



Hydrogen as a Vector of the Energy Transition in Algeria: National Roadmap, Implementation Challenges, and Regional Opportunities

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Abstract ;

This article explores hydrogen as a key driver of Algeria's energy transition within its 2040 national roadmap. It underlines its potential to decarbonize hard-to-electrify sectors and support economic diversification beyond hydrocarbons. The analysis highlights Algeria's structural advantages, including strong solar resources, existing infrastructure, and proximity to European markets. A phased development strategy learning, deployment, and industrialization is proposed. Regulatory, financial, and human capacity reforms are identified as essential conditions for success. Despite significant opportunities, cost, technology, and market uncertainties remain major challenges.

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1. Introduction

The energy transition has become a major public policy priority worldwide. This evolution is driven by climate change concerns, energy market volatility, and the need to strengthen energy security. In this context, hydrogen particularly when produced from renewable or low-carbon sources has emerged as a strategic energy carrier. It is increasingly considered a key solution for decarbonizing sectors that are difficult to electrify, such as heavy industry, long-distance transport, refining, and dispatchable power generation.

Like many countries pursuing carbon neutrality objectives, Algeria has recently adopted a national strategy for the development of renewable and clean hydrogen. This strategy is embodied in an operational roadmap extending to 2040, with longer-term ambitions related to industrial development and export activities. The initiative forms part of a broader vision aimed at diversifying the national economy, enhancing the value of renewable energy resources, strengthening energy security, and preparing for a gradual transition beyond hydrocarbon dependence. It also reflects growing international dynamics, particularly the increasing European demand for green hydrogen and low-carbon derivatives, as well as the emergence of new regional and global energy value chains (Messaoudi, Settou, & Allouhi, 2024).

Algeria possesses several comparative advantages that could support the development of a competitive hydrogen sector. These advantages include abundant solar and wind resources, extensive gas and electricity infrastructure, significant industrial experience in hydrogen and ammonia production, geographical proximity to European markets, and a growing scientific and technical workforce. Nevertheless, the success of this strategy depends on more than resource availability alone. It requires an appropriate regulatory framework, effective institutional coordination, technological progress, substantial financial investments, and the development of a robust industrial ecosystem.

Against this background, a central question arises: *to what extent does Algeria's national hydrogen strategy reconcile energy transition objectives, economic viability, and strategic positioning within future regional and international value chains, while addressing existing technological, institutional, and financial constraints?*

This article seeks to answer this question through four main objectives. First, it examines the role of hydrogen in the global energy transition and reviews major international trends. Second, it analyzes the foundations and strategic ambitions of Algeria's hydrogen policy, highlighting the country's energy, industrial, and human capital assets. Third, it presents the development pathways envisaged for the period 2023–2040, including domestic applications, industrial uses, and export opportunities. Finally, it discusses the operational roadmap and the regulatory, institutional, industrial, and financial measures required for successful implementation.

Methodologically, the study adopts a descriptive and analytical approach based primarily on documentary research. The analysis combines qualitative assessment with a quantitative synthesis of data collected from official and academic sources. The documentary corpus includes international scientific literature, national policy documents,

regulatory texts, technical reports, industrial studies, and official roadmaps related to hydrogen development.

The research process was conducted in three stages. The first stage consisted of reviewing international literature on energy transition scenarios, hydrogen production pathways, technology maturity levels, and leading hydrogen strategies adopted by the European Union, Japan, South Korea, the United States, China, and selected hydrocarbon-producing countries. The second stage focused on collecting and analyzing national data concerning renewable energy resources, energy infrastructure, industrial capacities, regulatory frameworks, and human capital development. The third stage involved synthesizing the collected information within an analytical framework linking Algeria's strategic assets, development vision, and implementation roadmap.

To support the analysis, tables and figures are used to illustrate technological pathways, priority sectors, implementation phases, and key milestones of the national roadmap. This approach facilitates international comparison and provides a clearer understanding of the opportunities and challenges associated with hydrogen development in Algeria.

The adopted methodology offers a comprehensive perspective on the energy, industrial, technological, and strategic dimensions of hydrogen deployment. It also provides an operational understanding of how Algeria can progress from pilot projects and learning phases toward large-scale industrialization and export-oriented development.

2. Hydrogen in the Global Energy Transition

2.1 The Role of Hydrogen in the Decarbonization of Energy Systems

The transition toward carbon-neutral energy systems requires the decarbonization of sectors that remain difficult to electrify, particularly heavy industry, long-distance transport, and dispatchable power generation. In this context, hydrogen has emerged as a strategic energy carrier capable of complementing direct electrification and supporting the integration of renewable energy sources (Ameli, Strbac, Pudjianto, & Ameli, 2024).

Hydrogen is not a primary energy source but an energy carrier that enables the storage, transport, and utilization of energy produced from different sources. When generated through renewable or low-carbon processes, it can contribute significantly to greenhouse gas emission reductions while enhancing the flexibility and resilience of energy systems.

International energy scenarios project a substantial increase in hydrogen demand by 2050, reflecting its growing role in industrial decarbonization, clean transport, and large-scale energy storage. The pace of deployment, however, remains closely linked to production costs, infrastructure availability, and market development (Hydrogen Council, 2017).

Figure 1 illustrates the projected cost of hydrogen delivered to Germany by 2040, including both production and transport costs. Significant differences appear across supply sources.

