

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

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Submitted:20/09/2021

Accepted:29/10/2021

Published:03/11/2021

### Abstract:

The paper focuses on the opportunity to produce green hydrogen in Algeria as part of a sustainable energy transition while exploring the associated opportunities and challenges. The research uses a descriptive-analytical approach to assess the potential for Algeria to diversify its energy portfolio. The results revealed Algeria's strategic advantage is evident in its existing oil and gas infrastructure, including pipelines and liquefied gas stations, as well as its ample renewable energy resources, particularly solar and wind power. Additionally, its closeness to European markets further enhances its advantageous position. Algeria's advantageous circumstances enable a substantial and dependable contribution to local and global energy needs as a sustainable and stable source of green hydrogen. The study discusses three main areas that affect Algeria's involvement in the green hydrogen market: operational constraints related to cost reduction in production, investment problems in renewable energy sources, and financial obstacles related to acquiring enough funding.

**Keywords:** 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 successful due to their numerous advantages, including versatile applications, high energy density, and convenient transport and storage. However, they have a significant drawback regarding their environmental impact, which is the leading cause of global warming.

Climate change poses a significant challenge for the whole globe. In 2015, the world community reached a consensus to implement measures to limit global temperature increase to below two°C over the levels seen before the industrial era during the current century. An increasing number of governments have vowed to attain net-zero carbon dioxide (CO<sub>2</sub>) emissions by the middle of the century to restrict global warming to 1.5°C.

Experts often assert that achieving climate goals, as defined in the Paris Accord, may be accomplished by implementing a transformation plan that focuses on enhancing energy efficiency, decreasing the usage of non-bio renewables, using nuclear energy, reusing carbon, recycling bioenergy, implementing carbon capture and storage, and utilizing hydrogen.

Recently, there has been a growing recognition among governments, corporations, and society about the need to transition the energy system towards a more sustainable trajectory. It has sparked renewed interest in green hydrogen as a sustainable, dependable, cost-effective fuel. Hydrogen, a carbon-free energy carrier, produces only water as a byproduct when combusted, making it a clean fuel with no emissions.

During the Osaka Summit 2019, G20 leaders highlighted green hydrogen as a crucial technology for facilitating sustainable energy transitions. Algeria was motivated to create a plan for achieving a carbon-free energy future, which included developing a roadmap for the generation of green hydrogen. Algeria has ample natural resources, particularly solar, geothermal, and wind energy, making it a prime location for generating environmentally friendly hydrogen.

This article aims to address the question: What are the prospects and obstacles associated with the production of green hydrogen in Algeria?

To address the challenge, we chose to methodically split this study into two primary axes, as shown below:

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<sub>2</sub>O) or methane (CH<sub>4</sub>). It must be purified into pure Hydrogen (H<sub>2</sub>) before being used in fuel cell electricity. Hydrogen fuel mixes with oxygen from the air in a fuel cell through an electrochemical mechanism to produce power and water. (USDE, 2020)

Hydrogen has enormous energy compared to other energy carriers (see Table). 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	120 MJ/kg	50 MJ/kg	43 MJ/kg	15 MJ / kg	44.8MJ/kg	50 MJ / kg
Energy						

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 hydrogen energy is relatively high, yet its volumetric density is extremely low. It must be transformed before it can be stored in a usable quantity, reducing the pressure to 700 bar: 7 liters of Hydrogen can hold the same amount of energy as 1 liter of gasoline or 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)
- Ensifying hydrogen allows it to function at lower pressures but requires more energy, making it the most expensive option.
- Several storage solutions (batteries, mass storage in salt caverns) are available depending on the desired purpose.
- 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: heat via direct burning with oxygen or 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. These types are often subsumed under the

term "grey hydrogen." Steam Methane Reforming SMR, (is a transformation process that employs oxygen from water steam in a heat chamber to extract methane ( $\text{CH}_4$ ) and create ( $\text{H}_2$ ). The process is still highly polluting since it produces more than 9 kilograms of  $\text{CO}_2$  for every kilogram of Hydrogen generated.

**Blue Hydrogen:** The carbon released during manufacturing is collected with a CCUS technique to decrease  $\text{CO}_2$  emissions. Blue Hydrogen follows the same process as grey Hydrogen. The EU defines blue Hydrogen 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. The gasification of garbage might also do it.

