North Africa's assets in the green-hydrogen energy transition

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Abstract. With the roll-out of Morocco's green-hydrogen roadmap, massive amounts of renewable energies will be put on-line. To substitute 2MT/yr of ammonia imports from Morocco's global phosphate fertilizer industry, an additional 8 GW renewable capacity will be needed. As the country's peak power load has reached 6.7 GW in 2021, this would more than double the country's peak power generation capacity. Beside record-low production costs achieved when combining the Atlantic trade winds blowing on the Sahara coastline with Solar PV generation, Morocco's green-hydrogen greatest advantage remains its interconnectivity to European gas pipeline networks. As transportation costs of green-hydrogen from remote countries (such as Chile) can double its price once reconverted in Europe, Morocco's pressurized green-hydrogen can be delivered by existing pipelines directly to European end-users. As a result, Morocco raised its energy transition target submitted to the United Nations Framework Convention on Climate Change UNFCCC from 52% to over 80% of renewable capacities by 2050. Considering the country's hydrogen road map reference and optimistic scenarios forecasting 78 GW to 131 GW of additional renewable capacities dedicated to green-hydrogen production by 2050, this target can be effectively met. For that to happen, storing large amounts of hydrogen will be critical. Morocco disposes of a pioneering experience in Underground Geological Storage of energy carriers. Initiated since 1978, the country stores over 80% of its butane consumption in bedded salt deposits. This operational experience in energy carrier underground storage with sound geological prospects will make seasonal storage of massive amounts of green-hydrogen economically competitive. These, along with other critical operational synergies in hydrogen generation, integrated uses and infrastructures are likely to make Morocco's Green-hydrogen roadmap very effective.

1. Initiating Morocco and Mauritania's green-hydrogen developments

Supported by a Special Service Agreement from the United Nation Industrial Development Organization under contract TF/INT/03/002/11-68 signed in 2005, Sahara Wind identified the costs, economics and environmental benefits of producing green-hydrogen from the Atlantic Trade winds blowing over North Africa's Sahara coastline. An Engineering Report on the Perspectives of a Wind-Hydrogen Energy Pilot Project in Tarfaya, Morocco was subsequently produced detailing the benefits of using green-hydrogen as both fuel and feedstock for the region's industries. This can be attested by Sahara Wind's multiple participation at international events as well as our published papers and presentation section [1] on this topic starting from 2006 [2]. With co-funding from the North Atlantic Treaty Organization in implementing the NATO SfP-982620 'Sahara trade winds to hydrogen: applied research for sustainable energy systems' project [3] initiated in 2006 with key stakeholders in Morocco and Mauritania, the production of green-hydrogen has been considered very early-on in its regional dimension to support the massive roll-out of renewable energies. Indeed, the North Atlantic Trade Winds blowing over 2000 km of desert coastline where capacity factors above 60% of electricity generation can be reached, 11 500 TWh [4] of green electricity can be produced at very low costs. Complemented by 20 000 TWh of solar PV electricity [4], green-hydrogen can be generated almost continuously. This drives down the costs of green-hydrogen, enabling it to compete against grey and blue hydrogen, generated through reforming fossil fuels feedstock, with CO_2 sequestrations in the latter case.

At capacity factors higher than 60% from trade winds compared to 25% at best for Solar PV generation, wind energy provides the bulk of the electricity needed for green-hydrogen generation. A first 50 kW wind test site commissioned at the Tiniguir wind test site near the city of Dakhla in 1995 [5] confirmed the wind's quality on an operational basis. To determine its range and geographical distribution, Sahara Wind conducted a regional wind measurement assessment in Morocco and Mauritania with co-funding from NATO a decade later. It would not be until 2013 however, that the first of several commercial wind farms started operations in the area. These confirmed the outstanding quality of the Atlantic trade winds and their significant energy potential on the Sahara coastline in Morocco and Mauritania.