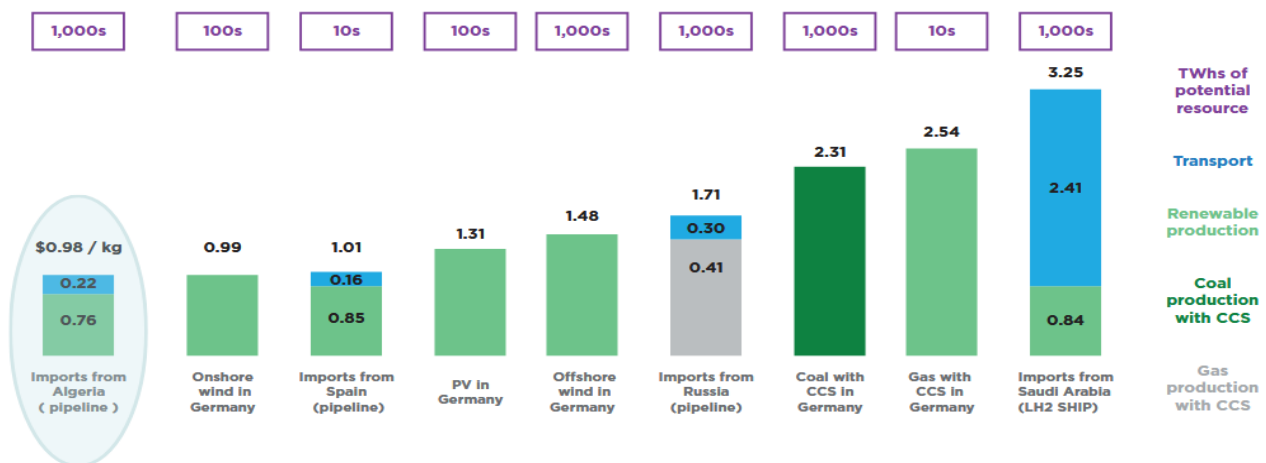
Among the countries considered, Algeria emerges as one of the most competitive suppliers, with an estimated delivered cost of approximately USD 0.98/kg through pipeline transport. This cost level is comparable to, and in some cases lower than, domestic

renewable hydrogen production costs in Germany. By contrast, imports from Spain remain slightly more expensive, while hydrogen produced from offshore wind, natural gas with carbon capture, or long-distance maritime imports exhibits considerably higher costs (Seeger, et al., 2025).

Algeria's competitiveness is supported by several structural advantages, including exceptional solar resources, geographical proximity to European markets, extensive gas transport infrastructure, and significant industrial experience in the energy sector. These factors substantially reduce transportation costs and facilitate future integration into European hydrogen supply chains.

Beyond cost competitiveness, hydrogen represents a strategic opportunity for Algeria's economic diversification. The development of a hydrogen industry could enable the country to create new industrial value chains, strengthen its position in Mediterranean energy markets, and gradually prepare for a post-hydrocarbon economy. Consequently, hydrogen should be viewed not only as an export commodity but also as a catalyst for industrial transformation and sustainable economic development.

Figure 1: Comparison of the cost of hydrogen delivered to Germany (production + transport) from different countries, 2040 horizon.



Source: Global Gas Report 2020.

2.2 Hydrogen Typologies and Technological Maturity

Hydrogen can be produced through different technological pathways that vary in terms of carbon intensity, production costs, and technological maturity. The classification commonly used in international literature distinguishes several categories according to the source of energy and the associated level of greenhouse gas emissions.

Grey hydrogen is produced from fossil fuels, mainly through steam methane reforming, without carbon capture. Although technologically mature and currently dominant in global production, it remains highly carbon-intensive (IEA, 2019).

Blue hydrogen combines fossil-fuel-based production with carbon capture, utilization, and storage (CCUS) technologies. It is generally regarded as a transitional solution capable of reducing emissions while relying on existing natural gas infrastructure.

Green hydrogen is produced through water electrolysis powered by renewable electricity. It is widely considered the most sustainable long-term pathway and occupies a central position in decarbonization strategies worldwide.

Other emerging pathways, such as turquoise hydrogen produced through methane pyrolysis and pink hydrogen generated using nuclear electricity, remain at earlier stages of deployment and continue to face technological and economic challenges.

From a technological perspective, most hydrogen production technologies have already reached relatively high levels of maturity. Current challenges relate less to production itself than to large-scale deployment, cost reduction, storage solutions, transport infrastructure, and market integration.

Table 1. Hydrogen Typologies, Production Processes, Carbon Intensity, and Technological Maturity

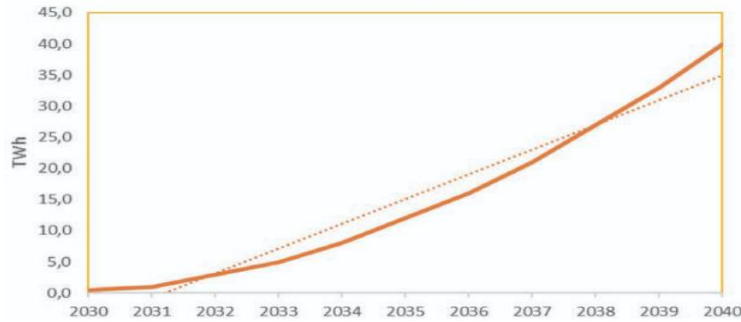
Hydrogen Type	Production Process	Carbon Intensity	Technological Maturity (TRL)
Grey Hydrogen	Steam Methane Reforming (SMR)	High	9
Blue Hydrogen	SMR + CCUS	Medium	8–9
Green Hydrogen	Renewable-powered Electrolysis	Very Low	7–9
Turquoise Hydrogen	Methane Pyrolysis	Low	5–7
Pink Hydrogen	Nuclear-powered Electrolysis	Very Low	6–8

Source: Adapted from IEA (2023) and Global Hydrogen Review (2023).

