Algerian Green Hydrogen Production Opportunities and challenges in light of a sustainable energy system

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Abstract:

The energy transition has become a major issue for the next 30 years due to the inherent necessity to decrease global greenhouse gas emissions. This study aims at examining green hydrogen production opportunities in Algeria and various usage options. By analyzing the green hydrogen market, manufacturing methods, and potential costs

The results of the study concluded that Algeria's existing oil and gas infrastructure (pipelines, liquefied gas terminals, etc.), industrial gas industry, outstanding wind and solar energy potential, and closeness to European markets make it a producer of green hydrogen. And it enables Algeria to not only expand and diversify its energy mix but also to maintain its part of the global energy market and fulfill growing local demand.

Key words: Hydrogen; Green Hydrogen; Energy Carrier; Renewable Energy; Electrolysis; Algeria.

JEL Classification Codes: Q42, Q2, Q28, Q55,O31.

1. Introduction :

Carbon-rich fuels such as petroleum, gas, and coal have been a success story due to a variety of benefits, including a wide range of applications, high energy density, and ease of transport and storage, but they have a major drawback in terms of their environmental impact as the primary contributor to global warming.

Climate change is a serious problem for the entire planet. In 2015, the international community agreed to take steps to keep global temperature rises well below 2° C above pre-industrial levels this century. A rising number of nations have pledged to achieve net-zero carbon dioxide (CO_2) emissions by the middle of the century, with the objective of keeping global warming to 1.5° C.

Experts generally believe that attaining climate objectives with Transformation plan sustainable energy, such as those outlined in the Paris agreement, be through raise energy efficiency; reduce non-bio renewables; Use nuclear; carbon reuse; recycle bioenergy; carbon capture and storage; hydrogen.

In recent years, governments, businesses, and society have all become increasingly aware of the need to put the energy system on a more sustainable path. This has rekindled interest in green hydrogen's as a clean, reliable, and inexpensive fuel. Because hydrogen is a carbon-free energy carrier, it generates only water when burned, making it a clean fuel with zero emissions.

G20 leaders emphasized green hydrogen as one of the essential technologies for enabling sustainable energy transitions during their Osaka Summit in 2019. This is what prompted Algeria to develop a strategy to transition to a carbon-free energy future by establishing a road map for the production of green hydrogen. Algeria is a country with abundant natural resources, especially solar, geothermal, and wind energy, making it an ideal area for the production of green hydrogen.

In this essence, this paper tries to answer the following question: What are the opportunities and challenges of green hydrogen production in Algeria?

In order to answer the problem, we decided to systematically divide this research paper into two main axes, as follows:

Firstly: Green Hydrogen as Energy Carrier.

Secondly: Algeria’s potential to produce green hydrogen.

2. Green Hydrogen as Energy Carrier

Although hydrogen is abundant on Earth, it is nearly always found as a component of another chemical, such as water (H_2O) or methane (CH_4), and must be purified into pure hydrogen (H_2) before being used in fuel cell electric. Through an electrochemical mechanism, hydrogen fuel mixes with oxygen from the air in a fuel cell to produce power and water. (USDE, 2020)

When compared to other energy carriers (show table1), hydrogen has an enormous amount of energy. One kilogram of hydrogen has three times the energy of one kilogram of gasoline.

Table1: Comparison of energy carriers

type	Hydrogen	Methane	Gasoline	Wood	Diesel	Natural gas
Amount Energy	120 MJ/kg	50 MJ/kg	43 MJ/kg	15 MJ / kg	44.8MJ/kg	50 MJ / kg

Source: Joseph Melin .(2021). Hydrogen Vector of clean energy. Retrieved 08 25, 2021, from Air liquid: https://energies.airliquide.com/resources-planet-hydrogen/vector-clean-energy

Hydrogen Properties are (Burchard., 2020):

- The specific energy of hydrogen is quite high, yet its volumetric density is extremely low.It must be transformed before it can be stored in a usable volumey reducing the pressure to 700 bar: 7 liters of hydrogen can hold the same amount of energy as 1 liter of gasoline or by liquefying it to compress it even further by chilling it to 253°C: 1 liter of gasoline is equal to 4 liters of liquid hydrogen. (IFPEN, 2018) b
- Densifying hydrogen allows it to function at lower pressures, but it also requires more energy, making it the most expensive option.
- Depending on the desired purpose, several storage solutions (batteries, mass storage in salt caverns) are available.
- Hydrogen is often delivered in compressed form over a global network of pipelines totaling more than 4,500 kilometers, with 1,600 kilometers in Europe and 2,500 kilometers in the United States.
- Energy may be recovered from previously-stored hydrogen in two ways: as heat via direct burning with oxygen, or as electricity via a fuel cell the global reaction generates just water in both situations. (IFPEN, 2018)

The color of hydrogen is determined by its GHG emissions and manufacturing method (Matthes, Aruffo, & Retby-Pradeau, November 2020, p. 6):

Grey hydrogen: Black hydrogen is produced from hard coal, brown hydrogen from lignite and grey hydrogen from natural gas. Collectively, these types are often subsumed under the term "grey hydrogen". Where is used Steam Methane Reforming SMR, (is a transformation process that employs oxygen from water steam in a heat chamber to extract methane (CH_4) and create (H_2)). Now the process is still extremely polluting, since it produces more than 9 kilograms of CO_2 for every kilogram of hydrogen generated.

Blue hydrogen: The carbon released during manufacturing is collected with a CCUS technique to decrease CO_2 emissions. Blue hydrogen follows the same process as grey hydrogen. Blue hydrogen is defined by the EU as fossil-based hydrogen with carbon capture.

Yellow hydrogen: is produced by electrolysis using mixed-source electric energy, such as nuclear or waste-to-hydrogen. It might also be done by the gasification of garbage.

Turquoise hydrogen: produces hydrogen through an endothermic process using natural gas or biomass as an energy source, with solid carbon as a by-product. While pyrolysis for biomass is a somewhat filthy process in terms of the environment, pyrolysis through natural gas might be intriguing if the energy is obtained from renewable sources.