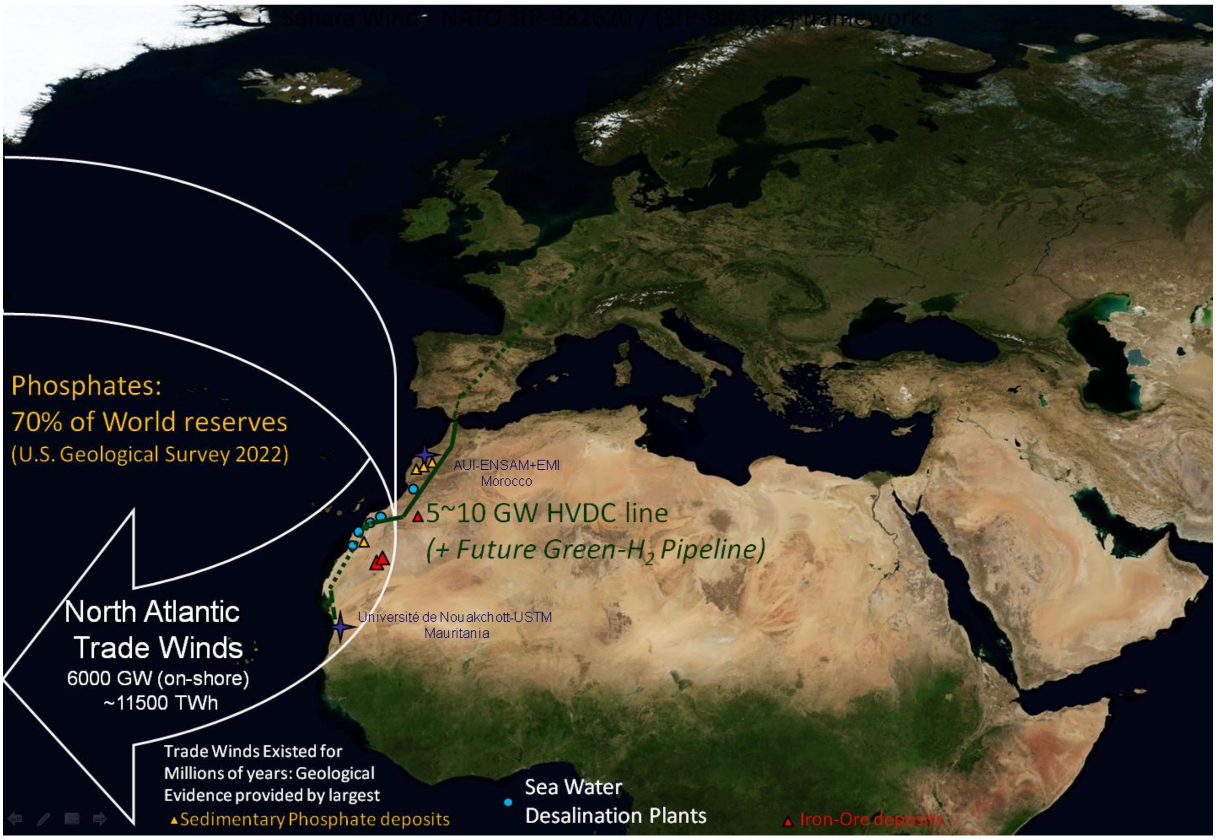

Figure 1. North Atlantic trade winds (at the origin of 70% of world phosphate deposits) blowing over the Sahara coastline, with NATO SfP-982620 academic project partners and relevant existing and planned infrastructures.

Through academic partnerships with key stakeholders Africa's first wind hydrogen system was commissioned in 2012 at the University of Al Akhawayn in Morocco [6], with a further one delivered to the University of Nouakchott in Mauritania. Synergies for using green-hydrogen in the country's iron-ore mining and Morocco's phosphate and fertilizer industries were clearly identified within this framework since 2006. This can be attested through the NATO SfP-982620 project stakeholders [7] and support letters from CERPHOS, the R&D branch of OCP-Group Morocco's phosphate conglomerate [8]. This is critical as the roll-out of massive green-hydrogen production facilities can significantly enhance the operational balancing of Sahara Wind's projected regional HVDC transmission infrastructure shown in 'figure 1', feeding both North African and European electricity markets. By bridging a 1500 km distance gap separating the Sahara coastline from North Africa's load centers already interconnected to Europe, the access to one of the world's most competitive wind energy resource leverages the region's main global industries by de-carbonizing their local value-added processes. This is well in line with the European Union's Carbon Border Adjustment Mechanism (CBAM) proposal adopted on July 2021 [9], which Morocco aims to comply and benefit from with the EU, its first trade partner.

Sahara Wind's subsequent pilot project in partnership with the International Institute of Water and Sanitation - Office National de l'Eau Potable ONEP-IEA and proposed co-funding from NATO (SfP-984382) aimed at setting up a green corporate headquarter at Morocco's Power and Water utilities ONEE (Office National de l'Electricité et de l'Eau potable) failed to concretize with the newly created Moroccan Research Institute for Solar Energy and New Energies (IRESEN) first call for projects in 2011. As ONEE and ONEP-IEA's headquarters are located on the grounds of Africa's second largest water treatment station in Rabat, multiple on-site uses for chlorine in water purification and co-generated green-hydrogen were possible [10]. These included among others hydrogen for backup storage and clean mobility demonstrators in partnership with Morocco's automotive industry.