From the Algerian perspective, both blue and green hydrogen pathways offer significant strategic potential. In the short and medium term, the country's abundant natural gas resources and existing industrial infrastructure provide favorable conditions for blue hydrogen development. In the longer term, Algeria's exceptional solar and wind resources could support large-scale green hydrogen production at competitive costs. Accordingly, the national hydrogen roadmap adopts a progressive approach that combines transitional and renewable pathways in order to balance economic feasibility, technological learning, and long-term climate objectives.

Figure 2 presents the projected evolution of global hydrogen production by 2040. The trajectory suggests gradual acceleration after 2035, driven by technological progress, declining renewable energy costs, increasing carbon constraints, and expanding infrastructure networks.

For Algeria, this global trend creates a favorable window of opportunity. The period 2025–2035 will be crucial for developing pilot projects, attracting investment, strengthening institutional capacities, and establishing the industrial foundations required for participation in future regional and international hydrogen markets. Successful implementation during this phase will largely determine the country's ability to become a competitive producer and exporter of low-carbon hydrogen in the Mediterranean region.

Figure 2. Projected Global Hydrogen Production to 2040

Source: Adapted from International Energy Agency (2021), Net Zero by 2050: A Roadmap for the Global Energy Sector.

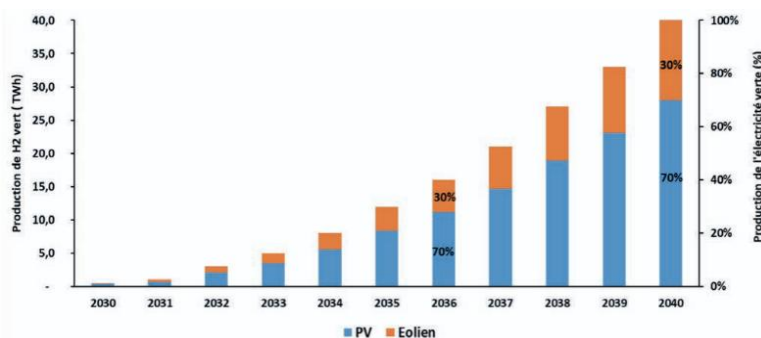
2.3 International Dynamics and Benchmark National Strategies

In response to climate urgency and energy security imperatives, many countries have adopted national hydrogen strategies. These strategies reflect differentiated priorities depending on the availability of energy resources, the structure of electricity systems, and industrial policy objectives.

The European Union positions green hydrogen as a central pillar of its pathway toward carbon neutrality, combining the domestic development of electrolyzer capacity with the structuring of import corridors from regions with high renewable potential. By contrast, countries such as Japan and South Korea which have limited domestic energy resources prioritize strategies focused on securing hydrogen imports. The United States and China adopt a mixed approach, investing simultaneously in technological innovation, equipment industrialization, and the creation of large-scale domestic markets (Zhang, Pan, & Wang, 20225).

Beyond quantitative targets, these strategies differ in their technological choices regarding low-carbon electricity generation for electrolysis. As illustrated in Figure 3, the projected expansion of green hydrogen production by 2040 is accompanied by the growing dominance of solar photovoltaic power, which is expected to account for approximately 70% of the electricity dedicated to hydrogen production, compared with around 30% for wind energy. This distribution reflects the rapid decline in photovoltaic costs and its strong deployment potential in high-irradiation regions. Wind power plays a complementary role by enhancing the stability of electricity supply and improving electrolyzer load factors.

Figure 3: Distribution of green hydrogen production by electricity generation technology, 2040 horizon.



Source: Global Hydrogen Review 2023.

The near-exponential growth in production shown in Figure 3 confirms that green hydrogen relies on the massive expansion of renewable capacity and on close integration between the electricity and industrial sectors. It also suggests that future competitiveness will largely depend on access to abundant, low-cost solar resources, thereby granting a strategic advantage to regions with strong photovoltaic potential.

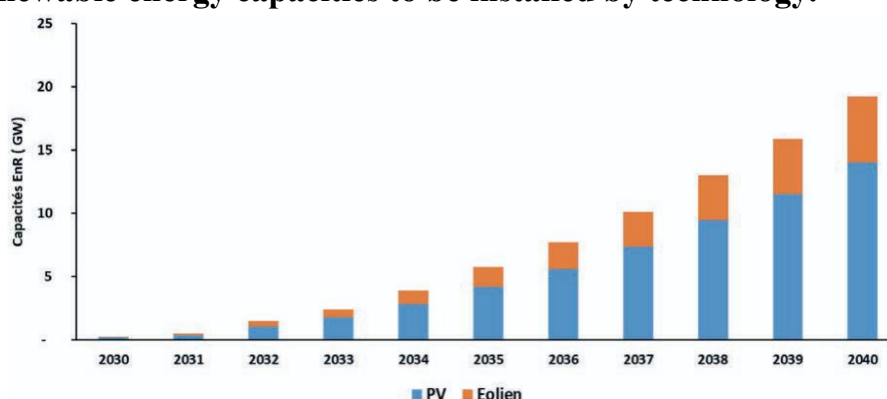
Overall, international dynamics demonstrate that hydrogen is not only a decarbonization instrument but also a lever for geo-economic repositioning, structured around comparative advantages in renewable energy resources.

2.4 Renewable and Electrolysis Capacity Requirements: Industrialization Constraints of Green Hydrogen

In green hydrogen deployment pathways, the large-scale availability of renewable electricity constitutes the central determinant of competitiveness. Countries endowed with strong solar and wind potential generally adopt a strategy based on the complementarity of photovoltaic and wind generation profiles, in order to optimize electrolyzer load factors and reduce the levelized cost of hydrogen.