**Turquoise Hydrogen:** Hydrogen is produced through an endothermic process using natural gas or biomass as an energy source, with solid carbon as a byproduct. While pyrolysis for biomass is a filthy process in terms of the environment, pyrolysis through natural gas is intriguing if the energy is obtained from renewable sources.

**Green Hydrogen** is created by electrolyzing water in an electrolyzer using energy 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. However, this technology has yet to mature on a commercial scale. (Doan, et al., 2018)

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

- Hydrogen can aid in integrating more variable renewable energy into the electrical grid, reducing the temporal and geographical mismatch between supply and demand. It is 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, and 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

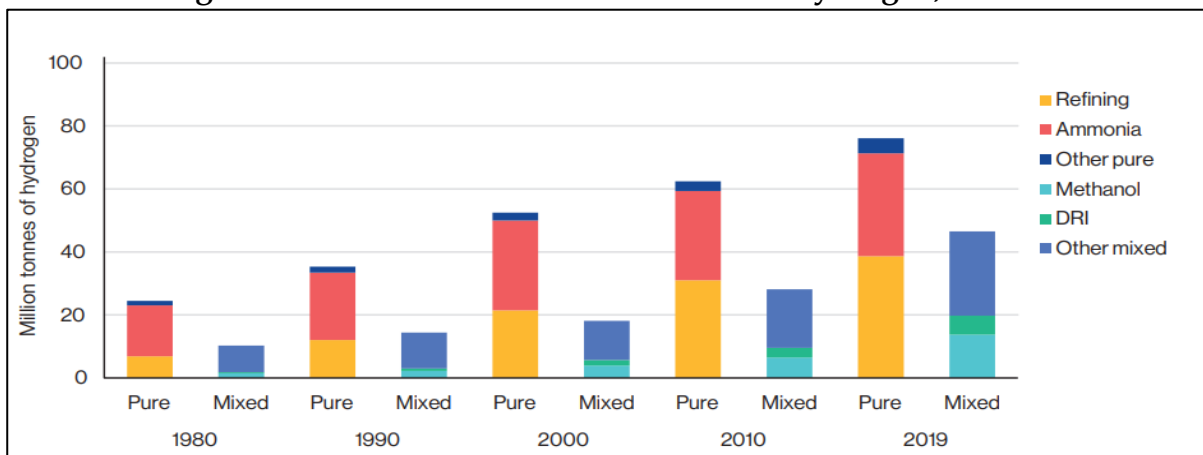
into existing natural gas networks- it can assist in improving air quality, particularly in metropolitan areas where this has become a severe public health issue.

- 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, contributing to greater energy security.

Hydrogen distribution to industrial customers is currently a big industry worldwide. Hydrogen demand, which has increased by more than thrice since 1975- hydrogen production is nearly entirely 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<sub>2</sub> emissions of about 830 million tons per year.

2019 global hydrogen production was around 75 Mt per annum of pure H<sub>2</sub> and 45 Mt H<sub>2</sub> mixed with other gases. (see figure1), roughly 55 percent of Hydrogen produced worldwide is utilized for ammonia synthesis, 25% in refineries, and about 10% for methanol generation. The remaining applications account for only around 10% of global hydrogen generation. (IEA, August 2020, p. 18)

**Figure01: 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 is worth noting that about 85% of Hydrogen is created on-site for captive Consumption, and only 15% is transported by pipeline, so there is 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. It may be supplied using a diversity of renewable