Following the signature at Ministerial level of the German-Moroccan Energy Partnership PAREMA in 2012, it won't be until 2017 that Morocco's green-hydrogen opportunities would be explored. In 2017, PAREMA organized the first Moroccan-German Energy Day in Rabat, during which the "Power-to-X Technology" was presented by the Fraunhofer IWES Institute, on the basis of a study published in Germany identifying Morocco as a potentially key player in this technology, given its geographical location and unique wind and solar resources. In 2018, IRESEN undertook an exploratory trip to Germany and a feasibility study of the scope for PtX in Morocco was launched. IRESEN engaged with the Fraunhofer institute on a 10 Hypotheses 'Study for discussion the opportunities of "Power-to-X" in Morocco' published in 2019 [11]. The study clearly identified the potential for substituting Morocco's 2 MT/year of grey ammonia imports by OCP-Group, the country's state owned phosphate conglomerate to support its global fertilizer export business, and tap a share of the future green ammonia export market.

In order to reinforce its renewable energy development strategy and provide a framework to support further studies, Morocco's Ministry of Energy Mines and Environment created a national commission on green-hydrogen on July 04th 2020 [12]. Composed of major public stakeholders the ministry published a green-hydrogen strategy document in 2021 [13]. The latter lists objectives and time frames centered on scaling-up an industrial ecosystem on green molecules, particularly hydrogen, ammonia and methanol. In order to gather support from industrial stakeholders, the Constituent Assembly of a "GreenH2 Cluster" for Morocco was held on March 18, 2021 [14]. With the advent of a new government in November, Morocco's newly renamed Ministry of Energy Transition and Sustainable Development made public the country's exhaustive and ambitious Green-Hydrogen Road Map [4].

2. Morocco's Green-Hydrogen Road Map

Green-hydrogen roll-out objectives have been laid out for the 2030, 2040 and 2050 time horizons through reference and optimistic scenarios. With an 8.0 to 14.6 GW of additional renewable capacities dedicated to green-hydrogen production and their relevant transformation processes in 2030 for the reference and optimistic scenarios, these would reach 78.2 to 131.5 GW respectively in 2050. Morocco's Green-hydrogen roadmap aims at exporting 75% of green-hydrogen produced in the form of ammonia. Power needs for sustaining local demand for ammonia used in Morocco's global fertilizer business has been established at 1.6 and 3.4 GW in 2030 culminating at 10.3 and 10.7 GW in 2050.

Table 1. Renewable Energy Capacity Required for Morocco's Green-Hydrogen Road Map. Source: Ministry Of Energy transition: Green-hydrogen Road Map [4].

Application	Unit	Reference			Optimistic		
		2030	2040	2050	2030	2040	2050
Renewable Energy Sources	GW(el)	8.0	36.7	78.2	14.6	60.4	131.5
Electrolysers	GW(H_2)	2.8	13.9	31.4	5.2	23.0	52.8
Desalination Plants	Mm^3p.a.	4.4	21.9	49.2	7.0	30.6	70.4
Capacities of Transformation Plants - PtL	GW(PtL)	0.4	2.1	5.3	0.8	4.4	11.6
Capacities of Haber Bosch Plant - PtA	GW(Am)	1.1	5.0	10.7	2.4	9.0	19.2

It must be noted that 25% of green-hydrogen produced in Morocco is also expected to be exported as liquid synthetic fuels. Upon adding these prospects resorting exclusively on desalination for water needs linked to Haber-bosh for Ammonia and Fisher Tropsh processes for Power to Liquids, the estimated combined renewable energy capacity reach these listed objectives as indicated earlier. The renewable capacities shown in the top row of 'table 1' represent massive amounts of renewable energies and require substantial investments.

Land availability and high renewable capacity factors, particularly for wind energy are critical ingredients to drive down green-hydrogen production costs. Where the ocean meets the desert, these elements are available on a distance spanning thousand(s) kilometers on the Sahara coastline [15].

2.1. Environmental and socioeconomic impacts

2.1.1. Scaled-up desalination. As it takes 1000 times less electricity to desalinate water than for electrolyzing it into green-hydrogen (0.044 MWh/10 Ton of water per Ton H2 versus at least 50 MWh/Ton H2 for its electrolysis), the massive amounts of renewables needed for green-hydrogen provide a critical scale needed to lower desalination costs. This will make fresh water available for others purposes such as urban uses and agriculture generating a multiplier effect on local economies. Justified on an operational basis and achieved at marginal cost optimizations, these environmental and socioeconomic impacts are significant.