As illustrated in Figure 4, achieving green hydrogen production targets by 2040 requires a substantial expansion of installed renewable capacity. The increase is continuous over the 2030–2040 period, reflecting a phase of accelerated industrialization. Solar photovoltaic clearly dominates capacity additions, highlighting the sustained decline in investment costs and its strong potential for rapid large-scale deployment. Wind energy retains a complementary role, helping to smooth electricity generation and improve electrolyzer utilization rates. The observed structure confirms that green hydrogen development depends on a close coupling between renewable energy policy and hydrogen industrial strategy: it cannot expand without a massive increase in low-carbon power generation capacity.

Figure 4: Renewable energy capacities to be installed by technology.

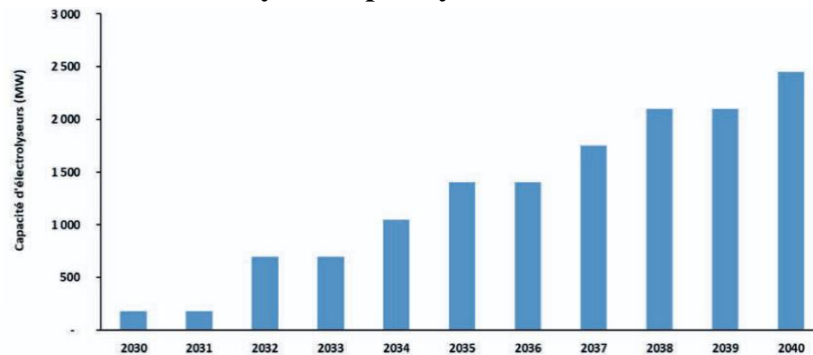


Source: Global Hydrogen Review 2023.

At the same time, the scaling of electrolysis capacity constitutes a second structuring lever. Figure 5 highlights the progressive increase in Proton Exchange Membrane (PEM) electrolyzer capacity required to support production trajectories. Growth becomes particularly pronounced after 2034, signaling the transition from a pilot phase to large-scale industrial deployment. PEM electrolyzers are favored in systems heavily supplied by variable renewable energy due to their operational flexibility, rapid response time, and

compatibility with the intermittency of solar and wind power. Their expanding capacity therefore reflects a strategy of dynamic integration between renewable electricity generation and hydrogen conversion.

Figure 5: Required PEM electrolyzer capacity to be installed.



Source: IEA (2021). Net Zero by 2050: A Roadmap for the Global Energy Sector.

The combined analysis of Figures 4 and 5 shows that competitiveness depends not only on the unit cost of production, but also on systemic coherence between the electricity mix, electrolysis technologies, and infrastructure development. Countries capable of aligning these three dimensions gain a decisive comparative advantage. This logic is particularly relevant for economies with strong solar potential, especially in North Africa and the Middle East, where the combination of abundant renewable resources, existing energy infrastructure, and export experience provides a strategic foundation for the industrialization of green hydrogen.

In this context, future competitiveness will be assessed not only at the level of production costs, but also across entire value chains. The ability to structure integrated industrial ecosystems, secure long-term offtake agreements, and establish credible certification mechanisms will become decisive factors for positioning in the international hydrogen market.

3. Foundations and Ambitions of Algeria's National Hydrogen Development Strategy

Algeria's national hydrogen strategy aims to support the global energy transition while leveraging the country's comparative advantages. It adopts an integrated approach combining energy resources, infrastructure, industrial capacity, human capital, and geostrategic positioning to promote sustainable economic diversification.

3.1 Renewable and Fossil Energy Potential Conducive to Hydrogen Production

Algeria possesses exceptional energy potential, both in fossil resources and renewable energy, providing a solid foundation for the development of multiple hydrogen production pathways.

The country's solar potential ranks among the highest in the world, with annual irradiation levels significantly exceeding those observed in Europe. This is complemented by substantial wind potential, particularly in the Saharan regions and the High Plateaus. Such abundance enables the prospect of large-scale renewable electricity generation dedicated to water electrolysis for green hydrogen production. At the same time, Algeria benefits from decades of experience in natural gas exploitation, opening immediate prospects for hydrogen production via steam methane reforming (SMR), with or without carbon capture

and storage (CCS/CCUS). This complementarity between green and blue hydrogen allows for a gradual pathway that reconciles climate imperatives, economic feasibility, and energy security.

3.2 Existing Energy Infrastructure and Proven Expertise

One of Algeria's main strengths in establishing a large-scale hydrogen sector lies in its already deployed heavy energy infrastructure, combined with proven industrial and operational expertise. These assets provide a solid basis for the progressive deployment of hydrogen, limiting transition costs and technological risks associated with building entirely new value chains from scratch.

Algeria benefits from a dense and strategic network of national and transnational gas pipelines, connecting major production basins to domestic consumption centers and European export markets, notably through the Medgaz and TransMed infrastructures. In addition, the country possesses gas processing facilities, liquefaction capacities, and specialized port installations dedicated to energy exports. These infrastructures offer tangible prospects for transporting hydrogen and its derivatives (ammonia, methanol, synthetic fuels), either through the gradual adaptation of existing networks (hydrogen–natural gas blending) or through the development of new export-oriented logistics chains (IEA, 2023).

Beyond export opportunities, these infrastructures could support the gradual decarbonization of Algeria's electricity sector. In particular, hydrogen–natural gas co-combustion in existing thermal power plants offers a transitional solution that reduces natural gas consumption while making use of existing generation capacities.

