X
RE: renewable energy
SNCFT: Tunisian national railway company
SNG : Synthetic Gas
SNTRI: Société Nationale de Transport Rural et Interurbain, Tunisian state owned company for intercity transportation.
STEG: Société Tunisienne d'Electricité et de Gaz, a state owned company for electricity and gas
STIR: Société Tunisienne des Industries de Raffinage, a state owned company for oil refining
TICAD: Tokyo International Conference on African Development
TIFERT : Tunisian Indian Fertilizers, a Tunisian-Indian joint venture company for fertilizers
TSP: Tunisian Solar Plan
TUNEREP: Tunisian Energy Reform Plan

Green Hydrogen's Potential for Lebanon - Stabilising Energy Essentials and Keeping an Eye on the Future

By Rani Al Achkar

Stabilising Lebanese Energy Supply in Unstable Time

Lebanon is a small country on the Eastern shores of the Mediterranean relying mostly on oil imports for its energy supply[8]. Since 2019 the country has been facing a multi-faceted crisis that has been described by the World Bank as "the most devastating, multi-pronged crisis in its modern history.[9]" This economic and financial crisis, has led to severe shortages in fuel supply, which in turn resulted in further blackout in the national electricity grid with public electricity supply not exceeding two hours per day.

But the country is accustomed to shortages in public electricity supply. Informal neighborhood-level private diesel generators were supplying up to 50% of electricity before beginning of the crisis in 2019. However, the crisis, and its resulting fuel shortages added to the end-consumers' loss of purchase power, resulted in the inability of these generators to cope with and supply longer hours of blackouts.

This is why those who can afford it are either subscribing to more expensive private generators that guarantee continuous supply over the long hours of blackouts, or resorting to rooftop solar photovoltaic systems with battery storage. All this highlights the vulnerability of the energy sector in Lebanon and the need for increased energy security.

While the peak electricity demand in 2021 was estimated at 3,700 MW, the production capacity by Electricité du Liban (EDL), the national utility, did not exceed 700 MW.

Urgent need for energy-supply diversification but hydrogen not in the mix

In the meantime, Lebanon has been planning to increase its generation capacity as well as diversifying its generation mix with more reliance on least-cost intermittent renewable energy sources. The IRENA Renewable Energy Outlook for Lebanon[10] published in June 2020 sets a 30% renewable electricity target by 2030, consisting of an installed additional capacity of 1,000 MW wind, 601 MW hydro, 2,500 MW utility-scale solar PV, 500 MW rooftop PV, and 13 MW biogas.

The World Bank's Least-cost Generation Plan[11] goes even beyond this target and sets an increase of renewable energy penetration to 32% in a base-case scenario and 35% in a preferable high renewable energy scenario in 2030. While both policy documents include heavy reliance on intermittent renewable energy sources, they marginally tackle energy storage - one pumped-hydro storage project of 49 MW/4 hours, and a total of 201 MW/213 MWh of battery energy storage systems – both documents fail to include any role for hydrogen in the electricity mix of the country in 2030.

On a similar note, Lebanon submitted in March 2021 its updated Nationally determined contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC)[12] which include an unconditional target for greenhouse gas (GHG) emission reduction of 20% compared to a business-as-usual scenario in 2030, (amounting to 7,790 Gg. CO2eq) which could be increased to 30% (amounting to 11,860 Gg. CO_{2eq}) if international support is granted. The document also fails to include any role for hydrogen in the climate mitigation actions of the country.

First steps in the context of a limited national hydrogen-market potential

Rare public announcements in the country tackle the role of hydrogen in its sustainable future, the latest among these being an interview[13] in September 2022 with the President- Director General of the Lebanese Center for Energy Conservation, whereby he states that "Lebanon is working on the development of a green hydrogen production plan."

[8] https://www.iea.org/countries/lebanon#data-browser, accessed November 2022.

[9] Lebanon Overview: Development news, research, data | World Bank, accesses November 2022.

[10] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Outlook_Lebanon_2020.pdf

[11] doc-100796-2022_05_21_01_43_29.pdf (energyandwater.gov.lb)

[12] Lebanon's 2020 Nationally Determined Contribution Update.pdf (unfccc.int)

[13] Attaqa Article, accessed November 2022.