2.1.2. *Environmental impact of brine disposal.* The Atlantic Ocean is exposed to climate-change related ice melting in both the Arctic and Antarctic which reduces its salinity. This threatens its circulation current dynamics. Changes in the large-scale ocean circulation, such as the Atlantic Meridional Overturning Circulation (AMOC), have a profound impact on global and regional climate systems, including Sahel and Indian summer monsoon rainfall, Atlantic hurricane activities, and Arctic climate [16]. Although negligible at this scale, the environmental impact (pending relevant studies) of large desalination units on the Sahara Coastline with brine discharged in the Atlantic could end-up being beneficial and help restore the ocean's salinity balance.

2.2. Electrolyser ancillary services to power grids

Large electrolysis green-hydrogen units can also provide services to local grids powered by massive amounts of intermittent renewable electricity. In terms of ancillary services to grid, large electrolysers can be good candidates to buffer excess renewable energy into green gas while providing effective grid support. Grid balancing services such as Frequency Containment Reserve (FCR), automated and manual Frequency Restoration Reserve (aFRR and mFRR), and Replacement Reserve (RR) differ by their full activation time, the time by which the contracted capacity can be fully activated after a signal from the TSO. These are particularly relevant to the amount of variable renewable energy penetration. Although linked to the structure of electricity markets and their rewarding mechanisms, congestion management can be a major cost component of system operations. As is the case in European countries, provision of grid services by electrolyzers could reduce the cost of hydrogen by up to 10% [17]. Within such context, the operational balancing of a 5-10 GW HVDC line phased roll-out from the Sahara Wind Project can be optimized on both renewable generation and electrolysis end-uses located close to Morocco's main load centers. This facilitates regional power dispatching and scale-up surplus renewable electricity exchanges with Europe.

2.3. Africa's electric interconnections to Europe

Figure 2. Morocco-Europe – MAPT existing interconnections and projected (in dash-line) source: https://www.med-tso.com/.

Morocco has been exporting electricity to Europe through its existing interconnections with the Iberian Peninsula shown in 'figure 2' [18]. These operational interconnections (2x700MW) will be expanded, as feasibility studies are under way for additional interconnections with Spain (+700 MW) to bring its cumulative transfer capacity at 2.1 GW and a new dedicated one with Portugal of 1 GW shown in dash-line above [19].

2.4. Green-hydrogen pipelines: North Africa's key competitiveness factor

Alike the European Union's expanding green deal objectives; many other countries are rolling-out green-hydrogen strategies and projects. According to their respective plans Saudi Arabia [20], Australia [21] and Chile [22] will be major players on the international green-hydrogen export market. Within such context, North Africa and Morocco's main green-hydrogen production asset remains its proximity to Europe. While Morocco's Green-Hydrogen Road Map focused on the export of green ammonia as it is used in its global phosphate-based fertilizer industry, the competitiveness of its green-hydrogen relies on the possibility of exporting it to Europe, to which Morocco is already connected by underutilized pipelines. This eliminates the need for costly, inefficient hydrogen to liquids transformation processes. These include Ammonia, Methanol with other PtX synfuels and LOHC (Liquid Organic Hydrogen Carrier) that are indispensable for reducing hydrogen transport costs over long distances. These conversion and transport costs can double the price of green-hydrogen delivered to Europe when produced in Chile for instance. This was indicated during the first edition of the Africa Green-hydrogen Forum [23], where Africa's green-hydrogen delivered by pipeline out-competes other alternatives by 2030. By transporting pressurized green-hydrogen directly to end users through existing and no longer used natural gas pipelines or by building dedicated new hydrogen pipelines, transport costs of green-hydrogen can be drastically reduced.