Green hydrogen: is created by electrolyzing water in an electrolyzer using energy generated from renewable sources including hydro, wind, and sun. GHG emissions throughout the manufacturing process are zero if all electrical inputs originate from renewable energy sources (and if desalinated water is required, it is powered entirely by solar and wind). (Journal of Energy Chemistry, 2021)

Other renewables-based solutions may be used to create green hydrogen from biogas-, except for SMR- as a sustainable resource but this is not mature technology at commercial scale yet. (Doan, et al., 2018)

Hydrogen technology has been discovered to be (IEA, August 2020, p. 13) :

- Hydrogen can aid with the integration of more variable renewable energy into the electrical grid, reducing the temporal and geographical mismatch between supply and demand. It's a potential long-term electricity storage solution in particular, and it may be utilized to provide backup power during periods of high demand and low renewable energy availability.
- Hydrogen can be utilized as a low-carbon fuel in sectors where achieving substantial GHG emission reductions is proving challenging, such as long-haul transportation and heavy industries -oil refining, ammonia production, methanol production-, where direct electrification is constrained.
- Because hydrogen does not produce particulate matter or sulfur dioxide when burned and produces no pollutants at all when used in fuel cells,- hydrogen could be blended

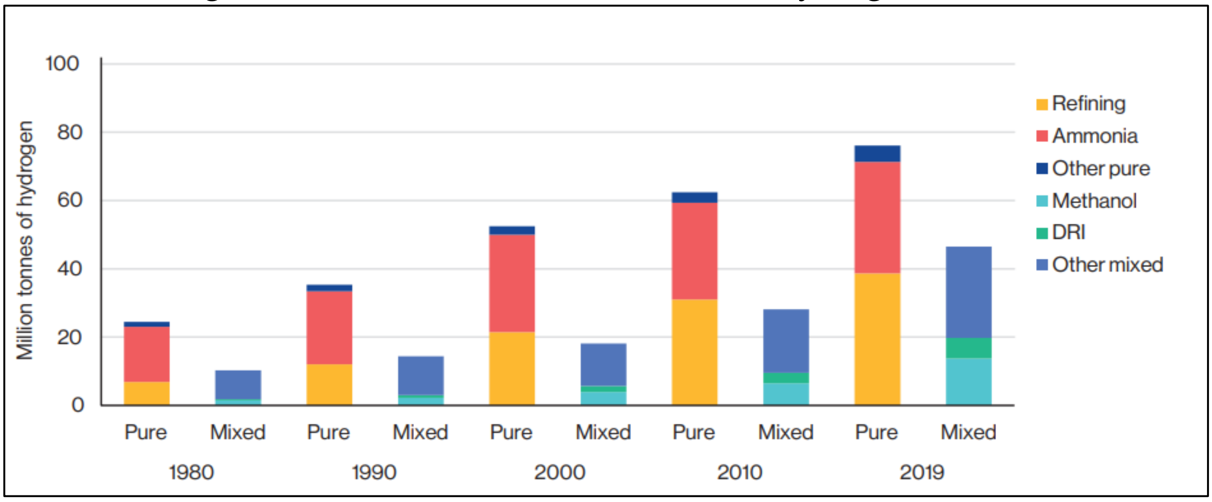
into existing natural gas networks- it can assist to improve air quality, particularly in metropolitan areas where this has become a serious public health issue.

- Hydrogen may be created from any energy source and used as a fuel or transformed into various products for energy purposes. This adaptability encourages the diversity of energy sources and applications, which contributes to greater energy security.

Hydrogen distribution to industrial customers is currently a big industry all over the world. Hydrogen demand, which has increased by more than thrice since 1975,- hydrogen production is nearly completely fueled by fossil fuels, with 6% of world natural gas and 2% of global coal going to the process- As a result, the generation of hydrogen results in CO_2 emissions of about 830 million tons per year.

In 2019 Global Hydrogen production is around 75 Mt per annum of pure H_2 and 45 Mt H_2 mixed with other gases. (Show figure1), roughly 55 percent of hydrogen produced worldwide is utilized for ammonia synthesis, 25% in refineries, and about 10% for methanol generation. Only around 10% of global hydrogen generation is accounted for by the remaining applications. (IEA, August 2020, p. 18)

Figure1: Evolution of annual demand for hydrogen, 1980-2019



Source: IEA (August 2020). Cross-cutting:Hydrogen. P18. Retrieved 08 25, 2021, from International Energy Agency https://www.iea.org/reports/hydrogen

It's worth noting that about 85% of hydrogen is created on-site for captive consumption, only 15% is transported by pipeline so there's no need for transportation and no market or transparency on current costs. (Burchard., 2020)

In many nations, hydrogen is the only zero-carbon energy carrier outside electricity and ammonia that is being seriously considered for low-carbon transportation, industrial decarbonization, and heat provision. May be supplied using a diversity of renewable and nonrenewable feedstock's and technical paths (show table 2), all of which emit variable amounts of greenhouse gases. In order for hydrogen to play a significant role in future low-carbon energy systems, its production must be both environmentally friendly and economically viable. (Anthony & Paul, 2020)

As a result, researchers have been exploring for new and more ecologically friendly ways to produce green hydrogen, with the goal of eliminating CO2 emissions from the process and the most environmentally friendly approach to make hydrogen is to divide water into hydrogen and oxygen using sunshine.

Table 2: hydrogen production methods, their advantages, efficiency, and cost

Hydrogen production Method	Advantages	Disadvantages	Efficiency [%]	Cost [$/kg]
Steam Reforming	Developed technology & Existing infrastructure	Produced CO, CO_2 Unstable supply	74–85	2.27
Partial Oxidation	Established technology	Along with H_2 Production, produced heavy oils and petroleum coke	60–75	1.48
Auto thermal Reforming	Well established technology & Existing infrastructure	Produced CO_2 as a byproduct, use of fossil fuels.	60–75	1.48
Bio photolysis	Consumed CO_2, Produced O_2 as a byproduct, working under mild conditions.	Low yields of H_2, sunlight needed, large reactor required, O_2 sensitivity, high cost of material.	10–11	2.13
Dark Fermentation	Simple method, H_2 produced without light, no limitation O_2, CO_2-neutral, involves to waste recycling	Fatty acids elimination, low yields of H_2, low efficiency, necessity of huge volume of reactor	60–80	2.57
Photo Fermentation	Involves to waste water recycling, used different organic waste waters, CO_2-neutral.	low efficiency, Low H_2 production rate, sunlight required, necessity of huge volume of reactor, O_2-sensitivity	0.1	2.83
Gasification	Abundant, cheap feedstock and neutral CO_2.	Fluctuating H_2 yields because of feedstock impurities, seasonal availability and formation of tar.	30–40	1.77–2.05
Pyrolysis	Abundant, cheap feedstock and CO_2-neutral.	Tar formation, fluctuating H_2 amount because of feedstock impurities and seasonal availability	35–50	1.59–1.70
Thermolysis	Clean and sustainable, O_2-byproduct, copious feedstock	High capital costs, Elements toxicity, corrosion problems.	20–45	7.98–8.40
Photolysis	O_2 as byproduct, abundant feedstock, No emissions.	Low efficiency, non-effective photocatalytic material, Requires sunlight.	0.06	8–10
Electrolysis	Established technology Zero emission Existing infrastructure O_2 as byproduct	Storage and Transportation problem.	60–80	10.30