In the meantime, Lebanon's hydrogen market is limited, with the total imports of hydrogen main products to the country not exceeding 600,000 USD in value annually over the last eleven years.

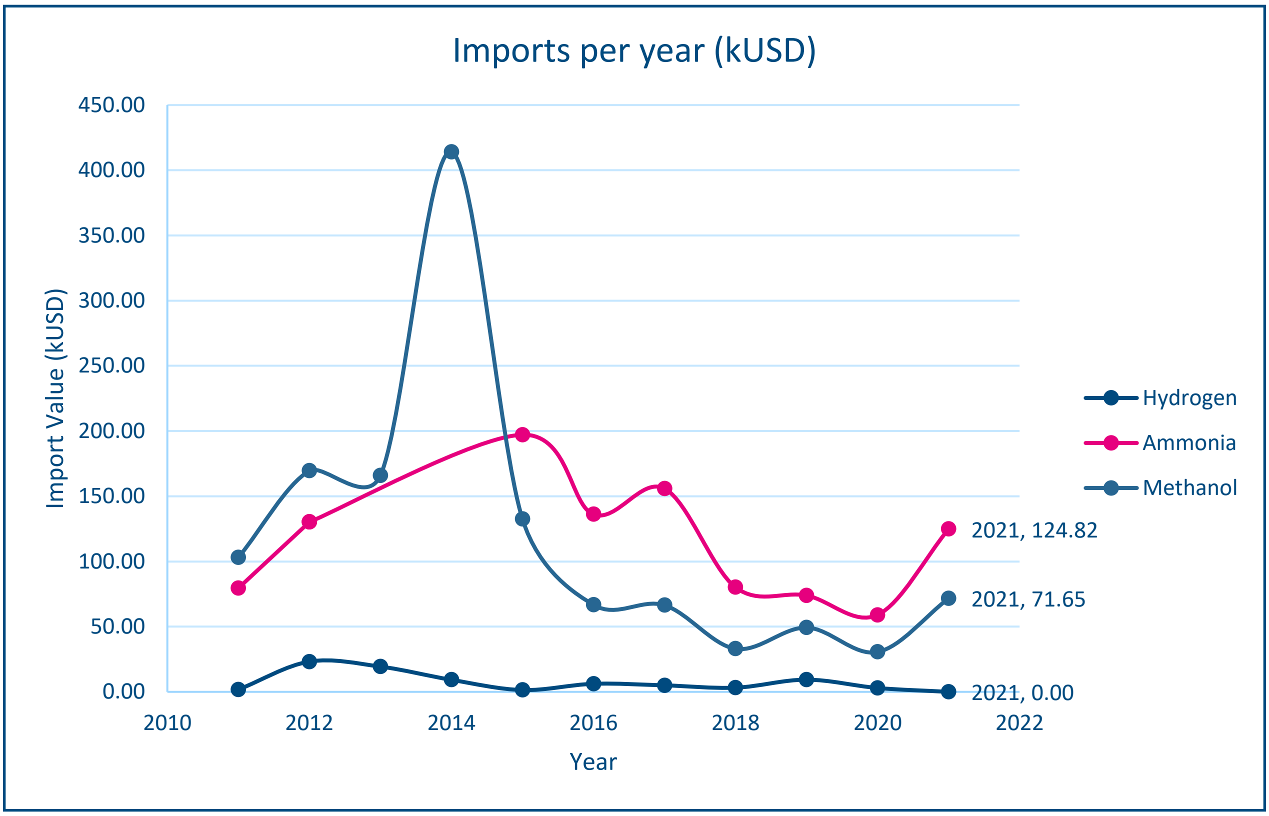

Figure 1 Imports of Hydrogen[14], Ammonia[15], and Methanol[16] to Lebanon between 2011 and 2021 (source worldbank.org)

It is to be noted that Lebanon does not have iron or steel industries, neither does the country have oil refineries or biofuel production. It is therefore estimated that the abovementioned imports of hydrogen products are mostly used in the chemical industry.