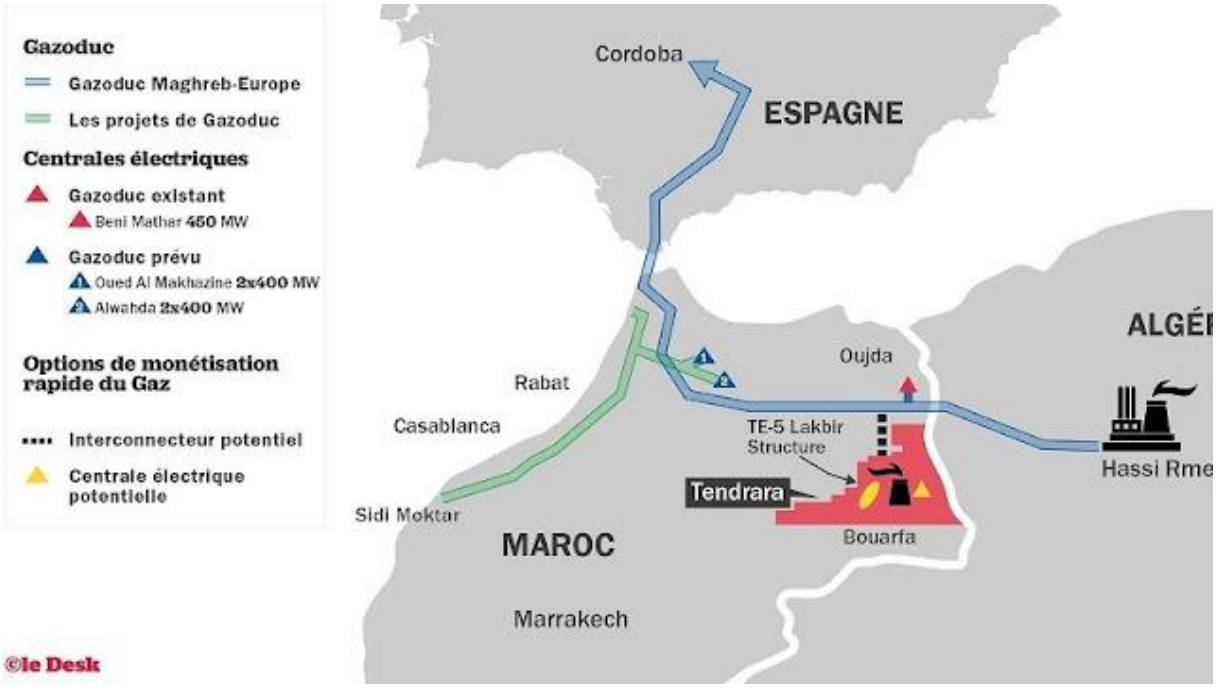

Figure 3. GME pipeline (in Blue) with planned extensions in Morocco (Source: https://ledesk.ma/).

This is the case of the GME Natural Gas pipeline shown in 'figure 3' connecting Algerian gas fields to Spain, Portugal and Europe passing through Morocco's territory which has been unilaterally closed by Algeria in November 2021 after 20 years of successful operation. This infrastructure is also adapted for occasional reverse flow imports from Spain's LNG terminals to supply Moroccan gas fired power plants. The latter powered up to 17% and went down to 8.5% of the country's electricity needs in 2021 [24]. A first shipment of LNG delivered and re-gasified in Spain to be piped in a gaseous form to Morocco's Gas fired power plants is for that matter imminent.

With the roll-out of Morocco's Green-Hydrogen Road Map and its significant capacities, the GME pipeline can also be used for future exports of green-hydrogen from Africa to Europe.

2.5. Building on larger pipeline infrastructures

Figure 4. Map of existing and projected pipeline Nigeria – Morocco (jeuneafrique).

Additional prospects arise with the building of a future Nigeria-Europe off-shore natural gas pipeline servicing most of West Africa. The latter whose lay-out is displayed in 'figure 4', is subjected to on-going feasibility studies [25]. Although its construction phase is not expected until 2027, this pipeline will enable most West African countries to access natural gas and power their growing electricity needs. Along with the prospects of blending green-hydrogen, recent natural gas findings under development in Senegal [26], Mauritania [27] and Ivory Coast [28] to name a few can also feed into this infrastructure and complement deliveries to their respective African and European markets.

2.6. Green-hydrogen seasonal underground geological storage

Due to its low energy content per unit volume at ambient temperatures, storing pressurized hydrogen is economically challenging. Considering such constraints, salt caverns have been used for the storage of energy carriers for over 50 years.

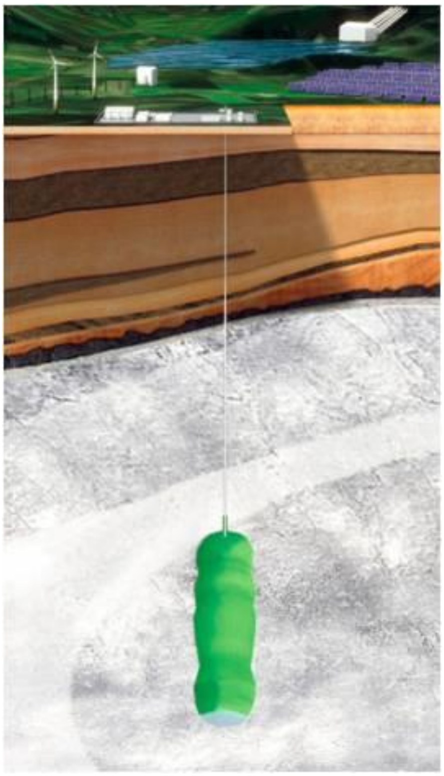

Figure 5. Underground gas storage in a manmade salt cavern.(*Compendium of Hydrogen Energy*, *2016 Source:* KBB UT).