Source: Shiva Kumar, S., and Himabindu, V. (2019). Hydrogen production by PEM water electrolysis – a review. Mater. Sci. Energy Technol. 2,PP 442–454. doi: 10.1016/j.mset.2019.03.002

At the moment, 96% of hydrogen is still created by converting fossil fuels, based production techniques such steam reforming, partial oxidation, and auto-thermal reforming, which emits a significant quantity of carbon dioxide (CO_2), that why the use of hydrogen is restricted. But Green hydrogen generation technologies such as electrolysis have provided a greener option for Hydrogen production; However, opponents point out that while the technique produces “green” H_2 and O_2, it is energy demanding. As a result, the process is not emission-free unless alternative renewable energy sources are explored to mitigate the energy penalty. Another issue is that green methods, such as electrolysis (green Hydrogen), have greater production costs as compared to traditional Hydrogen production systems (gray Hydrogen). Power consumption Approx. 5 kWh / Nm^3 H_2 (1 Nm^3 H_2 = 0.0899 kg H_2), Consumption of demineralized water about 1 liter / Nm^3 H_2 and Consumption of non-demineralized water About 1.5 to 2 times the consumption of demineralized water depending on the quality of the water available.

Table 2 indicates that electrolysis produces H_2 at a cost of $10.33 per kilogram of Hydrogen compared to current methods ($1.5–2.3 per kilogram of Hydrogen). As a result, “green” Hydrogen prices are another issue that the green Hydrogen position in the energy mix faces. (Kumar & Himabindu, 2019)

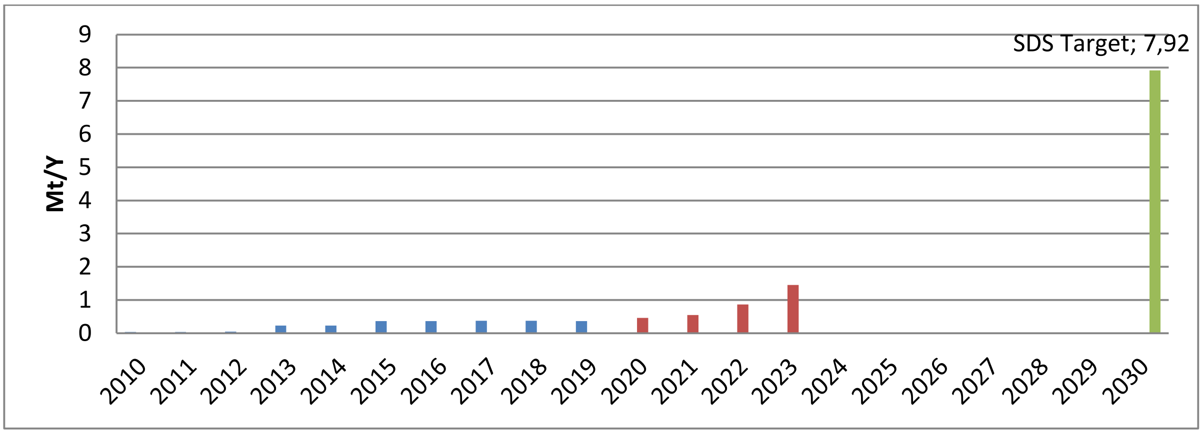
The cost of the renewable electricity required to operate the electrolysis unit is the most significant cost component for the generation of green hydrogen. New research of BloombergNEF (BNEF) finds that the Levelized cost of green hydrogen made from renewable electricity is set to fall faster by up to 85% from today to 2050, leading to costs below $1/kg ($7.4/MMBtu) by 2050 in most modeled markets. And it expects the average Levelized cost of solar PV to be 40% lower by 2050 than it did two years ago, driven by more automatic manufacturing, less silicon and silver consumption, higher photovoltaic efficiency of solar cells, and greater yields using bifacial panels. The cost of electricity will account for the majority of the cost of producing renewable H_2 by 2030, with electrolyzer-related costs accounting for the rest. (Tengler, 2021)

But low power costs aren't enough to make green hydrogen generation feasible; cost reductions in electrolysis plants investment cost of electrolysers , and their capacity factor - are also required (IRENA, 2020)

Developing green hydrogen production routes is critical for hydrogen to aid in clean energy transitions, production green hydrogen is around 0,04 Mt in 2010 to 0,55 Mt in 2021 It is expected to reach the 7.92 until 2030 (show figure 2).

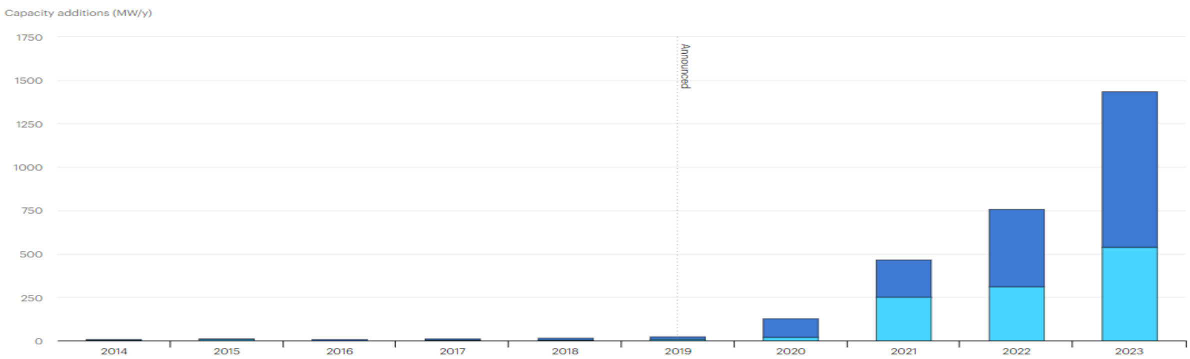
Green hydrogen production is ramping up, especially using electrolysis, From less than 1 MW in 2010 to more than 25 MW in 2019 (show figure 3), the number of projects and electrolyzer capacity deployed has risen substantially in recent years. Furthermore, project size has increased dramatically: most projects were less than 0.5 MW in the early 2010s, whereas the largest in 2017-19 were 6 MW, with others ranging between 1 and 5 MW.