and nonrenewable feedstock and technical paths (see Table 2), all emitting variable amounts of greenhouse gases. 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 new and more ecologically friendly ways to produce green Hydrogen to eliminate CO<sub>2</sub> emissions from the process, and the most environmentally friendly approach to making 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 and existing infrastructure	Produced CO, CO <sub>2</sub> Unstable supply	74–85	2.27
Partial Oxidation	Established technology	Along with H <sub>2</sub> Production, produced heavy oils and petroleum coke	60–75	1.48
Auto thermal Reforming	Well-established technology and existing infrastructure	They produced CO <sub>2</sub> as a byproduct of the use of fossil fuels.	60–75	1.48
Bio photolysis	Consumed CO <sub>2</sub> , Produced O <sub>2</sub> as a byproduct, working under mild conditions	low yields of H <sub>2</sub> , sunlight needed, large reactor required, O <sub>2</sub> sensitivity, high material cost.	10–11	2.13
Dark Fermentation	Simple method, H <sub>2</sub> produced without light, no limitation O <sub>2</sub> , CO <sub>2</sub> -neutral, involves to waste recycling	Fatty acids elimination, low yields of H <sub>2</sub> , low efficiency, necessity of huge volume of the reactor	60–80	2.57
Photo Fermentation	Involved in wastewater recycling, used different organic waste waters, CO <sub>2</sub> -neutral.	low efficiency, Low H <sub>2</sub> production rate, sunlight required, the necessity of massive volume of the reactor, O <sub>2</sub> -sensitivity	0.1	2.83
Gasification	Abundant, cheap feedstock and neutral CO <sub>2</sub> .	Fluctuating H <sub>2</sub> yields are due to feedstock impurities, seasonal availability, and tar formation.	30–40	1.77–2.05
Pyrolysis	Abundant, cheap feedstock, and CO <sub>2</sub> -neutral.	Tar formation, fluctuating H <sub>2</sub> amount because of feedstock impurities, and seasonal availability.	35–50	1.59–1.70
Thermolysis	Clean and sustainable, O <sub>2</sub> -byproduct, copious feedstock	High capital costs, element toxicity, and corrosion problems.	20–45	7.98–8.40
Photolysis	O <sub>2</sub> as a byproduct, abundant feedstock, No emissions.	Low-efficiency, ineffective photocatalytic material Requires sunlight.	0.06	8–10
Electrolysis	Established technology Zero emission Existing infrastructure O <sub>2</sub> as a 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 on production techniques such as steam reforming, partial oxidation, and auto-thermal reforming, which emits a significant quantity of carbon dioxide (CO<sub>2</sub>); that is why the use of Hydrogen is restricted. However, 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<sub>2</sub> and O<sub>2</sub>, it is energy-demanding. As a result, the process is only emission-free if alternative renewable energy sources are explored to mitigate the energy penalty. Another issue is that green methods, such as electrolysis (green Hydrogen), have more significant production costs than traditional hydrogen production systems (gray Hydrogen). Power consumption Approx. 5 kWh / Nm<sup>3</sup> H<sub>2</sub> (1 Nm<sup>3</sup> H<sub>2</sub> = 0.0899 kg H<sub>2</sub>), Consumption of demineralized water about 1 liter / Nm<sup>3</sup> H<sub>2</sub> Moreover, the Consumption of non-demineralized water is 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<sub>2</sub> for \$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 renewable Electricity required to operate the electrolysis unit is the most significant cost for the generation of green Hydrogen. New research by 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.

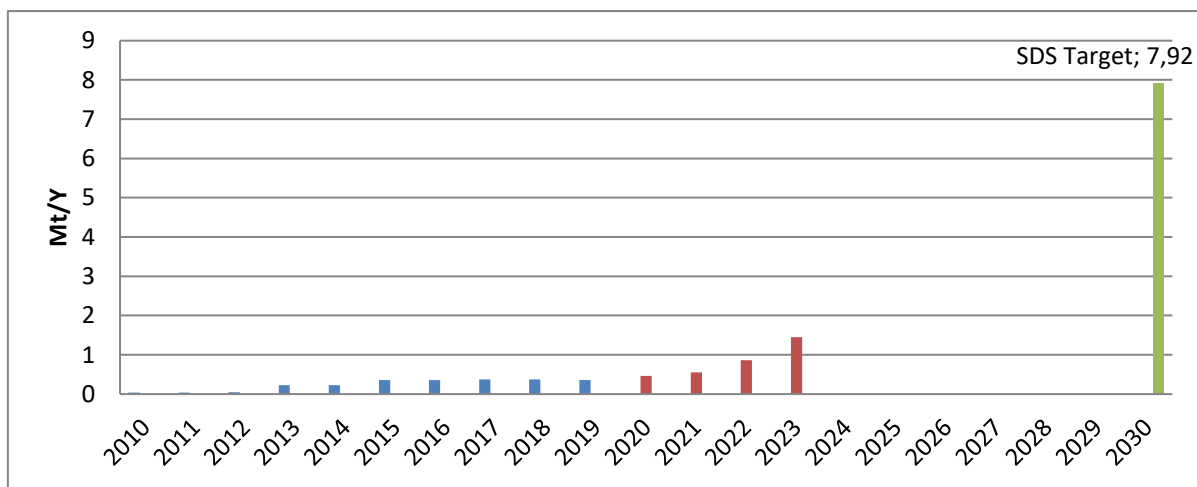
Furthermore, it expects the average Levelized cost of solar PV to be 40% lower by 2050 than two years ago, driven by more automatic manufacturing, less silicon and silver consumption, higher photovoltaic efficiency of solar cells, and greater yields using bifacial panels. The cost of Electricity will account for the majority of the cost of producing renewable H<sub>2</sub> by 2030, with electrolyzer-related costs accounting for the rest. (Tengler, 2021)