Built by water leaching introduced through a drilled bore hole, the resulting brine is pumped-out leaving a dry, hollow cavity in the salt deposit as shown in green in 'figure5'. As physical properties of rock salt are very strong and impermeable these cavities remain gas-tight at high pressures, making hydrogen storage possible.

Table 2. Existing hydrogen storage facilities and planned projects (IEA Hydrogen Review 2021).

Global Hydrogen Review 2021

Infrastructure and trade

Existing hydrogen storage facilities and planned projects

Name	Country	Project start year	Operator/ developer	Working storage (GWh)	Type	Status
Teeside	United Kingdom	1972	Sabic	27	Salt cavern	Operational
Clemens Dome	United States	1983	Conoco Philips	82	Salt cavern	Operational
Moss Bluff	United States	2007	Praxair	125	Salt cavern	Operational
Spindletop	United States	2016	Air Liquide	278	Salt cavern	Operational
Underground Sun Storage	Austria	2016	RAG	10% H_2 blend	Depleted field	Demo
HyChico	Argentina	2016	HyChico, BRGM	10% H_2 blend	Depleted field	Demo
HyStock	The Netherlands	2021	EnergyStock	-	Salt cavern	Pilot
HYBRIT	Sweden	2022	Vattenfall SSAB, LKAB	-	Rock cavern	Pilot
Rüdersdorf	Germany	2022	EWE	0.2	Salt cavern	Under construction
HyPster	France	2023	Storengy	0.07-1.5	Salt cavern	Engineering study
HyGéo	France	2024	HDF, Teréga	1.5	Salt cavern	Feasibility study
HySecure	United Kingdom	mid-2020s	Storengy, Inovvn	40	Salt cavern	Phase 1 feasibility study
Energiepark Bad Lauchstädt Storage	Germany	-	Uniper, VNG ONTRAS, DBI Terrawatt	150	Salt cavern	Feasibility study
Advanced Clean Energy Storage	United States	mid-2020s	Mitsubishi Power Americas Magnum Development	150	Salt cavern	Proposed

This can be attested by the operational status of existing hydrogen storage facilities and planned projects listed in 'table 2' above. Salt caverns have been used for many years to store hydrogen in the United States and the United Kingdom. Four hydrogen salt caverns sites are currently operational. The first was commissioned in 1972 at Teesside (United Kingdom) and utilized by Sabic Petrochemicals, and three are operational in Texas, including Spindletop (commissioned in 2016), the world's largest hydrogen storage facility.

2.6.1. *Morocco's salt cavern geological underground storage.* Morocco disposes of a pioneering experience in underground storage of energy carriers. Initiated since 1978, Morocco stores over 80% of its butane consumption in bedded salt deposits by the SOMAS Company at their Sidi Larbi facility near the city of Mohammedia [29]. This operational experience supported by adequate geological deposits available nationally can make the seasonal storage of massive amounts of green-hydrogen economically competitive.