First Things First: Future of Green Hydrogen Conditional upon Improving Grid and Renewable Energy Production

Lebanon is a small country with a small electricity production capacity, and a weak infrastructure. The state-owned electricity utility has been in constant financial deficit, estimated in 2018 at 1.8 billion USD[17], which has been further exacerbated by the financial and economic crisis that started in 2019. This has been reflected by EDL's inability to invest in grid expansion projects, which could create bottlenecks for future expansions of the generation capacity, especially renewable energy, having most potential in the Bekaa and Hermel area, while demand centers concentrate further west at the Mediterranean shores.

Available figures highlight that most of Lebanon's renewable energy potential is concentrated along one 220 kV transmission line spanning from Ksara till Qobeiat. Conveniently, this line is interconnected on both ends with Syria. It is also convenient that this line stops in Baalbeck, where an open cycle gas turbine power plant of 74 MW is located, initially conceived to operate on natural gas imported from Syria.

[14] Hydrogen imports by country |2020 (worldbank.org)

[15] Ammonia; anhydrous or in aqueous solution imports by country |2021 (worldbank.org)

[16] Alcohols; saturated monohydric, methanol (methyl alcohol) imports by country |2021 (worldbank.org)

[17] https://www.imf.org/-/media/Files/Publications/CR/2019/1LBNEA2019002.ashx

Hydrogen as a potential storage medium in power generation

Based on the above, hydrogen could have an important role in electricity storage applications in Lebanon as well as in providing valuable spinning reserves through blending and use in the Baalbeck power plant. It could also provide well needed flexible and back-up power generation to local communities in the Bekaa, and Baalbeck-Hermel areas, especially in case of disparity between investments in renewable energy and investments in grid expansion and conventional generation. This would decrease negative impacts on the fragile grid that may be caused by the intermittency of renewable energy generation in the area and by the bottlenecks in transporting this scale of renewable energy to the coastal areas.

Future industrial uses of Green Hydrogen in chemical and agricultural production but export not viable

It is to be noted, that the Bekaa and Baalbeck-Hermel areas host major industrial zones and facilities in the country. Green hydrogen could have a major potential in the industrial sector in the area, especially in food and chemical industries.

In the agricultural sector, the area is characterized by truck farming. This would emphasize the potential for hydrogen in fueling heavy vehicles for use in the agricultural sector as well as those used in transporting agricultural crops for the local market as well as for export.

On a similar note, the Bekaa and Baalbeck-Hermel areas are crossed by the main international route connecting Beirut Port to Chtawra in Lebanon and beyond, to Damascus and the Arab world. This route is the most important one for heavy vehicles across Lebanon, which could be reflected in a potential demand for hydrogen fueling network for heavy vehicles, especially when harmonized with similar efforts within the hydrogen strategies of destination Arab countries.

Finally, given the size of the country and the current state of the electricity infrastructure, it is not foreseen that hydrogen would have a potential for export in Lebanon on the medium term.

Future Scenarios see Green Hydrogen Beyond the Horizon until Renewable Production and Efficiency Issues Resolve

First and foremost, Lebanon needs a strong grid with an adequate production capacity that is able to meet and exceed its electricity demand, including a high penetration rate of renewable energy sources, in order to start looking into green hydrogen. Losing valuable kilowatt-hours in conversion losses could not be justified when electricity is not reaching the end-consumer for a large part of the day. A lot of efforts are needed in this regard, including but not limited to, heavy reforms and transparency, unbundling of the electricity sector, creation of a strong independent regulatory framework that enables renewables energy and achieves bankability of projects, development of credit enhancement tools for the offtaker, reduction of technical and non-technical losses, achievement of cost-recovery, investment in expanding generation capacity, and investment in grid expansion, among others.

Green Hydrogen safety in conflict-zones needs special attention

It is to be noted that, similarly to other fuels, hydrogen requires certain levels of safety. Moreover, due to its light nature, hydrogen is easy to seep through leaks, which may cause fire and explosions if not properly handled. Consequently, it should not be recommended to deploy hydrogen storage facilities in areas of frequent armed conflicts and high potential of stray bullets. Lebanon would need to improve its overall internal security level before promoting green hydrogen development, especially within the identified areas of Bekaa and Baalbeck-Hermel characterized by their high security risk (see British Embassy's travel advisory for Lebanon).