However, low power costs are not enough to make green hydrogen generation feasible; cost reductions in electrolysis plants investment cost of electrolyzers 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 and 0,55 Mt in 2021. It is expected to reach 7.92 by 2030 (see Figure 2).

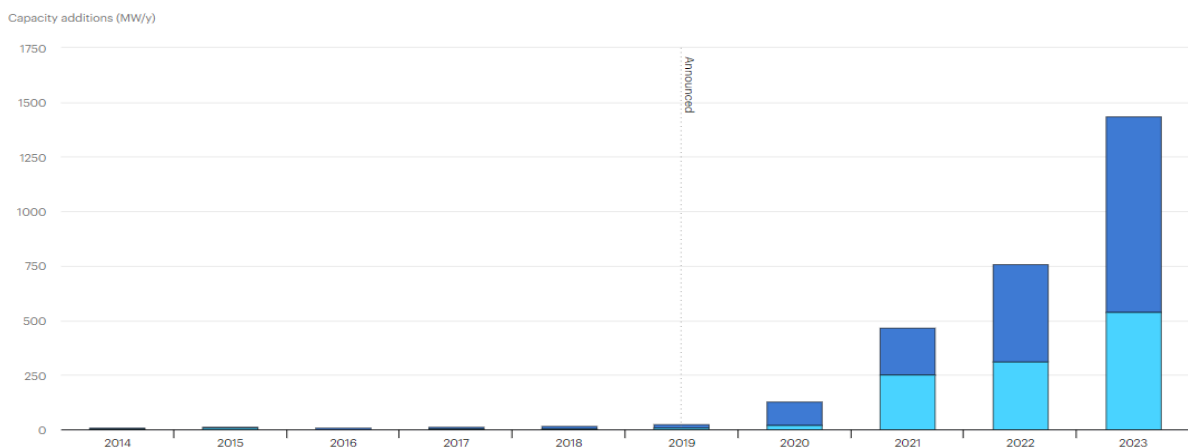
Green hydrogen production is ramping up, especially using electrolysis; from less than 1 MW in 2010 to more than 25 MW in 2019 (see Figure 3), the number of projects and electrolyzer capacity deployed has risen substantially in recent years. Furthermore, project size has increased dramatically: most 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 02: 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 03: 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, several announcements have been made for facilities with hundreds of megawatts of capacity that will begin operations in the early 2020s. (IEA, 2020)

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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 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 divided into oxygen and Hydrogen using a method that produces no CO<sub>2</sub>.
- Power-to-X sector coupling can 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<sub>2</sub> allows for CO<sub>2</sub>-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<sub>2</sub>) and oxygen (O<sub>2</sub>) by electrolyzing water (and carbon dioxide (CO<sub>2</sub>)) using a solid oxide, or ceramic, electrolyte (Zheng, et al., 2017).

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 because it operates at temperatures exceeding 700 degrees Celsius and captures and can store (CCUS) to reduce emissions further. It 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.