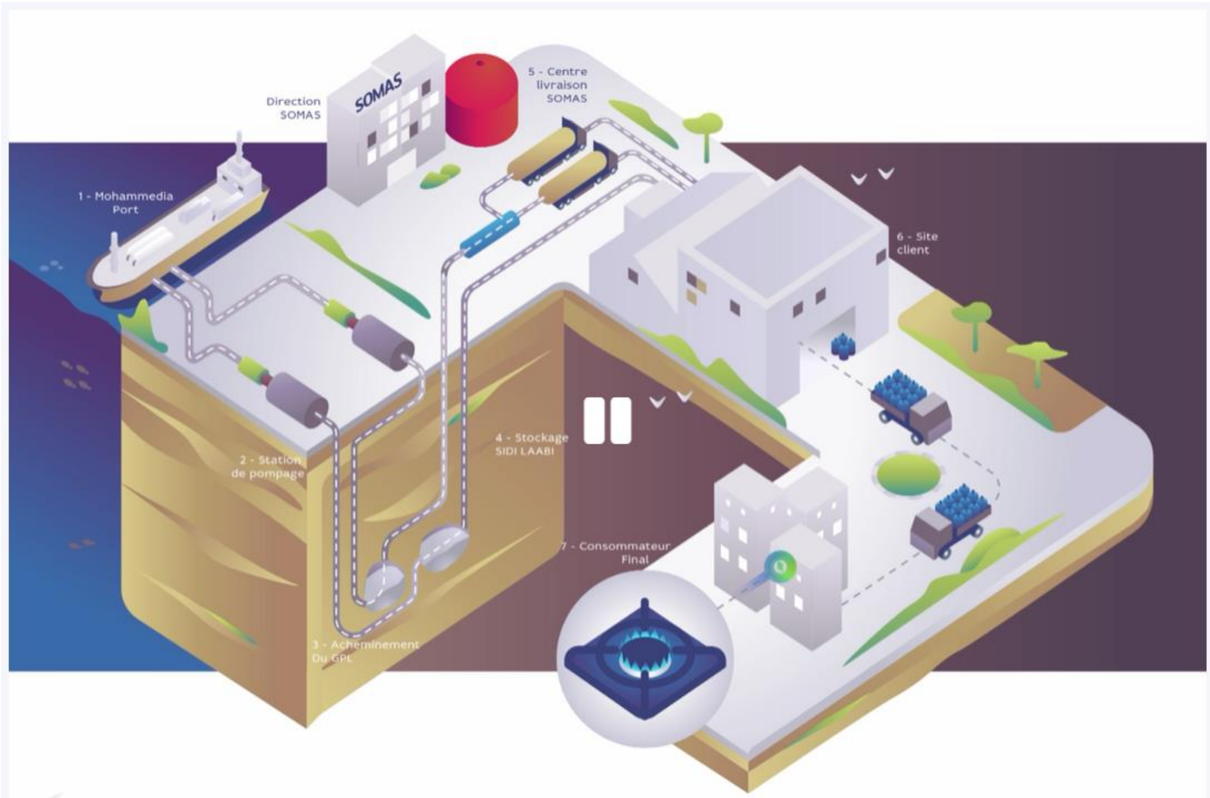

Figure 6. Butane Gas transport, storage and distribution from Mohammedia's port to end users (Source SOMAS https://somas.ma/notre-activite/).

Build using seawater leaching to dispose of the resulting the brine in the ocean (alike the Sidi Larbi facility illustrated in 'figure 6'), these caverns can store up to 10.000 T of green hydrogen for the more recent ones at very competitive costs to service chemical industries with a continuous flow of hydrogen. Morocco disposes of consistent salts deposits in both layered basins and deeper dome forms which can be used for pressurized underground geological storage of green hydrogen on a significant scale.

2.6.2. Connecting salt caverns to regional pipeline networks. When connecting these underground storage facilities to the pipeline networks that link Africa to Europe, access and delivery of green hydrogen can be continuously secured for both continents. By storing locally generated green hydrogen on a substantial scale, Morocco can serve as a hub for regional markets and support Europe's ambitious green energy transition. Long-term seasonal renewable energy, generated competitively and stored with minimal losses in the form of green molecules is thereby optimized. The building of green-hydrogen strategic reserves for end-user markets on both continents connected to these gas storage and pipe infrastructures can be distributed on a blended (with natural gas) or in pure green hydrogen form. Additional new green hydrogen pipelines could also be added to both planned and existing underutilized pipeline networks.

3. North Africa's regional green-hydrogen prospects

3.1. Morocco's green-hydrogen developments

In Morocco, trade wind-induced surface currents pushed massive amounts of plankton towards North Africa's shallow shores. This led to the accumulation of an exceptionally rich biotope whose remains decayed into the world's largest geological sedimentary phosphates deposits [30]. This process which took place within a lengthy time span from some 75-40 million years ago, led to the accumulation of over 70% of the world's know phosphates reserves [31] located primarily in Morocco's central plains.

3.1.1. Greening the world's largest exporter of phosphate-based fertilizer. Phosphates are mostly used in fertilizers manufacturing for which ammonia is also needed. Powered by massive amounts of renewable energies operating in optimal conditions, the cleaner carbon-free processing of the world's largest phosphate reserves into fertilizer provides an ideal cluster around which broader green-hydrogen exports can be consolidated. Although massive investments will be required to substitute OCP-Group's current grey ammonia imports (by green ammonia) for which off-setting mechanisms will have to be provided, this remains one of the main objectives of Morocco's Green-Hydrogen Road Map. Many additional synergies arise in the value-added phosphate processing industry where chlorine and hydrochloric acid from chlor-alkali electrolysis can be used as well [32] in phosphate rock upgrades into phosphoric acid and fertilizers. Provided there is a use for chlorine as is the case for phosphoric acid production of which OCP-Group is the world's largest exporter, valuable chlor-alkali cogenerated electrolysis by-products such as hydrogen can be used to produce ammonia, an indispensable ingredient in fertilizer production. The remaining caustic soda electrolysis by-product used in many industries is also a growing valuable export commodity.