Preliminary estimates regarding the partial substitution of natural gas with hydrogen highlight significant natural gas savings, both on an annual basis and cumulatively over the 2035–2040 horizon. These results, presented in Table 2, demonstrate the strategic value of hydrogen not only as a decarbonization vector but also as a tool for preserving national fossil resources.

Table 2. Potential Natural Gas Savings from Partial Substitution with Hydrogen in Power Generation (*Estimates based on a natural gas price of USD 15/MMBTU*)

Scenario	Description	Annual NG Savings (billion m ³)	Annual Value (billion \$)	Cumulative Savings 2035–2040 (billion m ³)	Cumulative Value 2035–2040 (billion \$)
S1	30% substitution of gas turbine consumption	2.7	1.5	16.4	9.1
S2	30% substitution of gas turbine consumption, including combined-cycle plants (SPE)	6.3	3.5	38.2	21.2

Source: Exploratory Study on the Power-to-X (Green Hydrogen) Potential for Algeria, Ministry of Energy Transition and Renewable Energies (2021).

These findings confirm that the gradual introduction of hydrogen into operating power plants could significantly reduce domestic natural gas consumption currently on a steady upward trend while strengthening national energy security.

In this perspective, pilot and demonstration projects are planned to assess the technical, technological, and economic parameters associated with hydrogen–natural gas blending. These projects will analyze hydrogen production performance under Algeria’s specific climatic and topographical conditions, the behavior of existing equipment, permissible blending ratios, and the investments required for infrastructure adaptation.

The national roadmap foresees a gradual scaling-up of co-combustion rates: an initial testing phase with hydrogen shares below 5% in high-consumption gas turbines, followed in the medium and long term by a gradual increase potentially reaching 25–30% by volume or even higher depending on the technical limits of each installation. This incremental approach aims to secure the technological transition while maximizing energy and environmental benefits (IEA, 2022).

Finally, this dynamic builds upon the recognized expertise of national operators, notably Sonatrach and Sonelgaz, in the design, operation, and maintenance of complex energy facilities, as well as in managing large-scale industrial projects and energy exports. This human and institutional capital constitutes a decisive comparative advantage for deploying pilot and, subsequently, industrial hydrogen projects. It fully aligns with Algeria’s strategic objectives of energy diversification, carbon footprint reduction, and positioning the country as a regional hub for hydrogen production and export, including its derivatives.

3.3 National Capacities and Structural Competitiveness Factors of the Hydrogen Sector in Algeria

The potential competitiveness of Algeria’s hydrogen sector is based on a set of structural determinants combining human capital, industrial base, energy resources, geostrategic positioning, and technological options. These factors constitute essential prerequisites for the gradual emergence of a national hydrogen ecosystem, particularly in its renewable and low-carbon segments, in line with international dynamics observed in emerging exporting countries (International Renewable Energy Agency, 2022).

From an academic and scientific perspective, Algeria benefits from a structured higher education system comprising more than one hundred institutions, supported by a network of laboratories and sectoral research centers. This institutional environment provides a favorable foundation for developing expertise in advanced energy technologies. It represents a strategic lever for training qualified human resources and strengthening applied research in key segments of the hydrogen value chain, particularly electrolysis, storage, and Power-to-X applications.

Moreover, the national industrial base constitutes a decisive asset. The experience accumulated in natural gas production, transport, and processing as well as in industrial hydrogen use provides a technical and organizational infrastructure that can be transferred to new low-carbon segments (IEA, 2023). This capacity is further reinforced by the gradual development of a domestic renewable energy sector, supported by one of the highest solar and wind potentials in the Mediterranean region.

Algeria’s geostrategic position also represents a major comparative advantage. Its proximity to the European market, combined with existing transnational energy and port

infrastructure, facilitates its potential integration into future supply chains for renewable hydrogen and energy derivatives (International Renewable Energy Agency, 2022).

Finally, the national strategy is based on multiple technological pathways, including steam methane reforming (SMR) with or without carbon capture and storage (CCS), as well as renewable-powered electrolysis. This technological flexibility, combined with the availability of low-cost solar resources and already amortized energy infrastructure, provides Algeria with favorable medium- and long-term economic competitiveness prospects, particularly in export markets.

Table 3. National Capacities and Structural Competitiveness Factors of the Hydrogen Sector in Algeria

Key Factors	National Strengths	Implications for the Hydrogen Sector
Human and scientific capital	109 higher education institutions; network of laboratories	Specialized training, R&D, progressive mastery of hydrogen technologies
Industrial base	Gas sector experience; existing infrastructure; diversified industrial fabric	Deployment of pilot projects, industrialization, technology transfer
Renewable energy	High solar and wind potential; emerging PV sector	Cost reduction, industrial integration, renewable–hydrogen synergies
Geostrategic position	Proximity to European market; transnational energy infrastructure	Access to export markets; integration into value chains
Technological flexibility	SMR, SMR+CCS, renewable electrolysis	Regulatory and technological adaptability
Economic competitiveness	Low-cost renewable resources; amortized energy assets	Competitive production in the medium to long term

Source: Author's elaboration based on International Renewable Energy Agency (2022).

4. Vision 2023–2040 and Hydrogen Development Pathways in Algeria

The national hydrogen development strategy follows a gradual and controlled trajectory, consistent with the roadmap defined by public authorities. It aims at the progressive integration of renewable and low-carbon hydrogen into the national energy system, moving from pilot-scale domestic and industrial uses toward the structuring of a fully-fledged sector oriented toward export markets.