Green Hydrogen storage does not align well with a nationwide post-traumatic stress disorder

In August 2020, an uncontrolled fire in a warehouse storing Ammonium Nitrate at the Port of Beirut resulted in a massive chemical detonation that devastated the country's capital. The event is engraved in the population's memory for years to come. In March 2022, rumors of improper hydrogen storage at EDL power plant in Zouk created a panic among the population to a point that led to a full-scale government public action to contain the situation and ease the population's concerns. Any future strategies, plans, or projects that may include storage of hydrogen products will have to invest massively in awareness raising and stakeholder engagement in order to ensure public acceptance, especially within nearby communities.

Strategic industrial and regulatory framework a precondition to establish Green Hydrogen pilots as proof of concept

Pilot applications for green hydrogen would help familiarize policy makers with the potential for green hydrogen and the importance of the role it can play in the energy mix of the future. However, these applications should be part of a larger strategy, whereby hydrogen clusters are created around renewable energy hubs, ideally along the Ksara-Qobeiat 220 KV line. This would help reduce production cost across a larger spectrum of applications as detailed in the previous section.

As of November 2022, a decentralized renewable energy law[18] is at the level of the Lebanese parliament. It is intended, among others, to facilitate peer-to-peer renewable energy power purchase agreements. Ratification of this law would allow producers of green hydrogen to procure the needed electricity directly from private renewable energy investors.

On the other hand, indirect supply of renewable electricity could be done through the purchase of renewable energy certificates (RECs) by the hydrogen production facility. In this regard, Lebanon has been approved in April 2022 for I-REC issuance [19], renewable energy facilities registered as per the International REC Standard could sell their RECs to the hydrogen production facility for the latter to demonstrate the green sourcing of the needed energy.

Dedicated national strategy on green hydrogen could keep Lebanon in the game

Finally, Lebanon has been lagging on the setting of a hydrogen vision and strategy, especially when compared to the rest of the world. However, this could present a learning and collaboration opportunity, especially with European countries and with the rest of the Arab World that has already advanced on this front. Once its infrastructure is ready, collaboration on policy, research, development, and application could catapult Lebanon's journey towards a future of green hydrogen.

[18] https://lcec.org.lb/ourwork/partners/RELaw#:~:text=This%20law%20sets%20a%20basis,and%2For%20renewable%20energy%20equipment, accessed November 2022

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The current state and future innovation potential of the renewable hydrogen sector in Egypt

By Dr. Mohamed Kamel

Introduction

Concerns about the implications of climate change have increased in recent years, which has fueled the drive for a low-carbon energy transition. Several governments all over the world are concerned about hydrogen's potential contribution to a decarbonized energy system in this context.

Egypt as a case-study of the hydrogen transition

Egypt might serve as a case study for other growing nations in general, and natural gas suppliers in particular, on how to optimize advantages by moving from current energy sources to blue hydrogen made from natural gas . "Egypt Vision 2030," Egypt's long-term energy strategy, outlined the sector's strategic goals, which included ensuring energy security, increasing the sector's GDP contribution, maximizing energy resource utilization by increasing production and energy sector dependability, lowering energy intensity and increasing energy efficiency, and finally, reducing environmental impact by limiting emissions .

Building on decades of green hydrogen experience in Egypt

Egypt was among the first MENA countries to produce and use green hydrogen. It was first produced in 1960 by the Egyptian Chemical Industries (KIMA) company using hydroelectricity from the nearby Aswan dam to manufacture green ammonia . Green hydrogen is the most suitable type of hydrogen for a completely sustainable energy transition because it is produced using renewable energy. Utilizing only electricity and purified water, the green hydrogen approach combines the production of renewable energy sources with water electrolysis to produce oxygen and hydrogen .

The Current Hydrogen Market in Egypt

Ready to go - Egypt’s long-established hydrogen market

Grey hydrogen, which is produced domestically using readily available local natural gas without reducing emissions, is extensively used by Egypt's most significant industries . In 2019, 1,824,540 tonnes of hydrogen are anticipated to be used in Egypt. Additionally, the estimated gas consumption for this hydrogen synthesis is 13% of Egypt's current domestic gas use. With an annual consumption of roughly 14 Bcm, or close to a quarter of Egypt's domestic gas use, the industry sector was the second-largest gas user after the power sector.

Furthermore, about 46% of all industrial sector consumption was accounted for by the fertilizer industry alone. The second and third largest industrial gas consumers in Egypt, respectively, were the iron and steel sector and the petroleum sector .