3.1.2. Other green-hydrogen prospects. In scaling-up the aforementioned renewable energy powered processes, a variety of other green-hydrogen applications can serve local industries as well as export markets. These applications including Fischer–Tropsch Liquid fuels such as methanol, diesel and kerosene along with green-hydrogen for power, industrial, domestic, shipping and transport applications are exhaustively assessed in different time horizons from 2030 to 2050 as detailed in Morocco's Green-Hydrogen Road Map [4].

3.2. Mauritania's green-hydrogen developments

While several large green-hydrogen projects have been announced for the export of green ammonia, the country's current main industrial asset remains its iron-ore mining industry, which can be gradually upgraded through scalable technologies into fossil-free steel production.

3.2.1. *Upgrading iron-ore exports into green steel.* Mauritania whose main industry revolves around iron-ore exports [33] can leverage its significant reserves and trade wind energy potential to produce carbon/fossil-free steel. The country's low-cost iron-ore extraction process, coupled to its outstanding wind and solar potential will make this alternative quite compelling. This will happen once scalable pilot plants for iron-ore green-hydrogen direct reduction into fossil-free steel will be commercially available [34]. Competitive fossil-free steel production tackles a critical environmental issue as global steel production is responsible for 7% to 9% of global anthropogenic CO2 emissions [36].

3.2.2. *Large green-ammonia exports.* Some of Africa's largest foreseen green-hydrogen projects are in Mauritania. Focused on the production of green ammonia led by project developers, feasibility studies are underway for the AMAN 30 GW Wind/Solar Australia-CWP Project at a US$40 Billion investment covering an area of 8,500 Km2 [37]. Additionally, a Memorandum of Understanding for pre-feasibility and feasibility studies with no exclusive development rights has been signed for a 10 GW Nour Project with the government of Mauritania covering an onshore and offshore area totalling approximately 14,400 km2 [38]. The latter includes green ammonia deliveries to the port of Rotterdam [39].

3.2.3. *Supporting regional power grid expansions.* Power grids are being expanded in Mauritania with the recent inauguration of the Nouadhibou –Nouakchott power line. This happens as interconnections to Senegal and Mali are also further extended. Consequently, regional integration of power networks from Morocco and Mauritania into West Africa will be reinforced, enabling massive renewable energy generation to be fed into grids and balanced by green-hydrogen production facilities. Upon adding existing and planned pipeline infrastructures to supply European markets, the region is set for well-integrated and promising economic developments.

4. Conclusion

The co-funding provided by NATO since 2007 for the 'Sahara Trade Winds to Hydrogen: Applied Research for Sustainable Energy Systems' initiated a process which paved the way to integrated regional green-hydrogen developments. It reinforced North Africa's current energy transition objectives with the crafting of more sustainable, integrated renewable energy projects and infrastructures. As a networked and stored energy carrier, green-hydrogen as a feedstock can leverage the region's mineral resources and establish value-added, carbon-free processing industries. Backed by Morocco and Mauritania's respective mineral assets, the crafting of energy transition strategies in successive phases can rely on the scalability and pooling of larger projects, industries and infrastructures. Sahara Wind's upstream development work for well-integrated, wide ranging transmission infrastructures, processes and applications may be accelerated considering the current geopolitical energy crisis in Europe triggered by the invasion of Ukraine by the Russian Federation. Indeed, the European Commission's recent plan published on 08-3-2022 aims to make Europe independent from Russian fossil fuels well before 2030. With its second biggest contribution after importing liquefied natural gas and diversifying gas pipeline supplies, green hydrogen plays a substantial role. An additional 15 million tonnes (mt) of renewable hydrogen on top of the 5,6 mt foreseen under the Fit for 55 is to replace 25-50 bcm per year of imported Russian gas by 2030. Of it 10 mt of hydrogen will be imported from diverse sources with an additional 5 mt of hydrogen produced in Europe [40]. With clearly defined road maps leveraging the region's outstanding renewable and mineral resources integrated to projects, industrial processes and infrastructures North Africa's green electricity and hydrogen exports to Europe are key assets to a broader energy transition. Within such context, the early support from NATO to Morocco and Mauritania under its Science for Peace energy security collaborative priority research topics was not only timely but also most relevant.

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