This vision is based on a clearly defined timeline combining regulatory adaptation, human capital development, the structuring of a specialized industrial base, and the establishment of appropriate financing mechanisms. Together, these levers support the sector's gradual scaling-up to ensure its technical and economic viability. By 2040, hydrogen is expected to become a strategic energy carrier contributing to the diversification of the energy mix, the reduction of greenhouse gas emissions, and the strengthening of Algeria's international positioning within emerging energy value chains.

4.1 Progressive Integration of Hydrogen into the Electricity System

The partial substitution of natural gas with hydrogen in existing thermal power plants represents a short- to medium-term priority action. This integration relies on an incremental

co-combustion (blending) approach, beginning with limited shares around 5% or less to ensure technical reliability and accumulate operational experience. A gradual increase is subsequently envisaged toward proportions ranging between 25% and 30%, depending on the technological constraints of gas turbines and combined-cycle power plants (Jalilinasrabad & Dincer, 2024).

Such an approach simultaneously allows for the reduction of national natural gas consumption thereby preserving strategic fossil resources the lowering of the carbon footprint of the electricity sector in line with national climate objectives, and the creation of an initial industrial outlet for domestic hydrogen production. It therefore constitutes a crucial transitional step between the experimental phase and the emergence of a large-scale hydrogen energy market.

The potential natural gas savings associated with these scenarios, presented earlier in Table 2, confirm the energy and economic relevance of this option and reinforce its role as an initial lever for the industrialization of the hydrogen sector in Algeria.

4.2 Production Pathways and Technological Capability Building

The Algerian vision is based on a pragmatic and evolving approach that combines multiple hydrogen production pathways in order to ensure a realistic transition toward a low-carbon economy. In an initial phase, so-called “blue” hydrogen produced from natural gas with carbon capture, utilization and storage (CCUS) represents a transitional solution consistent with the current structure of the national energy system. This option makes it possible to leverage existing gas infrastructure and established industrial expertise, while initiating emissions reductions.

In parallel, “green” hydrogen produced through water electrolysis powered by renewable energy is expected to gradually assume a central role. Its expansion will depend on the development of solar and wind capacities, the training of specialized skills, and the establishment of appropriate technical standards and regulatory frameworks. As these enabling conditions are progressively met, this pathway is set to become the main pillar of national hydrogen production.

The complementarity between these two pathways ensures supply security by relying both on abundant gas resources and on the country’s significant renewable potential. It also enables a gradual control of costs, as the transitional pathway supports the emergence of low-carbon technologies until they reach economic maturity. Finally, this strategy promotes structured technological learning: pilot and demonstration projects play a decisive role in building local expertise and in progressively developing a dedicated hydrogen industrial ecosystem.

4.3 Deployment Phasing, Industrial Structuring and Monitoring Indicators

The deployment of the hydrogen sector follows a progressive trajectory structured around three major stages, consistent with the national roadmap. This planning approach aims to simultaneously support technological learning, industrial structuring, and the emergence of a domestic market, while equipping public authorities with measurable indicators to assess the effective progress of the strategy.

The first phase (2023–2030) corresponds to an initiation and experimentation stage. It primarily focuses on establishing the regulatory framework, developing national skills, and launching pilot projects. During this period, hydrogen is introduced into the energy system through limited co-combustion operations at proportions of around 5% or less as well as through decentralized electrolysis units linked to national research programs. Uses remain concentrated on electricity generation and selected pilot industrial applications. Monitoring indicators for this phase include the number of demonstration projects implemented, the effective hydrogen blending rate in power plants, and the implementation of specialized training programs.

The second phase (2030–2040) marks the transition toward industrialization. Priorities include industrial integration, access to financing mechanisms, and the deployment of larger-scale production facilities. Power-to-X technologies begin to expand, and hydrogen blending rates in power plants gradually increase to levels between 25% and 30%, depending on technical constraints. Hydrogen applications broaden to include heavy industry and certain segments of heavy mobility, in addition to the electricity sector. Key monitoring indicators at this stage include installed industrial capacity, hydrogen production volumes, and the share of domestic demand covered (Schmidt, et al., 2017).

The third phase, beyond 2040, corresponds to sector maturity and international expansion. It is characterized by large-scale production, the development of derivative products such as ammonia and methanol, and the establishment of energy export hubs. Hydrogen thus becomes a vector of regional integration and a lever for positioning in international markets. Evaluation at this stage relies on export volumes, the proportion of green hydrogen in total production, and the consolidation of sustainable international partnerships.

This phased approach provides a structured framework for monitoring the progress of implemented actions, the strengthening of industrial and technological capabilities, and the evolution of priority uses, while offering concrete benchmarks for the continuous evaluation of the national strategy.

4.4 Synergies Between Phases and Long-Term Perspectives

The development trajectory of the hydrogen sector is built on logical continuity between the different phases of the program, with each stage preparing the conditions for the success of the next. The first phase primarily serves as a period of technological and organizational learning. Pilot projects make it possible to gain practical experience, identify local technical constraints (climatic conditions, water availability, adaptation of gas networks), and assess real production costs. The knowledge accumulated then forms the foundation for the next stage, characterized by a gradual scale-up to industrial deployment. In this way, lessons learned do not remain confined to the experimental stage but are transferred to larger-capacity installations, reducing investment risks and improving overall economic performance (Staffell, et al., 2019).

The transition from the second to the third phase corresponds to sectoral maturation. Industrial capacities consolidate, processes become standardized, and equipment becomes compatible with mass production. This stage is decisive for competitiveness, as it enables

unit cost reductions, supply chain optimization, and the establishment of national technical standards aligned with international benchmarks. It also prepares the integration of production into external markets, particularly European markets, where certification and traceability requirements are stringent.