Figure 2: Green hydrogen production, 2010-2030, historical, announced and in the Sustainable Development Scenario, 2030



Source: IEA.(June 2020). Hydrogen more efforts needed. Retrieved 09 12, 2021, from International Energy Agency: https://www.iea.org/reports/hydrogen

Figure 3: Global electrolysis capacity 2014-2023, historical and announced



Source: IEA.(June 2020). Hydrogen more efforts needed. Retrieved 09 12, 2021, from International Energy Agency: https://www.iea.org/reports/hydrogen

In March 2020, a 10 MW plant in Japan commenced operations, while a 20 MW facility in Canada is now under development. In addition, a slew of announcements have been made for facilities with hundreds of megawatts of capacity that will begin operations in the early 2020s. (IEA, 2020)

As well as assessing green hydrogen flexibility by supply-side encompasses demand-side flexibility is to sector coupling, which entails integrating renewables into a mature industry, energy, and mobility infrastructures utilizing green hydrogen fuel chain" Power-to-X technology".

The concept behind the green hydrogen fuel chain is to use excess renewable energy (solar and wind) to power electrolyzers that convert the energy into hydrogen, which can then be stored as liquid hydrogen fuel. This technique is also known as 'Power-to-X.' It's discusses ways for transforming electrical energy into liquid or gaseous chemical energy sources through electrolysis and subsequent synthesis processes. One of the most significant characteristics of this technology is that it (Siemens-Energy, 2020):

- electrolysis Water is divide into oxygen and hydrogen using a method that produces no CO_2.
- Power-to-X sector coupling has the ability to cut primary fossil energy usage by 50% while power demand increases by 25%;
- Power-to-X produces synthetic fuels for immediate application:, such as e-Methane, e-Methanol, e-Diesel, e-Gasoline, or e-Jet fuel;
- They may be blended progressively with fossil fuels until they completely replace fossil fuels as a primary energy source;
- Current gas pipelines, gas stations, and storage facilities, as well as existing and low-cost consumer applications powered by e-Fuels, can be utilized;
- Power generation: Modern gas turbines may run on a mixture of green hydrogen and natural gas, with a green hydrogen content ranging from 5 to 100%;
- Green Hydrogen may be stored, transferred through gas grids, and then re-electrified in gas turbines, combined cycle power plants, or fuel cell power plants;
- Industry: High need for heat; green H_2 allows for CO_2-free metal production; green hydrogen as a feedstock for ammonia and other goods.

As for the methods of electrolytic, there are three techniques:

- Solid **Oxide Electrolyzer cell (SOEC):** is a regenerative solid oxide fuel cell that produces hydrogen gas (H_2) and oxygen (O_2) by electrolyzing water (and/or carbon dioxide (CO_2)) using a solid oxide, or ceramic, electrolyte (Zheng, et al., 2017).

When compared to traditional technologies like alkaline electrolysis, our high-temperature SOEC – solid oxide electrolyzer cell – produces up to 30% more green hydrogen from the same amount of renewable power.

The SOEC's greater efficiency is due to the fact that it operates at temperatures exceeding 700 degrees Celsius, and capture and can storage (CCUS) to further reduce emissions. This distinguishes it from traditional electrolysis methods. (Jeppesen, 2020)

- **PEM-Electrolysis – dynamic, efficient, and clean:** J. H. Russell and his colleagues first recognized the enormous potential of PEM electrolysis for the energy industry in 1973.

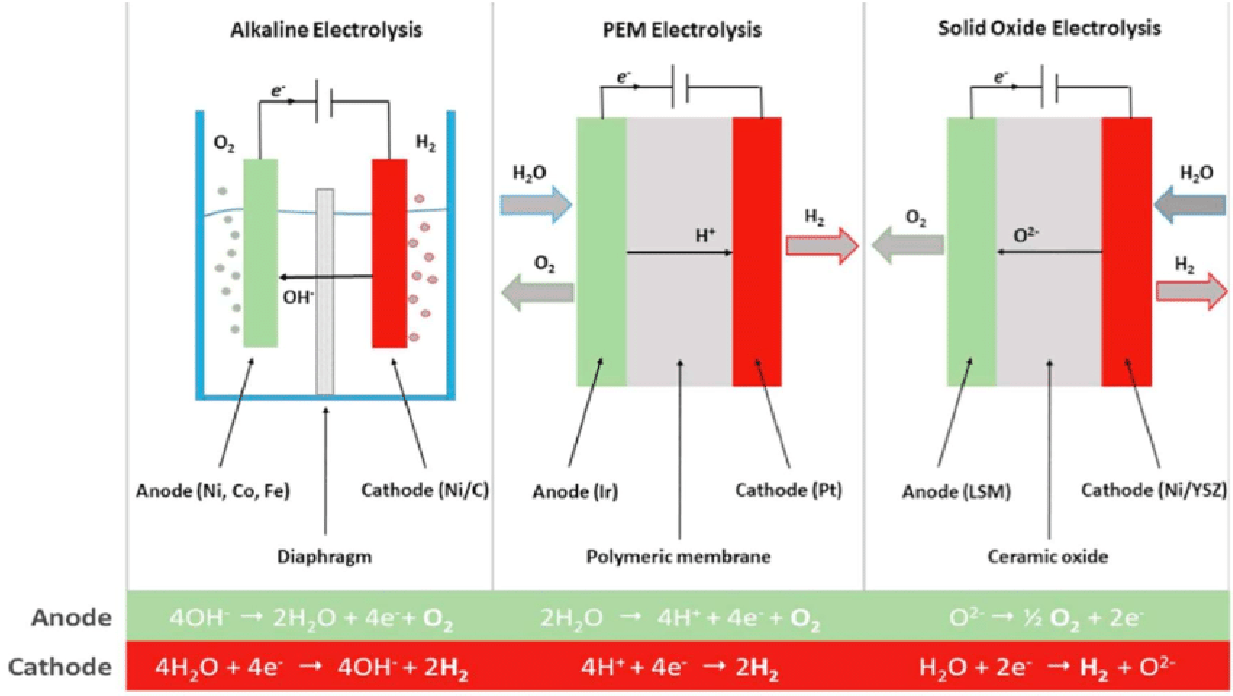
PEM takes its name from the proton exchange membrane. PEM's special property is that it is permeable to protons but not to gases such as hydrogen or oxygen. As a result, in an electrolytic process the membrane takes on, among other things, the function of a separator that prevents the product gases from mixing.