An Integrated Strategy for Egypt to change from grey to Green Hydrogen

Therefore, Egypt is reviewing and revising its Integrated Sustainable Energy Strategy (ISES) to 2040 to lay out its goals to raise the proportion of renewable energy in its electricity generation and create low-carbon hydrogen projects. Throughout the years 2021-2022, Egypt is actively working on several efforts and projects to create low-carbon hydrogen technology[6], such as agreement in writing (LoI) with German company Siemens in January 2021, the DEME of Belgium in April 2021, an MoU with Eni and EEHC in July 2021, Norwegian renewable energy provider Scatec in October 2021 for the coordinated development of projects utilizing green and blue hydrogen. Before June 2022, Egypt has established a high-level group made up of senior officials from various ministries to formulate a national hydrogen strategy with the support of the European Bank for Reconstruction and Development (EBRD).

Future Potential for Green Hydrogen in Egypt

Avoiding a carbon tax through Green Hydrogen in key export markets

Hydrogen will be crucial in the post-carbon era in all energy transition scenarios. The expanding request for clean hydrogen in Asian and European markets offers the best investment opportunities. Therefore, the target markets for Egypt's hydrogen are Europe and Asia. Egyptian exports to Europe may suffer if carbon border adjustment mechanism (CBAM) restrictions are installed. Therefore, the use of clean hydrogen in difficult operations would prevent the implementation of this potentially onerous CBAM tax on Egyptian imports, allowing Egypt to continually improve and even increase its trade with the EU . Egypt should therefore intensify its efforts to manufacture blue hydrogen from natural gas now that it has established close links with these countries that import energy. Future actions include producing an action plan to implement and create a national hydrogen strategy for Egypt and researching ways to localize the hydrogen industry in Egypt in collaboration with outside experts.

Need for reliable statistics to estimate future scenarios on Green Hydrogen

There is no information on the production or use of hydrogen, although the ministry of petroleum and mineral resources claims that Egypt uses all of the hydrogen produced locally in the steel sector, petrochemicals, fertilizer industry, and refining. Egypt now consumes 13% of the country's use of hydrogen synthesis gas domestically, according to estimates 6.

Competitive Green Hydrogen hinges on cheap electricity from renewable sources

Additionally, recent estimates showed that delivered supply of renewable electricity to electrolyzers would need to be extremely cost-competitive and well below US$ 25 per MWh to attain a competitive Levelized cost of green hydrogen. However, according to Mohamed Shaker, minister of electricity and renewable energy, green hydrogen would be incorporated into the 2035 Energy Strategy. Shaker noted that given the country's national capacity to generate 90 gigawatts of solar and wind energy, 7,650 square kilometers of hydrogen had been set aside for renewable energy projects .

What is Required for the Development of a Green Hydrogen Market in Egypt?

International partnerships to bring production to scale

The Egyptian government is actively attempting to establish a low-carbon hydrogen economy. However, it would take a long time to construct low-carbon hydrogen projects at the necessary scale in Egypt. A memorandum of understanding between the Egyptian and Indian governments aims to create an $8 billion green hydrogen manufacturing facility in the Suez Canal Economic Zone .

Some difficulties might have an impact on these developments in the case of Egypt, such as Renewable energy and electrolyzer scaling up. It would be necessary to build a sizable renewable energy capacity if Egypt decides to switch from the grey hydrogen, it currently produces and consumes to green hydrogen, which might be produced there. It would require a total of 36 GW of dedicated renewable power capacity, which is greater than 60% of Egypt's existing total electricity-producing capacity. For Egypt, this would provide a tough obstacle[6].

Water scarcity poses a risk to production capacity

Besides, the low-carbon hydrogen amounts would need to be stored before being consumed or transported, in addition to the production difficulties already outlined . Furthermore, a severe water shortage in primary source of freshwater (the Nile) in Egypt is a big problem where, to make 1 kg of green hydrogen using electrolysis, approximately 9 liters of water are needed. So, desalination of seawater, however, might be a way for Egypt to stop using fresh water .

Moreover, the creation of a legislative framework to enable enable the growth of a low-carbon hydrogen economy in Egypt is anticipated to be one of the main goals of the country's current national energy strategy[6]

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