From a long-term perspective, program evaluation is based on several structuring indicators. The reduction of carbon dioxide emissions constitutes a primary environmental objective, reflecting hydrogen's contribution to the decarbonization of the energy system. At the same time, natural gas savings represent a strategic issue for energy security and the preservation of exportable resources. The industrial competitiveness of the hydrogen sector measured by production costs and export capacity becomes a central economic indicator, alongside the degree of integration into regional and international markets.

Overall, this progressive and coordinated approach enables Algeria to build a solid and sustainable hydrogen sector. It supports economic diversification, enhances the valorization of national energy resources, and facilitates the transition toward a cleaner energy model, while positioning the country as a potential major player in the international hydrogen market.

5. Roadmap for the Implementation of the National Hydrogen Strategy

The roadmap represents the operational translation of the strategic vision outlined above. Its objective is to organize the progressive deployment of the hydrogen sector in Algeria through a coherent set of legal, institutional, industrial, and financial measures structured within a realistic and evolving timeline. The aim is not merely to launch isolated projects, but to sustainably establish a new energy ecosystem capable of integrating into the existing national energy system.

This approach is based on a comprehensive framework covering the entire value chain: hydrogen production, transport and storage, conversion into energy derivatives, as well as industrial, energy, and export uses. It must also remain consistent with national policies on energy transition, economic diversification, and international cooperation, in order to avoid institutional fragmentation and ensure convergence between public and private investments.

5.1 Adaptation of the Regulatory, Normative, and Institutional Framework

The primary condition for success lies in establishing a clear and dedicated regulatory framework for renewable and low-carbon hydrogen. Such a framework secures investments, reduces legal uncertainty, and facilitates the entry of international technological and financial partners. It must encompass all activities related to the sector from production to end uses, including transport, storage, and commercialization.

In this context, the development of specific regulatory texts governing hydrogen and its derivatives becomes essential. These texts should define hydrogen categories according to their carbon footprint, specify authorization procedures for installations, regulate renewable electricity purchase agreements, and establish certification rules enabling exports to international markets. Progressive alignment with international standards is a key challenge, particularly to ensure recognition of the “green” character of national production (CertifHy Project Consortium, 2019).

At the same time, technical and safety standards must be adapted. Hydrogen has specific physical properties low density, high diffusivity, and high flammability that require dedicated protocols for infrastructure, industrial equipment, and transport networks. Standardization efforts should therefore address pipelines, compression stations, storage units, and hydrogen-consuming industrial facilities.

Clarifying institutional roles is also crucial. The hydrogen sector involves multiple domains: energy, industry, environment, higher education, foreign trade, and transport. Structured intersectoral coordination must be established to avoid overlapping responsibilities, accelerate administrative procedures, and ensure strategic coherence. The creation of a national steering body or coordination authority would facilitate project monitoring and performance evaluation.

Taken together, these measures constitute an essential prerequisite for launching pilot projects and, ultimately, scaling up to industrial deployment. Without a stable regulatory framework, investments would remain limited and the sector would be unable to achieve the expected level of economic maturity.

5.2 Human Capital Development and Strengthening of National Capacities

The success of the hydrogen sector does not depend solely on infrastructure or financing; it also relies on the availability of national expertise capable of designing, operating, and maintaining installations. The roadmap therefore includes a structured effort in education, research, and innovation to support the sector's gradual expansion.

Within higher education, the creation of specialized academic programs becomes necessary. Universities and engineering schools will need to integrate dedicated curricula covering electrolysis, advanced materials, energy storage, fuel cells, and Power-to-X technologies. The objective is to train engineers, technicians, and researchers capable of mastering the entire value chain from hydrogen production to its industrial and energy applications.

National scientific research must also be strengthened. Applied research programs may focus on optimizing electrolyzers under local climatic conditions, reducing water consumption, improving catalysts, advancing solid or chemical hydrogen storage, and developing synthetic fuels. Joint involvement of universities, research centers, and public and private enterprises will foster local innovation and the development of national patents.

Furthermore, technical and industrial institutions must enhance their capabilities. This includes continuous training for professionals in the energy and industrial sectors, modernization of testing laboratories, and the establishment of experimental platforms. These mechanisms will ensure progressive technological appropriation and reduce external technological dependence.

These dynamic aims to guarantee sustainable and cumulative capacity building. Mastery of know-how is indeed a fundamental condition for developing a competitive local industry, strengthening national integration within projects, and maximizing the economic and technological benefits of the transition toward hydrogen.

5.3 Industrial Integration and Value Chain Structuring

The roadmap places a central focus on the gradual industrialization of both the renewable energy and hydrogen sectors. The goal is to move beyond the mere role of technology importer and to build a national industrial fabric capable of operating across the entire value chain. This approach addresses a dual imperative: securing technological supply and maximizing domestic economic benefits.

In this perspective, local manufacturing of equipment is a critical step. This includes electrolyzers, power electronics components, compression systems, storage tanks, transport infrastructure, and certain inputs required for hydrogen production. A phased integration is planned: initially, the local assembly of imported equipment would allow the acquisition of industrial know-how, followed by partial and eventually full production of specific components. This strategy fosters the creation of skilled jobs and reduces dependency on international supply chains (IRENA, 2024).

Alongside physical production, mastering associated services is equally important. Design, engineering, operation, and maintenance activities represent the most durable portion of the economic value in an energy industry. The development of specialized national engineering offices, industrial maintenance companies, and locally trained technical operators will help retain a significant share of value added domestically while ensuring the operational continuity of installations.

The emergence of an innovation ecosystem complements this framework. Partnerships between public enterprises, private investors, universities, and startups should encourage solutions adapted to the local context, particularly in energy optimization, water management, storage, and digitalization of networks. Cooperation between large industrial groups and innovative startups typically accelerates technological adoption and fosters applied innovation.