In contrast to traditional alkaline electrolysis, the highly dynamic PEM technology is ideally suited to harvest volatile energy generated from wind and solar power. (SIEMENS ENERGY, 2020)

- **Alkaline water electrolysis:** Although it is a rather pricey technique, alkaline water electrolysis is one of the easiest methods for producing hydrogen. Water electrolysis on-site might be more cost-effective than other approaches. This method is extremely clean, yielding hydrogen gas pure. Typically, an alkaline medium is used (25–30% KOH). The electrolysis of alkaline water works on a very basic concept. When a direct current is applied to water, oxygen and hydrogen are separated from it. Two water molecules dissociate and hydrogen arises at the cathode by this reaction.

(R.M.NavarroR.GuilJ.L.G.Fierro, 2015)

Figure 04: Operation principles and typical specifications of alkaline, PEM and SOEC



Efficiency	65%-70%	65%-70%	Up to 95%
CAPEX Range €/KWE	500-1000	900-1200	6000-8000
power	> MW	MW	KW
Temperature	60-100 C°	60-120 C°	>700 C°

Source: Pablo Jiménez-Calvo (June 2019). Synthesis, characterization, and performance of g-C3N4 based materials decorated with Au nanoparticles for (photo) catalytic applications. Thesis for: Ph.D. in Chemical-Physics of Material. Retrieved from: https://www.researchgate.net/figure/Operation-principles-of-alkaline-PEM-and-SOEC-58_fig9_336898971

Because alkaline electrolyzers are the most established electrolysis technology, they have a significant market share, particularly in large-scale projects both already operational and announced.

However, polymer electrolyte membrane (PEM) designs are already being used in a growing number of new applications. PEM electrolyzers are in the early stages of development compared to alkaline electrolyzers, however they are more flexibly operated and hence more suitable with fluctuating renewable power supply.

Projects using high-efficiency solid oxide electrolyzer cells (SOECs) to generate synthetic hydrocarbons are also starting to be disclosed, almost all of them in Europe. Electrolyzer customers, on the other hand, are split on whether the operational benefits of PEMs (flexibility) and SOECs (efficiency) outweigh the higher costs as compared to alkaline electrolyzers. (IEA, 2020)

3. Algeria's potential to produce green hydrogen

Algeria has enormous renewable energy potential, but it is the third largest CO_2 emitter in Africa was 180.6 million tonnes in 2019, growing at an average annual rate of 5.20%. CO_2 emissions per capita of Algeria increased from 1.3 tons of CO_2 per capita in 1970 to 4.23 tons of CO_2 per capita in 2019 growing at an average annual rate of 2.91%. Therefore, government action program has given priority to promoting renewable energy and significantly investment in green hydrogen. (WORLD DATA ATLAS, 2020)

The shift to a hydrogen economy is well underway. During the introduction of a significant Maghreb-European cooperation project (MedHySol in 2005), a project for the development of large-scale solar hydrogen production and exporting was announced. This project's success will be ensured by two phases. The first stage is to create a technical platform that will allow for the evaluation of new technologies for large-scale hydrogen generation from solar energy (10-100 kW) and the development of energetic rupture technologies. The project's second stage aims to use the most efficient and cost-effective technology to prototype large plants (1-1000 MW) (Bouziane, et al., 2009, p. 4922)

In 2020, the government committed to including hydrogen in its mix of energy exports 2030, as part of a green hydrogen production strategy that takes into consideration the untapped current potential.

Algeria is partnering (Sonatrach) with Italian energy company Eni, A road map was outlined for the joint assessment of the technical and commercial feasibility of a pilot project to produce green hydrogen using electricity generated from renewable sources (solar and wind), In order to preserve the country's water resources, the project will seek to use water produced by oil fields for the electrolysis processes necessary for the production of hydrogen after its appropriately treated. (MATALUCCI, 2021)

Eni has had a presence in Algeria since 1981 and now holds 48 mining licenses. The agreement seeks to improve technological collaboration between the two firms and assist the decarbonisation route for the transition to a low-carbon future. (Mandel, 2021)

Both businesses have agreed to work together to establish training programs in the upstream and emerging technologies connected to the energy transition areas through Eni Corporate University and the Institut Algerien du Petrole.

Eni claims to be Italy's largest hydrogen producer and user, and it has been utilizing hydrogen as a feedstock in traditional refining operations. It also uses hydrogen in its Venice and Gela biorefineries to produce hydrotreated vegetable oil (HVO) biofuels. The majority of its hydrogen comes via steam methane reforming (SMR).

Eni has been involved in a number of hydrogen production projects, including the Adriatic Blue project for blue hydrogen. For green hydrogen, Eni and Enel have agreed to develop two 10-MW electrolyser plants near Eni refineries, with green hydrogen production expected to begin in 2023. Cassa Depositi e Prestiti (CDP) and Snam are also participating in the project to decarbonize the energy system by developing green hydrogen production, transportation, and commercialization.

Algeria have been trying to benefit from the European Green Deal through partnerships with Germany energy companies for green hydrogen production by offering their renewable resources to become a pioneer in Africa in the field of renewable Energies program adopted in May 2021 to promote the renewable energies. The aim is to generate 15,000 MW of electricity from renewable energies annually by 2035, in the first phase should achieve 1000 MW per year. (DAFG, 2021). A draft roadmap for establishing a PtX industry in Algeria has been developed (time horizon: 2030 and 2050)

Table 3: draft roadmap to establish a PtX industry in Algeria

Horizon	Current Situation	Horizon 2025	Horizon 2030	Horizon 2040	Horizon 2050
Retrospective study (backcasting)	0% green H_2 X% RE -dominant methane reforming -diversification objective	5% green H_2 20% RE -Research and development	30% green H_2 50% RE -regulatory standards	60% green H_2 70%-90% RE - technology scaling	80% green H_2 -Technological disruption

Source: Tractebel Engie (02 15 .2021). Introduction de la thématique . Retrieved 09 12, 2021, from Partenariat Energétique Energiepartnerschaft Algérie-Allemagne: https://www.energypartnershipalgeria.org/fileadmin/user_upload/algeria/21_02_15_PE_DZA-DEU_-_Introduction_dans_la_th%C3%A9matique_PtX.pdf