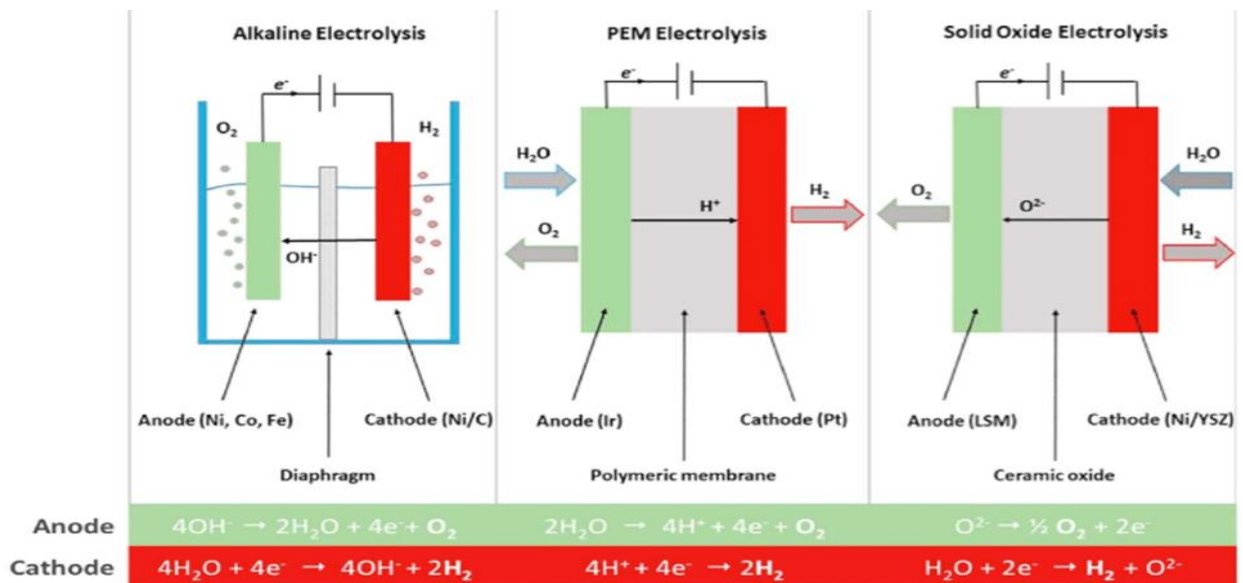
PEM takes its name from the proton exchange membrane. PEM's unique property is that it is permeable to protons but not gases such as Hydrogen or oxygen. As a result, in an electrolytic process, the membrane takes on, among other things, the function of a separator that prevents the product gases from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

Pure. An alkaline medium (25–30% KOH) is typically used. The electrolysis of alkaline water works on a fundamental 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-C<sub>3</sub>N<sub>4</sub> 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](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 that are already operational and announced.

However, many new applications already use polymer electrolyte membrane (PEM) designs. 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. On the other hand, Electrolyzer customers are split on whether the operational benefits of

PEMs (flexibility) and SOECs (efficiency) outweigh the higher costs compared to alkaline electrolyzers. (IEA, 2020)

### 3. Algeria's potential to produce green hydrogen

Algeria has enormous renewable energy potential, but Africa's third largest CO<sub>2</sub> emitter was 180.6 mw within tonnes in 2019, growing at an average annual rate of 5.20%. CO<sub>2</sub> emissions per capita in Algeria increased from 1.3 tons of CO<sub>2</sub> per capita in 1970 to 4.23 tons of CO<sub>2</sub> per capita in 2019, growing at an average annual rate of 2.91%. Therefore, the government action program has prioritized promoting renewable energy and significant investment in green Hydrogen. ( WORLD DATA ATLAS, 2020)

The shift to a hydrogen economy is well underway. A project for developing large-scale solar hydrogen production and exporting was announced during the introduction of a significant Maghreb-European cooperation project (MedHySol in 2005). Two phases will ensure this project's success. The first stage is to create a technical platform to evaluate 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 in 2030 as part of a green hydrogen production strategy that considers 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 been in Algeria since 1981 and now holds 48 mining licenses. The agreement seeks to improve technological collaboration between the two firms and assist the decarbonization route to 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 Institute 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 several hydrogen production projects, including the Adriatic Blue project for blue Hydrogen. For green Hydrogen, Eni and Enel have agreed to develop two 10-MW electrolyzer 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 has been trying to benefit from the European Green Deal through partnerships with German 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 renewable energies. The aim is to generate 15,000 MW of renewable energy electricity annually by 2035. 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**

Horizon	Current Situation	Horizon 2025	Horizon 2030	Horizon 2040	Horizon 2050
<b>Retrospective study (backcasting)</b>	0% green H <sub>2</sub> X% RE -dominant methane reforming -diversification objective	5% green H <sub>2</sub> 20% RE -Research and development	30% green H <sub>2</sub> 50% RE -regulatory standards	60% green H <sub>2</sub> 70%-90% RE - technology scaling	80% green H <sub>2</sub> -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](https://www.energypartnershipalgeria.org/fileadmin/user_upload/algeria/21_02_15_PE_DZA-DEU_-_Introduction_dans_la_th%C3%A9matique_PtX.pdf)