Thus, industrial integration aims to progressively increase the local content of projects, reduce long-term costs, and enhance the overall competitiveness of the hydrogen sector. It also serves as a lever for economic diversification by contributing to the creation of a new export-oriented industrial base.

5.4 International Cooperation, Technology Transfer, and Financing

The development of the hydrogen sector requires significant investments and access to technologies that are still evolving. For this reason, international cooperation is a crucial acceleration lever. It allows Algeria to benefit from experiences gained in other countries, access advanced technologies, and reduce risks associated with the initial deployment phases.

Bilateral and multilateral partnerships can operate on several levels. First, they facilitate the execution of pilot and demonstration projects, essential for validating technological choices under local climatic and energy conditions. They also contribute to strengthening institutional and managerial capacities, particularly in regulation, certification, and energy planning. Finally, they enable access to international financing mechanisms, often essential in the early stages of a capital-intensive emerging sector.

Mobilizing appropriate financing is indeed a key success factor. Hydrogen projects require high initial investments while their profitability is realized over the long term. Incentive schemes, public guarantees, risk-sharing mechanisms, and innovative financial instruments should accompany investments to attract private capital and secure industrial partners. As the sector matures and costs decrease, dependence on public support can be gradually reduced.

5.5 Gradual Deployment of the Sector and Milestones

The implementation of the roadmap follows a structured trajectory divided into three main phases, each corresponding to a different level of technological and economic maturity.

The first period, covering 2023–2030, corresponds to a phase of learning and initial deployment. It is characterized by the launch of pilot projects, the establishment of the regulatory framework, the training of national competencies, and the gradual introduction of hydrogen into selected energy and industrial applications. The primary goal is to acquire experience, reduce technical uncertainty, and lay the institutional foundations for future development (Mokrzycki & Gawlik, 2024).

The 2030–2040 period marks the transition to broader deployment and the creation of a domestic market. Technologies that have demonstrated reliability are gradually deployed at larger scales. Industrial and energy applications multiply, initial Power-to-X value chains emerge, and the first exports become feasible. This phase represents the sector's economic structuring and the emergence of stable demand.

Finally, the 2040–2050 period corresponds to full industrialization and large-scale export. Production becomes internationally competitive, national industrial chains are consolidated, and sustainable integration into international energy markets is achieved. At this stage, hydrogen fully establishes itself as a pillar of the energy system and a long-term driver of economic diversification.

6. Conclusion

The analysis presented in this article demonstrates that hydrogen is not merely an additional technological option within Algeria's energy policy, but rather a genuine instrument for the structural transformation of its energy and production systems. By integrating hydrogen into its strategic planning, Algeria aims not only to reduce the carbon intensity of certain uses but also to prepare for a gradual shift from its historically hydrocarbon-based energy model toward a more diversified economy aligned with international climate objectives.

A review of global trends highlights that renewable hydrogen is progressively becoming a cornerstone of decarbonization strategies, particularly in sectors that are difficult to electrify. In this context, Algeria's advantage lies in its ability to combine this transition with its structural strengths: abundant solar resources, existing gas infrastructure, industrial experience in molecular processes, and proximity to European markets. These factors potentially position the country strategically within future regional energy value chains. However, natural assets alone are not sufficient to guarantee the success of a

hydrogen sector; its development depends on a coherent set of institutional, industrial, and human conditions that must be established and maintained over time.

An examination of the national strategy and its 2023–2040 vision shows that the approach is based on controlled, phased progress. The initial learning phase aims to reduce technological and regulatory uncertainty; the deployment phase focuses on structuring a domestic market and industrial applications; while the industrialization phase targets sustained integration into the international low-carbon energy trade. This gradual logic is a key factor for viability, as it aligns investments with the actual maturity of technologies and evolving global demand.

The operational roadmap translates this vision into concrete actions: adapting the regulatory framework, developing human capital, structuring the industrial base, establishing international partnerships, and deploying financing mechanisms. All of these dimensions are interdependent. The absence of appropriate standards would slow investment, a skills gap would limit industrial integration, and insufficient international cooperation would hinder technology transfer and market access. Accordingly, the hydrogen strategy should be understood as a systemic policy rather than a sectoral one, simultaneously mobilizing energy, industrial, scientific, and commercial policies.

The opportunities are substantial. Domestically, the hydrogen sector can contribute to the progressive decarbonization of the energy system, the local valorization of renewable electricity, and the preservation of exportable gas resources. It can also stimulate the emergence of new industrial activities, generating skilled employment and technological know-how. Regionally, it offers Algeria the possibility to reposition itself as a supplier of low-carbon energy, not only in the form of hydrocarbons but also as decarbonized energy molecules and synthetic derivatives.

Nevertheless, significant challenges remain. The economic competitiveness of hydrogen will depend heavily on the declining costs of renewable energy, advances in electrolyzer technologies, water availability, adaptation of networks, and the establishment of appropriate financing mechanisms. It will also depend on the pace of international demand structuring and carbon certification standards. In this sense, the hydrogen strategy cannot be static: it must remain flexible, adjusting to technological advances as well as geopolitical transformations in the energy landscape.

Ultimately, the central question is not whether hydrogen will replace hydrocarbons in the short term, but to what extent it will enable Algeria to anticipate the transformation of the global energy system and become an active player rather than a passive follower. The success of this transition will depend on the alignment between strategic vision, public policies, and actual industrial capacities. If this coherence is maintained over time, hydrogen could become not only a decarbonization vector but also a lever for economic transformation and regional energy integration for Algeria by the mid-21st century.

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