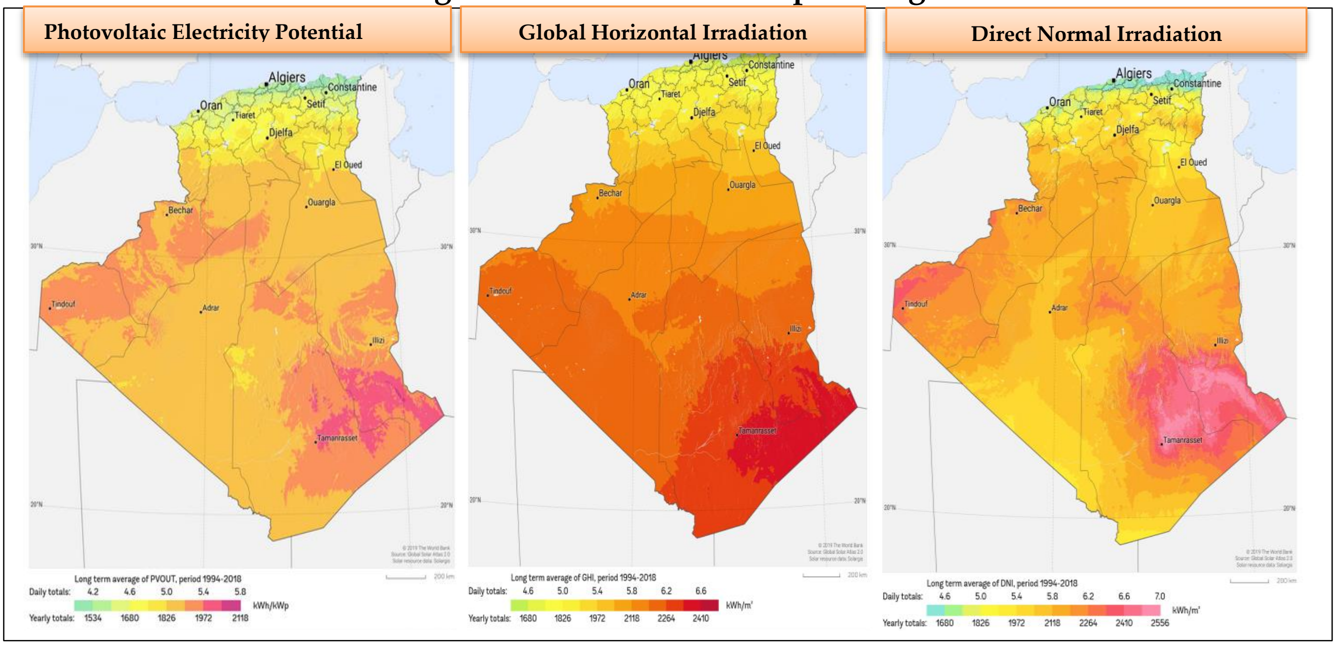
The government may use major enablers to significantly increase its green hydrogen production:

• **Generating capacity to a large amount of renewable:** Algeria is Africa's largest country, with a surface area of almost 2,381,741 square kilometers. The Sahara represents 75% of Algeria's territory which poses presenting opportunities for distributed Renewable energy. Solar power has been shown to be particularly suitable for Algeria, Wind energy is in second place, followed by geothermal energy.

A. Solar energy: Algeria is blessed with an abundance of solar energy and has a formidable opportunity to generate cost-effective, high-intensity electric power to fuel green hydrogen electrolyzers all year round.

Occupying a large area of the Solar Belt located in the latitude ranged from 22° to 31°N, and longitude ranged from 0°W to 12°E. the mean yearly sunshine duration in this area is more than 3000 hours per year, while the daily sunshine length in the Algerian north varies from 5 hours per day in the winter to over 11 hours per day in the summer. The southern part of the nation, on the other hand, has a longer daily sunlight period. The daily sunlight length in this location is always greater than 8 hours per day, and it may reach 12 hours per day during the hot season months. (BOUDRIES & R, 2008, p. 4481)

Figure 5: solar resource maps in Algeria



Region	Illizi	Tamanrasset	Tindouf	Bechar	Ghardaia	Adrar	Laghouat	biskra
Specific photovoltaic power output kwh/kwp	5.11- 5.59	4.98- 5.49	5.09- 5.29	5.07- 5.29	5.07-5.23	5.00- 5.22	4.77-5.19	4.74- 5.06

Source: Global Solar Atlas 2.0 (2020), Solar resource maps of Algeria . Retrieved 09 15, 2021, from Solargis: https://solargis.com/maps-and-gis-data/download/algeria

As illustrated in Figure 5, over the majority of the national area, total yearly solar energy of one square meter is around 2000 KWh/m²/y, with daily irradiation of 4.6-7 KWh/m². Furthermore, it appears that southern locations are more promising than others in terms of harnessing solar energy for green hydrogen generation. Tamanrasset and Illizi, in instance, have a high yearly solar energy potential of 2.4 and 2.2 MWh/m²/Y, respectively

Photovoltaic panels directly create power. Algeria's whole land can produce a total quantity of solar energy ranging from 4.2 to 5.8 kwh/kwp per day and 1534 to 2118 KWh/KWP per year. In terms of highest electrical potential, the Illizi, Tamanrasset, Tindouf, Bechar, and Adrar areas continue their dominance (show table of figure 5).

The evaluation of the solar electricity production shows the high potential of solar energy exploitation in the south of the country, hydrogen production from solar energy is largely recommended, with conducting a study on the effect of heat, dust, Humidity and inclination enhance solar panels efficiency.

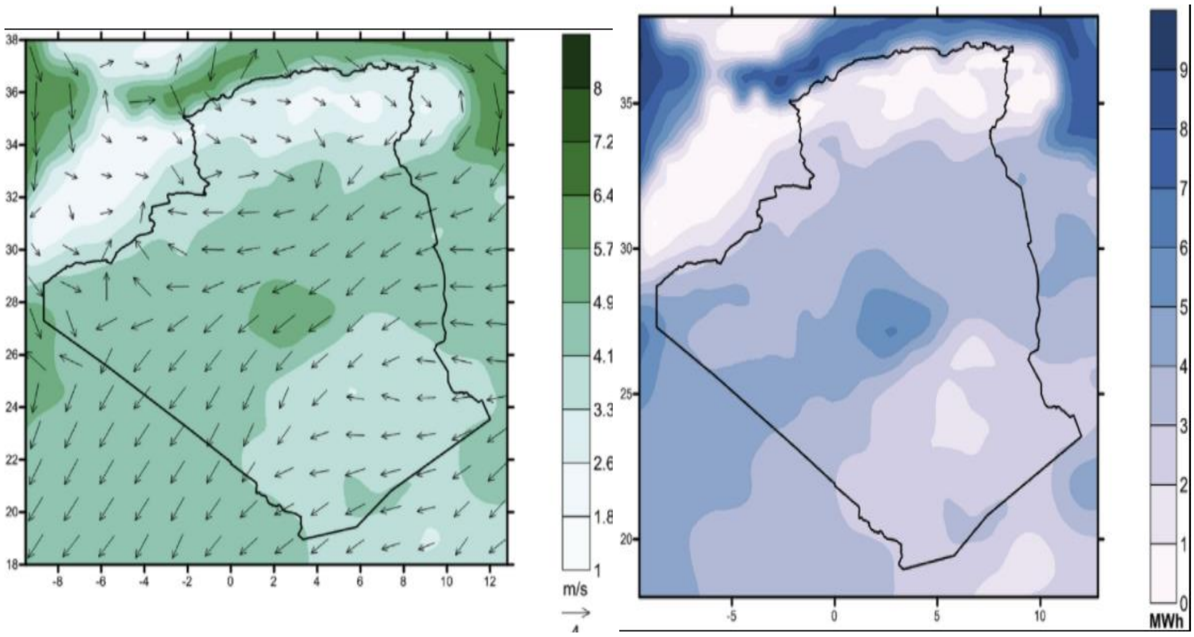
B. Wind energy: Algeria's diverse geographical, geographic, and climatic features result in a variety of wind behaviors. The wind speed is larger over the sea than on land, the Algerian Sahara is windier than the country's northern parts, with easterlies winds over the Sahara and westerly's over northern Algeria, and the wind speed in Algeria surpasses 5 m s1 in the south, with the windiest area confined to the following latitudes and longitudes: 26°–29°N, 1°W–5°E. Furthermore (Sidi Mohammed & João, 2020)