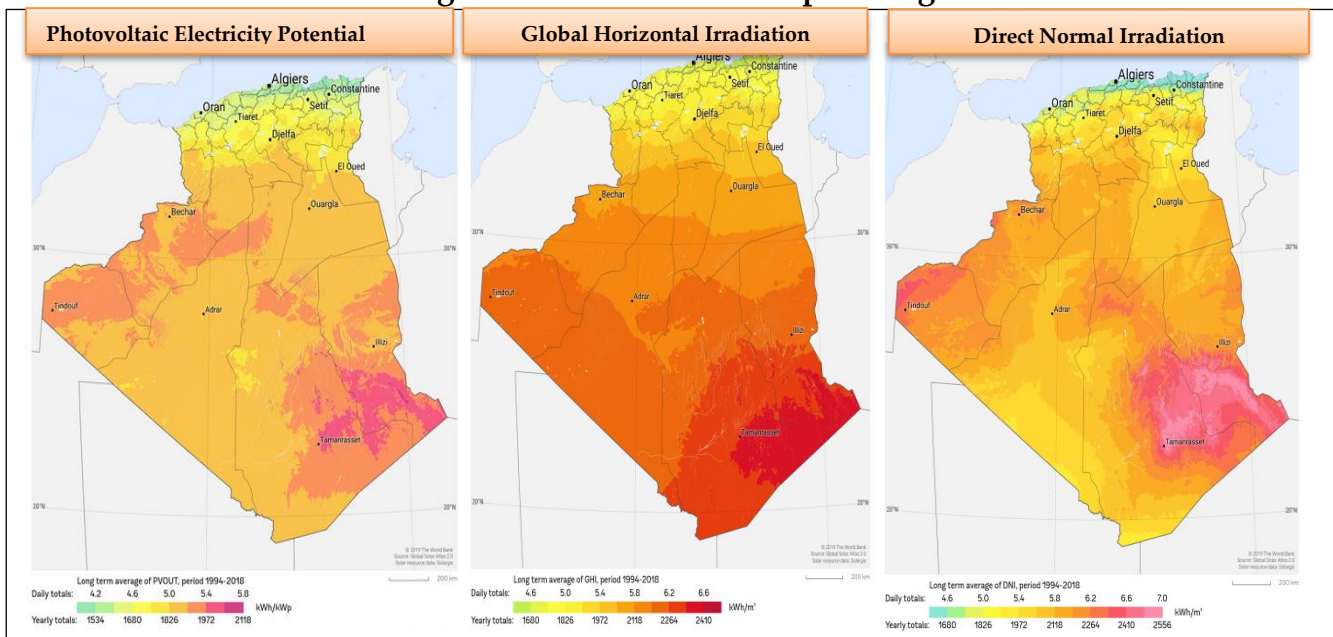
The government may use major enablers to increase its green hydrogen production significantly:

- **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 presents opportunities for distributed renewable energy. Solar power is particularly suitable for Algeria; Wind energy is in second place, followed by geothermal energy.

**A. Solar energy:** Algeria is blessed with abundant 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 ranging from 22° to 31°N and longitude ranging 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. On the other hand, the southern part of the nation has a longer daily sunlight period. The daily sunlight length in this location is always greater than 8 hours, and it may reach 12 hours per day during the hot season. (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 most of the national area, one square meter's total yearly solar energy is around 2000 KWh/m<sup>2</sup>/y, with daily irradiation of 4.6-7 KWh/m<sup>2</sup>. Furthermore, southern locations are more promising than others in harnessing solar energy for green hydrogen generation. Tamanrasset and Illizi, for instance, have high yearly solar energy potentials of 2.4 and 2.2 MWh/m<sup>2</sup>/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. Regarding the highest electrical potential, the Illizi, Tamanrasset, Tindouf, Bechar, and Adrar areas continue their dominance (see Table of Figure 5).

*The evaluation of solar electricity production shows the high potential of solar energy exploitation in the country's south. Hydrogen production from solar energy is primarily recommended, with a study on heat, dust, Humidity, and inclination enhancing solar panels' efficiency.*