The annual mean 10 m wind speed for the period 01-01-2000 to 31-12-2017 shows that the wind speed with 73 percent of the wind speeds exceeding 3 m/s. (Houdayfa & Nawel , 2020, p. 1187) The maximum mean wind speed equals to 5.3 m/s, with a predominantly East-North-Easterly wind located at the site of In Salah, with the following coordinates: 27.26°N and 2.73°E. and minimum mean wind speed with a value of 2.3 m/s predominantly blowing from the northwest, is located in the Batna region, in the Eastern part of Algerian Highlands, with the following geographic coordinates: 35.41°N and 6.02°.(Table 5 shows the regions that have high wind speed in 2021).

The windiest months in southern Algeria are March and August, with October and December being somewhat less windy. The windiest months in the north are February and April, whereas the least windy months are June through October. The Algerian region is windy during the day (12 UTC), while the winds are generally quiet at night. (Sidi Mohammed & João, 2020)

In accordance with figure 6 and table 4, most of the Algerian Sahara shows very satisfactory outcomes for wind energy creation, more 4 MWh/day, besides over the south easternmost locale, where the potential is frequently under 2 MWh/day, with a base worth of just 1.65 MWh/day.the site of In Salah, southern Algeria, is the area with the most elevated day by day wind energy conceivably produced, arriving at 6 MWh day−1. (Sidi Mohammed & João, 2020, p. 14)

Figure 6: Wind speed § wind energy of Algeria



A: Mean wind speed distribution over Algeria (contours), along with the prevailing wind direction (arrows), for the period 1981–2014 at 10m

B: The distribution of the daily wind energy potential (MWh day−1) for the Gamesa G52 wind turbine, with a rated capacity of 850 kW at 55 m

Source: Sidi Mohammed Boudia , Joao Andrade Santos.(2019). Assessment of large-scale wind resource features in Algeria. *Energy*.V°189. N° 116299 P12-15

Table 4: Power Density§Wind Speed for 10% windiest areas whit Height 10m in 2021

REGION	Illizi	Adrar	Tamanrasset	DJELFA	Ghardaia	NAAMA	El Baydah	Laghouat	Msila
Power Density W/m²	247	226	273	237	216	330	263	277	306
Wind Speed m/s	5.49	5.5	5.76	5.01	5.34	5.22	5.19	5.25	5.08

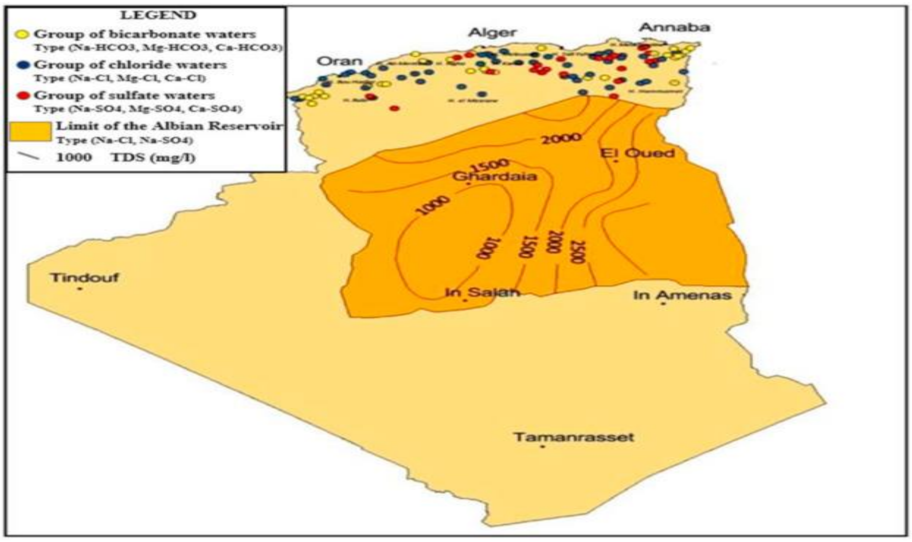
Source: Global Wind Atlas(2021). Retrieved 09 15, 2021, from: https://globalwindatlas.info/area/Algeria

C. Geothermal energy: Geothermal is another promising use for hydrogen production is good, particularly for the supply of heat, through hot water, for high-temperature electrolysis. Efficiency of electrolysis systems can be improved by operating at high temperatures. This reduces the energy needed to activate the electrolysis process. It has been suggested that heat could be obtained from geothermal sources. (Boudries, Khellaf, Aliane, L, & Khida, 2014)

Algeria has more than 282 hot and mineralized natural springs exist in Northern Algeria with most of them located in the northeast. The main utilization is balneology, which accounts for about 82% (44.37 MWt) of the total geothermal power utilization, 18% (10.28 MWt) is utilized for other applications such as space heating, heat pumps, and fish farming. About two-thirds of the geothermal resources can be classified in the low-temperature fields group whose temperatures are between 22 and 45 °C, and the remainder mainly in the moderate temperature fields group, whose temperatures are between 45 and 60 °C .and finally those whose temperatures are above 60 °C. The highest spring temperature recorded is 66 °C in the northwestern area “Hammam Bouhanifia”, and 98 °C in the northeastern area “Hammam Meskhoutine”. (Nacer, Abdelmalek, Müslüm, & Noureddine, 2021)

For the south, the sedimentary basin encloses the important hot water (50°C-120°C) reservoir. And Albian aquifer which is sited on a wide area of over 650,000 km2. The reservoirs in this area are dominantly composed of sandstone where the surface water temperature ranges from g from 40 to 62 °C. (Abdelkader, Salima, MM, & Khaled, 2018, p. 4)The Albian aquifer outcrops in the southwestern part in Adrar and In Salah where the minimum water temperature is about 20 °C, and dips towards the northeastern part in the Biskra region where the depth reaches 2600 m and the water temperature reaches more than 60 °C.

Figure: Location of the main geothermal resources in Algeria



Source: S. Ouali and .al. (2018). Cartographie et caractérisation des ressources géothermiques de l’Algérie. *Revue des Energies Renouvelables* Vol. 21 N°1. p60. Frome : https://www.asjp.cerist.dz/en/article/121759

• **Close proximity to a rapidly growing green hydrogen market:** Algeria could be an emerging green hydrogen producer by converting or expanding its existing gas distribution (show five gas pipelines. in the table 5) and storage infrastructure to cost-effectively ship locally produced green hydrogen to its target markets. Although Algeria has constructed a transcontinental gas pipeline network that has 37 pipelines totaling 12,193 miles (19,623 kilometers) for gas, oil, and condensate transportation.

As gas imports decline, Europe, with its anticipated rise in green hydrogen consumption and limited solar potential, is set to become an excellent offtake market for the North African manufacturer. Where European future demands of green hydrogen Can be expected to increase for Industry sector to 294TWh in 2030, 857TWh in 2040 and 1200Twh in 2050. 300Twh per year of hydrogen as a fuel in transport. The demand for direct hydrogen in the transport sector in 2050 can be expected to be 285Twh, with 68Twh in aviation and 217Twh in heavy road transport, In the power sector is estimated to be 12Twh in 2030, 301TWh in 2040, and 626Twh in 2050, accounting for 1%, 3%, and 7% of total EU and UK electricity demand in 2030, 2040, and 2050 respectively. Assumptions annual green hydrogen demand in buildings annual hydrogen would be around 150Twh with around 600Twh in 2050. (Anthony Wang, June 2021, pp. 11-12)

Table 5: Algeria's transcontinental natural gas pipelines

pipeline	Galsey to Italy	Medgas to Spain	Enrico Mattei to Italy via Tunisia	Pedro Duran Farell to Spain via Morocco	Trans–Saharan to Europe and from Nigeria to Algeria via Niger	TOTAL
Capacit" Billion"	238	280	1,340	390	1059	
Ength "miles"	534	125	1,025	325	2602	

Source: Shem Oirere. (November 2020).Sonatrach to Expand Pipeline Network in New Contracts. *Pipeline & Gas Journal*. Vol. 247, No. 11. Retrieved 09 17, 2021, from: https://pgjonline.com/magazine/2020/november-2020-vol-247-no-11/features/sonatrach-to-expand-pipeline-network-in-new-contracts

Today, green hydrogen represents only a limited part of the global supply. In the future transformation of green hydrogen into fossil-based hydrogen, and as a fuel and energy carrier beyond the energy industry, there are multiple Challenges that could be exceeded to produce green hydrogen in Algeria:

- Accelerate the completion of renewable energy projects, particularly solar and wind energy.
- Providing a significant amount of freshwater either through the establishment of sea water purification projects or through the exploitation of Albian groundwater.

- Setting Technical standards are an important prerequisite for the production of green hydrogen especially For the end user, (e.g. printing veaus, purities, pipeline transport security in the Fuel cell mobility, materials ...).
- Despite Algeria's considerable financial resources, that obtaining cash and credit was extremely difficult, if not impossible, for certain private investors. It is necessary to establish credit facilities and open the way for external financing Chain concepts backed by cryptocurrencies as a solution to the funding problem.
- Support green hydrogen companies with further enhanced legal and regulatory frameworks.
- Develop strategic vision for nation-al economic development in sustainable devel-opment and the green economy.
- Require a new set of human resources, adapted to the new vision of sustainable economic development.
- Establishing Management training centers, and preparing for artificial intelligence through Big Data creation and switching to 5G.
- Ensure strong R&D support to reduce costs and raise competitiveness
- Tax incentives can reduce the impact of high cost of capital on the profitability of the project. Alternatives are lower income or sales tax, or lower investment tax.

4. Conclusion:

Hydrogen will play a critical role in achieving the global Green Deal's climate goals by assisting in the decarbonization of harder-to-abate sectors. Algeria is demonstrating an energy transformation that will see it become Europe's leading supplier of renewable hydrogen by 2050. When it comes to generating and distributing green hydrogen, Algeria offers a number of advantages, including renewable energy, pipeline gas, and LNG export infrastructure, well as a long history as a dependable energy provider. However, as the race's newest participant, it will face substantial hurdles relating to renewable energy projects, particularly solar energy, large-scale water supply, management of hydrogen transportation technology via natural gas pipelines, and cost determination.

- **Results**

1. Hydrogen is produced by burning fossil fuel-based feedstocks (coal, natural gas, etc.) that emit a lot of CO_2. Green hydrogen, on the other hand, is the missing link in the

decarbonization of all industries. Is created by the use of renewable energy for electrolysis.

2. Electrolysis is green method, have greater production costs as compared to traditional Hydrogen production systems , Electricity is used to split water and create hydrogen in this process. The electricity for green hydrogen comes from renewable sources including wind turbines, solar panels, and hydropower. There is no carbon or Hazardous material released during the electrolysis process.

3. The production green Hydrogen Algerian is a chance to become a much closer partner with EU, which will help decarbonization, energy security, economic development, export, green job creation, and social stability.

4. To ensure the long-term survival of a hydrogen market, as well as the reconciliation of considerable supply and demand, A Bridge European and Algerian from green Hydrogen is necessary.

- **Recommendations**

1. Hydrogen may be transformed into a greener energy system enabler by switching to technologies water electrolysis driven by renewable energy or hybrid solar-wind in regions Adrar Tamanrassetand Laghouat.

2. The main challenge is in the production costs associated with Hydrogen from renewable sources. Existing infrastructure, such as natural gas networks, may be used to create low-cost, low-carbon hydrogen demand.

3. Although creating economies of scale is critical to cut costs significantly, R&D will also be crucial to reduce expenditures and improve the competitiveness of green hydrogen technologies.

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