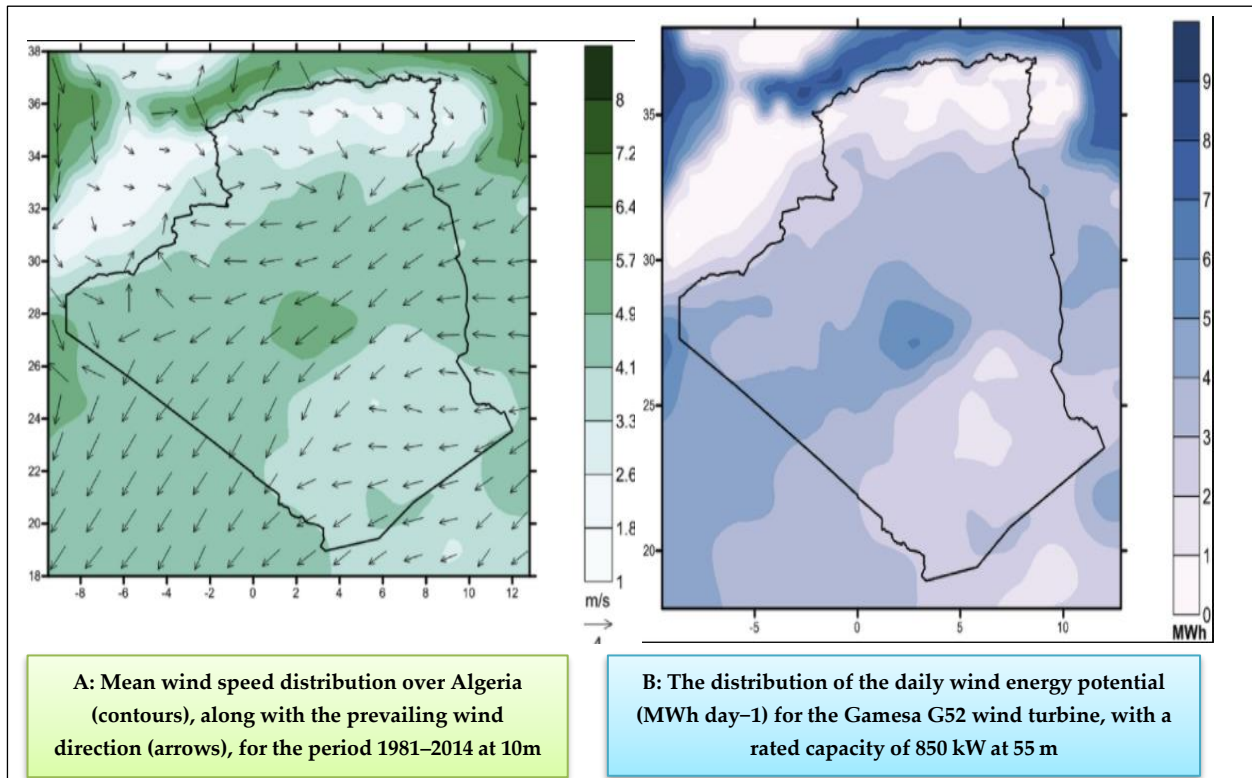
**B. Wind energy:** Algeria's diverse geographical geographic and climatic features result in various wind behaviors. The wind speed is more significant over the sea than on land; the Algerian Sahara is windier than the country's northern parts, with easterly winds over the Sahara and westerly over northern Algeria, and the wind speed in Algeria surpasses 5 m/s 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 01-01-2000 to 31-12-2017 shows that the wind speed with 73 percent of the wind speeds exceeded three m/s. (Houdayfa & Nawel, 2020, p. 1187) The maximum mean wind speed equals 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. Moreover, the 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 the Algerian Highlands, with the following geographic coordinates: 35.41°N and 6.02°E. (Table 5 shows the regions with high wind speed in 2021).

The windiest months in southern Algeria are March and August, with October and December being 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)

By Figure 6 and Table 4, most of the Algerian Sahara shows very satisfactory outcomes for wind energy creation, more than 4 MWh/day, except over the southeasternmost 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<sup>-1</sup>. (Sidi Mohammed & João, 2020, p. 14)

Figure 6: Wind speed & wind energy of Algeria



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

Table4: Power Density & Wind Speed for 10% of windiest areas with a Height of 10m in 2021

REGION	Illizi	Adrar	Tamanrasset	DJELFA	Ghardaia	NAAMA	El Baydah	Laghouat	Msila
Power Density W/m <sup>2</sup>	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>

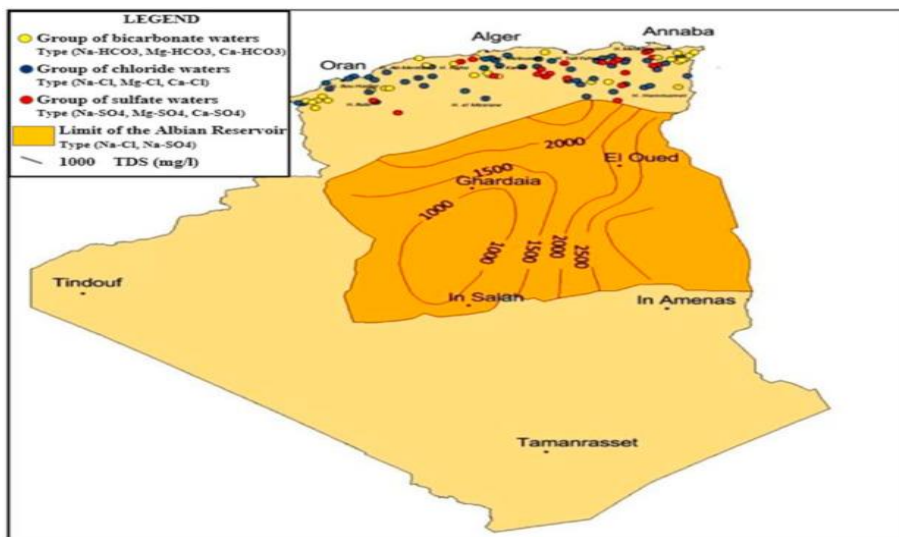
**C. Geothermal energy:** Geothermal energy is another promising use for hydrogen production, particularly for hot water heat supply and high-temperature electrolysis. Efficiency of electrolysis systems can be improved by operating at high temperatures. It reduces the energy needed to activate the electrolysis 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 in Northern Algeria, most located in the northeast. The primary 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)

In the south, the sedimentary basin encloses the essential hot water ( 50°C-120°C) reservoir. Furthermore, the Albian aquifer covers an area of over 650,000 km<sup>2</sup>. The reservoirs in this area are predominantly composed of sandstone, where the surface water temperature ranges from 40 to 62 °C.(Abdelkader, Salima, MM, & Khaled, 2018, p. 4) The Albian aquifer outcrops in the southwestern part of 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. From : <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 (see five gas pipelines. in Table 5) and storage infrastructure to cost-effectively ship locally produced green Hydrogen to its target markets. However, Algeria has constructed a transcontinental gas pipeline network with 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. It can be expected to increase for the 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. 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 of 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	2917
Ength “miles”	534	125	1,025	325	2602	4611

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, multiple Challenges could be posed 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 seawater purification projects or through the exploitation of Albian groundwater.

- Setting technical standards is an essential prerequisite for producing green hydrogen, especially for the end user (e.g., printing vehicles, purities, pipeline transport security in the fuel cell mobility, materials, ...etc).
- Despite Algeria's substantial financial resources, accessing capital and credit is difficult, if attainable, for confident private investors. Establishing credit facilities and enabling external finance is crucial for implementing cryptocurrency-supported chain ideas as a viable solution to the funding issue.
- Support green hydrogen companies with further enhanced legal and regulatory frameworks.
- Develop a strategic vision for national economic development in sustainable development and the green economy.
- Seeking a fresh team of Human Resources professionals capable of aligning with the new goal of sustainable economic growth.
- 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 the high cost of capital on the project's profitability. 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 decarbonizing harder-to-abate sectors. Algeria is demonstrating an energy transformation that will see it become Europe's leading supplier of renewable hydrogen by 2050. Algeria offers several advantages regarding generating and distributing green hydrogen, including renewable energy, pipeline gas, and LNG export infrastructure, and 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 much CO<sub>2</sub>. On the other hand, Green Hydrogen is the missing link in the decarbonization of all industries. It is created by the use of renewable energy for electrolysis.
2. Electrolysis is a green method with more significant production costs than traditional Hydrogen production systems; Electricity is used to split water and create hydrogen. The

Electricity for green hydrogen comes from renewable sources, including wind turbines, solar panels, and hydropower. No carbon or hazardous material is released during the electrolysis process.

3. The production of green Hydrogen in Algerian is a chance to become a much closer partner with the 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 and the reconciliation of considerable supply and demand, a European and Algerian bridge from green hydrogen is necessary.

#### ❖ Recommendations

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

2. The main challenge is 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 cutting costs significantly, R&D will also be crucial to reducing expenditures and improving the competitiveness of green hydrogen technologies

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